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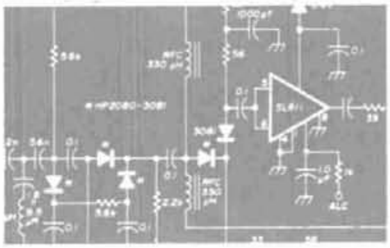
ham radio magazine

MARCH 1978



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10th anniversary issue

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More Details? CHECK—OFF Page 158

ham radio magazine

MARCH 1978

volume 11, number 3

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editor-in-chief

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ham radio magazine
is published monthly by
Communications Technology, Inc
Greenville, New Hampshire 03048
Telephone: 603-878-1441

subscription rates

U.S. and Canada: one year, $12.00
two years, $22.00
three years, $30.00

Europe, Japan, Africa:
(via Air Forwarding Service)
one year, $25.00

North America, South America, Australia
and Asia (except Japan):
(via Surface Mail)
one year, $18.00

foreign subscription agents

Foreign subscription agents are
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Microfilm copies
are available from
University Microfilms, International
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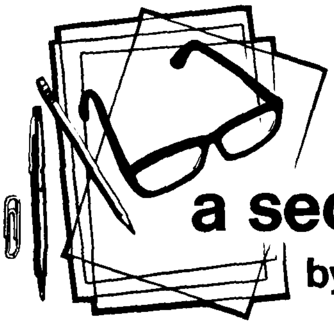
Order publication number 3076

Cassette tapes of selected articles
from *ham radio* are available to the
blind and physically handicapped
from Recorded Periodicals
919 Walnut Street, 8th Floor
Philadelphia, Pennsylvania 19107

Second-class postage
paid at Greenville, N.H. 03048
and at additional mailing offices
Publication number 233340

contents



a second look

by Jim Fisk

How time flies . . . it doesn't seem possible that it has been ten years since I put the final touches on the first issue of *ham radio* and sent it off to the printer. If you recall that very first issue, you'll remember that the cover featured a five-band ssb exciter designed by K1UKX. It was an all vacuum-tube layout, but ten years ago few hams were thinking in terms of solid-state station equipment, and the K1UKX exciter was as up to date as anything then in print.

To commemorate our tenth anniversary we're featuring a fully-synthesized high-frequency transceiver that reflects the current state of the art. A comparison of these two rigs graphically demonstrates the tremendous technological advances that have been made in the past few years. In 1968 there were a few rf small-signal transistors on the market, but practically none for rf power, and low-cost MOSFETs and integrated circuits were still a few years away. Less than half the active amateurs were still using a-m, but it was far from being a thing of the past, and the boom in portable vhf-fm equipment and repeaters was still far in the future. How things have changed!

You can still hear a few a-m stations on 75 and 160 (and a few on the vhf bands), but nearly everybody is now on sideband. In 1968 transceivers were starting to become popular but separate receivers and transmitters were still in widespread use. There were a few pioneers operating converted commercial fm gear on two meters but there were, perhaps, only a dozen repeaters in the entire country! Today there are hundreds of two-meter repeaters and the vhf wastelands of the late 1960s are crowded with signals.

Amateur radio in 1968 was attracting so few new members it was barely holding its own — in recent months it has shown more growth than ever in its history. Some oldtimers complain about the interference that comes with a larger amateur population, but only through larger numbers can we hope to attract the attention of manufacturers who will build equipment that incorporates the latest technological advances. Economics being what they are, you can't have one without the other — manufacturers aren't going to spend money developing state-of-art equipment for a dwindling number of consumers.

As amateur radio has changed during the past decade, so has *ham radio*. Although we weren't always the first to present the latest advancement in amateur radio state of the art, more often than not you read about it first in the pages of *ham radio*. As you read through this special 10th anniversary issue, you'll notice that we have reprinted a few articles from past issues which have long-term amateur interest. Those issues are long out of print, but since we receive so many requests for these particular articles, we thought it would be appropriate to reprint them for the benefit of readers who don't have a complete library of back issues.

Amateur radio, by its nature, is a very diversified hobby. Each ham follows his own special interests whether it's home construction, vhf-fm, RTTY, moonbounce, slow-scan television, or any of a multitude of others. If you don't see a technical or construction article that covers your particular plane of interest, it's because no one has taken the time to write it. If you have some ideas for station accessories or other amateur equipment that you think others would be interested in, I'd like to hear about it; even if you don't have the time to develop the project yourself, perhaps I can plant the idea with an author who will bring it to fruition.

To paraphrase the closing paragraph of my editorial in the first edition of *ham radio*, we will not stand on our laurels, nor will we stand still. We will always be looking for ways to improve because amateur radio is a dynamic hobby, always on the move. As the equipment, techniques, and challenges of amateur radio change, so will we. We'll constantly try to make *ham radio* more useful to you as well as more interesting and stimulating. We will never become complacent — we will always try to make *ham radio* better. It has always been our goal to keep our readers informed of advances in electronic technology, and we will continue to do so in the future, but we will also make a bigger effort to present more simple projects that you can duplicate in your home workshop. Viewed from here, that's a bigger challenge for the decade ahead than it was for the decade past.

Jim Fisk, W1HR
editor-in-chief

Ten years! It sounds like a long time, but here at *ham radio* magazine 1968 seems like just yesterday. Here we were starting up a fourth major amateur radio magazine in a field which many people felt could not even properly support the three that were already being published.

Ham radio was started with the strong conviction that a magazine featuring innovation and excellence far in excess of anything previously offered to the Amateur would be able to make a vital contribution to Amateur Radio while also insuring itself reasonable success as a business venture.

The contributions of the past ten years have now become very real. It was *ham radio* that really got amateurs thinking in terms of solid-state designs and began to put the vacuum tube into its proper perspective.

It was *ham radio* that first brought modern graphics to the ham publishing field and showed everyone just how good looking and easy to read an amateur magazine can really be.

It took *ham radio* to prove that it doesn't take a heavy dose of political in-fighting and sensationalism for an independent publisher to succeed in Amateur Radio. People everywhere welcomed the fresh positive outlook they found within our pages; soon the doubters realized that *ham radio* was here to stay and flourish.

For all of our accomplishments, by far the most important part of the magazine story has been you, our reader, and the outstanding loyalty you have given us over the last ten years. Your overwhelming response in the form of subscription orders soon put us at the lead of the independents and attracted the vital advertising support that was needed to put the whole operation on a sound financial footing. It has been your continuing support, encouragement, suggestions, and even a rap on the knuckles when necessary, that has helped us to steer our way and come up with a better magazine and improved service for you.

There are many many more great ideas floating around here in Greenville, and we are looking forward to putting many of them into action in the months ahead. With your help we can promise you that the next ten years at *ham radio* will be every bit as dramatic and exciting as the last ten have been, and in 1988 we should have an even greater story to tell.

Skip Tenney, W1NLB
publisher

presstop

AN AMATEUR'S RIGHT to a tower will reach the U.S. Supreme Court for the first time as a result of a long-standing battle by a West Coast Amateur with the City of Cerritos, California. An appeal challenging the Constitutionality of a municipal zoning ordinance regulating antenna height was filed with the Court in January.

In An Earlier Action the California Appellate had found the city's antenna limit Constitutional, and that court's decision was appealed to the California Supreme Court which refused to hear the appeal.

Since This New Appeal challenges the Constitutionality of an ordinance, the U.S. Supreme Court must hear the case. It may make the Court's fall session, in which case it could be heard yet this year. Thanks Personal Communications Foundation.

FORMER FCC COMMISSIONER Glen Robinson looks like President Carter's choice to head the U.S. negotiating team at the World Administrative Radio Conference in Switzerland next year. Robinson is presently on the faculty at the University of Virginia but was well respected for his contributions and expertise during his term on the Commission.

However, An Item in the current issue of Broadcasting raises the question of his qualifications for leading the U.S. effort at an International conference, an area in which he's had no experience. What effect, if any, his appointment will have on the Amateur Radio WARC position remains to be seen.

That Next WARC Advisory Committee on Amateur Radio meeting is now scheduled for March 29 in Washington, provided the next FCC Notice of Inquiry is out in time.

"WHISKEY CLUB" LEADER Jesse Runyan, of El Dorado, Kansas, also known as "34W-1" has had his Technician Class Amateur License WBØRIN suspended for the remainder of its term for his illegal activities. He's also been ordered to show cause why both WBØRIN and his CB license should not be revoked.

THE ENVIRONMENTAL PROTECTION Agency may be in Amateur Radio's future — the Senate Governmental Affairs Committee recommended giving the EPA authority over radiation hazards, including RF.

FCC LICENSE FEES will probably eventually be reinstated, while at the same time many licensees will be in line for a refund on previously paid fees. The reason for this seeming paradox is that the Commission is supposed to develop and institute an appropriate fee schedule, but will then have to refund the difference between what previous applicants actually paid and what "appropriate" fees should have been when fees were in effect during the 1970-1976 period.

FCC Docket Numbers will be much more descriptive from now on with a new numbering system that became effective January 1. The new numbers start with two letters indicating FCC bureaus ("SS" for Safety and Special Services, "BC" for Broadcast and so on), "78" to show it originated this year, plus the serial number of the Docket in that year. Thus this year's first Safety and Special Services Docket could be "SS Docket No. 78-4," showing that it's the fourth Commission Docket of 1978.

Restrictions On 220-MHz operation by Amateurs near the White Sands Missile Test Center have been lifted by the FCC. The ban had prohibited Amateur use of 220 in parts of west Texas and New Mexico during weekday working hours to prevent possible interference with missile range communications.

AMSAT NOW HAS a full time Administrative Assistant who'll relieve President Perry Klein at the telephone, handle membership applications, and maintain the mailing list. She'll also be taking over bookkeeping and other task areas that were previously handled by AMSAT volunteers.

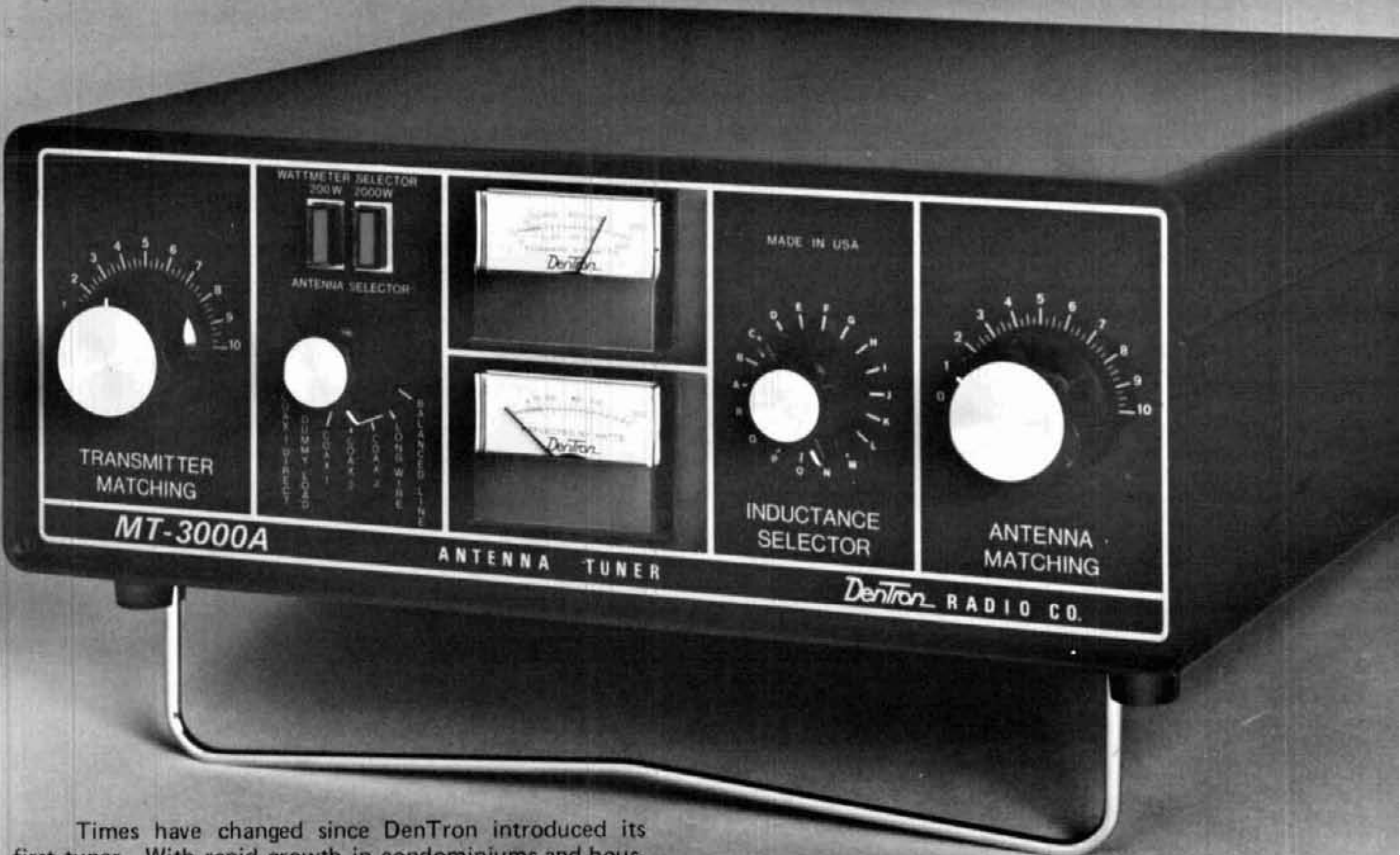
OSCAR 7 Will Be Operating Only on Mode B until further notice due to a battery overtemperature problem. Over charging is the problem, and since Mode B draws more current, the satellite will be kept in that mode until it leaves the period of maximum sunlight. Expectations are that the condition will last for about a month, and though it may switch itself back into Mode A for brief periods the command stations will return it to Mode B as quickly as possible.

Enough Solar Cell and battery cell donations have been received to take care of the first Phase III satellite.

4U1ITU In Geneva, Switzerland, will soon be on the satellite with a permanent station, according to Region 1 IARU News.

W9BRD IS RETIRING as QST DX Column editor with the March issue. Rod, who's done an outstanding job in his 30 years with "How's DX," is turning the reins over to W1VV.

Look closely at the new MT-3000A. You've never seen anything like it.



Times have changed since DenTron introduced its first tuner. With rapid growth in condominiums and housing developments, we have new problems that require new solutions.

DenTron decided to rethink the tuner and what its total capabilities should be.

The MT-3000A is a capsulized solution to many problems. It incorporates 4 unique features to give you the most versatile antenna tuner ever built.

First, as a rugged antenna tuner the MT-3000A easily handles a full 3KW pep. It is continuous tuning 1.8-30mc. It matches everything between 160 and 10 meters.

Second, the MT-3000A has built-in dual watt meters.

Third, it has a built-in 50 ohm dummy load for proper exciter adjustment.

Fourth, the antenna selector switch; (a) enables you to by-pass the tuner direct; (b) select the dummy load or 5 other antenna systems, including random wire or balanced feed.

The compact size alone of the MT-3000A (5½" a 14" x 14") makes it revolutionary. Combine that with its four built-in accessories and we're sure you'll agree that the MT-3000A is one of the most innovative and exciting instruments offered for amateur use.

At **$349.50** the MT-3000A is not inexpensive. But it is less than you'd expect to pay for each of these accessories separately.

As unique as this tuner is, there are many things it shares with all DenTron products. It is built with the same meticulous attention to detail and American craftsmanship that is synonymous with DenTron.

After seeing the outstanding MT-3000A, wouldn't you rather have your problems solved by DenTron?

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general-coverage high-frequency transceiver with digital readout

Design of a ssb/CW transceiver with exceptional performance which features synthesized frequency control from 1.5 to 30 MHz

The high-performance ssb/CW transceiver described in this article is unusual in that it provides coverage of the entire high-frequency spectrum from 1.5 to 30 MHz. Although the present amateur bands represent only about 12 per cent of this spectrum space, amateur activities such as MARS require additional frequency coverage. In addition, it's uncertain whether the amateur bands in the 1980s will be the same as they are now, or whether they will be expanded or reduced. Regardless of the outcome of the World Administrative Radio Conference of 1979, this transceiver will provide exceptional performance on any of the high-frequency amateur bands — both now and in the future.

In addition to its unusually wide frequency coverage, this transceiver includes features which are not available in commercial amateur equipment such as the built-in antenna tuner and ac power supply, nicad battery pack, and charger. The transceiver is completely portable and is equivalent to the latest military

By Ulrich L. Rohde, DJ2LR, 52 Hillcrest Drive, Upper Saddle River, New Jersey 07458

table 1. Operating specifications for the general-coverage high-frequency transceiver.

Frequency range	1.5 to 30 MHz
Frequency accuracy	100 Hz
Operating modes	CW and ssb
	receiver
Sensitivity	0.3 μV for 10 dB S + N/N
Image suppression	greater than 80 dB
I-f feedthrough	greater than 80 dB
Intermodulation distortion	2nd order: better than 65 dB (independent of level) 3rd order: better than 60 dB (2 times 0 dBm input level)
I-f bandwidths	500 Hz and 2.3 kHz
I-f shape factor	1:2 (CW); 1:1.7 (ssb)
First i-f	41 MHz
Second i-f	9 MHz
AGC operation	Response: 2 milliseconds Attack time: 0.75 second Hold time: 100 ms decay Threshold: 0.2 μV
AGC characteristics	Less than 6 dB audio change for rf inputs 0.2 μV to 1 volt

	transmitter
Output power	20 watts
3rd order IMD	−33 dB with respect to PEP output
Harmonic radiation	−65 dB
Non-harmonic spurious	−70 dB
Other features	RF speech processing and ALC Built-in antenna tuner matches 12 to 200 ohms at all phase angles Split frequency operation, *any* separation Built-in power supply and nicad battery pack
	digital synthesizer
Increments	1 kHz (100 Hz resolution with VCXO)
Switching speed	6 milliseconds
Synthesizer control	thumbwheel switch or optical shaft encoder
Memory	for independent transmit/receive frequencies

manpack designs such as the Hughes Aircraft PRC104, Tadiran PRC174, or AEG-Telefunken S6861. A complete list of specifications is shown in **table 1**; a block diagram of the transceiver is shown in **fig. 1**.

general description

In the receive mode the signal from the antenna is fed into the receiver through the antenna tuner, directional coupler, and filters to the PIN diode attenuator. There are a total of seven lowpass filters and three highpass filters — the correct filter is selected by digital logic which is controlled by the frequency synthesizer. From the PIN diode attenuator the input signal passes through a 32-MHz lowpass filter to a high-level SRA3H double-balanced mixer (+17 dBm local oscillator drive). The 41-MHz output signal from the mixer is amplified 10 dB in a push-pull amplifier

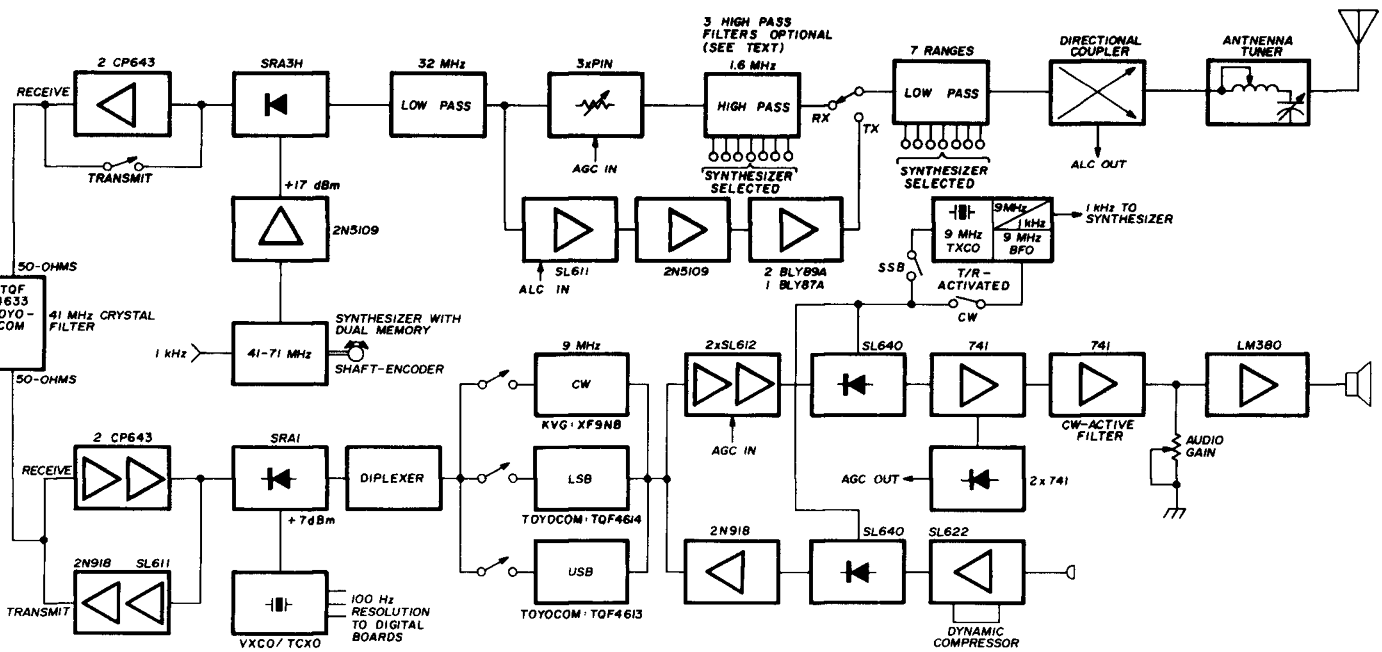


fig. 1. Block diagram of the high-frequency transceiver. The unit features a frequency synthesizer with memory, and built-in power supply and antenna tuner. Complete specifications are listed in *table 1*.

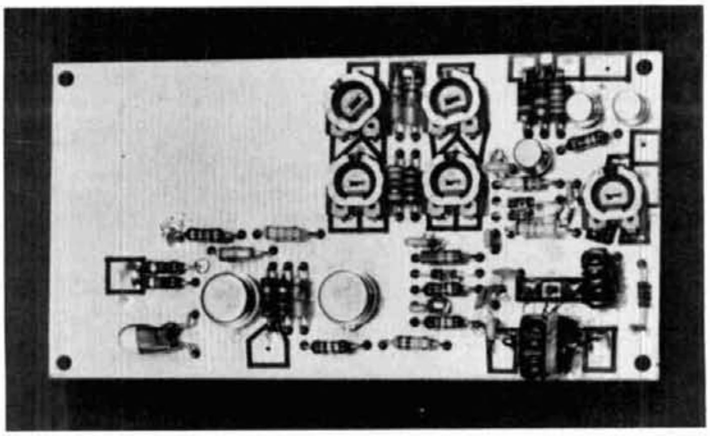


fig. 3. Photograph of the ALC board showing the directional coupler (lower right) and the potentiometer adjustments.

which uses two CP643 power fets. The push-pull amplifier provides an ideal wideband termination for the double-balanced mixer and compensates for losses through the following 41-MHz crystal filter; the crystal filter has a 3.5 kHz bandwidth with a shape factor of 1:2 (6 to 60 dB). The very low noise cascode amplifier following the crystal filter provides low noise and proper filter termination.

The amplified 41-MHz signal is down converted to 9 MHz with an SRA1 double-balanced mixer. An attenuator between the cascode amplifier and mixer is adjusted for as little gain as necessary to maintain good overload performance. The output of the double-balanced mixer drives one of three crystal filters through a diplexer. The 9-MHz i-f amplifier has 60 dB gain and drives an active double-balanced mixer for CW/ssb operation.

The agc is provided by an audio agc generator. The audio power stage produces 2 watts of output power. For CW operation an active audio filter is available for greater selectivity and improved signal-to-noise ratio.

Transmitting mode. In the transmitting mode a dynamic microphone with 200 ohms impedance is required to drive the dynamic speech compressor. The compressor provides constant output level into the double-balanced mixer which produces the double-sideband signal. This signal is amplified by a 2N918 stage before being converted into ssb by one of two crystal filters. A dc offset is used to produce the CW carrier signal.

At the output of the 9-MHz crystal filter the ssb signal is up converted to 41 MHz in the SRA1 double-balanced mixer and amplified in a two-stage amplifier. The 41-MHz signal is fed through a crystal filter, and by proper selection of the ALC attack/decay time rf speech processing is accomplished; the har-

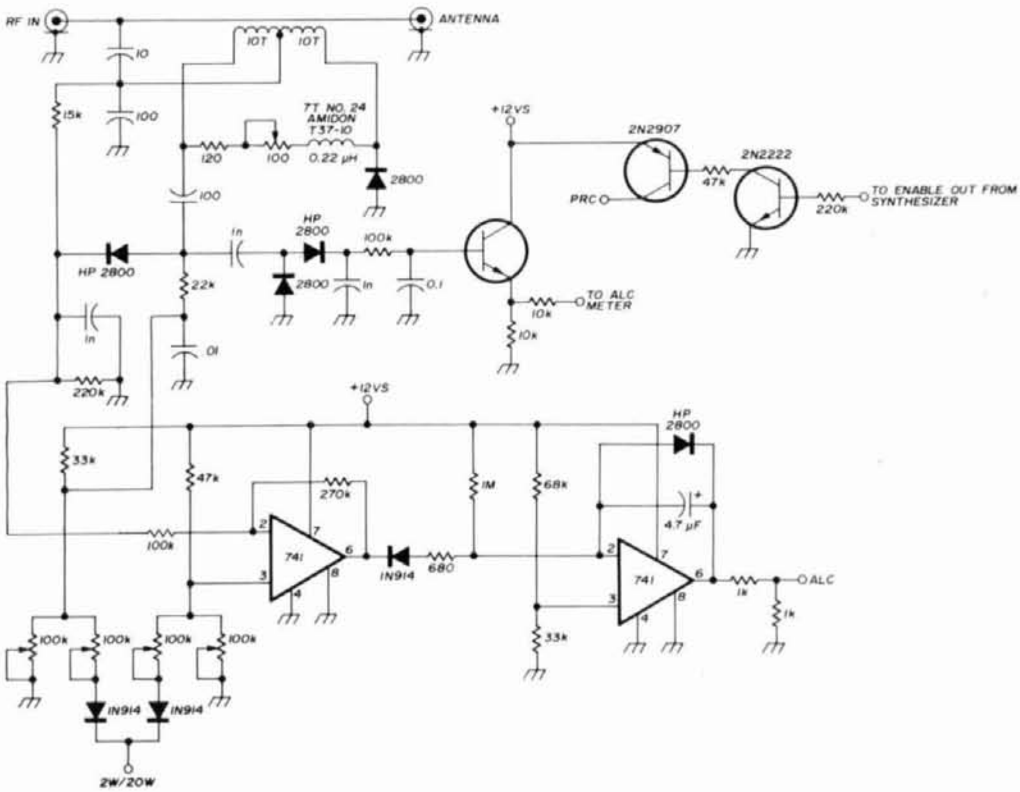


fig. 2. Schematic diagram of the ALC board which includes the directional coupler. In the tune position the rf power amplifier provides a constant two watts output for antenna tuning.

monics and spurious sidebands generated by the processing are kept under control by the 41-MHz crystal filter.

Following the 32-MHz lowpass filter the transmit signal is amplified to 20 milliwatts to drive the push-pull 20-watt rf power amplifier. The synthesizer automatically selects the proper lowpass filter (one out of seven) and the rf power is fed through the directional coupler and antenna tuning unit to the antenna.

CW operation. In CW operation the 1-kHz signal which is required as a reference for the synthesizer (derived from the 9-MHz temperature-compensated crystal oscillator [TCXO]) is converted into a 1 kHz sine wave and fed into the audio amplifier as a side-tone. A dc voltage is used to offset the double-balanced mixer to generate the 9-MHz carrier (derived from the 9-MHz TCXO) which is passed through the 9-MHz crystal CW filter. The rest of the CW signal processing is identical to that used for single sideband.

circuit description

The quasi-continuous antenna tuning unit has

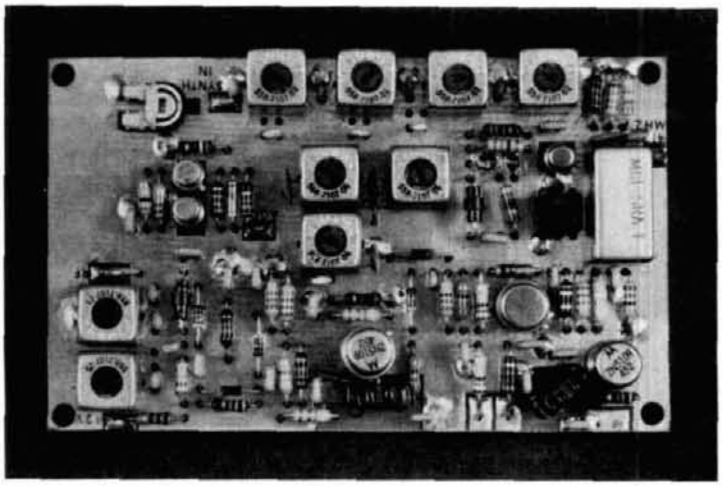


fig. 5. Rf input board showing the double-balanced mixer to the right and the lowpass filter for the synthesizer signal along the top edge of the board.

been previously described[1,2] and will provide a good match to a 6-meter (20 foot) whip at 1.25 MHz. The tapped inductors in the tuner are built with ferrite pot cores with an air gap; the tuning capacitors are sub-

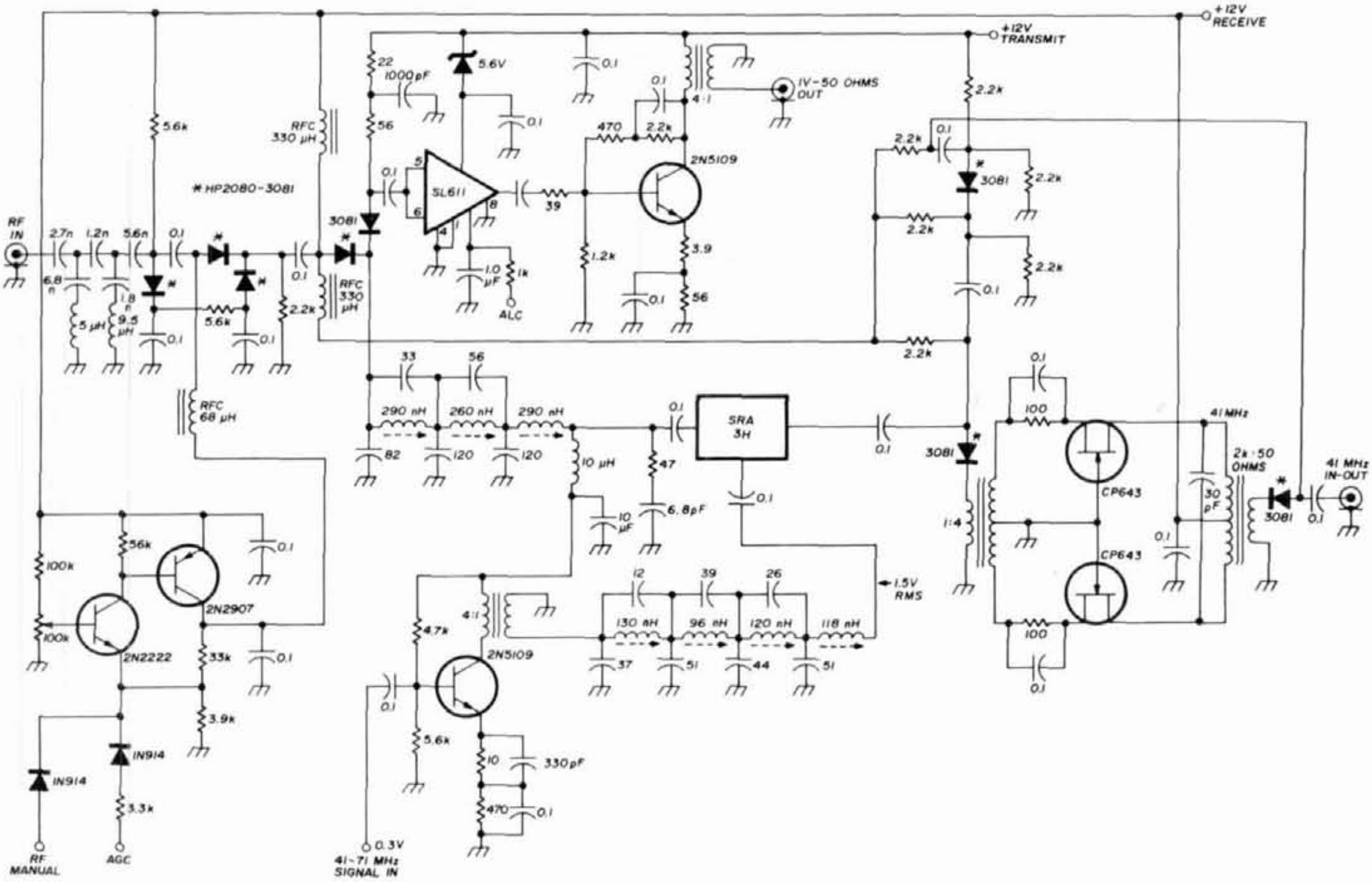


fig. 4. Schematic of the rf board with the input highpass-lowpass filter, PIN diode attenuator, and high-level transmit-receive mixer. The SL611 and 2N5109 at top center amplify the transmit signal.

miniature mica units which are switch selected from the front panel (knobs labelled L and C in the photograph of the transceiver). At the input of the antenna tuner is a 4:1 transformer which uses two 50-ohm coaxial cables wound on a 2.5cm (1 inch) ferrite toroid (TC9 material from Indiana General).

A schematic of the ALC board is shown in **fig. 2.** This board also includes the directional coupler and speech processor level adjustments. A photograph of the completed board is shown in **fig. 3.** Several new principles are used in this circuit; the voltages generated by forward and reflected power are combined and used for two purposes:

1. Forward power peaks generate the ALC action. The first 741 IC in the circuit acts as a threshold amplifier while the second 741 is connected as a Miller integrator with fast attack and slow decay time. This is an ideal circuit for rf speech processing (clipping with a duration of a few milliseconds).

2. This circuit also detects reflected power and protects the power amplifier stage at full output while generating a constant output power of 2 watts in the *tune* position for optimum adjustment of the antenna tuning unit. The series combination of the 120-ohm resistor, 100-ohm adjustable resistor, and the 0.22 μH inductor are for frequency compensation.

As was mentioned in the general description of the transceiver, the bank of seven lowpass filters is addressed by the frequency synthesizer; the proper filter is selected by miniature relays packaged in T05 cans made by Teledyne (winding information for the lowpass filters is available upon request from *ham radio*).

A set of optional highpass input filters is recommended to improve the second-order intermodulation distortion products (e.g., 8 MHz + 6 MHz = 14 MHz, 8 MHz − 6 MHz = 2 MHz). One highpass filter has a cutoff frequency of 7 MHz while the other has a cutoff at 10 MHz. When listening to the amateur 20-meter band at night, the combination of 8 MHz + 6 MHz is totally suppressed by the second highpass filter; when listening to the 7-MHz band the combination of 3.5 MHz + 3.5 MHz is suppressed by the first highpass filter.

At frequencies below 7 MHz no additional highpass filter is required because the receiver input is provided with a 1.5 MHz highpass filter which is in the circuit at all times and eliminates problems with

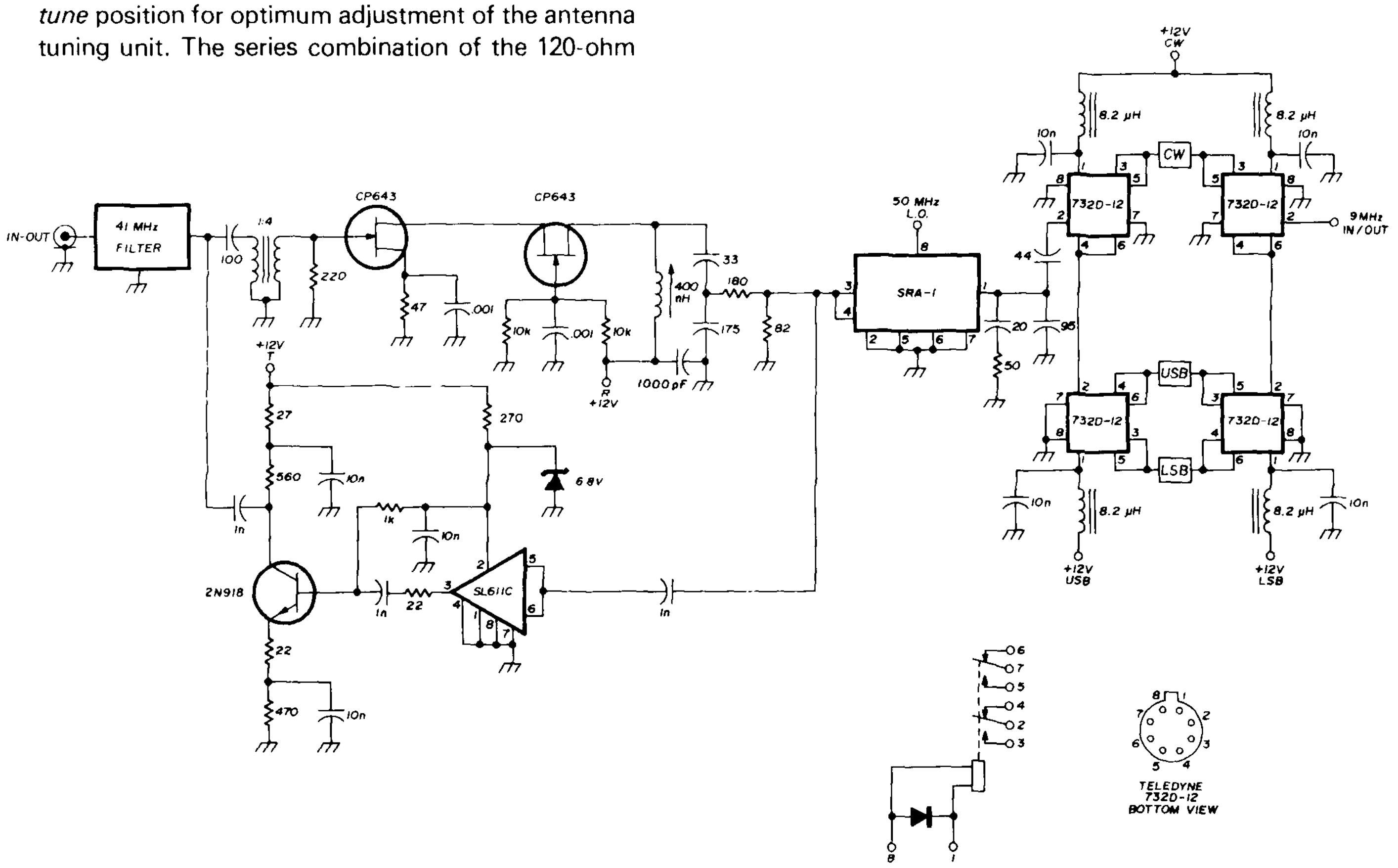


fig. 6. 41-MHz i-f and crystal-filter board. The overall gain of this stage is approximately 2 dB in the receive mode. The 9-MHz crystal filters are selected by miniature Teledyne relays which are housed in TO5 cans.

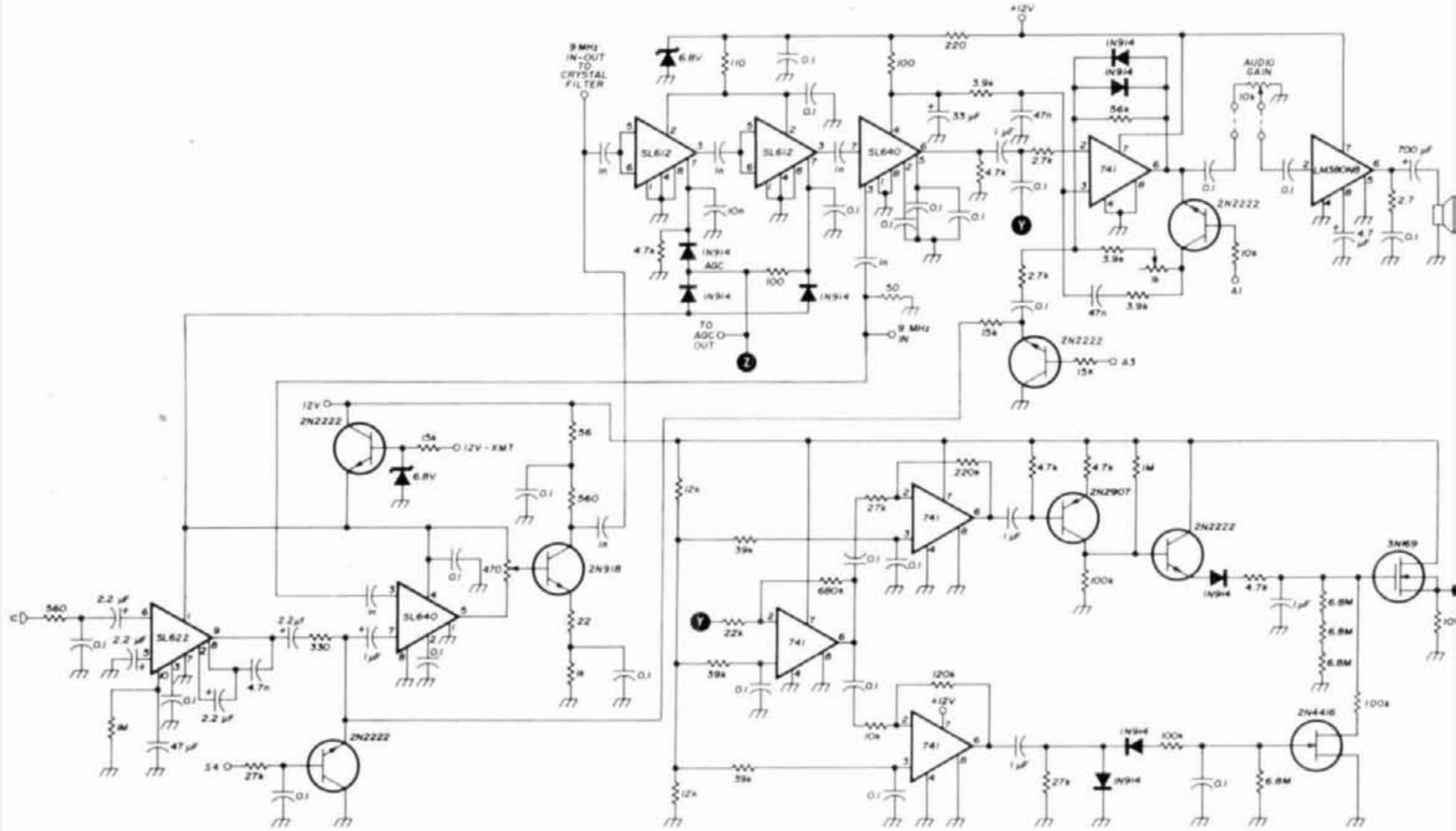


fig. 8. Schematic of the 9-MHz i-f and agc board. At the top are the two SL612 i-f amplifier stages, followed by the SL640 product detector, 741 audio preamp, and LM380 audio power amplifier. The circuit on the bottom generates the agc; see text for agc operation.

strong broadcast stations (this filter can be retuned to 1.6 MHz if local conditions require it).

receiver input

A schematic of the receiver input section is shown in **fig. 4**; a photograph of the input section circuit board is shown in **fig. 5**. I have previously described many of the performance filters in this circuit (see references 3 and 4). Following 1.5/1.6-MHz highpass filter the received signal passes through a three PIN diode attenuator which has almost constant input and output impedance. The agc voltage derived from the audio agc generator feeds the dc amplifier for the PIN diode attenuator. The 100k resistor permits adjustment of the agc level which should be set for a 3 to 5 μV input signal. The available agc range is 60 dB.

fig. 7. 41-MHz i-f and crystal-filter board. The 41-MHz crystal filter, and the two 9-MHz sideband filters, were specially made for the author by Toyocom in Japan. The 9-MHz CW filter is the latest design from KVG in West Germany.

The 32-MHz lowpass filter and the high-level double-balanced mixer following the attenuator are used in both the receive and transmit modes. In the transmit mode the 41-MHz input signal from the crystal filter is converted to the desired operating frequency in the high-level double-balanced mixer. The series combination of the 47-ohm resistor and the 6.8-pF capacitor provides adequate termination for the mixer in the transmit mode to keep the third-order IMD products below the distortion level of the output rf amplifier; the 32-MHz lowpass filter eliminates all unwanted harmonics.

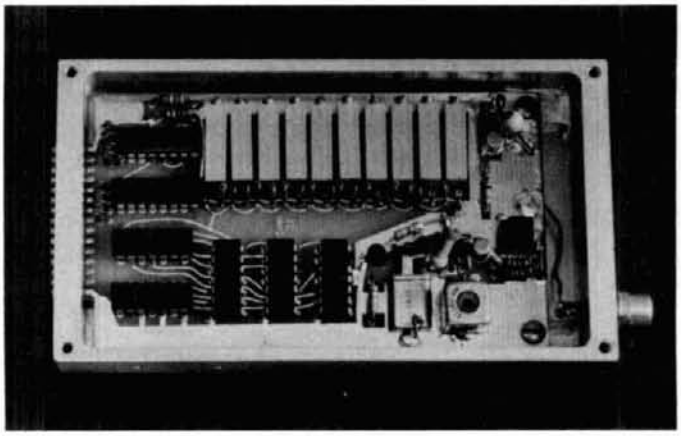


fig. 10. Photograph of the 50-MHz VCXO.

In the receive mode the push-pull fet amplifier provides the necessary wideband termination for the mixer and amplifies the received signal by about 10 dB. In the transmit mode this circuit is bypassed by switching diodes.

The 2N5109 stage amplifies the output from the frequency synthesizer and delivers +17 dBm of local-oscillator drive through a lowpass filter of elliptical design. The 2N5109 requires an input rf drive level of 300 mV.

Also on this board is an SL611 preamplifier IC and 2N5109 driver which boosts the 9-MHz transmit signal from the low-level mixer up to 1 volt. The SL611 also accepts the ALC voltage.

41-MHz i-f

Fig. 6 is the schematic of the first i-f board; a photograph of the board is shown in **fig. 7**. In the receive mode the signal from the 41-MHz crystal filter passes through a 1:4 step-up transformer which provides the necessary termination for the filter. The fet cascode circuit is a very low noise, unconditionally stable amplifier which feeds the SRA1 double-balanced mixer. The +7 dBm oscillator injection required by the mixer is provided by the TCXO.

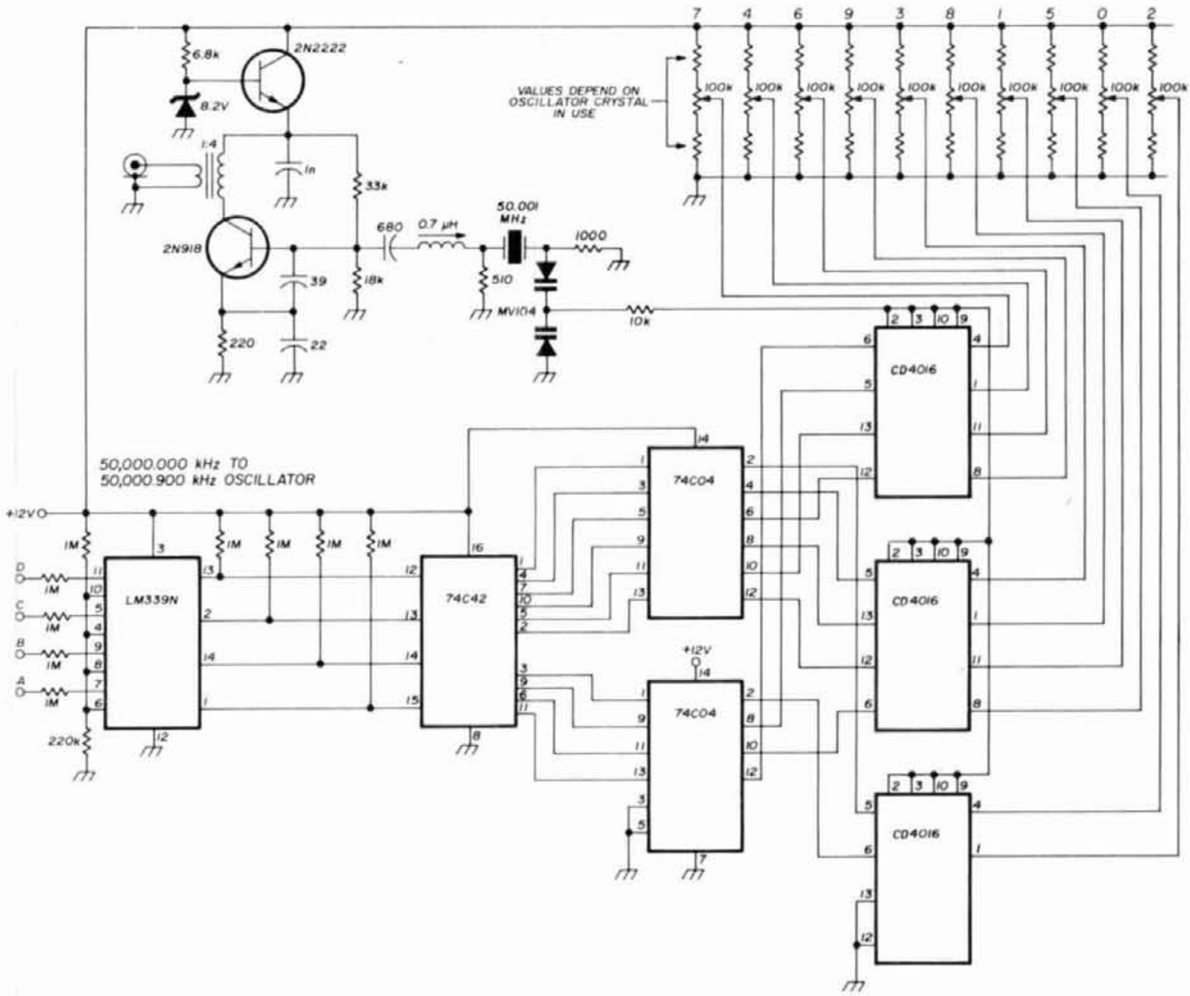


fig. 9. Schematic of the voltage-controlled crystal oscillator or VCXO. This circuit provides outputs in 100 Hz increments from 50.000 to 50.009 MHz, is stable and trouble free.

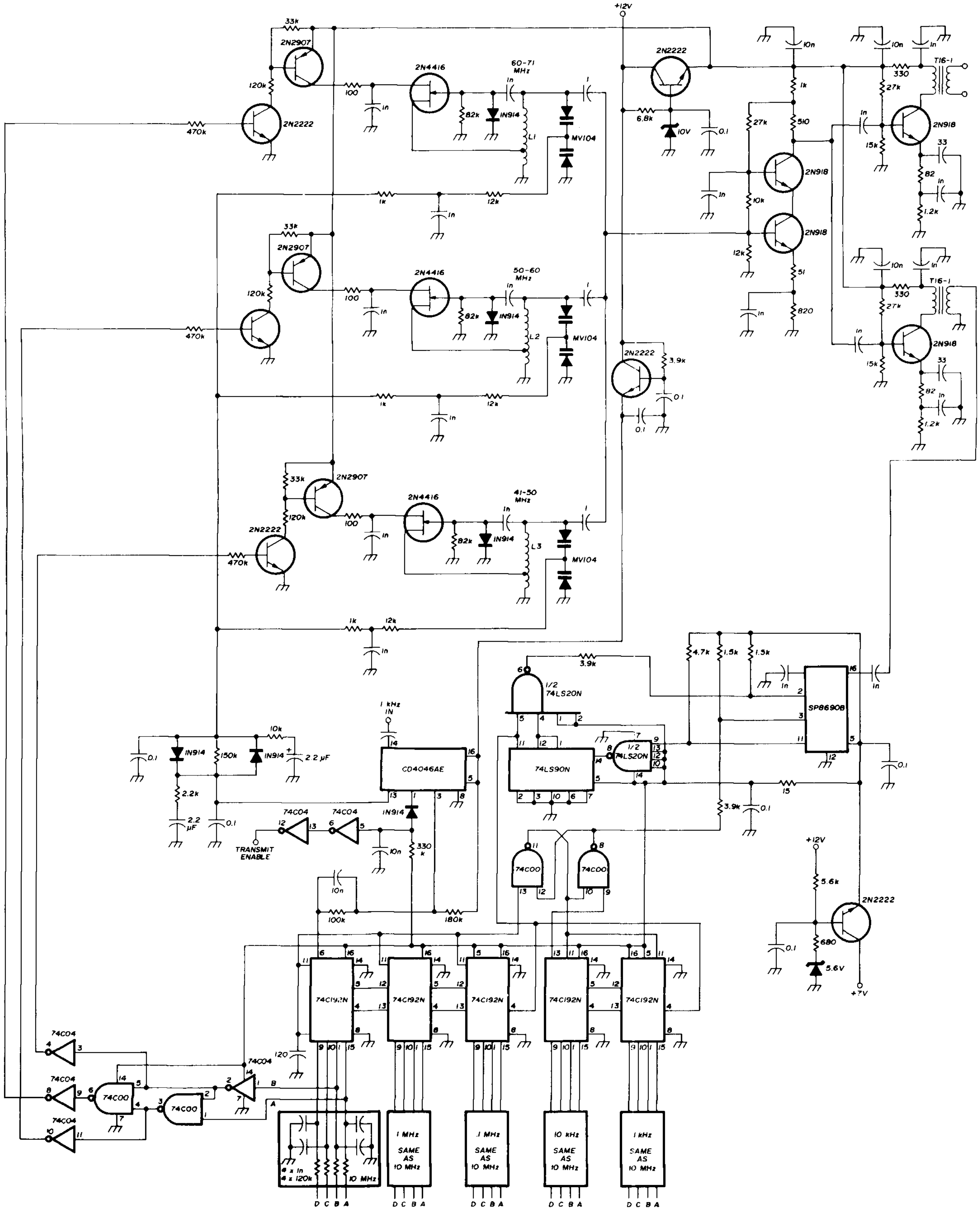


fig. 11. Schematic of the 41 to 71 MHz frequency synthesizer used in the general-coverage ssb/CW transceiver. Three VCOs are required: 41-50 MHz, 50-60 MHz, and 70-71 MHz. Input is either from thumbwheel switches or an optical shaft encoder.

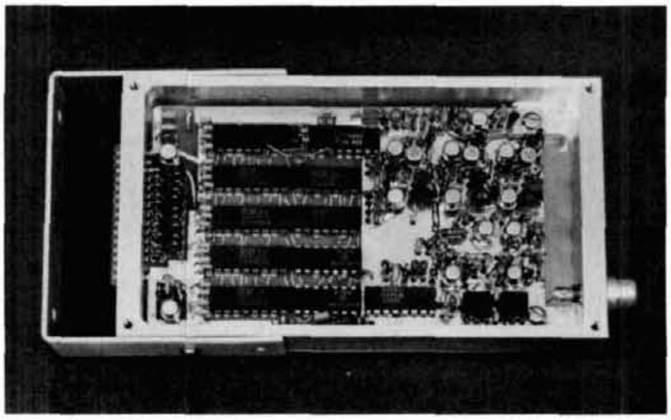


fig. 12. Photograph of the 41 to 71 MHz frequency synthesizer.

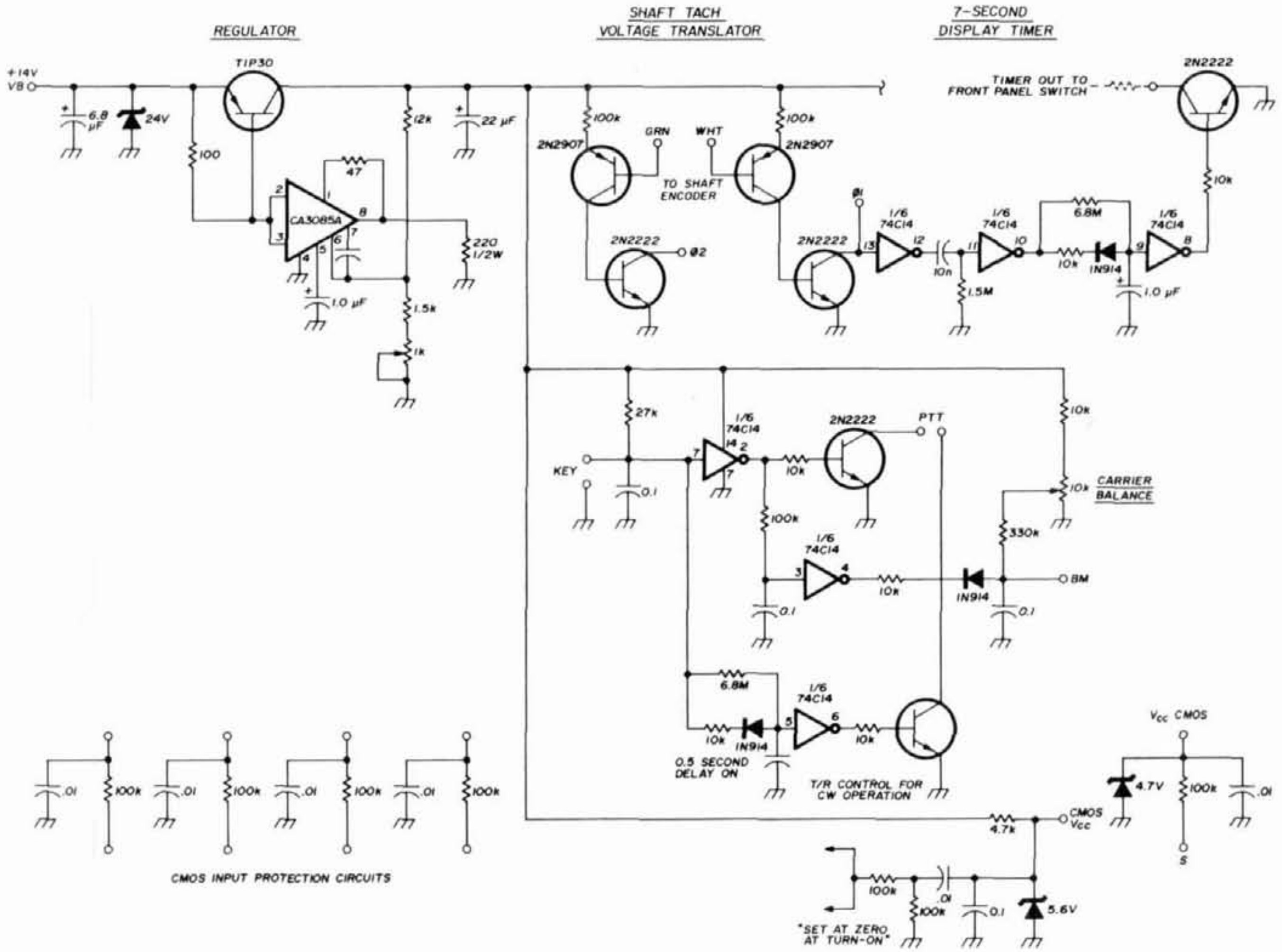
In the transmit mode the 9-MHz signal is filtered through one of three crystal filters, converted to 41 MHz by the SRA1 double-balanced mixer, amplified by the SL611 and 2N918, and passed on to the 41-MHz crystal filter. The 9-MHz crystal filters are selected by an arrangement of two miniature relays.

The 41-MHz crystal filter, and the two 9-MHz ssb filters, were made especially for me by Toyocom in Japan; the 9-MHz CW filter is the latest design from KVG in West Germany.

9-MHz i-f

The circuit of the main i-f/agc board is shown in **fig. 8**; a photograph of the unit is shown in **fig. 9.** In the receive mode the 9-MHz i-f input signal from the crystal filters is amplified by two Plessey SL612 i-f amplifier ICs and detected in the SL640 active product detector. The bfo signal is derived from the frequency synthesizer. At the output of the product detector the audio signal is amplified by the 741 operational amplifier and LM380 audio power amplifier. The audio signal from the product detector is also fed through the agc section (lower part of the schematic), amplified, and split into two channels. The 2N2907 at the output of the upper 741 amplifier is an audio detector; the following 2N2222 is a dc amplifier which charges the 1 μF capacitor.

The audio at the output of the lower 741 amplifier



is also detected and provides a negative voltage through the 2N4416 fet. The combination of the 0.1 μF capacitor and the 6.8 megohm resistor determines the agc hold time, while the 100k resistor in the drain circuit of the 2N4416, and the 1 μF capacitor, set the decay time. The 3N169 source follower provides the agc for the two SL612 i-f amplifiers and the PIN diode attenuator. (For more information on the operation of the various stages, see reference 5.)

In the transmit mode the audio from the microphone is fed into the SL622 which acts as a dynamic speech compressor and drives the SL640 double-balanced mixer IC. The 2N918 amplifier provides the necessary rf signal level for the up-conversion following the 9-MHz crystal filters.

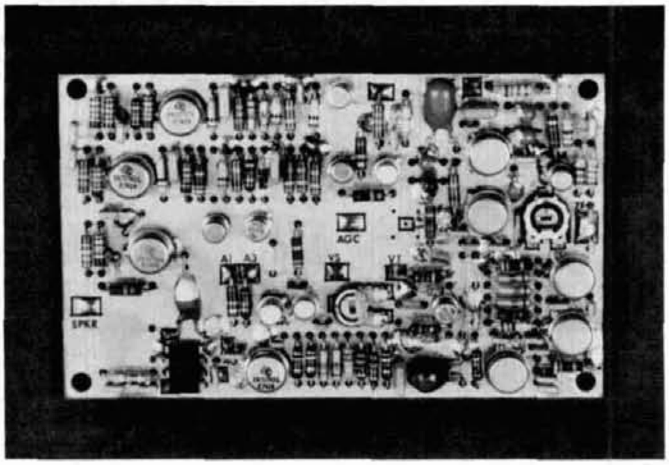


fig. 14. Photograph of the 9-MHz i-f and agc board. The agc circuitry is to the right, the i-f amplifier to the left.

crystal oscillator

Fig. 10 shows the schematic of the voltage-controlled crystal oscillator (VCXO) used in the transceiver; a photograph of the unit is shown in **fig. 11**. While analyzing frequency synthesis circuits for the transceiver, it was determined that it was not feasible to build a single-loop 100-Hz synthesizer because of the lack of loop gain. To do this would have required the use of very expensive diodes and coarse steering or presetting of the VCO to build a stable and low noise loop. Since this could not be done economically, the last digit (100 Hz) is achieved by pulling a 50-MHz crystal by the relatively small amount of 900 Hz, in 100-Hz increments from 50.0009 MHz down to 50.0000 MHz. The overall frequency stability of the transceiver is determined by this circuit, so the temperature coefficient of the 22 pF and 39 pF capacitors in the 2N918 oscillator circuit must be very carefully chosen. Since each crystal may require a different temperature coefficient capacitor for compensation, this is best determined by experiment.

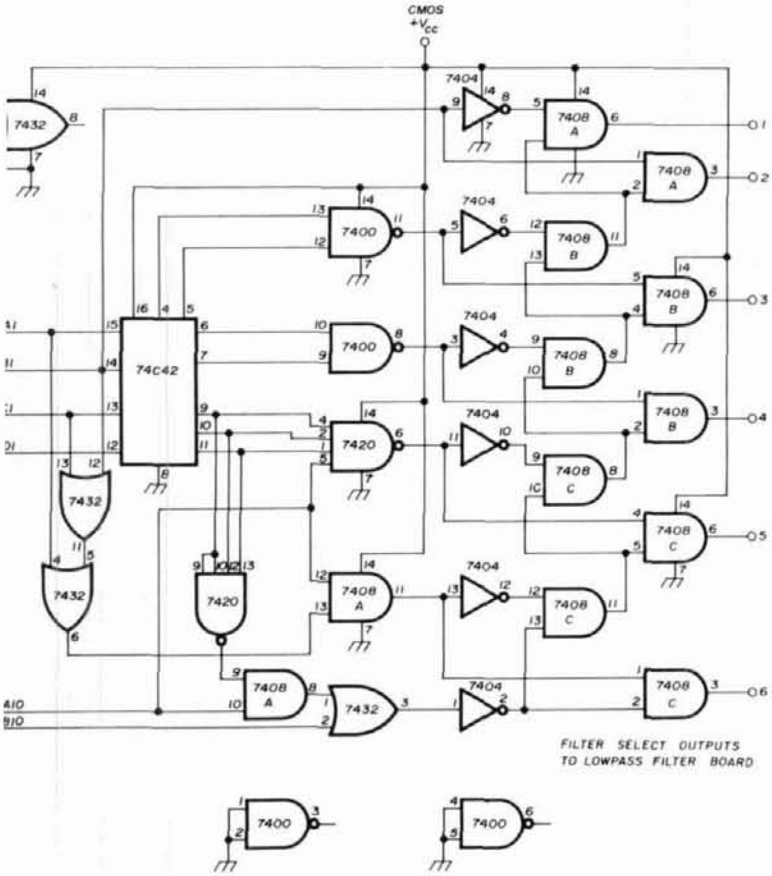


fig. 13. Schematic of the main dc control board. Included are the automatic lowpass filter selection circuits, right; transmit-receive control for CW operation, left; a 12 Vdc regulator; and 7-second display timer (see text).

To properly adjust the ten potentiometers in the VCXO requires the use of a good frequency counter. First enter 9 in BCD code at the input and set the 0.7 μH inductor and 100k potentiometer so the output is at 50.0009 MHz. Then enter 8 in BCD code and adjust the appropriate 100k pot for 50.0008 MHz. Continue in this fashion until all ten potentiometers have been set. If you run out of pulling range with the potentiometers, increase the size of the inductor and try again. Other than the adjustment procedure, which should give no problems if you use a counter, this oscillator is very simple and well behaved.

frequency synthesizer

The single-loop frequency synthesizer shown in **fig. 12** covers the range from 41 to 71 MHz in 1 kHz increments; a photograph of the synthesizer board is shown in **fig. 13**. Three VCOs are used in this circuit, each covering 10 MHz. The output from the VCOs is fed into a high isolation amplifier and two independent drivers. One driver feeds the 2N5109 amplifier on the receiver board (**fig. 4**), while the other amplifier drives the SP8690B swallow counter which is used

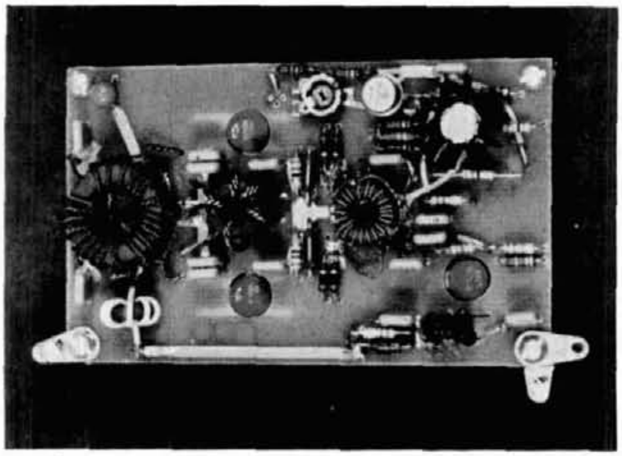


fig. 16. 20-watt rf power stage; the input is to the left, output to the right.

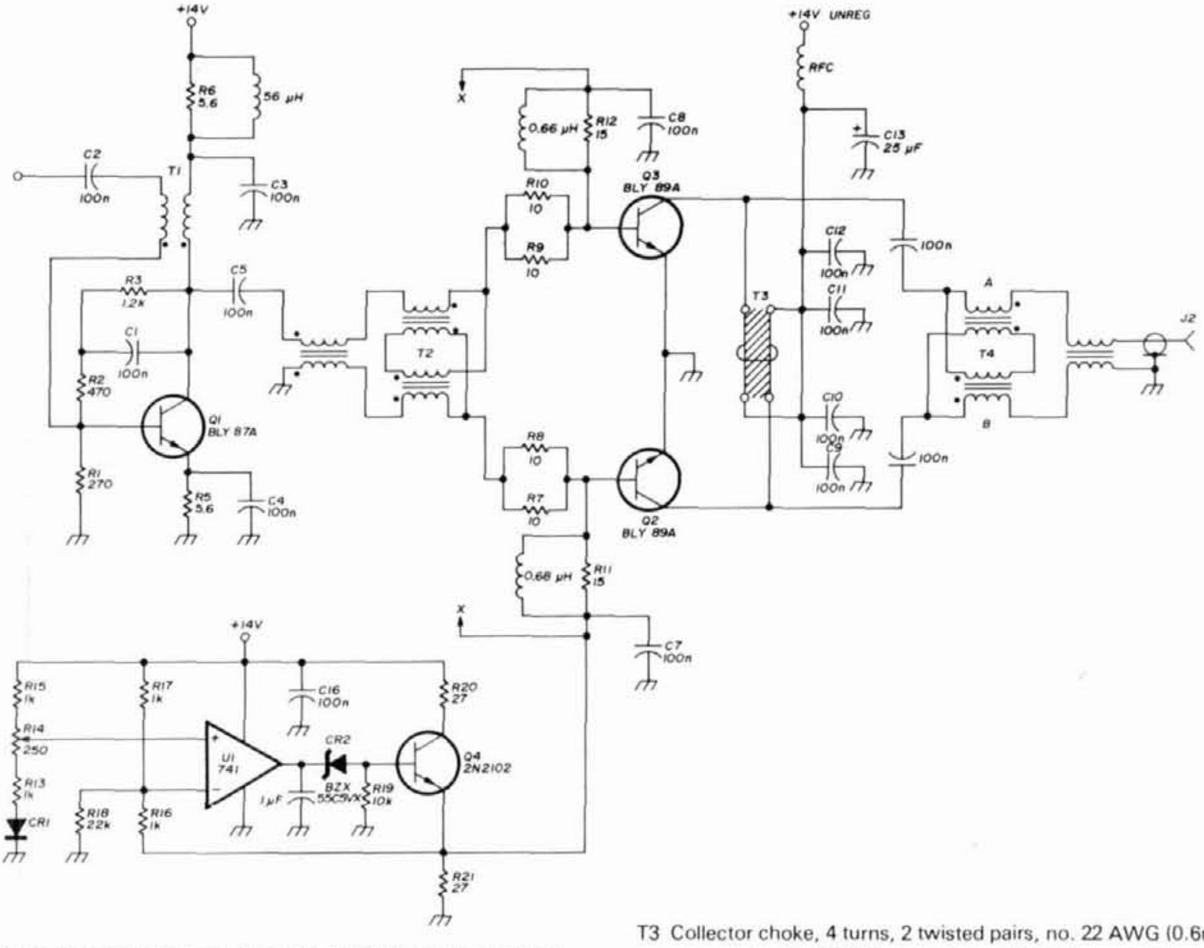
with the 74LS20 and 74LS90 to form the 100/101 synchronous counter. A more complete description of synthesizer operation, and the CD4046E phase detector, is contained in references 6 and 7.

A schematic of the 9-MHz reference oscillator is not shown; the TCXO I used in the transceiver was manufactured by McCoy.* The output of the TCXO feeds a divider chain which delivers the 1 kHz reference; the output of the TCXO is also used as the bfo. For CW reception a 9.001 MHz bfo signal is required; this is provided by a separate crystal oscillator circuit.

rf power amplifier

The 20-watt rf power amplifier used in the trans-

*McCoy part number MC 163x2-070W 9 MHz, manufactured by McCoy.



T1 1:7 transformer. 1/7 turns of no. 26 AWG (0.4mm) enameled on Indiana General F625-9-TC9 toroidal core.

T2 2:1 transformer balun. 8 turns, 2 twisted pairs, no. 31 AWG (0.22mm) emameled wire; 5 turns, 2 twisted pairs, no. 31 AWG (0.22mm) emameled wire; all windings 5 twists per cm (12 twists per inch) on Indiana General F624-19-Q1 toroidal core.

T3 Collector choke, 4 turns, 2 twisted pairs, no. 22 AWG (0.6mm) enameled wire, 2-1/2 twists per cm (6 twists per inch), on Indiana General F624-19-Q1 toroidal core.

T4 1:4 transformer balun. Windings A and B: 5 turns, 2 twisted pairs, no. 26 AWG (0.4mm) enameled wire; winding C: 8 turns, 2 twisted pairs, no. 26 AWG (0.4mm) enamaled wire; all windings 3-1/2 twists per cm (9 twists per inch); wound on Indiana General F617-8-Q1 toroidal core.

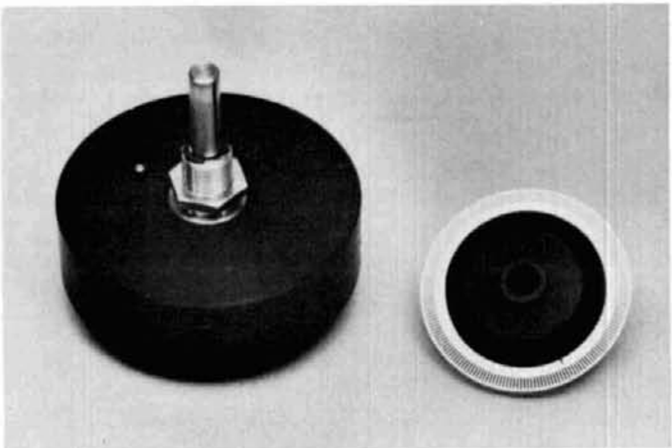
fig. 15. The 20-watt rf power amplifier in the high-frequency transceiver uses a BLY87A driver and push-pull BLY89As. The 741 op amp and 2N2102 provide constant dc bias; the 1N4448 is a temperature sensing device and should be mounted near the final power transistors.

ceiver is shown in **fig. 14**; a photograph of the assembly is shown in **fig. 15**. In this circuit the BLY87A driver transistor uses both voltage and transformer feedback to maintain flat gain and constant input impedance over the entire operating frequency range. Transistor Q3 in the push-pull final amplifier has an input stabilizing network consisting of R9 and R10 in series, and R12 in parallel for the rf path (R7 and R8 in series, R11 in parallel, make up the stabilizing network for transistor Q2). The voltage for the push-pull transistors is supplied through transformer T3; transformer T4 combines both phases and provides a single-ended 50-ohm output.

To maintain constant dc bias over a wide temperature range, a high-gain loop using a 741 operational amplifier is used along with a high-current 2N2102 transistor. The 1N4448 diode, which is the temperature sensing device, should be mounted very close to transistors Q2 and Q3.

control functions

The main dc control board for the transceiver is shown in **fig. 16**. The information from the thumbwheel switches on the front panel of the transceiver is fed in parallel to both this board and the 41-71 MHz synthesizer board (**fig. 12**). In addition to controlling lowpass filter selection, this board includes a 12-volt regulator, transmit-receive control for CW operation, and circuitry for the optical shaft encoder.



Photograph of an optical shaft encoder and its slotted encoding disc. The 180 slots are chemically etched in the disc. The disc is 1-5/8" (41mm) in diameter.

The optical shaft encoder generates two quadrature square waves or pulses which are a function of shaft rotation — the waveforms are generated by a

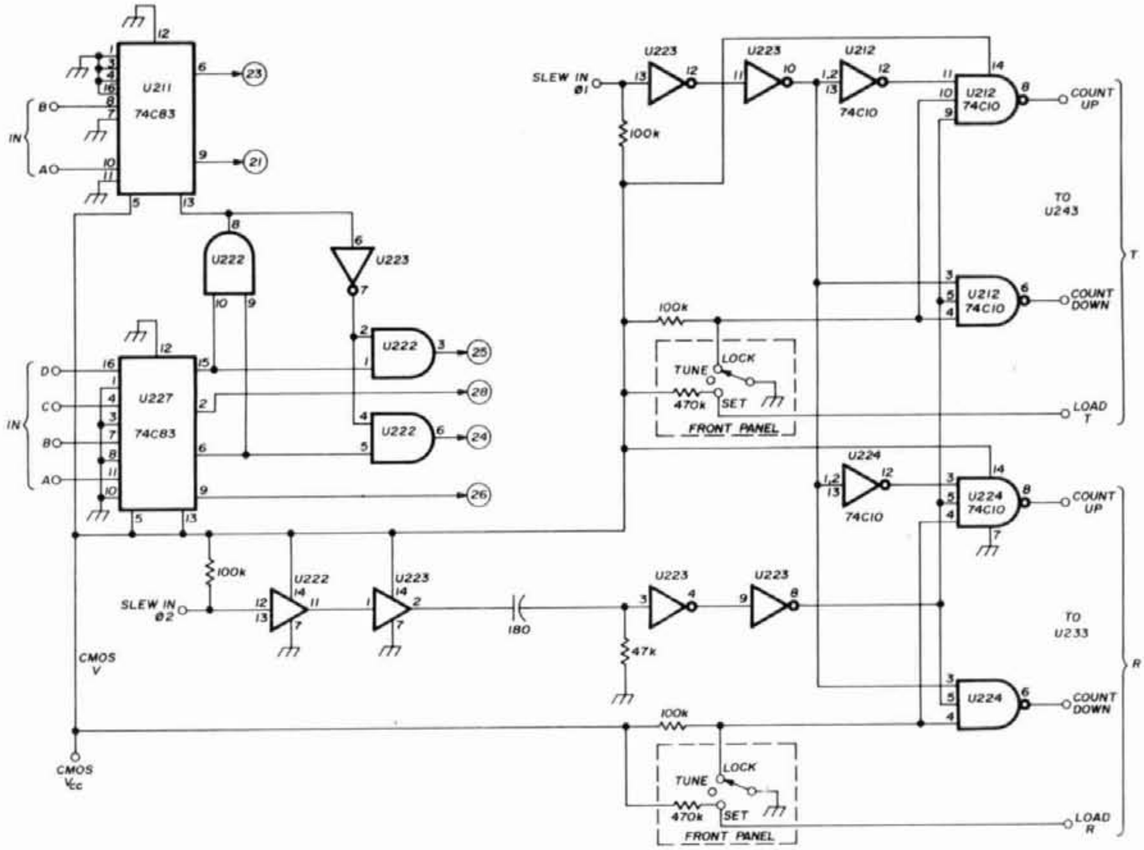


fig. 17. Tuner control logic provides for a digital readout of zero when the synthesizer is tuned to 41 MHz. Outputs to the right, labelled T and R, are connected to the lower and middle tuner boards (figs. 18 and 19).

slotted disc which interrupts the light path between two LEDs and two photo-detectors. The output from the shaft encoder is used to control the frequency synthesizer; since the shaft encoder used in this transceiver has 180 slots, the synthesizer tunes 18 kHz per complete dial revolution. For a more descriptive discussion of optical shaft encoders, see reference 8.

The two outputs from the shaft encoder are applied to the inputs of two 2N2222 transistors. The outputs — labeled phase 1 (ϕ1) and phase 2 (ϕ2) are used to feed the corresponding inputs labeled *slew in ϕ1* and *slew in ϕ2* in **fig. 17**.

The dc control board also includes a seven-second display timer so that whenever the frequency is changed and the display is not turned on, the LEDs will turn on for seven seconds to display the final frequency.

Since the thumbwheel switch and the LED display must show the digit zero when the synthesizer is set to 41 MHz, this is accomplished by the logic circuitry shown in **fig. 17**. The outputs labeled R and T in **fig. 17** are connected to the lower and middle tuner boards (**fig. 18** and **19**, respectively). These two boards have the necessary memory and display logic for the Hewlett-Packard 5082-7300 LED dot displays.

*The optical shaft encoder used in the transceiver was manufactured by Dr. Johannes Heidenhain GMBH in West Germany; it is available from their United States sales representative.

Internal construction of the optical shaft encoder. The LED light source is under the half-moon shaped shield on the left-hand side of the unit (right).

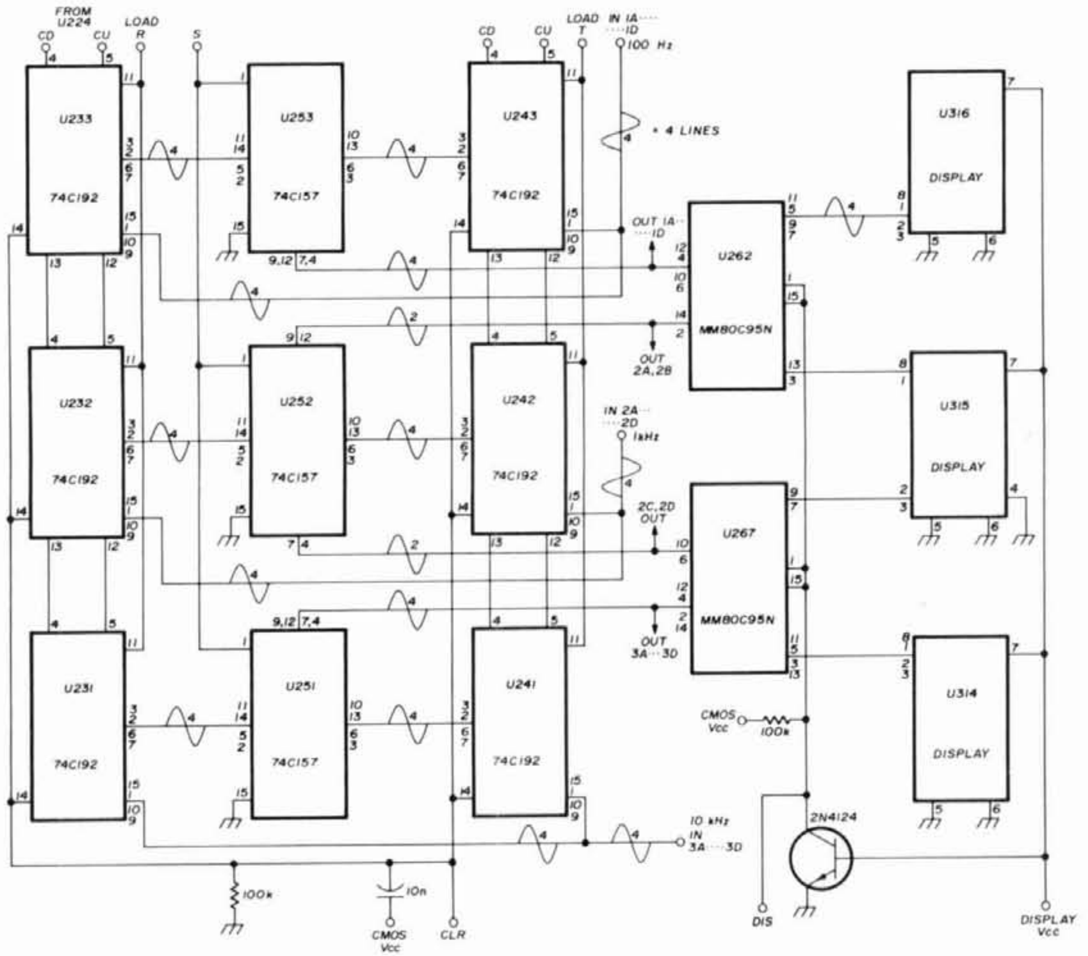
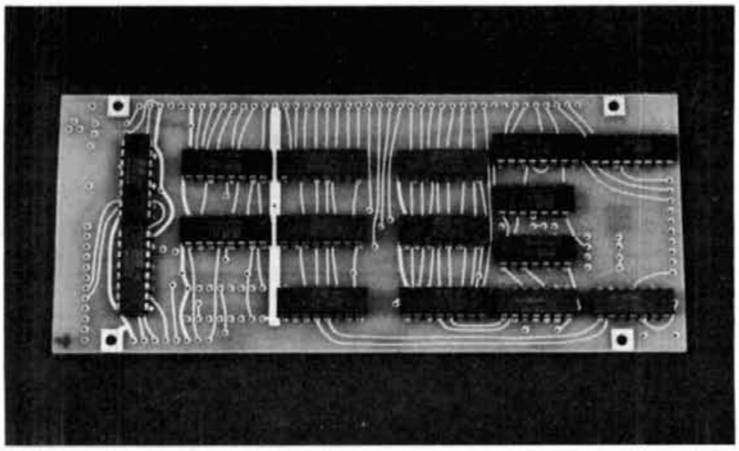


fig. 18. Middle tuner board with memories and decoding for the frequency synthesizer (100 Hz, 1 kHz, and 10 kHz digits).



Printed-circuit board for the middle tuner; other tuner board is similar.

The inputs from the thumbwheel switches to the memory are labeled 1A through 1D for the 100 Hz digit, 2A to 2D for the 1 kHz digit, and on to 6A through 6D for the 10 MHz digit.

summary

This transceiver was built more than a year ago, and since then it has been taken on a number of vacation trips, where it performed superbly, without difficulty, every time. The dual memory makes it ideal for DX operation because it allows for split frequency operation (receive and transmit can even be on separate amateur bands, if desired). The built-in power supply and nicad battery pack permit completely portable operation (this is the reason power input was limited to 20 watts); and the antenna tuner allows the use of a short whip or random wire antenna.

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ham radio

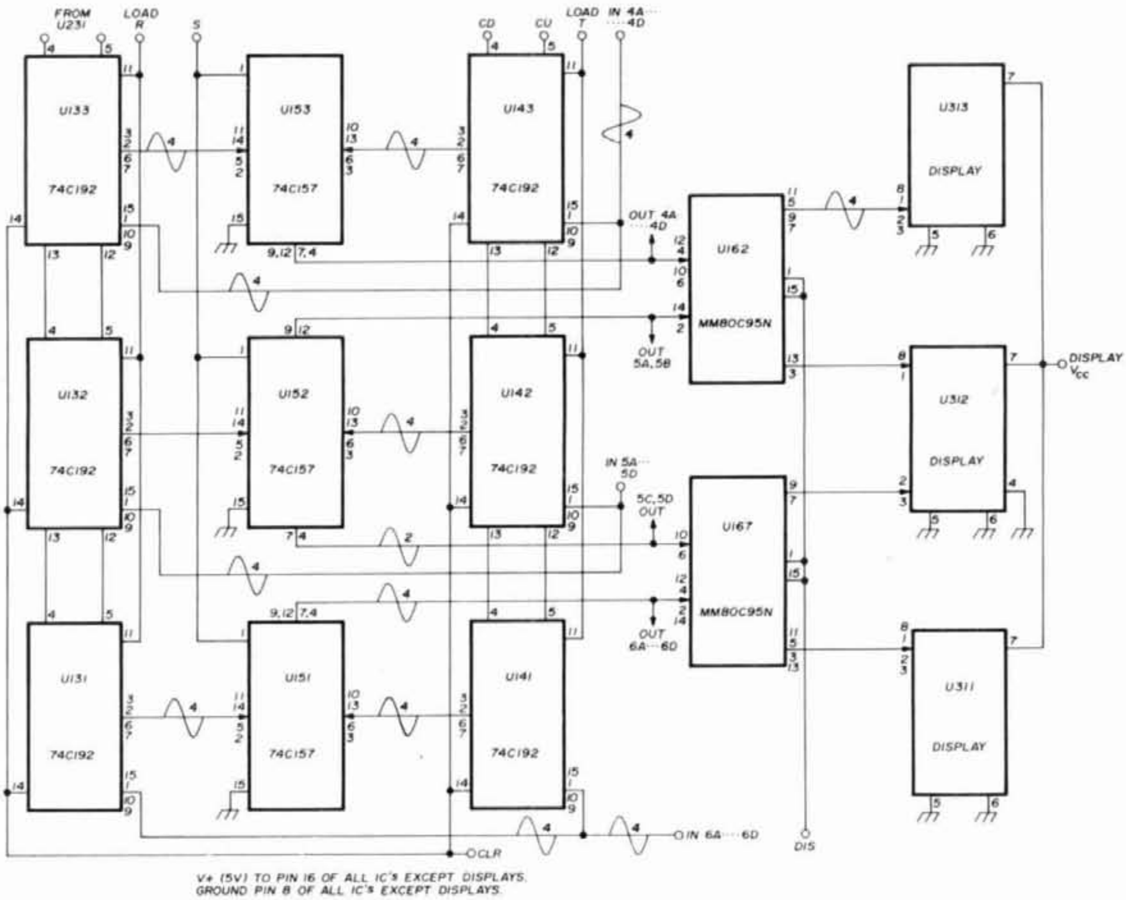


fig. 19. Lower tuner board with memories and decoders for the frequency synthesizer (100 kHz, 1 MHz, and 10 MHz digits).

a new approach to weak-signal communications

A new technique for obtaining solid copy during poor signal-to-noise conditions

For years, serious amateurs have been constantly improving their station capability. This is particularly true at vhf and uhf where noise figures have been honed to within a fraction of external noise, transmitter power and efficiency have been pushed to the limit, and antenna size now truly boggles the mind. We are now faced with the inevitable question of where does our next improvement come from, or are we at the end of the line for weak-signal work? This article will examine some of these questions and consider a possible approach which has not been previously applied to amateur work.

after the rf stage

In attempting to improve weak-signal capability the portion of the amateur station which has probably seen the least improvement, and possibly been the least understood, is that which follows the rf stages of the receiver. Let's start there.

Assume you are trying to copy a weak signal and can't quite hack it. What do you do? The most common idea is to narrow the selectivity to reduce the amount of noise coming through with the signal. This is perfectly valid and if you reduce the bandwidth by a factor of ten, you might expect to pick up 10 dB in signal to noise. Unfortunately, this is not the case — the improvement is considerably less.* There is some improvement, nevertheless, so the next question is how far can you go with this approach? Is there some limit, or can you continue to narrow bandwidth indefinitely and get as much weak-signal improvement as you desire?

bandwidth limits

There appear to be three possible limits when you narrow bandwidth to extreme values. The first is a practical limit that is set by the available state of the art (the matter of equipment stability and accuracy). It would be folly to design an i-f filter with a bandwidth of 2 Hz if the rest of the receiver (and the transmitter) couldn't set and maintain frequencies within that bandwidth!

The second limitation is built into the particular propagation mode you are using. In effect, propagation variations "modulate" the signal; in some cases propagation can cause a signal to have greater bandwidth than the narrow filter you are using. High-frequency signals are usually *narrower* than 2 Hz, but tropo scatter may easily be wider, and aurora is sometimes many hundreds of Hz wide.

The third limitation involves keying speed. If you narrow your filter far enough, you must also reduce keying speeds so that all the signal components will pass through the filter bandwidth. (Yes, CW has a frequency spectrum just like the newer, fancier models!) A good rule-of-thumb is that the keying speed in words per minute should be equal to the filter bandwidth in Hz. This also gives the best signal-to-noise ratio. If you were to narrow the filter any more (to cut out more noise) you would also begin to cut out signal components. If you increase band-

By Walter F. Bain, W4LTU, Route 2, Box 286, Lovettsville, Virginia 22080

*If receiver bandwidth were the only filtering in the act, this would be perfectly true. The human ear provides considerable additional filtering, however, so the *effective* bandwidth is substantially narrower than that of the receiver alone. When you further narrow receiver bandwidth, you are trying to pick up an improvement you largely already have.

width, you let in more noise for the same amount of signal.

Therefore, if you want to go down to bandwidths of 1 or 2 Hz to pick up the signal-to-noise improvement, you must go to some pretty slow keying speeds. This should not be considered a genuine limitation, however, for amateurs who want a contact badly enough will go to outlandish lengths; a typical vhf meteor scatter contact may average only a few words per hour!

These, then, are the limitations to improving signal-to-noise ratios by bandwidth narrowing techniques. Since there is not a sizeable improvement available before these limitations show up, where do we go from here?

a closer look

First, are we attacking the right problem? Let's closely examine just what happens when the signal-to-noise ratio is not adequate. Assume that bandwidth and keying rate have been optimized; the detected waveform (without noise) would look much like that of **fig. 1A** where the characters are fully rounded by the filter. For ease in handling let's square-up this detected wave to get back to a square-wave corresponding to the original keying waveform, **fig. 1B**. For the discussion that follows, it is essential that the signal be in binary form, corresponding either to key-up or to key-down.

I am also going to dispense with the idea that the signal is made up of dots and dashes. Instead, I will define it in terms of the shortest element it contains, which is called a *bit*.* A dot happens to be one bit, a dash is made up of three bits. The space between the dot and dash is also one bit although it happens to be a key-up bit. Normal spacing between letters is three bits (key-up). This may be somewhat different from the way you usually look at International Morse, but it allows each element to be treated separately.

Now let's get back to the effects of not having adequate signal to noise. As the signal-to-noise ratio is decreased, some of the bits are in error; that is, they are reversed from what they should be, indicating key-up when they should indicate key-down, or vice versa (see **fig. 2**). Note that the bits can't come out with in-between values if the squaring-up was done correctly — only key-up or key-down.

*This shortest element is basic because it sets the bandwidth of the optimum filter.

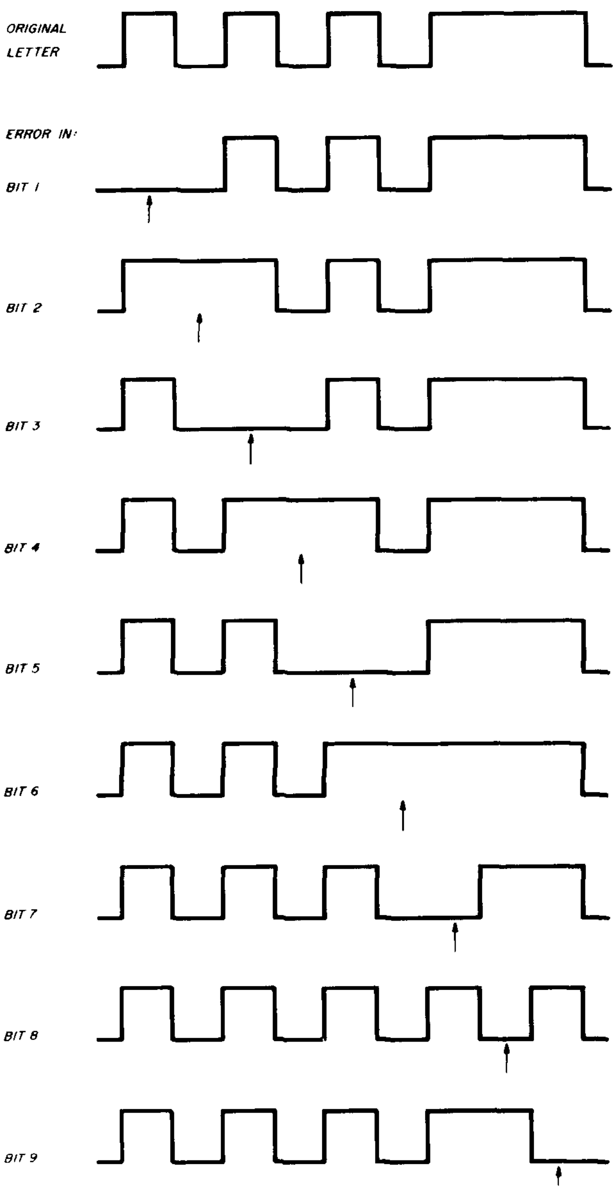


fig. 2. Effect of a single error on the Morse letter V; error in various positions.

Where, and how often do these errors appear when the *signal-to-noise ratio* gets too low? The errors are statistical in nature so we can state only the probability of error, or what per cent of a large sam-

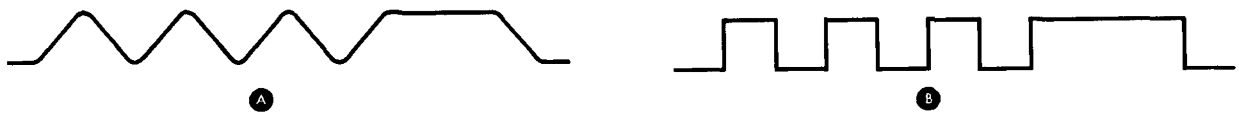


fig. 1. Detected waveform of the Morse letter V, optimized bandwidth (A). At (B) is the same waveform after being squared up.

ple of bits will be *in error*. This probability of error (Bit-Error Rate or BER) increases as the signal-to-noise ratio decreases, and it is possible to draw curves of BER *vs* signal-to-noise ratio as shown in **fig. 3**. Is this an actual measure of our weak-signal limitation rather than just signal to noise? Not quite; there's one more thing to be considered.

Assume the BER is 1 in 100 (a group of 100 received bits is likely to contain 1 bit error). This sounds pretty good, but remember that 100 bits make up about 8 letters or characters in International Morse.

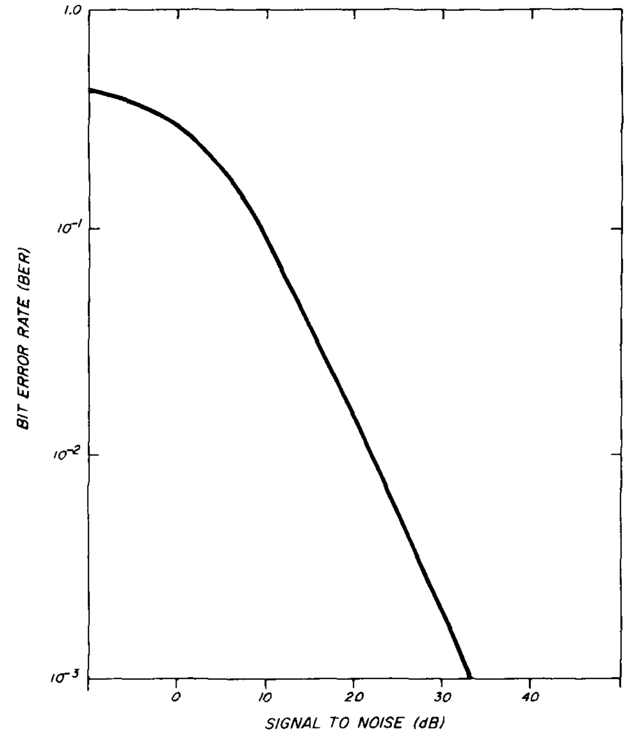


fig. 3. Bit error rate (BER) vs signal-to-noise ratio, fading signal.

Therefore, this one bad bit, wherever it may fall, is likely to foul up one whole character out of 8. This means that the Character-Error Rate (CER) is 1 in 8, which is not so good! Now we have arrived at a basic measure of weak-signal performance: the signal-to-noise ratio determines the BER, and the BER in turn sets the CER. It is the CER that actually limits our ability to communicate.

a new approach

Now that we have struggled through optimum bandwidth, bits, BER, and CER, are we any closer to a solution to the original question of how to further improve weak-signal capability? Perhaps. Instead of the perpetual struggle to improve signal-to-noise ratio, we now have a new handle on the problem and can wrestle with CER instead. Let's ask a new question: "How can we *improve* CER for the *same* signal-to-noise ratio?"

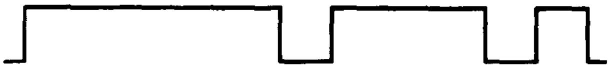


fig. 4. Received Morse letter with a single error.

Fig. 4 shows a Morse character which has been mangled by a single error. Amateurs have always been skillful at salvaging and improvising, so let's see what can be done with this rather badly damaged character. Let's first eliminate any characters which it could *not* have been.

1. It can't be the letter Z because it differs from the garbled letter in bits 4, 6, and 8 (the character has only one error, and it can't be in three places at once).

2. It can't be the letter X either, as X differs at bits 4, 8, and 10.

3. Neither can it be a mangled O because of differences at bits 4, 6, 8, and 10. It would require *four* errors to change an O into the character of **fig. 4.**

4. It can't be any of the shorter letters such as U, R, D, W, G, K, V, F, L, B, M, H, A, N, S, I, T, or E, as the 3-bit spaces on either side of the letter accurately define its length. It can't be any of the longer letters, J, Y, or Q for the same reason. (The effect of errors on the spaces will be discussed later.)

Even though the letter was mangled, there was enough left of it that we were able to eliminate 24 letters which it could *not* have been! The only two re-

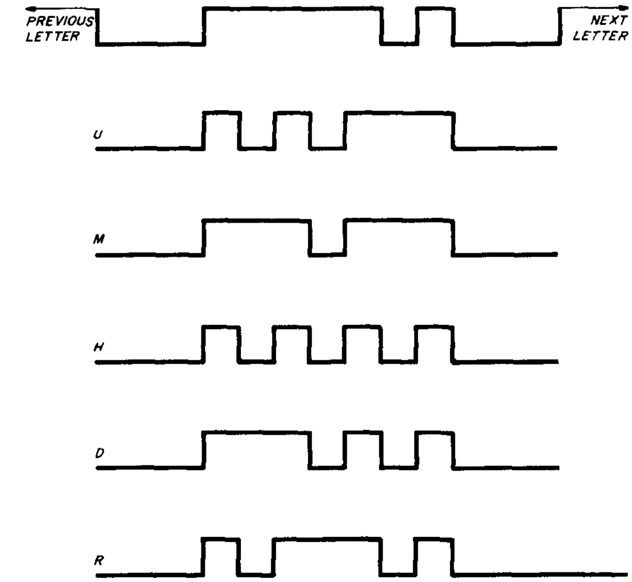


fig. 5. Received 7-bit Morse character with a single error (top), compared with 7-bit letters it could be.

maining letters are P or C; it could be a P with an error at bit 2, or a C with an error at bit 4.

What did this exercise accomplish? Instead of the letter being a total loss, enough has been recovered to narrow the choice down to one of only two letters. This is an improvement from about 4 per cent to 50 per cent.

a possible solution

This looks promising, even if we only partially recover copy which would otherwise be lost. And nothing has been done to improve the signal-to-noise ratio! But was this just a fluke? Is it possible to pull this off with other letters? Let's try another example and see.

Assume you receive the character shown in **fig. 5**. The error rate is such that the average is one error per character. The 3-bit spaces are intact so this is a 7-bit character; shown below it are the 7-bit characters it might be:

1. It can't be a U which differs in three separate bits.

2. It can't be an M either; this differs in two bits, too much to be caused by a single error.

3. H doesn't fill the bill — it differs in two spots.

4. D and R differ in only *one* position from our unidentified character and this *can* result from the single error.

So once again it has been possible to take a mangled Morse character and narrow it down to only two possibilities; in this case it is either a D or an R.

Do all International Morse characters have this capability? Let's check out a character like H. **Fig. 6** shows that an error in just one bit will not only garble the character, but will actually transform it into some other character which then appears flawless. This is particularly insidious, as there is no way to determine by simple examination that an error is present, much less correct it. (The occurrence of errors is statistical, so although an error may be probable, it is not guaranteed!) The letter H is so bad in this respect that a single error almost anywhere transforms it into another character(s) which appears valid (an error on bits 3 or 5 makes it look like two perfect letters, EI or IE).

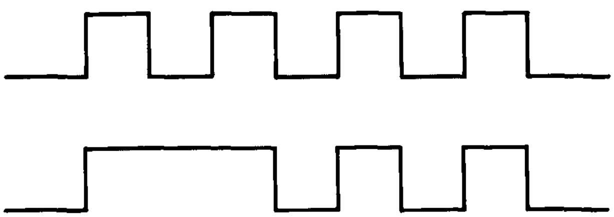


fig. 6. One effect of a single error on the Morse letter H.

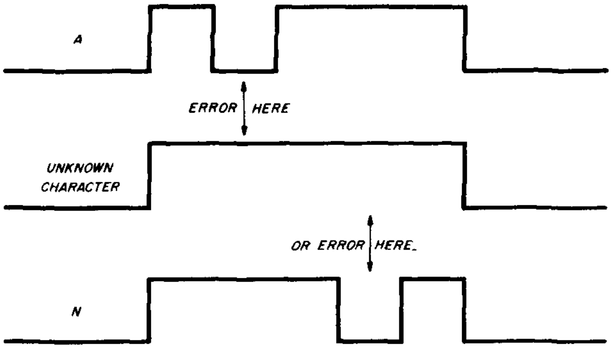
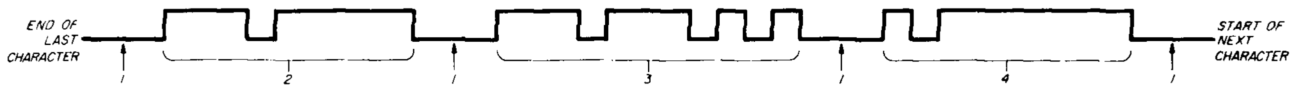


fig. 7. Possible ambiguity resulting from a single error when the Morse characters differ in only 2 bits.

Therefore, it appears that not all Morse characters can be narrowed down to a few possibilities after suffering an error. Is there some way of measuring or evaluating the ability of a character to do this? If you look at **fig. 5** and **fig. 6** you see that the "good" characters had a fair number of bits which differed from the bits in the corresponding positions in the other characters. The "bad" characters such as H have the fewest number of corresponding bits which are different. This is logical, for if a large number of bits differ, then a single error in any position cannot overcome the overall difference. If only a few bits differ, then an error is more likely to cause a change that cannot be resolved. It is this difference which allows us to narrow down the number of possibilities as to what the character actually was before the error. The greater the number of differing bits, the more distinctive the character is.

Just how much difference is necessary to survive the effect of a single error? Since a single error can reduce the difference by only a single bit, you might think that one additional bit-difference would suffice to identify the character. Unfortunately, the one error could just have easily hit the *other* character on the *other* difference bit to yield the same mangled character — you would never know the difference. Perhaps an example would clarify this. The characters A and N differ in two bits, 2 and 4. If you receive an unknown character as shown in the center of **fig. 7** you have no way of knowing whether it is an A with an error in the second bit, or an N with an error in the fourth bit. Therefore it is actually necessary for the Morse character to have differences in at least *three* bits to be sure of correcting a single error.

This provides the basis for a method of measuring the ability of a Morse character to resist an error. It must differ from other characters in at least three corresponding bits. Let's go through the Morse alphabet and pick out the error-resisting characters. We must compare each character only with those of equal length, since it has been assumed for now that character spacing is error-free.



1. The three-unit spacers appear intact; this defines character length and makes it easier to decypher the garbled message.
2. Unless there is more than one error in the first character, this can only be a K or a G. Since K is not used in ERMA it must be a G.
3. The second letter is a perfect Z, but Z is not an ERMA character. It might be a P with four errors, or an O with 1 error. The chances of 4 errors per character are much less than 1 error per character, so it must be an O.
4. The third letter could be an L or a V with two errors, but since neither of these is an ERMA character, this can only be a W.

fig. 8. Short message showing the value of the Error Reducing Morse Alphabet (ERMA). The signal-to-noise ratio is so poor the copy averages 1 bit error per character. The correct copy is GOW.

It turns out that there is a unique alphabet of eleven Morse characters which are *immune* to a single bit-error. This Error Reducing Morse Alphabet (ERMA) is as follows:

E T S M R G W P O J J̄*

Does ERMA really work? Let's try a simple example and see. Assume the copy shown in **fig. 8** has been received badly garbled but we know it consists only of ERMA letters. The signal-to-noise ratio is so poor we are averaging one bit-error per character — "no-copy" if the conventional alphabet were being used.

By using ERMA it has been possible to recover copy that would otherwise have been lost. How is it possible to do this at such a poor signal-to-noise ratio? The ERMA letters have a greater *redundancy* than other Morse letters, so they convey character identification in more than one way. If part of the character is mangled, the *remaining part is still sufficient to identify the character.* The net result is that you can now tolerate a much lower signal-to-noise ratio and poorer bit-error rate but still maintain a useable character error rate; and CER is the basic measure of communications ability.

How many dB can be picked up this way? This is not a fair question because you cannot directly equate CER and signal-to-noise ratio. Rephrase the question: "For the same CER, what is the difference in signal-to-noise needed with ERMA and the signal-to-noise needed with a conventional alphabet?" For a CER of about 1 in 8, ERMA can tolerate a BER close to 10^{-1}. A conventional alphabet would require a BER near 10^{-2}. Checking back to the curve of **fig. 3**, this corresponds to an advantage of about 12 dB.

*J̄ (- •) is a perfectly good Morse character, although it's not used in English.

errors in character spacing

Now, what about that matter of the spacing between characters? I have been putting this off so far by always assuming that the error falls only within the characters and never within the space separating them. We should be so lucky! An error which falls in the center of a standard 3-bit space would neatly link two characters, making it impossible to sort out. Two characters would be lost by just one error!

This problem is greatly relieved, however, by the simple expedient of using an *even* number of bits between characters rather than the more traditional odd number of three bits. Four bits for spaces is probably the optimum value. Two bits would run a greater risk of *linking* errors, and six bits is probably more than necessary.

The use of an even number gives a significant advantage by a rather subtle means. The bit stream for each character is in effect *slipped in phase* relative to the previous character. This is best shown in **fig. 9** where a series of Hs and Ss are drawn, first with 3-bit spacing and then with 4-bit spacing. Note that with the 4-bit spacing the phase slip causes the bits of one character to occur in *even*-number positions and

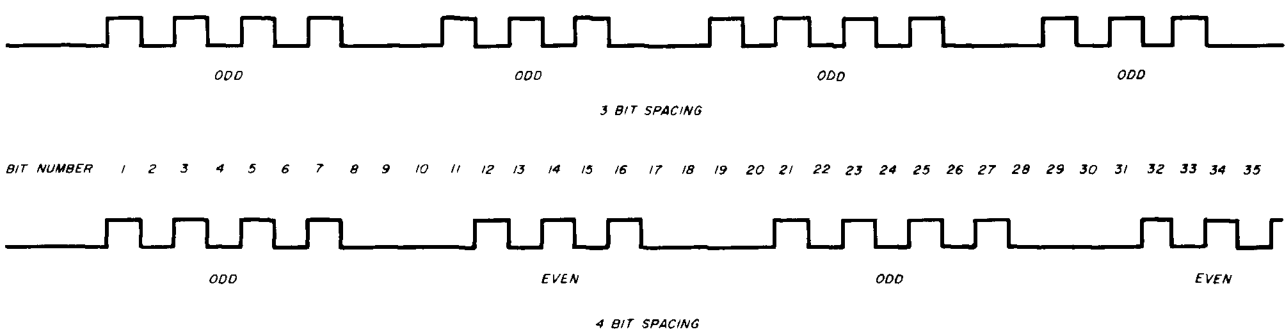


fig. 9. Comparison of 3- and 4-bit spacing, showing the odd-even "phase slip" that occurs between characters when 4-bit spacing is used.

those of the next character to fill *odd*-number positions, etc. This is a big help in sorting out characters during heavy error conditions. On the other hand, the 3-bit spacing makes this impossible.

Let's now give ERMA a real baptism of fire by letting the errors fall where they may. **Fig. 10** shows a set of ERMA letters, 132 bits in total length. To simulate a BER of 1 in 11, a total of 12 errors have been inserted at randomly determined positions. Character spacing is 4-bits throughout. (Before you tackle this you may want to look through the **appendix** which gives some hints on spotting errors.)

using ERMA

Having struggled along this far, you are entitled to ask an obvious question; "How in the name of Samuel F. B. Morse are we supposed to actually communicate using this alphabet of only 11 letters?"

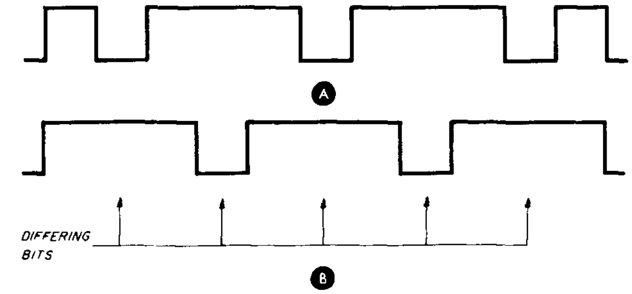
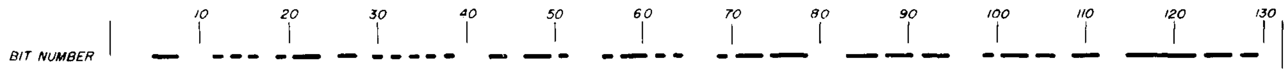


fig. 11. Differing bits for the ERMA letters P and O.

If your call is W6PO you might have a chance, but if you have a combination like W4LTU you would be out of luck.

There is nothing sacred about any alphabet, including ERMA; it's just a set of symbols that stand for something else. Let's treat the ERMA alphabet as



bits	
1-11	No problem — clean 4-bit spacers with a T in between.
8-18	The second spacer is only 2 bits long so has an error. It's possible that bit 16 is in error, but then the letter would be an I (not ERMA) or another T with an additional error (2 total). More likely there is a single error in bit 19 and the letter is S.
17-42	This is badly garbled; there is obviously more than one letter and several errors. To sort it out start at bit 21 and work carefully several bits at a time.
21-27	Bits 21 to 23 could be a T, but it's followed by a 2-bit spacer. Perhaps bits 26 and 27 are errors (to give 4-bit spacing) but in that case bit 28 must also be an error if the next character starts there; requires 3 errors to justify the letter T which is unlikely. If bit 25 is an error, the letter is M and no other assumptions are required. (Note that the letter is not likely to be the letter G as the following bits are "out of phase," indicating a new letter has started.)
28-31	The spacer following is only 2 bits, indicating an error. If bits 21 to 27 are the letter M, then the error must be at bit 30 for a 4-bit spacer.
32-38	This is a perfect H but is not used in ERMA. It could be an M with 2 errors, or an R with 1 error. Following the rule of assuming the least number of errors, it must be an R.
39-55	There's obviously a problem here because of the 2-bit spacer in the middle. If it's assumed there are two characters with a 4-bit space, however, there are even more inconsistencies; any efforts to extend the spacer to 4 bits results in 2-bit dashes or an 8-bit spacer, both impossible. This is the result of the out-of-phase effect which indicates there are not two characters, but one. Therefore, the 2-bit gap is not a mangled 4-bit spacer but a 2-bit gap within a single character. This makes it easy; bit 45 is in error and the character is G.
52-68	Perfect spacers and a perfect L, but L isn't used in ERMA so there is an error. The simple solution is that there is a single error in bit 63 and the correct letter is W.
65-83	This may look alright at first glance, but note that the last dash is 4 bits long and the following spacer is 5 bits, both impossible. If a 4-bit spacer is assumed by correcting bit 83, some impossibilities are generated in the following character. Therefore, it is corrected by assuming bit 79 is an error; this gives a 5-bit dash at the end of the letter, but neatly breaks down to a 3-bit and a 1-bit if bit 78 is also an error. The character is a P with errors at both bit 78 and bit 79.
80-98	No errors here; it's a perfect ERMA letter O. Assume no errors if there is no evidence of them.
95-114	This might be two letters, but if it's corrected to something like RT there is only a 3-bit spacer between the letters. There is no way to insert a 4-bit spacer without causing other problems. This indicates that all the bits in this group are in phase and it must be a single character. There is a single error at bit 107 and the letter is J.
112-132	There are obvious problems here. Both spacers have only 3 bits; also within the group is an 8-bit dash and a 2-bit dash. Remember that the previous character was a J, ending at bit 111. Therefore, the 4-bit spacer must extend through bit 115, which must be an error. This leaves a 7-bit dash (bits 116 through 122). This might be an R with two errors, or an M with one error (these are the only two ERMA possibilities). It is followed by a flawless 3-bit dash, however, which must be a part of the character. The 2-bit dash which follows must also be taken into account. This is resolved by working back from the start of the following character (not shown) to get a 4-bit spacer; this requires that bit 129 is in error. Then if it falls into place — it's the lengthy letter J with errors at bits 115, 119, and 129.

fig. 10. A message sent with the ERMA characters, total length of 132 bits. The bit-error rate is 1 in 11 (error positions randomly chosen). Four-bit character spacing is used throughout. The analysis shows that ERMA provides solid copy at a bit-error rate which would have given about 30 per cent copy with the conventional Morse alphabet.

just that, a set of symbols which can be used to spell out the normal alphabet. To do this simply arrange a 5x6 *matrix* with two ERMA letters serving to define each letter in the normal alphabet.*

	G	W	P	O	J	$\bar{J}$
R	A	B	C	D	E	F
M	G	H	I	J	K	L
S	M	N	O	P	Q	R
T	S	T	U	V	W	X
E	Y	Z	1	2	3	4

For example, if you wanted to send the letter W, you would send the ERMA pair: TJ. This technique slows down the rate of communication, but remember that one of the assumptions made earlier was that you were willing to slow down if you could improve your weak-signal capability.

There is yet another scheme for using the ERMA advantage that is even simpler. Still thinking in terms of symbols, why not use only two ERMA letters, one representing a dot and the other a dash? This reduces speed even further, but if that bothers you, send the ERMA letters at a faster rate; you still come out ahead.

This last scheme leads to another point concerning ERMA. If you plan to use only two of the eleven letters, is there any best choice? You might assume the shortest characters are the best because they offer the least speed reduction. However, not all ERMA letters were created equal. In **fig. 10**, where ERMA was given its baptism of fire with noise, sharp-eyed readers may have noticed that certain ERMA letters were easier to salvage than others. A ponderous letter like J, for example, has enough redundancy that it can actually withstand two errors anywhere within the character and still be recognizable. On the other hand, the letter E survives only if its spacers are reasonably intact.

What governs this degree of error resistance? Again, it is determined by the number of bits that are different from the corresponding spots in other letters. Earlier I showed that a difference in 3 bits is necessary to survive a single error. It turns out that a difference in 5 bits gives full immunity to two errors. **Fig. 11** shows this in comparing the letter P and the letter O. Note that in five positions the bits are different in the two letters. This guarantees that no matter where the two errors strike you can still positively identify the letter.

Extending this idea, a difference in 7 bits is needed

*If you insist on having a full set of numbers available, you can use ten ERMA letters to form a three-dimensional matrix, 3x3x4, to give you a full 36 letters and numbers.

†Minimum, depends on spacers and adjacent letters. For other ERMA letters, values given are for the letter alone.

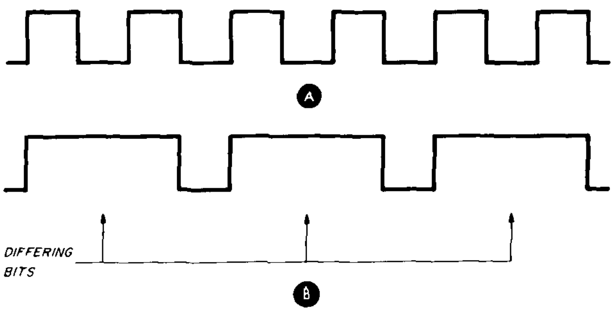


fig. 12. Differing bits for a simple repetition of dots (A) and dashes (B).

to correct three errors; a difference in 6 bits corrects two errors and in addition will detect a *third error* but not tell you where it is! The following tabulation clearly shows the advantage of using the longer ERMA letters:

letter	number of different bits	number errors it can withstand
E,T,S	3†	1
M,R	3	1
G,W	4	1
P,O	5	2
J,$\bar{J}$	6	2

Why not simply use repeats? Well, if you are going to use two high-redundancy ERMA letters, such as P and O, to stand for dots and dashes in sending a conventional alphabet, there is another obvious question. If you take the time to send the entire letter P when you want to convey a dot, then why not just use that same amount of time to send a string of dots? Wouldn't this simple repetition of what you actually want to send be even better? Amateurs have been making good use of repeats for many years; isn't it just as good as this ERMA routine?

Let's take a look at both methods and compare them. Remember that the ability of a Morse character to survive errors depends on the number of bits in which it differs from other characters. The more bits that are different, the more errors it can survive and still be read correctly; the ERMA letters P and O differ in 5 bits so they can survive two errors and still be readable.

Now let's try the method of simple repetition. **Fig. 12** shows a string of dots of the same total duration as the letter P or O. Below the dots is a string of dashes; you must be able to tell the difference even with errors present. Note that the string of dots and the string of dashes differ in only *3 bits*, so can survive only a *single* error. Thus the ERMA letters P and O show a greater error immunity than simple repetition of the same duration! This advantage also holds for other length Morse characters. The ERMA letters M and R can survive a single error, but a similar length of repeated dots and dashes cannot correct *any* errors. For longer lengths, the advantage of ERMA is even greater.

summary

Let's try to quickly recap what I've covered in this article; those of you who have stuck with it this far deserve every possible break!

1. Narrowing bandwidth helps, but there are limits.

2. Errors appear in individual bits — Bit-Error Rate or BER.

3. Each error can wreck an entire character — Character-Error Rate or CER.

4. CER limits ability to communicate; attack it, not signal-to-noise ratio.

5. Certain characters are more resistant to errors than others.

6. Evaluate error resistance and select only the best letters — ERMA.

7. Use ERMA to convey the conventional alphabet.

8. ERMA is better than simple repetition.

ERMA and similar techniques can allow amateurs to greatly improve weak-signal capability without the burden of staggering increases in hardware costs. *These techniques can be either applied to existing* bandwidths, or added to optimized bandwidths. As long as the detected signal is squared up to binary form, the method can be applied anywhere. Remember those immortal words, "To err is human, to correct is divine."

appendix

Following are some guidelines for correcting errors in ERMA copy. They are not all inclusive, but are designed to provide a starting point.

1. If several possibilities exist, choose the one which assumes the least number of errors.
2. A single error cannot change an ERMA letter into another ERMA letter.
3. A single error cannot divide an ERMA letter into two ERMA letters.
4. A single error can only distort an ERMA letter or change it into a non-ERMA letter.

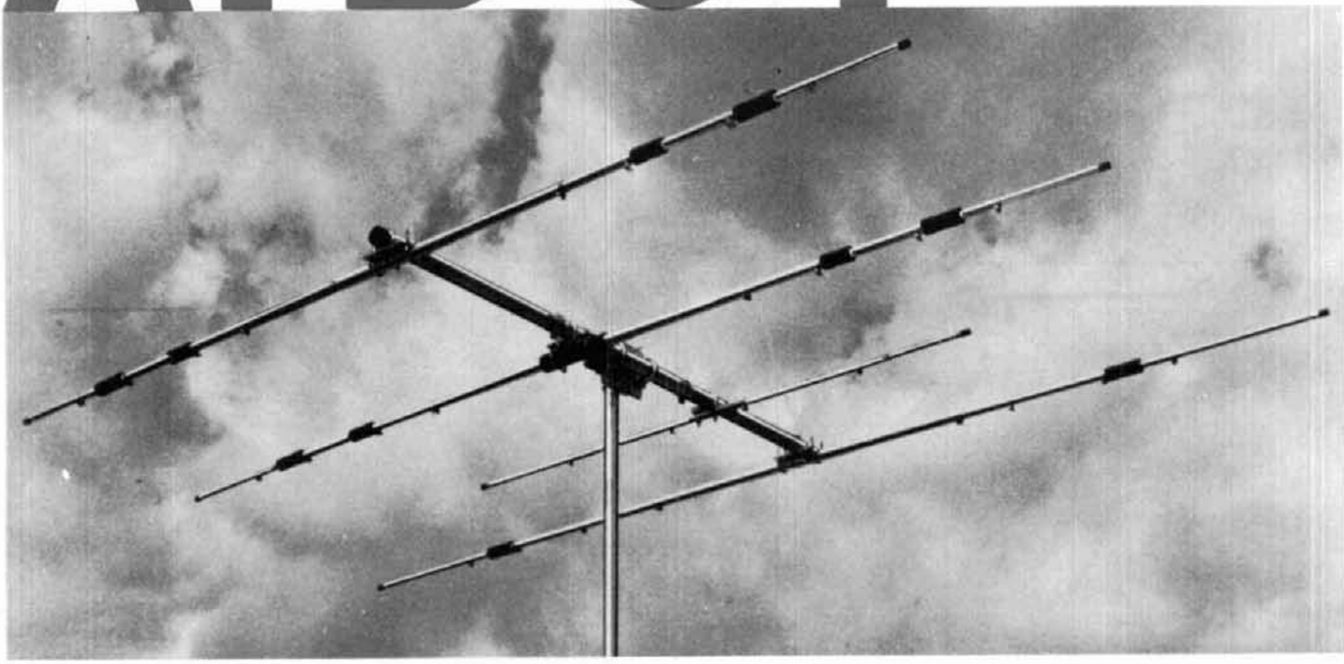
error indicators

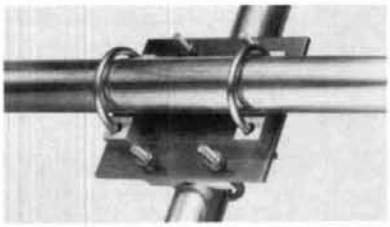
The following cannot exist in normal copy so are positive indicators that one or more errors are present, either within the given sequence or in a directly adjacent bit.

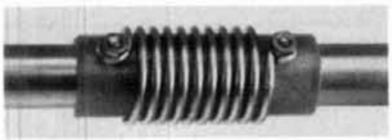
2-bit key-down	2-bit key-up
4-bit key-down	3-bit key-up
5-bit key-down	5-bit key-up
6-bit key-down	6-bit key-up
7-bit key-down	7-bit key-up

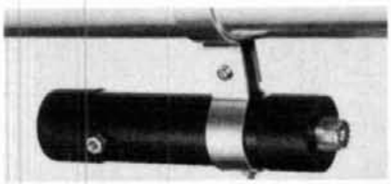
ham radio

ATB-34









More Details? CHECK — OFF Page 158

pi network design

Pi networks are used extensively in amateur rf power amplifiers — here's the recipe for a pi

Pi networks have been used extensively for years, primarily for coupling final amplifiers to antennas. Useful for impedance matching, pi networks can also be used with mobile antennas and at receiver inputs. Since the pi network is a lowpass filter, it can reduce TVI caused by high-frequency transmitters. Component values make all the difference in application so the ingredients should be selected with care.

Fig. 1 shows the general circuit and component value equations for the pi network. The equations differ slightly from the usual methods but will provide the desired match. Allowance of parallel capacitance at each end of the network will give direct results and accommodate strays or stray-plus-circuit capacitances. Values of C_a or C_o must be finite and depend on the application; stray capacitance is always present.

The Q in the equations is a *design parameter, not* the component Q. It's value selection will determine higher frequency rejection, the resistive or *real* part of impedance presented to a source, as well as component values.

Fig. 1 gives two choices in calculation, T (a temporary value) and R_6. T *must* be positive or at least zero for solution. Results giving a negative T require a change either in end resistance or Q, and possibly both; increasing an end resistance is preferable and ways will be shown later on how to handle that situation. The value of R_6 is dependent on which end resistance is highest. It will be negative if R_o is highest.

Reactances X_c and X_d must *both* be negative for a *solution. If a positive value results, parallel end capacitance may have to be changed. In most cases a positive value comes from calculation error, so use care in handling terms. Some sources may present a parallel end inductance; this must be shunted with a fixed capacitor to cancel it at the operating frequency. Handling this situation is discussed later.*

design example

Suppose a pi network is required for a 40-meter rf power amplifier. The amplifier has a tube type final; the center frequency is chosen as 7.15 MHz with design Q of 5. Initially

$R_o = 5000\ ohms$ (this will be the source end)
$C_o = 8\ pF$ (tube and socket stray capacitance)
$R_a = 50\ ohms$ (load end)
$C_a = 3\ pF$ (stray capacitance in connector)
$X_o = -2782.43\ ohms$
$X_a = -7419.81\ ohms$

Initial calculations result in $R_5 = 4950$ but $T = -18.25 \times 10^6$ so a solution cannot be done directly. The source end resistance is changed to 500 ohms but C_o is kept the same. This gives

$R_5 = 450\ ohms$	
$R_4 = 650\ ohms$	
$R_6 = -1850\ ohms$	
$X_L = 139.655$	$L = 3.1806\ \mu H$
$X_d = -127.181$	$C_d = 175.02\ pF$
$X_c = -56.6797$	$C_c = 392.72\ pF$

The design Q change was not done since this has other effects which are shown later. An R_o of 500 ohms might be alright for a transistor final but it won't fit the tube circuit. Fortunately, there's an alternative.

cascading and the virtual resistance

Two networks can be cascaded so the load end of one network becomes the source end of the following network. The latter has been calculated so we can try for the first with

$R_o' = 5000\ ohms$
$R_a' = 500\ ohms$ (to match the example given)

By Leonard H. Anderson, 10048 Lanark Street, Sun Valley, California 91352

The same values of X_o and X_a can be used again, assuming the same stray capacitance; it is always best to stay on the high side for strays. The new network with same frequency and design Q has values of

R_5'	$= 4500$	X_c'	$= -705.030$
R_4'	$= 6500$	L'	$= 31.086\ \mu H$
R_6'	$= -18.5 \times 10^3$	C_d'	$= 10.302\ pF$
X_L'	$= 1396.55$	C_c'	$= 31.572\ pF$
X_d'	$= -2160.65$		

The manner of cascading is shown in **fig. 2**. The center resistance of **fig. 2A** is termed the *virtual resistance*. It's value is $R_a' = R_o$ but it does not appear physically in the circuit; virtual resistance is a mathematical technique which allows cascading of networks and must be the same at each network's design frequency.

Parallel capacitances at the midpoint can add. This also includes any assumed strays. Total C_m for both networks is 217.59 pF; you could assume a stray of 3 pF at this point since it is physically only one capacitor. Total network response calculations require the sum of all capacitors in parallel, including strays.

what happens in tuning?

Most pi network designs have a fixed inductor or at least a fixed value per band. The two capacitors nearest the antenna are made variable to accommodate impedance differences at the antenna. Each pi network design has different limits of equivalent parallel resistance that it will match. To find the resistance limits with a fixed inductor, the inductance equation can be solved for Q

$$Q = \frac{R_o + R_a + 2\sqrt{R_oR_a - X_L^2}}{X_L}$$

This presents two unknowns: Q and R_a. Minimum R_a occurs when the square-root term reduces to zero. This also reduces the minimum Q equation to

$$Q_{min} = \frac{X_L^2 + R_o^2}{X_LR_o}$$

This brings up an interesting point when the inductor is held at a fixed value: matching to a lower load resistance will result in a lower Q than originally planned! Also, matching to a higher load resistance results in a higher Q. This case is found by letting $R_a = nR_o$ so that

$$Q_{high} = \frac{R_o(n+1) + 2\sqrt{nR_o^2 - X_L^2}}{X_L}$$

where n is an arbitrary fraction giving practical R_a, but must be less than unity.

By now it is apparent that minimum load resistance is the critical factor in pi network design. It can be found by solving the first Q equation's square-root term group to yield

$$R_a(min) = X_L^2/R_o$$

Taking the first network example (500 to 50 ohms) with a fixed X_L and solving for minimum load resistance:

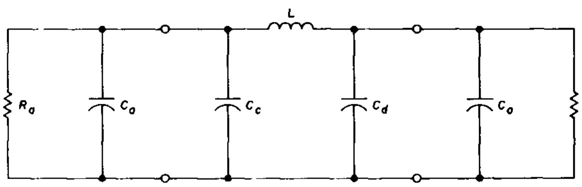
$$R_a(min) = 39.0070 \text{ ohms}$$
$$Q_{min} = 3.85956$$

Capacitor values are then found by recalculating everything except inductive reactance:

$R_5 = 460.993$	$X_c = -142.334$
$R_4 = 279.309$	$C_d = 151.30\ pF$
$R_6 = -1650.47$	$C_c = 156.39\ pF$
$X_d = -147.035$	

As a shortcut, the minimum R_a case will result in total end capacitive reactance equal to the inductive reactance. The high end resistance, letting $n = 0.5$, gives

$R_a(high) = 250$ ohms	$X_d = -87.3164$
$Q_{high} = 10.0219$	$X_c = -61.2418$
$R_5 = 250$	$C_d = 254.93\ pF$
$R_4 = 3534.44$	$C_c = 363.47\ pF$
$R_6 = -1476.50$	



NETWORK

$X_o = -1/(2\pi F C_o)$

F = CENTER FREQUENCY

$T = R_o R_a Q^2 - R_5^2$

$R_4 = \sqrt{T}$

$X_L = \dfrac{Q R_o R_5^2}{R_5^2 + R_6^2}$

$X_o = -1/(2\pi F C_o)$

$R_5 = R_o - R_a$

SEE TEXT IF T IS NEGATIVE

$R_6 = R_4 - R_o Q$

CHOOSE

R_6 NEGATIVE

$$X_d = \frac{X_o R_o R_5}{X_o R_6 - R_o R_5}$$

$$X_c = -\left[\frac{R_a X_a R_5}{X_a(R_6 + R_5 Q) + R_5 R_a}\right]$$

R_6 POSITIVE

$$X_d = -\left[\frac{X_o R_o R_5}{X_o R_6 + R_o R_5}\right]$$

$$X_c = \frac{R_a X_a R_5}{X_a(R_6 - R_5 Q) - R_5 R_a}$$

fig. 1. Pi network and its design equations. The equations are from reference 4.

High resistance capacitor values *seem* wrong since they are higher than the original 50-ohm values. This is a result of keeping the inductor at a fixed value; each network will match the 500-ohm source at 7.15 MHz. Also, and important for harmonic suppression, the Q will change.

what to do about load reactance

No antenna is perfect so you can expect the reactance to change as well as the resistance. Capacitor C_c will compensate for antenna parallel reactance. If the antenna (or transmission line) reactance is capacitive, C_c is reduced; if it is inductive, C_c is increased. For practical variable capacitor values, the change should be around 50 per cent of C_c.

In this example the C_c range will be about 78 to 590 pF or 7.5:1, maximum to minimum. This is practical but we have found a definite lack of matching ability for the low resistance case. Maximum allowable vswr for that condition will be only 1.28:1 and an additional matching network may have to be added. Capacitor C_c alone will take care of parallel reactance but both capacitors must be changed for parallel resistance and reactance other than 50 ohms.

thinking in terms of admittance and the vswr circle

Antenna impedance can be represented by series equivalents of $R+jX$ or parallel equivalents $G+jB$ in admittance form. The admittance form is a bit easier to think of since the pi network has a load-end shunt variable.

The Smith chart is invaluable for seeing what happens with a network when the load changes. **Fig. 3** is a normalized Smith chart showing the admittance matching range of the first example (dotted line). Normalization merely means that all conductance and susceptance values have been divided by 0.02 mho (50 ohms) since we are really concerned about the ratio of antenna admittance to a target value. Target admittance (or impedance) is usually the transmission line as well as design goal of the antenna.

Tranmission line length is usually arbitrary. Vswr is a ratio of actual admittance magnitude to a desired value or target. Neglecting line losses and assuming arbitrary line lengths, the antenna admittance will appear somewhere on a circle whose center is that of the chart with a radius determined by distance from center to antenna admittance. This is the vswr circle.

If you don't have an RX noise bridge but do have a fairly accurate vswr indicator, there is a shortcut to finding the radius; use a compass or divider and draw it using the normalized R or G line numbers higher than 1.0 for the vswr radius.

The matching area of the example is rather lopsided. You could match any vswr up to 5:1 by simply changing the transmission line length. This would move the matching area to wherever desired. The problem is that you have to measure the line end admittance to find out which way to move.

A better choice for a final amplifier network is to try for a symmetrical matching area on the chart. A 2:1 vswr is a reasonable design goal. This fits many antennas and line lengths don't have to be juggled.

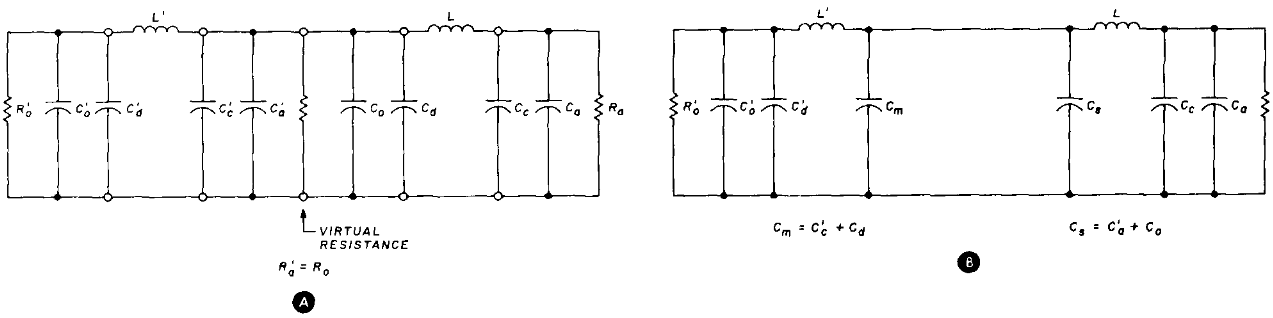


fig. 2. Two pi networks in cascade are shown at (A). Combined pi networks are shown in (B).

new component with an old circuit

A rule of thumb is that low R_o:R_a ratios yield lower possible $R_a(min)$ values with a fixed inductor. A variable inductor could be used, of course, but this adds another tuning element and possible mechanical problems. A pi network for a vacuum tube usually needs two networks in cascade so a low R_o:R_a ratio can be achieved by changing the virtual resistance, but there is another way.

A 4:1 toroidal balun with broadband characteristics will reflect an equal ratio of both conductance and susceptance. In addition to transforming impedance from 50 to 200 ohms, a well-insulated transformer is useful for draining off static charges during thunderstorms.

The modified cascaded network using the balun is shown in **fig. 4**. The admittance matching area of this circuit is shown by the solid outline in **fig. 3** and is just short of meeting the 2:1 vswr goal. Calculation is done with a load resistance of 200 ohms since the modified network sees this through the balun.

Target values at 7.15 MHz, design $Q=5$, $R_o=500$, and the same stray capacitance as before are

$R_5=300$	$X_c=-110.227$
$R_4=1552.42$	$L=5.0697\ \mu H$
$R_6=-947.583$	$C_d=132.62\ pF$
$X_L=227.753$	$C_c=201.94\ pF$
$X_d=-167.847$	

Holding the inductor fixed and calculating the minimum R_a gives

$R_a(min)=103.743$ (25.9357 at the line)
$Q_{min}=2.65087$
$C_d=89.735\ pF$
$C_c=94.735\ pF$

Since minimum R_a is very close to a 2:1 vswr, n is set to 0.8 for an $R_a(high)$ of 400 ohms or 100 ohms on the other side of the balun. High resistance values are

$Q_{high}=7.33141$
$C_d=164.97\ pF$
$C_c=188.77\ pF$

Calculation at equivalent line resistances of 30, 40, and 75 ohms shows that C_c and C_d will be maximum at 25.9 ohms. The C_d minimum occurs at 100 ohms but C_c minimum is close to the 50-ohm design target (it increases slightly going towards 100 ohms).

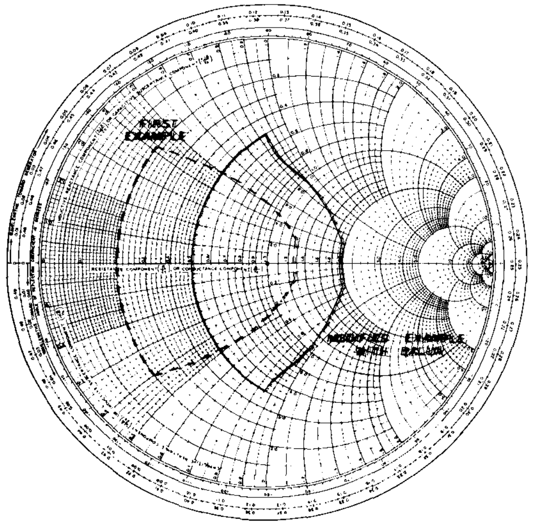


fig. 3. Admittance matching range of the pi network discussed the first example in the text (dashed lines). The solid lines show the modification of matching range available by using a balun.

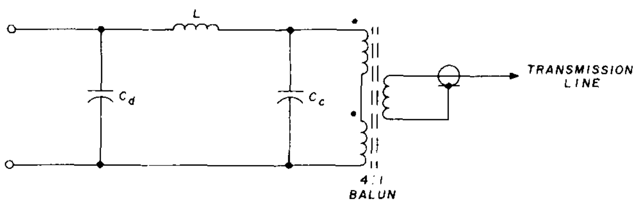


fig. 4. Basic arrangement of 4:1 balun between the transmission line and the output of the pi network.

Using a 50 per cent variation of C_c to compensate for variations in line susceptance requires a practical range of 55 to 342 pF, easily obtainable. C_d must cover 135 to 248 pF if used in a single network. The single network matching area is shown in **fig. 3**. Cascading networks allows a slight increase in area. If this is done, the virtual resistance must change in calculations but another penalty occurs: three variables are required for tuning.

Q and harmonic suppression

Harmonic suppression varies with design Q; and the design Q varies with tuning when a fixed inductor is used. As a general idea of Q change with tuning, the first example's voltage response is shown in **fig. 5**. This set of curves must be considered on the basis that the data assumes *both* load and source resistances remain constant with frequency. In actual fact, both load and source admittance is frequency sensitive. Sensitivity varies with the final amplifier circuit and antenna when used in a transmitter. A general rule of thumb is that antenna admittance variation at harmonics will make little difference in suppression. An exception might occur if the feedpoint of the antenna is at a voltage node at a harmonic. Effect is still slight.

The major effect of the pi network at harmonics occurs at the source end. Regardless of circuit, the network appears as a single, slightly lossy capacitor to the amplifier. The impedance of the first example at 14.3 MHz (the second harmonic) is $1.14-j79.5$ *ohms* looking into C_o and assuming a perfect load. Impedance at 21.45 MHz (third harmonic) is $0.08-j45.1$ *ohms* under the same conditions. The amplifier must be able to work at the fundamental frequency yet be stable with a capacitive load at harmonics.

Source impedance at harmonics is generally low and depends on the particular circuit. This is a separate analysis problem with many variations. The network still looks capacitive at harmonics.

It is a good idea, regardless of the amplifier circuit, to use two sections in cascade. The source-end section can use a lower design Q but retain the virtual resistance for cascading. C_o' is tuned just once, leaving C_m and C_a variable for matching. This increases harmonic suppression capability without adding more variables.

The normalized resistance and reactance of the first circuit example is graphed in **fig. 6** and assumed to be looking into C_o. Curves are for design *Q*s of 3.86, 5, and 10. Other circuits will show a slight deviation but the general effect is the same.

A general rule is that the resistance and reactance change slowly near band center for stability. Design *Q*s lower than 5 are preferred. This is achievable by using the two-section configuration with a low-*Q* source end. Variations to the source due to tuning are reduced.

Individual component *Q* should be high to avoid losses; component *Q* of 100 or greater is preferred. This is easy with capacitors but inductors should be toroids or airwound. A 0.3 dB loss is insignificant at the other end whether running 10 watts or a kilowatt, but that loss with a kilowatt means local heating of about 67 watts.

receiver applications

All that was said about transmitter applications applies here. Many expensive receivers are mismatched — the so-called communications receivers with 3:1 tuning bands show wide input impedance variations.

An RX noise bridge can be used to check a receiver input. The noise source itself should be padded to avoid overload and saturation, particularly with solid-state receivers, because overloading the front end can change the impedance reflected back to the antenna terminals.

Old receivers with 300-ohm input options should have the pi network placed there. Variations will still be found so the impedance must be checked.

An advantage gained in the high-frequency bands is a reduction of interference from nearby CB rigs when the receiver is used at 15 meters and below. There is some advantage gained in attenuation below

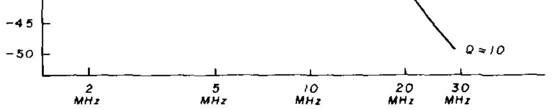


fig. 5. Voltage response of a pi network vs *Q*. Center frequency is at 7.15 MHz.

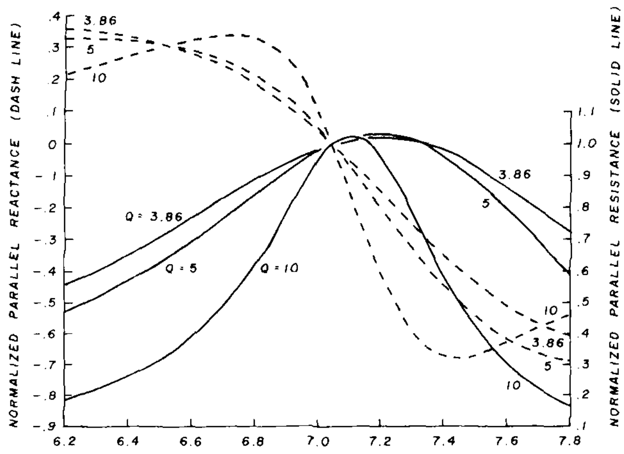


fig. 6. Normalized resistance and reactance vs *Q* around the design center frequency of the pi network (7.15 MHz in this case).

the center frequency due to mismatch loss. The input impedance to a pi network is reactive on either side of the center frequency, actual loss will depend on the antenna.

Mobile antennas in the high-frequency range can use the pi network in place of the common L-network. The same is true of short verticals. It is wise to use a wideband 4:1 balun with a bridge in measuring such antennas because of low resistances. Don't forget to divide the impedance by 4 (or multiply with admittances) when using the balun.

Interstage matching in any amplifier chain can also be done. Higher design *Q* can be used, but with caution: the reactance variation is greater and may result in instability. There are a dozen other 3-component matching networks available which can be found in the references. About half of these will be better for interstage applications.

Proper design and operation with any matching network depends on knowing the source and load characteristics. With amplifiers at either end, you should check to see what happens with reactive conditions out of band.

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transmitter matching networks

Complete data for building networks to match the output impedance of your transmitter to the input impedance of a linear power amplifier

Most transmitters are designed for 50-ohm output loads and the use of 50-ohm coax cable has become the standard for antenna systems used by amateurs. As the typical transmitter these days has 100 to 175 watts output, it is often used as an exciter to drive a linear amplifier to higher output power. These units normally are cathode-driven and are characterized by an input impedance that falls in the region of 20 to 200 ohms. Although in many cases the exciter can drive such an amplifier directly with satisfactory results, the use of a properly-terminated matching network can be beneficial in a variety of ways: It allows maximum energy transfer (most output), presents the best load to the exciter, minimizes harmonic radiation (TVI, etc.), and allows barefoot operation without retuning.

Perhaps other advantages will come to mind. Some exciters have only a 50-ohm output, and cannot be retuned for other impedances.

input impedance

The input impedance of linear amplifiers is rarely the same from one band to another. Some amplifiers are not operated at zero-bias and actually drive the grid through a passive resistor. These systems usually present about the same impedance from one band to another, of course, but are rarely 50 ohms to start with.

Formulas have been given to enable the calculation of the input impedance of a grounded-grid, cathode-driven amplifier. However, such formulas are all but worthless since they do not take the frequency into consideration. Measurements taken at the input of such amplifiers usually show a rather impressive variation from 10 to 80 meters, indicating that a formula would be quite misleading. These variations are caused by the manner in which the rf is isolated from the filament transformer (and hence the house wiring). Two methods are used to ac-

By Irvin M. Hoff, W6FFC (reprinted from the January, 1973, issue of *ham radio*)

complish this: filament chokes, such as bifilar-wound coils, or low-capacitance filament transformers.

The best uniformity is normally obtained with the low-capacitance filament transformer, but such a transformer is not always available, and in any event would need to be mounted within a few inches of the tube base. This is not always convenient, so filament chokes are more commonly used. These chokes range from commercially-available units to home-made – the latter usually being two number-12 double-enameled wires wound simultaneously around a round ferrite rod until 11 turns (you would count 22 with the two wires) are on the rod. With proper bypassing these chokes allow the 60-Hz filament current to pass, but to not allow the high-frequency rf signal into the filament transformer.

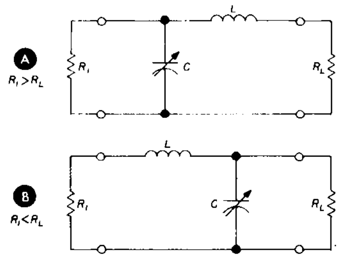


fig. 1. L-networks. The circuit in A is a step-down L-network; B shows a step-up L-network.

Factors which seem to contribute to variations in input impedance from band to band include the voltage on the final amplifier, the type of tube or tubes being used, the frequency involved, and the type of rf chokes used.

matching

I once had a Johnson Pacemaker 90-watt ssb transmitter. This unit could tune as high as 300 ohms on the output. I did not think any type of matching network to my linear was needed, but one day, while operating on 10 meters, I got a bad rf burn on my mouth when I came too close to the microphone. This led to an investigation of the input impedance, and I found on that particular transmitter it was only 15 ohms on 28 MHz; the Pacemaker could not handle this low impedance at all. A simple pi-network was used, and when incorporated for other bands, I found I not only increased the output power, but I could also then switch immediately from high power to barefoot, a distinct advantage over the previous system.

Various articles have been written regarding the use of networks between the exciter and the linear, and this is now standard practice for most commercial units. These usually have input networks incorporated into the design, and are often adjustable if you wish to optimize them for a specific part of the band. They are usually switched automatically as you change the band selector.

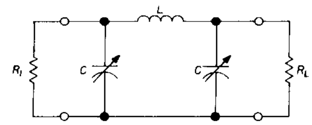


fig. 2. A typical pi-network. R_i is the input load, R_L the output load.

Such networks are usually made up of pi networks although a few use the more simple L-network. The pi network is usually preferred as greater control and uniformity are possible from band-to-band since the *Q* can be predetermined for consistent performance over a wider variety of impedances. The L-network is more simple, but it is also somewhat more difficult to adjust for optimum swr.

L-networks have been covered adequately in other texts,[1] so only an example will be shown here (see **fig. 1**). Although this is a very simple circuit, it has several minor disadvantages.

For one thing, in the L-network *Q* cannot be controlled, and is usually very low. Also, if the network is used for all hf amateur bands, the capacitor often has to be switched from one end of the coil to the other. Further, the L-network has very little exciter loading due to the low *Q* and it offers very little harmonic suppression.

A typical pi network is shown in **fig. 2**. It offers predictable performance because the *Q* may be preselected. It also offers a good load for exciter stability, and can easily be used for all hf amateur bands.

input impedance

The input impedance of the network may be determined by testing; use of formulas should be avoided

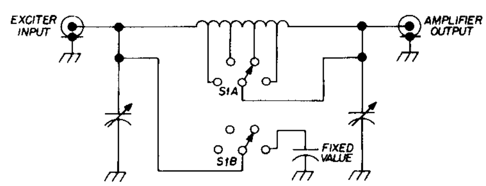
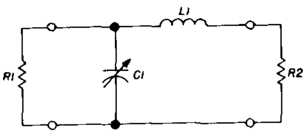
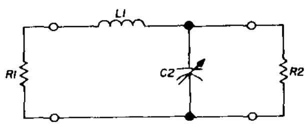


fig. 3. A typical pi-network for transmitter matching. The switch selects the proper tap for the various bands; the second switch section may be used to switch in parallel fixed values on the lower frequency bands.

table 1. L-network component values. Data is for matching a 50-ohm transmitter to a cathode-driven amplifier. The *Q* is set by the ratio of the input and output impedances and is shown for approximately the middle of each amateur radiotelephone band. The *Q* at the top of the band would be slightly less, at the bottom of the band it would be slightly greater.



R1 OHMS	F MHZ	C1 PF	L1 UH	C2 PF	R2 OHMS	'Q' QUAL.
50	1.9	4188	2.09	--	10	2.0
50	3.8	2094	1.05	--	10	2.0
50	7.2	1105	0.55	--	10	2.0
50	14.2	560	0.28	--	10	2.0
50	21.2	375	0.19	--	10	2.0
50	28.5	279	0.14	--	10	2.0
50	1.9	3420	3.42	--	20	1.2
50	3.8	1710	1.71	--	20	1.2
50	7.2	902	0.90	--	20	1.2
50	14.2	458	0.46	--	20	1.2
50	21.2	306	0.31	--	20	1.2
50	28.5	228	0.23	--	20	1.2
50	1.9	3420	5.13	--	30	0.8
50	3.8	1710	2.56	--	30	0.8
50	7.2	902	1.35	--	30	0.8
50	14.2	458	0.69	--	30	0.8
50	21.2	306	0.46	--	30	0.8
50	28.5	228	0.34	--	30	0.8
50	1.9	4188	8.38	--	40	0.5
50	3.8	2094	4.19	--	40	0.5
50	7.2	1105	2.21	--	40	0.5
50	14.2	560	1.12	--	40	0.5
50	21.2	375	0.75	--	40	0.5
50	28.5	279	0.56	--	40	0.5



R1 OHMS	F MHZ	C1 PF	L1 UH	C2 PF	R2 OHMS	'Q' QUAL.
50	1.9	--	11.24	3746	60	0.4
50	3.8	--	5.62	1873	60	0.4
50	7.2	--	2.97	989	60	0.4
50	14.2	--	1.50	501	60	0.4
50	21.2	--	1.01	336	60	0.4
50	28.5	--	0.75	250	60	0.4
50	1.9	--	9.27	2649	70	0.6
50	3.8	--	4.64	1324	70	0.6
50	7.2	--	2.45	699	70	0.6
50	14.2	--	1.24	354	70	0.6
50	21.2	--	0.83	237	70	0.6
50	28.5	--	0.62	177	70	0.6
50	1.9	--	8.65	2163	80	0.8
50	3.8	--	4.33	1081	80	0.8
50	7.2	--	2.28	571	80	0.8
50	14.2	--	1.16	289	80	0.8
50	21.2	--	0.78	194	80	0.8
50	28.5	--	0.58	144	80	0.8
50	1.9	--	8.43	1873	90	0.9
50	3.8	--	4.21	937	90	0.9
50	7.2	--	2.22	494	90	0.9
50	14.2	--	1.13	251	90	0.9
50	21.2	--	0.76	168	90	0.9
50	28.5	--	0.56	125	90	0.9
50	1.9	--	8.38	1675	100	1.0
50	3.8	--	4.19	838	100	1.0
50	7.2	--	2.21	442	100	1.0
50	14.2	--	1.12	224	100	1.0
50	21.2	--	0.75	150	100	1.0
50	28.5	--	0.56	112	100	1.0
50	1.9	--	8.41	1529	110	1.1
50	3.8	--	4.21	765	110	1.1
50	7.2	--	2.22	404	110	1.1
50	14.2	--	1.13	205	110	1.1
50	21.2	--	0.75	137	110	1.1
50	28.5	--	0.56	102	110	1.1
50	1.9	--	8.50	1416	120	1.2
50	3.8	--	4.25	708	120	1.2
50	7.2	--	2.24	374	120	1.2
50	14.2	--	1.14	189	120	1.2
50	21.2	--	0.76	127	120	1.2
50	28.5	--	0.57	94	120	1.2
50	1.9	--	8.61	1324	130	1.3
50	3.8	--	4.30	662	130	1.3
50	7.2	--	2.27	350	130	1.3
50	14.2	--	1.15	177	130	1.3
50	21.2	--	0.77	119	130	1.3
50	28.5	--	0.57	88	130	1.3
50	1.9	--	8.74	1249	140	1.3
50	3.8	--	4.37	624	140	1.3
50	7.2	--	2.31	330	140	1.3
50	14.2	--	1.17	167	140	1.3
50	21.2	--	0.78	112	140	1.3
50	28.5	--	0.58	83	140	1.3
50	1.9	--	8.88	1185	150	1.4
50	3.8	--	4.44	592	150	1.4
50	7.2	--	2.34	313	150	1.4
50	14.2	--	1.19	159	150	1.4
50	21.2	--	0.80	106	150	1.4
50	28.5	--	0.59	79	150	1.4
50	1.9	--	9.04	1129	160	1.5
50	3.8	--	4.52	565	160	1.5
50	7.2	--	2.38	298	160	1.5
50	14.2	--	1.21	151	160	1.5
50	21.2	--	0.81	101	160	1.5
50	28.5	--	0.60	75	160	1.5
50	1.9	--	9.19	1081	170	1.5
50	3.8	--	4.60	541	170	1.5
50	7.2	--	2.43	285	170	1.5
50	14.2	--	1.23	145	170	1.5
50	21.2	--	0.82	97	170	1.5
50	28.5	--	0.61	72	170	1.5
50	1.9	--	9.35	1039	180	1.6
50	3.8	--	4.68	519	180	1.6
50	7.2	--	2.47	274	180	1.6
50	14.2	--	1.25	139	180	1.6
50	21.2	--	0.84	93	180	1.6
50	28.5	--	0.62	69	180	1.6
50	1.9	--	9.51	1001	190	1.7
50	3.8	--	4.76	501	190	1.7
50	7.2	--	2.51	264	190	1.7
50	14.2	--	1.27	134	190	1.7
50	21.2	--	0.85	90	190	1.7
50	28.5	--	0.63	67	190	1.7
50	1.9	--	9.67	967	200	1.7
50	3.8	--	4.84	484	200	1.7
50	7.2	--	2.55	255	200	1.7
50	14.2	--	1.29	129	200	1.7
50	21.2	--	0.87	87	200	1.7
50	28.5	--	0.64	64	200	1.7
50	1.9	--	9.83	937	210	1.8
50	3.8	--	4.92	468	210	1.8
50	7.2	--	2.59	247	210	1.8
50	14.2	--	1.32	125	210	1.8
50	21.2	--	0.88	84	210	1.8
50	28.5	--	0.66	62	210	1.8
50	1.9	--	9.99	909	220	1.8
50	3.8	--	5.00	454	220	1.8
50	7.2	--	2.64	240	220	1.8
50	14.2	--	1.34	122	220	1.8
50	21.2	--	0.90	81	220	1.8
50	28.5	--	0.67	61	220	1.8
50	1.9	--	10.15	883	230	1.9
50	3.8	--	5.08	441	230	1.9
50	7.2	--	2.68	233	230	1.9
50	14.2	--	1.36	118	230	1.9
50	21.2	--	0.91	79	230	1.9
50	28.5	--	0.68	59	230	1.9
50	1.9	--	10.31	859	240	1.9
50	3.8	--	5.16	430	240	1.9
50	7.2	--	2.72	227	240	1.9
50	14.2	--	1.38	115	240	1.9
50	21.2	--	0.92	77	240	1.9
50	28.5	--	0.69	57	240	1.9
50	1.9	--	10.47	838	250	2.0
50	3.8	--	5.24	419	250	2.0
50	7.2	--	2.76	221	250	2.0
50	14.2	--	1.40	112	250	2.0
50	21.2	--	0.94	75	250	2.0
50	28.5	--	0.70	56	250	2.0

because the calculations rarely approximate the observed results.

The easiest and quickest method of measuring input impedance would be to use a variable impedance bridge, such as the RX noise bridge.[2] The *ARRL Handbook* also contains an excellent rf impedance bridge that may be easily built. These rf impedance bridges are basically a small swr bridge with a variable leg in the bridge so you can match the load impedance.

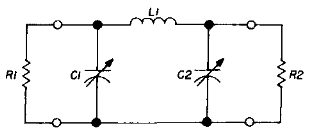
When making the impedance measurement the high voltage must be on the amplifier, and the meter hooked as close as possible to the place the network will be added.

There are probably no typical impedances, but as a general rule I have found that most amplifiers I tested fell in the neighborhood of 150 to 200 ohms on 80 meters, and around 15 to 30 ohms on 10 meters. The rest of the bands came somewhere in between. In many cases 20 meters offers a fairly decent match to 50 ohms with no network at all.

If the input impedance is measured directly at the filament of the power tube it will be considerably less than 50 ohms on ten meters, and considerably more than 50 ohms on 80. The data shown below is for my own 4-1000A linear with 6000 volts on the plate.

	impedance at tube base (ohms)	impedance at network (ohms)
80 meters	180	100
40 meters	155	60
20 meters	75	22
15 meters	50	40
10 meters	40	65

table 2. Pi-network component values. Data is for matching a 50-ohm transmitter to a cathode-driven amplifier. The *Q* has been chosen quite low to obtain broadband characteristics. The *Q* figure in the last column shows the worst-case condition at the bottom of the band using the inductance value shown.



R1 OHMS	F MHZ	C1 PF	L1 UH	C2 PF	R2 OHMS	'Q' QUAL.
50	1.8	4909	1.85	7612	10	3.6
50	3.5	2600	0.94	4153	10	3.8
50	7.0	1179	0.49	1678	10	3.3
50	14.0	579	0.25	801	10	3.2
50	21.0	384	0.16	528	10	3.2
50	28.0	300	0.12	439	10	3.4
50	1.8	3828	2.56	4992	20	3.3
50	3.5	2028	1.30	2679	20	3.4
50	7.0	920	0.68	1157	20	3.0
50	14.0	451	0.34	562	20	3.0
50	21.0	300	0.23	372	20	3.0
50	28.0	234	0.17	298	20	3.1
50	1.8	3403	3.08	3978	30	3.3
50	3.5	1802	1.56	2120	30	3.4
50	7.0	817	0.82	940	30	3.0
50	14.0	401	0.41	459	30	3.0
50	21.0	266	0.27	305	30	3.0
50	28.0	208	0.20	241	30	3.1
50	1.8	3090	3.54	3310	40	3.2
50	3.5	1636	1.79	1757	40	3.3
50	7.0	742	0.94	790	40	3.0
50	14.0	364	0.47	387	40	3.0
50	21.0	242	0.32	257	40	3.0
50	28.0	189	0.23	202	40	3.1
50	1.8	2872	3.95	2872	50	3.2
50	3.5	1521	2.00	1521	50	3.3
50	7.0	690	1.04	690	50	3.0
50	14.0	339	0.53	339	50	3.0
50	21.0	225	0.35	225	50	3.0
50	28.0	176	0.26	176	50	3.1
50	1.8	2689	4.33	2542	60	3.2
50	3.5	1427	2.20	1346	60	3.3
50	7.0	643	1.15	611	60	3.0
50	14.0	315	0.58	300	60	3.0
50	21.0	209	0.39	199	60	3.0
50	28.0	157	0.29	149	60	3.0
50	1.8	2559	4.68	2306	70	3.3
50	3.5	1361	2.37	1221	70	3.4
50	7.0	609	1.24	554	70	3.0
50	14.0	298	0.62	272	70	3.0
50	21.0	198	0.42	181	70	3.0
50	28.0	148	0.31	135	70	3.0
50	1.8	2432	5.01	2104	80	3.3
50	3.5	1295	2.54	1114	80	3.4
50	7.0	576	1.33	506	80	3.0
50	14.0	281	0.67	248	80	3.0
50	21.0	187	0.45	165	80	3.0
50	28.0	140	0.34	124	80	3.0
50	1.8	2319	5.34	1939	90	3.3
50	3.5	1237	2.71	1027	90	3.4
50	7.0	546	1.42	466	90	3.0
50	14.0	267	0.71	229	90	3.0
50	21.0	177	0.48	152	90	3.0
50	28.0	133	0.36	114	90	3.0
50	1.8	2216	5.66	1799	100	3.3
50	3.5	1184	2.87	953	100	3.4
50	7.0	520	1.50	432	100	3.0
50	14.0	253	0.76	212	100	3.0
50	21.0	168	0.50	141	100	3.0
50	28.0	126	0.38	106	100	3.0
50	1.8	2120	5.96	1679	110	3.3
50	3.5	1135	3.02	889	110	3.4
50	7.0	495	1.58	403	110	3.0
50	14.0	241	0.80	198	110	3.0
50	21.0	160	0.53	131	110	3.0
50	28.0	120	0.40	99	110	3.0
50	1.8	2036	6.26	1577	120	3.3
50	3.5	1092	3.17	835	120	3.4
50	7.0	473	1.66	379	120	3.0
50	14.0	230	0.84	186	120	3.0
50	21.0	152	0.56	123	120	3.0
50	28.0	114	0.42	93	120	3.0
50	1.8	1959	6.54	1488	130	3.3
50	3.5	1052	3.32	788	130	3.4
50	7.0	453	1.74	358	130	3.0
50	14.0	220	0.87	175	130	3.0
50	21.0	146	0.58	117	130	3.0
50	28.0	109	0.44	87	130	3.0
50	1.8	1887	6.82	1410	140	3.3
50	3.5	1015	3.46	747	140	3.4
50	7.0	434	1.81	339	140	3.0
50	14.0	210	0.91	166	140	3.0
50	21.0	139	0.61	110	140	3.0
50	28.0	104	0.46	83	140	3.0
50	1.8	1821	7.09	1342	150	3.3
50	3.5	981	3.60	710	150	3.4
50	7.0	417	1.88	322	150	3.0
50	14.0	201	0.95	158	150	3.0
50	21.0	133	0.63	105	150	3.0
50	28.0	100	0.47	79	150	3.0
50	1.8	1757	7.36	1279	160	3.3
50	3.5	949	3.73	678	160	3.4
50	7.0	400	1.95	307	160	3.0
50	14.0	193	0.98	151	160	3.0
50	21.0	128	0.66	100	160	3.0
50	28.0	96	0.49	75	160	3.0
50	1.8	1697	7.62	1223	170	3.3
50	3.5	918	3.86	648	170	3.4
50	7.0	384	2.02	294	170	3.0
50	14.0	185	1.02	144	170	3.0
50	21.0	122	0.68	96	170	3.0
50	28.0	92	0.51	72	170	3.0
50	1.8	1641	7.88	1173	180	3.3
50	3.5	890	3.99	621	180	3.4
50	7.0	369	2.08	282	180	3.0
50	14.0	178	1.05	138	180	3.0
50	21.0	117	0.70	92	180	3.0
50	28.0	88	0.53	69	180	3.0
50	1.8	1589	8.12	1127	190	3.3
50	3.5	863	4.12	597	190	3.4
50	7.0	355	2.15	271	190	3.0
50	14.0	170	1.08	133	190	3.0
50	21.0	113	0.72	88	190	3.0
50	28.0	84	0.54	66	190	3.0
50	1.8	1538	8.37	1085	200	3.3
50	3.5	837	4.24	575	200	3.4
50	7.0	342	2.21	261	200	3.0
50	14.0	163	1.11	128	200	3.0
50	21.0	108	0.74	85	200	3.0
50	28.0	81	0.56	64	200	3.0
50	1.8	1512	8.58	1054	210	3.4
50	3.5	824	4.35	558	210	3.5
50	7.0	335	2.27	253	210	3.1
50	14.0	160	1.14	124	210	3.0
50	21.0	105	0.76	83	210	3.0
50	28.0	79	0.57	62	210	3.0
50	1.8	1515	8.75	1035	220	3.4
50	3.5	826	4.43	548	220	3.6
50	7.0	335	2.32	249	220	3.1
50	14.0	160	1.17	122	220	3.1
50	21.0	106	0.78	81	220	3.0
50	28.0	79	0.58	61	220	3.0
50	1.8	1518	8.91	1016	230	3.5
50	3.5	828	4.52	538	230	3.6
50	7.0	335	2.36	244	230	3.2
50	14.0	160	1.19	120	230	3.1
50	21.0	106	0.79	80	230	3.1
50	28.0	79	0.60	60	230	3.1
50	1.8	1520	9.08	999	240	3.6
50	3.5	829	4.60	529	240	3.7
50	7.0	335	2.41	240	240	3.3
50	14.0	160	1.21	118	240	3.2
50	21.0	106	0.81	78	240	3.2
50	28.0	79	0.61	59	240	3.2

The amplifier uses a low-capacitance filament transformer. The first column of figures is the impedance measured right at the tube base; the second column shows the impedance at the end of a 6-foot (1.8m) length of RG-58A/U where my matching network is placed.

You can instantly see the futility in trying to cut a piece of coax to just the right length to provide proper matching on a number of different bands. This table also illustrates how unpredictable it would be to try to use a formula to find the impedance!

In one rig I built, using a pair of 813s and a commercial FC-30 filament choke, the impedance varied widely: from 12 ohms on ten meters to over 200 ohms on 80 meters. Replacing the commercial filament choke with a homemade bifilar-wound unit gave results that varied much less, from about 30 ohms minimum on one band to 130 ohms on 80 meters. These figures are given only to illustrate the wide impedance variations possible from 3.5 through 29 MHz, and are unlikely to be typical of what you may experience with your own particular amplifier.

wattmeter method

Many amateurs don't have access to an rf impedance bridge. You can still match the exciter to the amplifier, but it will take longer. The name of the game is low swr between the two units, so a wattmeter makes a good trial-and-error method of initially tuning the network. Once the settings have been found, you can mark them on the box and paste on tabs or use the sheet of paper I use.

In this case you observe, from the computer charts, the approximate inductance and capacitance, and start out by setting the inductance somewhere near what you think would be appropriate. With about half-power on the transmitter, rotate the variable capacitors while observing the reflected power.

If it does not go to zero, tap up or down on the inductor and try again (the tap on the coil should be temporary until properly selected). This same technique is used on each different band.

using a swr bridge

This is the least desirable of the various methods. It will usually work, but is the most time-consuming of all and can be misleading. If you think you have gotten it just right, switch to the exciter barefoot and see if the antenna presents approximately the same load, plate current, output power, etc. without returning the exciter. This will provide a check on your accuracy, and is, of course, the desired end result anyway — the ability to switch from antenna to amplifier with similar results.

network placement

In commercial rf power amplifiers the matching network is usually quite near the tubes in the amplifier, and normally there is a separate network for each band. The appropriate network is switched in automatically with the band-selector knob.

It is not at all necessary to have the networks in the same cabinet with the rest of the transmitter. You may find it considerably more convenient to install the network a few feet away from the amplifier where it can be changed quickly whenever you bandswitch. This is the arrangement I have used successfully for a number of years. I have a short piece of coax connecting the network to the input of the amplifier. The length of the coax is in no way critical, but once the network is adjusted, of course, the coax length should remain the same.

A piece of paper was temporarily placed on the front panel of the enclosure, the correct settings for the various bands found, and the paper marked. Then a nicer looking paper was drawn up with markings for those settings, typewritten with the band-markings, and attached to the front panel. This allows very rapid setting of the network whenever I bandswitch, yet only one coil and two variable capacitors are used.

Other methods may come to mind that will work adequately for your purpose. Trying to put the networks into the amplifier usually makes additional problems with regard to space, synchronizing with the bandswitch, etc. Thus, the remote installation may appeal to some of you who do not have space in the amplifier or the technical capability of providing mechanical selection when the bandswitch is rotated.

components

Even with 100-watts output, there is only about 1.4 rf amps flowing. Consequently, rather small inductors, such as B&W stock can be used successfully. B&W type 3018 comes in 4-inch (10cm) lengths, 8 turns per inch (2.5cm); the full 4 inches (10cm) is 9.4 microhenries. B&W type 3014 is also 8 turns per inch (2.5cm), 3-inches (7.5cm) long, and 4.8 microhenries. These should give you ideas, and a wide variety of similar inductances are available.

Even with 100-watts output, the voltage across 50 ohms is only about 70 rms. Almost any type of variable capacitor, including the common 365 pF broadcast type, will be more than adequate. You can easily find these for free from junker a-m radios of another era, and usually in gangs of two or three on the same shaft.

You will probably want a bandswitch for the network. Any type of switch capable of handling small amounts of rf will be adequate, and the additional pole/poles may be used to switch in fixed values for the lower frequencies, if desired. Ceramic or steatite switches are recommended.

Fixed capacitors should be rated for at least 150 or 200 volts, and capable of handling rf currents. Mica transmitting types are excellent. Low-cost door-knob capacitors are also good and are usually capable of handling kilowatt outputs.

Some commercial amplifiers use fixed capacitors and a slug-tuned variable inductor. Unless you have some means of determining the actual impedance to be matched, tuneup could be very time consuming, and fairly costly unless a large supply of capacitors suitable for rf is available. Also, many of the available slug-tuned inductors will not handle the amp or two of rf current without damage.

summary

Some method of matching the exciter's 50-ohm output impedance to the input of a linear amplifier should be offered. A good, simple but effective method is to build a single, variable pi-network and place it in a convenient place a few feet from the amplifier. A rf wattmeter may be used for initial tuneup, and simple markings placed on the box containing the network so rapid band changes can be made. Tables are included for both pi networks and L-networks. These were computer-derived and include values for 1.9 through 29.7 MHz.

references

1. Robert Leo, W7LR, "How to Design L-Networks," *ham radio*, February, 1974, page 26.
2. Frank Doting, W6KNU, and Robert Hubbs, W6BXI, "RX Noise Bridge for Accurate Impedance Measurements," *ham radio*, February, 1977, page 10.

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More Details? CHECK—OFF Page 158

introduction to operational amplifiers

Operational amplifiers have invaded amateur radio — here are the basic facts on their theory, selection, and application

If you have been keeping up with the current electronics literature, you've surely seen articles on the integrated circuit operational amplifier. Perhaps you've wondered just what it is and what it can do for you. The fact is, it can do just about anything you wish, and do it better than conventional circuits.

Tube versions of the op amp have been around for a long time. They were originally used in analog computers to perform mathematical operations such as addition, subtraction, and averaging. The main objection to these circuits was their huge physical size. Recent advances in solid-state technology have produced op amps at very reasonable cost with active elements formed on a single chip of silicon. A complete amplifier now occupies less space than many of the discrete components used in the original vacuum-tube operational amplifiers.

The IC op amp is so useful in amateur radio applications that I've prepared this article to acquaint you with it. The first part of the article discusses some of the more popular circuits and gives the equations describing the relationship between input and output. Then comes a description of the op amp's gain characteristics. The last part of the article is devoted to some applications you'll find useful around your amateur station.

typical circuit

The input stage of the op amp is a high-impedance differential voltage amplifier. This is followed by other voltage amplifiers. The output stage is a low-impedance power amplifier.

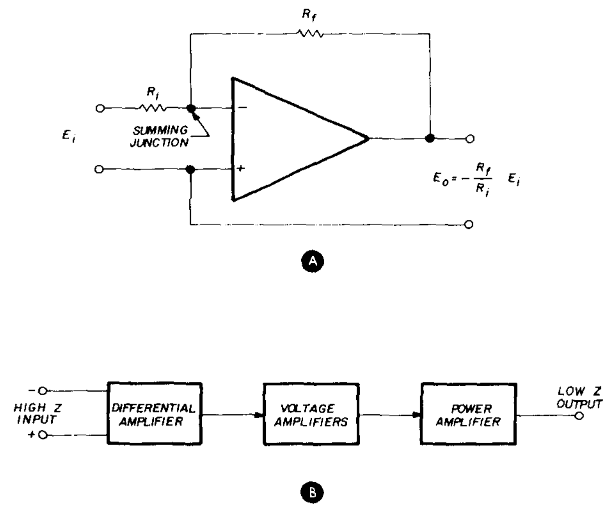


fig. 1. Typical operational amplifier circuit, (A), and block diagram of its three stages (B). Many arrangements of feedback elements are possible.

Fig. 1 shows a typical circuit. Resistor R_f feeds the output to the negative input, which is sometimes called the summing junction. The negative input is isolated from the driving signal, E_i, by resistor R_i, which represents the circuit's input resistance. The negative input is 180 degrees out of phase with the output and is at ground potential. Under these conditions, no current flows into the amplifier, because

By Donald W. Nelson, WB2EGZ, 9 Green Ridge Road, Voorhees, New Jersey 08043 (reprinted from the November, 1969, issue of *ham radio*).

current in R_f and R_i is equal and opposite. Ohm's law says that the output voltage, E_o, is related to the input voltage, E_i, in the same proportion as the values of R_f and R_i. The negative sign in the equation of **fig. 1** means that the phase has shifted 180 degrees.

definitive examples

The following op amp circuits are ideal representations. Nothing is perfect, of course, but I've used examples of a perfect amplifier to provide definitive examples. A perfect amplifier would have these characteristics:

1. Infinite open-loop gain.
2. Infinite input impedance and zero output impedance.
3. Zero response time (the output changes simultaneously with changes in input).
4. Zero offset. With no voltage between the input terminals, the output voltage will be zero.

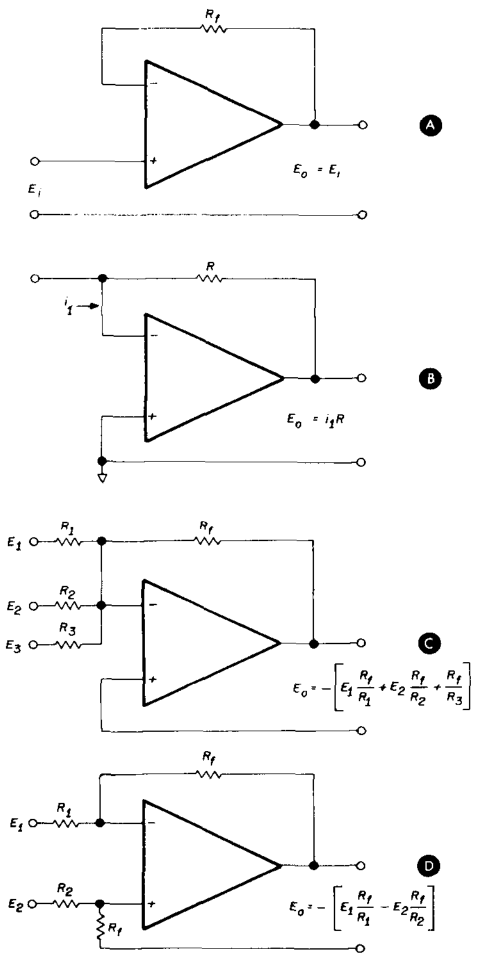


fig. 3. Other examples of op amp voltage amplifiers. A voltage follower is shown in (A), current-to-voltage transducer, summing amplifier, and difference amplifier are shown in (B), (C), and (D).

The important things to remember about these characteristics, which are called summing junction restraints, are:

1. No current flows at either positive or negative input.

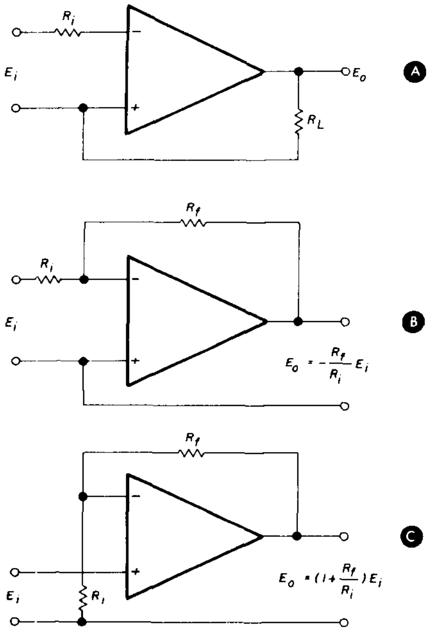


fig. 2. Three common op amp circuits. An open-loop circuit is shown in (A), useful as a voltage comparator. The circuits in (B) and (C) are inverting and non-inverting amplifiers.

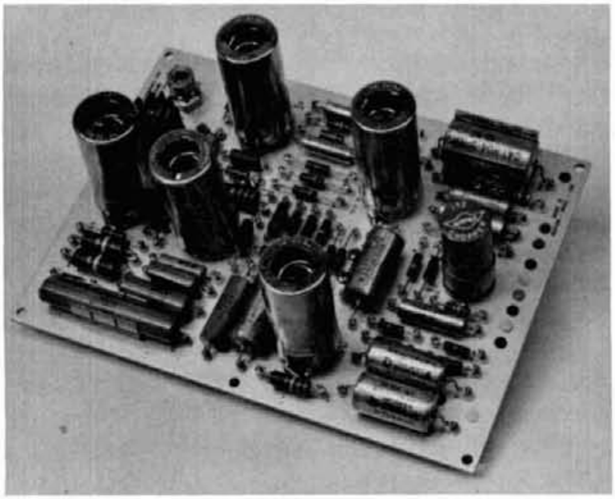
2. Both inputs are at the same potential.

open-loop operation

No feedback is used in the circuit of **fig. 2A**. The amplifier is running wide open. If the input is other than zero, the amplifier will be driven into saturation. An op amp isn't often used in the open-loop mode because of practical considerations. One use, however, is in a voltage comparator circuit. If two ac voltages are applied to the input, the open-loop amplifier will follow their potential difference. As the voltage on the positive terminal changes from that on the negative terminal and vice versa, the amplifier will swing as far as its supply will allow.

inverting and noninverting amplifiers

Two widely used arrangements of the op amp are illustrated in **figs. 2B** and **2C**. In the circuit of **fig. 2B** (which is the same as that of **fig. 1**), the output signal is inverted with respect to the input. If a square-wave, for example, with positive-going pulses is applied to the input, the output pulses will be negative. Gain will be proportional to R_f and R_i. The sign in the right-hand member of the transfer



The Philbrick-Nexus USA4JT "grandpappy of op amps." Very few amplifiers can match its performance. However, this fine unit has been retired to the back shelf because of its large size, aging characteristics, and high power consumption.

function (relationship of input to output) will be negative because of the 180-degree phase reversal.

In the noninverting circuit of **fig. 2C** input and output are in phase, which accounts for the plus sign in the equation.

voltage follower

A variation of the noninverting amplifier, the voltage follower, is shown in **fig. 3A**. Note that the output is connected to the negative input. The positive input is driven directly by the input signal, E_i. Output is equal to input: a unity-gain amplifier. This circuit is used for following voltage references. The limitations of the cathode follower (or emitter follower in transistor circuits) are minimized.

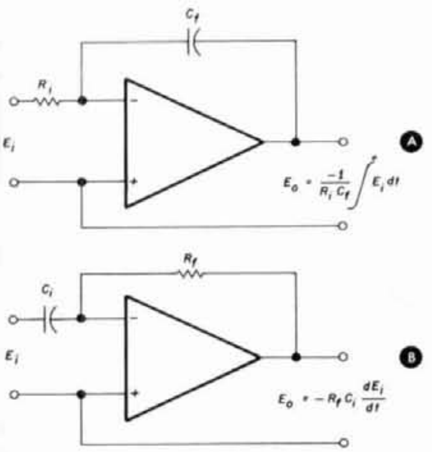


fig. 4. Voltage waveform integration and differentiation may be performed by (A) and (B). These circuits are used for precise filtering.

transducer, adder, subtractor

The circuit of **fig. 3B** is a current-to-voltage transducer. It can be used to drive a meter, recorder, or other voltage-operated indicating instrument from limited current sources.

Voltage inputs are added directly in the summing

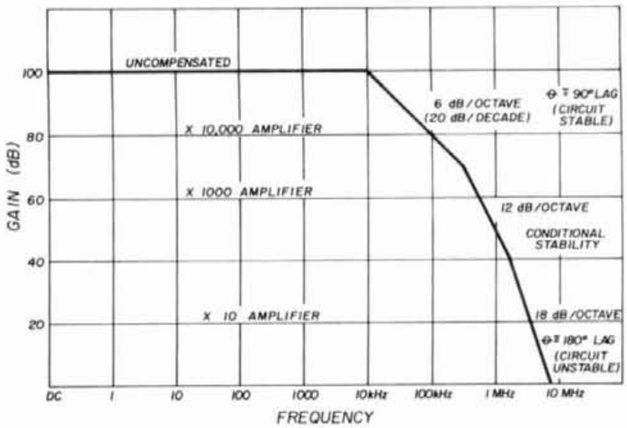


fig. 5. Gain-bandwidth characteristics of uncompensated amplifier. Instability occurs as gain attenuation exceeds 18 dB/octave because of 180° phase lag.

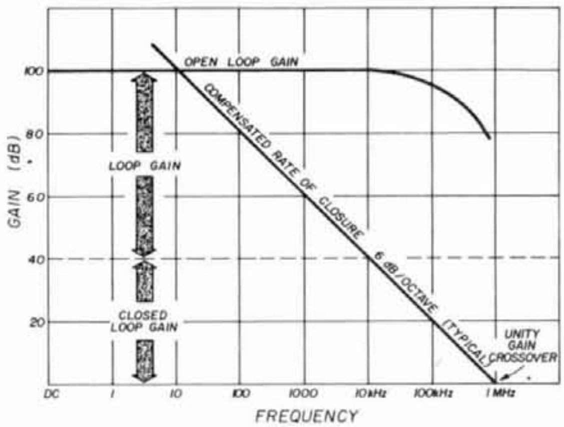


fig. 6. Bode plot of compensated amplifier. Response is limited so that 180° phase shift occurs before unity gain is reached.

amplifier of **fig. 3C**. The op amp is shown here in one of the operations for which it was originally used. Each input may be weighted by using different resistor values. Input weighting is proportional to the gain of the particular input: E_1 will have a weight of 2 if $R_f = 2k$ and $R_1 = 1k$. If $R_2 = 500\ ohms$, E_2 will have a weight of *4*.

The circuit of **fig. 3D** is sometimes called a balanced input amplifier or symmetrical subtractor (difference amplifier). It's used when neither side of the signal being amplified is at ground potential, as across a current-sensing resistor. Other inputs may be added where inputs to the negative terminal are additive, and those to the positive terminal are subtractive.

integrator and differentiator

By using a capacitor in the feedback loop (**fig. 4A**), the op amp may be used to integrate voltage waveforms. When the capacitor is in the input, **fig. 4B**, the signal is differentiated. Both differentiator and integrator, as shown, are purely theoretical.

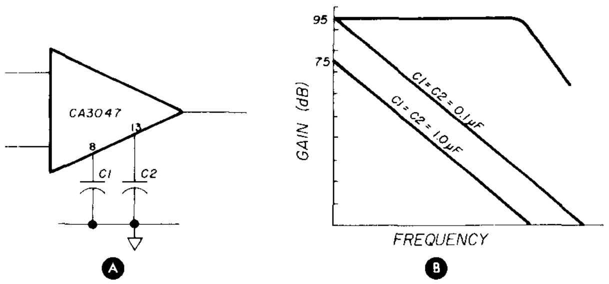


fig. 7. Compensating by bypassing. As capacitor values increase, (A), amplifier open-loop response moves to the left, (B).

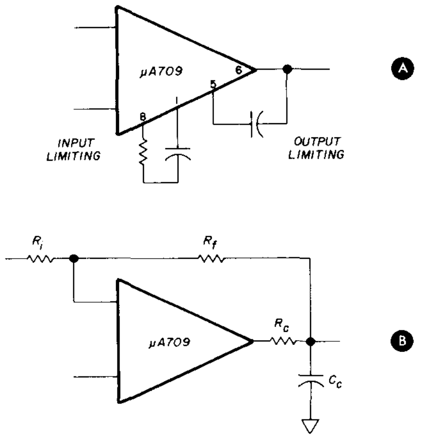


fig. 8. Response limiting at amplifier output. Capacitive compensation, (A), or the RC network in (B) are frequently used to supplement input compensation.

practical limitations

Most errors in a practical operational amplifier with known characteristics can be calculated. If the amplifier is properly chosen for a particular application, these errors may be negligible or can be compensated. With an understanding of amplifier gain, frequency response, and phase shift, you'll be able to apply compensation methods to tame the op amp of your choosing.

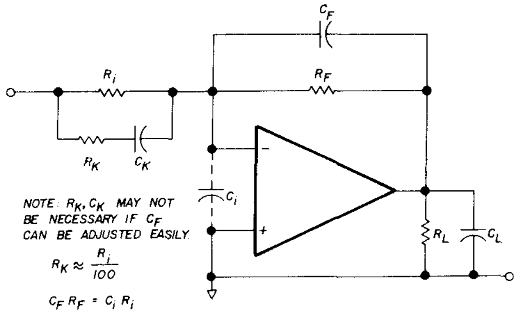


fig. 9. Compensation for op amps with discrete components. Input loading, stray wiring capacitance, and output loading must be compensated.

Several definitions of gain must be understood:

1. **Open-loop gain**. This is the ratio of output-to-input voltage at any frequency. No feedback is used. Typical open-loop gains are from 10^4 to 10^9 in commercially available amplifiers.
2. **Closed-loop gain**. When feedback is used, the amplification is called closed-loop gain. For reasons to be discussed, closed-loop gain is rarely less than unity.
3. **Loop gain**. This is the difference between open and closed-loop gain. Usually, errors are minimized with greater loop gain.

Characteristics such as gain attenuation with frequency (also called roll-off) and phase shift, which are common to all amplifiers, are especially important when considering operational amplifiers. As men-

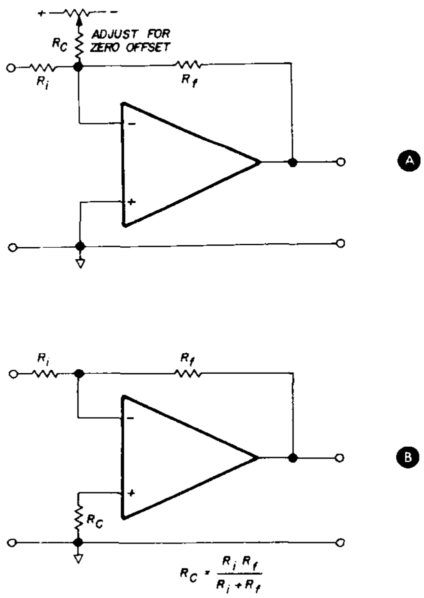


fig. 10. Compensation for dc offset error in an inverting amplifier. Adjustable current offset compensation is shown in (A); drift-compensating resistor in (B).

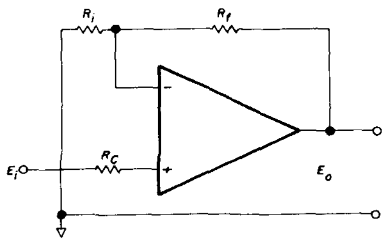


fig. 11. Drift compensation in a non-inverting amplifier. *Input voltage swing is a limitation; R_c is now the input resistor.*

tioned previously, phase shift through the amplifier must be less than 180 degrees when feedback is employed. Any additional phase shift must be compensated, or the circuit will oscillate.

In **fig. 5**, gain-bandwidth characteristics are shown for an uncompensated amplifier (not necessarily typical). The phase shift (lag) increases as the gain is affected by feedback. The amplifier becomes unstable when the roll-off exceeds 18 dB/octave because of the 180-degree phase lag. In well-designed amplifiers, this limit occurs below unity gain. Even with compensation, the amplifier can't be controlled when 18 dB/octave is reached; therefore, operating below unity gain is usually impractical. Some amplifiers may be difficult to control at gains slightly above unity.

compensation

Amplifier compensation will limit frequency response, but roll-off and phase shift will be controlled. A plot of a compensateed amplifier's response is shown in **fig. 6**. This type of presentation is called a Bode plot; it illustrates the limited gain roll-off (rate of closure with the unity-gain point in the frequency response of the amplifier).

Most op amp data sheets give enough information to make a Bode plot. This will allow you to analyze the results of intended compensation. The Bode plot is the easiest way of showing the characteristics of compensation.

The simplest way to stabilize an amplifier in which a large amount of feedback is used is to bypass some signal point in the circuit. IC op amps such as the RCA CA3047 and Fairchild μA702 have terminals specifically provided for this. **Fig. 7** shows an example. If the bypass capacitors (**fig. 7A**) are increased in value, the amplifier open-loop response will shift to the left (**fig. 7B**).

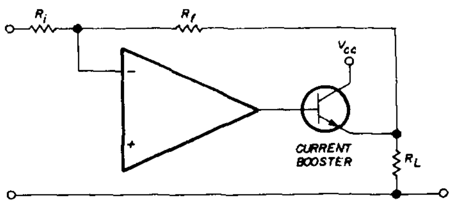


fig. 12. Increasing current output. If output current capability is too low, a booster amplifier can be used to reduce output impedance.

As the Bode plot shows, the high-gain, high-frequency characteristics are very limited with this configuration. The simple addition of a series resistor

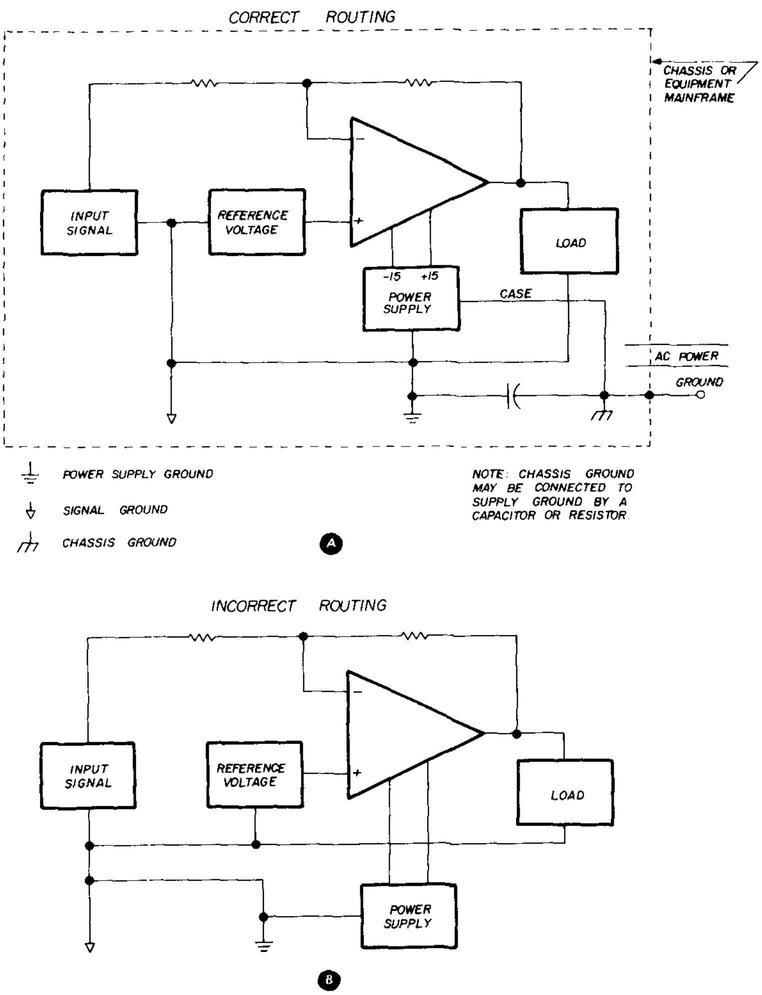


fig. 13. Correct routing (A), and incorrect routing (B), of load return in an op amp layout. Incorrect routing will cause an error in reference voltage.

with the bypass capacitor will yield greater bandwidth.

Output limiting is another popular form of compensation (**fig. 8**). Amplifiers such as the Fairchild μA709 have a special terminal just for this purpose (**fig. 8A**). The technique of **fig. 8B** is also useful. Output compensation is frequently used to supplement some form of input compensation such as that suggested in **fig. 8A**. While every compensation problem is unique, we may generalize and say that the compensations shown above are required by the peculiarities of integrated circuits.

Amplifiers using discrete components are internally compensated to a degree. With discretes, the main compensation is for output loading, C_L, stray wiring capacitance, and input loading, C_i. Compensation techniques are shown in **fig. 9**. This is by no means the last word in compensation; it's only in-

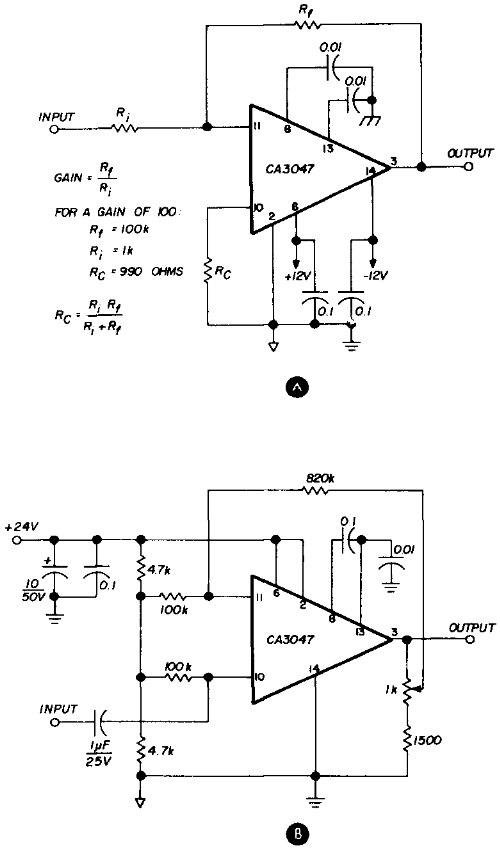


fig. 14. Complete circuits for the basic inverting amplifier, (A), and non-inverting amplifier, (B). Gain of non-inverting ac circuit is approximately 10 and may be trimmed for precise gain.

tended to help you when some published circuit won't work.

offset error

Among the imperfections of a practical op amp is the mismatch of components that prevents the amplifier from having exactly zero output with zero input. This may well be the most serious problem you'll encounter in dc operation of a high-gain amplifier. The basic compensation methods are shown in **fig. 10**.

input/output limitations

Input impedance and voltage swing generally may be neglected in the conventional inverting amplifier

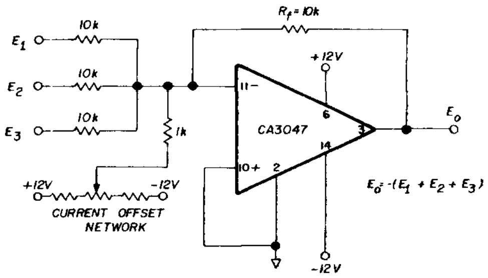


fig. 15. Typical adder. Offset compensation is similar for all computing circuits.

shown in **fig. 10**. The input impedance will be equal to the input resistor, R_i, because the input is a virtual ground. The amount of drift may be considered a limitation of input. The simplest compensation for this is shown in **fig. 10B**, where a resistor is used in the positive input.

Drift may be compensated similarly in a noninverting amplifier as shown in **fig. 11**. The difference here is that R_c is now the input resistor. In this circuit, the input voltage swing is a limitation. This is called "common-mode voltage swing" on the data sheet.

Output impedance, being some value greater than zero, will introduce small circuit errors. It is desirable to keep Z_{out} low. This may be done by using the greatest loop gain possible. A booster amplifier also reduces Z_{out} although such an addition probably wouldn't be considered unless the output current capability is too small. The most common current booster is the pass transistor in a precision power supply as suggested in **fig. 12**.

Beware of the limitation of output voltage swing, especially in IC amplifiers. This is a luxury that closely relates to the price of the op amp. The 30-volt p-p capability of RCA's CA3047A is high for an IC.

One input error that's elusive — at least to me — is the common-mode error. Variously defined, this error arises from the effect of a change in one input on the signal fed to the other input. Common-mode

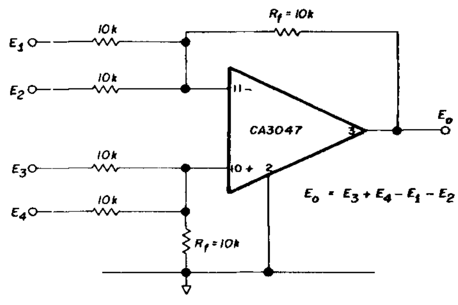
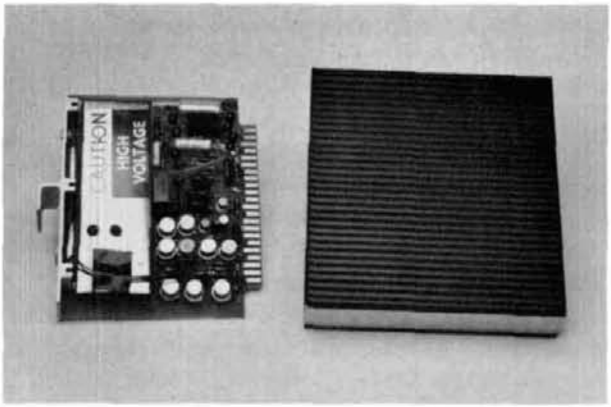


fig. 16. Adder-subtractor. Large values of feedback resistors will result in a gain greater than unity.



A noteworthy successor to the best tube op amps is the Fairchild A00-7. It features discrete components, built-in compensation, and chopper stabilization.

error is *smallest when the common-mode rejection* ratio is high. This error is important when differential inputs are used, or when the amplifier is operated in the noninverting mode.*

Always look for the least-expensive amplifier that will satisfy your requirements. Some suggestions to guide the newcomer are outlined below.

1. High loop gain is desirable. Usually this implies the need for high open-loop gain.
2. *Sufficient output voltage swing and output current* to the load must be considered.
3. Offset voltage and drift must be checked for compatibility with your circuit.
4. Offset current is particularly important in circuits such as the current-to-voltage converter.

*Slewing rate is another limitation of practical op amps. Briefly, it is the maximum rate of change of output voltage with time. It must be considered when pulses of fast rise time are employed or high frequency, high level sine wave signals must be processed. *It also is a limitation to using operational amplifiers at high frequencies.* A thorough treatment of this parameter would be quite lengthy; however, a careful examination of the Bode plot will show slewing rate will change with compensation. Interested *readers will find a discussion related to an integrated-circuit op amp* (MC-1530) in the Motorola *Integrated Circuit Handbook*, 1968 edition, p. 10-74. **Editor**

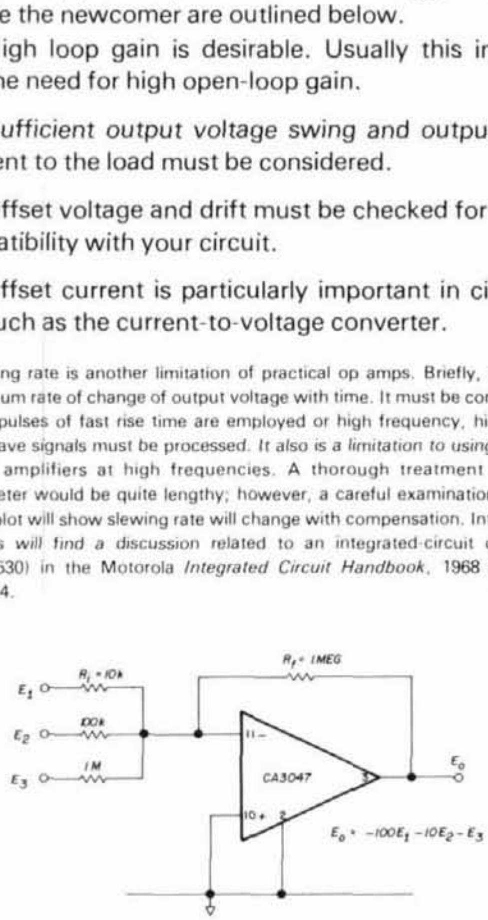


fig. 17. Weighted adder. The sum of the inputs is a function of the feedback resistor; and any reasonable combination of R_f and R_i is permissible.

5. Common-mode voltage is important for noninverting and dual-input circuits.
6. Power-supply ripple, drift, and regulation are most important when the supply is used as a reference. However, all op amps work better with a high-quality supply.

The best over-all performance in op amps is obtained from those using discrete components — in fact, tube types. The least expensive and most interesting to experimenters are the integrated-circuit op amps. Despite their low cost, performance is excellent.

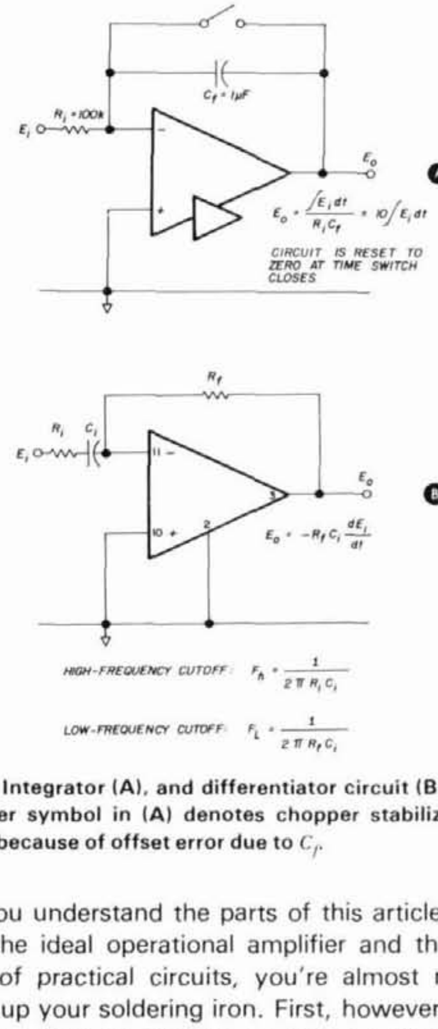


fig. 18. Integrator (A), and differentiator circuit (B). Double amplifier symbol in (A) denotes chopper stabilization required because of offset error due to C_f.

If you understand the parts of this article dealing with the ideal operational amplifier and the limitations of practical circuits, you're almost ready to warm up your soldering iron. First, however, I'd like to give a few precautions on layout and choice of components.

capacitors and bypassing

Poor layout in an op amp circuit may cause its response to peak at the higher frequencies. Under certain conditions, oscillation will result. The problem can exist even with a neat layout. In stubborn cases, peaking may be *cured with a mica bypass* capacitor (try 100 pF) directly at the noninverting input. This is appropriate only for an inverting amplifier. The problem is rare when the amplifier is used in the noninverting mode.

More frequently, oscillation results from improper bypassing in the power supplies. A 0.1-μF capacitor

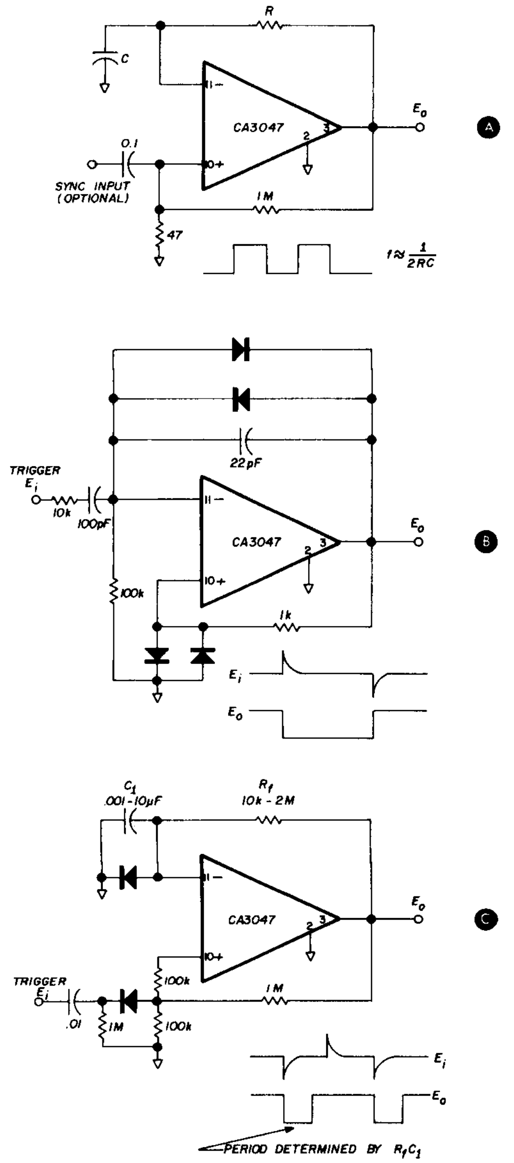


fig. 20. Examples of the multivibrator. Circuit at (A) is free-running, or astable; (B) is a bistable multivibrator, or flip-flop. Monostable, or one-shot, is shown at (C).

on each power-supply lead at the amplifier socket is good practice. Low-inductance, laminated ceramic capacitors are perfect for this.

Capacitors can be critical in some circuits where low leakage is important. Dura-mica types are excellent for compensation purposes. High values and higher precision, such as would be required for tim-

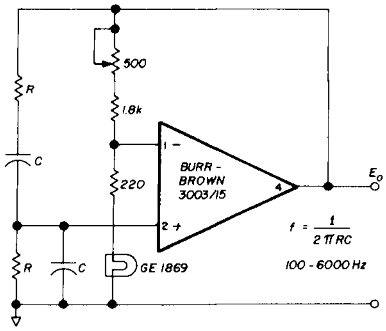


fig. 19. The Wien bridge oscillator. The circuit is temperature sensitive; stability is improved by the lamp, which operates at low-current level.

ing circuits, will call for Mylar or Polystyrene capacitors.

resistors and diodes

The giant called *loop gain*, which is restrained by an operational system, will create problems when noise and unwanted reactances exist. Therefore, certain precautions must be observed with respect to other circuit components.

Resistors must be chosen with care in systems where accuracy depends on the resistor. Wirewound resistors have low noise and excellent stability. However, they have the largest shunt capacitance and series inductance of all types. Also they're not usually available in values above one megohm, and they're expensive.

Carbon composition resistors shouldn't be used where high stability is required, such as in the input and feedback circuits. Although they produce noise, these resistors are inexpensive and are satisfactory in less critical parts of the circuit.

Metal film resistors have excellent characteristics and provide a good compromise between the wirewound and composition types. Their upper range is ten megohms. Higher resistance values are available from Victoreen and Pyrofilm in the form of glass-enclosed, deposited-carbon construction. While there's little choice in precision resistors above ten megohms, you should be aware that some high-

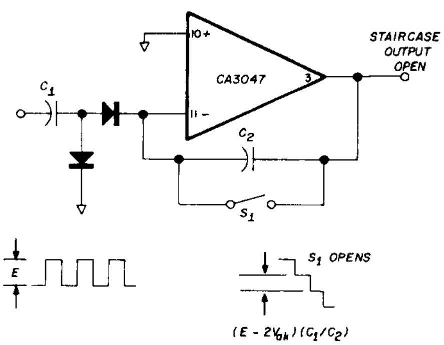


fig. 21. Staircase generator. Ramp output results if a dc signal is applied to pin 11 through a resistor.

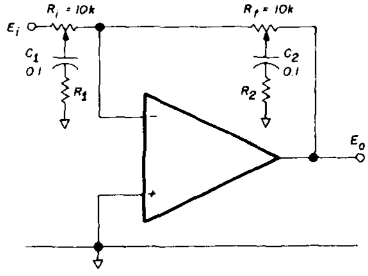


fig. 22. Phase-shift network for system stabilization. Lead and lag compensation are shown.

resistance types are voltage sensitive. They're not precise at voltages other than their test voltage – usually 10 volts. Be careful not to get dirt or perspiration on these, as it may reduce their resistance.

Clamping diodes are frequently used in op amp circuits. Low-leakage, low-capacitance diodes such as the 1N914 or 1N457 types should be used. *Never* use germanium diodes unless the leakage allowances are high enough.

triple grounds

Three grounds should be used: *signal ground, power-supply ground,* and *chassis ground.* This triple grounding technique is essential to minimize voltage drops that would create system errors. At some point, all grounds may be connected, but not necessarily. Consider each system with respect to the voltage drops that will develop. For example, with high output current (load current), the load return to power supply ground must be direct. The reference signal, using signal ground, must not be transmitted through the same wire. **Fig. 13** illustrates some basic grounding techniques; however, the subtleties of the ground loop aren't always easily controlled. A little experimentation with the preceding concepts in mind could lead to a better solution.

compendium of op amp circuits

I've devoted the remainder of this article to a description of some of the more common applications for the operational amplifier. These circuits are just a starting point. I'm sure that ham ingenuity will result in many more interesting variations. Who

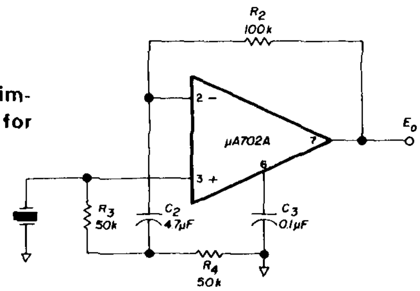


fig. 23. High input impedance amplifier for crystal transducer.

knows? Perhaps someone will adapt one of these circuits to a communications problem and revolutionize the industry. In any event, I hope these ideas will inspire more experimentation. If you come up with a new use for the op amp, the market is wide open for your ideas.

basic computer circuits

While basic computing circuits may not be your idea of a construction project, such applications of the op amp serve to identify what follows. As a matter of fact, with a little thought and planning, these

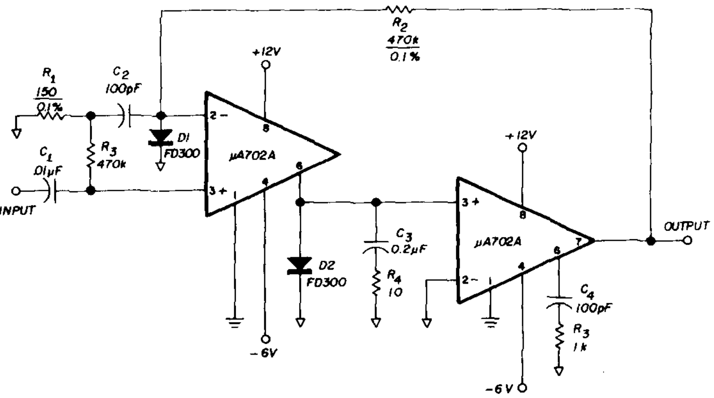


fig. 24. Precision ac amplifier. Gain is 70 dB; input impedance is 200 megohms.

circuits might be just the thing for a science fair presentation.

To recap, the basic inverting and noninverting op amps are shown in **fig. 14** with all the component values. You'll recall that the inverting amplifier shifts the phase of the input signal 180 degrees; that is, a positive-going input produces a negative-going output. The output signal will be in phase with the input in the noninverting amplifier.

Typical compensation is shown in the circuits of **fig. 14**. The following circuits are simplified. Compensation and proper bypassing are essential, of course. The RCA CA3047 is inexpensive and altogether adequate for the applications shown.

An adder is shown in **fig. 15**. The offset network is typical for all computing circuits. An alternate would be a voltage offset circuit, which is usually connected to the positive input. The currents from these three inputs are summed, and the negative of this sum appears at the output. Feedback at the negative input means that the input is a virtual ground, so the three inputs are effectively isolated, and no interaction exists among them.

An adder-subtractor circuit is shown in **fig. 16**. Note the equation of the circuit: the output voltage equals the sum of the noninverting inputs minus those on the inverting inputs. Thus, we have a subtracting circuit. By making the two resistors in the feedback circuit larger, greater-than-unity gain may be obtained.

If we change resistor values, a *weighted* adder results, as shown in **fig. 17**. The feedback resistor value affects the sum of the inputs. The weight of the adder is proportional to input gain, which is determined by the feedback resistor.

Other mathematical operations in computers are integration and differentiation. The former is used to

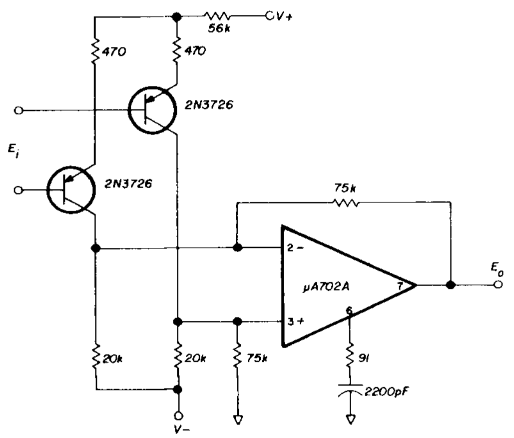


fig. 25. Low-noise tape head amplifier. Matched transistor pair reduces noise and increases input impedance.

find the area under a curve; the latter determines the slope of a curve at any point. In the integrator of **fig. 18A**, an fet input amplifier should be used because of the error caused by bias current. Also the capacitor leakage must be very low — 1 nanoamp or preferably, less.

Gain response of the integrator is maximum at the low frequencies and decreases linearly with increasing frequency. Amateur application of such a circuit would be in a lowpass filter following a speech clipper to attenuate harmonics.

In the idealized differentiator, gain increases indefinitely with frequency. To eliminate high-frequency noise problems, gain limiting is provided by R_i in the circuit of **fig. 18B**. This circuit is also useful for filter applications; frequency response is determined by the RC constants according to the equations shown.

oscillators and waveform generators

Of the many operational amplifier circuits used in computers, probably the most popular amateur adaptations are oscillators and their close relatives, the multivibrators.

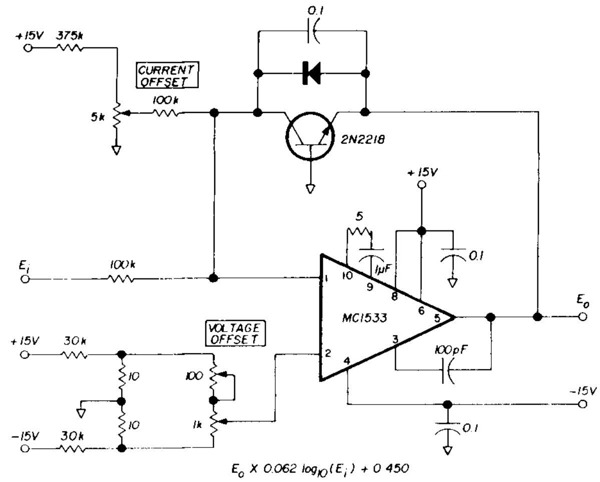


fig. 26. Logarithmic amplifier. Circuit operates over a frequency range of six decades.

If you need an oscillator with an unusually pure sine wave output, the Wien bridge[1] circuit in **fig. 19** is a good candidate. It is inherently temperature dependent, however. In the circuit shown, stability is improved with a lamp operating at very low current.

The multivibrator circuits in **fig. 20** have appeared in various forms in many amateur publications. They're used in electronic keyers, frequency counters, square-wave generators, and a host of other circuits where a controlled signal source is required.

The circuit of **fig. 20A** is an astable, or free-running multivibrator. Its uses include a timing-pulse

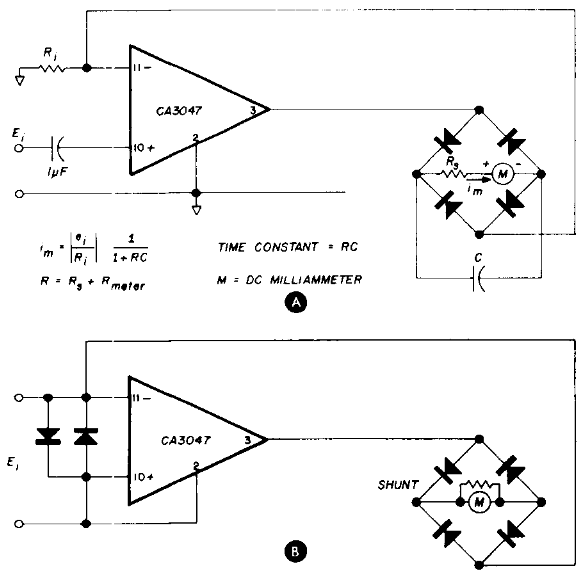


fig. 27. Lossless ac meter circuits. A high-impedance dc meter is preferred for the millivoltmeter circuit, (A); a low-impedance meter should be used in the milliammeter circuit, (B).

generator, or clock, in counters. Feedback to the positive input is called "bootstrapping." This effectively increases circuit gain until it approaches infinity.

The bistable multivibrator (**fig. 20B**) has two stable states, each of which changes only when triggered by a pulse of opposite polarity. This circuit is used as a memory storage, counter, or shift register in computers. Its principles are often used in amateur circuits with little or no modification.

The monostable multivibrator, **fig. 20C**, is also called a one-shot. It has one stable state, which can be changed by an external pulse. It will then return to its original state after a time period determined by its RC constants. The one-shot is used for a time delay or to produce a pulse of specific width when triggered.

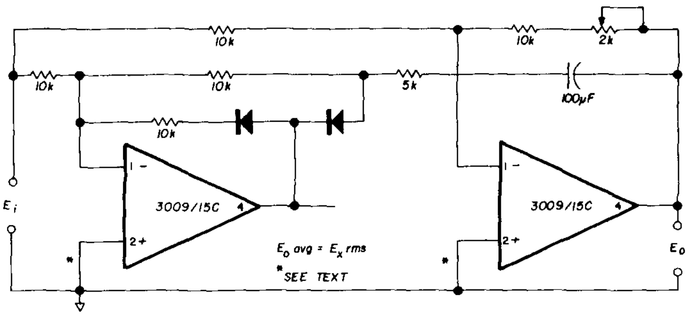


fig. 28. Ac-to-dc converter. Circuit has an input range from 6 mV to 6 volts rms at 10 to 1000 Hz. Amplifier is a Burr-Brown IC.

An application where the integrator feedback capacitor is allowed to charge is shown in **fig. 21.**[2] During a finite period, the input pulses will add algebraically until the amplifier saturates. When the switch is closed, the output returns to zero. The circuit shown generates a staircase waveform; it can be used as a ramp generator if a dc signal is applied to pin 11 through a resistor. Successively opening and closing the switch would give a sawtooth output. Systems frequently require phase compensation for stability. Precise adjustment may be made with the technique shown in **fig. 22**. Adjustable lag is obtained by changing the input bypass capacitor; lead adjustment is provided by varying the feedback resistor. Resistors R_1 and R_2 may be necessary to stabilize the system.

amplifiers

In addition to the basic amplifier circuits previously shown, I've included some useful variations.

The circuit of **fig. 23** is often used in dynamic instrumentation such as vibration measurements. It's a high input impedance amplifier using a crystal as a transducer.[3] A possible adaptation for amateur use would be a crystal microphone preamp.

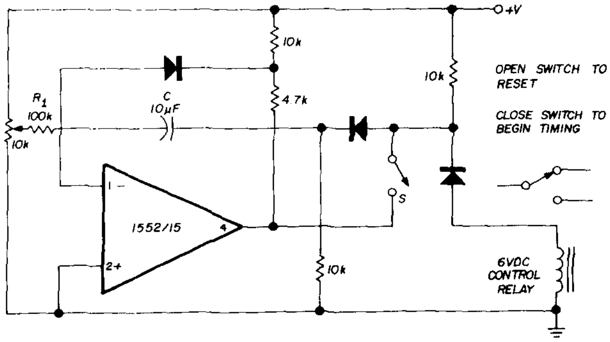


fig. 29. Timing control circuit. Minimum delay is determined by $R1 \cdot C$, maximum delay is infinite.

The amplifier in **fig. 24** has a gain of 70 dB and an input impedance of 100 megohms.[3] Diodes are used to prevent latch-up. Because of the high-frequency characteristics (100 kHz) with the compensation shown, special attention should be given to layout and power-supply decoupling.

The tape-head amplifier[3] of **fig. 25** uses a matched pair of 2N3726s to reduce noise and increase input impedance. Despite the fact that it uses no input resistor (purists may object to classifying this circuit with op amps), the circuit does suggest a technique for improving common-mode rejection and increasing the common-mode range for any op amp.

A widely used instrument is the log amplifier (or log converter). It has the capability of compressing input voltage ranges of several decades into a useful linear range. Some uses for this circuit (**fig. 26**) are in filter measurements, leakage measurements, and as a computer power-function generator. The amplifier shown uses a diode-transistor combination in the feedback circuit to achieve the conversion function.[4] Both current and voltage offsets are required for operation over a 6-decade input range. With an input of 0.13 mV to 100 volts, the output is from 220 to 580 mV.

Fig. 27 shows two lossless ac meter circuits. The millivoltmeter circuit, **A**, uses an op amp to compensate for diode, resistor, and meter losses. The

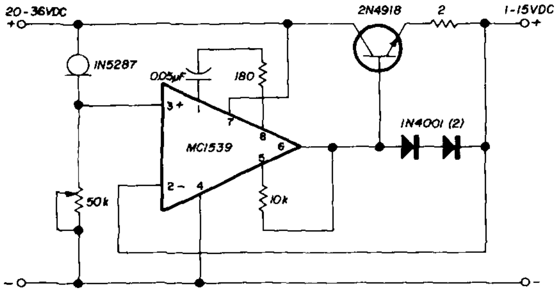


fig. 30. A power supply that provides up to 200 mA between 1 and 15 volts. Regulation is better than 0.01%!

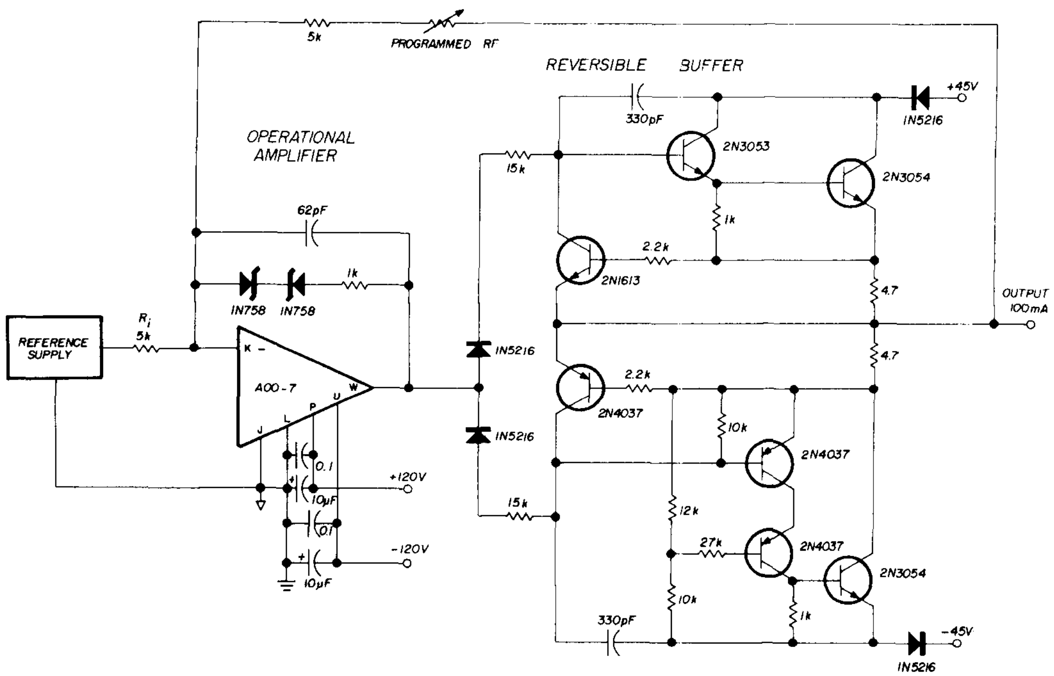


fig. 32. The op amp in a filter circuit. Filter in the feedback circuit yields an output with response characteristic of the filter element.

response time, which is usually low, can be increased by increasing either the meter series resistor, R_S, or the averaging capacitor, C.

The current-sensitive counterpart of the millivoltmeter, shown in **fig. 27B**, has zero drop across its terminals. Limiting diodes at the input should have very low leakage. No charging capacitor is necessary, because the current is averaged by the meter. Low-impedance dc meters are practical in this circuit, whereas the millivoltmeter performs more efficiently with a high-impedance meter.

In measurement and control circuits, it's frequently necessary to convert ac to dc. The circuit of **fig. 28** using Burr-Brown amplifiers[1] consists of a full-wave rectifier and a filter.

The time delay circuit in **fig. 29** requires an amplifier with a high-impedance input such as that provided by an fet. The Burr-Brown 3521H is such an amplifier. Of the many uses for this circuit in amateur applications, an example would be to control timing of voltage turn-on in a power supply. Circuit response time would be limited by relay action.

The Motorola MC1539 op amp is the center of precision in the circuit of **fig. 30**[5]. This supply provides up to 200 mA at any voltage between 1 and 15 volts. Regulation is better than 0.01%. The unusual reference supply consists of a constant-current diode (type 1N5287) and a 50 kilohm potentiometer.

The amplifier has a gain of 120,000, so it won't load the reference. Note that output compensation is between pins 5 and 6, and input compensation is between pins 1 and 8. The circuit is protected against burnout from short circuits.

voltage reference

A more sophisticated reference supply uses its own op amp, a National Semiconductor LM101 (**fig. 31**).[6] The 1N827 reference diode is temperature compensated. Regulation is 0.01 mV/V, and temperature stability is ±0.05% from −55°C to 125°C. Short-circuit protection for the reference is provided internally. The LM101 needs only one compensating component, the 33-pF capacitor (the commercial version is the LM301A). If you'd like an alternate circuit, see National Semiconductor LM343 op amp data sheet, ±65 V output!

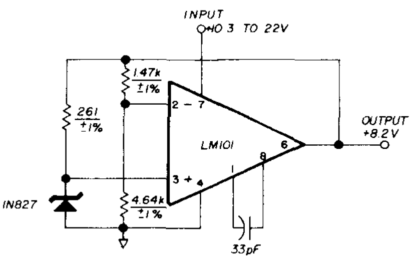


fig. 31. Voltage reference source. Regulation is 0.01 mV/V; temperature stability is ±0.5% from −55° to 125°C.

active filters

A nice thing about active filters is that you don't need inductors to achieve near-ideal mathematical

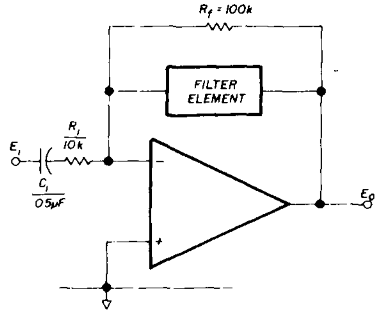


fig. 33. A Twin T filter for use in an op amp circuit. Bandpass is 1000 Hz; with input and feedback resistors of 10k and 100 the gain would be 10. The product C_iR_i should be greater than twice CR.

response characteristics. Another good feature is high input impedance, which means that matching is not a consideration.* While compensation for the operational amplifier is necessary, filter reactance trimming is not. Once you've calculated component values for a specific response, you're done.

A circuit that's easy to understand is shown in **fig. 32**. A filter in the feedback circuit of a conventional inverting amplifier yields an output with the response characteristic of the filter.

A possible filter is the Twin T shown in **fig. 33**. A 1000 Hz bandpass filter is in the basic circuit. If $R_i = 10k$ and $R_f = 100k$, the gain will be 10 at 1000 kHz. The Twin T is one of the simplest (first order) filter elements; however, it has relatively low Q, so don't expect miracles from it.

The circuit of **fig. 34** may be used with an active high pass, or low pass, or rejection-notch filter by inserting the appropriate filter element. Reference 7 provides more information for active filter designs.

Another practical approach toward building an improved filter is to precede a conventional filter with an op amp follower (**fig. 35**). This circuit eliminates filter input loading problems. Although resistor R is chosen to equal the filter input impedance, the resistor is really used to match the input of the preceding stage. The input impedance of the op amp is arbitrary.

A follower on the filter output would be useful if a varying load is used. The purist will argue that this isn't a true active filter. I'm willing to concede the point, but I hasten to add that it's a *handy technique*. I encourage the amateur to take it from here.

*True for this circuit, but not for controlled source and negative immitance converter techniques. **Editor**

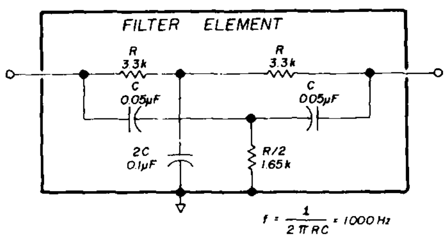


fig. 34. Preceding a conventional filter with an op amp follower to eliminate input loading. Input impedance of amplifier is arbitrary, as explained in the text. Resistor R should equal the input impedance to the filter.

a parting thought

I've presented some basic data on one of the most interesting and challenging products of modern solid-state technology. The circuits shown are the most commonly used, but by no means do they cover the entire field of possible applications.

If you wish to adapt these circuits to your needs, a good grasp of op amp theory is essential; the material listed in the references will supplement that in the first part of this article. Some possible projects that come to mind are:

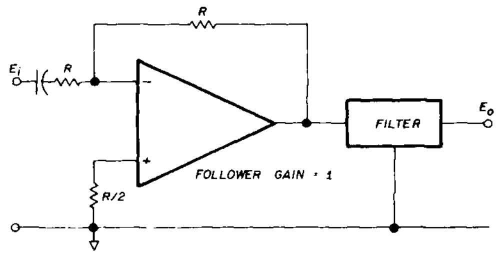


fig. 35. Preceding a conventional filter with an op amp follower to eliminate input loading. Input impedance of amplifier is arbitrary, as explained in the text. Resistor R should equal the input impedance of the filter.

1. An ultra-stable oscillator (for system synthesis).
2. A precision filter for selective calling.
3. A high-impedance meter for measurement of h_{fe} or g_{fs}.
4. A precision digital power supply.
5. Science Fair computer projects.

I'm sure you've thought of a few projects, too.

references

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2. H. A. Wittlinger, "Application of RCA CA3033 and CA3033A, etc.," RCA, Electronic Components, Harrison, New Jersey.
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ham radio

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Drake TV-5200-LP

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Drake TV-42-LP

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an IC op amp update

Following the work of Nelson, Author Jung brings you up to date with state-of-the-art IC operational amplifiers

The first operational amplifier article in this issue discussed the fundamentals of op amp design theory, some specs, and also earlier representative examples. Although there has been a great deal of new device activity since that article was originally published, take heart; it can all be sorted out. In this update article I'll discuss a number of different communication related applications for op amps, with attention directed to which device to choose for optimum performance, for a given application. The emphasis will be on the simple and straightforward devices, their uses, and limitations.

As a starting point, what is the standard in IC op amps? It has to be said that for a general purpose device, it is the 741. General purpose has come to mean a unit which can be used with ±5V to ±18V (dual) or +10V to +36V (single) supplies. In addition, it has a small-signal bandwidth of 1 MHz, a slew rate of 0.5 V/μS, input bias currents of 100 nA or less, and an offset voltage of 2 mV, all of these specs being typical. There are probably a hundred or more IC op amps which can meet this definition. However, I'll concentrate on the more common and readily available types (**table 1**).

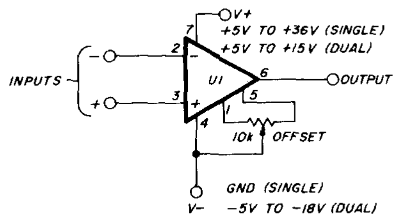


fig. 1. Standard pinout diagram for 8-lead IC op amps. When shown in a schematic diagram, the power connections are always mandatory, though sometimes they may just be implied. The offset null connections are not 100 per cent universal, and therefore the individual data sheets should be consulted.

Fig. 1 shows what has now become the standard pinout for single IC op amps. You'll note that the pin numbers marked on the leads correspond to the 8-pin (round can or mini-dip) configuration. The 5

By Walter Jung, 1946 Pleasantville Road, Forest Hill, Maryland 21050

pins, exclusive of the offset pins, are the *absolute minimum* required for op amp connections, and you cannot make a circuit work without all of them. Power pins (V+ and V−) are always there, although in some drawings they may only be implied for simplicity.

A 741 can be made to function in about 90 out of 100 op amp circuits, so it's a handy device to have around. For basic experiments and study, it is easily the best device since it's essentially foolproof. You don't have to bother with compensation components either, because it is internally compensated. Other op amps (such as the 709, 748, and 301A), use additional external compensation components. If you have some of these on hand, they also can be used in many of the following circuits (if the devices are compensated for unity gain as shown in **fig. 2**). Generally though, other devices mentioned will all be internally compensated, unless otherwise noted.

Standard op amp power supply voltages are ±15 volts, but this is not a very rigid requirement. If you have a balanced dc power supply providing between ±5 and ±15 volts, it will suffice for most of the circuits we'll discuss; you could also use a pair of 9 volt batteries. In general, you'll want to include a pair of

table 1. Common op amps and their manufacturers.

devices	manufacturer
μA709, μA740, μA741, μA759, μA791, μA798, μA799	Fairchild Semiconductor 464 Ellis Street Mountain View, California 94040
ICL8007	Intersil 10710 N. Tantau Avenue Cupertino, California 95014
MC1456, MC1436, MC1741S, MC3403, MC1458, MC3471	Motorola Semiconductor Box 20924 Phoenix, Arizona 85036
LM301A, LM307, LM318, LM324, LM348, LM349, LF356, LF357, LM358	National Semiconductor 2900 Semiconductor Drive Santa Clara, California 95051
RC4558, RC4136	Raytheon Semiconductor 350 Ellis Street Mountain View, California 94040
CA3140, CA3130, CA3160	RCA Solid State Division Route 202 Somerville, New Jersey 08876
NE532, NE534, NE535, NE536, NE5534	Signetics 811 E. Arques Avenue Sunnyvale, California 94086
TL080 Series TL071 Series TL061 Series	Texas Instruments Dallas, Texas 75222

table 2. Standard pinout single op amp devices.

bipolar		fet	
device	**remarks**	**device**	**remarks**
741 (748)	general purpose	3140	general purpose fet
307 (301A)	general purpose	356 (357)	high performance fet
1456	high slew rate	TL081 (TL080)	general purpose fet
1436	high voltage	TL071	low noise TL081
343 (344)	high voltage	3160 (3130)	CMOS output
759	high current		
799	single supply	740	first
		536	generation
		8007	fets
318	very high speed		
5534	low noise		
1741S	high slew rate		
535	high slew rate		

good rf bypasses, such as 0.1 μF ceramic capacitors across the supply lines, preferably near the IC. Or, you may want to construct a simple dc supply, (2, 3, 4) using IC regulators. For most IC op amp circuits, regulation is not at all critical and IC voltage regulators are more than adequate.

With regard to **fig. 1**, the only other circuit detail not yet mentioned is the offset pot. The method shown is common to many units, such as the 741, but is not *completely* universal. If your circuit requires offset nulling, double check the data sheet to be sure of the method. Often, the need for an offset adjustment can be eliminated by careful circuit design.

The recent arrival of the fet input IC op amp, with wide availability and low cost, is one of the happier developments in recent years. A number of bipolar and fet devices are listed in **table 2**. All ICs listed in this chart can be substituted in the pinout diagram shown (excluding offset null). In some cases a dual listing is shown; the second is the uncompensated version of the basic device.

A fact which further serves to demonstrate the maturity of IC op amps is the preponderance of multiple units, both duals and quads. A few of the more popular ones are listed in **table 3**. As can be seen, many of them are dual or quad versions of single op amps. There are no wholly universal types, but the 1458 and 4558 are probably the most popular duals (**fig. 3A**), likewise the 324 and 4136 are the most popular quads. In the quads, there are two generally accepted pinouts (**fig. 3B**) corresponding to the 324 and 4136.

applications

Having very briefly looked at popular standard ICs, it's time to examine some specific op amp applications. This treatment is somewhat unique, because it shows only a few device part numbers. It's intended that almost any device listed in **tables 2** and **3** can be used in these circuits with the appropriate connections. The circuit discussion, however, will emphasize which device is the best choice, and why.

gain blocks

Probably one of the most common uses of IC op amps is as a gain block, to raise signal levels or buffer a source. The basics of inverting and non-inverting gain stages are quite straightforward, but a lot can be said about tailoring a gain stage to specific uses, while getting around device limitations.

In **fig. 4A**, an op amp inverter is connected for split supply use. Gain is simply R2/R1, while the input impedance is equal to R1. The practical problem with this circuit is that high gains tend to result in a low input impedance. This can be alleviated by fixing R1, and raising R2. If a fet input amplifier is used, R1 and R2 can be made as large as convenient, many megohms being entirely practical. The practical limit is that at very high values of R2, stray capacitance will begin to limit bandwidth.

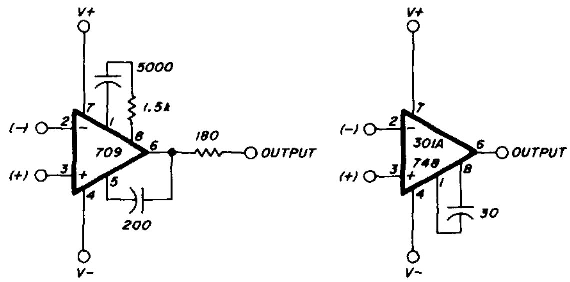


fig. 2. Some op amps are not internally compensated and may require external capacitors for compensation. The examples shown here have been compensated for unity gain.

A dc response is obtained with the input directly connected to R1. At high gains (100 or more), offset at the output may be prohibitive, requiring offset nulling. For ac use, the blocking action of C1 causes the dc gain to be unity (for any ac gain) and thus offset is not amplified. This is the preferred connection when only ac gain is required. Note that C1 and R1 have a low-frequency rolloff which sets the lowest usable frequency. The high-frequency bandwidth can be controlled by either of two means. If gain is very high (⩾ 40 dB), the amplifier's gain bandwidth will cause a rolloff at the op amp's unity-gain frequency divided by the stage gain. For example, a 741's unity response occurs at 1 MHz, thereby limiting bandwidth to 10 kHz with 40 dB of gain. Wider bandwidth units, such as the 4558, will increase the total bandwidth.

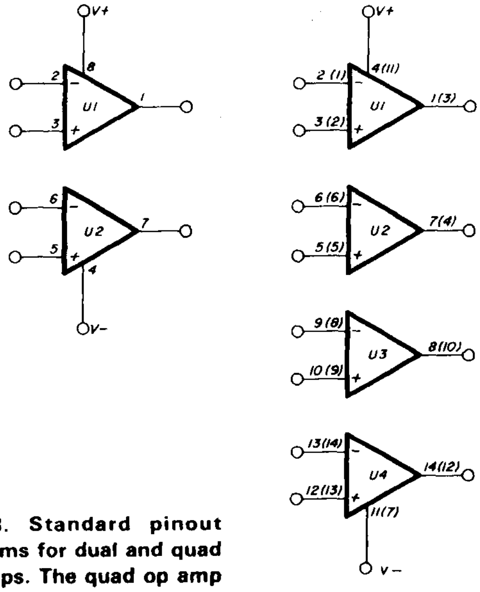


fig. 3. Standard pinout diagrams for dual and quad op amps. The quad op amp can be in either of two different patterns, with the second set in parenthesis.

1'ST NUMBER DENOTES 324 PIN NUMBERS
(2) DENOTES EQUIVALENT 4136 PIN NUMBERS

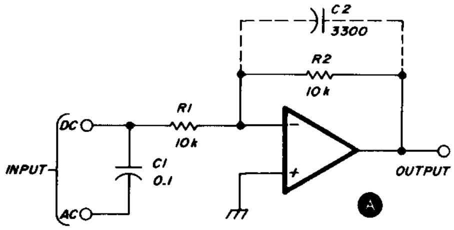
For working gains *not* limited by amplifier rolloff, the bandwidth can be set by a capacitor (C2) connected across R2. In the example shown, C2 sets the 3 dB bandwidth to 5 kHz. An interesting basic characteristic of the inverter is that it can be used for gains *less* than unity, when R2 R1. This can be useful when it is required to reduce the gain of a stage to zero, or some low value less than unity. Compression agc or amplifiers make good use of this factor.

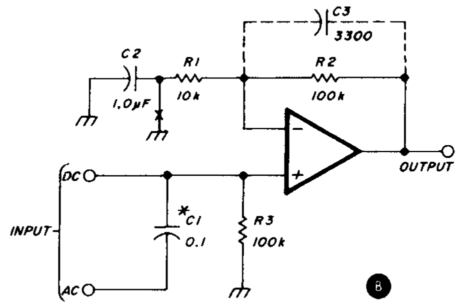
A non-inverting gain block is shown in **fig. 4B**; the

table 3. Standard pinout dual and quad op amp devices.

bipolar		fet duals	
device	remarks	device	remarks
1458	dual 741	TL082	dual TL081
358	low power, single supply	TL072	low noise
2904	low power, single supply	TL062	low power
532	low power, single supply		
798	low power, single supply, class AB output		
4558	"faster" 741, low noise		
bipolar quads		**fet quads**	
device	**remarks**	**device**	**remarks**
324	low power, single supply, class B op	TL084	quad TL081
3403	low power, single supply, class AB op	TL074	low noise TL084
4136	"faster" 741, low noise (pnp input)	TL075	low noise, 4136 pinout
		TL064	low power
348 (349)	quad 741 (npn input)	3471	high speed

fig. 4. A standard op amp inverting gain block is shown in A. The gain of the IC is $R2/R1$, with the input impedance being $R1$'s value. For ac use, the low frequency rolloff occurs at $f_L = \frac{1}{2\pi R1C1}$, while the high frequency rolloff is $f_H = \frac{1}{2\pi R2C2}$. B illustrates a non-inverting configuration. In this case the gain is $\frac{R1+R2}{R1}$. The low frequency rolloff will occur at two frequencies, $f_{L1} = \frac{1}{2\pi R3C1}$ and $f_{L2} = \frac{1}{2\pi R1C2}$. There will only be a single high frequency rolloff, $f_H = \frac{1}{2\pi R2C3}$





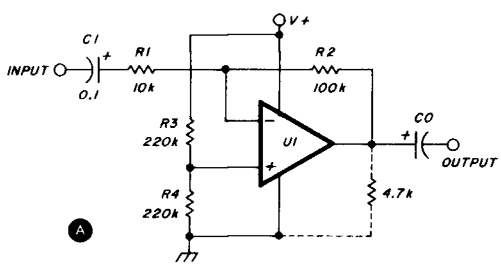
general gain of this stage is $\frac{R1 + R2}{R1}$. The intrinsic input impedance is very high (assuming R3 is not connected), as it looks directly into the input to the amplifier. If the amplifier is a fet type, the bias current will be only a few picoamps, while in bipolar units it is typically on the order of 50-100 nA. The non-inverting stage is therefore inherently best when minimal loading of the source is required, such as timing capacitors or high impedance transducers.

Gain can be manipulated by either R1 or R2, as convenient, with no effect on input impedance. The minimum gain of this circuit is unity, with R1 open and R2 shorted. Breaking the dc path of R1, and inserting C2 causes amplification of only the ac component. Input ac coupling is provided by C1, with R3 as a bias return. R3 is shown as nominally 100k ohms but a fet amplifier can allow 10 megohms or more here, without compromise.

The same bandwidth limitations apply to the non-inverting amplifier as the inverting amplifier. C3 can be used to reduce bandwidth at a specific point. Note that in this circuit, C3 can reduce the gain to a minimum of unity.

For both of these circuits, large-signal bandwidth is limited by the slew rate of the op amp used, and can be quite independent of the external components. If you require high output voltages (10 volts peak) at frequencies of more than 10 kHz, a high-slew rate op amp is in order. Most fet amplifiers have slew rates of 5 V/μS or more, allowing full power to 100 kHz or more. Reference 5 will provide some further insight into optimizing general purpose gain blocks. The absolute limit on voltage swing depends either on the op amp or its power supplies. Standard units can swing about ±10V with ±15 V supplies. High voltage devices, like the 1436 or 344, can swing ±20 V or more, with +28 V supplies. For rated output, loading should be 1k ohm or more. If lower impedances are used, they will not necessarily damage the device, but may result in reduced output due to current limiting.

Since a great many op amp audio amplifiers use a single power supply, it is appropriate to configure the previous gain blocks for a single voltage. **Fig. 5A** shows the inverting mode. Again R1 and R2 set the gain, with C1 and C_0 providing input and output coupling. Assuming a zero dc level at the input and



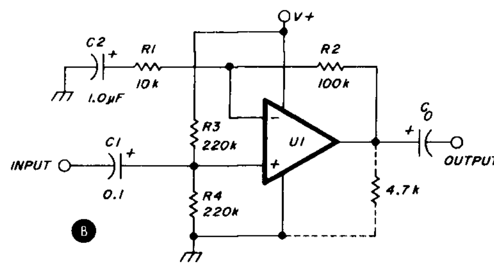


fig. 5. The inverting and non-inverting configurations can be connected for a single supply voltage. The voltage divider provides one half of the supply voltage as a reference to the op amp. In the case of the class-B output stages, the resistor can be added to reduce cross-over distortion.

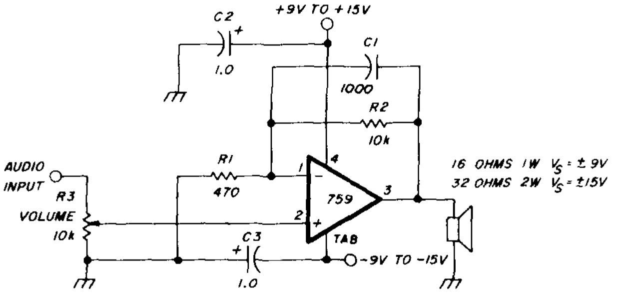


fig. 6. The Fairchild 759 can be connected as a 1 or 2 watt monitor amplifier. For 1 watt operation, the supply must be ±9 volts with a 16 ohm speaker; for 2 watts, ±15 volts with a 32 ohm speaker. The IC package must be connected to a heat dissipating device.

output, C1 and C_0 must be polarized as shown. R3 and R4 form a $\frac{V+}{2}$ divider, which biases the amplifier output for the maximum signal swing. For most general-purpose op amps, this is all that is required.

Some op amps have class-B output stages for reduced power drain. Examples are the 358 and 324 units which have 0.7 and 1.5 mA quiescent drains, making them highly suited for battery or other power uses. However, the class-B output stage does generate cross-over distortion, which may be objectionable. An optional pull-down resistor (4.7k) can be used to minimize this affect. It should be adjusted to suit the particular application.

monitor amplifier

Recently there have appeared on the market several op amps which can furnish substantial output power, with the convenience and simplicity of general op amps. One of these is the Fairchild 759 illustrated as a 1W/2W monitor amplifier circuit in **fig. 6**. The 759 has a peak output current of 350 mA, and a supply range similar to other op amps (36 volts). Thus, the power it can deliver to a given load is related to the impedance and supply voltages used. As shown here it can furnish 1 or 2 watts to a 16 or 32 ohm speaker, with supplies of ±9 or ±15V, respectively.

The device is furnished in a heatsink type package, which should be attached (but insulated) to a chassis or other heat radiator. This circuit is attractive because of its simplicity, and can be adapted to suit other gain requirements. Gain is 20 for the values shown, with the response rolled off by C1 at 15 kHz.

A higher power "op amp with muscle" is the 791 (Fairchild) which has a 1 A output. There are also several high voltage devices which can be used to drive external transistors providing many watts of output. Examples are the Signetics NE540 and NE541, the Motorola 1436, and the National 343 and 344.

push-pull driver

An interesting technique which will produce 6 dB more voltage and power output, for a given supply voltage, is shown in **fig. 7**. This circuit is a push-pull driver, which effectively doubles the output voltage swing across a floating load. The circuit is quite cost effective when used with one of the dual op amps in **table 3**. Gain is adjusted by R1 or R2, and it may be adapted for single supply bias by lifting the grounded end of R5 and applying a potential of $\frac{V+}{2}$ to the input of U2 and the bottom of R5.

parallel driver

A handy idea, when a single op amp just won't supply enough output power, is the parallel driven circuit shown in **fig. 8**. Here U1 and U2 are two op amps of a similar type, with their inputs driven in parallel. The outputs are combined through low value resistors, with output current being approximately doubled. Additional similarly connected stages can also be used, such as 3 or 4 sections of a quad unit. The output resistors force the current to be shared equally between the op amp outputs. While their values are not critical, they should be at least 50 ohms.

Some single op amps have noteworthy power or voltage characteristics and are very attractive for use in this type of circuit. Examples are the Signetics 5534 which has a 30 mA output stage, and high voltage types such as the 1436, 343, or 344 which can swing up to 80 V p-p in this circuit.

variable voltage reference

The circuit in **fig. 9** is useful for the generation of a

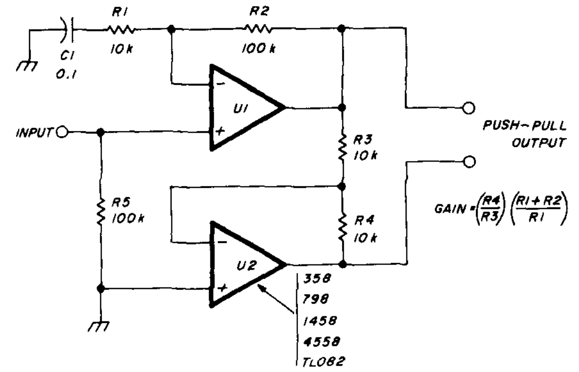


fig. 7. If the load is floating, two op amps can be connected for push-pull operation. This method will provide 6 dB more voltage and current output, for a given supply voltage.

buffered and stable reference voltage source, while being readily adaptable to a wide range of output voltage and current requirements. This method takes advantage of the ability of a number of op amps to operate from a single supply voltage, with their inputs *at or at near ground* potential. The basic reference voltage is developed by the LM336, a stable, 2.5 V, monolithic zener diode with a low (20 ppm/°C) temperature coefficient. Because of the low-dynamic impedance of this diode (less than 1 ohm), the 2.5 V is extremely stable when the diode is biased for a current of 1 mA. R4 applies some fraction of the 2.5 V to the op amp, which amplifies it by a factor of 4 to yield a +2.5 to 10 V output.

Output current rating is dependent upon op amp, of course, and will be about 10 mA for general purpose types. The 759 can supply up to 350 mA if desired, or other devices can be buffered by an npn

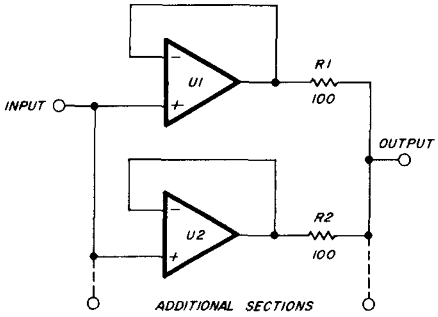


fig. 8. Similar op amps can be connected in parallel, providing additional output current. The outputs must be connected through low-value resistors.

emitter-follower stage. If greater output range is desired, the circuit can be operated from a higher supply voltage with R2 adjusted accordingly. R3 *should be selected to maintain about* 1 mA of current in the LM336.

digitally-programmable voltage source

A buffered, digitally programmed voltage source is shown in **fig. 10**. This circuit is quite useful as a repeatable, programmable lab source with a basic range of 0 to 2.55 V (10 mV per step), or 0 to 25.5 V (100 mV per step). The output is adjustable, in binary fashion, with an 8 bit TTL compatible input control.

This circuit uses an MC1408 8-bit D/A converter, which provides 1.99 mA full scale. The current in turn is converted to a buffered voltage by U2. R3 determines the basic voltage range, being 1280 ohms for a 2.55 V scale, or 12.8k for 25.5 V (the op amp used must be capable of handling these output voltages). A 741 or other general purpose op amp is adequate for a 2.55 V range, but a high-voltage single-

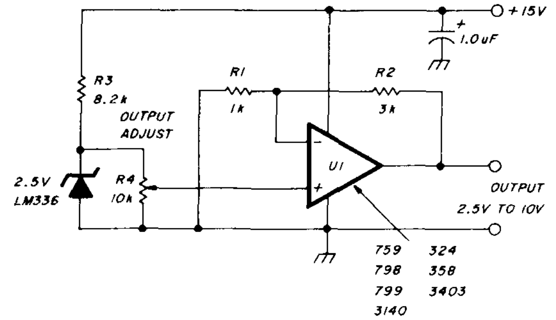
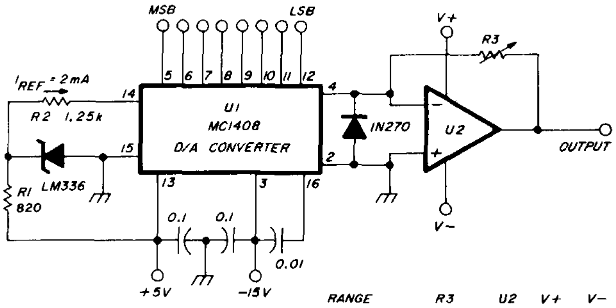


fig. 9. Combining a high-quality zener diode with an op amp will produce a variable voltage reference. In this case, the op amp has a dc gain of 4, giving a voltage range of 2.5 to 10 volts.

supply type is more appropriate for the 25.5 V range. For this, the 759 is suggested. It can also be used for the lower scale, of course, and is attractive because of its high output current.

Like the voltage-reference source, regulated current sources are also useful as basic circuit elements, especially for control and measurements applications. **Fig. 11A** illustrates a simple current source, which uses only a reference diode and a single resistor to set the output current. The reference diode is driven in bootstrap fashion by the op amp, causing the reference voltage V_z to appear across R5. The regulated output current is I_o, which may be any value less than I_z, but must be substantially greater than the op amp's bias current. If a fet op amp is used, this circuit can be used from 1μA up to a level approaching I_z. In this case, it is 10 μA.

The current in the zener is set by R1 to provide a minimum zener current (1 mA), taking into consideration the supply voltage and R_L. With $R_L = 1$ *meg*, the circuit has a compliance voltage of 10 volts. The weak point of this circuit is the fact that the zener



RANGE	R3	U2	V+	V−
0 TO +2.55V	1280 OHMS	741	+5V	−15V
0 TO +2.55V	12.80 k	759	+28V	GND

fig. 10. Instead of using a straight analog control, this circuit uses a D/A converter to form a digitally-programmable voltage source. The binary coded, TTL information will produce either of two voltage ranges, 0 to 2.55, or 0 to 25.5 volts. Full scale calibration is achieved by trimming R3.

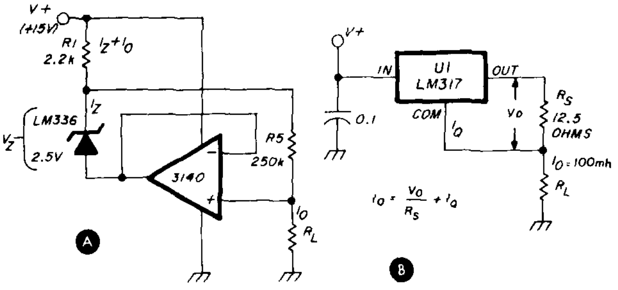


fig. 11. A simple current source combines a zener diode with an op amp in a bootstrap configuration (*A*). For higher currents, any of the three-terminal regulators can be used as constant-current sources (*B*). The current setting resistor is connected between the output and ground terminals of the device.

current changes with supply voltage and R_L. Although the LM336's low impedance mitigates this, it is still the ultimate limit to precision. For a higher performance version of this circuit, the zener can be replaced by a 2.5 V three-terminal voltage reference, such as the Analog Devices AD580 or the Motorola MC1403. Reference 6 includes a discussion of this type of circuit

For currents higher than a few mA *three-terminal* references and regulators can be used very effectively, with the addition of only one resistor, to set the output current, as shown in **fig. 11B**. This schematic is quite general as shown, and can use any of the three-terminal devices. The AD580 and MC1403 are usable up to 10 mA, while the LM317 can handle one ampere or more (it must, however, have a minimum load current of 10 mA).

low-voltage ohmmeter

A circuit which employs several of the previously described principles, as a low-voltage ohmmeter, is shown in **fig. 12**. Two desirable factors incorporated in this ohmmeter are a low applied voltage, (0.1 V), and an output which is linearly proportional to the unknown resistance. It can accurately measure resistances to below one ohm.

The heart of the circuit is a current source, composed of U1, CR1, and R_Y. This circuit, with R_Y selected for the appropriate range, furnishes a constant current to the unknown, R_X. For example, with the values shown, I_X is 100 μA, and 1k ohm R_X will drop 0.1 V. The voltage dropped across R_X is indirectly read from U1's summing point by amplifier U2. This node, being of a much lower impedance, allows U2 to be a relatively high bias current device such as a 741. U1 is a fet input unit (356) giving best accuracy at high R_X levels (low levels of I_X). Alternately, a 3140 can be used with somewhat less preci-

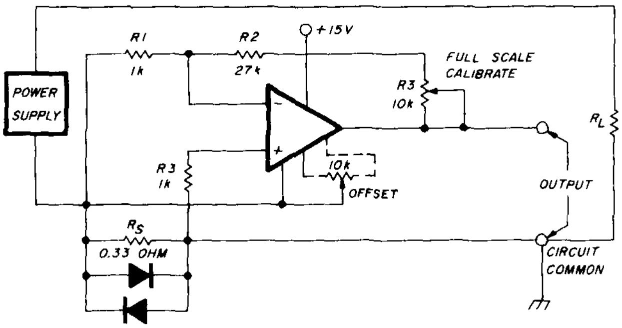
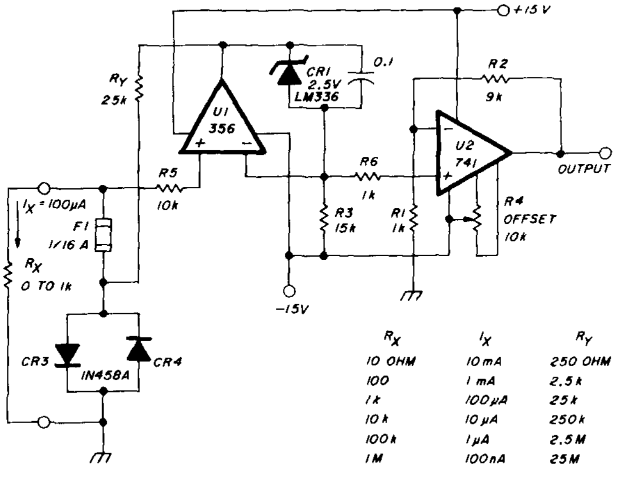


fig. 13. The supply-current monitor uses the voltage drop across a low-value resistor to indicate the current being drawn in the circuit. One side of the resistor and op amp are referenced to ground. The voltage difference across the resistor is amplified by the op amp, producing a 10-volt output that corresponds to one ampere of current.

sion. U2 operates as a straight dc amplifier, with a gain of 10, scaling the 0 to 100 mV unknown voltage to 0 to 1 V at the output. Thus, a 1k R_X resistor can be read as 1.000 (k) on a DVM scale. The circuit can overrange at least 100 per cent, therefore, 2 volt scaled instruments can read up to 2k ohms full scale (or 200 mV at the input). The dynamic range of the circuit is over five decades.

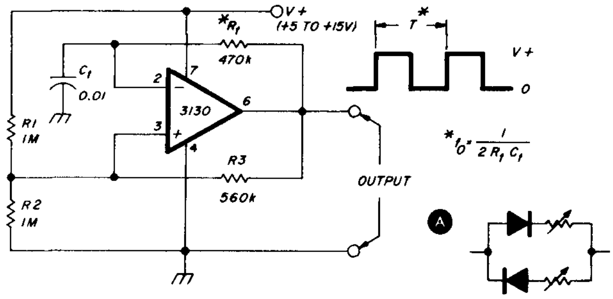
Since the maximum voltage handled by U2 is only 100 mV, it should be offset nulled to eliminate zero error for best low-scale accuracy. This is done by shorting the input and adjusting for 0.000 V out of U2. For full-scale calibration, the individual range values of R_Y should be trimmed for correct output, with a reference value for R_X.

If the circuit is to be used to probe equipment, overvoltage/current protection is warranted. A 1/16 A fuse and clamp diodes CR2-CR3 protect the range resistors; with R5 *protecting the op amp*. The diodes used for CR2 and CR3 must be low leakage types, such as those specified in **fig. 12**.



R_X	I_X	R_Y
10 OHM	10 mA	250 OHM
100	1 mA	2.5k
1k	100µA	25k
10k	10µA	250k
100k	1µA	2.5M
1M	100nA	25M

fig. 12. This low-voltage ohmmeter combines a stable constant current source with a dc amplifier. In this diagram the ohmmeter will read 1000 ohms full scale.



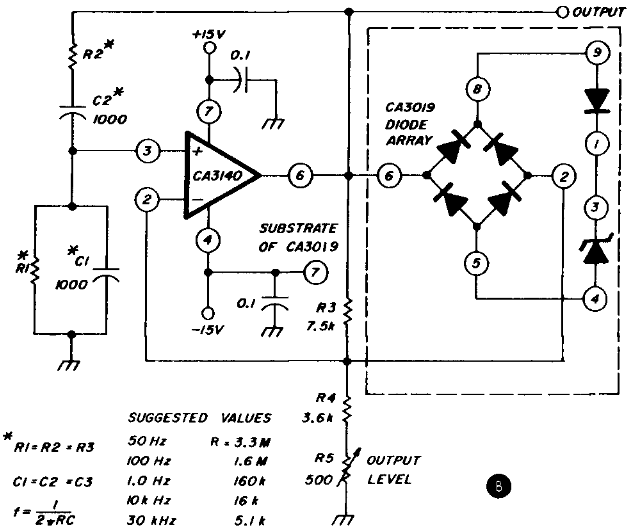


fig. 14. This square-wave generator (*A*) can cover the range of 1 Hz to over 1 MHz by proper component selection. Symmetry of the output waveform is controlled by connecting diodes in series with R_t (see text). The wide-range Wein bridge oscillator shown in *B* at right uses a diode array to provide amplitude control.

Fig. 13 illustrates how the differencing input voltage feature of the op amp can be used to monitor the current in a supply line. A sampling resistor R_S is inserted in the line to develop a voltage proportional to the supply current. This voltage is then amplified and referenced to the circuit common point by the op amp, which can be a 799 for medium to high currents ($\geqslant 10\mu A$), or a 3140 for very low currents. R3 is trimmed to calibrate the output, in this case, 10V = 1 ampere.

Techniques such as this, which functionally do nothing more than replace a series ammeter, will become more important as forms of automated control pervade the amateur station. The output as shown, could be directly processed by an A/D converter, for instance.

op-amp signal sources

The test bench can always use simple, inexpensive, and high performance signal sources. **Fig. 14** illustrates two examples of oscillators which capitalize on some features displayed by modern IC op amps.

A simple (and probably familar) op amp based astable multivibrator is shown in **fig. 14A**. This circuit generates square waves over an extremely wide range, from well below 1 Hz to over 1 MHz (with suitable values, of course). The RCA 3130 used, a +5 to +15 V device, has a CMOS output stage. Thus, it can drive either 5 V TTL or 10-15 V CMOS logic stages directly, since its output swings from rail to rail (V+ to ground). Rise and fall times of the circuit are quite fast, on the order of 100 nS. Although shown here as a 100 Hz source, R_t and C_t can be readily scaled for different ranges. For control of symmetry, R_t can be replaced by two resistors in series with a reverse connected diode. If higher output swings are desired, other (uncompensated) op amps can be used. Examples which are capable of high speed are the 301A, 748, TL080, and 357 units.

The classic Wien bridge oscillator is often seen in the literature[7] and is a true stalwart for the generation of low-distortion sine waves. The circuit of **fig. 14B** shows how the 3140 can be used in conjunction with diode array, providing amplitude control.

Two problems which beset this type of oscillator are high distortion at high frequencies, (due to limited slew rate in the amplifier) and amplitude "bounce." The 3140 has a high inherent slew rate of 9 V/μS, which allows full output (20 V p-p) to over 100 kHz. The use of a zener diode clamp for amplitude control allows fast agc, without the bounce or overshoot of thermistors. A range of suggested values is given in this figure, and RCA's data sheet[8] for the 3140 discusses this circuit in further detail.

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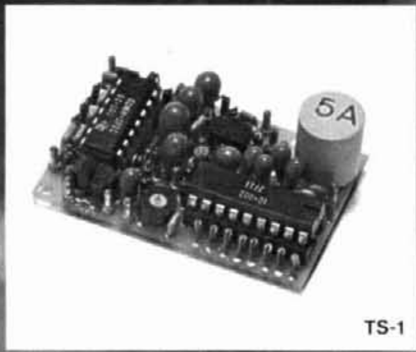

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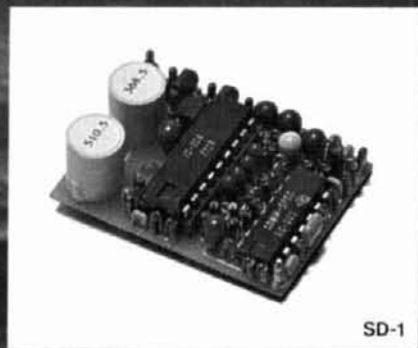
PE-2



SD-1

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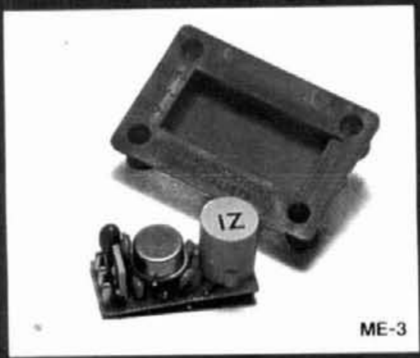
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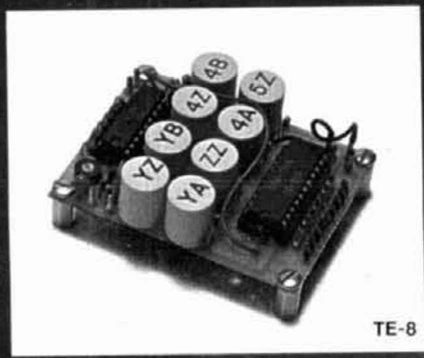
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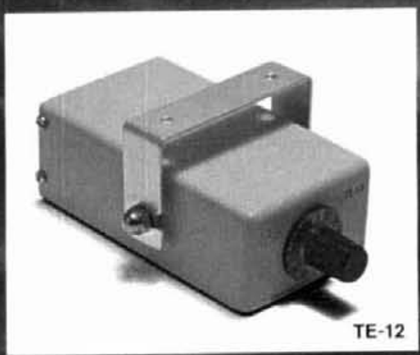
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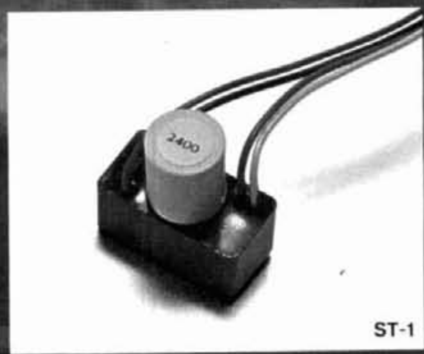

ST-1

high-frequency hybrids and couplers for amateur applications

Hybrid and coupler circuits borrowed from the microwave domain have many uses at the lower frequencies — here are some applications for amateur use

Microwave hybrids are extremely versatile devices. They have many applications not necessarily restricted to the microwave region. This article explains how these circuits may be put to use at the higher amateur frequencies where communication may be enjoyed without the interference and noise created by thousands of commercial kilowatt transmitters.

When hybrids are mentioned, many hams think of bifilar-wound coils on toroidal forms. However, the circuits described here may be constructed from coaxial line for vhf or uhf use. For the higher frequencies, they may be constructed using stripline, microstrip, or waveguide techniques. Three devices are considered:

1. The half hybrid (**fig. 1**). This is a degenerate form of a 4-port device that may be used as a power combiner or divider.

2. The branch directional coupler, **fig. 2**, which is a quadrature hybrid with some interesting applications for moonbounce work and ssb.

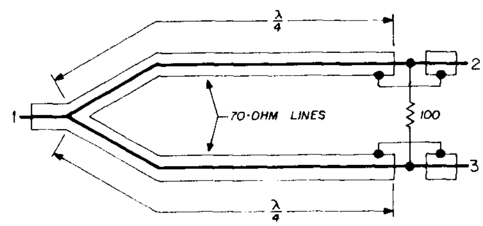


fig. 1. The half hybrid, useful as an isolator between two power sources. Impedance at each port is 50 ohms.

3. The coaxial rat race (**fig. 3**). Sometimes called a 180° hybrid, this circuit may be used as part of a balanced modulator or to match or balance two equal loads (as in combining equal sections of an antenna array).

the half hybrid

This is the simplest of the devices described. It consists of a Y or T junction, two quarter-wavelength matching transformers, and a bridging resistor.

By Henry S. Keen, W2CTK, (reprinted from the July, 1970, issue of *ham radio*)

If the half hybrid is fed at port 1 (**fig. 1**), the signal will divide equally between ports 2 and 3. Because no phase difference exists at ports 2 and 3 when properly terminated, no voltage appears across the resistor; therefore, no power is absorbed. If an imbalance exists due to a mismatch, however, part of the signal will be absorbed by the resistor and part will be reflected to the generator. If the generator impedance is 50 ohms, it will absorb the reflected portion. The isolation between output ports is independent of the match provided by the loads.

If you look at the circuit quickly, the source of this isolation may seem vague; but if the circuit is redrawn as in **fig. 4**, the path from port 2 to port 3 resembles the familiar bridged-T network. In this circuit, a signal at port 2 will be nulled at port 3. Therefore, the load impedance at each port is not a factor in the isolation between ports.

The half hybrid may be used to provide isolation between two power sources, such as a pair of power transistors. A fail-safe arrangement is thus obtained, whereby failure of either component will not affect the load presented to the other unit. Power output will decrease by 6 dB because input power will be dissipated in the bridging resistor, but loading conditions presented to the source will remain unchanged.

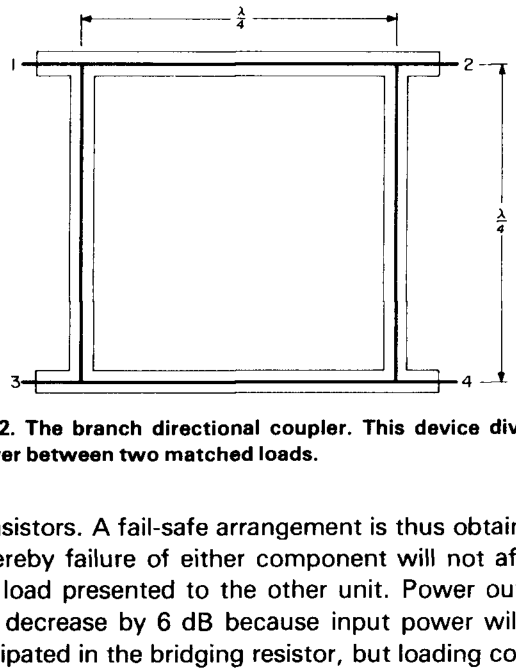


fig. 2. The branch directional coupler. This device divides power between two matched loads.

In applications requiring high reliability during prolonged unattended operation (as in fm repeaters), half hybrids as combining networks offer a passive means of ensuring uninterrupted service without resorting to complex switching mechanisms.

branch coupler

The branch coupler is a 4-port device. It divides input power between two matched loads. The isolation between two input ports is a measure of the match provided by the loads. A 90° phase difference exists between the signals at the two output ports, because one signal travels one-quarter wavelength farther than the other. This device can be used for sampling a portion of the signal for reference or comparison purposes.

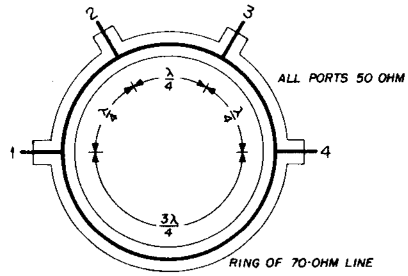


fig. 3. Coaxial rat race, or ring coupler. It can be used to balance similar sections of an antenna or as a balun.

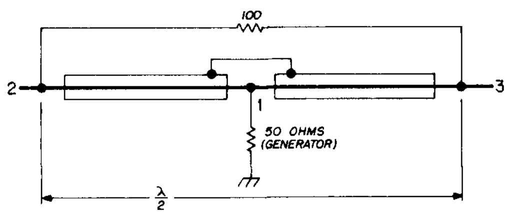
analysis

To understand the design principles of the branch coupler, consider the case of the 3-dB version in which the input power is divided equally between the two load ports.

In a perfectly matched coupler no signal exists at port 3, so this port can be short-circuited without affecting power distribution (**fig. 5**). This would make branches 1-3 and 3-4 shorted quarter-wavelength stubs, shunted across ports 1-4. Thus they may be removed, leaving only branches 1-2 and 2-4.

If power is to divide equally between ports 2 and 4, port 4 must present a 50-ohm load at port 2. The characteristic impedance of branch 2-4 must therefore be 50 ohms, thus establishing an impedance of 25 ohms at port 2. To match this to a 50-ohm input, branch 1-2 must have a characteristic impedance of 35 ohms, which can be obtained with two 70-ohm coaxial line sections in parallel.

When the network is "reassembled," branch 1-3 will be the same as branch 2-4; while branch 3-4 will be the same as branch 1-2. For a general solution of



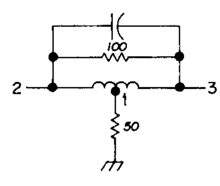


fig. 4. Equivalent circuit of the half hybrid. Note the resemblance to the bridged-T network.

the design, the branch impedances will be:

$$1\text{-}3 = 2\text{-}4 = \sqrt{\frac{Power\ (2)}{Power\ (4)}}$$

$$1\text{-}2 = 3\text{-}4 = \sqrt{\frac{Power\ (2)}{Total\ power}}$$

Several applications of the branch coupler are of interest for amateur work. For example, a 3-dB coupler can be used as a phasing power divider to feed a circularly polarized antenna. Another use would be as a 90° phase shifter for phasing-type ssb generators.

Let's first consider the power divider. If a signal fed to port 1 produces clockwise phase rotation, feeding port 3 will produce counter-clockwise rotation. If both ports are fed simultaneously, linear polarization

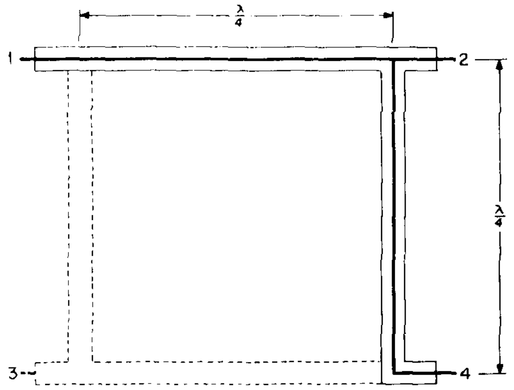


fig. 5. The branch coupler. If port 3 is short-circuited, branches 1-3 and 3-4 may be removed.

will result. A line stretcher in one of the inputs would permit adjustments to any desired phase angle.

A received signal of the same polarization as that transmitted would appear at the same port from which it was transmitted. A signal of opposite phase rotation, such as a reflected signal, would appear at the other port.

In microwave applications, isolation from 40 to 50 dB has been obtained under ideal conditions. The thought occurs that this idea might be useful for moonbounce work; however, I have no information as to how much the circular polarization would be degraded.

single sideband

Single-sideband phasing techniques have been used in microwave receiver design to phase out the image signal. This method also offers a theoretical 3-dB reduction in front-end noise.

A block diagram of such a system is shown in **fig. 6.**[1] The second 3-dB hybrid operates as a combining network designed for the intermediate frequency. Balanced mixers could be used to cancel the noise contributed by the local oscillator.

At lower frequencies, the branch coupler may be synthesized with appropriate values of L and C. An equivalent quarter-wavelength line may be constructed for any desired characteristic impedance (**fig. 7**). The absolute values of each reactance at the design

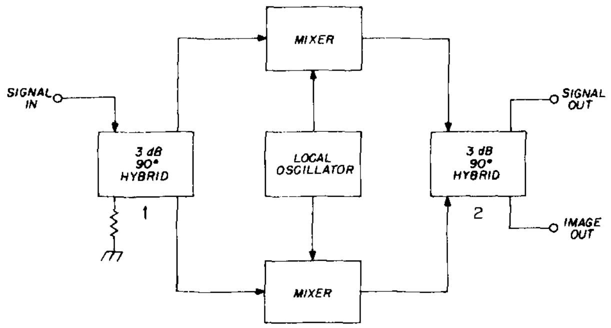


fig. 6. The branch coupler used to phase out frontend images in ssb receiver applications.

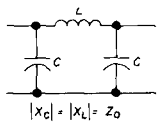
frequency should equal that of the line being synthesized. The capacitors in the final version, **fig. 8**, are identical in value.

coaxial rat race

The standard form of the 50-ohm rat race, or ring coupler, is shown in **fig. 3**. It consists of a closed loop of 70-ohm line with a circumference of three 1/2 wavelengths. The four ports are located 1/4 wavelength apart, with first and fourth ports connected by a 3/4-wavelength line.

A signal fed to port 2 divides in two; each half travels around the loop in opposite directions. The path to port 4 is a half-wavelength longer than that to port 2, so the two signals arrive at their respective

fig. 7. Synthesized quarter-wavelength line of impedance Z_0.



loads in phase opposition. Port 3, located midway between the two loads, will therefore receive no signal. The loads must be identical for this cancellation to occur.

As a matter of interest, both loads can be removed, leaving only the loop with ports 1 and 3. Cancellation will occur at the center frequency. This dual-path structure is known as a re-entrant filter.

If the signal is fed to port 3, the two loads will be fed in phase. Any in-phase reflections of equal magnitude from ports 2 and 4 will arrive at port 1 out of phase and will therefore cancel. If the loads are unequal, and the reflected signals differ in amplitude or phase, or both, then cancellation will be incomplete, causing a signal to appear at port 1. In some applications, a matched load may be placed at the odd port to absorb the imbalance.

The rat race offers an excellent means of adjusting signal balance between similar sections of an antenna array. A detector-indicator, such as a receiver

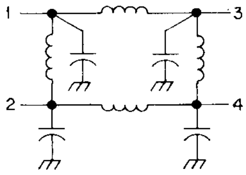


fig. 8. Lumped-constant equivalent circuit of the branch coupler.

with an S-meter connected at port 3, would show imbalance between array sections. Identical lengths of transmission line must be used between ports 2 and 4 and their respective loads to avoid complications due to phase differences.

The rat race also functions well as a balun. When used for this application, the balanced load impedance is twice that of the coax input line, and port 3 is usually grounded.

capacitively-coupled hybrid

The capacitively-coupled hybrid shown in **fig. 9** is another form of the 90° or quadrature hybrid. Coaxial line of any convenient characteristic impedance can

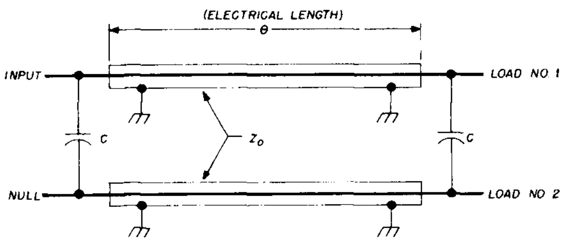


fig. 9. Capacitively-coupled hybrid is another form of the 90° or quadrature hybrid.

be used in its construction as long as the correct line length and proper coupling capacitances are used. The electrical length of the line elements is computed from:

$$Coupling\ (dB) = -20\ log_{10} cos\ \theta$$

The reactance of the coupling capacitors is:

$$X_c = Z_o\ tan\ \theta$$

Thus, for a 3 dB hybrid using common 50-ohm coaxial cable, the lines would have an electrical length of 45°, and the coupling capacitors would each exhibit 50 ohms reactance.

50-ohm rat race

If you don't happen to have any 70-ohm line handy, you can make a rat race with 50-ohm line, which is suitable for spot frequency or narrowband work. In this version (**fig. 10**) ports 1 through 4 are separated by 0.153 wavelength of 50-ohm line. The

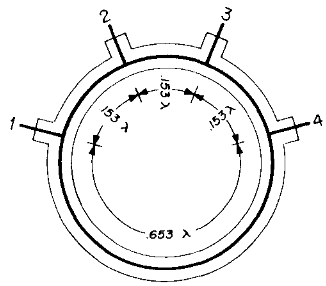


fig. 10. Coax rat race constructed with 50-ohm line.

long side is 0.653 wavelength, taking into account the cable's velocity factor.

At lower frequencies, the rat race is replaced by a center-tapped transformer. In the higher-frequency regions, where waveguide is used, a device known as the "magic Tee" performs the same function.[2]

In all regions of the radio spectrum, hybrid devices exist in one form or another, which can contribute much to the versatility of equipment design.

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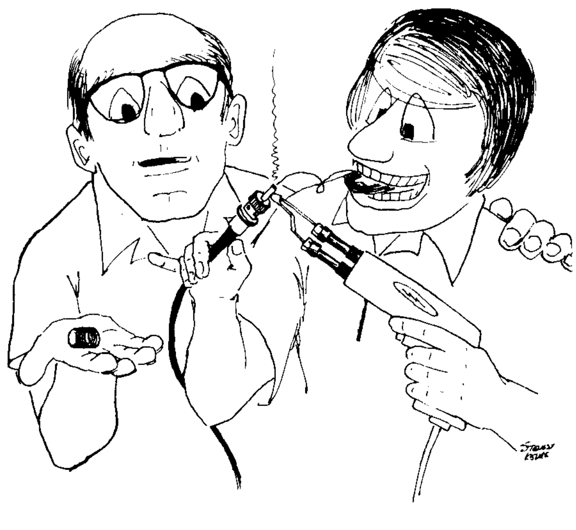

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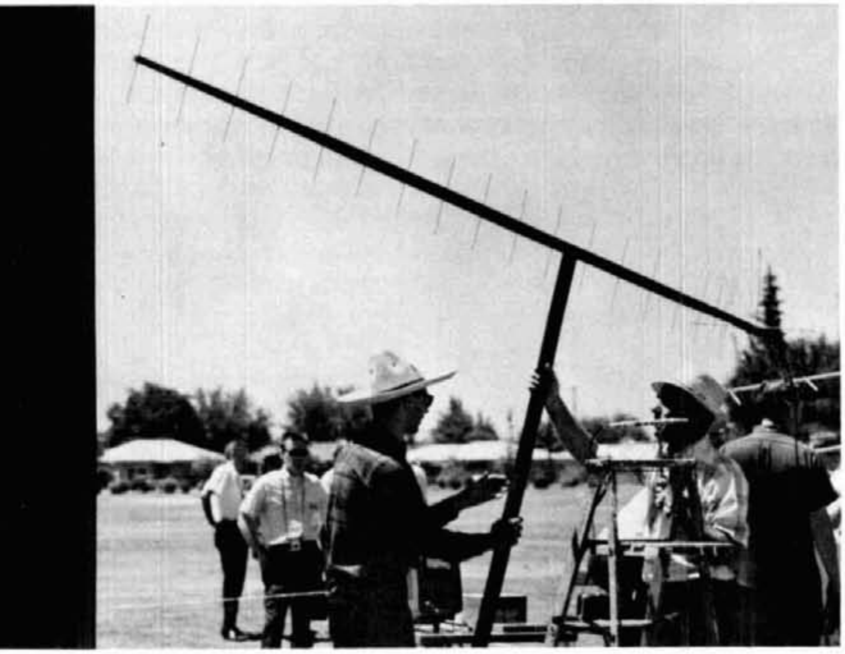


direct methods for measuring antenna gain

How to obtain meaningful vhf antenna gain data using simple equipment

For the amateur interested in top station performance on any band, antenna refinement definitely produces the most rewarding return per unit of effort and expense.

Only in the antenna system, which includes the feedline and supporting structure as well as the radiator, can improvements increase performance for both transmitting and receiving. Unfortunately, however, the antenna system is usually the most neglected part of an amateur station. Performance tuning, if done at all, is usually limited to adjusting the driven element length, sliding the clamps on the T match, or adjusting the gamma capacitor for the lowest standing wave ratio. Except for using the swr bridge, *antenna scope* impedance bridge, or field-strength meter, most amateurs seem content to leave antenna tuning to the manufacturers.

The manufacturers can't build antennas to meet all performance demands. Commercially built antennas are designed for "average" installation conditions. All too often these just don't exist in many amateur installations. Most amateurs are plagued by poor soil conductivity, height restrictions, nearby objects, and a host of other adverse conditions that affect antenna performance. These adverse effects can be reduced by tuning the antenna system once you have some dependable quantitative data as a baseline for optimization.

The degree of improvement by tuning is limited with simple antennas. With the more elaborate arrays used above 14 MHz, it's possible to obtain performance increases up to 3 dB with small antennas. Improvements of 7 to 8 dB are possible with larger arrays.

By Bruce Clark, K6JYO (reprinted from the July, 1969, issue of *ham radio*)

The following paragraphs present simple methods for measuring vhf antenna gain directly, with good accuracy. Once you *know* what your antenna is doing, you can make the right adjustments to optimize performance. A few examples are also given of some rather startling results obtained by amateurs who were introduced to these methods.

direct measurements

The average amateur can measure antenna gain with adequate precision using simple equipment. The measurement results are much more meaningful than, say, a measured standing-wave ratio of 1.02-to-1 on the transmission line. All this indicates is that the feedline is taking power. The antenna may or may not be radiating in the desired direction or with the desired efficiency.

Of the many methods of measuring antenna gain, two are within the capability of the amateur. These are the attenuator/receiver method, and the matched-detector method. Both are comparison tests using a reference antenna and the antenna to be tested. Received signals provide the measurement data.

These methods are more reliable and provide more repeatable data under varying site conditions than those using transmitted signal/field-strength meter or measured-pattern methods.

attenuator/receiver method

The attenuator/receiver method is block diagrammed in **fig. 1**. Basically, the system uses an accurate attenuator combined with the station receiving system. The signal-source output should be as low as possible and still provide a usable signal at the receiver S-meter when the reference antenna is connected. For most situations 100 mW is adequate. The source should be stable and free of spurious outputs.

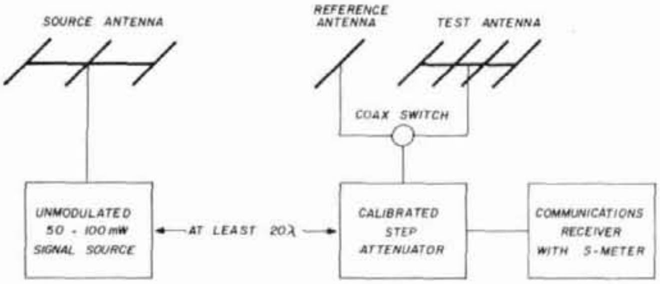


fig. 1. Test equipment for the attenuator/receiver method. The source antenna should be as high as possible, in the clear, and at least 20 wavelengths from the antenna under test.

WA6KKK and WB6MGZ aim 18.6-dB 1296-MHz dish.

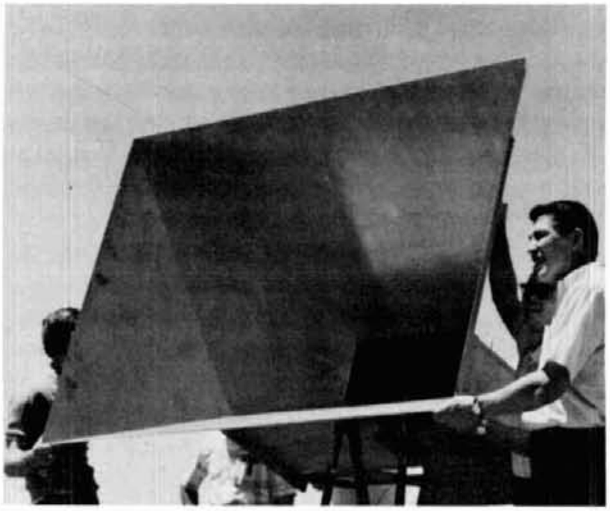
procedure

Set up the source antenna in the clear at least 20 wavelengths from the test antenna. A nearby amateur's tower, flag pole, or TV mast is a good support. Turn on the source, and adjust the attenuator for a reference level on the receiver (anywhere between S-6 and S-9 will do). Record the number of dB used on the attenuator to obtain the reference value on the S meter. Switch to the test antenna, and peak the antenna for maximum signal. Adjust the attenuator for the same S-meter reading obtained with the reference antenna. Record the new attenuator reading. The difference between attenuator readings is the amount of gain (or loss) between the two antennas.

Repeat the process several times, moving the reference antenna for an average level. Note that some variation is introduced by moving the reference antenna. This can be reduced by using a directional source antenna to reduce ground reflection contributions to the received signal (discussed later). In addition, the source antenna should be moved between several different sites at varying distances. Several measurements should be made at each site. The resultant gain figure should be the average of at least six readings.

Note also that feedline losses are included in these measurements. If known, they can be added to the measured antenna gain to get the actual gain of the antenna. Although less impressive, the measured figure is a more practical value, especially above 50 MHz where feedline loss contributions are significant.

The attenuator/receiver method will give accuracies on the order of ±1 dB. It's limited by the accuracy and resolution of the attenuators, but is probably the most applicable method for amateur work.



W6MMU's big horn for 432 — 11.7 dB.

The matched detector method is very popular with the West-Coast vhf crew. It requires more sophisticated equipment, but gives greater resolution and quicker readout. The absolute accuracy is still limited by the reference antenna performance due to reflections. The averaging procedure should be used here also if absolute gain figures are desired.

Either a high (1 watt) or low (10 mW) source signal, modulated with a 1-kHz audio tone is used (**fig. 2**). The type of source determines the detector type. A crystal diode detector similar to a Telonic XD-series, or a home-built equivalent,[1] will give a square-law output at low input levels. This is ideal for the vswr meter readout.

procedure

The vswr meter is a 1-kHz, sharply tuned, gain-stable, low-noise audio amplifier driving an rms ac vtvm. The 1-kHz modulation is detected and amplified. This signal drives the meter, which is calibrated directly in dB. By adjusting the vswr meter gain range (0-60 dB in 10-dB steps), a reference level can be obtained with the reference antenna. The test antenna is then connected to the detector, and the gain increase (or decrease) noted.

Although the initial cost is high ($200), the vswr meter is available in surplus outlets for approximately $40 to $60 for the earlier Hewlett-Packard HP-415 series. Others by PRD and General Radio are also available.[2]

If the source power is too high, the crystal diode detector will be driven out of the non-linear, square-law portion of its curve. The resultant output will deviate, and the vswr meter reading will be high. This can be prevented by:

1. Keeping the source power output very low.
2. Inserting a calibrated attenuator (3 to 6 dB) ahead of the detector mount (**fig. 2**).
3. Using the vswr meter with a wider range detector called a bolometer (thermistor) mount. Although not as sensitive, the bolometer mount provides good results when used with sources of 1 to 2 watts output.

reference antennas

No study of antenna gain measurement would be complete without a word on reference antennas. Classically, the isotropic radiator is a point source that illuminates all points equally on the inside surface of a sphere. It is used as the reference antenna in nearly all theoretical work. However, it's not possible to produce such an antenna, so the matched 1/2-wave dipole is often used as a reference antenna.

The dipole has a disadvantage. Because of its broad pattern, it's extremely sensitive to ground effects and to near-field reflections from the signal source. These reflections add or detract from the desired free-space signal and produce an output that varies from the ideal (average) value.

NBS standard reference antenna

Absolute accuracy of measurements depends on the accuracy of the reference dipole, so it is im-

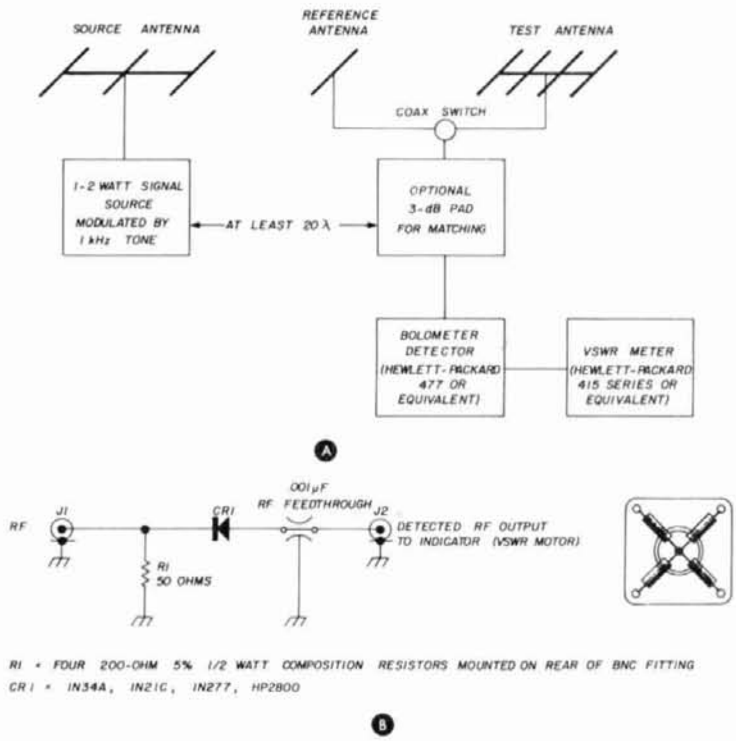


fig. 2. Setup for the matched detector method. A bolometer is used in (A). An easily constructed diode detector substitute for the bolometer is shown in (B). The 3-dB pad will improve the match between detector and antenna, especially at uhf.

portant to average the reference dipole readings under different site conditions. Recently, highly accurate standard reference antennas have been designed and employed by the National Bureau of Standards (NBS) and some amateurs, among them W6VSV and W6HPH. Basically a simple directional array designed for low side-lobe content and high front-to-back ratio, the NBS standard antenna has a gain of 7.7 dB over a reference dipole, measured under laboratory conditions in an anechoic chamber (see **fig. 3**).

The measurement repeatability is on the order of ±0.1 dB or better. The NBS standard antenna is used in a manner identical to that of the reference dipole, but there is less variation due to reflections. Also, one must remember to add the 7.7 dB reference-antenna gain figure to those from the vswr meter with the test antenna in the line. For example, if the test antenna measures 2.3 dB when the reference antenna measures 0 dB, the antenna gain is 10 dB.

results

These techniques are regularly employed by top vhf-uhf amateurs to obtain the most from homebrew and commercial arrays. In the past few years, antenna contests at hamfests have become popular proving grounds where new winning combinations have been discovered. A case in point is the reawakened popularity of the Yagi antenna at 432 MHz. It has resulted from careful optimization of several scaled-down designs that didn't work at all (or poorly at best). Another case is the 1 to 2 dB gain increase from adding directors to collinear arrays — a method now adopted by at least one manufacturer.

The accuracy of the results is amazing. My own 32-element, 432-MHz array measured 15 dB at the West-Coast Uhf Conference in Fresno and 16.2 dB at the Hughes Radio Club contest in Fullerton (after some matching deficiencies were discovered).

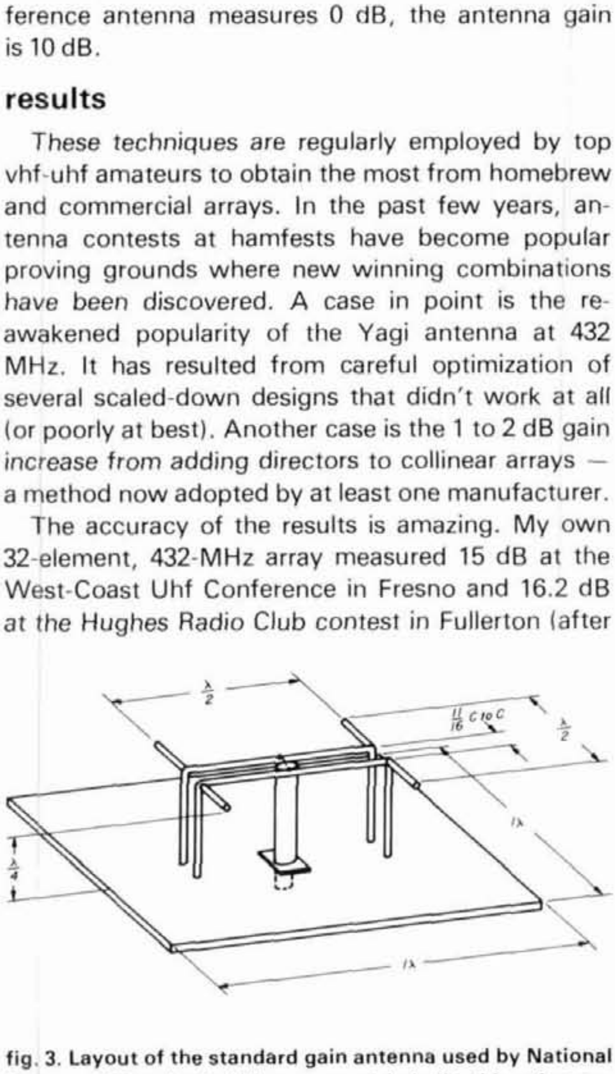


fig. 3. Layout of the standard gain antenna used by National Bureau of Standards. When accurately built, this reference antenna will provide 7.7 dB over an isotropic radiator ±0.25 dB. Element diameter is about 0.01λ (3/8" or 10mm at 432 MHz).

K7ICW's 30-element Yagi for 1296 MHz yielded −2.5 dB!

As for the repeatability of results from site-to-site, tests of the popular 6-foot boom Tilton Yagi at 432 MHz resulted in consistent measurements yielding 12 to 13 dB in contests from Missouri to California. W5ORH's twin bi-square beam measured 8.0 dB at three different sites using three different test methods. These examples are exceptions. Typically, however, results haven't varied more than ±2 dB when good equipment and normal care were used in making the measurements.

some surprises

At one contest several owners of supposedly high-gain commercial arrays really had their eyes opened. One 432-MHz Yagi, with a manufacturer's claim of "over 17 dB forward gain," measured *negative* 2 dB off the front and +6 dB off the back. Cutting the antenna in half got about +8 dB forward gain.

Another homebrew 13-element Yagi from a popular vhf handbook measured +1.9 dB gain over a dipole. (The owner had substituted a wooden boom for the original metal boom and hadn't reduced the element lengths to compensate. Trimming the elements and matching the feed brought the gain up to 12.3 dB — not a bad increase.)

It should be obvious that antenna gain measurement is worthwhile for the amateur. From my experience, it gets results we all desire: better reports and more consistent contacts.

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graphical solution

of impedance-matching problems

Using simple geometry to design and analyze a variety of impedance-matching networks

One of the most common problems in radio circuits is matching one impedance to another. The problem might be that of matching a transmitter output stage to a resistive load, or the load may have a reactive component, as is usually the case when attempting to transfer power to an antenna.

Many articles have been written covering the mathematics of this problem and also the application of the Smith chart.[1] Impedance-matching problems can be solved readily with sufficient accuracy for practical purposes with no more equipment than a straightedge, compass, and graph paper. The graphical method lends itself to multiple-component networks involving complex impedances, without resorting to trigonometry or complex algebra. It allows a visual choice of constants and shows forbidden approaches in choosing impedance paths.

The method presented in this article will allow you to solve most impedance problems encountered in amateur work. The geometric principles are easy to follow, and you'll need to make only a few simple computations. Rules are given for constructing the diagrams. Typical examples and solutions are shown. The examples are presented without mathematical proof, however. For those who wish to pursue the classical approach, some excellent material will be found in references 2, 3, and 4.

a starting point

First consider the familiar methods known as the "leaning ladder" diagram for determining the resultant of two resistors or reactances in parallel (**fig. 1**).

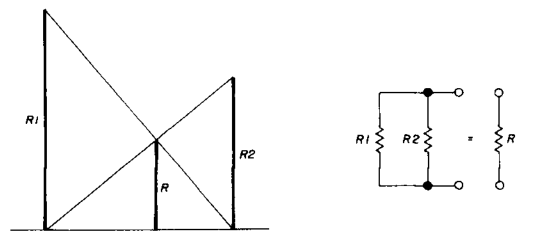

fig. 1. The "leaning ladder" diagram for finding the resultant of two resistances or reactances in parallel.

Two perpendicular lines with lengths proportional to the two resistors or reactances are erected with arbitrary separation from a common baseline. Lines are then drawn from the top of each perpendicular to the base of the other. A third perpendicular is now drawn from the intersection of these lines to the baseline. The length of this new perpendicular is proportional to the combined resistance or reactance of the two parallel elements.

What happens, however, when two reactances of opposite sign are to be evaluated? The same pro-

By I. L. McNally, W1NCK, and **Henry S. Keen, W2CTK** (reprinted from the December, 1969, issue of *ham radio*)

cedure is followed as before, except that the perpendicular lines representing the reactances will be located on opposite sides of the baseline (**fig. 2**). Again connect the end of each perpendicular to the base of the other, extending the lines until they intersect. The length of a perpendicular from this point of intersection to the baseline represents the combined reactance of the two paralleled elements. The side of the baseline where the intersection takes place determines whether the resultant, X_R, is inductive or capacitive.

Now suppose a reactance is to be paralleled with a resistance. How do you determine the impedance of such a combination? Semicircles are constructed upon rectangular coordinates, with diameters proportional to the paralleled resistance and reactance, intersecting at point **A** (**fig. 3**). A line, **O-A**, from the

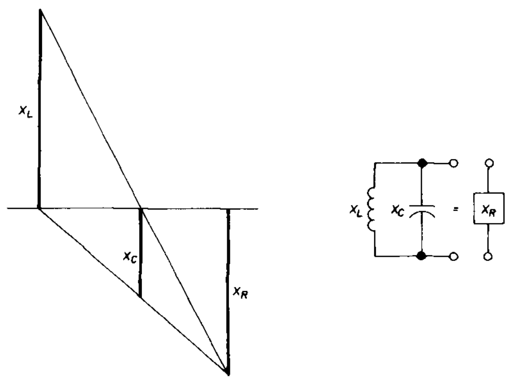

fig. 2. Diagram for finding resultant impedance of two reactances of opposite sign.

origin to the point of intersection, will be proportional to the impedance of the combination. The projections of this point of intersection upon the resistive and reactive axes will then be proportional to the resistance, R_S, and reactance, X_S, respectively, which make up the series equivalent of the parallel combination.

Because an angle inscribed in a semicircle is always a right angle, it is easily shown that the point of intersection, **A**, lies on a straight line connecting the ends of the two diameters. This construction leads to a well-known diagram frequently used to solve L networks, (**fig. 4**). An L network is merely a transformation from a parallel resonant circuit, seen looking in at *Z1*, to a series resonant circuit, seen looking in at *Z2*.

rules for construction

By combining these diagrams, it's possible to solve a variety of matching-network problems. The geometry of **fig. 5** is the basis of solving all problems us-

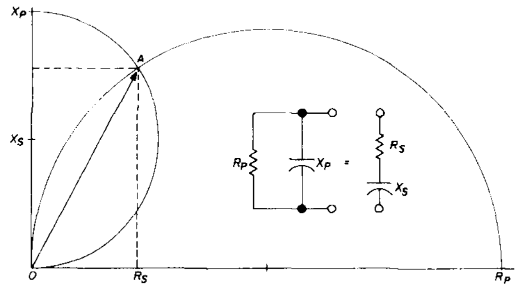

fig. 3. Geometry for solving parallel-to-series transformation.

ing this method. General rules for using the method are:

1. Adding a series of reactances moves the impedance on a vertical line — up for inductive reactance and down for capacitive reactance.

2. Adding a parallel reactance moves the impedance along a circle with its center on the horizontal axis. It rotates clockwise for capacitive reactance and counter clockwise for inductive reactance.

3. When choosing impedance paths, it is not permissible to use a path passing through the origin of coordinates.

The method permits rapid comparison of different network designs without a knowledge of complex algebra, and a clear picture is given of what happens when parameters are modified.

We'll begin with the pi network since this is one of the most-used circuits in amateur work. Other circuits will then be described which will provide a foundation for solving most impedance-matching problems. Some numerical examples will then be given to show step-by-step procedures.

pi networks

The pi network can be considered as two cascaded L networks, designed to transform both input and output impedances to a common internal transfer im-

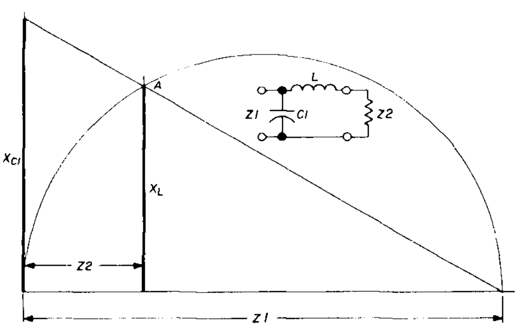

fig. 3. Geometry for solving parallel-to-series transformation.

pedance, which must be lower than either terminal impedance. This internal transfer impedance determines the network Q, a fact that becomes apparent from a consideration of the design diagram (**fig. 6**).

To design a pi network, begin at the origin of a set of rectangular coordinates, and construct a semicircle above the horizontal axis, with diameter proportional to *Z1*. (*Z1* is the greater of the two terminal impedances.) Similarly, from the origin construct a second semicircle below the axis. Its diameter is proportional to *Z2*, the lesser of the two terminal impedances.

Because an infinite number of solutions exist to a pi-network problem when terminal impedances are specified, an assumption must be made for one of the three reactances. This is necessary to establish the internal transfer impedance. There are certain advantages if the reactance of the output capacitor, C2, is made equal to the load resistance, *Z2*. However, network Q requirements frequently dictate a lower value as discussed later.

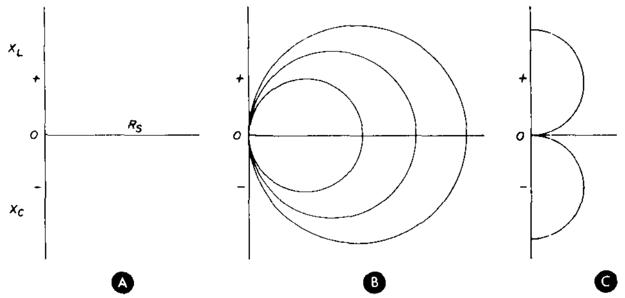

fig. 5. Basic geometry for graphical solution of impedance problems. Series resistance is plotted along the horizontal axis and series reactance on the vertical axis, as at (*A*). Parallel resistance and parallel reactance circles are constructed as in (*B*) and (*C*) respectively.

The assumed reactance X_{C2}, of the output capacitor becomes the diameter of a third semicircle, beginning at the origin and constructed downward below the horizontal axis. The point of intersection between this and the *Z2* semicircle is point **A**. From this point a vertical line is drawn to intersect the original *Z1* semicircle at point **B**. The length of the line segment, **AB**, represents the required reactance of X_L.

A straight line is now drawn from the extreme end of the *Z1* diameter through point **B**, intersecting the vertical axis at point **C**. Line **OC** will then be proportional to X_{C1}, the reactance of the required input capacitor.

The intersection of inductive reactance line **AB** with the horizontal axis is point **D**. The significance of this point is that line segment **OD** represents the internal transfer impedance of the network. The Q of

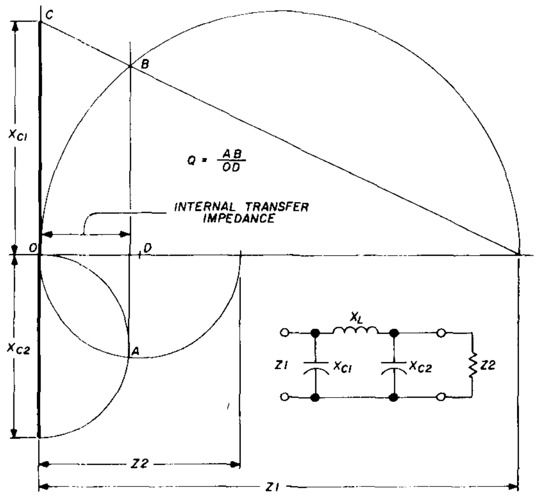

fig. 6. The pi network diagram. Circuit *Q* is determined by the internal transfer impedance.

the network, when driven by a current generator such as a screen-grid tube or a transistor, will be equal to the inductive reactance, **AB**, divided by the internal transfer impedance, **OD**. The Q will also be equal to $Z1/X_{C1}$ plus $Z2/X_{C2}$, which can be proven identical.

When driven by a resistive source, such as a triode, the network is loaded from both ends, and the effective Q may be cut in half.

tee networks

Although the T network is not as well known as the pi network, it is a very useful circuit and is quickly solved graphically. With the T network, we may assume the internal transfer impedance as equal to or greater than the sum of the terminal impedances *Z1* and *Z2*, usually by a factor of two or more. The graphical design procedure, with reference to **fig. 7** is as follows:

Construct a semicircle with horizontal diameter *greater* than the sum of the terminal impedances.

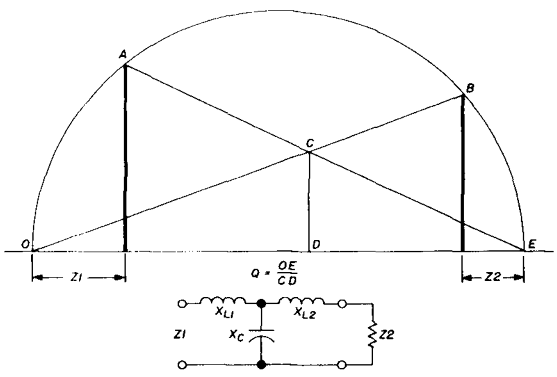

fig. 7. Solving the T network. The internal transfer impedance is equal to or greater than *Z1* + *Z2* by a factor of two.

Mark off, from opposite ends of the diameter, line segments proportional to the two terminal impedances. From these two points erect perpendiculars to intersect the semicircle at points **A** and **B** respectively. Connect points **A** and **B** to the remote ends of the diameter, intersecting each other at **C**. A perpendicular, **CD**, to the diameter will be proportional to the reactance of the capacitor, **C**. The *Q* of this network, as driven by a current generator, will be equal to the diameter of the semicircle divided by the line segment **CD**. The sum of $X_{L1}/Z1$ plus $X_{L2}/Z2$ will give an identical result.

Although the derivation of this diagram may seem obscure, if perpendiculars are erected at the ends of the diameter, and the slant lines extended to intersect these perpendiculars, we will have the two super-imposed L-network diagrams. The line segments of these end perpendiculars will each represent a capacitive reactance corresponding to one of the two cascaded L networks making up the complete T network. The extended slant lines can then be seen to represent the leaning-ladder diagram, with line **CD** being the result of both capacitive components in parallel. All construction exterior to the semicircle, therefore, will be redundant and can be omitted.

If the semicircle is constructed so that its diameter is equal to the sum of the two terminal impedances, all reactances will be of the same magnitude, differing only in sign, and will be equal to the geometric mean of the terminal impedances. The *Q* of such a network would be quite low, being equal to the sum of the two terminal impedances divided by the square root of their product.

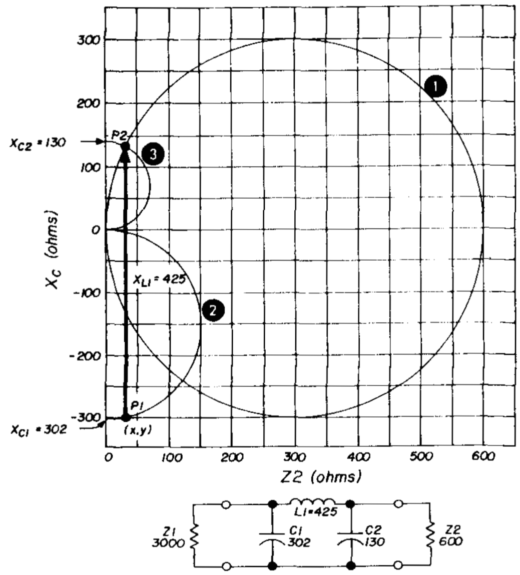

fig. 8. Solution to problem 1: matching 3000 + j0 ohms to 600 + j0 ohms with a pi network. Arrows indicate impedance path.

When the pi network is designed so that $Z2 = X_{C2}$, excursions of *Z2* will have minimum effect on *Z1*. Resonance will be maintained by retuning X_L. A network is possible whereby a two-to-one range of *Z2* (assumed purely resistive) will, in turn, cause *Z1* to vary from the target impedance by less than five per cent.

Similarly, design of the T networks so that $Z1 = X_{L1}$ will permit *Z1* variations of the same magnitude, with the network output still presenting a match to the load (within the same limits). Resonance is maintained by retuning C1.

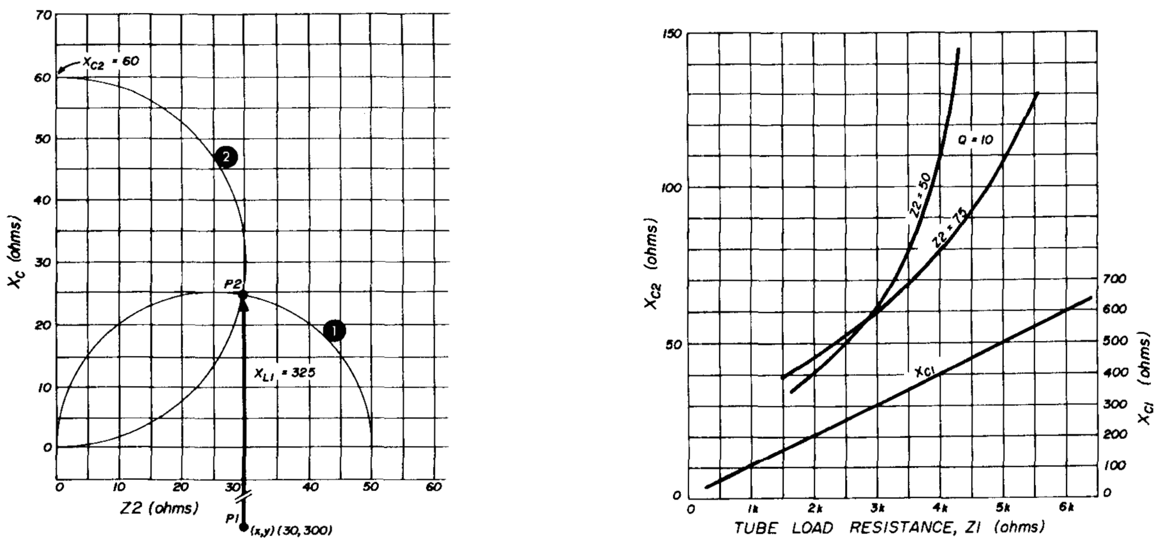

fig. 9. Solution to problem 2: matching 3000 + j0 ohms to 50 + j0 ohms with a pi network — a common problem in transferring tube output impedance to an antenna transmission line. Expanded scales for R2 = 50 ohms are shown at (*A*). At (*B*) the curves are limited to R2 = 50 or 75 ohms and Q = 10.

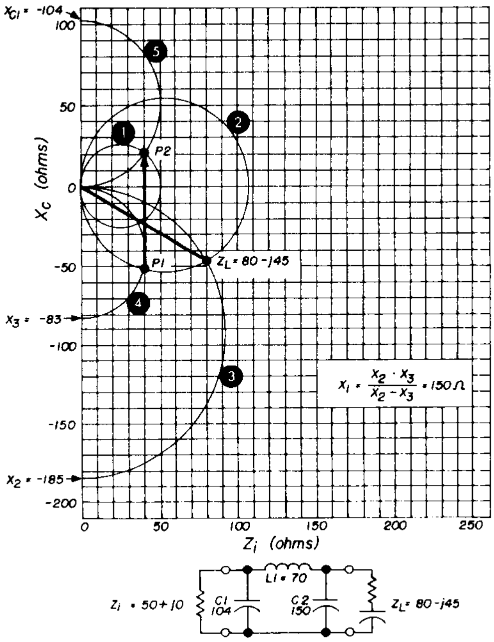

fig. 10. Solution to problem 3: matching an antenna load of 80 - j45 ohms to 50 + j0 ohms with a pi network. This has a three step impedance path: Z_L to P1 to P2 to Zi.

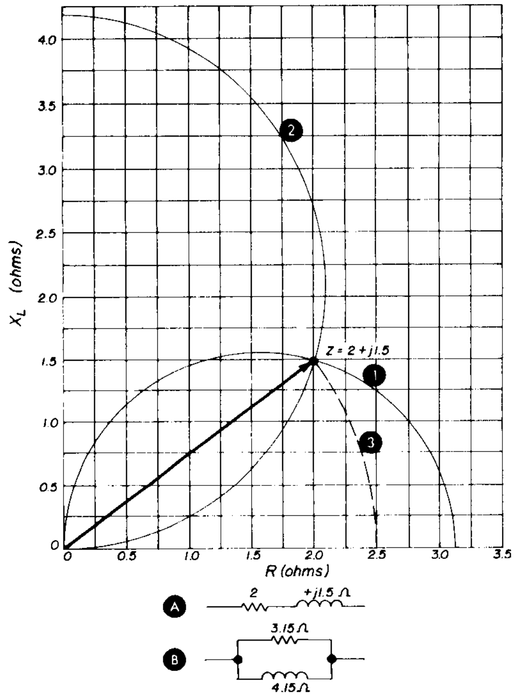

fig. 12. Solution of series-to-parallel transformation. The resultant impedance is 2.5 ohms.

In either network the terminal impedance, $Z1$, is assumed the higher of the two. Although $Z1$ has been treated at the input end, either network is completely reciprocal.

examples using pi networks

Problem 1. Match 3000 + j0 ohms to 600 + j0 ohms with a pi network. In this case, $Q = 10$.

1. Draw a 600-ohm circle (1), **fig. 8**.

2. Calculate point (x,y) and plot:

$$y = \frac{R1}{Q} = \frac{3000}{10} = 300$$

$$x = \frac{R1}{Q^2} = \frac{3000}{100} = 30$$

3. Erect a vertical line from point **P1** (x,y) to intersect the 600-ohm circle at point **P2**. This is X_L to scale (425 ohms).

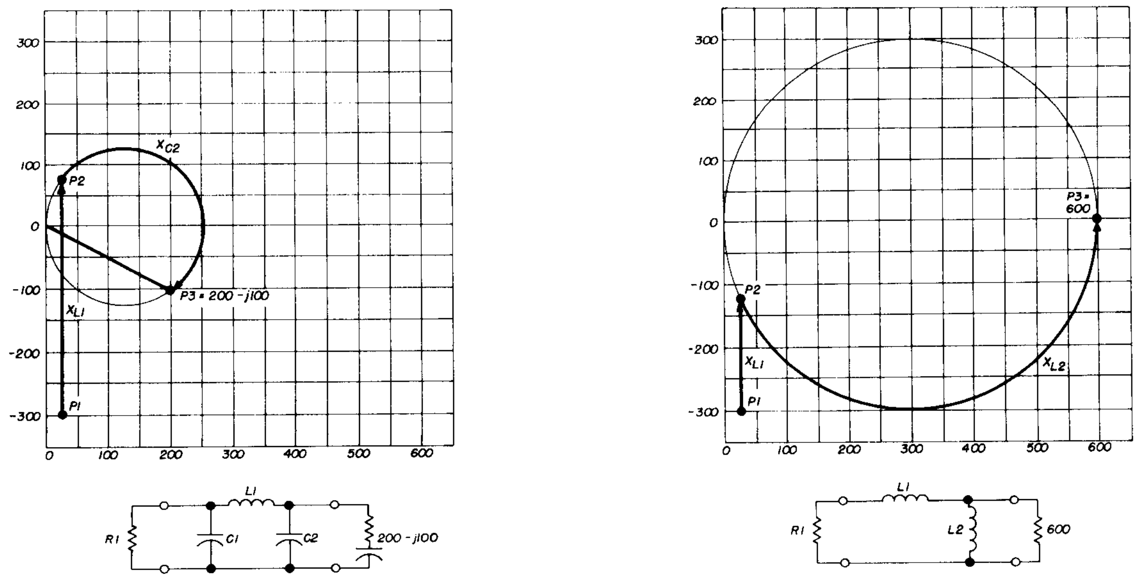

fig. 11. Examples of correct impedance paths. Both show networks for matching typical power amplifier tube impedances to various loads. Note that the impedance paths must not pass through the origin of coordinates.

4. Draw circle (2). Its intercept on the vertical axis at 302 ohms is X_{C1}.
5. Draw circle (3). Its intercept on the vertical axis at 130 ohms is X_{C2}.
6. Solution: L1 = 425 ohms
   C1 = 302 ohms
   C2 = 130 ohms

Problem 2. This is the same as problem 1, except $Z2 = 50$ *ohms* (**fig. 9**).

1. Draw a 50-ohm circle (1), **fig. 9A**.
2. Erect X_{L1} through $X = 30$ to intersect the 50-ohm circle at point **P2**. This scales to $y + 25$, or $X_{L1} = 325$ *ohms*.
3. Draw circle (2) through point **P2**. It will intersect the vertical axis at $X_{C2} = 60$ *ohms*.
4. Solution: L1 = 325 ohms
   C1 = 302 ohms
   C2 = 60 ohms

Some pi-network curves for common tube load resistance are shown in **fig. 9B**.

Problem 3. Match an antenna load of 80 – j45 ohms to 50 ohms using a pi network (**fig. 10**).

1. Construct a 50-ohm circle (1).
2. Plot $Z_L = 80 - j45$ *ohms*.
3. Construct circle (2) through Z_L.

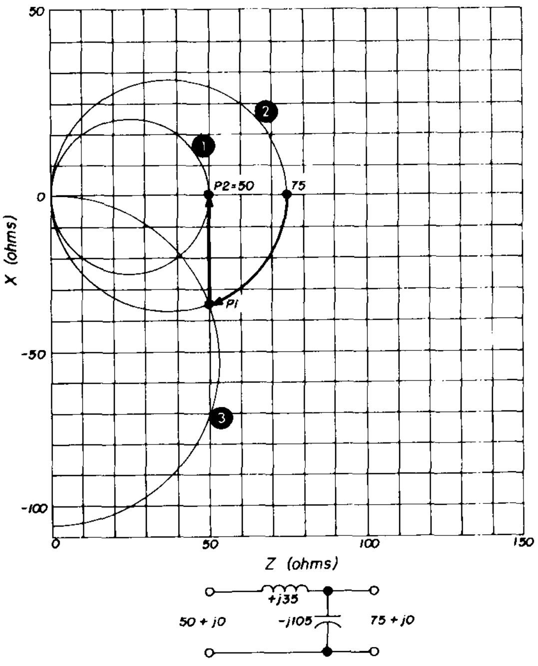

fig. 13. Examples of 2-step impedance path from 75 ohms to 50 ohms in an L network.

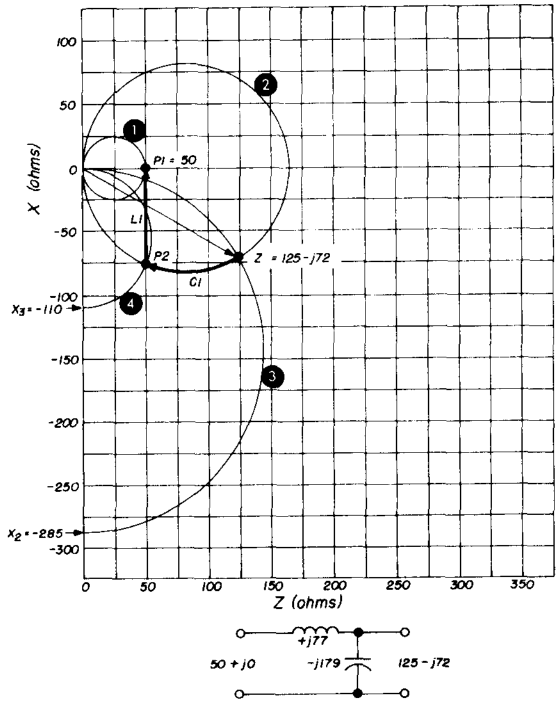

fig. 14. Matching a 50-ohm resistive load to a complex load. The impedance path is from Z_L to P2 to P1.

4. By inspection the maximum value of X_L is about 75 ohms. Select a value of 70 ohms and fit it vertically as **P1**, **P2** between circles (1) and (2).
5. Construct circle (3) through Z_L. It will intersect the vertical axis at – 185 ohms ($X2$).
6. Construct circle (4) through **P1**. It will intersect the vertical axis at – 83 ohms ($X3$).

$$X1 = \frac{X2 \cdot X3}{X2 - X3}$$

$$= \frac{(-185)\ (-83)}{(-185) - (-83)} = \frac{185 \cdot 83}{-102}$$

$$= -150.5\ ohms$$

This is a capacitive reactance added by moving from Z_L to **P1**, along circle (2).

choice of impedance paths

Recall that the internal transfer impedance must be lower than either terminal impedance. The internal transfer impedance determines the *Q* of the pi network. From **fig. 6**, line segment **OD** determines this parameter. Therefore, from the rules of construction for graphical solution to these problems, it is not permissible to choose an impedance path through the origin of coordinates. Examples of correct impedance paths are shown in **fig. 11**; hence, these show transformation between typical tube output impedances and various load impedances. Note that

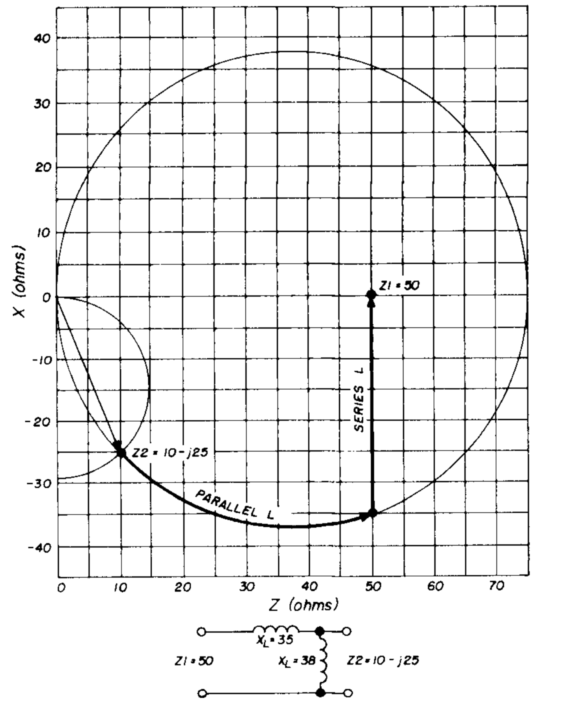

fig. 15. Another example of impedance paths in network design. Three different 2-step paths are shown from *Z2* **to** *Z1* **as well as the "forbidden" path through the origin.**

the paths do not pass through the origin. While a 600-ohm terminal impedance is not too common in most rf circuits these days, the example does indicate the principles to be followed when designing these networks.

solving series and L networks

Problem 1. Given the series circuit of **fig. 12A**, find the equivalent parallel circuit.

1. Plot the impedance vector $Z = 2 + j1.5$.
2. Construct circle (1) with its center on the horizontal axis, which passes through the origin and Z as shown. It will intersect the horizontal axis at 3.15 ohms resistance.
3. Construct circle (2) with its center on the vertical axis, which passes through the origin and Z. It will intersect the vertical axis at 4.15 ohms inductive reactance. The equivalent parallel circuit is shown in **fig. 12B**.
4. Solution. Scaling the Z vector gives an impedance of 2.5 ohms (3).

Problem 2. In the network of **fig. 13**, it is desired to find X_L, X_C, and C for a frequency of 3.9 MHz.

1. Construct circles (1) and (2) through 50 ohms and 75 ohms as shown.
2. Construct line **P1-P2**, which is X_L series and scales 35 ohms.
3. Construct circle (3) through **P1**. It will intersect the vertical axis at − 105 ohms. This is X_C parallel capacitive reactance obtained in moving clockwise from 75 ohms along circle (2) to **P1**, which is directly below **P2**, the 50-ohm point.
4. Solution.

$$L = \frac{X_L}{2\pi f} = \frac{35}{2\pi \times 3.9} = 1.43\ \mu H$$

$$C = \frac{10^6}{2\pi f X_C} = \frac{10^6}{2\pi \times 3.9 \times 105} = 386\ pF$$

$$X_L = 35\ ohms$$

$$X_C = 105\ ohms$$

Problem 3. Match 50 + j0 ohm to $Z_L = 125 - j72$ ohms, a complex load (**fig. 14**).

1. Construct a 50-ohm circle (1).
2. Plot $Z_L = 125 - j71$
3. Construct circle (2) through Z_L.
4. Construct a vertical line from **P2** to **P1**. This is the series X_L and scales 77 ohms.
5. Construct circle (3) through the origin and Z_L. It will intersect the vertical axis at − 285 ohms ($X2$).

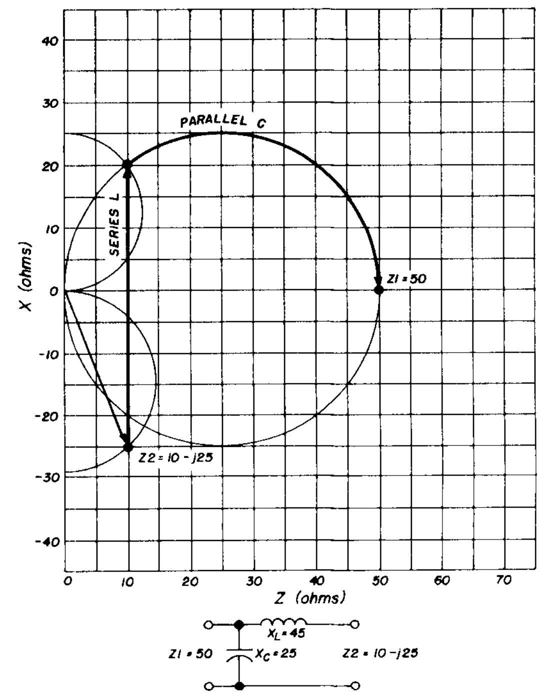

fig. 15A. Impedance path through matching network consisting of series L and parallel C.

6. Construct circle (4) through the origin and **P2**. It will intersect the vertical axis at − 110 ohms ($X3$).

7. When neither of the terminal points is on the horizontal axis, as in this case with Z_L and **P2**, it is necessary to compute the value of reactance involved in moving from $Z2$ to **P2**.

$$X1 = \frac{X2 \cdot X3}{X2 - X3}$$

$X1$ = added reactance

$X2$ = initial reactance

$X3$ = final reactance

$$X1 = \frac{(-285)\ (-110)}{(-285) - (-110)}$$

$$= -179 \text{ capacitive}$$

8. Solution $L1 = j77$ ohms, and $C1 = j170$ ohms.

In **fig. 15** are examples of three different choices of impedance paths in going from $Z2$ to $Z1$ using three network combinations to match a resistive 50-ohm load to a complex load of 10 − j25 ohms. Again, the "forbidden" path is not to be used because it passes through the origin.

summary

We have shown examples of solving the most common impedance-matching problems using simple geometric methods. The following notes are offered in adopting these methods for solving a wide variety of problems.

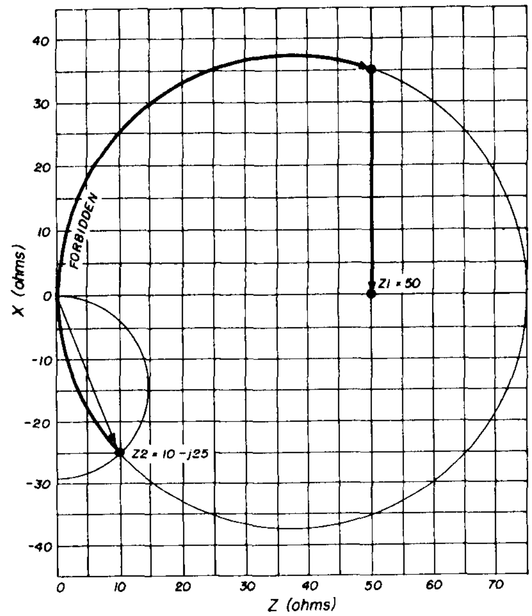

fig. 15C. Impedance path through parallel and series *L*, respectively.

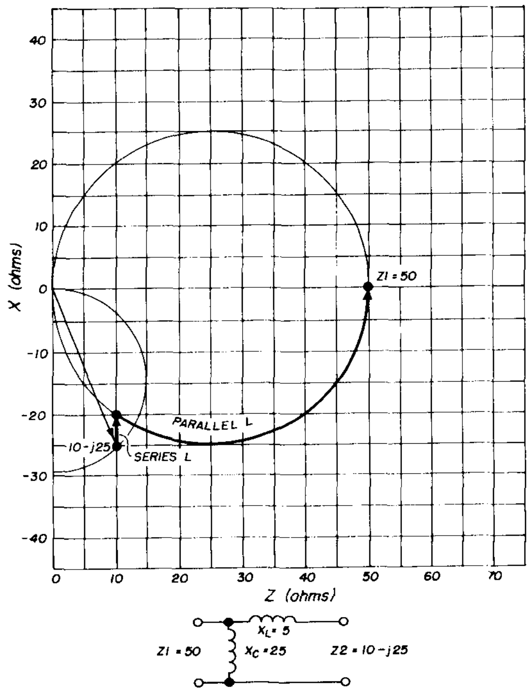

fig. 15B. Impedance path through matching network consisting of series and parallel *L*, respectively.

1. The L-network is one of the most useful circuits known for matching nearly all direct-coupled tank systems. The examples show how to match a high-resistance to a low-impedance reactive load. If the converse is desired, it is only necessary to convert the reactive load to its equivalent parallel components.

2. T networks are useful as harmonic attenuators in low-impedance transmission lines. These can be readily solved by treating them as two cascaded L sections and combining the capacitances.

3. The pi network is used to match a wide range of load impedances with reasonable tank-circuit Q. Contrary to some popular notions, the pi network will not match a tube to any length of wire. The circuit is load-limited by the ratio of tube load and circuit Q if it is to perform as an efficient transformer.[3]

references

1. J. R. Fisk, W1DTY, "How to Use the Smith Chart," *ham radio*, November, 1970, page 16 (reprinted this issue).
2. F. E. Terman, "Electronic and Radio Engineering," McGraw-Hill, New York, 1955.
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ham radio

More Details? CHECK—OFF Page 158

how to use the Smith Chart

A discussion of the Smith chart with examples of its use in transmission-line problems

Although articles on the Smith chart have appeared in the amateur magazines from time to time, amateurs have made little use of this handy transmission-line calculator — probably because it has been difficult to measure complex impedances with simple homebuilt equipment. However, this problem has been solved with the simple impedance bridge described by W2CTK — at least for the high-frequency range.[1] With careful attention to lead dress and component layout this instrument should be usable on six and two meters as well.

A quick glance at the Smith chart suggests a formidable array of curved lines and circles that would cause the most hardened technician to go into fits of despair. On the other hand, if you spend a little time with the chart and look at each of its component parts, it's not really very complicated. Perhaps the one thing that scares many prospective users is its unfamiliar circular shape; it's not at all like the straight-line graphs you're accustomed to. However, when you understand the chart and have mastered its use you'll be able to solve complex impedance and transmission-line problems much easier and faster than ever before.

layout of the chart

The Smith chart is basically a circle which contains various circular scales. The horizontal line through the center marked *resistance component* is the only straight line on the chart and is called the "axis of reals" (see **fig. 1**). Constant resistance circles are centered on the axis of reals, tangent to the rim of the chart at the infinite resistance point. All the points along a constant-resistance circle have the same resistive value as the point where it crosses the axis of reals.

Superimposed over the resistance-circle pattern are portions of other circles tangent to the axis of reals at the infinite resistance point, but centered off the edge of the chart (**fig. 2**). The large outer rim of the chart is calibrated in relative reactance and is called the "reactance axis." Any point along the same constant-reactance circle has the same reactive value as the point where it intersects the reactance axis on the rim of the chart. All points on the Smith chart above the axis of reals contain an inductive-reactive component and those below the axis of reals contain a capacitive-reactive component. Since the calibration points go from zero to infinity, *any* complex impedance can be plotted on the chart.

The impedance coordinates on the Smith chart would be of little use without the accompanying peripheral scales (**fig. 3**). These scales relate to quantities which change with position along a transmission line. Two scales are calibrated in terms of wavelength along the transmission line: one, in a clockwise direction, is "wavelengths toward generator," and the other, counter-clockwise, is "wavelengths toward load." The entire length of the circumference of the chart represents one-half wavelength.

By James R. Fisk, W1HR, (reprinted from the November, 1970, issue of *ham radio*)

normalized numbers

Normalized values must be used when plotting impedances on the Smith chart.* Normalized impedance is defined as the actual impedance divided by the characteristic impedance of the transmission line.

Normalizing is done to make the chart applicable to transmission lines of any and all possible values of characteristic impedance. For example, a 50-ohm coaxial transmission has a normalized value of 50/50 or 1. On this basis an impedance of 120 ohms would have a normalized value of $120/50 = 2.4$ ohms. Similarly, $z = 0.8$ ohms (the lower case indicates a normalized value) would correspond to a value of 0.8 times the characteristic impedance of the line or $0.8 \times 50 = 40$ ohms.

What has been said about coaxial cable with regard to normalized impedance applies equally to waveguide, where a characteristic impedance of 400 ohms at a specific frequency would be considered unity in normalized form. All other values would be related to this value, so that a 560-ohm component would have the value $560/400 = 1.4$ ohms in normalized terminology, while $z = 0.9$ in normalized form would actually be $0.9 \times 400 = 360$ ohms.

plotting values on the chart

Any complex impedance, regardless of value, may be plotted on the Smith chart. For example, assume the load on a 50-ohm transmission line is 42.5 − j31.5 ohms. This is equal to 0.85 − j0.63 when normalized. To plot this point on the chart, locate 0.85 on the axis of reals and note the corresponding constant-resistance circle (**fig. 4**). Next locate 0.63 on the periphery of the chart. The quantity $(-j)$ indicates a capacitive-reactive component so the value 0.63 is on the lower half of the chart. Note the constant-reactance circle representing −j0.63. The complex impedance 0.85 − j0.63 is at the intersection of the constant-resistance and constant-reactance circles.

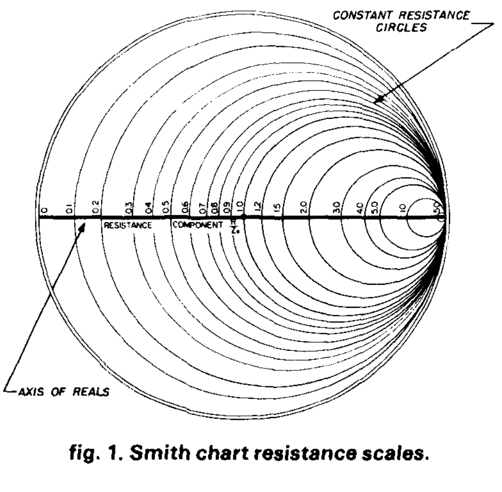


fig. 1. Smith chart resistance scales.

Draw a line from the center of the chart through this point to the outer rim. With the point 1.0 on the axis of reals as the center, scribe a circle that intersects the impedance point. This circle is known as the "constant-gamma circle," and its radius is equal to the coefficient of reflection. The constant-gamma circle crosses the axis of reals at two points; the point

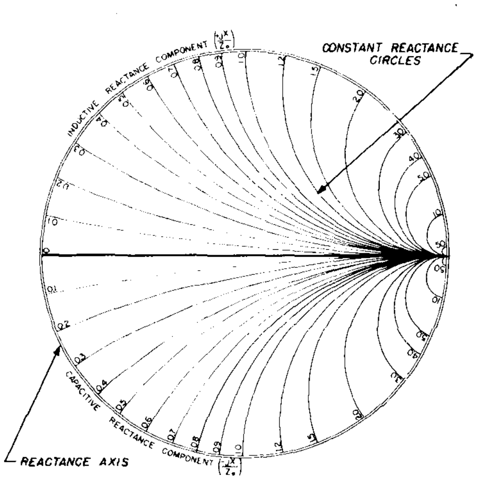


fig. 2. Smith chart reactance scales.

of intersection to the right of center is the standing wave ratio (2.0 in this case).

If the voltage were measured at this point on the transmission line, it would be found to be a maximum. Conversely, the point of intersection one-quarter wavelength away on the left-hand axis of reals is a point of voltage minimum (this point is also equal mathematically to the reciprocal of the swr).

The point at the intersection of the radial line and the angle of reflection coefficient scale represents the phase of the coefficient of reflection. This is the angle by which the reflected wave leads or lags the incident wave. When these two waves add in phase to give maximum voltage, the impedance is resistive and greater than the characteristic impedance of the line and the angle of the coefficient of reflection is zero.

As you move away from the zero-phase-angle point in a clockwise direction toward the generator, the reflected voltage lags the incident voltage, and the phase angle is negative for the first quarter wavelength. The reactive component of the impedance in this region is negative or capacitive.

At the quarter-wavelength (90°) point the incident and reflected waves are out of phase and the angle of the coefficient of reflection is ±180°. As you continue in a clockwise direction the two waves become

*Since 50-ohm systems are standard for military and industrial use, 50-ohm Smith charts are available. On a 50-ohm Smith chart the center point has a value of 50 ohms.

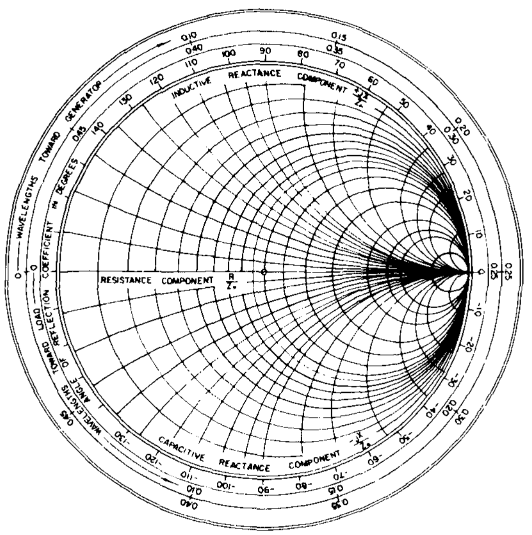


fig. 3. Smith chart peripheral scales.

increasingly more in phase and between one-quarter and one-half wavelength from the voltage maximum the reactive component is inductive, the reflected wave leads the incident wave, and the reflection coefficient has a positive angle.

A number of parameters are uniquely related to one another as well as to the magnitude of reflections from the load and are conveniently plotted as scales at the bottom of the Smith chart. These parameters are vswr, coefficient of reflection, vswr in dB, reflection loss in dB, and attenuation in 1-dB steps.

using the smith chart

The general utility of the Smith chart is best illustrated by showing examples of its more common uses. Use of the radially-scaled parameters will be shown in the same way.

Example 1. Finding standing-wave ratio. A 75-ohm transmission line is terminated with a load impedance $Z_L = 30 - j90$ ohms. What is the swr? (See **fig. 5.**)

1. Normalize the load impedance by dividing by 75

$$\frac{30-j90}{75} = 0.4 - j1.2$$

2. Locate this point on the chart.

3. Construct a constant-gamma circle so its circumference passes through this point.

4. The swr is defined by the point where the constant-gamma circle crosses the axis of reals on the right-hand side. In this case swr = 6.4.

5. The swr may also be determined with the radial nomograph. This is simply accomplished by marking a distance equal to the radius of the constant-gamma circle on the radial scale labeled "standing wave voltage ratio." The value of swr in dB may also be determined from this scale.

$$swr_{dB} = 16.1\ dB$$

Example 2. Finding the reflection coefficient (ρ) and angle of the reflection coefficient (θ) for voltage and current. A 50-ohm transmission line is terminated with a load impedance $65 - j75$ *ohms*. What is the reflection coefficient and angle of reflection coefficient? (See **fig. 6**).

1. Normalize the load impedance

$$\frac{65-j75}{50} = 1.3 - j1.5$$

2. Locate this point on the chart and draw a line from the center of the chart through it to the outer scale.

3. Construct a constant-gamma circle.

4. The reflection coefficient may be calculated by measuring the radii of the constant-gamma circle and the Smith chart to its first periphery and by computing their ratio. Smith-chart radius = 57/16 inch; constant-gamma radius = 32/16 inch.

$$\rho = \frac{32}{16} \div \frac{57}{16} = 0.56$$

5. The coefficient of reflection may also be found on the radial nomograph. Simply mark the radius of the constant-gamma circle on the scale labeled "reflection coefficient of voltage." The constant-gamma radius intersects the radial scale at 0.56. The "reflection coefficient of power" may also be determined from this same scale at 0.314.

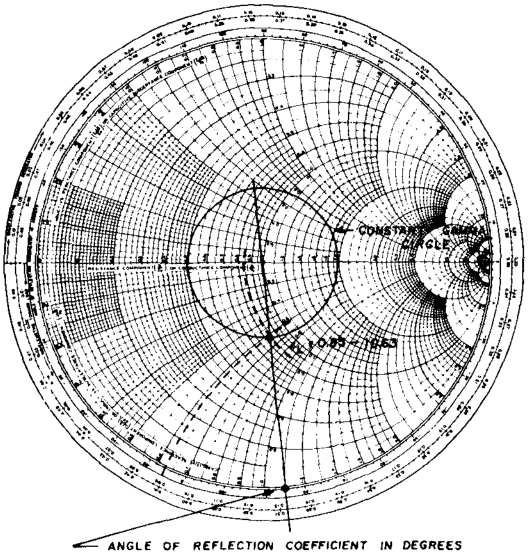


fig. 4. Plotting impedance coordinates on the Smith chart.

6. *The angle of the reflection coefficient* is defined by the intersection of the radial line plotted in **step 2** and the "angle of reflection coefficient in degrees" scale on the rim of the chart.

$$\rho = -46^\circ$$

Example 3. Finding input impedance. A 50-ohm transmission line 20 feet long is terminated with $Z_L = 50 - j50$ *ohms.* What is the input impedance at the sending end of the line at 14.1 MHz? (See **fig. 7.**)

1. Normalize the load impedance

$$\frac{50 - j50}{50} = 1 - j1$$

2. Find the length of the transmission line in meters by multiplying by 0.3048.*

$$20\ feet \times .3048 = 6.096\ meters$$

3. Find the electrical length of the transmission line at 14.1 MHz. First, determine the wavelength at 14.1 MHz. Free-space wavelength is found by dividing the speed of light by frequency

$$\lambda = \frac{3 \times 10^8\ meters\ per\ second}{14.1 \times 10^6\ cycles\ per\ second} = 21.276\ m$$

Calculate the electrical length of the transmission line

$$\theta = 360^\circ \left(\frac{6.096\ m}{21.276\ m}\right) = 102^\circ = 0.28\ wavelength$$

4. Plot the impedance coordinates from **step 1** on the chart and draw a line from the center of the chart through this point to the outer scale.

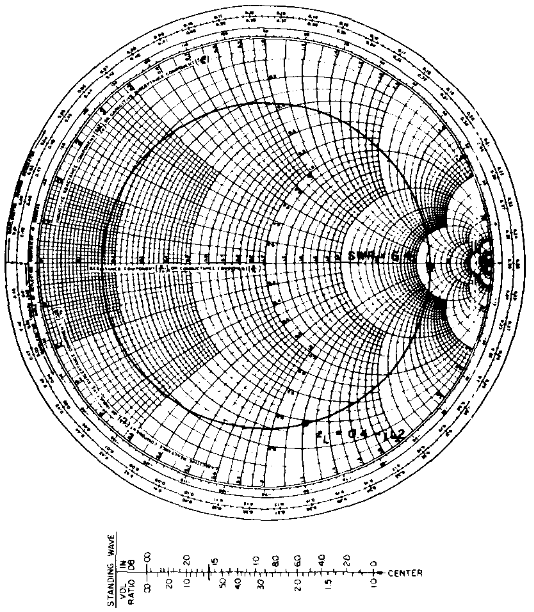


fig. 5. Using the Smith chart to find swr (example 1).

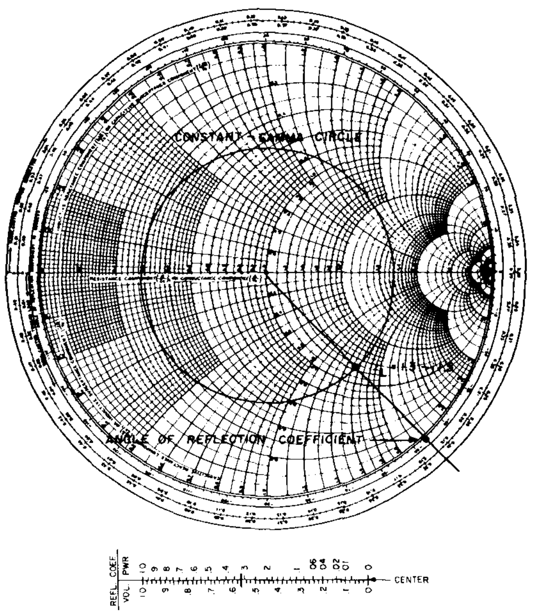


fig. 6. Finding reflection coefficient with the Smith chart (example 2).

5. Draw another line from the chart center to the outer scale at a point 0.28 wavelength clockwise (toward the generator) from the line drawn in **step 3.** Swing an arc from the center of the chart through z_L to this line. The intersection is at $z_L = 0.62 + j0.7$, the normalized input impedance. To find the actual impedance this value must be multiplied by the line's characteristic impedance

$$Z_i = 50(0.62 + j0.7) = 31 + j35$$

Example 4. Calculating load admittance. The impedance of a load terminating a 50-ohm transmission line is 75 + j82 ohms. What is the admittance of the load? (See **fig. 8.**)

1. Normalize the load impedance

$$z_L = (75 + j82)/50 = 1.5 + j1.64$$

2. Plot this point and draw a line through the center to the outer scale on the opposite side of the chart.

3. Swing an arc through z_L to the line on the opposite side of the chart. The point of intersection denotes the *normalized* admittance

$$y_L = 0.305 - j0.33$$

4. Calculate the actual admittance by multiplying the characteristic admittance of the system times the normalized admittance. The characteristic admittance (Y_o) is equal to the reciprocal of the character-

*Although all the computations may be made in feet (or inches) the metric equivalents are easier to work with. To convert from inches to centimeters, multiply by 2.54.

istic impedance

$$Y_o = \frac{1}{Z_o} = \frac{1}{50} = 0.02 \ mho$$

Therefore, the admittance is

$$Y_L = 0.02\,(0.305 - j0.33)$$

$$= .0061 - .0066 \ mho$$

Example 5. Determining the effect of a characteristic impedance change. A 50-ohm transmission line, 0.15 wavelength long, is terminated with 100 – j0 ohms. The 50-ohm line is fed from a 72-ohm line. What is the vswr in the 72-ohm line? (See **fig. 9**.)

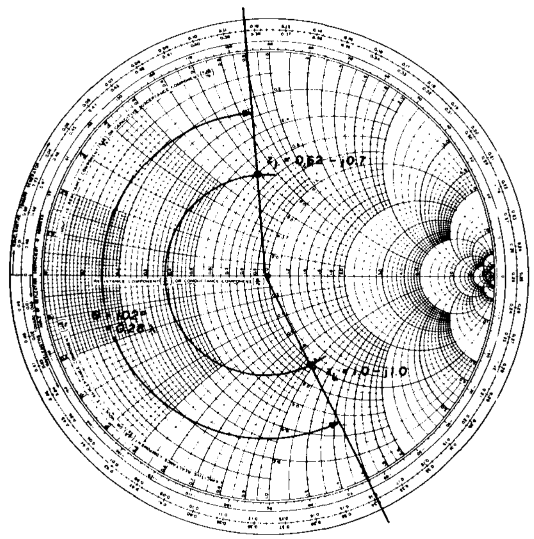


fig. 7. Using the Smith chart to find input impedance (example 3).

1. Normalize the load impedance

$$z_L = (100 - j0)/50 = 2 - j0$$

2. Determine the input impedance at the point where the two transmission lines are connected, 0.15 wavelength from the load. Plot the normalized load impedance on the chart and draw a line from the center of the chart through this point. Note that the line crosses the "wavelengths toward generator" scale at the 0.25 wavelength mark (**fig. 9A**).

3. Move 0.15 wavelength in a clockwise direction along the "wavelengths toward generator" scale to the 0.40 wavelength mark. Draw a line from this mark through the center of the chart. Swing an arc through z_L. The intersection of the arc and the radial line denote the input impedance to the 50-ohm transmission line 0.15 wavelength from the load

$$z_A = 0.68 - j0.48$$

4. Find the impedance at point X (**fig. 9C**) and normalize to the 72-ohm line. The impedance at point X

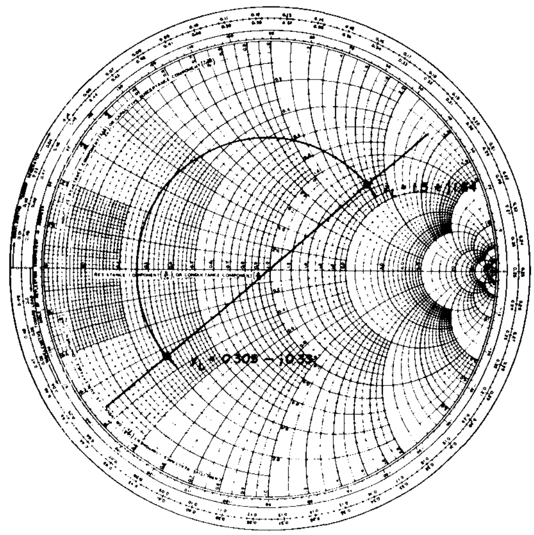


fig. 8. Calculating load admittance (example 4).

is $50(0.68 - j0.48) = 34 - j24$ ohms. Normalize this value to the 72-ohm line

$$(34 - j24)/72 = 0.47 - j0.33$$

5. Plot this point on the chart (**fig. 9B**) and draw a circle through z_A to the "axis of reals." The vswr in the 72-ohm line is 2.5:1. The vswr can also be found with the radial nomograph as outlined in **example 1**.

In the upper vhf region ordinary capacitors and inductors cannot be relied upon to act as pure reactances, and sections of transmission line are often used in their place since *any* input reactance may be obtained with the proper length of open- or short-circuited line.

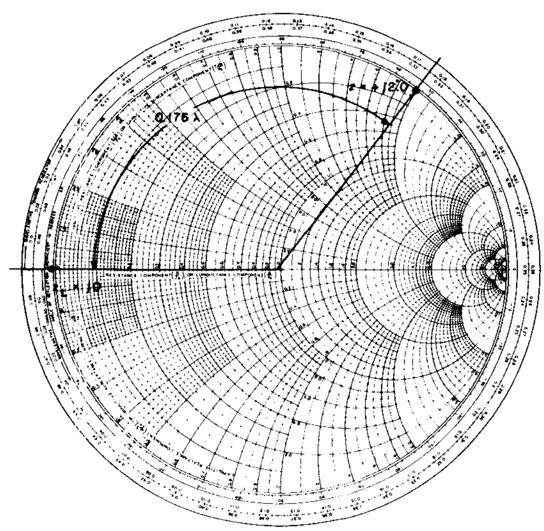
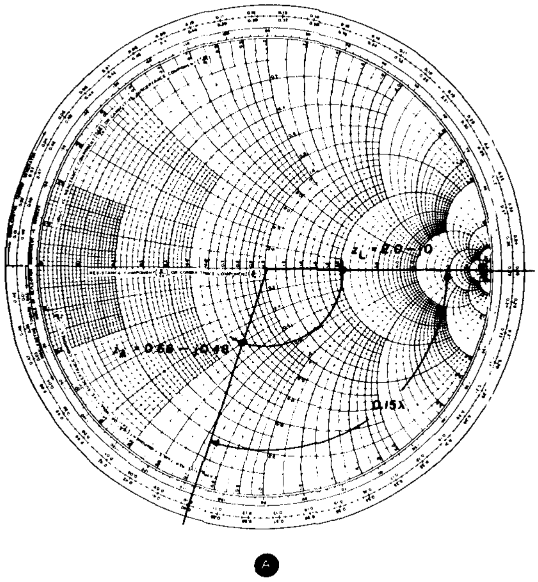
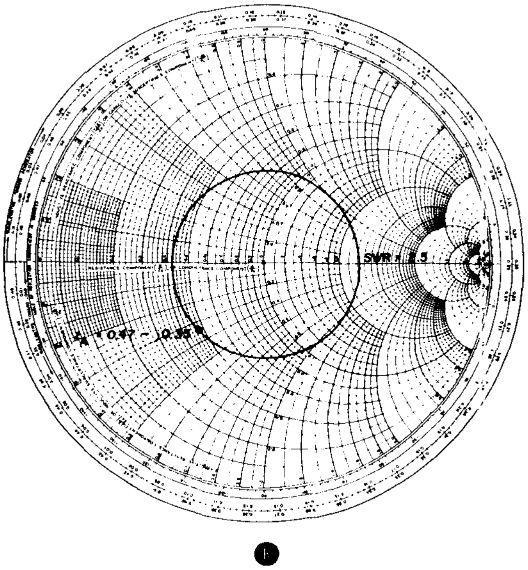


fig. 10. Using a transmission line as a circuit element (example 6).





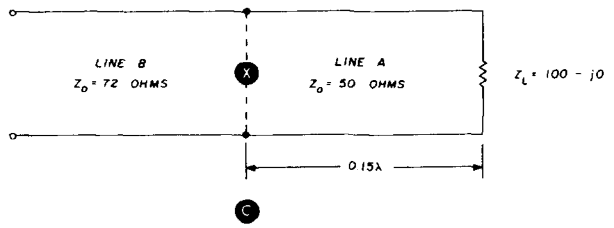


fig. 9. Determining the effect of a characteristic impedance change (example 5).

Example 6. Transmission lines as circuit elements. It is desired to obtain +j100 ohms reactance with a 50-ohm short-circuited transmission line as the circuit element. What length is required? (See **fig. 10**.)

1. Normalize the desired reactance

$$z = (+j100)/50 = +j2$$

2. Since the line is short-circuited,

$$Z_L = 0 + j0, \text{ and } z_L = 0 \text{ ohms.}$$

3. Plot these two points on the chart and draw lines from the center of the chart through each of them. On the "wavelengths toward generator" scale there is a distance of 0.176 wavelength between the two lines. Therefore, *a transmission line 0.176 wavelength long is required for a reactance of +j100.* (At 144 MHz, +j100 represents an inductance of 0.11 μH.)

Example 7. Finding matching stub length and location. A 50-ohm transmission line is terminated with a load impedance of 32 + j20 ohms. A matching stub is to be used to provide a match to the line. Both the length of the stub (l_s) and its distance from the load (l_d) are variable; find l_s and l_d. (See **fig. 11**.)

1. Normalize the load impedance

$$z_L = (32 + j20)/50 = 0.64 + j0.4$$

2. Locate this point on the chart and draw a line through it and the chart center, extending the line through the peripheral scales in the negative, or bottom, portion at $0.336\lambda (\theta = -62°)$

3. Construct a constant-gamma circle through z_L, on through the admittance point y_L, and intersecting the unity *conductance* circle ($G = 1$) at point **A**.

4. Draw a line from the chart center through point **A** to the outer scale at $0.348\lambda (\text{or } \theta = -71°)$. l_d, the distance from the load to stub, is the distance from 0.336 to 0.348.

$$l_d = (0.348 - 0.336) = 0.012\lambda$$

$$\theta = 71° - 62° = 9° \text{ (4.5 electrical degrees)}$$

5. To find the length of the stub, determine the amount of susceptance necessary to match out the load. The required susceptance is the difference between the susceptance at point **A** and the susceptance at the center of the chart. The susceptance at point **A** is −j0.67. The required stub susceptance is

$$B = +j0.67$$

6. Determine the equivalent stub reactance by taking the reciprocal of the susceptance (as described in **example 4**).

$$X = -j1.49$$

7. Locate the reactance −j1.49 on the rim of the chart (point **B**). Determine the distance between the short-circuit point and the required reactance (point

B) along the "wavelengths toward generator" scale. $l_s = 0.344\lambda$. ($\theta = 248°$, 124 electrical degrees).

For practical reasons it may not be possible to place a shunt stub only 4.5° from the load. It may be necessary to increase the distance l_D to the next point where $G = 1$ (not R = 1), represented by point C, **fig. 11A**. In this case l_D would be measured, clockwise from 0.336 through 0.50 to 0.151. Using the reflection coefficient scale, from $\theta = -62°$ to 180° plus 180° to +71°, which totals 227°R, or 113.5 electrical degrees. This represents 0.316λ. This will require a +jX stub, length shown as l_s (C), of the same numerical reactance value as before.

lossy lines

All the examples shown so far have assumed no attenuation in the transmission line. Since all lines have some loss, this must be considered to find the actual case. However, at many amateur frequencies loss is low enough to be neglected. Nevertheless, at 144 MHz and above, line loss should be considered when using the Smith chart.

Attenuation along a uniform transmission line causes the impedance point to spiral inward toward the center of the chart when moving toward the generator; when moving toward the load the impedance point spirals outward toward the rim of the chart. The rate at which the spiral approaches the center (or the rim) depends upon the attenuation as well as the starting point. Impedance points near the rim are affected more per dB of attenuation than points near the center.

The attenuation effect is easily determined with the scale at the bottom of the Smith chart labeled "transmission loss, 1-dB steps." Since the intial point on this scale must apply to any point on the chart, it is laid out without numerical calibration. The opposite attenuation effects of moving toward the load as opposed to moving toward the generator are indicated by arrows on the scale which show the proper direction to move the corrected impedance point. Thus, to determine the effect of 2-dB attenuation, simply mark off two 1-dB intervals in the proper direction along the scale from the initial starting point before reading the actual impedance coordinates.

Example 8. Impedance transformation through a lossy line. A 50-ohm transmission line 24 centimeters long is terminated with 10 − j10 ohms. What is the input impedance to the line at 250 MHz if the attenuation of the line is 2 dB? (See **fig. 12**.)

1. Normalize the load impedance

$$z_L = (10 - j10)/50 = 0.2 - j0.2$$

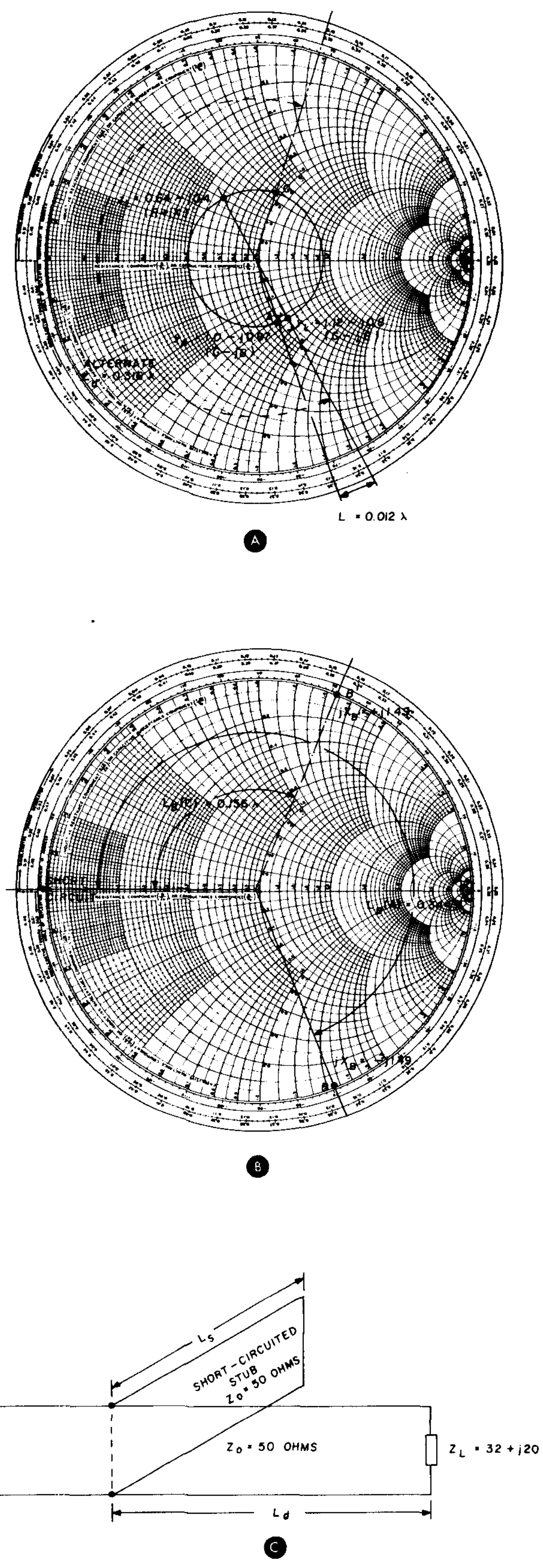


fig. 11. Finding matching stub length and location (example 7).

2. Find the electrical length of the line at 250 MHz.

$$\lambda = \frac{300 \times 10^8}{250 \times 10^6} = 120\ cm$$

The electrical length of the line is

$$\theta = 360^\circ\left(\frac{24cm}{120cm}\right) = 72^\circ = 0.2\ wavelength$$

3. Plot the impedance from **step 1** on the chart and draw a line from the center of the chart through this point to the outer scale.

4. Draw another line from the chart center to the outer scale at a point 0.2 wavelength clock-wise (toward the generator) from the line passing through z_L. Swing an arc through z_L to this line. The intersection point denotes $z_i = 0.71 + j1.52\ ohms$. This is the normalized solution for the lossless case. The rf energy from the generator is attenuated 2.0 dB on reaching z_L, and the voltage reflection coefficient is lower than the lossless case. Since the voltage reflection coefficent varies directly with the *power ratio* of one-way line attenuation, the reflection coefficient is reduced to

$$antilog\ \frac{2.0\ (dB)}{10} = 0.631$$

5. The reflection coefficient (ρ_o) for the lossless case is 0.68 (found on the scale at the bottom of the chart). The actual coefficient of reflection may be calculated by multiplying the lossless coefficient of reflection by the power ratio from **step 4**.

$$0.631\rho_o = 0.631\ (0.68) = 0.429$$

6. Swing an arc equal to the ratio $\rho_1 = 0.429$ so it intersects the line drawn through z_i; the radius of this arc can be found on the "voltage reflection coefficient" scale on the bottom of the chart. The normalized impedance for the lossy case is $1.08 + j1.05$. The actual input impedance is

$$Z_i = 50(1.08 + j1.05) = 54 + 52.5\ ohms$$

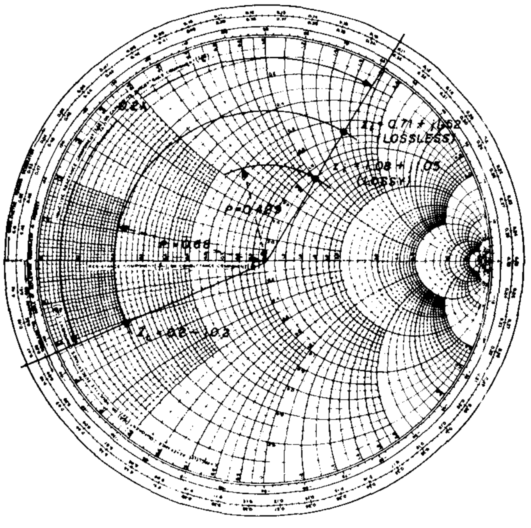


fig. 12. Impedance transformation through a lossy transmission line (example 8).

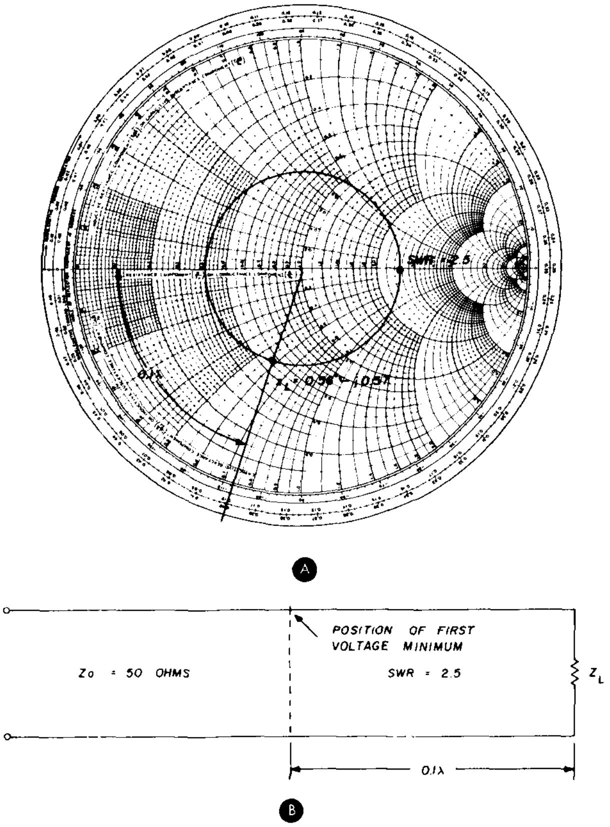


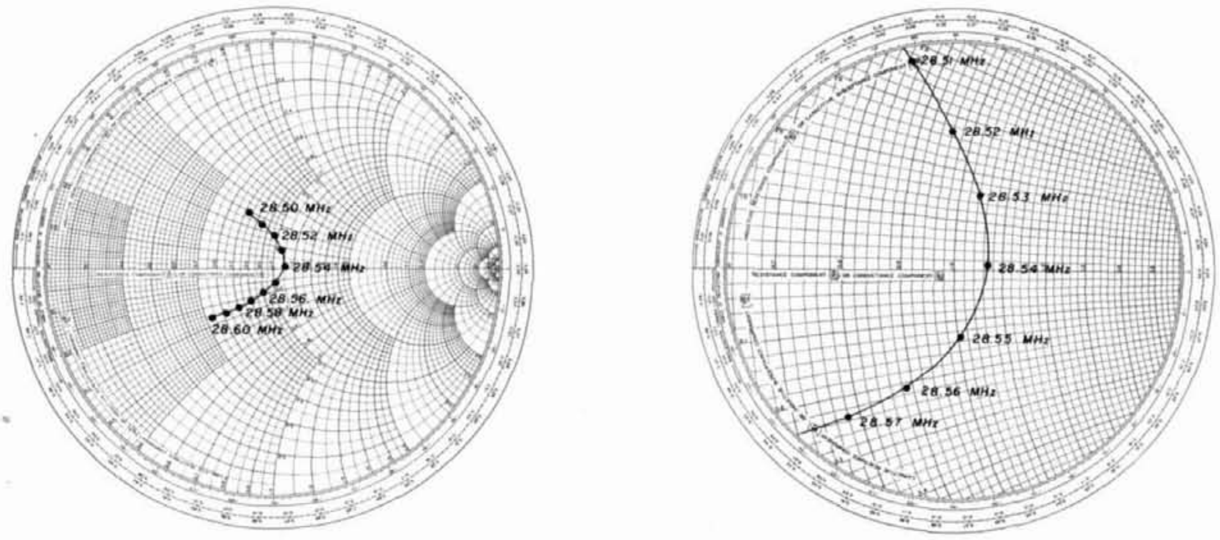
fig. 13. Using the Smith chart to find load impedance from vswr and position of the first voltage minimum on a slotted line (example 9).

slotted lines

At frequencies above 300 MHz conventional impedance-measuring instruments give way to the slotted line. A slotted line is essentially a section of transmission line with a small opening so you can use a probe to measure the voltage along the line. Vswr is easy to determine with the slotted line since it's the ratio of the maximum voltage along the line to the minimum. With the known vswr and position of the first voltage minimum, the impedance of the load can be quickly found with the Smith chart.

Example 9. Calculate the load impedance from the vswr and position of the first voltage minimum. A 50-ohm transmission line has a vswr of 2.5; the first voltage minimum is 0.1 wavelength from the load. What is the impedance of the load? (See **fig. 13.**)

1. Draw a radial line from the center of the chart



A B

fig. 14. Use of the expanded Smith chart. Impedance points in A are too close together; expanded chart in B is easier to work with.

through the 0.1 wavelength mark on the "wavelengths toward load" scale.

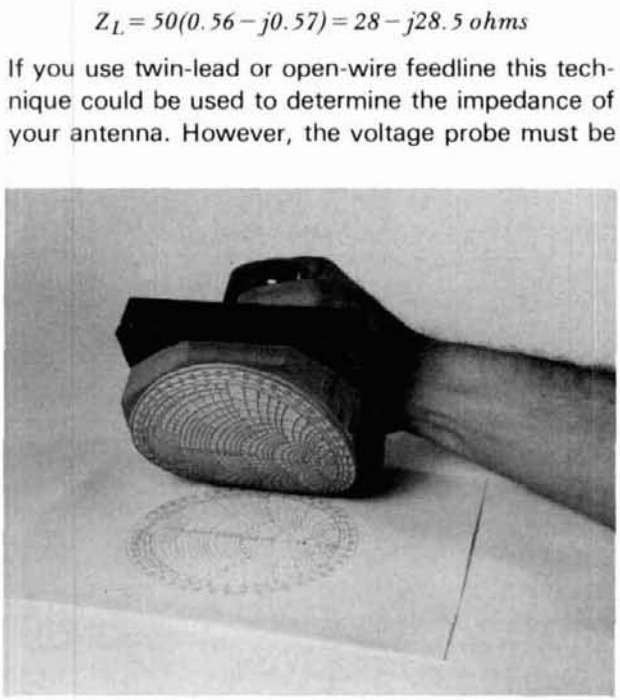
2. Find the 2.5 point on the axis of reals and draw a constant-gamma circuit through this point to intersect with the 0.1-wavelength line.

3. Read the coordinates of this intersection to obtain the normalized impedance of the load

$$z_L = 0.56 - j0.57$$

$$Z_L = 50(0.56 - j0.57) = 28 - j28.5 \text{ ohms}$$

If you use twin-lead or open-wire feedline this technique could be used to determine the impedance of your antenna. However, the voltage probe must be held a uniform distance away from the line for all measurements, and must not be so close that it disturbs the electric field around the conductors.



The Smith chart rubber stamp is 10cm (4 in) in diameter.

expanded smith charts

The more closely an antenna is matched to a transmission line, the closer the impedance points are to the center of the Smith chart. In a well-designed system the impedance points may be so close to the center of the chart that it's difficult to work with them. When this happens it's best to use an expanded Smith chart. Two versions are commonly available: one with a maximum swr of 1.59, the other with a maximum swr of 1.12.

The use of the expanded Smith chart is shown in **fig. 14**. In **fig. 14A** the impedance plot of a well-matched 10-meter beam over the low end of the phone band falls very close to the center of the chart. When these same impedance points are plotted on the expanded Smith chart in **fig. 14B** they are much easier to read and work with.

where to buy them

Smith charts can usually be purchased at college bookstores in small quantities, or in larger quantities from Analog Instruments Company or General

*Smith charts from Analog Instruments come in packages of 100 sheets, $4.75 the package. For standard charts order 82-BSPR; expanded charts (maximum swr = 1.59), order 82-SPR; highly expanded (maximum swr = 1.12), order 82-ASPR. Analog Instruments Company, Post Office Box 808, New Providence, New Jersey 07974.

Smith charts from General Radio are available in pads of 50 sheets, $2.00 per pad. For standard charts, normalized coordinates, order 5301-7560; 50-ohm coordinates, order 5301-7569; normalized, expanded coordinates, order 5301-7561. General Radio, West Concord, Massachusetts 01781.

Radio.* If you buy directly from the manufacturer, there's a minimum order quantity, so it might be a good idea to get your radio club to sponsor the purchase.

Another solution is the Smith-chart rubber stamp shown in the photo. This stamp is 10 cm (about 4 inches) in diameter and presents an adequately detailed grid structure for most engineering problems. The rubber surface of these stamps is cast from metal dies, and is dimensionally compensated for rocker-mount ellipticity and shrinkage. The capacity is well over a million impressions so you should never be able to wear it out. The stamps are available in standard (vswr = ∞) or expanded form (vswr = 1.59 or 1.12) from the Analog Instruments Company. Cost is $14.75 each.

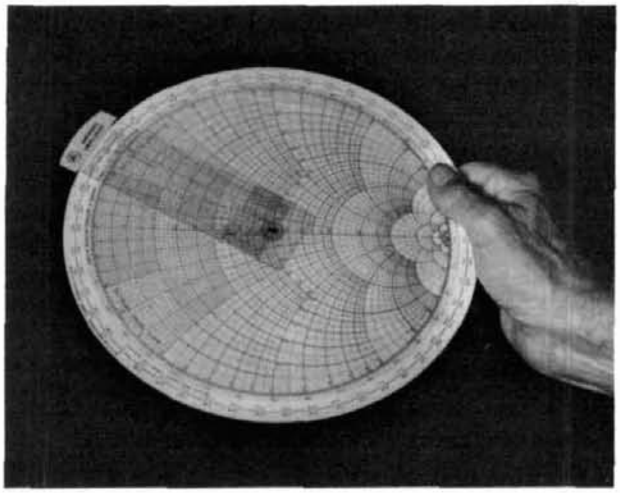


fig. 15. Smith chart calculator provides rapid answers to complex impedance problems.

If you don't need a permanent record of your Smith chart calculations, the calculator shown in **fig. 15** provides rapid answers to complex impedance problems. This calculator is constructed from two laminated plastic discs and a radial arm pivoted at the center with a sliding cursor. This calculator, which is 9-1/2 inches (24 cm) in diameter, is priced at $9.95 and is available from the Ham Radio's Communications Bookstore, Greenville, New Hampshire 03048.

references

1. Henry S. Keen, W2CTK, "A Simple Bridge for Antenna Measurements," *ham radio*, September, 1970, page 34.
2. Philip H. Smith, "Transmission Line Calculator," *Electronics*, January, 1939, pages 29-31; and "An Improved Transmission Line Calculator," *Electronics*, January, 1944, pages 130-133 and 318-325.
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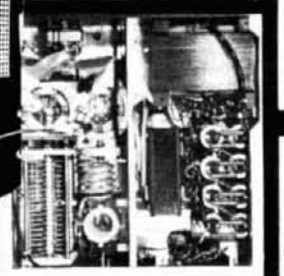

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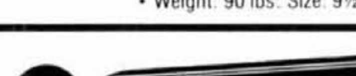

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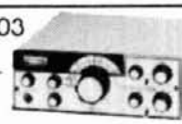

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More Details? CHECK—OFF Page 158

numerical smith chart

How to use the hand-held programmable calculator to execute Smith-chart problems

In this day of handheld programmable calculators, the graphical solution of transmission-line problems with the Smith chart seems unnecessarily cumbersome. Presented here is a derivation of the formulas upon which the Smith chart is based along with a program I have written for the HP-25 programmable calculator which numerically does Smith Chart transmission-line calculations.

The derivation and program are presented in such a way that it is possible to go directly to the program (page 6) and the explanation of its use.

formula derivation

Suppose you have a *lossless* transmission line of characteristic Z_o (ohms), of electrical length θ (in degrees), at frequency f (in Hz), terminated with the complex impedance $R+jX$ (ohms) at the far end (**fig. 1**). You wish to determine the impedance Z_i of this line as seen from the near (input) end.

A constant voltage source of frequency f is connected to the input and time is allowed for the system to relax into a steady state. The voltage of the source is now the sum of two distinct and measurable voltages: *incident* (outgoing) and *reflected*.

*To generalize Ohm's law to ac circuits it's necessary to write voltages and current in the complex form $ae^{j\omega t}$ rather than in the more familiar form $a \cdot \sin\omega t$.

Suppose at the input end the outgoing voltage at time t (seconds) is

$$V_o(t) = ae^{j360ft} \quad (1)$$

referenced to the bottom conductor.* Let t_o be the time required for this voltage to reach the far end. Then the outgoing voltage which appears across the termination at time t is exactly $V_o(t-t_o)$, the outgoing voltage that appeared at the input terminals t_o seconds in the past (**fig. 2**)!

Let the reflected voltage appearing at the termination at time t be $V_r(t)$. Then the reflected voltage appearing at the near end is $V_r(t-t_o)$.

In effect there are two generators: one at the input end generating an outgoing voltage of value $V_o(t)$, and a generator at the far end simultaneously generating a reflected voltage of value $V_r(t)$.

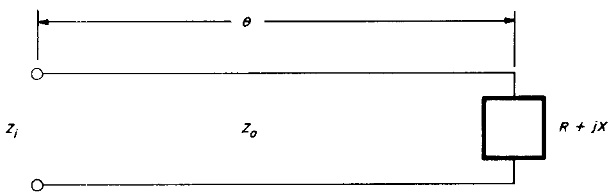

fig. 1. Lossless transmission line with characteristic impedance Z_o, electrical length θ, and terminated with $R+jX$. Formulas are given in the text for calculating the input impedance of the line Z_i.

Let's first examine what is happening at the far end. At the termination the outgoing current, together with the reflected current, must total the current through the termination.

$$\frac{V_o(t-t_o)}{Z_o} - \frac{V_r(t)}{Z_o} = \frac{V_o(t-t_o)+V_r(t)}{R+jX} \quad (2)$$

The minus sign before the second term corrects for the fact that reflected current is moving right to left rather than left to right (this is essentially why the standard reflectometer circuit can separate incident

By C. R. MacCluer, W8MQW, 1105 Orchard, Lansing, Michigan 48912

voltage from reflected voltage). Dividing through by $V_o(t-t_o)$ and setting

$$\rho = \frac{V_R(t)}{V_o(t-t_o)}$$ (the complex coefficient of reflection)

we obtain

$$\frac{1-\rho}{Z_o} = \frac{1+\rho}{R+jX}$$

Solving for ρ

$$\rho = \frac{R+jX-Z_o}{R+jX+Z_o} = \frac{r+jx-1}{r+jx+1} \quad \textbf{(3)}$$

Therefore

$$\rho = -\frac{1-z}{1+z} = \frac{z-1}{z+1} \quad \textbf{(4)}$$

where

$$z = \frac{R+jX}{Z_o} = r+jx \text{ (normalized termination)}$$

Meanwhile, back at the input end of the transmission line, the source voltage V is the sum of the outgoing and reflected voltages

$$V = V_o(t) + V_r(t-t_o) \quad \textbf{(5)}$$

The current I drawn from the source is the total of the outgoing and reflected currents

$$I = \frac{V_o(t)}{Z_o} - \frac{V_r(t-t_o)}{Z_o} \quad \textbf{(6)}$$

(The minus sign is used for reverse current, as before.) Therefore, the impedance Z_i is found by dividing **equations 5** and **6**.

$$Z_i = \frac{V}{I} = \frac{V_o(t) + V_r(t-t_o)}{\dfrac{V_o(t)}{Z_o} - \dfrac{V_r(t-t_o)}{Z_o}}$$

$$= Z_o \, \frac{1 + V_r(t-t_o)/V_o(t)}{1 - V_r(t-t_o)/V_o(t)} \quad \textbf{(7)}$$

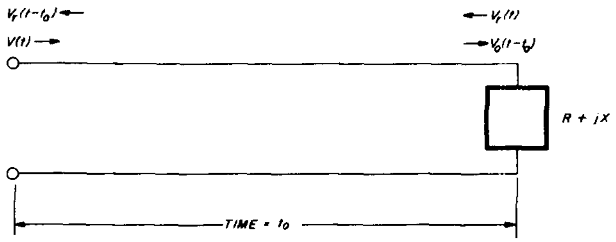

fig. 2. If a constant voltage source, $V(t)$, at frequency f is connected at the input, and t_o is the time required for the voltage to reach the far end, then the outgoing voltage which appears across the termination at time t is exactly $V_o(t-t_o)$, the outgoing voltage that appeared at the input terminals t_o seconds in the past.

The quantities $V_o(t)$ and $V_r(t-t_o)$ differ possibly in amplitude and phase, but not in frequency, so their quotient is constant! Therefore

$$\frac{V_r(t-t_o)}{V_o(t)} = \frac{V_r(t-2t_o)}{V_o(t-t_o)} =$$

$$\left(\frac{V_r(t)}{V_o(t-t_o)}\right)\left(\frac{V_r(t-2t_o)}{V_r(t)}\right) \quad \textbf{(8)}$$

But

$$V_r(t-2t_o)/V_r(t) = e^{-j2\theta}$$

Hence

$$\frac{V_r(t-t_o)}{V_o(t)} = \rho e^{-j2\theta} \quad \textbf{(9)}$$

Combining **equations 7** and **9** yields the Smith chart formula for lossless lines:

$$Z_i = Z_o \left(\frac{1+\rho e^{-j2\theta}}{1-\rho e^{-j2\theta}}\right) \quad \textbf{(10)}$$

where

$$\rho = \frac{z-1}{z+1}$$

$$z = \frac{R+jX}{Z_o} = r+jx$$

lines with loss

Let's now assume that the transmission line is

$V_r(t) = ae^{j(\omega t+\phi)}$ and so

$$\frac{V_r(t-2t_o)}{V_r(t)} = \frac{ae^{j[\omega(t-2t_o)+\phi]}}{ae^{j(t+\phi)}} = e^{-j2\omega t_o}$$

But

$$2\omega t_o = 2 \bullet 360 f t_o = 2\theta$$

lossy, say A dB per degree of length. Power P_1 introduced at one end of the line will be attenuated to power P_2 at the other end where

$$-A\theta = 10 \log \frac{P_2}{P_1} \quad \textbf{(11)}$$

Dividing through by 10 and exponentiating yields

$$P_2 = P_1(10^{-A\theta/10})$$

Thus outgoing voltage will be decreased (attenuated) by a factor of $\alpha = 10^{-A\theta/20}$ at the termination and reflected voltage has also decreased by the factor α at the near end (**fig. 3**).

table 1. Example of HP-25 Smith chart calculations to find the complex impedance at the generator (input) end of a transmission line, reflection coefficient, and vswr, given the complex impedance of the termination.

	R_L	jX_L	L	f	v	θ	Z_o	R_i	jX_i	ρ	vswr
	(ohms)		(ft)	(MHz)		(deg)	(ohms)	(ohms)			
1	73	+j16	85	3.6	0.66	169.62	50	63.29	+j22.45	0.226	1.58:1
2	32	−j5	100	7.1	0.66	393.57	50	34.98	+j12.49	0.227	1.59:1
3	50	j0	250	3.8	0.66	526.61	73	51.47	−j 8.99	0.187	1.46:1
4	100	+j100	100	14.2	0.66	787.14	50	18.14	−j35.40	0.620	4.27:1
5	18.14	−j35.40	100	14.2	0.66	787.14	50	15.18	+j26.18	0.620	4.27:1
6	75.00	−j30.00	—	—	—	90	50	28.74	+j11.49	0.304	1.87:1
7	28.74	−j11.49	—	—	—	90	50	75.00	−j30.00	0.304	1.87:1

With these losses in mind let's again derive the Smith chart formulas. In our calculations at the termination replace $V_o(t-t_o)$ with $\alpha V_o(t-t_o)$. In the calculations at the input end replace $V_r(t-t_o)$ with $\alpha V_r(t-t_o)$. The result will be the Smith chart formulas for transmission lines with loss

$$Z_i = Z_o \frac{1+\rho\ e^{-j2\theta}10^{-A\theta/10}}{1-\rho\ e^{-j2\theta}10^{-A\theta/10}} \quad (12)$$

where

$$\rho = \frac{z-1}{z+1}$$

$$z = \frac{R+jX}{Z_o}$$

In practice suppose a transmission line has length L (feet) and a loss of d dB per 100 feet. Since $A\theta = Ld/100$, the attenuation factor

$$\alpha^2 = 10^{-A\theta/10} = 10^{-Ld/1000} \quad (13)$$

HP-25 program

Suppose you have a *lossless* transmission line of characteristic impedance Z_o (ohms) of electrical length θ (degrees) at the frequency f (MHz) terminated in a complex impedance $R_L + jX_L$ (ohms). You wish to compute the impedance Z_i of this line as seen from the input end (**fig. 1**). The HP-25 program in **fig. 4** can be used to calculate Z_i. To use this program, follow the following steps:

1. Key in program.

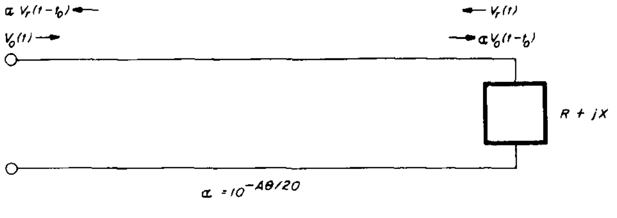

fig. 3. When a transmission line is lossy, the outgoing voltage is attenuated by the factor $\alpha = 10^{-A\theta/20}$ at the termination, and reflected voltage is also decreased by the factor α at the input end.

2. Store load resistance R_L in Register 0 (R_L STO 0).

3. Store load reactance jX_L in Register 1 (X_L STO 1).

4. Calculate line length θ in degrees using the following formula, and store in Register 2 (θ STO 2)

$$\frac{360Lf}{984v} = 0.3659\ \frac{Lf}{v} \quad (feet)$$

$$\frac{360Lf}{299v} = 1.204\ \frac{Lf}{v} \quad (meters)$$

where L is the length of the line in feet or meters, f is the frequency in MHz, and v is the transmission line's velocity factor.

5. Store transmission line impedance Z_o in Register 3 (Z_o STO 3).

6. Press R/S key to run program.

7. Calculator displays real part R_i of the input impedance (reactive part jX_i is in the y register).

8. Press $x \rightleftarrows y$ key to display reactive part jX_i of the input impedance.

9. Coefficient of reflection ρ is available in Register 5.

10. Manually calculate vswr from

$$vswr = \frac{1+\rho}{1-\rho}$$

Several sample runs are shown in **table 1**.

It is a commonly held misconception that transmission lines transform symmetrically; many amateurs believe that if a transmission line terminated with Z1 yields Z2 at the input (generator) end of the line, the same line terminated with Z2 will yield Z1 at the generator. Except for lines which are one-quarter wavelength long ($\theta = 90$ *degrees*), or multiples thereof, this is not true. For example, a shorted 45° (λ/8) length line of characteristic impedance Z_o has impedance

$Z = jZ_o \tan 45° = jZ_o$, yet this same line, when terminated by jZ_o, is equivalent to a shorted quarter-wavelength line and hence has infinite impedance.

The special case of the quarter-wavelength transmission line is illustrated in lines 6 and 7 of **table 1**. Here a 50-ohm transmission-line termination of 75 – j30 ohms is transformed to 28.74 + j11.49; the same line terminated with 28.74 + j11.49 yield 75 – j30 at the generator end.

To use the HP-25 program in **fig. 1** to calculate the impedance of the termination Z_L given the impedance Z_i at the generator, store the real part R_i in register 0 (R_i STO 0, Step 2), and the reactive part jX_i in register 1 (X_i STO 1, Step 3). In Step 4 store $-\theta$ in Register 2 ($-\theta$ STO 2).

program modification for lines with loss

Suppose that the transmission line is lossy. Modify the previous HP-25 program by inserting an R/S between Steps 34 and 35, renumber succeeding steps, and at Step 28 replace the GTO 43 with GTO 44. To use the modified program, Steps 1 through 5 are the same as before.

6. Compute the factor $\alpha^2 = 10^{-Ld/1000}$ where d is the loss of the line in dB per 100 feet. Store the result in Register 6 (α^2 STO 6).

7. Press the R/S key; the routine will stop at Step 35 at the inserted R/S.

8. Recall the factor α^2 from Register 6 and press X.

9. Press R/S key.

10. Calculator displays the resistive part of Z_i (reactive part of Z_i is contained in the y register).

11. Compute the swr at the input as before.

To compute the swr at the termination, calculate

$$\rho' = \rho/\alpha^2 = \rho 10^{Ld/1000}$$

and proceed as before with ρ replaced by ρ'.

To use this program "backwards" (to find the termination impedance Z_L given the input impedance Z_i), store Z_i in Steps 2 and 3, store $-\theta$ in Step 4, and in Step 6 store $1/\alpha^2 = 10^{Ld/1000}$. The swr calculated at Step 11 will now be the swr at the termination. To calculate the swr at the input end of the line, the value ρ' found in Register 5 must be replaced by $\rho = \rho'\alpha^2$ before proceeding as in Step 11.

As an example, consider the amateur who uses his 75-meter dipole for two-meter fm. Assuming 120 feet (36.6m) of RG-58/U coaxial cable ($v = 0.66$, $d = 5.7$ *dB loss/100 feet* at 144 MHz), what is the swr at the input end of the line? (The antenna feedpoint impedance is assumed to be 2000 – j800 ohms.)

$$\theta = 0.3659 \frac{Lf}{v} = 0.3659 \frac{120 \cdot 144}{0.66} = 9579$$

$$\alpha^2 = 10^{-Ld/1000} = 0.207$$

$$Z_i = 52.83 - j21.35 \text{ ohms}$$

$$swr = 1.49{:}1$$

Because of high line loss, the swr at the input end of the line is only 1.5:1, even with the outrageous mismatch at the antenna! In contrast, consider the same case with a lossless transmission line:

$$Z_i = 2.99 - j64.16$$

$$swr = 44{:}1$$

The two HP-25 programs presented here are invaluable time savers when it comes to making transmission line calculations. I have also written a facile program for the HP-67 programmable calculator which includes all the above features.*

ham radio

HP-25 Program Form

Title Transmission line impedance transformation (complex Z_I given Z_L)

Switch to PRGM mode, press [f] [PRGM], then key in the program. LOSSLESS LINE

DISPLAY LINE	DISPLAY CODE	KEY ENTRY	X	Y	Z	T	COMMENTS
00							
01	00	0					
02	236104	STO X4					
03	2403	RCL 3					
04	237100	STO ÷0					
05	237101	STO ÷1					
06	2401	RCL 1					
07	32	CHS					
08	01	1					
09	2400	RCL 0					
10	41	–					
11	1509	→P					
12	01	1					
13	2400	RCL 0					
14	51	+					
15	2401	RCL 1					
16	21	X↔Y					
17	1509	→P					
18	21	X↔Y					
19	22	R↓					
20	71	÷					
21	22	R↓					
22	41	–					
23	32	CHS					
24	21	X↔Y					
25	22	R↓					
26	2404	RCL 4					
27	1561	X≠0					
28	1343	GTO 43					
29	22	R↓					
30	2402	RCL 2					
31	02	2					
32	61	X					
33	41	–					
34	21	X↔Y					
35	2305	STO 5					
36	1409	→R					
37	2300	STO 0					
38	21	X↔Y					
39	2301	STO 1					
40	01	1					
41	235104	STO +4					
42	1306	GTO 06					
43	22	R↓					
44	21	X↔Y					
45	2403	RCL 3					
46	61	X					
47	1409	→R					
48	1300	GTO 00					
49							

REGISTERS	
R_0	R
R_1	X
R_2	θ
R_3	Z_o
R_4	
R_5	
R_6	
R_7	

fig. 4. HP-25 program for calculating the impedance as seen at the input end of a lossless transmission line while terminated in a complex impedance.

*Copies are available from *ham radio* upon receipt of a self-addressed, stamped envelope.

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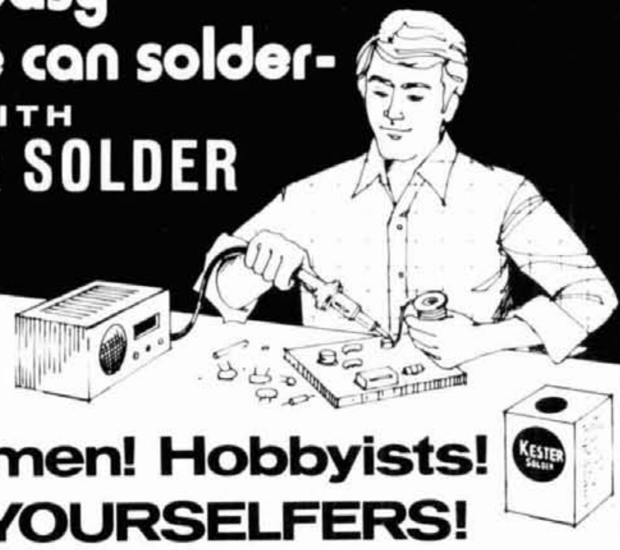

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More Details? CHECK — OFF Page 158

comments

10 GHz Gunnplexers

Dear HR:

I was very happy to see the article on 10 GHz in April, 1977, *ham radio*. This band has been of interest to me for more than 20 years. In 1955, I built a system using reflex klystrons and obtained good results. Two years ago, I built a system similar to the one described and have obtained results much the same as discussed in the article.

In the new system, two Microwave Associates 86656D transceivers are used. As can be seen in the photograph, the horns are homemade. In the enclosure, the microphone amplifier is on the left, an inexpensive fm broadcast receiver is on the right, and the voltage regulator is at the rear. These transceivers do not have a varactor diode; the Gunn diode bias voltage controls all frequency changes, both modulation and basic frequency. This system seems to work quite well.

I've experienced the same frequency stability problems described, even with very good voltage regulation. Temperature variations are mostly to blame.

So far I have not developed any form of afc system. The crystal control method looks like it would keep the Gunn transmitter close to a given frequency but it also appears quite complicated. I like the idea of using the afc or discriminator output to control the voltage regulator. It appears to be quite simple yet, will provide a perfect lock.

Allen C. Webb, W5RLG
Richardson, Texas

receiver recovery in the SB102

Dear HR:

The *ham notebook* article (March, 1977) by W2CNQ, regarding excessive recovery delay in the CW mode of Heathkit's SB102, is not unique as the same problem occurs in other Heath transceivers. The root of the problem may well lie in the fact that all SB100 series, HW100s, and HW101s are not the same, some having been modified, while others are later models.

Opening up the screen voltage supply line to cut off pentodes and tetrodes is not without its problems, especially since small amounts of current can flow from plate to screen. There's an additional problem if other tubes are connected to the same screen line. This was originally described in the article by Peterson and Williams (*QST*, January, 1969) which points out that the screen voltage from 6146s (with continuous plate voltage) had been observed to rise as much as 20 volts when the screen supply was opened.

Accordingly, the placement of very high back resistance silicon diodes in the screen circuit of the 6146s and 6CL6 driver, will in most cases prevent the screen voltage, at V2, from rising during the receive condition (in the CW mode).

Changing tubes will help in many instances, but the root of the problem will remain if it is due to small amounts of current circulating back through the supposedly "open" screen circuit.

W. H. Fishback, W1JE
Chatham, Massachusetts

regulated power supplies

Dear HR:

I must congratulate K5VKQ on his article concerning the design of regulated power supplies. I feel that this type of article is needed by most amateurs.

I would like to point out that in the design example, with an average input voltage to the regulator of 13.5 Vdc, and a current drain of 1 ampere, the regulator must dissipate 8.5 watts, with an output voltage of 5 volts. However, the LM309K will only dissipate 3.5 watts, without a heatsink at an ambient temperature of 25° centigrade. Therefore, potential builders/designers should consider power dissipation in the regulator, $P_{DISS} = (V_{IN} - V_{OUT})(I_{LOAD})$. Allowable power dissipation values *vs* ambient temperature curves are readily available in most data books, along with recommended heatsink types.

Wayne Whitman, W9HFR
Oconomowoc, Wisconsin

mospower fet

Dear HR:

As pointed out by Johnson in the *RCA Review* (March, 1973) and in the United States Patent 3,174,462, all types of fet devices have a diffusion mode of operation which ideally provides a device transconductance — per-unit-current of approximately

39000 micromhos of transconductance per milliampere of drain current. The junction fet can provide this transconductance over as much as five orders of magnitude variation in drain current. Over this range, it behaves essentially like a bipolar transistor.

Transconductance efficiency, the percentage of transconductance per unit current which the user can obtain from a practical device in his circuit, is of major importance to amateurs since it controls both the efficiency of the device as a low noise (front end) amplifier, and also the power handling ability of mospower devices. In the low noise application, maximum efficiency is required, while in power applications, quite low values of efficiency may be desirable.

All solid-state amplifiers are voltage-gain limited, not current-gain limited. For this reason, the output supply voltage which may be used with an rf amplifier can be expressed in terms of a simple equation:

$$V_{dd} = A/\varkappa$$

where V_{dd} is the drain supply voltage, $\varkappa$ is the (decimal) value of transconductance efficiency, and A is a small number, typically near unity, but almost never over ten. (This equation may easily be confirmed from data sheets on power electron tubes as well as transistors of all kinds.)

If freedom from oscillation and spurious transients is necessary, overall stage voltage gain for any solid-state rf amplifier must be limited to approximately ten. (To prevent TVI, for example.) Use of voltages higher than indicated by the equation lead to a variety of problems, excess phase shift, improper bandpass responses, excessive dissipation, or birdies.

The field-effect transistor, and particularly the mospower unit, may lead to a breakthrough in the application of semiconductors to rf power amplifiers, possibly breaking the present practical limit of 50 watts per device for bipolar devices in the common-base configuration. The fet uses an insulated-gate structure similar to that described in the patent for diode fet devices, with corresponding power and frequency response characteristics. It looks like a bipolar transistor but forms a channel against the insulated gate. Since the device is forward biased, it behaves as a bipolar transistor so is limited by the high value of $\varkappa$, near unity, which is typical of bipolar devices.

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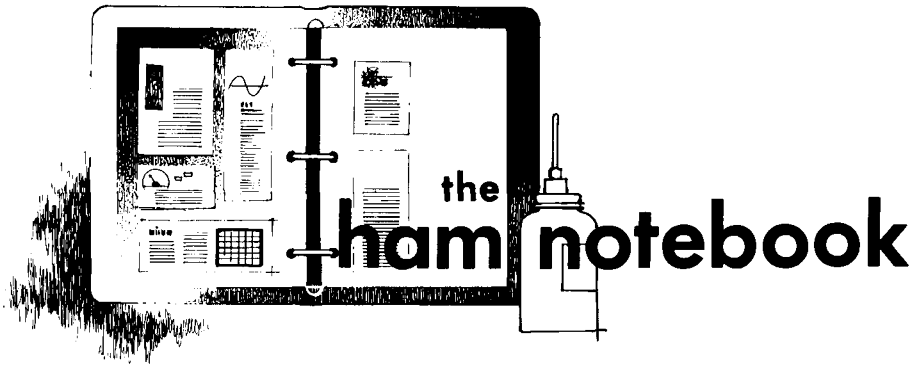


remote-switching circuit

A reliable and inexpensive circuit for remote frequency control of a vhf transceiver can be made from three NAND gate ICs. The circuit could also be used for other applications requiring remote selection of one of a number of mutually exclusive functions. The use of CMOS gates permits operation from an automobile electrical system or other 12-volt source, providing a high degree of noise immunity, and freedom from rf interference. Suitable ICs are the RCA CD4011A and 4012A, or the corresponding Motorola MC4011CP and 14012CP.

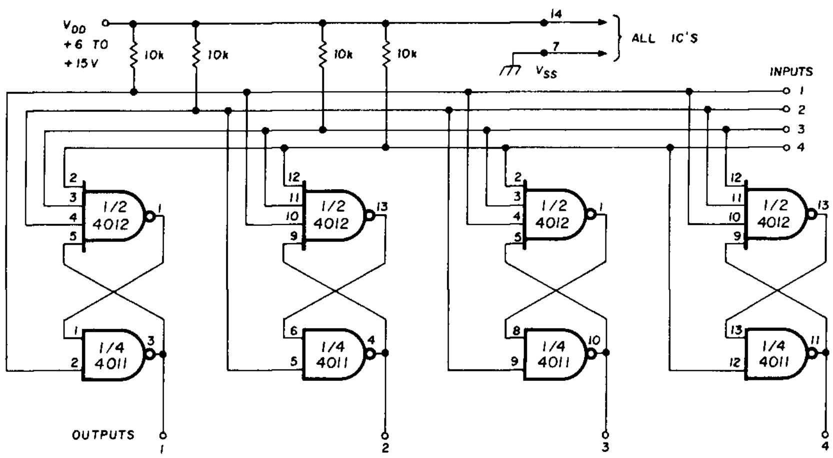


fig. 1. Remote switching circuit employing CMOS NAND gates.

The circuit shown in **fig. 1** consists of four flip-flops, each made up of one 4-input and one 2-input NAND gate. Momentarily grounding any input will drive the corresponding output high, and all other outputs low. Unless power is interrupted, additional pulses on the same input have no effect; the circuit remains in a stable state until another input is momentarily grounded. The outputs may be used to drive other logic devices directly, but an external buffer will be needed if the current approaches the safe limit of 10 mA.

Pat Shreve, W8GRG

a TTL and CMOS logic probe

The circuit shown in **fig. 2** is designed to indicate the logic states in TTL and CMOS circuits. In addition, it will indicate the presence of positive- and negative-going pulses, substituting for a high-speed triggered oscilloscope. In the schematic, Q1 is used as a high-impedance buffer preceding one of the NAND gates. CR1 acts as the buffer before a second gate. With a logic 0 input, the **A** section of the 4011 will turn LED2 off, and the **B** and **C** sections will turn LED1 on. A logic 1 on the input reverses the levels causing LED2 to be on and LED1 to be off.

A 555-type timer IC acts as a one-shot multivibrator, triggered by either positive- or negative-going pulses. With S1 open, LED3 will come on for approximately 200 ms regardless of the input pulse width. After the input pulse, with S1 closed, LED3 will remain permanently on.

In normal operation, a logic 0 input will cause both LED1 and LED3 to light, with LED3 remaining on for only 200 ms. For a logic 1 input, only LED2 will light. With S1 closed, the circuit will indicate whether a negative- or positive-going pulse has occurred. If positive-going, LED1 and LED3 will remain on; LED2 and LED3 will remain on after a negative-going pulse has occurred. The input and correct displays are summarized in **table 1**.

table 1. LED displays for different input conditions.

input	LED1	LED2	LED3	S1 closed?
logig 0	on	off	on 200 ms	no
logic 1	off	on	off	no
positive-going pulse	on	off	on	yes
negative-going pulse	off	on	on	yes

Howard M. Berlin, W3HB

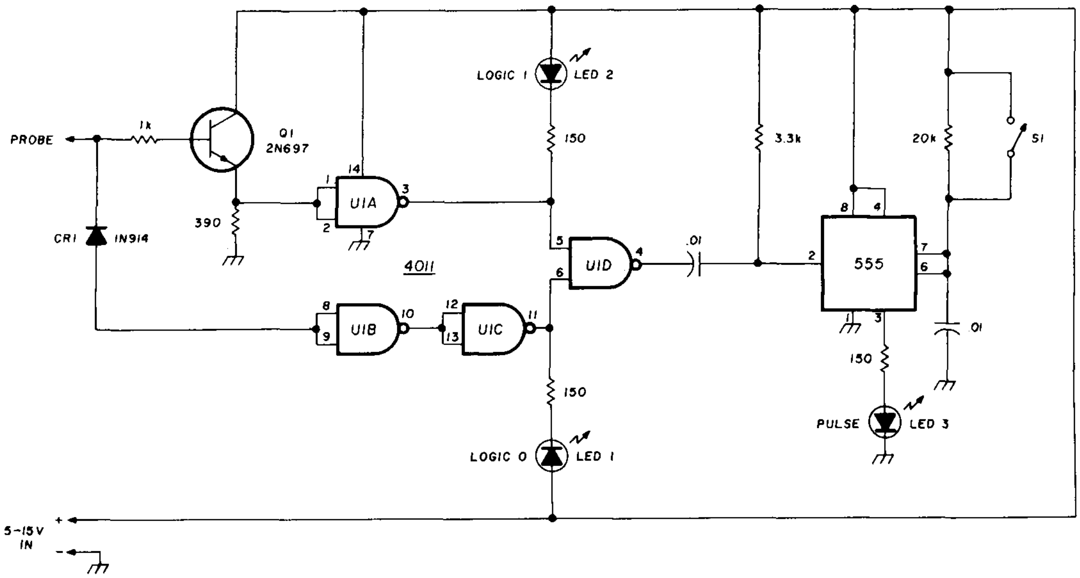


fig. 2. Schematic diagram of the TTL and CMOS logic probe. Since a CMOS gate is used in the probe, the supply voltage can be between 5 and 15 volts. The 555 timer will produce a 200 ms pulse after being triggered.

voltage adapter for MSI/LSI circuits

For experimenting with integrated circuits, it is necessary to have a bench power supply with at least two voltage levels. With the scheme shown in **fig. 3**, it is possible to supply +12, −12, and +5 volts from a single regulated 24-volt source for use with many LSI circuits. The +12V and −12V supplies can be adjusted either in the same direction by varying the 24V source, or in opposite directions by adjusting the potentiometer.

Resistor R1 is used to decrease the power dissipated in the LM309K voltage regulator. A 2.2 ohm value is correct, but it is possible to change it depending upon the current necessary on the +5 volt line (the input voltage to the LM309K must always be greater than 7 volts for a good regulation). All the small components are mounted on a 2 x 1-3/4-inch (5x4.5cm) pc board, and the two TO-3 cases are mounted on a commercial heatsink.

J. A. Piat, F2ES

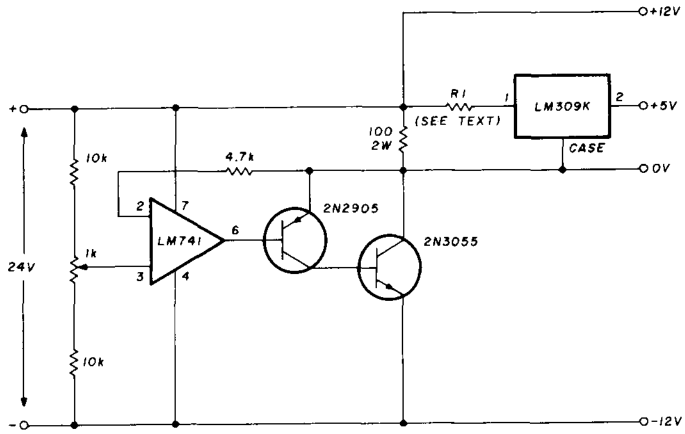


fig. 3. Schematic of the voltage adapter for LSI/MSI circuits. Value of resistor R1 is discussed in the text. Printed-circuit for this simple circuit is shown in fig. 2.

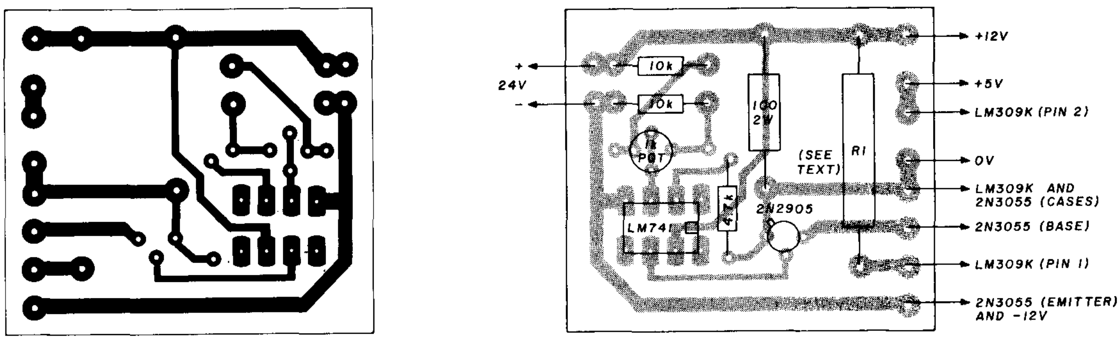


fig. 4. Full-size printed-circuit board layout and component placement diagram for the MSI/LSI voltage adapter.

NEW products

For literature on any of the new products, use our *Check-Off* service on page 158.

Kenwood TS-700S and VFO-700S

Kenwood has announced the new TS-700S, an all-mode, 2-meter transceiver. Based on the popular TS-700A, the TS-700S incorporates several new features such as a digital readout with "Kenwood Blue" digits, high-gain receiver pre-amp, a 1-watt low-power switch, built in vox, and CW Sidetone. It operates all modes: upper and lower sideband, fm, a-m and CW. The completely solid-state circuitry provides stable, long-lasting, trouble-free operation. You can operate the rig from your car or boat on 12-V dc, or as a home station with its built-in power supply. Frequency coverage is 144 to 148 MHz. The TS-700S automatically moves its transmit frequency 600 kHz for repeater operation; simply dial in your receive frequency and the radio does the rest for simplex, repeater, or reverse modes. Or, select your frequency by plugging a single crystal into one of the 11 crystal positions for your favorite channel. You'll have transmit/receive capability on 44 channels with 11 crystals.

The VFO-700S is a handsomely styled companion to the TS-700S. This unit provides you with the extra versatility and luxury of having a second vhf in your vhf shack, which is great for split-frequency operation and for tuning off frequency to check the band. The function switch on the VFO-700S selects the vfo in use, and the appropriate frequency is displayed on the digital readout in the TS-700S. In addition, a momentary-contact "frequency check" switch allows you to spot check the frequency of the other vfo.

List price of the TS-700S is $679, and the VFO-700S lists at $119. Both units are available from authorized Trio-Kenwood dealers throughout the United States. For a list of authorized dealers and more information on the TS-700S and VFO-700S, write: Trio-Kenwood Communications, Inc., 1111 West Walnut Street, Compton, California 90220.

directional wattmeter with variable rf output

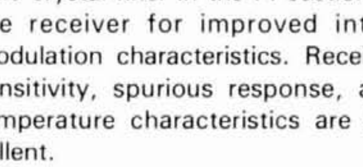
The Bird model 4431 is a new *Thruline* rf directional wattmeter for the measurement of forward or reflected CW power, with the additional feature of an adjustable rf sampling output for frequency analysis on a scope, spectrum analyzer, or frequency counter. The wattmeter is designed for ±5 per cent power measurement from 100 milliwatts to 5000 watts, over the frequency range of 2 to 30 MHz and up to 1000 watts from 30 to 1000 MHz. In addition, the standard model 43 plug-in elements in discrete bands and power levels are used. No plug-in elements are needed for rf analysis. The sample signal is adjustable from 15 dB to over 70 dB below the main line signal, offering all important protection from overload for high-sensitivity instruments.

Thruline model 4431 has a low insertion vswr of 1.07 at most settings. A major feature resulting in this low vswr value is the use of the patented QC Quick Change Connectors, which permit mating with male or female N, BNC, TNC, UHF, C, SC, HN, GR Type 874, and 7/8-inch (22mm) EIA lines without the need for performance-degrading adapters.

The model 4431 price is $175. Plug-in elements range from $36 to $42. Delivery time is 90 days ARO, from Bird Electronic Corporation, 30303 Aurora Road, Cleveland (Solon), Ohio 44139.

Kenwood TR-8300 fm transceiver

A new transceiver from Trio-Kenwood, the TR-8300, offers high quality and superb performance as a result of many years of improving vhf/uhf design techniques. The TR-8300 is capable of fm operation on 23 crystal-controlled channels. Over a 10-MHz segment of the band from 440 to 450 MHz. The transmitter and receiver sections may be independently adjusted to cover 5-MHz segments at a time.

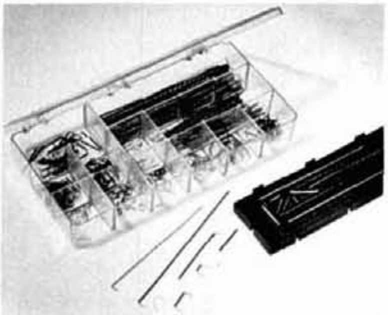


The TR-8300 incorporates a five-section helical resonator and a two-pole crystal filter in the i-f section of the receiver for improved intermodulation characteristics. Receiver sensitivity, spurious response, and temperature characteristics are excellent.

Maximum transmitting power is a husky 10 watts from the meticulously designed and assembled final stage. It may be set to provide either this 10-watt output, or a low 1-watt output, by means of a push-button switch. Additionally, the TR-8300 includes a special monitor circuit which enables the user to listen to his own modulation and make frequency adjustments.

The list price of the TR-8300 is $299 and the unit is available from authorized Trio-Kenwood dealers throughout the United States. For a list of authorized dealers and more information on the TR-8300, write Trio-Kenwood Communications, Inc., 1111 West Walnut Street, Compton, California 90220.

breadboard jumper wire kit



Each breadboard jumper wire kit contains 350 wires, cut to 14 different lengths from 0.1 inch (2.5mm) to 5 inches (12.7cm) long. Each no. 22 AWG (0.6mm) wire is stripped, tinned, and bent 90 degrees for good contact insertion. The color of the PVC insulation represents its length, while the sectional clear plastic storage box keeps everything organized.

For further information, contact Hammond Manufacturing Company Limited, 385 Nagel Drive, Buffalo, New York 14225.

quick charge cordless soldering station

Ungar, a Los Angeles based manufacturer of industrial soldering tools, announces the availability of their latest addition . . . a new cordless

More Details? CHECK—OFF Page 158

Quick Charge soldering station. The new impressive design allows the operator unrestricted freedom for access to hard-to-reach intricate assemblies. It is an ideal station for the professional who assembles breadboard prototypes, services radio and TV, builds electronic kits or does touch-ups and repairs. The station is useful in the field or at the workbench.

The *No. 200 Soldering Station* consists of a rugged rechargeable iron with a quick charge nickel-cadmium battery. It is designed to accept two rigid interchangeable tips, and the charging holder completely recharges the battery in 4 hours. Outstanding features of Ungar's new *Quick Charge Soldering Station* include a well-balanced lightweight pencil iron with indicator light, and a convenient easy-touch operating control with interlock "off" switch. A built-in lamp illuminates the tip and work area. Two quick-heating, interchangeable, element tips are available in chisel and micro-spade configuration. The slim design offers operators good visual control of soldering applications. A charging holder allows the iron to charge in its rest position and provides long battery life. Additionally, the holder has a convenient built-in sponge tray for efficient tip cleaning and care.

The complete station is molded in high-impact plastic. The charging holder is rated at 120 volts ac input, 3.2 volts dc at 285 mA output, UL listed.

For additional information, or a demonstration, call your authorized distributor or contact Ungar, Division of Eldon Industries, Inc., 233 East Manville Street, Compton, California 90220; telephone (213) 774-5950.

rf transistors for increased output power at uhf

A new series of rf power transistors that extends rf power output capabilities to 80 watts in the 100- to

More Details? CHECK—OFF Page 158

500-MHz range has been introduced by Motorola. The devices are designed for broadband operation as class A, AB, B, and C transmitter amplifiers in uhf communications equipment operating from a 12-28 volt power supply. Pertinent statistics for the newly introduced uhf transistors are as follows:

Device	P_{out}*(W)	Gain* (dB) minimum
MRF321	10	12
MRF323	20	10
MRF325	30	8.5
MRF326	40	8.5
MRF327	80	7.3

*Performance at 28V, 400 MHz.

To achieve the reliability required for military applications, an all-gold metallization system is employed for all devices. Gold is used for the top metal of the transistor, for the associated MOS capacitors, for the bonding wires, as well as for package plating. The reliability advantage achieved results from the elimination of "aluminum migration" and corrosion due to contact of dissimilar metals.

To attain the critical performance specifications over the indicated wide band of ultra-high frequencies, a variety of technological innovations is employed including a double-element internal matching network in the 40- and 80-watt transistors giving broadband, high-performance not available from the previous generation of devices. Internal matching inductors are formed from carefully calculated wire bonds. A programmed wire-bonding machine automatically forms the exact wire length, height and curvature. This affords excellent repeatability of input impedances. Proper placement of elements within the chip structure, to eliminate hot spots at high power levels, is achieved by means of computer-aided design and verified through infra-red scanning techniques. The resulting devices all withstand a 30:1 output load vswr at rated voltage and power output conditions. The new devices are available from Motorola distributors.

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Jim Wood W3WJK
Trustee WR3AHE
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D. Totel W9NJM
Wheaton Community Radio Amateurs, Inc.
Chicago area

August 21, 1977

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Attn.: Mr. Joe de Courcelle

Dear Mr. de Courcelle:

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The repeater is being used at WR2APM, Levittown, New York. To say that this area is an agglomeration of 2 meter repeaters is an understatement; there are eight 2 meter machines within a five miles radius of the site. Quite naturally therefore, one of my primary concerns was the selectivity of the machine that I chose to replace our G.E. machine. Your repeater has certainly fulfilled our expectations. It is selective to the point that an over deviated signal will not hold the machine.

I have found the machine completely satisfactory in all respects including its ability to maintain specifications; even during long periods of key down.

I am especially pleased with the personal service you have given me. During the initial set up of the machine you and your staff were always there, whether at your office or home -day or night- to answer my questions and otherwise assist me with problems I incurred while interfacing other equipment. When a pass transistor failed I had another within a couple of days. The service you have given me, in itself, would justify purchase of the SCR 1000.

With all best wishes, I am,

Yours truly,

Joseph A. Oley,
Trustee, WR2APM

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Jim Todd WA5HTT
Dallas TX

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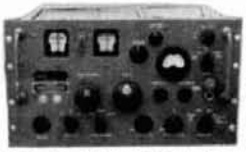

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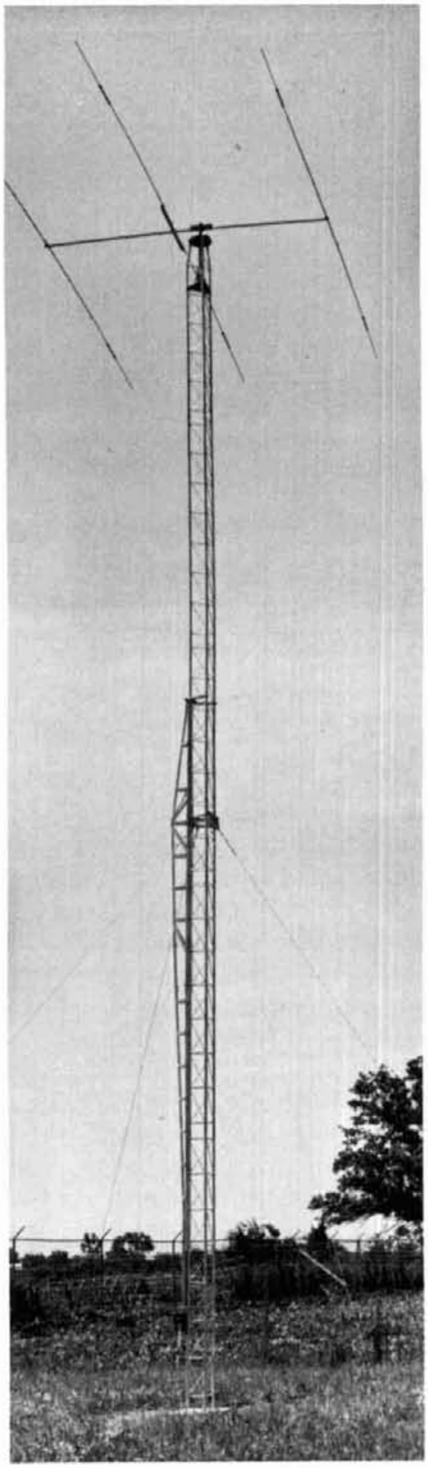

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New Swan Antenna Tuners:
steady your impedance at 50 Ohms

Your transceiver just met its match!

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flea market

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flea market

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12.50/set

THE LAST CHANCE!

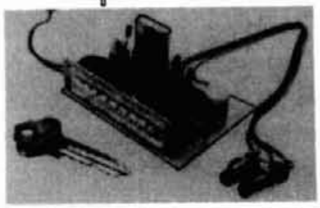
THAT'S RIGHT! THE LAST CHANCE TO BUY OUR SUPER POPULAR MK-05 MINI MOBILE SIX DIGIT CLOCK KIT at this super low price. The response has been great but supplies are starting to run low. So order NOW!

Features:

- Quartz crystal timebase
- Toroid & zener noise & overvoltage protection.
- Magnified .15", 6 digit LED readout
- Complete with presettable 24 hr. alarm.
- 9–14 VDC @ 40 to 50 ma.
- Readouts can be suppressed
- EASY, QUICK ASSEMBLY!
- All components required included (you supply the speaker).
- Top quality drilled & plated PC Boards
- Clock board: 2.6" x 2"
- Readout board: 2 3/8"x.75"

Small enough to mount in the instrument panel.

$12.95



OVERVOLTAGE PROTECTION KIT: $6.95
Provides cheap insurance for your expensive equipment. Trip voltage is adjustable from 3 to 30 volts. Overvoltage instantly fires a 25A SCR and shorts the output to protect equipment. Should be used on units that arefused. Directly compatible with the PS-12 and PS-14. All electronics supplied. Drilled & plated PC board. (Order OVP-1).

2N6028
Programmable unijuction super for oscillators, timers, time delay etc. **50c**

SPECIAL!
Limited Qty! LM567 Tone Decoders while they last! **99c**

2N6111 PNP Transistors
40Watt 3A TO-220 case
2/$1.00

ROCKER SWITCHES
DPDT Rocker Switches
5/$1.00

220mfd @25V Axial Cap **7/$1.00**

500mfd @35V Axial Cap **5/$1.00**

1100mfd @ 35 Axial Capacitor **4/$1.00** **Sprague**

741 Amps
8 pin mini dip
5/$1.00
1458 Dual 741's
8 pin mini dip
3/$1.00

Heatshrink Tubing
A very good asst. of 3/32", 1/8", 3/16" 1/4" & 7/16" 6" lengths 12 pcs.
75c

MICRO TRIMMER CAPS
Tiny 4-40 pfd trimmer used originally in watches!
3/$1.00

MJ900; MJ1000
Complimentary Darlington. PNP. NPN power transistor. 8 amps. pair for **$3.**

Multicolored 26 Conductor Ribbon Cable
No. 28 wire with a woven binder. Super Flexible!
10' roll – $2.95
50' roll – $9.95

Above item *FREE!* **with $15.00 purchase or more!**

MC1469R
500ma postive regulator. 3 to 30 volts. with complete specs and applications.
$1.25 - house no.

MC1351P FM IF
AMP. 14 pin IC. Complete FM sound subsytem, similar tc LM2111. house no.
5/$1.00

WESTON MICRO
PC mount trim pots. Single turn 1K. **3/$1.00**

2N3569 NPN
epoxy TO-5 case. VCEO=60; Hfe=300 800MW power
6/$1.00

No. 30 Wirewrap
Wire. Kynar jacket. 4 colors. 100 ft. of each color. **$4.00 (400')**

CA3011 Wideband IC **50c**

BULLET LUCKY NUMBER FOR MAR. IS: 159943 (Number worth $100.; numbers are in catalogs.)

FANTASTIC NEW SOUND SYNTHESIZER IC $3.95 each
Make any sound under the sun with this 28 pin marvel! Single IC contains: Noise generator, super low frequency OSC, VCO, one shot, mixer envelope control and amp. works from a single 5 to 9 VDC source. With 8 page manual.

MK-06 Clock/Calendar Auto Home Clock Kit

We designed this to be a SUPER CLOCK with ALL the features you want. Quality double sided PC boards make assembly easy. Mobile (12VDC) or home (12VAC)

- Large ½" LED Readout
- AM/PM Indication
- 28/30/31 day calendar displays automatically or manually
- Display can be dimmed or blanked
- Flashing Colon counts the seconds
- Intergal Timebase is adjustable
- Presettable Alarm with Snooze Feature.
- Noise and voltage protection circuits
- Single front mounted rotary switch selects all functions

21.50

Mini Grandfather Clock Kit – $39.95
Just in case you have spent the last six months in Siberia, we will tell you one more time that **Bullet** has the **ONLY** Completely **Electronic Grandfather Clock Kit** in the world that has all the below listed features. The biggest problem we have is to try and describe how unique and fascinating this clock really is! The **Swinging LED Pendulum and Matching Tick-tock sound** are available only on our clock. In addition the electronic chime notes each hour (ie: 3 times for 3 o'clock). Housed in the optional **Solid Hardwood Case**, the unit makes a beautiful addition to any room as well as a great gift.

- ½" 4 digit LED readout
- Adjustable tone & duration on chime
- Simulated swinging pendulum uses LEDS
- All CMOS construction
- All electronics, switches and transformer included
- Quality plated PC boards (2) 6.5" x 4.5"

BEAUTIFUL HARDWOOD CASE FOR MG-01: Case is cut, grooved and finished for clock. Includes ruby front filter. Quick, easy assembly requires only 4 screws (inc.)
$19.95

You've read the reviews on our MK-03 clock/Timer Kit. Wait till you see the new MK-03A 6 Digit Clock/Timer Kit:

- Separate 24 hour clock and 24 hour elapsed timer functions.
- Presettable alarms on both clock and timer
- Smaller more compact kit is 2¼" wide x 3 5/8" long x 1½"
- Super revised manual makes assembly easy
- Many options available by adding switches.
- Sold less case & switches.

$28.95 (Will fit standard 3 1/8" instrument case)

More Details? CHECK — OFF Page 158

flea market

SELL OR TRADE QST, CQ, 73 and HR. Many Complete Years QST. All 73 Magazines to 1975. SASE for list W5VRA Bob Willsey, Box 144, Martha, OK 73556. 405-266-3326.

CQ and QST 1950-1975 issues for sale. Send SASE if ordering Ham Radio, 73, or other CQ and QST issues. One dollar minimum order and all issues cost 25¢ each, including USA shipping. Send chronological list and full payment to W6LS, 2814 Empire, Burbank , California 91504.

SAVE $$$. Build your own: LINEAR AMPLIFIERS, 50-100 watt solid state. FREQUENCY COUNTER, 300 MHz, 7 digit, crystal accuracy, portable/mobile, memory! BASE ANTENNA, omnipolarized! Omnidirectional! VOX-COMPRESSOR AND MORE! Construction plans $3.00 each, 3 up/$2.50 each. Specify desired band. PANAXIS, Box 5516-AS3, Walnut Creek, CA 94596.

EZ does it best. Deals, that is, on Yaesu, ICOM, Drake, Swan, Cushcraft, Larsen, KLM, DenTron, VHF Engineering and Wilson. For new or used gear call, see or write WØEZ, Bob Smith Electronics, 12 So. 21st St., Fort Dodge, Iowa 50501. (515) 576-3886.

STOP LOOKING for a good deal on amateur radio equipment — you've found it here — at your amateur radio headquarters in the heart of the Midwest. This month's special: CDE HAM-III heavy-duty rotor for only $114.95, prepaid anywhere in the United States! We are also factory authorized dealers for Yaesu, Kenwood, Drake, Collins, Wilson, Ten-Tec, Atlas, ICOM, DenTron, KLM, Tempo, Regency, Hy-Gain, Mosley, CushCraft, Alpha, Swan, and many more.Write or call us today for our low quote and try our personal and friendly Hoosier service. HOOSIER ELECTRONICS, P. O. Box 2001, Terre Haute, Indiana 47802. (812) 238-1456.

TECH MANUALS for Govt. surplus gear — $6.50 each: SP-600JX, URM-25D, OS-8A/U, TS-173/UR. Thousands more available. Send 50¢ (coin) for 22-page list. W3IHD, 7218 Roanne Drive, Washington, DC 20021.

WHY WAIT UNTIL THE NEXT HAMFEST? Your call sign and handle custom printed on a quality T-shirt. Colors available: white, black, tan, gold, red, yellow, or blue. Sizes: Small-Medium-Large-Extra Large. Clubs quantity discounted. $6.00 — TEE-SHIRTERY, K9PM, P.O. Box 101-B, Medinah, Illinois 60157.

Coming Events

RARS SIXTH ANNUAL HAMFEST, April 23, Crabtree Valley Mall, US 70 West, Raleigh, NC. Big, big flea market — all under cover. Fantastic prizes. Ladies activities, meetings. Walk to nearby motels, restaurants, shopping. More info? Write RARS, Box 17124, Raleigh, NC 27609.

27TH DAYTON HAMVENTION at Hara Arena, April 28, 29, 30, 1978. More room this year! Technical forums, exhibits and huge flea market. Program brochure mailed March 6th to those registered within past three years. For accommodations or advance flyer, write Hamvention, P.O. Box 44, Dayton, OH 45401 or call 513-854-4126.

8TH ANNUAL NORTH FLORIDA SWAPFEST 11-12 March 1978, Ft. Walton Beach, FL. Details: John Lakin, W4MMV Secretary, Playground Amateur Radio Club, Box 873, Ft. Walton Beach, FL 32548.

MASSACHUSETTS: The Wellesley Amateur Radio Society is conducting its annual auction on Saturday, April 15, 1978, beginning at 11:00AM at the Wellesley High School Cafeteria on Rice Street, Wellesley, Massachusetts. Talk-in on – 96:36, 04-64 and 52. Doors open at 10:00AM. Contact Kevin P. Kelly, WA1YHV, 7 Lawnwood Place, Charlestown, Massachusetts 02129.

THE 4TH ANNUAL NORTHWESTERN PENNSYLVANIA HAMFEST, May 6th, Crawford County Fairgrounds, Meadville, PA. Gates open at 8:00 $2 prize ticket required for admission — $1 to display. Children FREE. Hourly door prizes, refreshments, commercial displays welcome. Indoors if rain. Talk-in 04/64 and 52. Details CARS, P.O. Box 653, Meadville, PA. 16335.

HAMFEST APRIL 1-2 by Mecklenburg Amateur Radio Society, Inc., W4BFB at new Civic Center in Charlotte, N.C. Plenty of parking, fun, and excitement. Come and enjoy with us!

MECKLENBURG AMATEUR RADIO SOCIETY — 1978 ARRL-sanctioned Hamfest, April 1st & 2nd, 1978, Charlotte Civic Center; plenty of parking available. Details from W4BFB, 2425 Park Road, Room 023, Charlotte, NC 28203.

More Details? CHECK—OFF Page 158

BREAD BOARD JUMPER WIRE KIT

Each kit contains 350 wires cut to 14 different lengths from 0.1" to 5.0". Each wire is stripped and the leads are bent 90° for easy insertion. Wire length is classified by color coding. All wire is solid tinned 22 gauge with PVC insulation. The wires come packed in a convenient plastic box.

JK1 . . . . $10.00 / kit

SOCKET JUMPERS

Mates with two rows of .025" sq. or dia. posts on patterns of .100" centers and shielded receptacles. Probe access holes in back. Choice of 6" or 18" length.

Part No.	No. of Contacts	Length	Price
924003-18R	26	18"	$ 5.38 ea.
924003-06R	26	6"	4.78 ea.
924005-18R	40	18"	8.27 ea.
924005-06R	40	6"	7.33 ea.
924006-18R	50	18"	10.31 ea.
924006-06R	50	6"	9.15 ea.

JUMPER HEADERS

Solder to PC boards for instant plug-in access via socket-connector jumpers. .025" sq. posts. Choice of straight or right angle.

Part No.	No. of Posts	Angle	Price
923863-R	26	straight	$1.28 ea.
923873-R	26	right angle	1.52 ea.
923865-R	40	straight	1.94 ea.
923875-R	40	right angle	2.30 ea.
923866-R	50	straight	2.36 ea.
923876-R	50	right angle	2.82 ea.

INTRA-CONNECTOR

Provides both straight and right angle functions. Mates with standard .10" x .10" dual row connectors (i.e. 3m, Ainsley, etc.) Permits quick testing of inaccessible lines.

Part No.: 922576-26 **No. of contacts:** 26 **Price** $6.90 ea.

INTRA-SWITCH

Permits instant line-by-line switching for diagnostic or QA testing. Switches actuated with pencil or probe tip. Mates with standard .10" x .10" dual-row connectors. Low profile design. Switch buttons recessed to eliminate accidental switching.

Part No.: IS-26 **No. of contacts:** 26 **Price** $13.80 ea.

CRYSTALS

THESE FREQUENCIES ONLY

Part #	Frequency	Case/Style	Price
CY1A	1.000 MHz	HC33/U	$5.95
CY2A	2.000 MHz	HC33/U	$5.95
CY2.01	2.010 MHz	HC33/U	$ .99
CY3A	4.000 MHz	HC18/U	$4.95
CY7A	5.000 MHz	HC18/U	$4.95
CY12A	10.000 MHz	HC18/U	$4.95
CY14A	14.31818 MHz	HC18U	$4.95
CY19A	18.000 MHz	HC18/U	$4.95
CY22A	20.000 MHz	HC18/U	$4.95
CY30B	32.000 MHz	HC18/U	$4.95

CONNECTORS

PRINTED CIRCUIT EDGE-CARD

156 Spacing-Tin-Double Read-Out

Bifurcated Contacts — Fits .054 to .070 P.C. Cards

15/30	PINS (Solder Eyelet)	$1.95
18/36	PINS (Solder Eyelet)	$2.49
22/44	PINS (Solder Eyelet)	$2.95
50/100	PINS (Wire Wrap)	$6.95
50/100A (.100 Spacing)	PINS (Wire Wrap)	$6.95

25 PIN-D SUBMINATURE (RS232)

DB25P	PLUG	$3.25
DB25S	SOCKET	$4.95

SWITCHES

¼" mounting holes

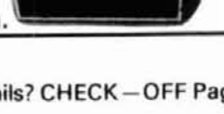
Type	Part No.	Pole	Function	1-9	10+
TOGGLE (sub-miniature)	JMT121	SPDT	on-off-on	$1.95	$1.43
	JMT123	SPDT	on-none-on	1.65	1.21
	JMT221	DPDT	on-off-on	2.55	1.87
	JMT223	DPDT	on-none-on	2.15	1.58
TOGGLE (Printed Circuit)	MPC121	SPDT	on-off-on	$2.05	$1.53
	MPC123	SPDT	on-none-on	1.75	1.31
	MPC221	DPDT	on-off-on	2.65	1.97
	MPC223	DPDT	on-none-on	2.25	1.68
PUSH BUTTON	PB123	SPDT	maintained	1.95	1.47
	PB126	SPDT	momentary	1.95	1.47
PUSH BUTTON Minature	MS102	DPST	momentary open	.35	.30
	MS103	SPST	momentary closed	.35	.30
DIPSWITCH SPST	206-4	8 pin dip	4 switch	1.75	1.65
	206-7	14 pin dip	7 switch	1.95	1.85
	206-8	16 pin dip	8 switch	2.25	2.15

1/16 VECTOR BOARD

	0.1 Hole Spacing Part No.	P-Pattern L	W	Price 1-9	10 up
PHENOLIC	64P44 062XXXP	4.50	6.50	1.72	1.54
	169P44 062XXXP	4.50	17.00	3.69	3.32
EPOXY GLASS	64P44 062WE	4.50	6.50	2.07	1.86
	84P44 062WE	4.50	8.50	2.56	2.31
	169P44 062WE	4.50	17.00	5.04	4.53
	169P84 062WE	8.50	17.00	9.23	8.26
EPOXY GLASS COPPER CLAD	169P44 062WEC1	4.50	17.00	6.80	6.12

INSTRUMENT/ CLOCK CASE

Injection molded unit. Complete with red bezel. 4½" x 4" x 1-9/16".



$3.95 ea.

MICROPROCESSOR COMPONENTS

8080A	CPU	$16.00	CDP1802	CPU	$19.95
8212	8 Bit Input/Output	4.95	MC6800	8 Bit MPU	24.95
8214	Priority Interrupt Control	15.95	MC6820	Periph. Interface Adapter	15.00
8216	Bi-Directional Bus Driver	6.95	MC6810AP1	128 x 8 Static RAM	6.00
8224	Clock Generator/Driver	9.95	MC6830L8	1024 x 8 Bit ROM	15.00
8228	System Controller Bus Driver	10.95	Z80	CPU	29.95

CPU'S

8080A	Super 8008	16.00
2650	8 BIT MPU	26.50
P8085	CPU	29.95

SR'S

2504	1024 Dynamic	$3.95
2518	Hex 32 BIT	7.00
2519	Hex 40 BIT	4.00
2522	Dual 132 Bit SSR	2.95
2524	512 Dynamic	.99
2525	1024 Dynamic	3.00
2527	Dual 256 BIT	3.95
2529	Dual 512 BIT	4.00
2532	Quad 80 BIT	3.95
2533	1024 Static	5.95
3341	Fifo	6.95
74LS670	16 x 4 Reg	3.95

UART'S

AY-5-1013	30K Baud	$5.95

ROM'S

2513(2140)	Char. Gen.-upper case	$9.95
2513(3021)	Char. Gen.-lower case	9.95
2516	Char. Gen.	10.95
MM5230	2048 BIT (512 x 4 or 256 x 8)	1.95

RAM'S

1101	256 x 1	Static	$1.49
2101	256 x 4	Static	5.95
2102	1024 x 1	Static	1.75
2107-5280	4096 x 1	Dynamic	4.95
2111	256 x 4	Static	6.95
7489	16 x 4	Static	2.49
8101	256 x 4	Static	5.95
8111	256 x 4	Static	6.95
8599	16 x 4	Static	3.49
21L02/91L02	1024 x 1	Static	2.25
74200	256 x 1	Static	6.95
93421	256 x 1	Static	2.95
MM5262	2K x 1	Dynamic	3 for 1.00
UPD414(2104)4K		Dynamic 16 Pin	5.95

PROMS

1702A	2048	Famos	$9.95
5203	2048	Famos	14.95
82S23	32 x 8	Open C	5.00
82S123	32 x 8	Tristate	5.00
74S287	1024	Static	7.95
3601	256 x 4	Fast	3.95
2708	8K	Eprom	19.95
2716	16K	Eprom	34.95
6301-1	1024	Tri-State Bipolar	3.49
6330-1	256	Open Collector Bipolar	2.95

SPECIAL REQUESTED ITEMS

FCM3817	$5.00	11C90	19.95	7205	19.95	9368	3.95		
AY-3-8500-1	9.95	4N33	3.95	ICM7045	24.95	LD110/111	25.00/set		
AY-5-9100	17.50	8T20	7.50	ICM7207	7.50	95H90	11.95		
AY-5-9200	14.95	8T97	2.00	ICM7208	22.00	MC3061P	3.50		
AY-5-9500	4.95	HD0165	7.95	ICM7209	7.50	MC4016 (74416)	7.50		
AY-5-2376	14.95	MCM6571	13.50	MK50240	17.50	MC1408L7	8.95		
8374	1.95	MCM6574	13.50	DS0026CH	3.75	MC1408L8	9.95		
82S115	25.00	MCM6575	13.50	TIL308	10.50	74C922	9.95		

CLOCK CHIPS

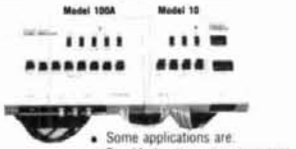
MM5309	$9.95
MM5311	4.95
MM5312	4.95
MM5314	4.95
MM5316	6.95
MM5318	9.95
MM5369	2.95
MM5841	9.95
CT7001	5.95

PARATRONICS

Featured on February's Front Cover of Popular Electronics

Logic Analyzer Kit Model 100A

$229.00/kit



- Analyzes any type of digital system
- Checks data rates in excess of 8 million words per second
- Trouble shoot TTL, CMOS, DTL, RTL, Schottky and MOS families
- Displays 16 logic states up to 8 digits wide
- See ones and zeros displayed on your CRT, octal or hexadecimal format
- Tests circuits under actual operating conditions
- Easy to assemble — comes with step-by-step construction manual which includes 80 pages on logic analyzer operation.

(Model 100A Manual - $4.95)

- Some applications are:
  - — Troubleshooting microprocessor address, instruction, and data flow
  - — Examine contents of ROMS
  - — Tracing operation of control logic
  - — Checking counter and shift register operation
  - — Monitoring I/O sequences
  - — Verifying proper system operations during testing

PARATRONICS TRIGGER EXPANDER - Model 10

Adds 16 additional bits. Provides digital delay and qualification of input clock and 24-bit trigger word. — Connects direct to Model 100A for integrated unit).

Model 10 Kit - $229.00
Baseplate — $9.95
Model 10 Manual — $4.95

B+K PRECISION

3½-Digit Portable DMM

- Overload Protected
- .3" high LED Display
- Battery or AC operation
- Auto Zeroing
- 1mv, 1Va, 0.1 ohm resolution
- Overange reading
- 10 meg input impendence
- DC Accuracy 1% typical

Ranges: DC Voltage = 0-1000V/ AC Voltage: 0-1000V
Freq. Response: 50-400 HZ
DC/AC Current: 0-100mA
Resistance: 0-10 meg ohm
Size: 6.4" x 4.4" x 2"

Model 2800 $99.95

Comes with test leads, operating manual and spare fuse

Accessories:

AC Adapter BC-28	$9.00
Rechargeable Batteries BP-26	20.00
Carrying Case LC-28	7.50

CSC

100 MHz 8-Digit Counter

- 20 Hz-100 MHz Range
- .6" LED Display
- Crystal controlled timebase
- Fully Automatic
- Portable — completely self-contained
- Size — 1.75" x 7.38" x 5.63"
- Four power souces, i.e. batteries, 110 or 220V with charger 12V with auto lighter adapter and external 7.2-10V power supply

MAX-100 $134.95

ACCESSORIES FOR MAX 100:

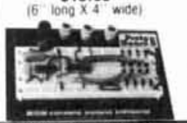
Mobile Charger Eliminator use power from car battery — **Model 100 — CLA $3.95**

Charger/Eliminator use 110 V AC — **Model 100 — CAI $9.95**

CONTINENTAL SPECIALTIES

PROTO BOARD 6

$15.95
(6" long X 4" wide)



Other CS Proto Boards

PB100 - 4.5" x 6"	$ 19.95
PB101 - 5.8" x 4.5"	29.95
PB102 - 7" x 4.5"	39.95
PB103 - 9" x 6"	59.95
PB104 - 9.5" x 8"	79.95
PB203 - 9.75 x 6½ x 2¾	80.00
PB203A - 9.75 x 6½ x 2¾ (includes power supply)	129.95

PROTO CLIPS

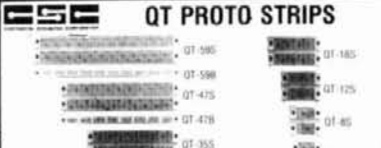
14 PIN	$4.50
16 PIN	4.75
24 PIN	8.50
40 PIN	13.75

DESIGN MATES

- DM1 - Circuit Designer $69.95
- DM2 - Function Generator $74.95
- DM3 - RC Bridge $74.95

LOGIC MONITOR for DTL, HTL, TTL or CMOS Devices **$84.95**

CSC QT PROTO STRIPS



QT type	# holes	price
QT-59S	590	12.50
QT-59B	bus strip	2.50
QT-47S	470	10.00
QT-47B	bus strip	2.25
QT-35S	350	8.50
QT-35B	bus strip	2.00
QT-18S	180	4.75
QT-12S	120	3.75
QT-8S	80	3.25
QT-7S	70	3.00

Experimentor 300	$ 9.95
Experimentor 600	$10.95

$5.00 Minimum Order — U.S. Funds Only
California Residents — Add 6% Sales Tax

Spec Sheets - 25¢ — Send 35¢ Stamp for 1978 Catalog
Dealer Information Available

NOW OPEN SATURDAYS

James ELECTRONICS

1978 CATALOG NOW AVAILABLE

1021-A HOWARD AVE., SAN CARLOS, CA. 94070
PHONE ORDERS WELCOME — (415) 592-8097
Advertised Prices Good Thru March

The Incredible "Pennywhistle 103"

$129.95 Kit Only

The Pennywhistle 103 is capable of recording data to and from audio tape without critical speed requirements for the recorder and it is able to communicate directly with another modem and terminal for telephone "hamming" and communications for the deaf. In addition, it is free of critical adjustments and is built with non-precision, readily available parts.

Data Transmission Method	Frequency-Shift Keying, full-duplex (half-duplex selectable)
Maximum Data Rate	300 Baud
Data Format	Asynchronous Serial (return to mark level required between each character)
Receive Channel Frequencies	2025 Hz for space; 2225 Hz for mark
Transmit Channel Frequencies	Switch selectable: Low (normal) = 1070 space, 1270 mark, High = 025 space, 2225 mark
Receive Sensitivity	−46 dbm accoustically coupled
Transmit Level	−15 dbm nominal. Adjustable from −6 dbm to −20 dbm
Receive Frequency Tolerance	Frequency reference automatically adjusts to allow for operation between 1800 Hz and 2400 Hz
Digital Data Interface	EIA RS-232C or 20 mA current loop (receiver is optoisolated and non-polar)
Power Requirements	120 VAC, single phase, 10 Watts
Physical	All components mount on a single 5" by 9" printed circuit board. All components included

Requires a VOM, Audio Oscillator, Frequency Counter and/or Oscilloscope to align.

NEW! BULB-ENERGY SAVER

Bulb lasts 3 or more times longer. Fits Standard Socket 6 watts to 200 watts

BULB-ENERGY SAVERS used for years by major industrial users — now available for home or office use. Bulb Savers can cut electrical bills by as much as 3%.

BULB-SAVERS lengthens light life by:

1. Acting as an electrical "shock absorber", turns the bulb on slowly, eliminating the "thermal shock". Bulb life increases 300 percent.
2. Banishes Current "Surges". Cushions line voltage surges when other loads cut power line.
3. Reduces Energy Consumption

BES-1 1-9 $1.50 ea. 10+ 1.25 ea.

DIGITAL STOPWATCH

- Bright 6 Digit LED Display
- Times to 59 minutes 59.59 seconds
- Crystal Controlled Time Base
- Three Stopwatches in One: Times Single Event — Split & Taylor
- Size 4.5" x 2.15" x .90" (4½ ounces)
- Uses 3 Penlite Cells

Kit — $39.95
Assembled — $49.95
Heavy Duty Carry Case $5.95

Stop Watch Chip Only (7205) $19.95

IMC 3½ DIGIT DPM KIT

- New Bipolar Unit
- Auto Zeroing
- .5" LED
- Auto Polarity
- Low Power
- Single IC Unit

Model KB500 DPM Kit $49.00
Model 311D-5C-5V Power Kit $17.50

JE700 CLOCK

12 or 24 Hour

The JE700 is a low cost digital clock, but is a very high quality unit. The unit features a simulated walnut case with dimensions of 6" x 2½" x 1". It utilizes a MAN72 high brightness readout, and the MM5314 clock chip.

115 VAC

KIT ONLY **$16.95**

HEXADECIMAL ENCODER 19-KEY PAD

- 1 - 0
- ABCDEF
- Shift Key
- 2 Optional Keys

$10.95 each

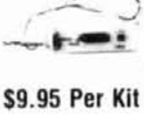
New 63 KEY KEYBOARD

$29.95 IN STOCK

This keyboard features 63 unencoded SPST keys, unattached to any kind of P.C.B. A very solid molded plastic 13" x 4" base suits most applications.

HD0165	Encoder Chip (encodes 16 Keys)	$7.95 ea.
AY-5-2376	Encoder Chip (encodes 88 Keys)	$14.95 ea.

JE803 PROBE



The Logic Probe is a unit which is for the most part indespensible in trouble shooting logic families TTL, DTL, RTL, CMOS. It derives the power it needs to operate directly off of the circuit under test drawing a scant 10 mA max. It uses a MAN1 readout to indicate any of the following states by these symbols: (HI) 1 (LOW) 0 (PULSE) P. The Probe can detect high frequency pulses to 45 MHz. It can't be used at MOS levels or circuit damage will result.

$9.95 Per Kit
printed circuit board

T²L 5V 1A Supply

This is a standard TTL power supply using the well known LM309K regulator IC to provide a solid 1 AMP of current at 5 volts. We try to make things easy for you by providing everything you need in one package, including the hardware for only

$9.95 Per Kit

More Details? CHECK—OFF Page 158

flea market

UNIVERSITY OF PITTSBURGH ARA (W3YI) second annual Hamfest, Sunday, April 2, 1978, from 10:00AM to 5:00PM in the Student Union Building across from the Cathedral of Learning. Check-ins on .69/.09 and .52/.52; for details SASE to the University of Pittsburgh Amateur Radio Association W3YI, Box 304, Schenley Hall, Pittsburgh, PA. 15260; or call Mark Bell WA3VJL at 412-931-6700, or Harry Bloomberg WA3TBL at 412-624-7768.

THE PIONEER VALLEY REPEATER ASSOCIATION (PVRA) Flea Market and Auction Sunday, April 9, 1978, 10:00AM — 5:00PM at the Newington High School, Willard St., Newington, Conn. Set-up time starts at 9:00AM. This is an event for everyone: Family activities, food available, free parking, Flea Market and Auction will run simultaneously in separate rooms. Auction will be held at regular posted intervals. A guided tour of the League's new headquarters building will start at 2:00PM. Those planning to take this tour, please drop Arnie, K1NFE, a note indicating how many will be in your party. Talk-in on 19/79, 04/64 and 52 Simplex. Admission $1.00, Tables $5.00, auction commission 10%. For additional information and guaranteed Flea Market space, contact: Arnie DePascal, K1NFE, 20 Iowa Pl., Bristol, Conn. 06010.

AMATEUR COMPUTING 78 microcomputer festival, July 22-23, Sheraton National Motor Hotel, Arlington, Virginia. Those interested in presenting a paper, participating in a panel discussion, displaying an amateur computer system or sponsoring a tutorial should submit a letter of intent along with a one-page abstract or outline by April 15 to John Wall Miller, Program Chairman, 6921 Pacific Lane, Annandale, VA 22003, telephone (703) 256-5702. Especially welcome will be topics concerning amateur radio applications of microcomputers. Authors will be provided with instructions for preparation of camera-ready papers which are due by June 1.

MIDLAND AMATEUR RADIO CLUB Swap Fest Saturday and Sunday, March 18 and 19th. County Exhibit Building on Highway 80 just east of Midland, Texas. Preregistration $3.50 per person, $4.00 at the door. Door prizes. Please send registration fees to: Midland Amateur Radio Club, Box 4401, Midland, Texas 79701.

COLUMBUS AMATEUR RADIO CLUB Annual Hamfest April 8-9, 1978, Columbus Municipal Auditorium fairgrounds. Spacious, air-conditioned exhibit area, prizes, flea market, Saturday night banquet, FCC exams, and a luncheon at the Hamfest site. Contact Eddie Kosobucki, K4JNL, 5525 Perry Ave., Columbus, GA 31904.

MIDWEST SPRING CONVENTION — Saturday, April 1, 1978, Holiday Inn-Holidome, Kearney, Nebraska. Flea Market, Auction, ARRL Forum, "Ladies Day", and Evening Banquet with John McKinney, WØAP, FCC Monitoring Division, guest speaker. Over $2,500.00 in door prizes including Wilson Mark II with touchtone and microwave oven. For reservations contact Chuck, WØCRK, Midway Amateur Radio Club, RR 3, Box 232B, Kearney, Nebraska 68847.

ARIZONA: Tucson Hamfest, April 28-30, 1978 Ramada Inn (just off North I-10) Technical session with demonstrations, Microprocessors, Solar Poser, QRP, Fast/Slow Scan, RTTY, Remote Base, etc. Prizes, Ladies Programs, Banquet, Exhibits, Swap Meet. Sponsored by Old Pueblo Radio Club. Write OPRC, 1361 E. Edlin, Tucson, AZ 85711.

17th ANNUAL MICHIGAN CROSSROADS HAMFEST Saturday 3/4/78 8:00 opening Marshall High School, Exit 110 from I-94 near I-69. Over $300 in door prizes. Check in 146.07/67 146.52 for lucky QSL card. Donation $1.50 advance, $2.00 at door. Table donation 50¢ each foot. Contact K8UCQ, Goodrich, 110 Perrett, Marshall, MI 49068. (616) 781-3554.

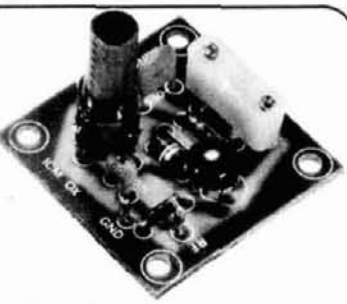
KNIGHT RAIDERS AUCTION/FLEA MARKET Saturday, March 18, at St. Joseph's Church, East Rutherford, N.J. — Doors open at 10:00AM — Free admission & parking. Tables: $6 at door, $5 in advance. Talk-in on 146.52. Call Bob Kovaleski 201-473-7113 eves. for futher info. Send reservations/checks to: Knight Raiders VHF Club, Inc., P.O. Box 1054, Passaic, N.J. 07055.

STERLING-ROCK FALLS AMATEUR RADIO Society Hamfest March 5, 1978, Sterling High School Field House, 1608 4th Avenue, Sterling, Illinois. Indoor flea market restricted to radio and electronic items only. Tables obtained at door, or bring your own. ($3.00 for ½ table, $6.00 for full table). Free parking available, including campers and trailers. Admission: $1.50 advance, $2.00 after Feb. 15th, 1978 or at the door. Write — Don Van Sant, WA9PBS, 1104 5th Avenue, Rock Falls, IL 61071. Make checks payable to Sterling-Rock Falls Amateur Radio Society. Talk in 146.94 simplex.

More Details? CHECK—OFF Page 158

for the experimenter!

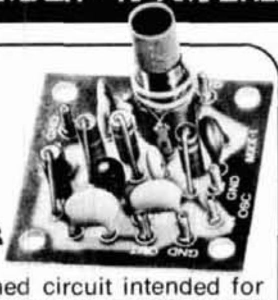
INTERNATIONAL CRYSTALS & KITS
OSCILLATORS • RF MIXER • RF AMPLIFIER • POWER AMPLIFIER



OX OSCILLATOR

Crystal controlled transistor type. 3 to 20 MHz, OX-Lo, Cat. No. 035100. 20 to 60 MHz, OX-Hi, Cat. No. 035101
Specify when ordering.

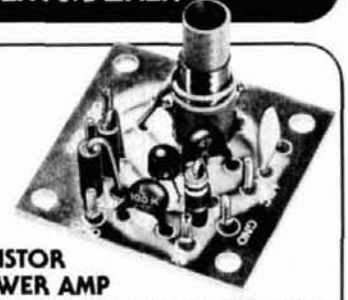
$4.95 ea.



MXX-1 TRANSISTOR RF MIXER

A single tuned circuit intended for signal conversion in the 30 to 170 MHz range. Harmonics of the OX or OF-1 oscillator are used for injection in the 60 to 179 MHz range. 3 to 20 MHz, Lo Kit, Cat. No. 035105. 20 to 170 MHz, Hi Kit, Cat. No. 035106
Specify when ordering.

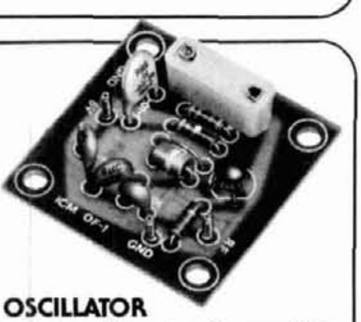
$5.50 ea.



PAX-1 TRANSISTOR RF POWER AMP

A single tuned output amplifier designed to follow the OX or OF-1 oscillator. Outputs up to 200 mw, depending on frequency and voltage. Amplifier can be amplitude modulated. 3 to 30 MHz, Cat. No. 035104
Specify when ordering.

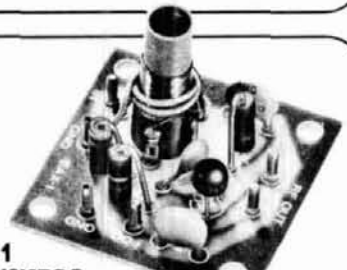
$5.75 ea.



OF-1 OSCILLATOR

Resistor/capacitor circuit provides osc over a range of freq with the desired crystal. 2 to 22 MHz, OF-1 LO, Cat. No. 035108. 18 to 60 MHz, OF-1 HI, Cat. No. 035109
Specify when ordering.

$4.25 ea.



SAX-1 TRANSISTOR RF AMP

A small signal amplifier to drive the MXX-1 Mixer. Single tuned input and link output. 3 to 20 MHz, Lo Kit, Cat. No. 035102. 20 to 170 MHz, Hi Kit, Cat. No. 035103.
Specify when ordering.

$5.50 ea.

BAX-1 BROADBAND AMP

General purpose amplifier which may be used as a tuned or untuned unit in RF and audio applications. 20 Hz to 150 MHz with 6 to 30 db gain. Cat No. 035107
Specify when ordering

$5.75 ea.

.02% Calibration Tolerance
EXPERIMENTER CRYSTALS
(HC 6/U Holder)

Cat. No.	Specifications	
031080	3 to 20 MHz — for use in OX OSC Lo *Specify when ordering*	$5.95 ea.
031081	20 to 60 MHz — For use in OX OSC Hi *Specify when ordering*	$5.95 ea.
031300	3 to 20 MHz — For use in OF-1L OSC *Specify when ordering*	$4.75 ea.
031310	20 to 60 MHz — For use in OF-1H OSC *Specify when ordering.*	$4.75 ea.

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ICM

International Crystal Mfg. Co., Inc.
10 North Lee
Oklahoma City, Oklahoma 73102

More Details? CHECK—OFF Page 158

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XF9-B	2.4 kHz	SSB RX/TX	$47.75
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XF9-E	12.0 kHz	NBFM	$51.40
XF9-M	0.5 kHz	CW (4 pole)	$35.95
XF9-NB	0.5 kHz	CW (8 pole)	$63.95

Export Inquiries Invited

Shipping $1.25 per filter

9.0 MHz CRYSTALS (Hc25/u)

XF9001	9000.0 kHz	Carrier	$4.15
XF901	8998.5 kHz	USB	$4.15
XF902	9001.5 kHz	LSB	$4.15
XF903	8999.0 kHz	BFO	$4.15
F-05	Hc25/u	Socket Chassis	.50
F-06	Hc25/u	Socket P.C. Board	.50

ALSO AVAILABLE FROM KVG
10.7 MHz CRYSTAL FILTERS AND XTAL DISCRIMINATORS
OSCILLATOR CRYSTALS 50 kHz TO 150 MHz
Write for Details

PRE-SELECTOR FILTERS

ELIMINATE IMD "BIRDIES" FROM YOUR RECEIVER. CLEAN UP YOUR TRANSMITTER OUTPUT.

432 MHz	PSf432	$39.95
1296 MHz	PSf1296	$39.95
1691 MHz	PSf1691	$52.45

Shipping $3.50

RECEIVE CONVERTERS

MODELS FOR ALL BANDS 50 MHz THRU 1296 MHz. LOW NOISE OPTIONS AT 432 MHz.

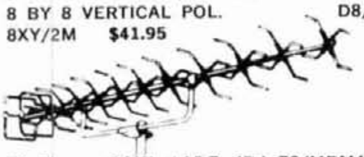
STANDARD I.F. 10M. IF OPTIONS 6M & 2M
POWER 12V D.C. Shipping $2.50

MMc144	N. F. 2.8 dB typ.	$49.95
MMc432	N. F. 3.8 dB typ.	$59.95
MMc1296	N. F. 8.5 dB typ.	$69.95

ANTENNAS (FOB CONCORD, VIA UPS)

144-148 MHz

8 OVER 8 J-SLOT +12.3 dBd	D8/2M	$41.95
8 BY 8 VERTICAL POL.	D8/2M-VERT.	$49.95
8XY/2M		$41.95



420-450 MHz MULTIBEAMS

48 EL.	GAIN +15.7 dBd	70/MBM48	$47.95
88 EL.	GAIN +18.5 dBd	70/MBM88	$73.50

UHF LOOP YAGIS

26 LOOPS GAIN +20 dBi

1250-1340 MHz	1296-LY	$56.95
1650-1750 MHz	1691-LY	$83.95

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TPL 1/4 KILOWATT LINEAR AMPLIFIER

TPL proudly presents the first true power 1/4KW SSB/AM, FM or CW solid state 2 meter linear amplifier

A remote control plug allows you to operate with the amplifier ON or OFF, or in SSB/AM, FM or CW from the dashboard.

The 2002 utilizes the latest state of the art engineering including microstrip circuitry and modular construction. The three final transistors combine to produce 250W when driven by 15W or more at 13.8VDC.

POWER INPUT:
5-20W Carrier FM or CW
20W PEP maximum SSB or AM

POWER OUTPUT:
200-250W carrier FM or CW
300W PEP SSB or AM

FREQUENCY RANGE:
144 to 148 MHz*
* will operate with slight degradation at 142-150 MHz.

HARMONIC ATTENTUATION:
All Harmonics Attenuated
60 dB or Greater

CURRENT DRAIN:
FM-40 Amps @ 250W
SSB-30 Amps @ 300W PEP

DUTY CYCLE:
FM 50% @ 150W 33% @ 250W
SSB 60% @ 150W 50% @ 250W

Model 2002 $479.00

can be ordered for repeater application
for additional information contact

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G.E. T.P.L. SPECIAL

FE53JA6, FRONT MOUNT, 150-170 MHz, 12 volt, 35 watts, fully solid state receiver, 4 tubes in transmitter, sold LESS accessories, not bench tested

(early model) $35.00

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More Details? CHECK—OFF Page 158

ALL-MODE VHF amplifiers

FOR BASE STATION & REPEATER USE

MODEL	INPUT	OUTPUT	PRICE
V70	10-20W	60-70W	$298
V71	1-5W	60-70W	$329
V130	25-40W	110-130W	$389
V131	1-5W	110-130W	$419
V135	5-10W	110-130W	$419
V180	10-15W	180-200W	$525
Universal 19" Rack Mount			$25

* All units: Harmonics exceed – 60 dB specification of FCC R&O 20777

- ☆ 143-149 MHz No Tuning
- ☆ AM - FM - CW - SSB
- ☆ Low Harmonics
- ☆ Heavy Duty
- ☆ No Power Supply Needed
- ☆ Illuminated Panel Meter
- ☆ + 13.5V/3 Amp Socket
- ☆ 115 or 230V AC
- ☆ 60dB Spurious
- ☆ Fully Protected Output
- ☆ Internal T/R Switch
- ☆ U.S. Manufactured
- ☆ 19" Rack Panel Option
- ☆ Size 8-1/2 x 13 x 7" H

Only two things are needed to put this power house on the air with your handy-talky or mobile transceiver: a two foot piece of coaxial cable and a 115 or 230 volt AC outlet. That's all. You do not need anything else. The mobile transceiver can be powered directly from the accessory socket located in the rear panel of the RFPL amplifier. It puts out + 13.5 volts at 3 amperes. This is sufficient for powering most 15 watt transceivers.

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- BOONTON 250A RX mtr bridge meas res. cap. ind. 500kHz-250MHz 625
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- HP120B 450kHz gen pur scope 215
- HP160B (USM105) 15mHz scope with reg horiz, dual trace vert plugs 375
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- HP170A (USM140) 30mHz scope with reg horiz, dual trace vert plugs 475
- HP175A 50mHz scope with reg horiz, dual trace vert plugs 565
- HP202B LF Osc .5Hz-50kHz 10v out 75
- HP205AG Lab audio gen .02-20kHz 195
- HP212A Pulse gen .06-5kHzPRR 65
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- HP616 Sig gen 1.8-4gHz FM-CW 365
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- HP803A VHF Ant bridge 50-500mHz 135
- HP2801A Prec dig thermometer -80 to 250 deg Cels with 1 osc. less sensors 1295
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- Tek190 Sig gen(const ampl) 50mHz 125
- Tek 545 (mil vers by Hickok-Lavoie) 33MHz gen pur scope less plugin 495
- Tek565 Dual beam 10mHz scope less plug-ins (3 series) 625
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TWO SIZES	W	D	H	PRICE
	14	8.3	3	$13.50*
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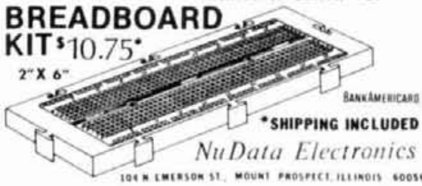
BLUE BASE SPECIFY WHITE OR BLACK TOP

BREADBOARD KIT $10.75*

2" X 6"



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*SHIPPING INCLUDED

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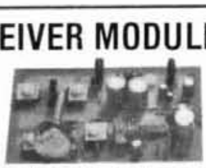
RECEIVER MODULE KIT



Use this module as the heart of your homebrew receiver or transceiver. Your direct conversion receiver can have excellent sensitivity and still reject strong signals. Module operates from 9 to 15 volts with low idle current drain. Up to 1 watt output drives your speaker or headphones. Use with your VFO or build one from our kit.

Receiver module kit	39.95 ppd
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specify 80 or 40 meters with order

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SPECSCAN-S Programmable Scanner

.. . The ONLY Digital Scanner made for the IC-22S. It adds a whole new dimension to 2M FM. If any other accessory can make your IC-22S as versatile as the SPECSCAN-S does, Buy It!

- **Scans the entire 146-147 MHz Band in 15 kHz steps, automatically, or manually**
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- **Can be used as a remote programming unit with the radio hidden under the seat, etc.**
- **Exclusive VARI-SCAN™ control allows full control of scan rate *in either direction*!**
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• Small enough to carry in your hip pocket, 2-3/16 x 3-1/4 x 4 inches • Matches low and high impedance by interchanging input and output • SO-239 coaxial connectors • 12 position tapped inductor. Stacked toroid cores • At 1.8 MHz tuner matches 25 to 200 ohms.

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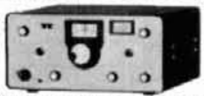
TEN-TEC
CENTURY 21



An ideal CW transceiver for the beginner or for a second rig. This is not a toy, but a quality, solid-state transceiver. 70 watts input; 80, 40, 20 meter coverage (15 and 10, too, with accessory crystals). Full break-in and built-in CW filters. With features like this and a low, low price, what are you waiting for?

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Model 43

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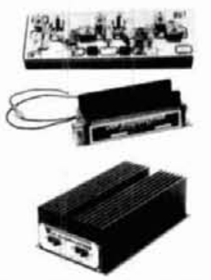

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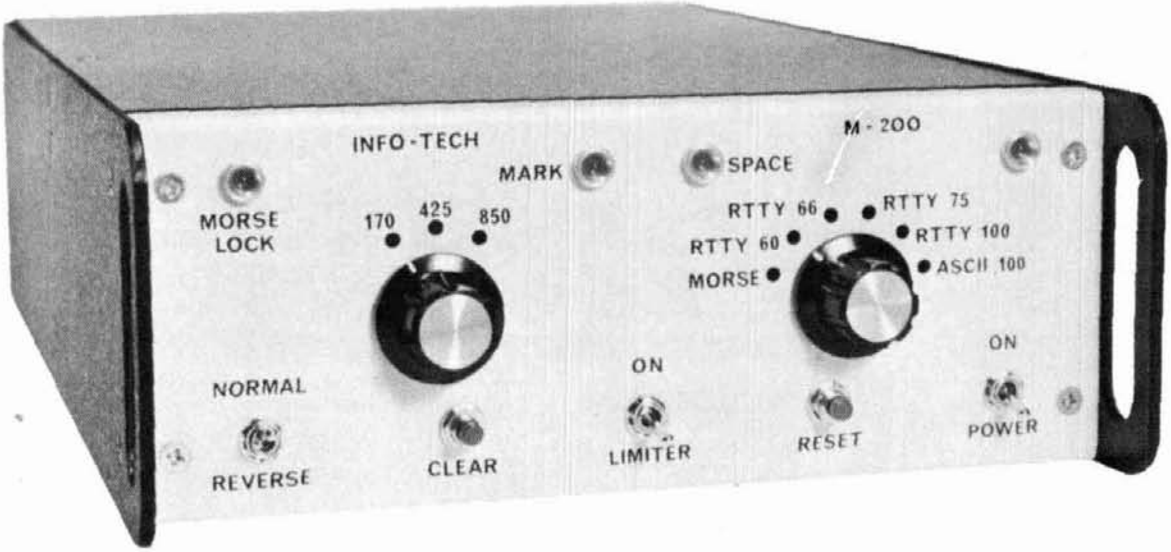

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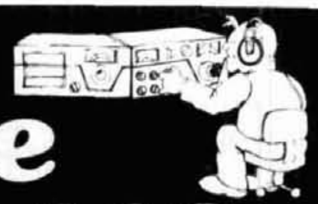

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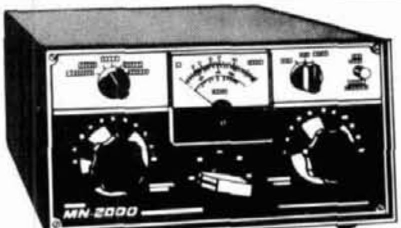

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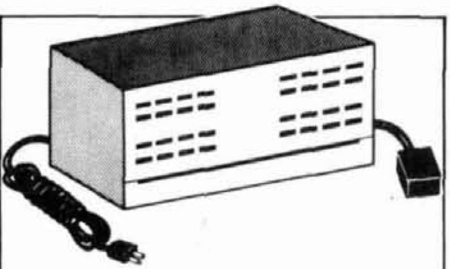

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