FM Repeater Circuits Manual

A 73 PUBLICATION

73 Inc., Peterborough NH 03458

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Ken Sessions, Jr.
K6MVH

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Introduction

We have tried, in this book, to provide you with every conceivable circuit that you might need for use with a repeater. Some of the material has been published elsewhere . . . in books, in magazine articles, in application notes of manufacturers . . . some has been lifted from commercial equipment designs . . . while other circuits come from the file of yet unpublished articles on hand at 73 Magazine.

The circuits were compiled by Ken Sessions K6MVH, one of the pioneers of two meter FM and former editor of the FM Journal and 73 Magazine. This book is intended for amateurs, experimenters and technicians interested in repeater operation and repeater circuits and who already have the Repeater Handbook by Sessions, published by Sams, which covers repeater systems basics.

Wayne Green W2NSD/1
Publisher

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PART I

The Basic FM Repeater

FM Repeaters...Where They Stand

The editor wishes to acknowledge the contributions of Robert Kelty (WB6DJT) whose article, *Examing FM Repeater Operation*, provided much of the information contained in this chapter.

Interest in amateur FM repeaters has grown in less than ten years to be a significant segment of VHF activity to which even diehard traditionalists are now turning. Hardly a major community exists around the country in which there is not some FM operation; and now, equipment suppliers are beginning to give serious attention to FM'ers. Repeaters grew up under regulations not orginally envisioning such operation, yet were recognized in general as remotely controlled stations. Traveling around the country, one readily sees that each operates in a slightly different manner, with groups tailoring their nets to their own requirements.

Until late 1968 the ARRL, amateurdom's "official voice," hardly knew what a repeater (or remote base) was and League publications carried little more than occasional mention. Meanwhile growth and interest has continued.

Operation of remotely controlled equipment for group benefit has a certain cost reality; a successful repeater calls for organized support, often in club form, to insure permanency. In California a relay council was organized as early as 1966 to administer matters such as frequency coordination, standards, and to do advance planning at a level that would benefit all repeaters. Throughout the country individual groups began interfacing or providing means to tie to each other and the ARRL board of directors saw that repeater people were serious about what they were doing and had the finances and organization to continue growth almost without limit. The publication of an FM repeater handbook[1] in 1969 gives adequate evidence that remote operation by VHF and UHF amateur operators from rf-advantageous permanent locations is indeed here to stay.

The importance of a large new segment of amateur interest was wisely recognized by ARRL directors almost belatedly and, seeing that the "Buffalo Petition" was a seriously considered necessity, they moved in 1969 to appoint a special committee to study repeater activity with an eye toward recommending FCC rules changes that would both correct inadequately written sections and enhance operation. In addition, the board voted for ARRL involvement at headquarters and for inclusion of a chapter on repeaters in the yearly handbook to stimulate interest. A separate League VHF handbook is still under consideration.

In 1970 the committee's final report and recommendations were released, but not until after the FCC had proposed restrictions that shook the amateur world.

The FCC's recommendations were:

1. No crossband operation. This would mean that site-to-site links would be illegal through any type of radio interconnection. It would wipe out many existing 6-to-2-meter systems and many UHF/VHF setups.
2. Only one transmitter to be energized per receiver, with no retransmission of repeater signals. This meant: no multioutput repeaters; no links; no cross-connected repeaters; and no cross-country systems.
3. Transmitters and receivers would be authorized on specific subbands only. This would not only eliminate a large percentage of the nation's most successful repeaters, but would seriously inhibit future growth of new repeaters.

There were a number of other restrictions and recommended improvements, some of which were highly desirable from the standpoint of repeater development, others of which were nearly catastrophic to progress. But the aggregate of the FCC's suggestions showed clearly that

[1] Radio Amateurs FM Repeater Handbook, Ken W. Sessions, Jr., Editors and Engineers, New Augusta, Indiana.

Washington did not understand nor did they approve of the fast-growing thing called repeater operation.

The amateurs reacted quickly and almost en masse to the FCC's call for comments on the proposed rules. Repeater owners all over the country drafted comments and filed them (complete with original and no less than fourteen copies). Repeater groups called special meetings, and large organizations published pamphlets. The news appeared as full-blown features in 73 Magazine, and Ham Radio Magazine conducted a special mailing.

The FCC office was deluged with responses by the deadline for filing comments, and before long the furor died. The consensus among amateurs was that the FCC had enough comments from interested individuals and groups to give the officials a real education in the whys and wherefors of repeaters.

Unofficially, during the quiet, the FCC has been studying the comments carefully, with the expectation of eventually becoming armed with enough facts to make a completely new and more realistic set of recommendations. Until that day comes, repeaters are still on the upswing; and the growth is not likely to ease significantly unless drastic restrictive measures are again recommended by the legislators in Washington.

Getting the License

Licensing of a remotely controlled station has never been a major hangup, the procedure being almost adequately described in section 97.43 of Regulations. The applicant conforms in part by checking certain blocks on his standard form 610B and by submission of block diagram and description of proposed means of controlling the installation to prevent operation not in compliance with regulations.

For the most part, systems run cleanly and the intent of regulations is not circumvented purposely to the detriment of the service. Still, repeater operation is more closely comparable to PSIT[2] radio services rather than to

[2] Public Safety, Industrial, Land Transportation, often called "commercial" land mobile.

"ham" type activity. Fixed, portable, and mobile operation on fixed frequencies naturally became abbreviated to the point that callups, logging, identifying, and control methods are somewhat different from that in which an operator hunts for a QSO with someone he may not know. Net operation always seems to be a cohesive that fosters good operating procedures because of the necessity of a good "net image" in the eyes of outsiders. The occasional maverick soon finds himself unwanted.

One of the rule sections being carefully considered by the FCC is that of licensing. The present "remotely controlled station" category has too many implied restrictions.

In essence, a remotely controlled station is not described as a repeater. It appears that this valuable and now very popular application of equipment was not considered in original rulemaking and that the authors only thought in terms of remote base operation by individuals. The Commission has nevertheless considered applications on individual merit, granting licenses where the intent and presentation was in order. Hundreds of such installations are now in operation on prime coverage sites serving many thousands of VHF and UHF enthusiasts.

It is difficult to imagine that there are any licensees who don't recognize that the letter of the rules under which they operate is not being complied with. Many have tried to minimize this enigma by licensing as many as 38 individual controls points,[3] licensing wives who are at home most of the day, placing control stations at places of business where monitoring can be accomplished, relying on an unlisted telephone which will deactivate the transmitter when dialed, or via a primary power control switch arrangement at a 24-hour answering service which can be turned off by an unlicensed operator on request. All are honest attempts to comply as closely as practical to the rules as written. All are clever interpretive applications.

Properly licensing and operating a station is even more involved when one considers not only the VHF mobile relay but interfaced UHF, interconnection to other stations,

[3]Grizzly Peak VHF Amateur Radio Club, Richmond, California (WB6AAE).

extension to multiple pickup receivers, or selectively keying transmitters. Configurations take many forms.

A solution suggested by the California Amateur Relay Council is to establish two additional categories of station under Section 97.3 (Amateur Unattended Station, and Amateur Repeater Station), then license on a per case basis as described under 97.3 (with certain modifications), submitting proposed configuration as at present. Licensing procedures would thus be preserved more realistically. Any new legislation will almost certainly employ this concept.

Staying Within the Existing Law

Maintaining control of unattended transmitters has been a handicap to licensees because of rules rather than equipment.

Currently popular methods of insuring that only authorized stations perform the control function (placing the remote transmitter on the air) include "dial up" for the period of use, number sequencing known only by authorized stations, and "per transmission" coding (pulse tone or continuous subaudible). Occasionally rumblings are heard concerning discrimination against outsiders or maintaining "closed" relays, but trustees are merely maintaining control while insuring that cost sharing is in effect. Purists new to VHF repeaters seldom see that the co-op station is a relatively new concept borrowed from "business radio" until they realize dollar investment in equipment, maintenance, and club costs.

As for suspending radiation in the event of deviation from terms of license, a means can be provided and described in license applications. Certainly a trustee is clever enough to meet this requirement in his own way when held responsible. Responsibility can be enforced should such need arise by virtue of the trustee's application, license grant, and terms of license.

Identification

Despite relaxation of identification requirements in the past two years, many amateurs, especially those who have operated below 30 MHz for long, tend to dual identify, give location, and identify again. At one time this may have been practical and of some value, but today – especially when operating through remote VHF equipment, which usually is devoid of marginal signals – there is little need to prolong the callsign ritual. Operators who feel insecure or wish to prove to listeners their superb range will continue to take opportunities to give mobile locations frequently but the practice seems merely for display. Ragchewing will still be popular but has taken a slightly different hue, and those operators who are still yearning for a wall certificate for staying on the air for extended periods have found that laudatory rewards are hard to come by on FM.

Identification of remotely controlled transmitters at intervals, in voice or electromechanically, is another area describable in shades of gray. A remote base can be identified without confusion, as can a repeater; however, when several people operate the station, who gives the assigned call? Or on a remote base with a UHF "up" and "down" link, is identification of the down link to be made? Or for that matter is it to be continuously monitored? Another level of interpretation is added when more than one station is operated simultaneously or interfaced. Many just tend to throw in a series callsigns and let it go at that, for better or worse.

The FCC does now require a three-minute identification, even though this is not spelled out in the rules. James Barr, Chief of the FCC branch governing ham radio says that the Commission has exercised its prerogative by imposing the three-minute requirement, and stipulates that in other cases the rules were relaxed to allow repeater operation.

Station Logging

Log requirements for unattended stations are not defined in FCC Rules, Part 97.403, except that one could contend that a control station should comply with each subsection and record time of each sequence of communications, signature of operators using the station, and location of stations transmitting. The FCC has unofficially dropped the requirement that all use stations sign the log of a repeater. But even with the relaxation, rules pose heavy burdens on repeater users.

It is close to universally agreed that recording time of retransmission capability; technical parameters such as power, frequency, and emission; date and time of changes of items to be logged; and signature of operator making adjustments combine to provide an adequate log. Redundancy of items that appear in individual logs should be eliminated. RM-1542 would have a "maintenance" log only, filled in during periods when the repeater site is visited for service or repair.

The ARRL study group has done a comprehensive job of evaluating the amateur repeater picture, drawing from its members as well as from discussions with repeater groups around the country. The best we can hope for is that the FCC carefully considers the 73 Magazine petition (RM-1542) and the ARRL recommendations before drafting its final release. By so doing, the FCC will be formally recognizing the importance of this dynamically growing segment of amateur activity.

National Standards for Repeater Operation

Much of the information provided in this chapter was adopted from the article *A Look at Amateur FM Standards*, by Robert Kelty, 73 Magazine, Feb. 1970.

The first decade of amateur FM repeater operation in the United States has been a period of growth and stabilization. Today because of the unpredicted popularity of repeaters and channelized operation on the VHF amateur bands, we are faced with such problems as:

- Frequencies for new systems
- Channelizing
- Logical frequency pairing
- Deviation and bandwidth
- Tone frequency standards
- Guard channels
- Command methods
- Selective calling standards

Many systems have grown in their present shapes because of availability of equipment, long-term usage of certain channels, patterning from successful schemes, or because it seemed the "right" thing to do at the time. In most cases, systems developed so that members were served as necessary. Later, groups began thinking nationally, resulting in the establishment of accepted "standards" for repeaters. But the trend to standardization came too late to be a universal answer to incompatibility between systems.

One area is narrowband, the other wide. So-called national frequencies are used with a variety of input frequencies, depending on area. UHF users find a wild variety of pairings and come to the conclusion that this band is haphazardly planned, with frequencies confidential.

But all is not so bleak. With a little forethought, users can still plan together, applying techniques known as spectrum engineering, frequency administration and conservation, or whatever name suits.

Frequencies of Operation

Today there are 63 standard FM channels on 2 meters. Little more than a year ago there were but 31. The 31 channels were spaced at 60 kHz intervals, starting from 146.04 and extending to 147.84 MHz. As more and more people came into FM, the requirement for additional frequencies became apparent – particularly for additional channels reasonably close in frequency to the most popular of the older channels. The more ancient pieces of surplus FM equipment were set up for wideband operation (30 kHz bandwidth), so there wasn't much anyone could do about increasing the concentration of channels. Not then.

But finally, more modern equipment began to find its way into the ham market – equipment designed to operate within a bandwidth of not much more than 10 kHz. And specially designed amateur FM gear made the scene. So, as amateurs began to acquire this later vintage gear, they also began to "split" their channel spacing. Now, rather than establishing wideband channels at 60 kHz intervals, the FM'ers have established narrowband channels at alternate 30 kHz frequencies, as shown in Table I.

Even though the early 31 channels are earmarked for wideband operation, it is a fact that many users have abandoned their insistence for that mode. Many – indeed most – of the active FM groups have settled on a compromise standard that consumes a bandwidth of around 20 kHz. This compromise allows use of the older wideband gear as well as the newer narrowband units within a single compatible communications system.

Not all the FM channels are active yet, of course, but the number is growing all the time. Those channels that lie between 146.31 and 147.0 are the most popular, with the lower channels being used chiefly for repeater inputs and the upper ones for repeater transmitting frequencies. Across

Table I. 2m FM Channel Allocations

NARROW	WIDE	NARROW	WIDE
146.01	146.04	146.97	147.0
146.07	146.10	147.03	147.06
146.13	146.16	147.09	147.12
146.19	146.22	147.15	147.18
146.25	146.28	147.21	147.24
146.31	146.34	147.27	147.30
146.37	146.40	147.33	147.36
146.43	146.46	147.39	147.42
146.49	146.52	147.45	147.48
146.55	146.58	147.51	147.54
146.61	146.64	147.57	147.60
146.67	146.70	147.63	147.66
146.73	146.76	147.69	147.72
146.79	146.82	147.75	147.78
146.85	146.88	147.81	147.84
146.91	146.94	147.87	

Note: Though there are no known wideband repeaters on channels designated as narrowband, it is not uncommon to operate narrowband repeaters on channels designated as wideband.

the country, 146.94 MHz is the single most popular channel, and was once referred to as the national "calling frequency." The prominence of repeaters has pretty well eliminated the need for a calling channel per se, because where a repeater is there is generally a monitor on a continuous basis. Still, 146.94 is often used for point-to-point communications as well as repeater operation. And in areas where there are no repeaters, you're still likely to find a great deal of activity on 146.94.

The second "big" channel is 146.76 MHz. Where areas were very active on 146.94 on a "simplex" basis before the advent of the 2 meter repeater, the repeater groups have had to select an alternate. (Most have found that it is foolhardy to install a repeater whose output frequency is the same as that used by all the active hams in the area.) "Seven-six," as it is called, was a logical second choice because of its popularity as a simplex channel over various parts of the U.S. Today, a number of the heavily congested metropolitan areas (other than California) use seven-six as the prime repeater output. Chicago, many cities in Ohio, Washington (state), and the lower eastern seaboard are examples of areas where seven-six reigns supreme as a repeater output.

The 450 band is a world apart. Only the coordinators and trustees seem to know what really is in service and all admit there is more than meets the eye up there where channel frequencies are semiprivate. In general, though, 50 kHz channelizing is the rule, and most control lies between 440 and 450 MHz. Efforts have been made to standardize, and many groups have adopted 5 MHz separation utilizing 440–444 outputs with 445–449 inputs. TV repeater experimenters have been a potential hazard, but recent concessions, after realization that FM'ers are serious, agreed to TV in the 435–440 portion of the spectrum.

The standards differ on 6 meters, too. In fact, with the exception of an article in 73 Magazine some time ago, this is the first work in which a set of standards for 6 meter operation has been published nationally. As Kelty noted, armchair planning has always been subject to criticism and rationalizing as to why it won't work; moreover, existing nets complicate matters by the requirement that their functions not be overlooked in the drafting of any master plan. As a result, plans have a tendency to fall apart as quick as they are formulated. Nontheless, no one can deny the need for at least a minimum set of standards for the benefit of those who intend to set up their first repeater in an all-new area. It is for this reason, and in the interest of national unity, that the plan submitted by the Southern California FM Association was selected as that plan to be published here. This appears in Table II, a complete tabulation of standards for FM operation on all amateur bands where FM is developing: 29–30 MHz, 52–54 MHz, 146–148 MHz, 220–225 MHz, and 440–450 MHz.

As stated, repeaters today are exceedingly popular. It is the exception where a fairly good-sized metropolis does not have at least one 2-meter repeater in operation. If you're thinking about buying an FM transceiver, You'd do well to check into the local situation. See if there's a repeater in your area (or two, or three) – then, when you order your rig, make sure you get enough crystals to make full use of

Table II. National Standards for FM Operations

2m FM Channels

146 010 S	146 640	147.270 S R
146.040	146 670 S	147.300 R
146.070 S	146.700	147.330 S
146 100	146.730 S	147.360
146 130 S	146.760	147.390 S
146.160	146.790 S	147.420
146.190 S	146.820 R	147.450 S
146.220	146.85 S R	147.480
146.250 S	146.880 R	147.510 S
146.280	146.910 S R	147.540
146.310 S	146.940 R	147.570 S
146.340	146.970 S R	147.600
146.370 S	147.000 R	147.630 S
146.400	147.030 S R	147.660
146.430 S	147.060 R	147.690 S
146.460	147.090 S R	147.720
146.490 S	147.120 R	147.750 S
146.520	147.150 S R	147.780
146.550 S	147.180 R	147.810 S
146.580	147.210 S R	147.840
146.610 S	147.240 R	147.870 S

10m FM Channels

29.020 S	29.360
29.040	29.380 S
29.060 S	29.400
29.080	29.420 S
29.100 S	29.440
29.120	29.460 S R
29.140 S	29.480 R
29.160	29.500 S R
29.180 S	29.520 R
29.200	
29.220 S	29.540 S R
29.240	29.560 R
29.260 S	29.580 S R
29.280	29.600 R
29.300 S	29.620 S R
29.320	29.640 R
29.340 S	29.660 S R
	29.680 R

450 MHz FM Channels

The 450 MHz FM spectrum is included in the ten megahertz from 440 to 450 MHz. Channels are established at 50 kHz increments throughout. Repeaters are separated by 5 MHz. The upper frequency should be the repeater input; the lower, the output.

6m FM Channels

52.525	53.020 S	53.520 R
52.540 S	53.040	53.540 S R
52.560	53.060 S	53.560 R
52.580 S	53.080	53.580 S R
52.600	53.100 S	53.600 R
52.620 S	53.120	53.620 S R
52.640	53.140 S	53.640 R
52.660 S	53.160	53.660 S R
52.680	53.180 S	53.680 R
52.700 S	53.200	53.700 S R
52.720	53.220 S	53.720 R
52.740 S	53.240	53.740 S R
52.760	53.260 S	53.760
52.780 S	53.280	53.780 S
52.800	53.300 S	53.800
52.820 S	53.320 S	53.820 S
52.840	53.340 S	53.840
52.860 S	53.630 R	53.860 S
52.880	53.380 S R	53.880
52.900 S	53.380 S R	53.900 S
52.920	53.420 S R	53.920
52.940 S	53.440 R	53.940 S
52.960	53.460 S R	53.960
52.980 S	53.480 R	53.980 S
52.000	53.500 S R	

220 MHz FM Channels

220.020	221.020	222.020	223.020	224.020
220.060	221.060	222.060	223.060	224.060
220.100	221.100	222.100	223.100	224.100
220.140	221.140	222.140	223.140	224.140
220.180	221.180	222.180	223.180	224.180
220.220	221.220	222.220	223.220	224.220
220.260	221.260	222.260	223.260	224.260
220.300	221.300	222.300	223.300	224.300
220.340	221.340	222.340	223.240	224.240
220.380	221.380	222.380	223.380	224.380
220.420	221.420	222.420	223.420	224.420
220.460	221.460	222.460	223.460	224.460
220.500	221.500	222.500	223.500	224.500
220.540	221.540	222.540	223.540	224.540
220.580	221.580	222.580	223.580	224.580
220.620	221.620	222.620	223.620	224.620
220.660	221.660	222.660	223.660	224.660
220.800	221.800	222.800	223.800	224.800
220.740	221.740	222.740	223.740	224.740
220.780	221.780	222.780	223.780	224.780
220.820	221.820	222.820	223.820	224.820
220.860	221.860	222.860	223.860	224.860
220.900	221.900	222.900	223.900	224.900
220.940	221.940	222.940	223.940	224.940
220.980	221.980	222.980	223.980	224.980

Standard amateur deviation: ±15 kHz. 36F3 emission is recommended on all channels except those channels marked "S". S channel emission is 16F3. Channels marked "R" are RACES frequencies as promulgated by the Office of Civil and Defense Mobilization.

all the repeaters within your range. (Be sure to check with the local groups before you do too much operating, though. Some repeaters are actually set up as clubs, and you must become a dues-paying member before you'll be welcomed on a regular basis.)

Deviation/Modulation

One word you'll hear a lot when you're operating FM is "deviation." This is roughly comparable with "modulation level" of AM; deviation, however, is a function of frequency variation (and, of course, bandwidth) rather than audio amplitude, even though they may seem the same from the point of view of the listener.

In general, the standard deviation level for amateurs is on the order of ±10 kHz (the compromise mentioned earlier between wideband and narrowband). If your transmitter is set up for anything much greater than this figure, your signal may be so broad that other stations cannot even detect your signal at all. Overdeviation looks like noise to a good receiver, and its squelch will lock you out. On the other hand, if your deviation level is set too low, your audio may be deficient in terms of apparent amplitude. And if your signal is weak into someone's receiver, his noise may be a lot louder than you are. At 10 kHz your signal should work out fairly well into a wideband receiver, and you should have no trouble getting into narrowband units if you don't hit the mike too hard. In commercial service, special deviation meters are used to make sure all the units within a communiciations system are uniform. But with amateur repeaters, things aren't that critical; you can ordinarily set it satisfactorily by adjusting the level while getting reports from one of the other fellows using the system.

Tones

You'll hear quite a lot about "tones" on FM (if you haven't been hearing it already). Why would amateurs be concerned about something so unlikely? In a word, the answer is "control." Repeaters often require simple switching sequences – perhaps to turn them on or off under certain circumstances, to change antennas, or to shift to an alternate frequency. As you probably already know, though, there is usually nobody manning the repeater physically; so the control switching must be accomplished via radio signals. If you could send ordinary dc signals over the air, the switching functions could be simplified, but of course that is quite impossible. The only practicable approach is to convert the control voltage to a type of signal that *can* be transmitted via rf. Here, tone signals qualify nicely.

An audio tone of a specific frequency can be detected from a large array of audio signals. If such a detector circuit is set up so as to key a relay whenever that particular tone signal is present, the remote switching problems are solved.

In commercial two-way service, repeaters and remote stations have been using tone signals for years to control functions, and the result has been the standardization of specific tone frequencies. These, like FM channels themselves, appear at fixed intervals across the audio spectrum. Figure 1-1 shows the allocation of control frequencies currently in use by amateurs.

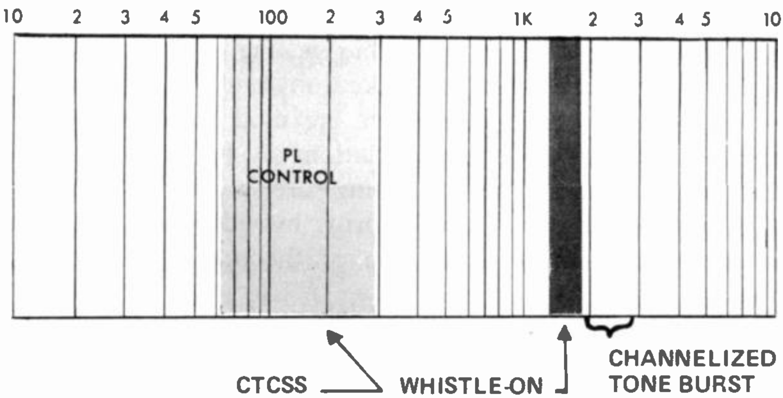


Fig. 1-1. Audio spectrum showing tone allocations.

Notice that a frequency "block" at the lower end of the usable audio spectrum is set aside for control – this is in addition to the "channelized" control frequencies on the upper end.

Another block appears in the 1.5–1.65 kHz range. This portion of the spectrum is typically used for control of uncritical functions. This particular block is used because of the simplicity by which a control signal can be initiated. For example, when you pucker up and whistle, the signal you generate will fall in this "uncritical" block. And here is the spectrum used by those so-called "whistle-on" repeaters.

The control frequencies above the whistle-on block are set up at intervals of precisely 150 Hz. Officially, the "channels" are 1650, 1800, 1950, 2100, 2250, 2400, 2550, 2700, and 2850. These signal frequencies are far enough above the ordinary "voice" range that it is difficult to simulate the signals by whistling. So amateurs use simple electronic tone generators.

Many repeaters require the presence of a short "tone burst" as a prerequiste to causing the repeater to operate. The concept, called "tone burst entry," is very common where several repeaters overlap in coverage. Suppose, for instance, that you live in an area served by several repeaters, all of which use 146.34 MHz as their input frequency. It would be annoying for other users if you triggered all repeaters each time you transmitted. To obviate such a possibility, repeater groups will select certain tone frequencies for control. Thus, you might transmit a short tone of, say, 1950 Hz to trigger one of the repeaters, and another, of perhaps 2100 Hz for another. The whole business usually works out pretty well.

The block of low frequencies is used for the most critical applications, and normally where *continuous* control signals are required (as opposed to *tone bursts*). It is the rare repeater that uses these low frequencies (called *continuous tone carrier squelch system*) for control, however; so there is no need to go into any great detail about the applications and tone generation techniques.

Guard Channels

Faced with the problem of where to establish a common meeting ground for members of various groups, each operating on its own discrete frequencies, then idea of guard channels has become an acceptable solution and has proved successful where implemented. 52.525 and 146.94 are the most popular choices. By guarding these channels or using a receiver scanner which samples more than one channel, a surprising flexibility is possible. By guarding one's regularly used calling and working frequency, we can provide ourselves with even better systems, both at home and while traveling.

Understanding the Carrier-Operated Repeater

The complicated repeater is not really so complex after all. . .it's only a matter of understanding the simple operations that are taking place when somebody transmits on the input frequency.

In spite of what the local repeater talent would have you believe, the big machine up there on the hill – or on the top floor of the city's biggest building – is really a pretty simple arrangement of gear. That is not to say that it hasn't been sophisticated, with the incorporation of perhaps a remotely controlled telephone, some sexy control devices, or maybe an automatic input-frequency switching and selection system. But strip off all the chrome and there's not much dazzle left. A repeater is something anyone can build – and without as much effort as you might think.

The most basic repeater is carrier-operated; when the receiver portion senses the presence of a signal, the transmitter stage comes on. And whatever happens to be on the incoming carrier is retransmitted on a frequency not too far distant from the receiver itself – usually just far enough so that the transmitter's operation does not cause overloading of the still-operating receiver. And when the incoming carrier drops out, the transmitter shuts off. A simple arrangement – but how is it done?

Understandably, a repeater is a bigger mystery to the devoted AM operator. His thinking is limited generally to the workings of the typical AM receiver, and he finds it difficult to see how a receiver can be easily and cheaply made to operate next to a transmitter on the same band without "blocking." He may also have trouble understanding how the transmitter of a repeater can be made to come on without fail when a signal appears, yet *not* come on when noise and garbage are present on the repeater input channel. Which brings us to the reasons why VHF repeaters are virtually always FM.

It is not within the scope of this book to get involved with AM versus FM in terms of operational performance. There are many convincing arguments for FM on that basis alone, but they are, after all, just that: arguments. The prime reasons that repeaters are made to operate in the FM mode are that FM receivers are inherently less susceptible to the normal interferences of the amateur bands and FM receivers are factory-equipped with electronic switches capable of reacting to the presence or absence of legitimate signals.

As it happens, the typical interference noises that occur on the VHF bands are amplitude-modulated. Fortunately, FM receivers are, by their nature of operation, deaf to AM signal components. FM receivers have built-in limiters that reject amplitude-modulated signals. When the AM signal is riding on a healthy carrier, the FM receiver filters out the audio completely and permits only the rf to come through. If the AM signal is weak and noisy to start with, the FM's electronic switch doesn't even believe it's a signal at all, so nothing gets through to the speaker – not even the noise.

The electronic switch is a squelch. To the wives of hams, it is perhaps the greatest invention since earplugs. The squelch on an FM receiver keeps the audio amplifier (and, thus, the speaker) shut off unless a definite signal is present. The big difference between the squelch on an FM receiver and one on an AM receiver is that the FM squelch can't be fooled by noise.

The fact that FM squelches are trick-proof makes them particularly adaptable to repeater applications. If the squelch is used to trigger the transmitter when a signal is sensed, and to turn the transmitter off when the signal goes away, the mysteries of carrier operation begin to disappear. An AM repeater operated by the squelch typically found in AM receivers would keep the repeater transmitter keyed every time the noise level at the repeater site rose a bit. And if the repeater were adjusted to compensate for the noise, half the signals on the input frequency wouldn't be capable of actuating the repeater.

This can be explained on the basis of another phenomenon: For more reasons than those already cited, fairly weak FM signals are virtually noise-free while weak AM signals must compete with the noise. (This statement is made with the assumption that the listener is receiving on a receiver designed for the mode. Many would-be FM'ers never quite made it over from AM to FM after comparing AM signals with those of FM and deciding that, watt for watt, AM was better. But they made their judgments based on comparisons made with their AM receivers! All the noise that was there – but unhearable by the FM receivers – probably all but wiped out those "band-wasting" FM stations.)

Where repeaters are concerned, noise can work to the advantage of the FM'er, even though to the detriment of the AM'er. The reason: FM squelches are noise-operated; the higher the noise level on the band, the less apt the repeater will be to get keyed on. A signal, regardless of its strength, has the peculiar characteristic of quieting the noise. And with carrier operation, when the noise goes, the repeater transmitter comes on. Since noise is always present in the absence of a signal, the transmitter of a carrier-

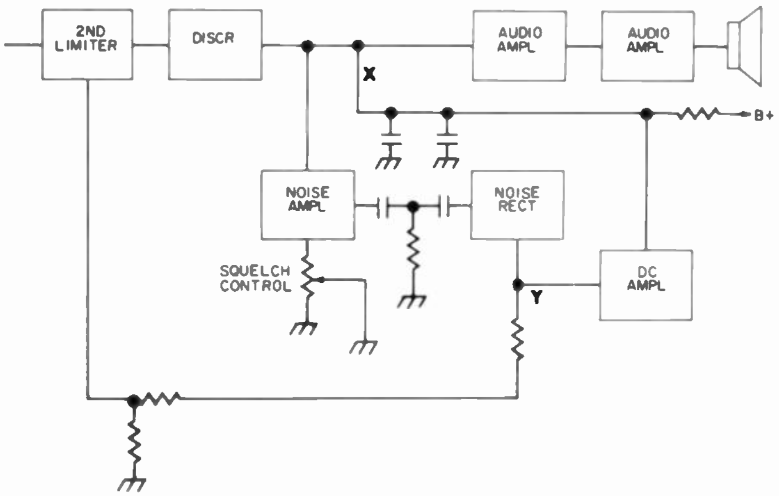


Fig. 1-2. Combination schematic and block diagram showing squelch arrangement in typical FM receiver.

operated repeater cannot be keyed unless a signal is present.

A typical FM squelch circuit is actually a very simple device. Its formidable appearance on a receiver schematic is attributable to the Rube Goldberg manner in which it operates. Consider the block diagram of Fig. 1-2, where the last four stages following the low i-f of a General Electric Progress Line FM receiver are pictured across the top. The audio-carrying low i-f signal is fed from the second limiter to the discriminator, which separates the af from the rf, and feeds the audio to the amplifiers and speaker. By electronically turning the audio amplifier on and off, the signal reaching the speaker can be controlled. And this is precisely the function of those elements shown below the four top blocks.

The object of the network of components in the squelch train is to provide a negative voltage at point X when no signal is present. This negative voltage keeps the audio amplifier cut off so the speaker is silenced. The B+ applied to point X through the series resistor keeps the signal biased positively unless the dc amplifier is conducting. And the dc amplifier will not conduct unless there is no signal present. Or, stated more simply, the dc amplifier does not conduct when a signal is sensed by the receiver.

The audio signal from the discriminator, as previously mentioned, always bears noise unless a signal is on hand to quiet the audio line. This noise is amplified to the extent required for effective squelch action (adjusted by the squelch control), and rectified. The positive output voltage is fed to the dc amplifier along with a negative signal from the second limiter.

The second limiter grid supplies the negative signal through critical balancing resistors. The signal here is relatively stable because the limiter operates in a state of near saturation even when no carrier is present. Since the noise rectifier supplies a positive signal, the dc amplifier sees the balanced sum of the two supply points. An imbalance exists when the noise rectifier output increases to the point that causes the dc amplifier to conduct.

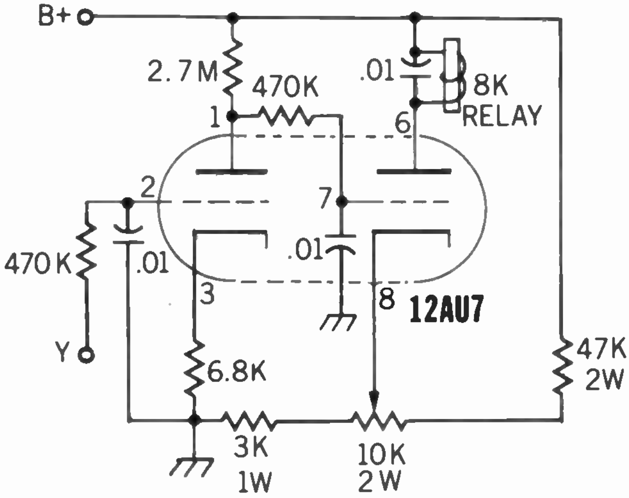


Fig. 1-3. Carrier operated relay.

The capacitors along the X line are included in most receivers to hold the squelch open for a short time after the carrier drops out. This prevents rapid on-off fluttering of the repeater transmitter when a weak station is operating on the input frequency. The squelch "tail" can be lengthened by raising the value of these capacitors (thus increasing the charge time), and almost eliminated completely by removing them altogether.

Getting a transmitter to turn on and off in response to an incoming signal is simply a matter of applying the squelch principle to an additional stage. The carrier-operated relay schematic shown in Fig. 1-3 is a modified version of the type GE used on its nontransistorized commercial repeaters, and it is perhaps the most popular single circuit in use by amateurs today.

Undoubtedly, a number of prospective repeater builders will look at the circuit and be appalled by the fact that it is not solid-state. Well, there's a good reason. Solid-state carrier-operated relays are available and easy enough to build, but the amateur world isn't quite ready for them yet. Solid-state devices require low-voltage dc; most repeaters are tube-type. And it is a lot simpler to build a tube-type relay circuit for a tube-type receiver (with its already available power supply) than it is to build a solid-state relay and be saddled with the task of building up a special power supply to drive it.

The signal input to the 12AU7 grid of Fig. 1-3 is provided from the point marked Y on Fig. 1-2. The mechanical relay in the plate circuit of the second half of the tube is a current-sensitive relay with a coil resistance of 8–10 kΩ. The push-to-talk circuit of the repeater is keyed indirectly by the contacts of this relay.

The 10 kΩ pot in the cathode circuit should be rated for 2W and should be a wirewound type. This pot sets the threshold of the audio squelch.

Just one last word or two about carrier-operated repeaters: The relay shown in Fig. 1-3 should never be used to perform direct switching of push-to-talk circuits. The contacts of these sensitive relays are generally quite delicate and are thus easily fouled. Regardless of a repeater's inherent simplicity, the plate relay should always be made to drive a "slave," which should be a heavy-duty type with as many contacts, both normally open and normally closed, as possible.

In one way or another, a carrier-operated relay figures into just about every automatic operation of a repeater, for active as well as passive applications. The normally closed position allows disconnection of functions during transmit, removal of voltages during control selection, and operation of timers for automatic shutdown when the repeater is unused for predetermined periods. The normally open position allows audio and push-to-talk switching, timer keying for automatic shutdown on excessively long transmissions, and initiation of functions that must occur during the presence of a carrier. To be universally applicable to any possible control function, the carrier-operated relay slave should have several sets of unused contacts in addition to contacts which provide these basic logic signals:

- Ground when signal is present on repeater input and only then.
- Control voltage available when signal is present and only then.
- Ground when no signal is present and only then.
- Control voltage available when no signal is present and only then.

As you look through the circuits in this book, you'll find a number of uses for all these functions.

Tone Decoders for FM Repeaters

An interesting and unforeseen problem developed as a result of the tremendous growth in popularity of FM repeaters: When two or more repeaters operate with overlapping coverage on the same input or output frequency, mobile operators occasionally find themselves triggering more than one repeater. The mobile operator who does so may thus cause interference by his unintentional keying of the repeater in a neighboring community.

As a rule, shifting the frequencies of one of the repeaters is no solution, because both relay stations will want to be on the nationally accepted standard (146.34 MHz input, 146.94 MHz output). Such standardization is a boon to the mobileer who has a limited supply of crystals and must travel across the country or from one area to another once in a while.

But there are workable solutions. More and more, repeaters in highly congested areas are going to a "tone-burst entry" approach or a "whistle-on" system of keying. With a whistle-on system, the control circuits are all at the repeater site. The repeater is never operative unless specifically activated by one of the users.

A broad whistle on the input frequency energizes a decoder at the repeater site, which in turn activates the automatic signal-relaying system. Typically, the repeater stays on, once activated, retransmitting the signals of all carriers on the input. When the traffic dies down a bit – that is, after a short period of no signals – the repeater shuts down again, and cannot be used unless someone deliberately calls for it by whistling on the input.

When multiple-repeater conditions are more severe, the tone-burst keying system is the more satisfactory solution. Here, a specific tone frequency – usually 1700 to 2000 Hz – must be present briefly at the outset of every transmission before a signal can be automatically relayed. In practice, all who intend to use the repeater will install simple audio oscillators in their transmitters, connecting them in such a way that the tone comes on briefly each time the transmitter is keyed. The tone, decoded at the receiver of the relay station, is used to activate the repeater – but only for the duration of a single carrier.

Since this handbook is organized into logical sections, circuits for tone generators (encoders) are included in *Part III, The User Mobile*, while the decoding elements – to be installed at the repeater – are included in this chapter (*Part I, The Basic FM Repeater*). The decoders described herein are fully compatible with all encoders described in Part III, and need only be adjusted slightly for frequency variations.

Basic Considerations

The most critical element of any tone-access system is the decoder. When some problem exists in the encoder, or when the encoder frequency shifts a bit, or when the encoding level goes up too high or down too low, the control operator can solve the problem with a few local adjustments. But when the decoder starts acting up, the impact can be a great deal more severe: In the first place, the decoder is installed at the repeater site, which is, more often than not, situated atop some remote mountain peak – miles (and sometimes hours) from physical accessibility. Second, while an encoder malfunction affects one individual's operation, a decoder problem affects the operation of every user of the repeater. Thus, care in building and sound conservatism in design are paramount considerations in deploying a tone control scheme.

The K6ASK Decoder

I have had occasion to use many decoders during my days of remote control and repeater operation – some homebrew, some commercial. (Virtually every aspect of remote control involves the installation of a tone decoder somewhere along the way. And I can truthfully say that I have never come across a circuit that offered performance superiority over the one shown in Fig. 1-4.

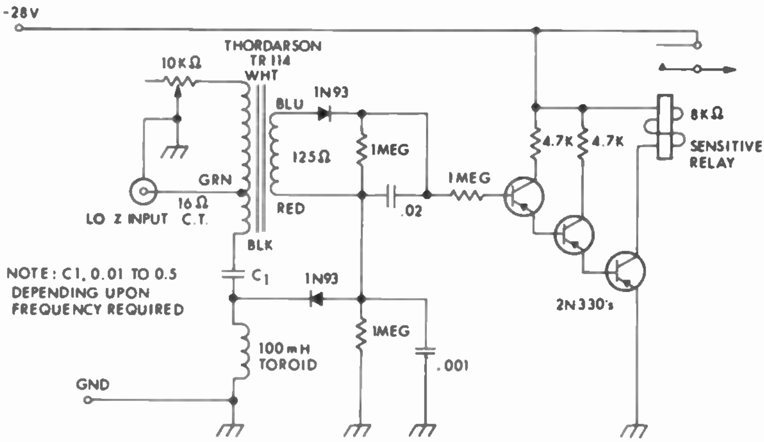


Fig. 1-4. K6ASK single-tone decoder circuit.

I hasten to add that I can lay no claims as to design, for the circuit illustrated was conceived, built, debugged, and perfected by Bob Mueller (K6ASK), of Alhambra, California. Nor is this the first time the circuit has been published. I have incorporated copies of the circuit in past articles dealing with remote control of telephones, function selection in repeaters, and coded signaling for selective-call applications. It simply is a good sound circuit and can be applied wherever there exists a need to perform a switching function in one place by radio command from another place.

Decoder Requirements. The response curve of the decoder must be selective enough to preclude the possibility of off-frequency signals triggering the system, yet broad enough to allow decoding under a variety of input signal conditions. Ideally, a control should be available so that the threshold sensitivity of the decoder could be adjusted.

Adjustment of the input sensitivity accomplishes the effect of narrowing or broadening the spectral response of the device. At the least sensitive setting, the decoder has an input bandwidth of about 50 Hz. As the series resistance to the input of the transformer is decreased, the bandwidth widens. In the most sensitive position, the decoder will respond to a bandwidth that includes random noises and high-pitched voices. Thus, the decoder should fulfill the requirements of the whistle-on crowd as well as the more critical needs of the tone-burst fans. (Both these concepts are described fully in the next chapter, where complete control circuits for typical repeaters are presented.)

The frequency of the decoder, using the values shown in the schematic, is 2300 Hz. This frequency can be shifted by the expedient of changing the value of capacitor C1. The 2300 Hz is fully appropriate for tone-burst applications, where voice tripping is to be avoided and whistle-on use discouraged. (The frequency is high enough to make whistling a difficult method of access.) It should be re-emphasized, however, that whistle-on use of this decoder is possible – using the values shown – by simple adjustment of the sensitivity control of the input transformer.

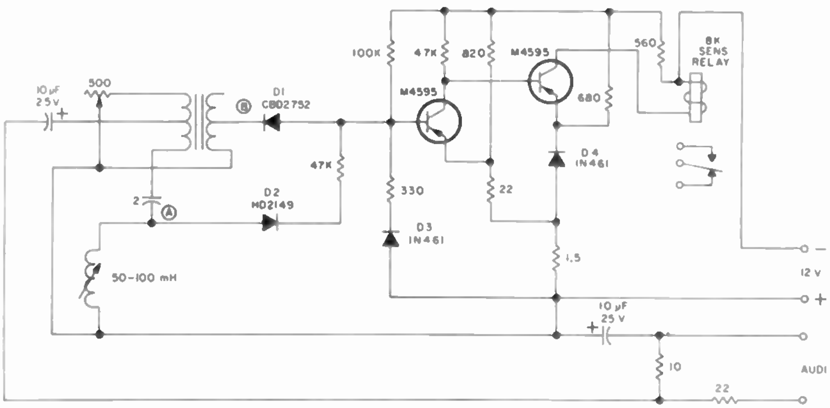


Fig. 1-5. Modified Motorola quick-response single-tone decoder.

The Motorola Decoder

The decoder shown in Fig. 1-5 is a particularly useful type because it has the capability of responding to extremely rapid tone pulses (as from a telephone dial). This circuit is a slightly modified version of Motorola's transistor decoder. One of the biggest advantages of this unit is that it has successfully withstood the test of time in commercial service.

Tone Frequency. The decoder is set to respond to tone signals in the frequency range of 2200–2900 Hz. Adjustment of the frequency-sensitive elements permits the pinpointing of any 50–75 Hz bandwidth within that range.

Of course, any frequency between 600 and 3000 Hz can be used, but the lower frequencies have serious disadvantages in practical applications. At frequencies between 600 and 1000 Hz, for example, ordinary conversation causes decoder triggering, and the result is errant and inadvertent operation of the functions to be controlled. Frequencies from 1 to 1.5 kHz can also be triggered by occasional voice signals; and a playful repeater user can toy with the phone by simply whistling.

Things begin to get more secure as the frequency goes up. But at 3 kHz, the audio processing capability of the transmitting and receiving equipment may be exceeded, particularly if there is inherent audio distortion in the system. The range from 2.25 to 2.85 kHz should prove ideal: It's difficult to voice-trip, it resists whistle-on attempts, and it is well within the frequency-response limits of most commercial FM units.

Decoder Alignment. Since impedances are critical when making voltage measurements at the decoder input terminals, an electronic ac voltmeter (vtvm) will be required. With the voltmeter connected across the receiver's audio output leads, have one of the repeater users transmit a tone. With the tone on the incoming signal, adjust the 500Ω pot on the decoder input for a reading of 400 mV. If this is not obtainable, set the 500Ω pot to midposition and adjust the receiver audio gain control. (If the receiver "speaker" audio connects directly to the transmitter, repeater levels will have to be readjusted.)

Next, connect the voltmeter (ac range) from the wiper arm of the 500Ω pot to point A of the 50–100 mH inductor, then adjust the inductor for a peak indication on the meter.

Move the voltmeter lead at point A to the cathode of diode D1 (point B), then *slightly* adjust the 50–100 mH inductor for a *dip* indication.

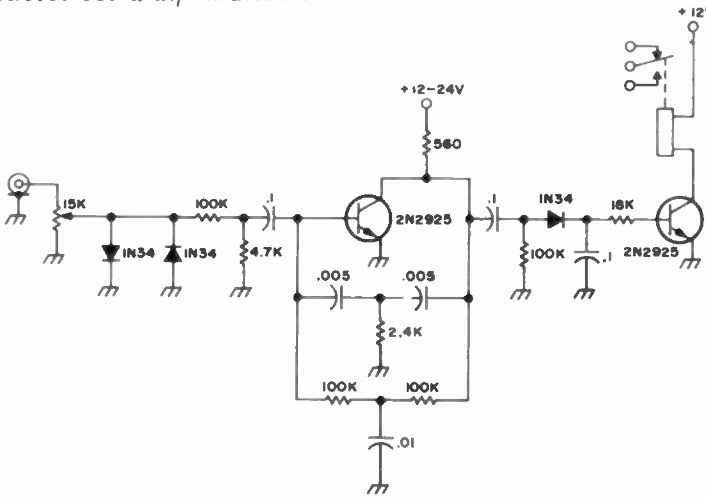


Fig. 1-6. The VE2BZK decoder uses two transistors – a twin-tee oscillator followed by a dc amplifier.

The VE2BZK Decoder

The VE2BZK decoder (Fig. 1-6) is a twin-tee circuit followed by a dc amplifier. The input level control can be brought down to give you a bandwidth as narrow as ±30 Hz. The two input diodes clip the incoming signal to a maximum value of 0.2V peak to peak; they can be any general-purpose germaniums.

The output of the decoder is rectified and fed to a standard dc amplifier; the relay in the collector of Q2 should close at about 6V and 6–10 mA.

The input should be connected to the discriminator output of the receiver. The input pot should be set up so that the relay closes reliably every time the encoder is keyed; it helps to have a friend stay home to adjust it while you drive around. A 30–50 μF capacitor can be connected after the diode to give a turn-on time delay of 3 to 5 seconds; this will not be applicable to standard repeaters, but it could prove quite beneficial for remote control for those of you who have friends with strange senses of humor. With the capacitor in the circuit, an audio generator sweeping your frequency will not trip the decoder.

A heavy duty relay must be connected at the output, since the contacts on a sensitive relay are rated at only a couple of watts.

The VE2BZK decoder has been configured for PC board construction by Stafford Electronics, 427 S. Benbow Rd., Greensboro, NC 27401. The boards are available for $1.75 (undrilled) or $3.50 (drilled). Order part number ST 4-71B. Size of the board is 2 x 4¾ in. Component layout is shown in Fig. 1-6B.

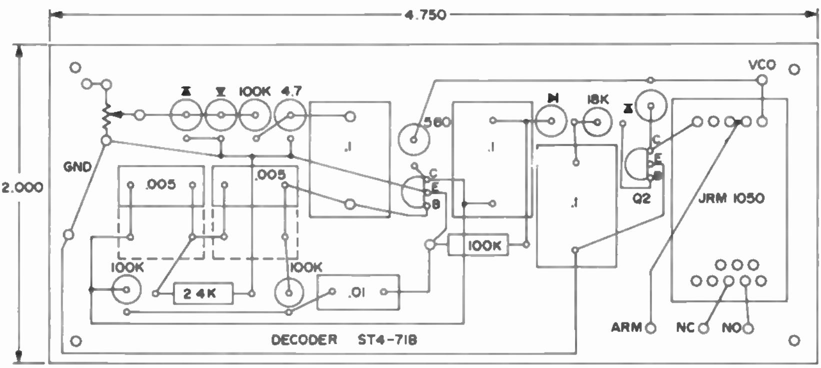


Fig. 1-6B. PC board parts arrangement for the VE2BZK decoder.

Interconnection

The simplest part of getting a tone-access system to work is the interconnection of the decoder itself. All you have to do is provide the proper power to drive the transistors and relay, then connect the speaker audio from the repeater receiver to the low-impedance input of the decoder. After that, it is simply a matter of making a few adjustments with respect to level (at the decoder input and at the receiver output). When the controls have been properly set, an incoming tone of the correct frequency will cause the plate relay in the decoder to close. Use of the relay's contacts is a matter that is best left to the judgment of the repeater owners, but the next chapter should give you plenty of ideas.

How to Control a Repeater with Tone

A few years ago, an amateur repeater typically consisted of not much more than a transmitter and a receiver, interconnected to operate as a repeater. But a number of factors have served to bring about a trend toward limited control of the repeater through the use of audio tones transmitted on the repeater's input frequency. When two repeaters are close enough to one another so that a user station triggers both repeaters when he attempts to use but one, a tone system is called for. When a group of amateurs band together to put up a repeater for the exclusive use of material supporters, again tones are required. When the repeater input frequency is commonly used for a simple channel (point-to-point, or direct), a tone system is the only way to insure that the repeater is only triggered when it is actually being used by one of the stations on the frequency.

Today, the toned repeater is at least as common as the straight "carrier-operated" repeater, and the trend towards tone control is certain to increase from here on out.

The three most common methods of tone control for amateur repeaters are, in order of popularity, "tone burst," "whistle-on," and "continuous-tone-carrier-squelch." The first two systems employ the use of a relatively high-pitched audio tone of short duration. The latter employs a continuously transmitted very-low-frequency "subaudible" tone of a specific and usually quite critical frequency. Each system has advantages the others do not share. It is up to the repeater designers to look at the merits of the three systems, then adopt the one that best meets their particular needs.

A tone-burst system installed in a repeater will require each user to transmit a short tone "burst" each time he wants to communicate through the repeater. The only practical method of utilization in such systems is for each user to install a tone oscillator in each of his transmitters, along with a simple timer to limit the duration of each tone burst, and a method for automatically keying the oscillator each time the transmitter push-to-talk circuit is actuated. Each user should also install a switch so that he can take the tone oscillator out of the circuit when he is not operating through the repeater.

But on the plus side, the tone-burst system is the simplest of all the systems to install at the repeater; it will consist of nothing more than a single relay and a timer to limit length of each transmission (assuming that a tone decoder is already installed at the repeater site).

The whistle-on system is the nicest from the standpoint of the users, who must possess no oscillators other than the one with which they were born. A simple brief whistle will turn on the repeater, and the repeater will operate from that point on in a purely carrier-operated manner. After a specified time period of inactivity (say, no incoming repeater signals for a few minutes), the repeater will shut down. To turn it on again, the next user will have to command it with another orally produced whistle. As with the tone-burst system, the whistle-on approach includes a transmission-limiting timer of a minute-and-a-half or so.

The whistle-on concept offers the most in terms of flexibility, but it requires two timers and a relay (in addition to the broad tone decoder). Interconnection, however, is quite simple.

The third approach, continuous-tone-carrier-squelch (most frequently referred to by Motorola's tradename of *PL*, for "Private Line"), is the least flexible, the most difficult to implement, and the most critical with respect to audio stability. It is also the most secure of the three, which is one of the reasons many amateurs elect to use this system for their "closed" repeaters.

There is little complexity at the repeater site with a PL system, since nothing other than the decoder itself is actually required, even though most amateurs like to add a delayed-dropout relay to avoid "chopping." But the problems faced by the users are manifold. Here, every transmitter that is intended to be used with the system must be equipped with highly stable low-frequency tone generators. And, unless great care is taken in the setup of all the stations, the repeater in use will sound like a bunch of stations who use unfiltered power supplies. A good PL system should be subaudible, but amateur setups – commercials, too, for that matter – seldom are.

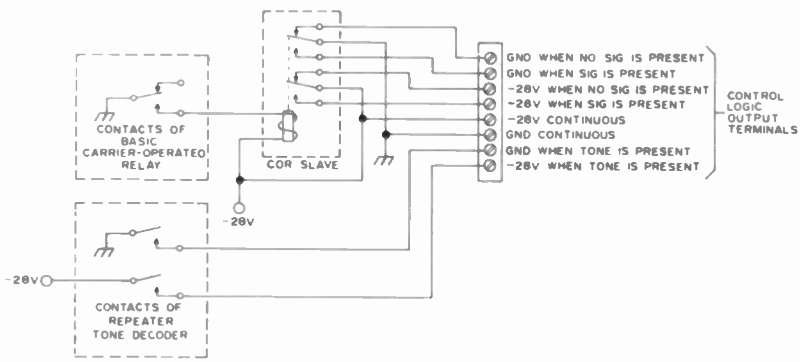


Fig. 1-7. A heavy-duty relay slaved to the carrier-operated relay, along with ground and voltage outputs from the tone decoder, can be used to provide a variety of very useful logic signals for all repeater control functions.

Basic Control Logic

Once the type of tone access approach is chosen, the repeater should be set up to provide the widest possible number of logic outputs, which can be used for an almost endless array of later control functions. The tone decoder, for example, should drive a relay to provide voltage and ground outputs when the proper incoming tone is sensed. And the carrier-operated relay should likewise be set up to drive a multicontact, heavy-duty "slave" that provides voltage and ground output signals for both the *signal* and the *no signal* states. These logic signals will prove invaluable as additional control functions are implemented.

The circuit of Fig. 1-7 shows how the logic signals are obtained and what they are. The control circuits described here and in other "repeater control" articles will always require at least some of the logic signals available on the terminal board.

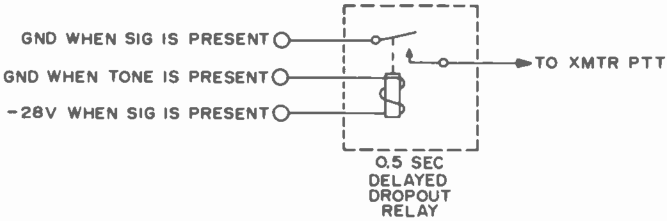


Fig.1-8. There are many methods for keying continuous-tone-carrier-squelch (PL) systems, but those employing delayed dropout relays are the most successful. Here, the tone and the signal must be present to hold the repeater on the air. Momentary tone variations because of weak signal will not cause "cycling" because of the delay, but the repeater will drop out instantly if the carrier itself drops out.

Control Logic and PL

A good example of how the logic signals can be used appears in Fig. 1-8, which is the heart of a PL control system. The coil of a delayed-dropout relay is fed with the ground output of the tone decoder and the voltage output from the carrier-operated relay. If the tone is erratic, the relay stays keyed because of the timer's delay of a half-second or so. But, since the carrier-operated relay ground output signal is used to key the transmitter push-to-talk circuit directly (through the contacts of the delay relay), any loss of signal will cause the repeater to shut down immediately. Thus, there is no "delayed squelch" arrangement, yet the users are protected from fluttering of the repeater that might be caused by borderline settings of their tone units.

Control Logic and Tone-Burst

The relay and timer circuit of Fig. 1-9 shows how the basic repeater logic signals can be used to control the tone-burst repeater. When a signal appears without the proper accompanying tone, the normally open contacts of the repeater control relay keep the COR ground signal from being fed to the repeater push-to-talk circuitry. When the correct tone appears, however, a ground signal from the tone decoder energizes the coil of the repeater control relay (whose voltage is supplied through the normally closed contacts of a 1.5-minute timer). The control relay pulls in and is latched by the COR ground signal now being supplied through the relay's own contacts.

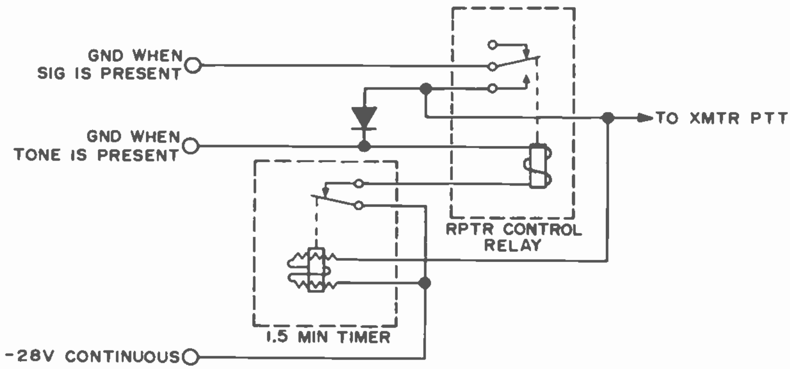


Fig. 1-9. Tone-burst repeaters can be set up with nothing more than a relay and a timer if the decoder and COR logic signals are available. Here, a short tone burst will energize the control relay, which latches as long as a carrier stays on the input. If the carrier stays on more than 1.5 minutes, the repeater will go off the air and a new tone will be required. Each transmission must be accompanied by the proper tone burst.

Even though the tone burst is short, the repeater control relay will keep the transmitter on the air as long as a signal stays on the input frequency – unless that time period happened to exceed a minute-and-a-half.

The timer is keyed at the same time the push-to-talk circuit of the transmitter is energized. And if the same signal is present for the timer's full period, it will pull in to break the circuit on the repeater control relay. The only way to get the transmitter on the air again if this occurs is for a new carrier to come on the frequency with the proper tone.

The control relay also drops out when any carrier disappears, so that each station who wants to use the repeater must either "tail-end" (seize the frequency before the preceding user drops his carrier) or be equipped himself with the proper access tone burst.

The diode in the circuit, by the way, is to keep the tone decoder ground signal from being overworked. Without the diode, the decoder ground signal would have to key the transmitter push-to-talk and the transmission-limiting timer. With the diode, the tone decoder ground can only trigger the repeater control relay.

Control Logic and Whistle-On

Not many people really understand the "whistle-on" approach. Some amateurs seem to think that if they can whistle to bring a repeater on the air, that process constitutes a whistle-on system. However, in spite of the fact that many tone-burst systems can be accessed by a whistle, a true whistle-on system is one that has been designed for access by whistling. And to be convenient, no whistle approach can require the users to whistle each time they transmit.

A whistle-on repeater may stay off the air for long periods. Stations can transmit as much as they want on the input frequency, but no repeater will be around to assist in their communications unless one of the users decides to call up the repeater by uttering a brief whistle. When the tone decoder at the repeater senses the presence of the whistle, on comes the repeater, *as a conventional carrier-operated system as long as the repeater is active with users.*

When the users all drift away, and the repeater becomes inactive, the repeater starts counting time. After a specified period, usually five minutes or so, the repeater will shut down. Another whistle must be sent to bring the repeater on again.

As with the tone-burst system, a timer is typically employed to limit the length of transmissions going through the repeater. Figure 1-10 shows the circuit and the logic required to produce a sound whistle-on repeater system.

Normally (when the repeater has not been whistled on), incoming signals cannot be fed to the push-to-talk because

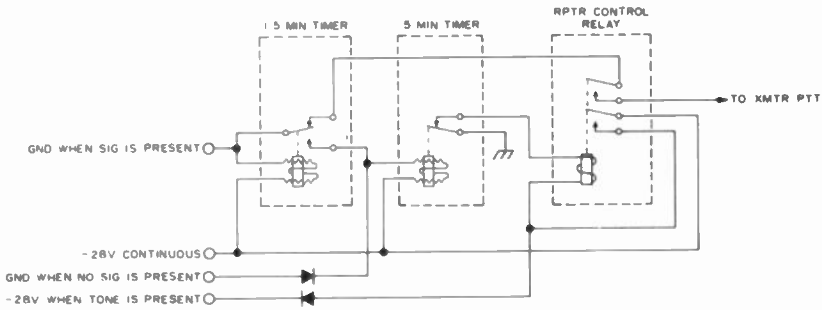


Fig.1-10. The complete whistle-on control system contains two timers and an ordinary relay. If a carrier stays on for more than 1.5 minutes, the push-to-talk circuit is disconnected. If the carrier stays on 6.5 minutes, the repeater shuts down and must be whistled on again. Also, if nobody uses the repeater for 5 minutes, shutdown will occur.

the COR ground signal goes no further than the normally open contacts of the repeater control relay. When the whistle is sensed, however, decoder voltage causes the control relay to pull in (and latch). Now all signals, tone equipped or not, will be repeated.

When a single transmission exceeds 1.5 minutes, the COR ground signal causes the timer to pull in and disconnect the push-to-talk. If the user was simply longwinded, he'll quit transmitting in a minute or two and the system can go right back into normal operation, with no new whistle required. But if the problem is more serious than a longwinded ragchewer, the whole repeater will shut down completely in five more minutes. The COR ground is rerouted after the first minute-and-a-half to the five-minute timer, which causes deenergization of the repeater control relay at the end of its period.

The five-minute timer is also used to shut down the system when nobody is using the repeater. A ground signal from normally closed contacts on the COR slave relay completes the circuit on the timer coil. This "double duty" provides for an extremely safe and self-controlling repeater system.

As with the tone-burst circuit, the diodes in the whistle-on system are for isolation. The one in the *no signal present* ground line keeps the circuit isolated from the *signal present* logic. The diode in the negative voltage line isolates the *tone present* signal from the *continuous −28V* terminal.

Tone Access and the FCC

The Federal Communications Commission has been riddled with requests from amateurs seeking to get a relaxation in the rules governing remote control and general operation of repeaters. The indications are quite strong that the relaxation may come, but not until repeater designers and builders prove beyond doubt that effective, failsafe, and adequate measures for autocontrol and subcontrol (tone access) can be demonstrated.

The need for monitoring from a fixed UHF facility has been challenged by amateurs and defended by the FCC. Commission spokesmen say they will not even consider allowing unmonitored repeaters, or control from a mobile, until a positive means can be shown for providing certain, reliable control under all operating conditions. Tone-access repeaters with backup timers for passive control are a giant step toward meeting this goal.

Improving Repeater Intelligibility

Use of a cathode follower to pick audio directly from the repeater's discriminator can do wonders for an ailing amateur relay system.

Ask any FM'er to describe what he thinks are the most common problems in the world of repeaters. Chances are he'll mention "desensitization." If he's a repeater owner, he'll probably tell you how he fought that isolation battle for days or weeks before he finally got the repeater transmitter and receiver percolating 600 kHz apart, in the same building.

Desensitization *is* a problem, and it's a common one. But it is no more common than the problem of unintelligibility – the problem of rotten, overlimited, asymmetrical re-pre-de-emphasized, lousy-sounding audio. And the reason bad audio is such a problem is that it just doesn't always seem serious enough to warrant the extra engineering necessary to change it.

There are plenty of chances for repeater audio to go bad. First, there's the receiver: If the low i-f is out of adjustment, certain voice frequencies will distort and loud signals will squelch out of the receiver's audio passband. There's the chance for microphonic tubes, or improper deemphasis circuitry.

Often, a repeater builder in a hurry to get a system going will connect the speaker leads of the receiver directly to the audio input of the transmitter. In doing so, he causes the receiver audio to be processed through so many circuits that degradation could take place even if by nothing more than the process of "diminishing returns."

Every stage loses something from input to output, and the slightest bit of distortion anywhere is immediately amplified and exaggerated in all subsequent stages. Consider the stages the audio must be cycled through faithfully: The repeater user speaks, and his microphone "transduces" the sonic waves into electrical signals. These signals are generated again in the output of the transmitter's af amplifier and phase modulator. The receiver processes the audio some more from the discriminator, through audio amplifiers, through the output transformer, and finally to the speaker, where the af is again "transduced" from electrical ac to air "pressure" waves. Considering what the audio must go through from one end of the system to the other, it is no wonder that some of our repeaters sound so bad.

All this doesn't come as any great surprise to most repeater owners. They know what's wrong and how to fix it. But sometimes they listen a little too subjectively to the product of their own handiwork. To them, it may just not sound bad enough to justify circuit modifications.

If you happen to know a repeater owner whose foot happens to fit the shoe of distortion, invite him to make the "comparison" test. At the repeater site, or near it, set up a two-channel receiver capable of monitoring the repeater input and output frequencies. This receiver must have the same bandpass limiting characteristics as the repeater receiver. Then, get someone to transmit a 1 kHz tone (at the receiver's maximum deviation-acceptance level) on the repeater input frequency. Switch the receiver quickly from the repeater input to the output. If the signal sounds cleaner on the input frequency than it does on the output, it's time to reroute some of the audio at the repeater.

There are a number of places where you can pick off audio on a receiver, but none will give a signal quite as "virgin" as the discriminator. If high-fidelity audio was transmitted, you'll be able to reclaim high-fidelity audio if you get it before it gets past the discriminator.

But getting audio from the discriminator presents other problems. For one thing, the discriminator "sees" the audio before the squelch does. Which means that every time the transmitter is keyed without the presence of a quieting signal, a bothersome "squelch noise" will be transmitted. (Phone patch operation is one such case; on-site operation of the repeater transmitter is another.)

Another problem is impedance matching. The discriminator represents an extremely high impedance audio load. The transmitter audio input is apt to be quite low by comparison, particularly if input level adjustments are to be made.

Still, there is no better signal source than the discriminator, if high-quality audio is to be a criterion. And the problems aren't problems when there's a simple solution.

Use of a cathode follower solves most of the problems. It provides excellent circuit isolation, matches a very wide range of impedances, and allows control of audio level without upsetting the receiver or transmitter audio adjustments. As a bonus, it allows completely independent local control of the repeater receiver's audio gain.

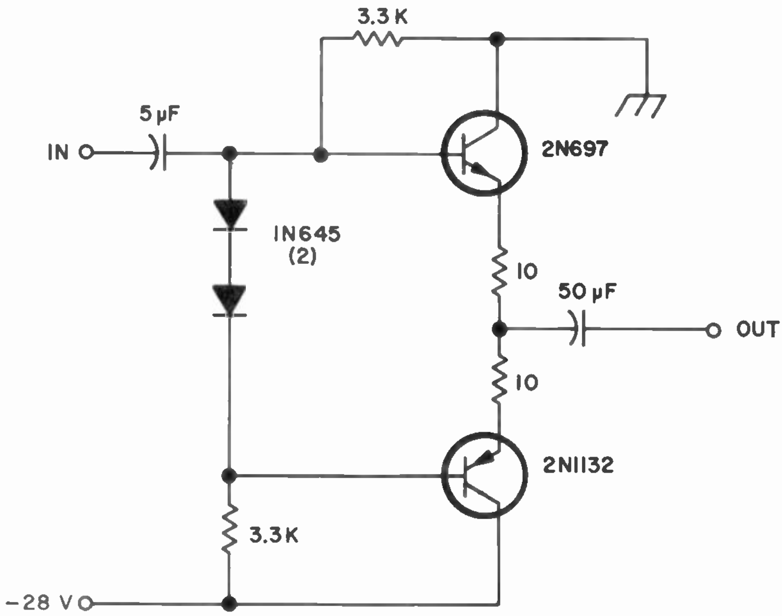


Fig. 1-11. This schematic from the U.S. Navy's handbook of "preferred circuits," shows an emitter follower that provides 12 dB gain. A high series resistence should be used between the discriminator and the audio input to prevent circuit loading.

The remaining "problem" is that of discriminator "squelch" noise being transmitted when the rig is keyed without a carrier. This is solved by routing the cathode follower output to ground during all no-signal periods. The normally closed COR contacts work great for this.

The transistor equivalent of a cathode follower is the emitter follower, which will do anything a tube can do. The circuit in Fig. 1-11 shows an emitter-follower audio circuit that should prove ideal for repeaters with 28V dc control.

If no dc control voltage source is available, however, the cathode follower will probably prove more valuable. The circuit shown in Fig. 1-12 uses a dual triode to give one stage of amplification to the audio signal. This circuit is basically the type once used by General Electric in its commercially manufactured repeaters.

A well-bypassed high value series resistor, on the order of 200 kΩ, should be used between the discriminator and the cathode follower for maximum isolation and to prevent circuit "loading." In most cases the audio can be picked right off the discriminator test point, but the audio lead should be shielded to prevent pickup and processing of stray noise and audio "garbage."

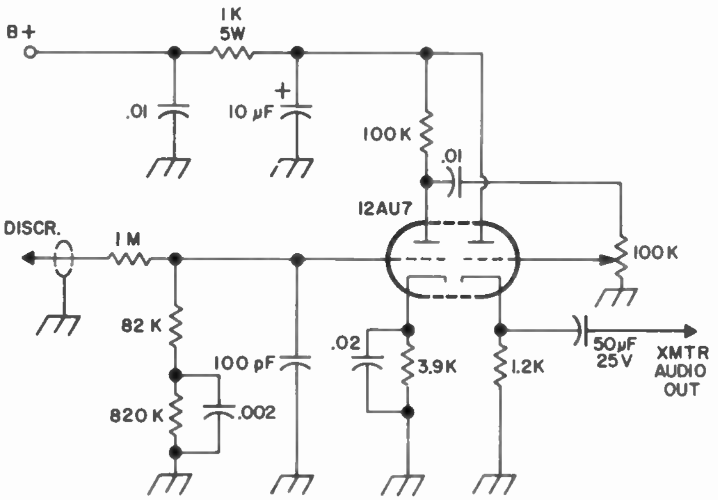


Fig. 1-12. This 12AU7 cathode follower is similar to the type used in commercial GE repeaters. As shown, the B+ plate supply is stabilized with a 1 kΩ resistor and filter capacitor.

The carrier-operated relay, if connected as shown in Fig. 1-13, does double duty by killing the receiver audio completely except when a carrier appears on the input. In this way, the repeater transmitter can be used by an on-site operator without his having to compete with squelch noise. The diode in the push-to-talk lead will prevent the COR from being triggered when the transmitter is keyed directly, and the 47 kΩ resistor provides isolation between the local mike and the audio circuit ground.

A Final Word About Quality

Repeater "listening conditions" aren't getting any better. More and more handie-talkie units are being used with repeaters, and repeater users are operating from such way-out noise sources as motorcycles, boats, skimobiles, and planes. As time goes by, repeater owners will find that effective audio will be a consideration surpassing "coverage" in importance. For after all, what good is a broad range of coverage when you can't make out the intelligence on the repeater output? But good audio *can* be built into the system. It's only a matter of taking a little extra time and putting in just a smidgen more effort.

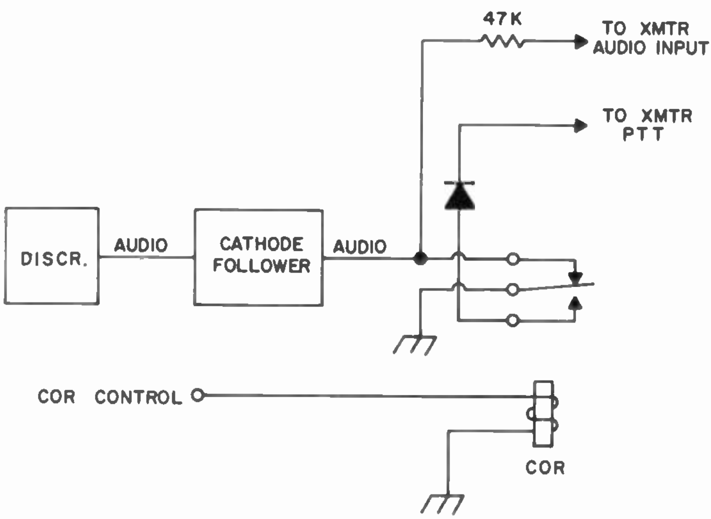


Fig. 1-13. The basic COR should be used to ground the receiver audio when no signals are on the input. The resistor in the audio line provides sufficient isolation so that a local mike can be used even though the audio line is grounded.

Effective Techniques for Minimizing Desensitization

If the receiving range of your repeater can't match the output capability, the problem could be desensitization. And chances are you can solve the problem by as simple a step as moving the antennas around a bit at the site.

Desensitization is far more common than most repeater owners want to admit. When you hear about the wonders of someone else's repeater, the fellow who tells you about it generally has a way of overlooking some of the less attractive aspects of it.

There have not appeared too many articles on defeating desensitization – virtually nothing in journals other than 73 Magazine. The measures that have been taken in most instances have been the result of dogged determination and untiring experimentation on the part of the amateurs who build the repeaters. Moreover, in the majority of installations, the problems don't seem serious enough to warrant the often rather dramatic and time-consuming effort described by the scant literature on the subject.

To minimize receiver desensitization in a typical repeater, some means must be employed to attenuate the transmitter signal at the receiving antenna location. The degree of attenuation required for any given repeater application can be predicted, however, with a fairly high reliability if certain key parameters are considered as "constants." And, since most amateur repeaters are similar in many respects, the constants aren't difficult to nail down. As rules of thumb, then, these can be considered to be: a transmitter output power of 50W or less; a receiver sensitivity of 0.5 μV (for 20 dB quieting) under normal, nontransmit conditions; use of conventional omnidirectional antennas, receiver selectivity typical of modern commercial two-way FM units, use of a well-matched antenna for both transmit and receive; and installation of high-quality, low-loss coaxial cable.

The cheapest and easiest method of minimizing desensitization is through careful separation of the repeater antennas. Assuming all the constants cited above apply to your own VHF repeater setup, you can readily determine how far apart your transmit and receive antennas must be placed by consulting the charts of Figs. 1-14 (6 meters) or 1-15 (2 meters).

Understanding Attenuation Requirements

It is easy to see from examination of the tabulated figures that the closer the repeater operating frequencies are to one another, the greater the attenuation required. With

HORIZONTAL SEPARATION

REPEATER OPERATING FREQ.	51.0	51.25	51.5	51.75	52.0	52.25	52.5	52.75	53.0	53.25	53.5	53.75
51.0			1K+	680	435	342	260	199	161	130	110	100
51.25				1K+	670	430	340	259	198	161	130	110
51.5	115				1K	660	425	338	258	197	160	130
51.75	90	112				1K	650	420	336	257	196	160
52.0	70	90	108				1K	640	415	334	256	195
52.25	62	70	89	105				998	630	410	332	255
52.5	55	61	69	88	103				995	620	405	330
52.75	47	54	60	68	87	100				990	610	400
53.0	42	46	53	59	68	86	99				985	600
53.25	36	40	45	52	58	68	85	98				980
53.5	32	34	38	44	50	57	67	84	97			
53.75	28	30	32	36	43	48	56	67	83	95		

VERTICAL SEPARATION (left side label)

HORIZONTAL SEPARATION, ft (right side label)

VERTICAL SEPARATION, ft

Fig. 1-14. Tabular listing of required antenna separation in feet for various 6 meter repeater frequency combinations. The gray area shows separation requirements for horizontally spaced antennas; the white triangle shows distances for vertically separated antennas (tip-to-tip).

HORIZONTAL SEPARATION

REPEATER OPERATING FREQUENCIES	146.04	146.10	146.16	146.22	146.28	146.34	146.40	146.46	146.52	146.58	146.64	146.70	146.76	146.82	146.88	146.94	147.0	ATTENUATION REQUIRED, dB
146.04		1156	1043	938	840	749	665	588	518	455	339	290	248	213	185	164	150	
146.10	160		1144	1032	827	830	738	653	578	506	442	336	288	245	211	183	163	
146.16	133	156		1132	1021	916	820	727	642	567	494	429	333	285	242	209	182	53
146.22	120	130	152		1120	1009	905	809	717	631	555	482	416	329	281	240	207	54
146.28	107	120	126	148		1108	997	894	797	707	620	543	470	404	326	278	238	55
146.34	95	106	117	123	144		1096	985	882	785	694	608	531	458	391	322	275	57
146.40	84	90	104	113	120	140		1084	973	870	773	682	596	519	446	379	318	58
146.46	74	83	88	101	110	117	136		1072	961	858	761	670	584	507	434	367	60
146.52	65	72	81	86	98	107	114	132		1060	949	846	749	658	572	495	422	62
146.58	57	63	70	79	84	95	104	111	128		1048	937	834	737	646	561	483	64
146.64	50	56	62	68	77	82	92	101	108	124		1036	925	822	725	634	549	66
146.70	44	49	54	60	66	75	80	89	98	105	120		1024	913	810	713	622	69
146.76	39	43	48	52	58	64	73	78	86	95	102	116		1012	901	798	701	72
146.82	34	38	42	47	50	56	62	71	76	83	92	99	112		1000	889	786	76
146.88	30	34	38	41	46	49	55	60	67	74	80	88	96	108		987	877	80
146.94	27	30	33	37	41	45	48	54	59	67	72	78	86	93	104		975	86
147.0	25	27	30	33	37	40	44	48	53	58	65	70	76	83	90	100		100

VERTICAL SEPARATION

REQUIRED ANTENNA-TO-ANTENNA SPACING, ft

Fig. 1-15. Minimum tip-to-tip spacing (in feet) required between transmit and receive antennas to achieve various attenuation values. Shaded area is for horizontal separation; white area is for vertical. Diagonal lines represent attenuation level attained by tabulated separation in typical case.

500 or 600 kHz of spectrum between the two frequencies – as with most of the 2 meter repeaters – some means must be employed to attenuate the transmit signal by about 60 dB (shown by diagonal line on Fig. 1-15). If no other method is used to obtain this isolation, it can be effected by placing the two antennas some 50–60 wavelengths apart horizontally or by spacing them about 8 wavelengths vertically.

Since the spacing is directly proportional to wavelength, the higher frequencies require less distance between antennas to achieve a given isolation value. It is easier, for example, to isolate 146.94 from a 147.00 MHz transmitter than it is to isolate 146.70 from 146.76 MHz, even though the spectrum between the two sets is the same (60 kHz). From Fig. 1-15, 100 ft of vertical separation is needed between the antennas on the top end of the spectrum, and 116 ft is required to give the same degree of attenuation for the lower set.

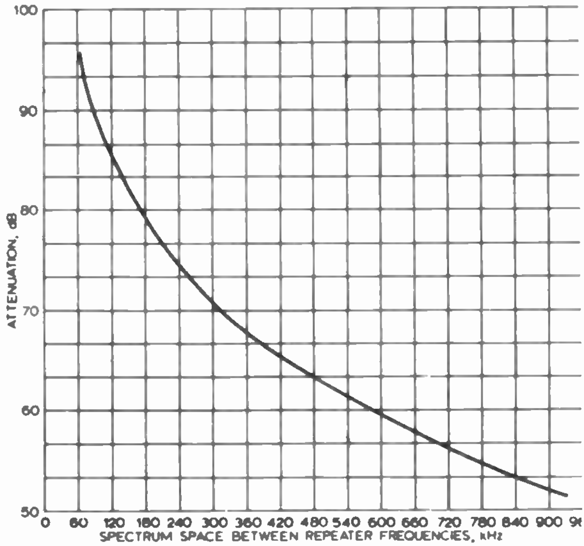


Fig. 1-16. Attenuation curve shows how isolation problems can be simplified by providing more spectrum between the repeater operating frequencies. As shown, the attenuation requirement gets extremely severe with close-spaced channels.

The curve of Fig. 1-16 shows the attenuation required as a function of spectrum spacing between the two repeater operating frequencies. When you consider that each 6 dB of attenuation represents halving the field strength (in measurable voltage) at the receiving antenna, it is not too difficult to see why repeater owners keep the transmit and receive frequencies as far apart as possible. Consider the attenuation requirement for a 60-kHz-separated repeater, for example, as compared with a repeater system with operating frequencies spread by 600 kHz. As the frequencies are brought together, the attenuation requirements get downright formidable.

If your tower will not permit the minimum separation distance as determined by the charts, you will have to plan on either more spectrum between the transmit and receive frequencies or incorporation of additional isolation measures, such as cavities or hybrid rings. (See "Desensitization," p. 137, Radio Amateur's FM Repeater Handbook. Editors and Engineers. Ltd., New Augusta. Indiana 46268.) The only other alternatives are placing the receiver site physically at some distance from the transmitter or separating the two antennas horizontally by mounting them on two different towers.

It should be understood that an isolation factor of 60 dB (which the 600-kHz-spread figures are based on) is a minimum, and it results in a desensitization level of about 2 dB – a value considered acceptable by most amateur and professional repeater men.

Horizontal separation is usually a last resort because it may take as much as ten times the distance horizontally that it takes vertically to achieve a given attenuation level. In the 60 dB attenuation example above, for instance, a vertical separation of only 45 ft does the job. If the antennas are to be separated horizontally, however, the physical spread between the two antennas must be increased by no less than 322 ft. This characteristic is attributable to the fact that antennas typically radiate most of their energy in an almost perfect horizontal plane. Not only does the transmit antenna pump out more radiation horizontally, but the receiving antenna is pulling in signals better along that plane. With vertical separation, though, both antennas are placed in a position least susceptible to direct radiation of the other.

Another major disadvantage of horizontal separation with a single-site repeater is the excessively long runs of transmission line usually required. No matter what type of coaxial cable is used, a 400 ft run means plenty of signal loss – particularly at the higher frequencies. Figure 1-17 shows just how much loss you can expect with RG-8A/U and foam-line equivalents at the various VHF and UHF frequencies of interest to amateurs. At moderate power levels, extremely long runs of conventional coax would seem almost prohibitive, even at 150 MHz. A figure of 0.025 dB/ft for signal attenuation may not seem like much, but it results in a 10 dB loss with a 400-ft length of transmission line – which is a power loss of a full order of magnitude, turning fifty watts into a measly five.

Use of a very high grade of line, such as Communication Products' rigid Foam-Flex, will cut the loss to about 1

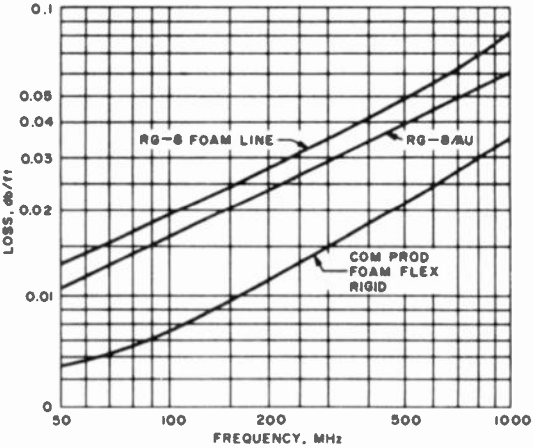


Fig. 1-17. This chart shows the superiority of foam line over conventional RG–8A/U cable. For a 0.5 dB less loss with their "equivalent" foam line at 150 MHz, and only 1 dB of total loss with ComProd's rigid foam line.

dB per hundred feet; a better alternative, of course, but still a significant loss. And consider the cost of a 400 ft length of this "good stuff." It isn't cheap!

Clearly, horizontal separation of antennas is not a sound solution from a single site under ordinary conditions, particularly on the lower VHF frequencies.

All this discussion is not meant to be a course in repeater planning; the object is merely to help you determine the best possible way of providing good solid repeater coverage using only the facilities that you have available.

Tricks You Can Do

If you looked at the vertical separation charts of Figs. 1-14 and 1-15 and decided that there was not enough room on your tower to accommodate both your repeater antennas, don't resort too soon to going the horizontal route. There are still a few more aces you can play.

Many service specialists – both commercial and amateur – are surprised to learn that when "gain" antennas are spaced vertically, one or the other of the two may be moved a few inches *horizontally* to yield an *effective* increase in separation distance and a positive improvement in signal isolation by as much as 3 dB. This interesting

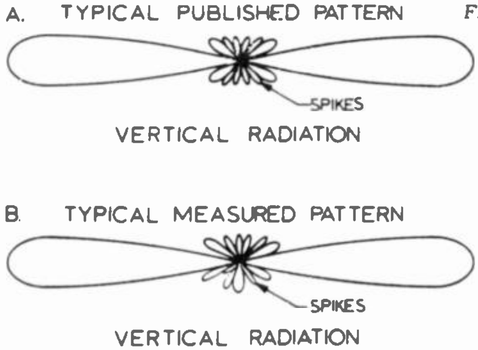


Fig. 1-18. The measured radiation characteristics of an antenna will often differ from that specified, particularly with the minor lobes directly above and below the radiator. Published patterns show symmetrical minor lobes with a null directly above and below the antenna. Actual measurement may show nulls slightly off-axis from the radiator. Experimentation with one of the repeater antennas will quickly show where the null points are.

phenomenon can be explained on the basis of individual antennas (though virtually all of the collinear omnidirectional antennas are similar). From the typical pattern of Fig. 1-18, you will notice that a collinear omnidirectional gain antenna produces lobular "spikes" below the radiator and along the same axis. Most antenna manufacturers publish typical patterns (as in Fig. 1-18A) that show a symmetrical placement of these minor lobes. In practice, however, these lobes are not necessarily symmetrical, even though they are always present. Their appearance will depend on such factors as antenna placement, distance from tower, size of mast, etc., and they will rarely form the symmetrical arrangement sketched in Fig. 1-18A. The measured pattern will form a hodgepodge of lobe spikes as pictured in Fig. 1-18B.

If the lower antenna is positioned at the null between these spikes, maximum attenuation will result. If the lower antenna is centered on one of the lobes, however, adequate isolation may be very difficult to achieve. A few inches to a foot laterally may make all the difference in the world!

One excellent way to determine the best position for the second antenna is to take actual field-strength measurements at various candidate locations on the tower while the transmitter is pumping a signal into the first (mounted permanently). For vertical-separation checks, load the transmitter into the upper antenna (even though it may eventually become the receiving antenna), then do a thorough job of checking the field strength of the signal at various positions lower on the tower. When an optimum location is found, mount the antenna there loosely, then connect it directly to the field strength measuring device. While monitoring for a null, move the antenna as much as possible within its confines. Then secure it when the reading is optimum.

Another trick in common use is the inversion of one of the two vertically separated antennas. With gain antennas, this procedure may not offer some of the fallout advantages to be realized with groundplanes because most gain antennas have a characteristic radiation in an almost perfect horizontal plane. So there is rarely an actual signal improvement when a gain antenna is inverted, but the reduction in desensitization can certainly make it worthwhile. If the vertical lobes of the upper gain antenna (that is, the spikes extending directly below the upper antenna) are difficult to avoid with the lower, turning the *top one* upside-down and jockeying for position will almost certainly cure the problem, *provided the tip-to-tip spacing between the two antennas can be preserved*. If the tip-to-tip spacing must be compromised by inverting the higher of the two antennas, it might be wisest to try inverting the lower one. This tends to increase tip-to-tip spacing, but could cause problems of interference with other structures if the lower antenna is mounted in the vicinity of a rooftop, the ground, etc. Individual installations will have to be made on the basis of these considerations.

An important note: When a gain antenna is inverted, great care must be taken to insure that *absolutely no moisture* gets into the fiber-glass casing. A little water and you can kiss your expensive antenna goodbye.

Groundplanes make particularly good antennas for inversion because they characteristically have a very high angle of radiation (generally about 23 degrees above the horizon). Inverting the *lower* one will provide the highest degree of signal isolation, and will probably get you a little extra gain on the low horizon because of the change in primary radiation angle. Inverting the upper one may or may not help your desensitization, but it will certainly improve your radiation angle. Your best bet is to try it both ways – first the lower antenna, then the upper one. At least with groundplanes, there is no need to fear compromising the tip-to-tip spacing between antennas.

Split Sites

By far the most effective method for eliminating desensitization altogether is to "split" the repeater: separate the transmitter and receiver by a distance sufficient to preclude the effects of rf blocking. This often works out to be a considerably simpler process than repeater owners typically suspect. Getting the mountaintop repeater site is usually a fairly sticky business in the first place, but once it's in the bag there is seldom much difficulty in coming up with a second site somewhere near the first.

Look at your own repeater location. Chances are you have some radio "neighbors" – commercial two-way or governmental radio facilities sharing the same hill. Ever think about asking one of them to let you install your receiver in one of their buildings? Maybe they'd like to split *their* site as well, taking a similar advantage of *your* site.

The advantages of operating a split site are obvious. Transmit and receive frequencies can be extremely close-spaced (no need to stick to the old 600-kHz separation standard any more); receive capability can be enhanced by the addition of preamps without fear of rf degradation by high field strengths; input/output coverage can be matched extremely well, making the range of the receiver equal that of the transmitter; shielding requirements are minimzed (often totally unnecessary), simplifying the installation process.

Getting the signal from one site to the other can involve secondary "link" setups – subsidiary repeaters operating on a UHF frequency pair. Or it can involve leased telephone lines, if the two sites are close enough to justify it economically. As a third alternative, the two sites can be linked with an overground wire pair strung by the amateur repeater builders themselves. If the facility is on cleared and developed land, the third approach probably will be disallowed by the land leaseholders. But where the terrain between the two sites is high-foliage area, the homebrew wire stringing might be just the right approach.

Even if you can't string wire overground, you might find no objections to undersurface wire stringing – particularly when the landowner is made to realize that no unsafe voltages or currents are to be transferred over the line. Usually, undersurface wire is only required for esthetic reasons – which means you need bury it no deeper than the depth required to effectively conceal the line.

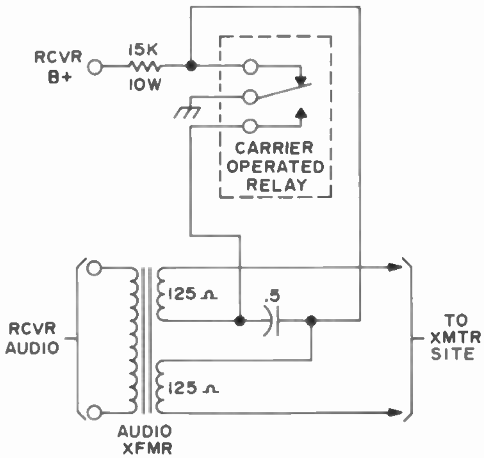


Fig. 1-19. At the receiver location (two-site repeater), a cathode follower feeds the receiver audio into a transformer continuously, but the receiver squelch keeps audio off the line until a carrier appears. The B+ leg of the two-wire line is held at ground potential by the normally closed COR. When a carrier appears, the ground is moved to the "return" leg and B+ is allowed to flow with the audio through the wire pair. The capacitor on the transformer secondary isolates the dc polarities without disturbing ac (audio) flow.

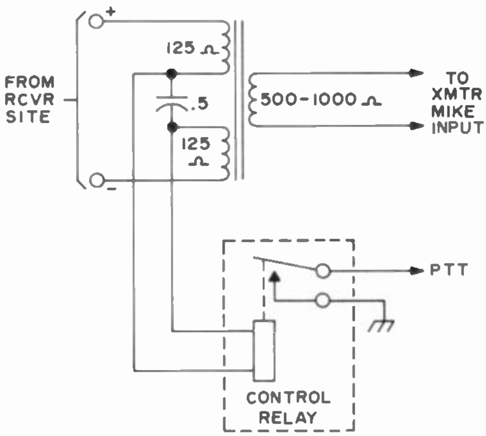


Fig. 1-20. Audio and dc decoupling is accomplished at the transmitter. The dc control voltage is used to trip a sensitive relay (10 mA) with a coil voltage of about 3500Ω which keys the push-to-talk circuit. The transformer, with split primary interconnected by a capacitor, passes the audio as the dc is routed at the primary.

A split-site repeater is no more complex than a single-site system – and often it is even simpler. A standard single-contact carrier-operated relay at the receiver can do all the switching necessary to send both audio and dc control signals to the transmitter site. Figure 1-19 shows one method for accomplishing this dual function.

At the transmitter site, the audio and control signals are decoupled from the line by another transformer/capacitor arrangement, and the circuit is complete. Figure 1-20 shows the transmitter-site setup. There is nothing particularly critical about the impedances of the transformers in either the receiver or the transmitter circuits; this is particularly true where cathode followers are used, due to their wide impedance-matching range. The most important characteristic is the split windings.

Audio anomalies can be remedied by adjusting the isolation capacitor values. The values shown (0.5 μF) were selected for their ability to reject the clicks of dc relay closures. Lowering the value will improve the low-frequency response, but it will increase the likelihood of allowing annoying clicks to be transferred over the line.

The resistor value shown in Fig. 1-19 is but an approximation. The actual value will depend on the pull-in current required by the control relay coil. The resistor should limit the current to no more than 150% of that required for relay operation, as determined by Ohm's Law.

Repeater owners sometimes appear reluctant to adopt a

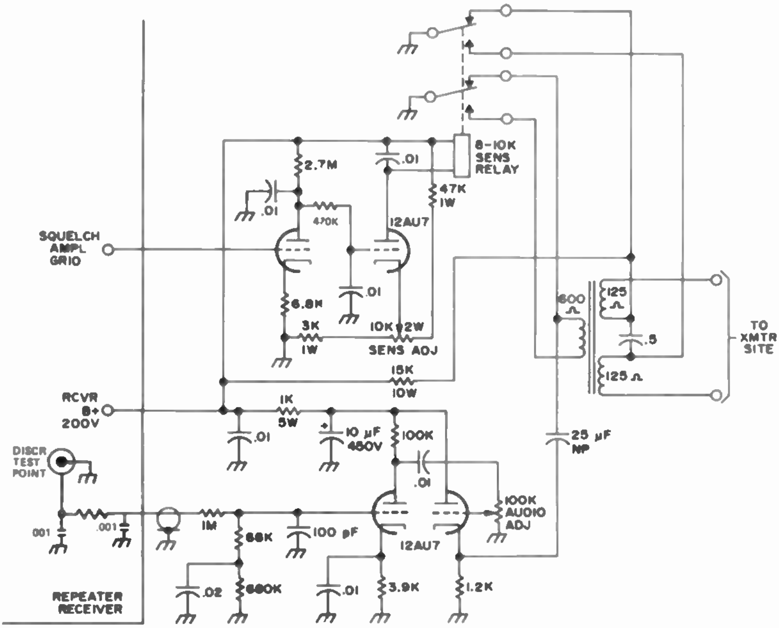


Fig. 1-21. Audio conditioning and carrier switching system. The audio transformer impedances are not critical, owing to the wide matching range of the cathode follower. The split secondary should match the primary of the transmitter-site transformer, however. The 100 kΩ pot in the cathode follower should be an audio type for smooth setting, though a linear taper will do the job.

wire pair for repeater linking because of some inexplicable fear of hum and audio level problems associated with mixing audio and B+. Such problems are nonexistent, however, in most two-site links. The secret is in the use of "balanced" lines. The transformers themselves, placed at both terminal points of the line, serve to balance the dc by virtue of the choke action of the windings through which the dc must pass. The only suggestion here would be to use good transformers.

For the benefit of the repeater builder who doesn't like to skip back and forth through a book to pick up bits and pieces of circuitry, Fig. 1-21 shows a complete receiver-site control scheme, which includes cathode follower audio processing, a carrier-operated relay, and a line transformer. All grounds shown are to the receiver chassis.

The Last Step

There is still one other repeater improvement technique that can be employed, but it is the one least used by repeater people. It takes practically no effort, and results in a system that is greatly improved in terms of actual usefulness. The trick? Nothing more complicated than a simple adjustment of the repeater squelch. But for some reason – no doubt intrinsically involved with ego in some way – repeater owners are all too frequently quite reluctant to do it!

The rule is this: Don't set a loose (sensitive) repeater squelch unless the transmitter can reproduce a weak input signal without degrading the performance of the receiver. The problems many mobile operators incur could be avoided completely if the local repeater talent would just adjust the repeater squelch to a realistic level. When signals are too weak into the system to overcome the desensitization problem, they should be kept from being repeated and providing an annoyance to the local stations who monitor the frequency. Repeater owners should bear in mind that even if a repeater can be activated by a weak station, this is not necessarily a guarantee that the output signal will be copyable by the users. And there is nothing so disconcerting as a repeater being constantly keyed by unintelligible signals.

Many convention-goers found this out at a recent hamfest when a hastily installed repeater was set to retransmit threshold signals. A number of walkie-talkies were turned off because of annoying and unintelligible garbage being relayed. A flick of the wrist at the receiver on the second morning of the FM convention, however, cured the problem, and the repeater was once more the useful and enjoyable communications medium that it was designed to be.

In short, if the range of the receiver doesn't match that of the transmitter, look for excessive desensitization. If you seem to have that problem whipped and the range imbalance still exists, try lowering the transmitter power. This will achieve the dual purpose of dropping whatever desensitization that may still exist and effectively bringing the range of the transmitter in to more closely approximate that of the receiver. Finally, set the squelch on the receiver so that those signals too weak to be copied do not even get repeated.

The result? Your repeater will be as busy as ever, but with cleaner signals – and you'll find more people monitoring more often during the inactive periods. But most important, your repeater may get the reputation for having input and output coverage that is ideally balanced. What better compliment to your system than to have people say, as they do of the Buffalo repeater, "If you can hear it, you can use it!"?

Solving Intermod Problems

Material presented in this chapter
is based on data provided by Donald L. Milbury (W6YAN),
whose article, *Technological Locusts That Plague the Age of Repeaters,* from which the information
was obtained, appeared in 73 Magazine, April 1971.

The heavy loading of active frequency channels on the amateur radio spectrum around metropolitan areas has produced increasing problems of interference – especially that ol' debbil called intermod. The combinations of frequencies that can mix together and produce intermodulation interference on a given frequency are practically countless. But the product chart of Table III does list the intermod products of the more commonly used 2 meter FM channels. By comparing this list of possible interfering frequencies against the frequencies in use in your own area, you should be able to narrow the search for the specific interfering frequencies. The products tabulated on this chart are derived from the equation 2A–B or 2B–A. where A and B are the mixing frequencies. Most intermod interference problems will result from this third-order intermod product.

Other Causes of System Degradation

Transmitter noise. Transmitter noise interference results from transmitter broadband noise radiation which is received on frequency and degrades or masks the desired signal. In general, transmitter noise is the result of noise components generated in the lower frequency multiplier stages being amplified through the final power amplifier and passed on to the antenna through the relatively broad selectivity of the amplifier output circuits. Transmitter noise generally is the dominant interference factor (over desensitization) at frequency separations up to 1 MHz.

Receiver Desensitization. Receiver desensitization is caused by strong, off-frequency signals that enter the front end of the receiver, driving it into saturation and thereby desensitizing the front end to the desired on-frequency signal.

The sorry fact is, any vacuum tube amplifier subjected to excessive grid drive voltages will draw grid current and undergo a shift in operating point. Depending on the circuit used, this grid current will produce a self-bias grid voltage. When a high bias voltage exists, it takes a correspondingly larger signal voltage to overcome the bias voltage before the tube can act as an amplifier. That's life.

Since a strong interfering signal cannot be completely eliminated from the rf stages, this signal can produce grid bias voltages which require stronger-than-normal signals to overcome the bias. This reduces the effective receiver sensitivity. The effect is principally noted in the second mixer. When the desensitization threshold is exceeded by a strong signal, the gain in the second mixer is reduced because of the signal amplification prior to the second mixer. As the level of the undesired signal becomes extreme, the first mixer is also affected.

Back to Intermod. Intermodulation is defined as the production, in a nonlinear transducer element, of frequencies corresponding to the sums and differences of the fundamentals and harmonics of two or more frequencies which are transmitted through the transducer. When two or more of these frequencies are "mixed," an infinite number of new frequencies are generated. Only a few, however, are located in that portion of the spectrum near the fundamental mixing frequencies.

The general equation for the intermodulation products is:

$$f_{im} = NB_1 \pm N_2(B-A)$$

Where A and B are the two mixing frequencies.

By substituting values of N_1 and N_2 of the equation, one can see that an infinite number of odd- and even-order intermod products are generated when two frequencies are

Table III. Intermod Product Chart

	146.40	146.43	146.46	146.69	146.52	146.55	146.58	146.61	146.64	146.67	146.70	146.73
145.22	146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83	145.80	145.77	145.74	145.71
146.25	146.10	146.07	146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83	145.80	145.77
146.28	146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83
146.31	146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95	145.92	145.89
146.34	146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95
146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01
146.40	146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07
146.43	146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13
146.46	146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19
146.49	146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25
146.52	146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31
146.55	146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37
146.58	146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43
146.61	146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49
146.64	146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55
146.67	146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61
146.70	147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67
146.73	147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73
146.76	147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79
146.79	147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85
146.82	147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91
146.85	147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97
146.88	147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03
146.91	147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09
146.94	147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15
146.97	147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21
147.00	147.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27
147.03	147.66	147.63	146.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33
147.06	147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39
147.09	147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51	147.48	147.45
147.12	147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51
147.15	147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57
147.18	147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63
147.21	148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69
147.24	148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75
147.27	148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81
147.30	148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87
147.33	148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93
147.36	148.32	148.29	148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99
147.39	148.38	148.35	148.32	148.29	148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05
147.42			148.38	148.35	148.32	148.29	148.26	148.23	148.20	148.17	148.14	148.11
147.45					148.38	148.35	148.32	148.29	148.26	148.23	148.20	138.17
147.48							148.38	148.35	148.32	148.29	148.26	138.23
147.51									148.38	148.35	148.32	148.29
147.54											148.38	148.35
147.57												

mixed. However, the even-order intermod products occur at frequencies well out of range of the problem area while the odd-order intermod products have frequencies which are close to the mixing frequencies.

The above discussion includes the intermod products of only two frequencies. A situation could exist where three or more frequencies mix to produce a product which could interfere with a system.

Diagnosis of Interference Problem

If one is faced with the problem of intermodulation interference, it would be extremely helpful to know the frequency of at least one of the signals being mixed. Often it can be recognized immediately where the interfering signal is intelligible. Also it is likely that one of the interfering transmitters is located geographically close to the receiver. If, on the other hand, neither frequency is known, the problem gets more complex. In a large metropolitan area there could be many possible combinations of frequency channels which could be mixing and producing interference.

Once the interfering frequency is known, the source of the mixing must be found. The intermod product is

146.76	146.790	146.82	146.85	146.88	146.91	146.94	146.97	147.00	147.03	147.06	147.09	147.12
145.68	145.65											
145.74	145.71	145.68	145.65									
145.80	145.77	145.74	145.71	145.68	145.65							
145.86	145.83	145.80	145.77	145.74	145.71	145.68	145.65					
145.92	145.89	145.86	145.83	145.80	145.77	145.74	145.71	145.68	145.65			
145.98	145.95	145.92	145.89	145.86	145.83	145.80	145.77	145.74	145.71	145.680	145.65	
146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83	145.80	145.77	145.74	145.71	145.68
146.10	147.07	146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83	145.80	145.77	145.74
146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95	145.92	145.89	145.86	145.83	145.80
146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95	145.92	145.89	145.86
146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01	145.98	145.95	145.92
146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07	146.04	146.01	145.98
146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13	146.10	146.07	146.04
146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16	146.13	146.10
146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25	146.22	146.19	146.16
146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31	146.28	146.25	146.22
146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37	146.34	146.31	146.28
146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43	146.40	146.37	146.34
146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49	146.46	146.43	146.40
146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55	146.52	146.49	146.46
146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61	146.58	146.55	146.52
146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67	146.64	146.61	146.58
147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73	146.70	146.67	146.64
147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79	146.76	146.73	146.70
147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85	146.82	146.79	146.76
147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91	146.88	146.85	146.82
147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97	146.94	146.91	146.88
147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03	147.00	146.97	146.94
147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09	147.06	147.03	147.00
147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15	147.12	147.09	147.06
147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21	147.18	147.15	147.12
147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27	147.24	147.21	147.18
147.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33	147.30	147.27	147.24
147.66	147.63	147.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39	147.36	147.33	147.30
147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51	147.48	147.45	147.42	147.39	147.36
147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51	147.48	147.45	147.42
147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57	147.54	147.51	147.48
147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63	147.60	147.57	147.54
147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69	147.66	147.63	147.60
148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75	147.72	147.69	147.66
148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81	147.78	147.75	147.72
148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87	147.84	147.81	147.78
148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93	147.90	147.87	147.84
148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99	147.96	147.93	147.90
148.32	148.29	148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05	148.02	147.99	147.96
148.38	148.35	148.32	148.29	148.26	148.23	148.20	148.17	148.14	148.11	148.08	148.05	148.02

produced in a nonlinear element which could be in the power amplifier of a transmitter or in the front end stages of a receiver. In some cases, the mixing can occur at some point outside the transmitter or receiver, such as a poor antenna-to-tower connection, or even a rusty drain pipe.

Using the Intermod Product Chart

The channels involved are listed at the left side of the chart and again at the top of the chart. By moving down a column headed by a frequency at the top and moving across a row headed by a frequency at the left, you can find the intermod product of these two frequencies at the intersection of the column and the row (as you find the distance between cities on a road map mileage chart). The most convenient starting point on the chart will be found on the page where your operating frequency is listed at the top and also on the left. At the intersection of this row and column you will also find your operating frequency.

From this point on the chart you can begin listing the possible interfering frequencies. The intermod product at your operating frequency will appear periodically on the chart to the left and right of the starting point. A pattern is established by moving up one row and to the left two columns, and by moving to the right two columns and down one row. The intermod product appears both to the left and right of the starting point for several pages. Wherever this product appears on the chart, it will occur at the intersection of the column and row headed by the possible interfering frequencies.

Example 1: Neither Frequency is Known. If your receiver frequency is 146.94 MHz refer to the spot on the chart where 146.94 MHz occurs at the top and the left side of the page. Moving to the side and up (and down) as indicated above, you'll find the frequency occurs at the intersection of the column and row headed by 146.88 MHz and 146.91 MHz, both of which are possible interfering frequencies. By continuing on in this manner both to the left and right of starting point you will find many combinations of channels which may be interfering with you. A knowledge of the channels in your area will probably narrow the possibilities to only a few channels.

Example 2. One Frequency is Known. If one of the interfering frequencies is known, the other frequency can easily be found. For example, assume that intermod interference is being experienced in a receiver operating on 146.94 MHz. One of the interfering or mixing frequencies is intelligible, and known to be operating at, say, 146.82 MHz.

To find the other mixing frequency, follow a two-step procedure. First, locate the 146.94 MHz product on the chart under the 146.82 MHz column and note that it intersects the row corresponding to 146.88 MHz. This frequency, 146.88 MHz, can be the unknown frequency (2A-B where A is 146.88 and B is 146.82). Next locate the 146.94 MHz product in the chart where it appears on the row opposite 146.82 MHz (left columns) and note it is under the column headed by 146.70 MHz. This frequency, 146.70 MHz, can also be the unknown frequency (2A–B where A is 146.82 MHz and B is 146.70 MHz).

Of course there are other equations that will produce intermodulation products, and intermodulation is not the only form of interference. The intermodulation product chart will be of assistance to you in showing a few of the combinations that can affect your system and through your own refinement and application of the chart, it can be of benefit to you.

PART II

Digital Identification

Although there are numerous methods by which a repeater can be identified automatically at predetermined intervals, the method that has gathered the strongest popularity is the CW approach, where a solid-state character generation scheme is used in conjunction with an audio oscillator and a timer to transmit the call letters of the repeater each time a carrier appears on the repeater input.

The first such circuit to appear in print was the WB6BFM identifier, published in FM Journal (January 1969). The author, Tom Woore, described a means for using a Karnaugh map to reduce the number of diodes in a typical identification matrix of integrated circuits.

Using Woore's basic idea, another amateur (P. J. Ferrell, W7PUG) gave the reduction process to a computer, and refined the overall character generation/logic system. Ferrell, in an article which appeared in 73 Magazine (September 1970), even offered to provide computer printouts of individual call-letter matrixes for other interested repeater owners along with circuit boards for his logic design.

Tom Yocom (WAØZHT) took Ferrell's work seriously, and used the original W7PUG article to spin off still another, this one accentuating the design aspects of construction. Yocom's goal was to simplify the design process so nonengineer hams might be able to apply common-sense principles to individual and unique call-letter situations.

All three of the aforementioned articles are presented in this section. The first is Woore's improved "Mod II" identifier unit. Woore's article is presented first because it has more background technical information and a summary of the logic symbols and terminology used in digital design. Next is Ferrell's article, which is complete in itself. Following this is the basic design article of Yocom's that was precipitated by the Ferrell ID unit. And finally, for those who don't like design or building, a description of the Curtis commercial ID unit is presented.

The WB6BFM Digital Identifier

The reliability of most electromechanical repeater identifiers leaves something to be desired. In many cases, an amateur repeater will operate as many as 500 times a day. According to a recent FCC ruling, each repeater must be identified at least every three minutes of operation. This means that the repeater may be identified just as many times as the repeater is operated. Most electromechanical devices such as relays, code-wheel devices, and tape decks cannot withstand the constant on/off operation of repeaters for any great length of time. Remember, those devices were for intermittent use – the code wheel for distress signals; the tape deck for listening pleasure, and so on. None of these devices were made to take the constant on/off use that is needed, let alone the environmental conditions.

One only has to climb to the mountaintop site after the first snow of the season because of an identifier failure to realize there ought to be a better way! Why not make the identifier solid state and eliminate those moving parts that wear out? Better still, why not use integrated circuits to accomplish the task? With a parts cost of less than $20, the Morse code digital identification unit (DIU) described herein does just that and it will outlast anything mechanical that you might otherwise put on top of a mountain.

The System

The DIU is unique in that it uses a simplified computer address principle for selecting the information it is programmed to send. There are four basic units in the DIU:

- Counter
- Matrix
- Signal logic
- Oscillator

The counter establishes which sequence is next. The matrix determines what instruction is next by the sequence. The signal logic converts the instruction information into the actual signal to be sent. The tone oscillator sends the requested signal. The whole system is based on a closed loop and therefore no standard clock is employed in the logic.

Logic Terms

To understand how the DIU works we must first become familiar with some of the simple logic terms that the system is based on.

High: Maximum output of logic unit (at least +1.5V)

Low: Minimum output of logic unit (less than +0.5V)

Inverter: Device used to produce opposite logic state of what is applied to it. Example: +2V into an inverter would produce a 0V output while a 0V input would produce a +2V output.

Symbol: 

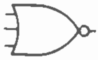
Or gate: Device used to give a high output when any of its input lines are high. Example: 3 input lines; one at +2V, the other two at 0V produces a +2V output on the output line of the gate.

Symbol: 

And gate: Device used to give a high output when *all* input lines are high. Example: 3 input lines; +2V on all 3 input lines of gate produces a +2V output on the output line of the gate.

Symbol: 

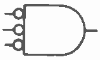
Nor gate: An inverted *or* gate; device used to give a low output when any of its input lines are high. Example: 3 input lines, one at +2V, the other two at 0V, produces a 0V output on the output line of the gate.

Symbol: 

Nand gate: An inverted *and* gate; device used to give a low output when *all* input lines are high. Example: 3 input lines, +2V on all 3 input lines of gate, produces a 0V output on the output line of the gate.

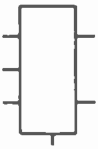
Symbol: 

For this article, *nor* gate logic was used to implement the *nand* functions; therefore, the definition for our purpose of a *nand* gate is a device used to give a high output when all of its input lines are low. Example: 3 input lines, 0V on all three input lines of a gate, produces +2V output on the output line of the gate.

Symbol: 

Note that the zero placed before or after the inverter, *nor*, and *nand* logic gates defines the expected state of the input or the output for the function to occur.

Flip-flop: A device used to store information a bit at a time. In the DIU application, a string of flip-flops is used as a counter. The purpose of the counter being to sequentially address the required instructions for the DIU.

Symbol: 

Unit: Smallest bit of information sent by the DIU (Dih, dah, or blank).

The DIU uses a MC700 series of Motorola integrated circuits due to their inexpensiveness and availability.

System Operation

A 0V signal through the start network (see Fig. 2-1) from the transmitter keying circuit resets all the flip-flops in the counter to the zero state. All Q' lines become high and all Q lines become low. Approximately 2V and 0V are fed into the diode matrix, which decodes the counter number into an instruction for the oscillator keying logic.

In the DIU there are four basic instructions: (1) send a dit, (2) send a dah, (3) send neither dit nor dah (blank), and (4) stop.

If the diode matrix decodes the first sequence count (0) to be instruction number 1 (send dit), the dit signal line from the matrix will be high. This will cause the dit inverter to have a low output and one-half of the "dit enable" gate will be enabled. Since the space line is also at "low" level at this time, a trigger pulse will be sent through capacitor C7 to the "dit" one-shot. (A one-shot is a monostable device used to generate a predetermined pulse-width.) The dit time pulse determined by the one-shot is sent through the "dit or dah" gate and the "dit or dah/blank" gate to enable the "dit or dah send" gate. The *nand* gate keys the oscillator circuit to produce the dit signal.

At the same time the dit is being sent by the one-shot to the oscillator, the "space" one-shot logic is being reset via the "dit, dah, or blank" gate, inverter, and "space enable" gate.

Upon completion of the dit signal, the "dit, dah, or blank" gate becomes high, making the inverter output low. Since the stop instruction has not been called for by the matrix, the "space enable" gate produces a high output. The high output in turn sends a pulse through capacitor C3 to trigger the "space" one-shot. (The space time period is used to separate the units of a letter. Example: D = dah-space-dit-space-dit.

The space period is the same as the period for the dit. The space signal, besides allowing for the time to distinguish the units of a letter, advances the counter through an inverter to the next unit and resets the "dit" and "dah" one-shots by discharging capacitors C5 and C7.

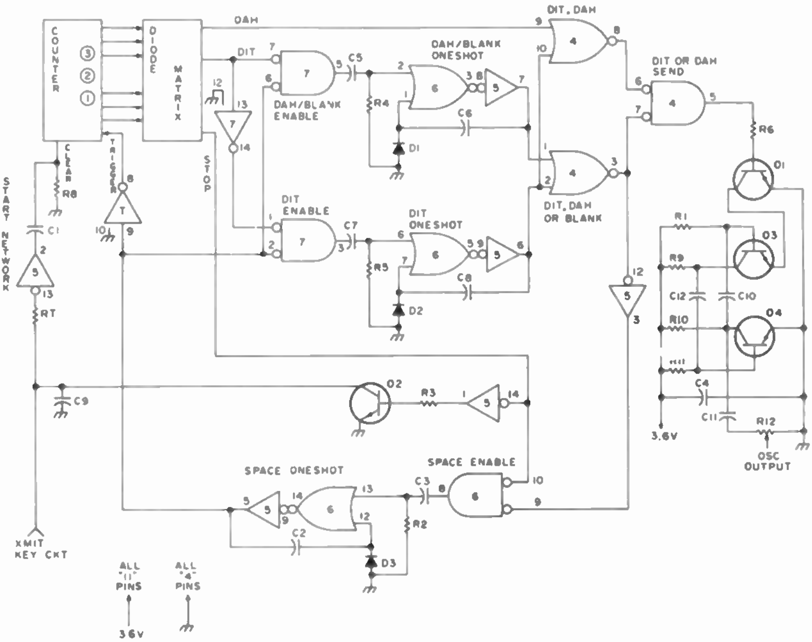
If the diode matrix decodes the next sequence to be instruction 2 (send dah), the dah signal line from the matrix will become high and the dit signal line will become low. When the space lines becomes low, the "dah/blank enable" gate will send a pulse through capacitor C5, triggering the "dah/blank" one-shot. The dah/blank pulse would then go through the "dit or dah" gate. These two gates would then enable the "dit or dah send" gate to trigger the oscillator for the dash period. The "space" one-shot is again triggered to advance the counter to the next unit.

If the diode matrix decodes the next sequence to be instruction 3 (send a blank), neither the dah nor dit line will become high. The same will occur as above for the dah except that when the signal reaches the coincidence gates the "dit or dah" gate will not be enabled. Thus the oscillator will not be keyed. This generates the blank period which is put between letters. (Example: DE = dah-space-dit-space-dit-blank-dit-blank) Again the loop through the "space" one-shot is triggered and the counter is advanced to the next unit of information.

The counter is advanced each time a unit of information is sent until it is advanced to the "stop" instruction. This instruction causes a blank to be automatically sent and stops the "space enable" gate from triggering the space one-shot. The DIU remains in the stop state until a reset pulse is sent to the counter from the transmitter keying circuit and the whole process starts over again.

Of course the DIU works much faster than it can be described. Depending on the component values selected for C2, C6, and C8, the DIU can function at any reasonable speed. The particular values used in the prototype and listed for Fig. 2-1 (see parts lists) causes the unit to identify at the rate of 42 wpm (2 seconds for DE W6FNO). If a faster or slower rate is desired, capacitor values should be changed accordingly. It should be noted, however, that C8 must be three times as large as C2 and C6 to give the proper character formation. This is a critical relationship and follows from the fact that a space and dit are identical in time length while a dash or blank is three times the length of a dit.

Transistor Q2 is used to lock on the transmitter keying circuit while the digital identification unit is sending its identification code. If a timer is used in conjunction with the identifier, the transmitter will be keyed for the duration of the identification every time the DIU is reset. This allows a complete sending of the identification regardless of whether the transmitter remains keyed by an



Parts list for DIU Logic Board and Diode Matrix

DIU Logic Parts	
R2-8	10 K ¼W
R9, R10	3.3 K ¼W
R1, R11	33 K ¼W
C1, C3, C5, C7, C9	.05 μ d disc 25V
C10, C12	.008 μfd disc 25V (1000 Hz)
C2*, C1, C8*	10 μfd/15V
C4, C6*	30 μfd/15V
*Must change in direct ratio	
IC1-3	Motorola 791P
IC4, 6, 7	Motorola 724P
IC5	Motorola 789P
Q1-4	2M3415 or equivalent
D1-3	1N34 or equivalent
IC sockets wire-wrap type	Vector R-714
22 pin PC socket	Vector R-644
Matrix Parts	
0-20 resistors	3.2 K ¼W
60-100 diodes	ge or si (all same type)
22-pin PC socket	Vector R-644

Fig. 2-1. Digital identification unit, logic and schematic diagram.

external circuit such as a COR (carrier-operated relay) or not. If this feature is not desired, Q2 should not be installed.

Transistor Q1 is used to key the oscillator, while Q3 and Q4 – along with the feedback and bias networks – make up the oscillator. The oscillator was designed to be fed directly to the grid of the modulator in the transmitter.

The Diode Matrix

Up until now very little has been said about the diode matrix other than the fact that it determines what instruction to give the keying logic. The actual construction of the matrix can be considerably simplified and consequently cheaper. Up to 70% of the diodes necessary for the diode matrix can be eliminated by using mathematics. A much more sophisticated, economical, and space-saving layout can be achieved using Boolean algebra. Thanks to Mr. Karnaugh, it is not necessary to give a complete discussion on Boolean algebra. The Karnaugh map is a device for mechanically determining the mathematical equivalent of the diode matrix. For the purpose of this discussion the MCW message will be "DE W6FNO." Of course, any other message can be developed by this method and consequently this discussion may be used for developing any matrix logic.

The first step in determining the diode matrix for the message is to break up the message into the units to be sent: · = dit, - = dah, x = blank. This is shown in the breakdown diagram Fig. 2-2.

It is seen that 30 units of message will be sent (0 is actually used for a blank). To convert units 0 to 29 into a diode matrix, the Karnaugh map is used (see Fig. 2-3.)

The numbers in the boxes correspond to the decimal equivalent to units on the output of the counter. The

```
0  1  2  3  4  5  6  7  8  9     11       14       17             22       25          29
x  -  .  .  x  .  x  x  .  -  -  x  -  .  .  .  .  x  .  .  -  .  x  -  .  x  -  -  -  S
                                                                                       t
                                                                                       o
                                                                                       p
```

Fig. 2-2. Unit breakdown diagram.

numbers across the top and along the side of the chart correspond to the binary output of the flip-flops – 1 for true or 0 for false. The letters written diagonally in the top left corner refer to the six flip-flops. Example: Box 17 has flip-flop A true, B false, C false, D false, E true, and F false. Written in Boolean form, 17 would be represented by AB'C'D'EF', where the apostrophe after the letter indicates that the flip-flop is false and, conversely, a letter without an apostrophe is true.

To simplify the matrix, a Karnaugh map is constructed separately (Figs. 2-3 and 2-4) for the dits and dahs to be sent. From Fig. 2-2, units 2, 3, 5, 8, 13, 14, 15, 16, 18, 19, 21, and 24 represent the dits to be sent in the message. In the dit Karnaugh map (Fig. 2-4) a 1 is placed in each box corresponding to the number. An X (not the X which represents a blank) is placed in all boxes after the stop code number. These are "don't care" conditions because the counter will not count to these codes.

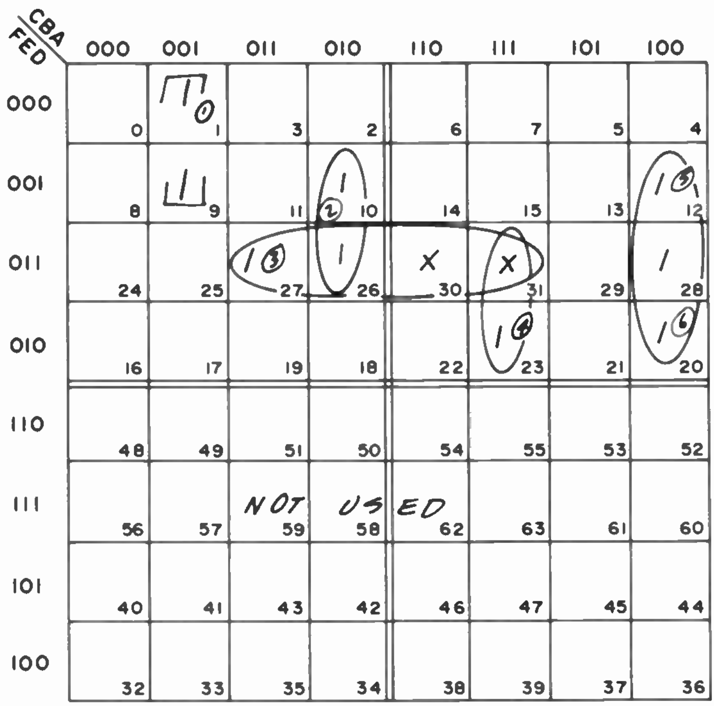


Fig. 2-3. Karnaugh map of dahs to be generated in DE W6FNO.

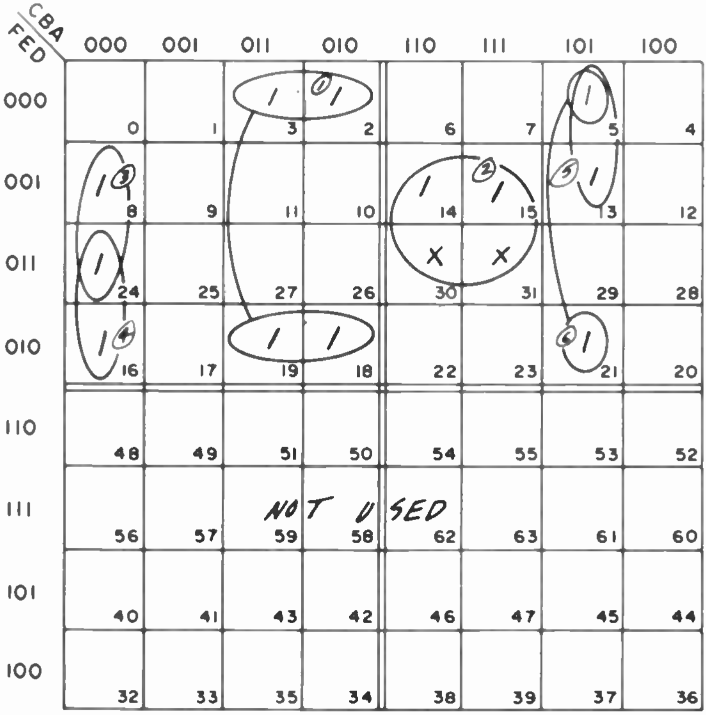


Fig. 2-4. Karnaugh map of dits to be generated in DE W6FNO.

From the dit Karnaugh map it can be seen that the third unit of information is a dit and that flip-flop A is true, B is true, C is false, D is false, E is false, and F is false or ABC'D'E'F'. To put this in matrix form, the Boolean algebra tells us that this dit would be represented by a diode connected to Q_a lead (the true lead of flip-flop A), another to Q_b, another to Q_c' (the false lead of flip-flop C), another to Q_d', another to Q_e'. Since there are only 30 units of information, flip-flop F is not used. A line may be used over any of the symbols to indicate the same thing as an apostrophe. It would normally take six diodes (seven when the F flip-flop is used) to send this unit of information. (See Fig. 2-5.)

Actually, it would take six diodes (seven when the F flip-flop is used) for each unit of information in the message or 29 x 6 = 174 diodes. The includes the diodes needed to *or* the dahs together and the dits together. This is where the Karnaugh map saves diodes. Again on the map

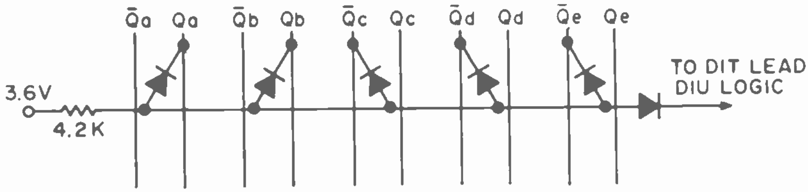


Fig. 2-5. Unit 3 information – dit.

in Fig. 2-4 any adjacent box or any box that changes just one variable from another box eliminated that variable. Boxes 8 and 24 simplify to A'B'C'D, eliminating the E flip-flop altogether. Boxes 3, 2, 19, and 18 also simplify since they change one variable at a time or BC'D'. Note that not only is 3 represented by BC'D' but also 2, 19, and 18, resulting in a savings of 20 diodes – 4 numbers x (5+1or) – (3+1or used) = 20. 24 and 15 combine with "don't cares" 30 and 32 to equal BCD. The final expression (though not the only expression that will work) for the dits is BC'D' + BCD + A'B'C'D + A'B'C'E + AB'CE' + AB'CD'.

Figure 2-3 was used to develop the dah equation which is AB'C'E' + A'BC'D + BDE + ABCE + A'B'CD + A'B'CE. 28 diodes were used to develop the dit matrix, 29 were used for the dah matrix, and 5 were used for the stop code, giving a total of 62 diodes for the entire matrix. Quite a few less than 174!

The final matrix appears in Fig. 2-6 for the message DE W6FNO. Note that any matrix of this magnitude can be determined by the above method. To expand to 64 units of information the mirror image of the first 32 units is used in the Karnaugh map. In Figs. 2-3 and 2-4 the "not used" portion would be used. The upper portion of Fig. 2-6 illustrates the wiring of the counter; note that it mates to the leads of the matrix.

Construction of the DIU

Since the publication of the first article on the DIU numerous people have sought printed circuit boards for the unit. In order to obtain the DIU logic, matrix, or power supply boards, write to Keith Whitehurst, Box 538,

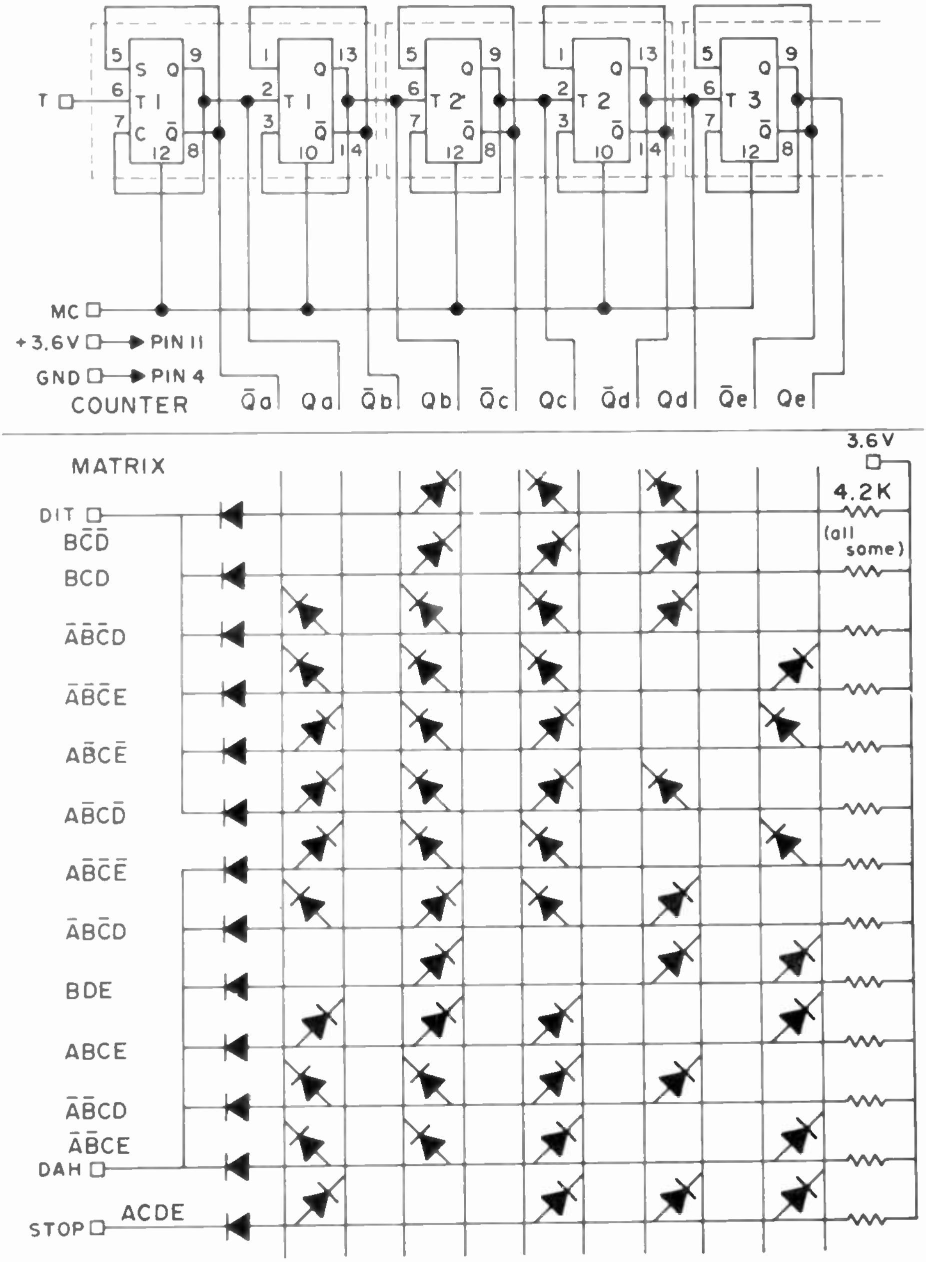


Fig. 2-6. DIU matrix and counter for sending DE W6FNO.

Claremont, Calif. 91711. The boards incorporate standard plugs at the end of each card for easy installation and removal. This feature is especially advantageous when one desires to change the DIU message. All component wiring is clearly labeled to facilitiate easy installation of components. The boards should be mounted in an rf shielded environment as stray rf tends to play havoc with the keying circuits of the DIU.

If at all possible, integrated circuit sockets should be mounted on the board. In the event they are not, care must be used in soldering the chips to the printed circuit board in order that the chips are not overheated. A small pencil soldering iron will do nicely for solderithe ICs to the PC board.

All parts are readily available from most electronic parts houses. The Motorola ICs, 3.9V zeners, and transistors were obtained from Hamilton Electro Sales.

Power Supply

Figure 2-7 illustrates the schematic of the DIU power supply. Any power supply may be used if the power output is 3.6V with less than 5% ripple (including voltage spikes).

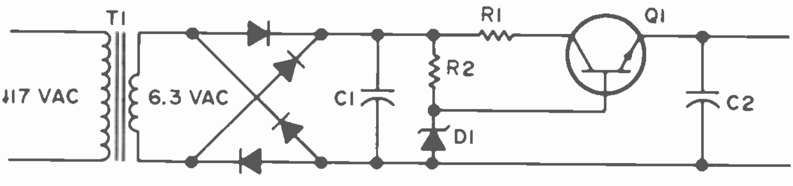


Fig. 2-7. DIU regulated power supply.

DIU Regulated Power Supply Parts List

T_1	Stancor P6465 117 VAC to 6.3 VAC, 600 Ma.
D_1	3.9 Volt Zener Diode, 1N748 Motorola
D	1 Amp, 12 Volt Diodes or HEP Bridge Rectifier
C_1	1000 ufd. at 12 Volts or greater
C_2	200 ufd. at 12 Volts or greater
R_1	10 ohm at 6.3 VAC input
	5 ohm at 3.2 VAC input
R_2	220 ohms at 6.3 VAC input
	110 ohms at 3.2 VAC input*
Q_1	2N4921, 2N3055 or HEP 245

*To be used with center tap 6.3 VAC and full wave rectifier.

Installation

The signals normally received and sent to and from the DIU should meet the following criteria:

1. From power supply – 3.6V dc, well filtered and regulated.

2. From transmitter keying circuit – 0V, transmitter keyed; approximately 6V transmitter unkeyed (filtered).

3. To transmitter keying circuit – identifier off: 10 MΩ; identifier keyed: 10Ω.

4. To modulator circuit – high impedance DIU oscillator output.

Note that all dc input lines to the DIU logic should be filtered. In some relay circuits the output of a bridge rectifier is used to directly key the transmitter relay. So the pulsating dc does not key the digital identification unit, a 60 μF capacitor (or greater) should be placed across the relay supply.

It is worthwhile to note that the original prototype, after nearly three years, is still operational atop Johnstone Peak in San Dimas, California, sending out for all to hear – DE W6FNO.

A Computer-Optimized Digital Identifier

The W7PUG Digital Identifier

A project to develop an automatic, solid-state CW ID generator was recently initiated by members of the Seattle repeater group. Although there have been a number of recent articles concerning such devices, [1-2-3-4] our starting point was the FM Magazine article by Woore,[2] appearing as the previous chapter. The outcome of this project must be classified as an engineering overkill. The resulting CW identification generator features a clocked character generator (for flawless CW with variable speed), inexpensive RTL integrated circuitry, and a computer-designed diode read-only memory matrix. Also included are "pulse" starting, a discrete "hold" voltage available during ID execution, and a continuously adjustable keying speed (from far too slow to far too fast). Not only are these generators ideal for repeater identification, but they may be used to identify any amateur station such as RTTY, ATV, etc.

The block diagram in Fig. 2-8 shows the major divisions of the ID generator. Many excellent articles covering RTL logic design have appeared in amateur literature[5-6] and the reader is referred to them for background material.

Program Counter and Start/Stop Flip-Flop

This six-stage ripple counter consists of three dual JK flip-flops. The first five cascaded stages are the program counter and count from 0 to 31. The last stage is employed as the start/stop flip-flop. Each stage of a ripple counter is arranged to toggle (change state) on the output of the preceding stage. A five-stage program counter has 32 distinct stages ($2^5=32$). When arranged as shown in Fig. 2-9, the program counter advances under the control of gate G1 which derives its input from the character generator. Each dot, dash, or blank character advances the program counter by one count. The last character (number 32) resets or clears the first five stages, but toggles the start/stop flip-flop to the "stop" or set position, thereby halting the character generator.

A positive pulse into the "preclear" input of FF6 clears the halt and allows the character generator to run, thereby initiating a cycle of operation. A five-stage program counter was chosen since virtually all amateur calls can be encoded in 32 characters worth of dots, dashes, and blanks. RTL JK flip-flops are adversely affected by capacitive output loads, and will not toggle reliably if the capacitance is too high. This fact precludes the use of silicon diodes in the *and* portion of the diode memory.

If the program counter output lines were buffered (isolated from the flip-flops with gates or inverters), then any type of diode could be used in any memory position; but germanium diodes have very low capacitance and may be connected directly to the flip-flop outputs, thereby saving the cost of 10 buffer stages.

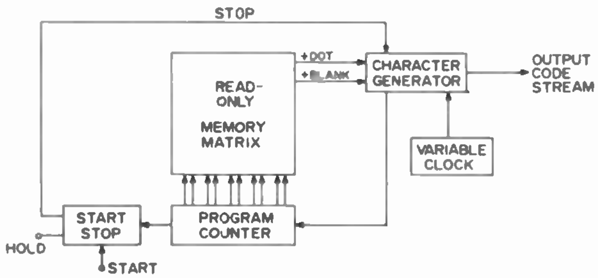


Fig. 2-8. CW ID generator block diagram.

Variable Speed Clock

The clock circuit must deliver a negative-going pulse with leading edge of less than a microsecond duration in order to toggle an RTL JK flip-flop. The pulse repetition rate should be variable to permit choice of code speed. The circuit is shown in Fig. 2-10 with a PNP silicon transistor

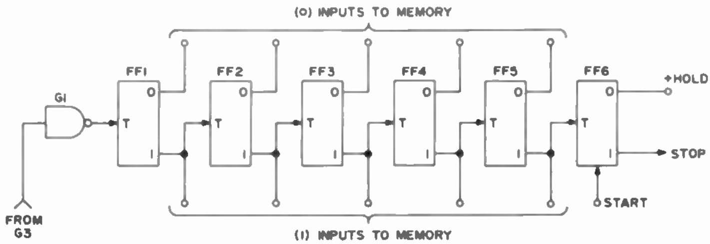


Fig. 2-9. Program counter.

paired with Gate G2. The net effect is a PNPN switch. Capacitor C charges to about 2V and then discharges through the gate with a leading edge which is very abrupt.

Nearly any of the new PNP silicon trasnsitors will work in this circuit. The minimum value for R is about 33 kΩ else sufficient current is available to hold the switch in conduction (just like a neon relaxation oscillator). For R much above 1 MΩ insufficient current is available to initiate the regenerative "snap" action. Values of R between these limits work well.

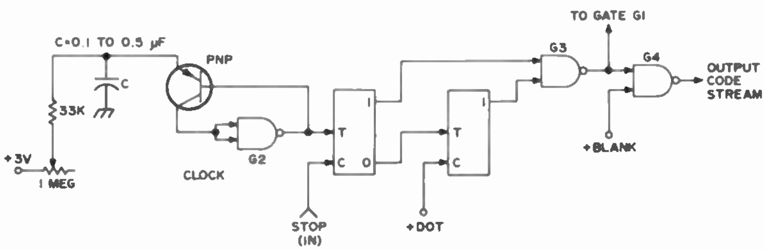


Fig. 2-10. Clock and character generator.

Character Generator

The electronic generation of Morse code requires the creation of dots, spaces, dashes, and blanks which have a precisely specified relative length. The dot and space are each of one unit duration, while the dash and blank are each of three units duration.

An extremely clever character generator was borrowed from the Micro-Ultimatic Keyer[7] and forms the heart of the ID generator. The character generator consists of two JK flip-flops (FF7 and FF8) and gates G3 and G4 as shown in Fig. 2-10. A positive (stop) voltage on terminal C of FF7 holds it in the clear state, thereby stopping the character generator. If the stop voltage is removed, the character generator toggles in such a manner as to produce a string of dashes at the output of gate G4. A positive (+DOT) voltage on terminal C of FF8 changes the string of dashes into a string of dots. A dash (or blank) requires four clock pulse intervals while a dot requires two. Gates G1 and G4 each invert the output of gate G3.

The output of gate G1 must be either a dot or dash character (never a blank), and is used to advance the program counter at the end of each character. The second input to gate G4 will blank out the output code stream, and is used to produce a blank character. If a blank is required, then a positive "+BLANK" input from the diode memory causes the dash generated by the character generator to be blanked out – which results in the transmission of a blank character.

Thus, the role of the diode read-only memory matrix is to provide just that sequence of +DOT and +BLANK inputs to the character generator which results in the transmission of the desired code stream. Gate G4 is the output with a plus representing "key down" and a zero representing "key up."

polarity of the (1) output

FF5	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o
FF4	o	o	o	o	o	o	o	o	+	+	+	+	+	+	+	+
FF3	o	o	o	o	+	+	+	+	o	o	o	o	+	+	+	+
FF2	o	o	+	+	o	o	+	+	o	o	+	+	o	o	+	+
FF1	o	+	o	+	o	+	o	+	o	+	o	+	o	+	o	+
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
+DOT	o	+	+	o	+	o	o	+	o	o	o	o	o	+	+	+
+BLANK	o	o	o	+	o	+	+	o	o	o	+	o	o	o	o	o
CHARACTER	—	·	·	x	·	x	x	·	—	—	x	—	—	·	·	·
		D			E				W					7		

Fig. 2-11. Diode memory inputs and outputs.

Diode Read-Only Memory Matrix

This is the hard part! Each desired code stream requires a distinct and different read-only memory design. A +DOT voltage must be produced by the diode memory for each program counter state the corresponds to a dot in the desired code stream, and a +BLANK is required for each blank character. An example is presented in Fig. 2-11.

Suppose that the first letters of the desired code stream were "DE (blank, blank)W7." The program counter states are shown corresponding to the required outputs from the diode memory matrix. A dash is seen to be the "default" condition; i. e. if neither a +DOT nor a +BLANK occurs, a dash results. Each of the 32 program counter states must be accounted for since they all appear on each ID execute cycle.

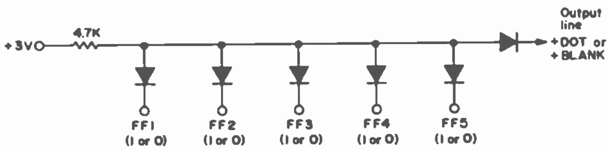


Fig. 2-12. Diode decoder for program counter.

Fig. 2-12 shows the method for decoding the program counter. The five terminals marked FF1 through FF5 are connected to either the 1 or 0 side of the respective flip-flop. If *any* of the five connections is low, then the whole common line is low. The only time the common line can be high is when all five input connections are high. For any given connection, this will occur exactly once during each program counter cycle. This type of diode decoder is often called an *and* gate since it has a high output only when all inputs are high.

Because of the diode output from the common line, these decoders may be paralleled to obtain the required +DOT and +BLANK functions. This paralleling is often referred to as an *or* gate since *any* high input results in a high output.

In the example of Fig. 2-13, the desired code stream has 15 dots and 9 blanks. If we employ a separate diode

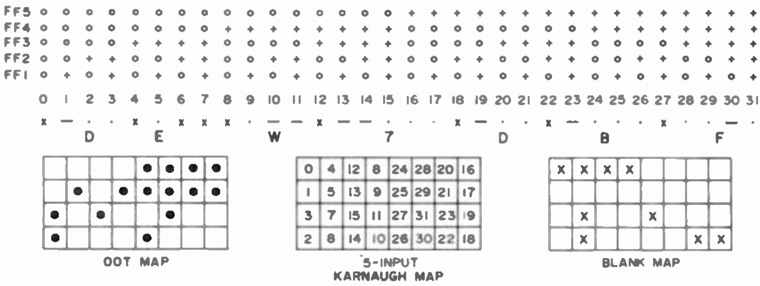


Fig. 2-13. Using the Karnaugh map.

decoder for each one, then a total of 24 decoders would be required: 15 would be paralleled to give the +DOT signal and the remaining 9 would be paralleled to provide the +BLANK signal. Each decoder requires 6 diodes for a grand total of 144 diodes to build a straightforward read-only memory using this technique.

Fortunately for us, the English philosopher George Boole published his *Investigation of the Laws of Thought*, in which he resolved the ambiguity of the words *and* and *or* by means of a kind of algebra. In 1938, eighty-four years later, Prof. D. E. Shannon (the *Information Theory Shannon*) put Boole's algebra or Boolean Algebra to use in the *Symbolic Analysis of Relay and Switching Circuits*. This classic paper has revolutionized switching design, and has led to the development of minimization techniques which can dramatically reduce the diode count of our ready-only memory. The details of these methods and the underlying theory are beyond the scope of this article, but for those who are fascinated by this stuff, standard texts are available which will quickly dispel the aura of "black magic" that seems to surround this area.[8]

For our purpose, a graphical reduction technique known as a *Karnaugh map* will be employed. Figure 2-13 illustrates the process for the code stream DE W7DBF. The polarity of the 1 output levels of flip-flops FF1 through FF5 are shown as the program counter steps from 0 (all FFs clear) to state 31 (all FFs set). The sample code stream begins with a blank and has three blanks separating the DE from the W.

A Karnaugh map organization of program counter states is presented, flanked on the left by the DOT map and on the right by the BLANK map for the desired code stream. Reduction is accomplished by "folding" the map about any of the dividing lines and pairing the marks (dots or blanks) which overlap. For example, folding the DOT map about the vertical centerline pairs dot 5 with dot 21, and dot 9 with dot 25, and dot 15 with dot 31. Successive pairing, then pairing pairs, etc. allows a reduction from the original 144 diodes to a total of 48 diodes arranged as shown in Fig. 2-14. Note that in Fig. 2-14, the 0/1 flip-flop lines are reversed for FF2 and FF4. This reversal materially simplifies printed circuit construction.

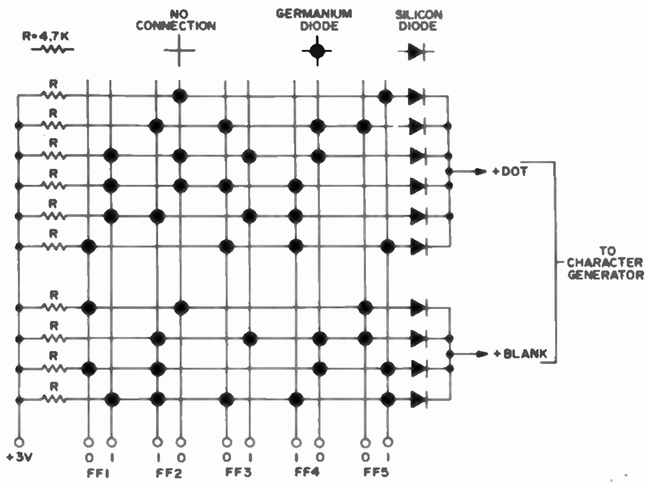


Fig. 2-14. Diode read-only memory matrix for "DE W7DBF."

As an example of pairing, consider the blanks in positions 0, 4, 8, and 23 of the BLANK map of Fig. 2-13. If the map is folded about the second vertical line (the one separating positions 4 and 12), then blank 4 pairs with blank 12, and blank 0 pairs with blank 8. If we fold again, then all four flanks coincide with each other. This is illustrated in Fig. 2-15. In Part A, the program counter states for positions 0 and 8 are compared. They differ in exactly one FF position (FF4) as all pairs must. A single diode decoder of the type shown in Fig. 2-12 could get

FF5	o	o		o	o	o		o	o	o		o
FF4	o	+			o	+						
FF3	o	o	=	o	+	+	=	+	o	+	=	
FF2	o	o		o	o	o		o	o	o		o
FF1	o	o		o	o	o		o	o	o		o
	0	8			4	12			Pairing A and B			
	(A)				(B)				(C)			

Fig. 2-15. Actual reduction procedure.

both blanks simply by neglecting to connect to FF4. It even saves one *and* diode.

Part B of Fig. 2-15 presents the same comparison for blank 4 and blank 12, and again they differ only in FF4. In part C, a comparison of the 0/8 with 4/12 pairs shows that these differ only in FF3. Thus, if a three-input diode decoder of the type presented in Fig. 2-12 were connected to FF1 (0), FF2 (0), and FF5 (0), it would give a +BLANK for all four desired program counter states (0, 4, 8, and 12). Without this reduction, 24 diodes (six for each blank) would have been required rather than the four actually required. This diode decoder may be found in Fig. 2-14 as the first line in the +BLANK group.

The foregoing example illustrates the use of a Karnaugh map. The actual reduction is performed as in Fig. 2-15. It should be noted that some states will not pair at all, such as blank 27 in Fig. 2-13. To pick up this blank, a full five-input diode decoder is required. From Fig. 2-13, we see that for blank 27, the program counter is in state "++0++" and the resulting diode decoder can be found in Fig. 2-14 as the bottom diode line.

The rule when pairing states is that the two program counter states can differ in exactly one flip-flop position. All other positions must agree, including any omitted connections as in Fig. 2-15, part C. If there is disagreement in more than one FF position, then these two states do not pair.

After completing the reduction process, check to make sure that every necessary state has been covered at least once by one of the final decoders; otherwise, you may be surprised at the resulting code stream. This type of calculation, once understood, is not particularly difficult, but it certainly is tedious and has lots of room for errors. Slight changes in the desired code stream (even position) can have a huge impact on the diode count.

For example, the diode count for the code stream in Fig. 2-13 is 48. If just the **DE** is slid one count to the right, a new code stream is formed which starts with two blanks, and has two blanks between the **DE** and **W**. The diode count for this new stream is 55. If this new stream is shifted two positions to the left, so that the two leading blanks become trailing blanks, then the diode count becomes 85. These effects are unpredictable, and for complete optimization each code-stream version must be reduced separately, and the results compared. This greatly increases the already great tedium of such calculations.

Computer Optimization

In order to minimize the pain of diode memory design, the task was subcontracted to a digital computer. The Seattle repeater group is extremely fortunate in having

```
EXECUTION BEGINS...


CODE STREAM [ -.. .   .-- --... -.. -... ..-.]
REQUIRES 48 DIODES AND 10 RESISTORS.

PLACE SILICON DIODES (S), GERMANIUM DIODES (G), AND
4.7K RESISTORS (R) IN THE FOLLOWING POSITIONS:

D B  0 1 2 3 4 5 6 7 8 9  +
S          G           G  R
S        G   G     G G    R
S      G   G   G   G      R
S      G   G G   G        R
S      G G     G G        R
S    G       G   G     G  R
  S  G     G         G    R
  S      G     G   G G    R
  S      G         G   G  R
  S    G G   G   G     G  R


EXECUTION COMPLETE...
```

Fig. 2-16. Computer printout.

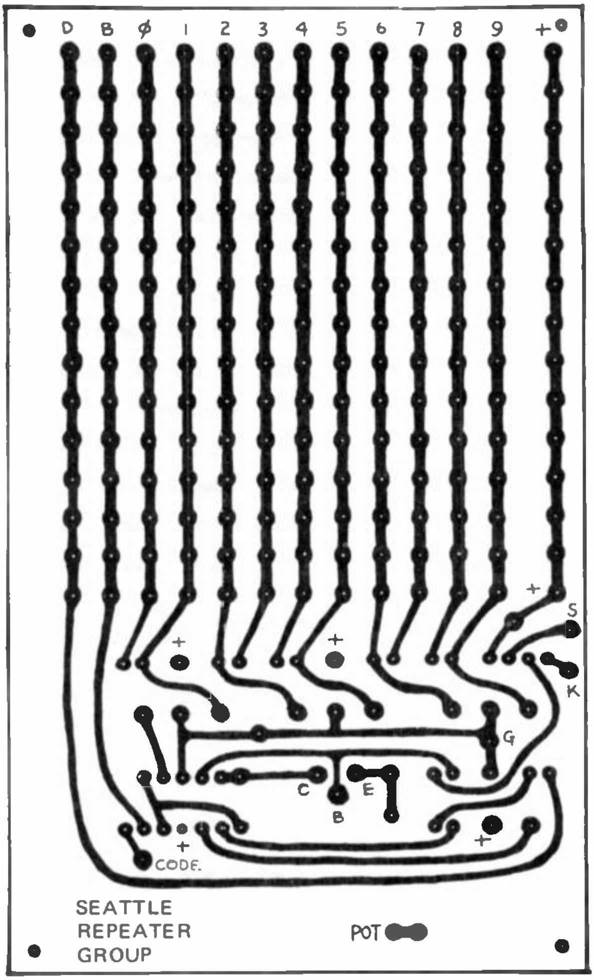


Fig. 2-17. Full-size reproduction of PC board bottom.

remote access to the University of Washington Computer Center's Burroughs B5500 computer, one of the nicest hardware/software systems ever put together. The resulting program in extended ALGOL accepts the desired code stream (in dots, dashes and blanks) as an input and performs a complete Boolean reduction for both +DOT and +BLANK diode decoders.

If the specified code stream is less than 32 characters (more than 32 characters are not allowed), then the computer assigns the necessary trailing blanks and performs

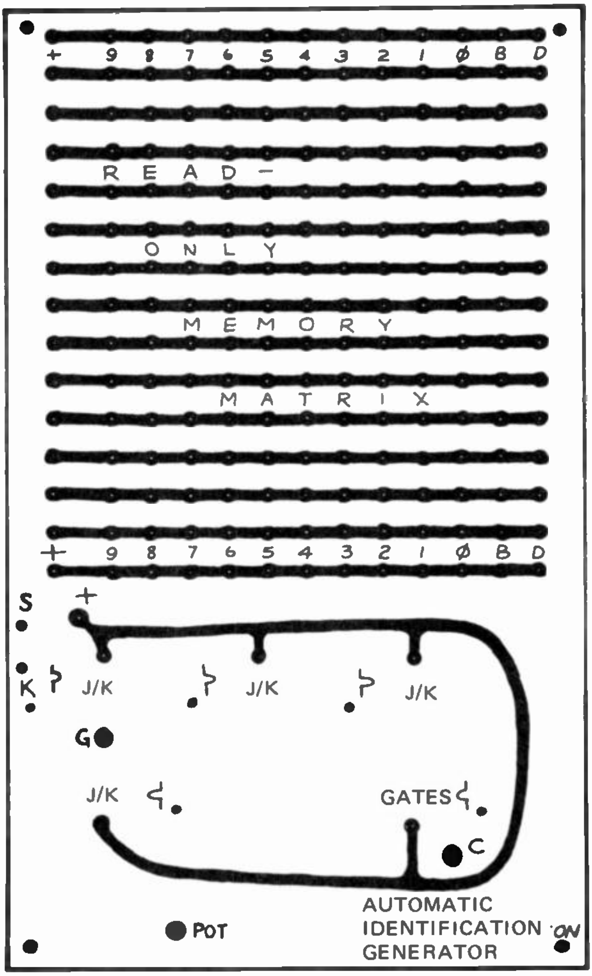


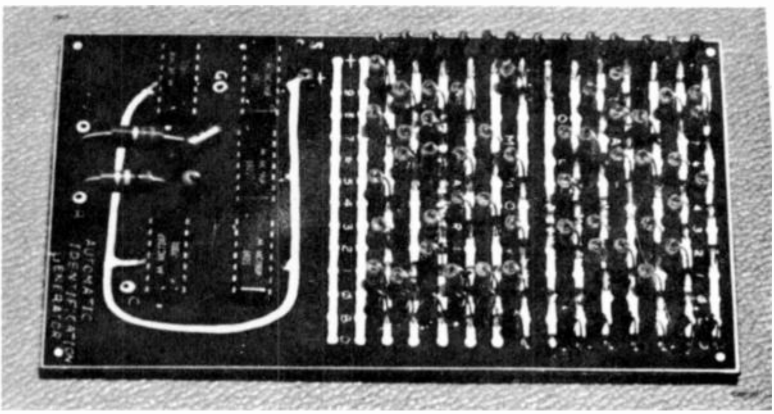
Fig. 2-18. Full-size reproduction of PC board top.

the required reductions, and repeats the process for each shift of the code stream until all the trailing blanks have become leading blanks. The code stream version having the smallest diode count is printed out along with diode and resistor counts and an actual map of the entire diode read-only memory matrix. Examples of the digital computer printout are shown in Fig. 2-16.

Construction

The four dual JK flip-flops are Motorola MC790P (or HEP 572) and the quad 2-input gate is a Motorola MC724P (or HEP 570). Virtually any PNP silicon transistors will function in the clock circuit. A HEP 57 is a good choice. Both germanium and silicon diodes are used in the diode read-only memory. Germanium diodes are employed for the *and* function, since their low junction capacitance will not load the JK flip-flops in the program counter. Either silicon or germanium diodes may be used in the *or* function, with silicon signal diodes preferred since they result in a higher noise margin for the memory. Cheap diodes are available from various solid-state supply houses. Poly Paks features 50 silicon or germanium diodes for $1.

Both sides of 3 x 5 in. double-sided PC board are shown in Figs. 2-17 and 2-18. A one-sided board was used for the first few models, with a second 3 x 3 in. board used to complete the matrix connections. This "cordwood" construction is a pleasure to look at, but a nightmare to wire up. If a diode goes "west" on a cordwood style generator, it is best to throw it away, since unsoldering about 80 diodes and resistors and then getting things back together is even worse than the initial construction effort. A double-sided epoxy–glass PC board is recommended for the ID generator. An operational generator should be enclosed in a metal box with all leads bypassed for rf. Even VHF/UHF fields have the ability to drive RTL logic circuitry absolutely crazy. Before undertaking the construction of this ID



Here's what the board looks like when the flatpacks and diode matrix are soldered in. The vertical placement of the diodes helps to keep the size down to this 3 x 5 in. circuit board (Photo by K7WMC.)

generator, the builder should obtain as many of the referenced ID generator articles[1-2-3-4] as can be found and read them over carefully. The additional background material will amply repay the effort involved.

The Seattle repeater group can supply a moderate number of tinned epoxy–glass circuit boards for this ID generator. The board is not drilled, but assembly instructions and a computer optimized diode map for the circuit board is included. Be certain to specify the desired code stream, keeping in mind the absolute limit of 32 characters (dots, dashes, and blanks). Unit cost is $10, and it may be obtained from the Seattle repeater group, 18235 46th Pl. S., Seattle WA 98188.

References

1. *A Digital Identification Generator*, Barry Todd K6ZCE, 73 Magazine, March 1967.
2. *IC Repeater Identifier*, Tom Woore WB6BFM, FM Magazine, January 1969.
3. *Automatic CW Identifier*, John Connors W6AYZ, Ham Radio Magazine, April 1969.
4. *A Digital Morse Code Generator*, Jerry Hall K1PLP, QST, June 1969.
5. *Digital Logic Devices*, QST, July 1968.
6. *Micro-Logic for Non-logic Users*, Hank Olson W6GXN, 73 Magazine, June 1967.
7. *The Micro-Ultimatic*, Tom Pickering W1CFW, 73 Magazine, June 1966.
8. *Logical Design of Digital Computers* Montgomery Phister. John Wiley & Sons 1958.

WAØZHT Design Data

In digital design, one frequently starts with a rather simple block diagram of the device desired and then proceeds to draw the detailed logic diagram consisting of the various *nand* and *nor* gates required to accomplish an objective. It is frequently useful to express some of the relationships mathematically using Boolean algebra. If you have mastered the subject you can then apply simplification rules to the equations to produce a less complicated statement of the problem. This is desirable because as you reduce the complication of the equation, you are in effect reducing the number of devices that will be required in the final circuit you construct. A simplified equation will lead to several benefits which come about as a result of less components:

1. Lower cost
2. Decreased construction time
3. Smaller area through less wiring and interconnection
4. Increased reliability
5. Simplified schematics
6. Lower power consumption

The previous chapter described Farrell's digital circuit that was used to automatically generate the CW identification for a repeater located in Seattle, Washington. His call-letter generator consists of a five-digit ripple counter which is used to control the characters generated. When you design the unit, you are basically saying things like this:

1. I want a dot when the counter equals 0.
2. I want a dash when the counter equals 1.

3. I want a dash when the counter equals 2.
4. I want a space when the counter equals 3.
5. I want a dot when the counter equals 4.
6. I want a space when the counter equals 5.
7. Etc.

If you examine the above statements you will be able to see that what has been specified is the sequence dot dash dash blank dot dash . . . in terms of a sequential counter. The basic logic problem becomes one of specifying when the dots, dashes, and blanks are required as a function of the value existing in the counter. One way is to use a lot of gates or diodes to in effect say, "If the binary pattern in the counter is 1 1 0 1 1 then I want a dash; if the binary pattern is 1 0 1 0 0 then I want a dot." This would imply that you would need a lot of gates with 5 inputs if you wanted to get the job done. If you hit the textbooks, you'll discover that someone else had already faced the problem and solved it for you.

The original article suggested the use of a Karnaugh map for minimizing the number of diodes required in the read-only diode memory. Karnaugh maps are helpful in many instances, particularly when the number of variables is four or less. Many people find that when there are more than four variables the map becomes rather difficult to understand. Of course, the world does have map experts but what amateurs need is a simpler approach to the problem of simplification of counter decoders.

The Tabular Method

Several textbooks describe a method that requires a fair amount of clerical work but only a limited amount of real thinking. I chose to use that method. The discussion that follows is aimed at showing you how to apply the "Tabular Method" to simplify counter decoders. (An excellent discussion of the method, with some sophisticated extensions, exists in "Switching Circuits for Engineers," by Mitchell P. Marcus.)

So that you can better understand the relevancy of the Tabular Method, let us analyze the decoding necessary for constructing a digital CW code identifier having a 6-bit counter. Although most amateur calls can be described without resorting to more than 32 different characters (dots, dashes, and blanks), let's generate a fancy message such as DE WAØZHT K. (Note that *any* message could be generated, e.g., RST 589 IOWA K.)

	VALUE OF COUNT							
CHARACTER STREAM	COUNT DECIMAL	COUNTER FLIP-FLOPS FF-A	FF-B	FF-C	FF-D	FF-E	FF-F	Number of 1's in binary count
blank	0	0	0	0	0	0	0	0
—	1	0	0	0	0	0	1	1
.	2	0	0	0	0	1	0	1
.	3	0	0	0	0	1	1	2
blank	4	0	0	0	1	0	0	1
.	5	0	0	0	1	0	1	2
blank	6	0	0	0	1	1	0	2
blank	7	0	0	0	1	1	1	3
blank	8	0	0	1	0	0	0	1
.	9	0	0	1	0	0	1	2
—	10	0	0	1	0	1	0	2
—	11	0	0	1	0	1	1	3
blank	12	0	0	1	1	0	0	2
.	13	0	0	1	1	0	1	3
—	14	0	0	1	1	1	0	3
blank	15	0	0	1	1	1	1	4
—	16	0	1	0	0	0	0	1
—	17	0	1	0	0	0	1	2
—	18	0	1	0	0	1	0	2
—	19	0	1	0	0	1	1	3
—	20	0	1	0	1	0	0	2
blank	21	0	1	0	1	0	1	3
—	22	0	1	0	1	1	0	3
—	23	0	1	0	1	1	1	4
.	24	0	1	1	0	0	0	2
.	25	0	1	1	0	0	1	3
blank	26	0	1	1	0	1	0	3
.	27	0	1	1	0	1	1	4
.	28	0	1	1	1	0	0	3
.	29	0	1	1	1	0	1	4
.	30	0	1	1	1	1	0	4
blank	31	0	1	1	1	1	1	5
—	32	1	0	0	0	0	0	1
blank	33	1	0	0	0	0	1	2
blank	34	1	0	0	0	1	0	2
blank	35	1	0	0	0	1	1	3
—	36	1	0	0	1	0	0	2
.	37	1	0	0	1	0	1	3
—	38	1	0	0	1	1	0	3
blank	39	1	0	0	1	1	1	4

Fig. 2-19. Basic count values and other data.

When the call is to be transmitted, your system will probably cause a push-to-talk relay to be activated. Consequently, it would be nice to begin the message with a blank to give the relay time to pull in. If the identifier is used in a complex system that supplies dial tone to its users, it may also be desirable to have a blank at the end so that the CW does not "run into" the dial tone. If you put these thoughts together, you will have a message the closely resembles the one described in Fig. 2-19.

Figure 2-19 contains additional information that will be referred to in different stages of our discussion of the simplification procedure. You should notice at this point that each character that composes the message has been paired with the value that would be in the counter when the character was to be generated. The value of the counter is shown in decimal and also in binary for your conversion convenience.

The zeroes and ones in Fig. 2-19 represent the binary equivalent of the decimal numbers shown in the "decimal count" column. A zero means that the associated flip-flop is *reset* while a one means that the flip-flop is *set*. (Some manufacturers refer to the outputs as Q and Q', corresponding to true and false; Q = true = 1 and Q' = false = 0.) For convenience in referencing the flip-flops that compose the various stages of the counter, the flip-flops are designated as A, B, C, D, E, and F (See Fig. 2-19). If flip-flop A is in the set, or true, state, we will write the letter A; however, if flip-flop A is in the reset, or false, state, we will write A' (read "A not"). Figure 2-20 shows the simple counter used in our discussion.

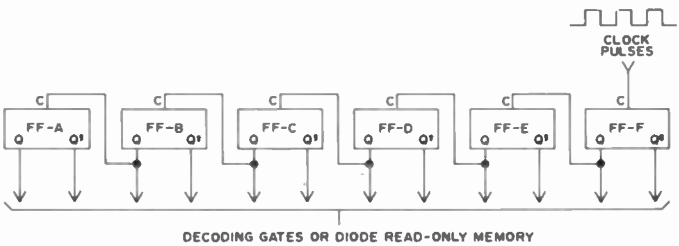


Fig. 2-20. Ripple counter described in the text.

You should notice that the binary expression of the count shows that a 6-stage counter is being used. This means that you could have as many as 63 characters in the message (saving the last value of the counter for stopping the sequence). The counter has 64 unique states, 000000 through 111111.

The Tabular Method can be used to help simplify logical states for various applications but if we address our attention just to the CW identifier previously mentioned, then what we want in this case is a simplified statement of when we need dots and when we need blanks (the character generator circuitry produces dashes unless programmed to generate something else). The equations that result from the simplification can be used to specify the gates that must be used if you choose to decode the counter with integrated circuits. Since W7PUG's system used a read-only diode memory, this discussion will address that mode of implementation and show how the Tabular Method will minimize the number of diodes required and produce a wiring map for use in constructing the decoder. For this example a "fancy" message is chosen so that the counter would have to be composed of 6 stages rather than only 4 or 5.

Since the circuitry generates dashes automatically, we have to generate expressions for only the dots and the blanks. The Tabular Method proceeds as follows:

Original	New-A	New-B
000000✓	000x00✓	00xx00*
- - - - - -	00x000✓	~~00xx00~~
001000✓	- - - - - -	
001000✓	0001x0*	
- - - - - -	00x100✓	
000110✓	001x00✓	
001100✓	- - - - - -	
100001✓	00011x*	
100010✓	1000x1*	
- - - - - -	10001x*	
000111✓	- - - - - -	
010101*	00x111*	
011010*	x00111*	
100011✓	100x11*	
- - - - - -	- - - - - -	
001111✓	0x1111*	
100111✓		
- - - - - -		
011111✓		

Fig.2-21. Values and reduction for blanks.

Expression for Blanks

We begin by extracting from Fig. 2-19 the binary values of the counter corresponding to when we need to have

BLANKS

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	000000	000100	001000	000110	001100	100001	100010	000111	010101	011010	100011	001111	100111	011111
0001x0		✓		✓										
00011x				✓				✓						
1000x1						✓					✓			
10001x							✓				✓			
00x111								✓				✓		
x00111								✓					✓	
100x11											✓		✓	
0x1111												✓		✓
00xx00	✓	✓	✓		✓									
010101									✓					
011010										✓				

Fig. 2-22. Tabular display for blanks.

blanks generated. This produces the list of values shown in Fig. 2-21. As the list is made, we arrange the values so that values with the same number of 1's are grouped together. (The rightmost column in Fig. 2-19 is used to facilitate this listing.) The values are segmented with broken lines to show those numbers having no 1's, one 1, two 1's, etc. In the case of the blanks you see that there are six basic groups of values.

The method now requires that each of the values in a particular group be compared to each value in the next group. In Fig. 2-21, this means that 000000 will be compared to 000100 and 001000; 000100 and 001000 will be compared to 000110, 001100, 100001, and 100010. The comparison operation consists of seeing if it is possible to derive the second number from the first number by changing only a single digit position. When 000000 is compared to 000100 you should see that you can get 000100 from 000000 by changing the digit that is in the fourth position from the left. Consequently, these two values give rise to a new value written as 000x00 (The x shows the position that was changed to make the second value.) This new value is written into a new list shown in Fig. 2-21 as new-A. Comparing 000000 with 001000 yields a new entry of 00x000 in list new-A.

When a value is used in one of the comparing operations, and an entry is made in a new list, the original values are checked off. You will note that Fig. 2-21 shows that all but two of the original values were used in this combining operation. Each time a new group of numbers are used as "the first number," a separating line is drawn in the new list. Additional new lists are made until no further combinations can be made. Figure 2-21 shows the complete set of lists for the analysis of blanks. The values that do not combine are not checked but have been suffixed with an asterisk (*) to indicate that they are to be used in the next step of the simplification.

When the comparisons have been completed, a tabular display such as that shown in Fig. 2-22 is prepared. The column headings consist of the original counter values that were supposed to produce blanks. A row is added for each value that was suffixed with an asterisk when the comparisons were made. For each of the values shown to the left of a row, we now make an examination to determine the

Rule 1 . . . A column, a, can be eliminated from the table if it has checks in every row that some other column, b, has checks. (The subset is saved.)

Rule 2 . . . . A column, a, can be eliminated if it has checks in the same rows as another column, b. (Given two identical columns, one can be eliminated.)

Rule 3 . . . . A row, z, can be eliminated if some other row, y, has checks in every column that z has, AND the number of 0's and 1's in z is equal to or greater than the number of 0's and 1's in y.

Fig. 2-23. Simplification rules.

	BLANKS													
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
	000000	000100	001000	000110	001100	100001	100010	000111	010101	011010	100011	001111	100111	011111
0001x0		✓		✓										
00011x				✓	✓			✓						
1000x1						✓					✓			
10001x							✓				✓			
00x111								✓				✓		
x00111								✓					✓	
100x11											✓		✓	
0x1111												✓		✓
00xx00	✓	✓	✓		✓									
010101									✓					
011010										✓				

Fig. 2-24. Tabular display for blanks after application of reduction rules.

original terms which can be "generated" from the terms identifying the rows. The "generation" consists of replacing the x or x's with both 0 and 1 and then checking off the original terms created. For example, if we take the first row, with 0001x0 we can generate 000100 by substituting 0 for x and we can generate 000110 by substituting 1 for x.

We now place check marks beneath the original terms generated; 000100 and 000110. Applying the same process to an entry such as 00xx00 would produce these original terms: 000000, 001000, 000100, and 001100. The columns corresponding to each of these original values has a check mark opposite 00xx00. If the term contains no x's, for example 011010, then you place a check mark in only one column. When all of the check marks are in place, the table is ready to be simplified by the application of a few simple rules. Figure 2-22 shows the table with all of the check marks entered properly.

Figure 2-23 lists the rules that are applied to the table to perform the actual reduction. Let's apply these rules to Fig. 2-22 and produce the slightly modified form shown in Fig. 2-24.

For ease of identification, the columns in Figs. 2-22 and 2-24 have been labeled with letters of the alphabet. Rule 1 can be applied to columns L and N thereby eliminating column L. Rule 1 can be applied to columns G and K thereby eliminating column K. Rule 1 can be applied to columns A and B, thus eliminating column B. Rule 2 can be applied to columns A, E and C, thereby eliminating C and E.

Figure 2-24 shows with shading the columns that have been removed from the table. The object of this last step is *hopefully* to eliminate rows in the table. In this particular case, no rows were eliminated. Had rows been eliminated, the corresponding terms would be dropped during the next step of our simplification.

The final step in the simplification is to write a statement for the quantity of interest. This simplification was for blanks so we will write a statement which combines the terms opposite rows that were *not* eliminated from the table. The result that we get is as follows:

BLANKS = 001x0 or 00011x or 1000x1 or 10001x or 00x111 or x00111 or 0x1111 or 00xx00 or 010101 or 011010

You should recall that the binary values correspond to the state of the flip-flops A, B, C, D, E, and F. We can thus rewrite the statement by replacing the 0's and 1's with the appropriate flip-flop designator and simply dropping the x's. Doing this, 0001x0 becomes A' B' C' D F'. The resulting equation for blanks is thus:

BLANKS = A'B'C'DF' or A'B'C'DE or AB'C'D'F or AB'C'D'E or A'B'DEF or B'C'DEF or AB'C'EF or A'CDEF or A'B'E'F' or A'BC'DE'F or A'BCD'EF'

In order to implement this equation, one diode will be required for each of the *or*'s for a total of 10 diodes. For each of the terms in the equation, there will be one diode per flip-flop named. Thus A'B'C'DF' will require the use of 5 diodes. There will thus be 56 diodes for the terms and 10 for the *or*'s for a total of 66 diodes. If we had not simplified, there would have been one diode for each value of the counter (14) plus 6 diodes for each value (6 x 14 = 84) or a total of 84 + 14 = 98 diodes. Application of the Tabular Method has thus reduced the number of diodes by approximately 30% – a 30% savings in parts and wiring! The savings that you will realize varies with the complexity of the message.

Expression for Dots

To be sure that you understand the simplification method, let's apply the technique to the values for dots.

	New-A	New-B
000010	00001x*	0x1x01*
------	------	0x1x01
000011	00x101*	011x0x*
000101	x00101*	011x0x
001001	001x01	
011000	0x1001	
------	01100x	
001101	011x00	
011001	------	
011100	0x1101	
100101	0110x1*	
------	011x01	
011011	01110x	
011101	0111x0*	
011110		

Fig. 2-25. Values and reduction for dots.

Figure 2-25 shows the binary values that have been removed from Fig. 2-19 and listed in groups based upon the number of 1's in the values. You will notice that this time we have only 4 groups of values. As in the previous example, the simplification begins by comparing 000010 to 000011. This comparison yields the entry 00001x in the second table. None of the remaining values in the second group can be derived from 000010 by changing only a single digit. The simplification continues by comparing all of the values in the second group to the values in the third group. These comparisons generate the new values 00x101, x00101, etc. In this case, by the time all of the group comparisons have been made, all of the original values have been used at least once and are therefore suffixed with a check mark. The values in the new table (new-A in Fig. 2-25) are then compared and used to generate new values when possible. You should note that when values involving x's are compared, it is necessary that the two values contain x's in the same positions *before* you check to see if the second value can be derived from the first value by changing a single zero or one. Figure 2-25 shows that the final result consists of 7 terms with asterisks. The next step is to construct the tabular display of the original values and the asterisked values derived from the comparisons. Figure 2-26 shows such a table.

	DOTS											
	A	B	C	D	E	F	G	H	I	J	K	L
	000010	000011	000101	001001	011000	001101	011001	011100	100101	011011	011101	011110
00001x	√	√										
*00x101			√			√						
x00101			√						√			
0110x1							√			√		
0111x0								√				√
0x1x01				√		√	√				√	
011x0x					√		√	√			√	

*=ROW HAS BEEN ELIMINATED BY APPLICATION OF RULES

Fig. 2-26. Tabular display for dots.

The next step is to place a check mark in the column or columns corresponding to the original values that can be derived from the asterisked terms. Figure 2-26 shows the completed table. Once again we must now apply the three rules shown in Fig. 2-23 to check marks in the tabular display.

	WITHOUT SIMPLIFICATION	WITH SIMPLIFICATION	REDUCTION
BLANKS	98	66	30%
DOTS	84	34	60%
TOTAL	182	100	45%

Fig. 2-27. Diode count.

Rule 1 can be applied to columns C and I thereby eliminating column C. Rule 1 can be applied to columns D and F thereby eliminating column F. Rule 1 can be applied to columns E, G, H, and K thereby eliminating columns G, H, and K. Finally, rule 2 can be applied to columns A and B thereby eliminating column A. We can now write a statement for dots in terms of the asterisked terms that still have at least 1 check mark in their row. The statement is:

DOTS = 00001x or x00101 or 0110x1 or 0111x0 or 0x1x01 or 011x0x

The statement is next written in terms of the flip-flop designators previously defined (A, B, C, . . .).

DOTS = A'B'C'D'E or B'C'DE'F or A'BCD'F or A'BCDF' or A'CE'F or A'BCE'

As in the case for the blanks, one diode will be required for each term to be *or*ed plus one diode will be required for each flip-flop mentioned in each term. The decoding for the dots will therefore require 6 + 28 = 34 diodes. Without simplification, the decoding would have required 84 diodes (12 + 72). Notice again that the simpliciation has been well worth the effort!

If we take a look at the total problem we see that simplification has been very worthwhile. Figure 2-27 shows the diode count with and without simplification.

To complete our discussion, let us address ourselves to the proper interpretation of the equations as they apply to the actual wiring of the read-only diode memory. It is helpful to construct a "map" that will help you find your way around the wiring details.

	FF-A	FF-B	FF-C	FF-D	FF-E	FF-F
00001X	0	0	0	0	1	X
X00101	X	0	0	1	0	1
0110X1	0	1	1	0	X	1
0111X0	0	1	1	1	X	0
0X1X01	0	X	1	X	0	1
011X0X	0	1	1	X	0	X

Fig. 2-28. Wiring map for dots.

Figure 2-28 is the wiring map for dots. Across the top of the map you will see the flip-flop designators. The various rows correspond to the individual terms that are in the reduced equation. Take an equation such as:

DOTS = 00001x or x00101 or 0110x1 or 0111x0 or 0x1x01 or 011x0x

For each of the terms, enter one row into the map. The 0's represent a diode connected to the false output of the flip-flop while the 1's represent a diode connected to the true output of the flip-flop. Where there are x's, no diodes are required. The map can thus be described by simply displaying the terms of the equation in a list! Such

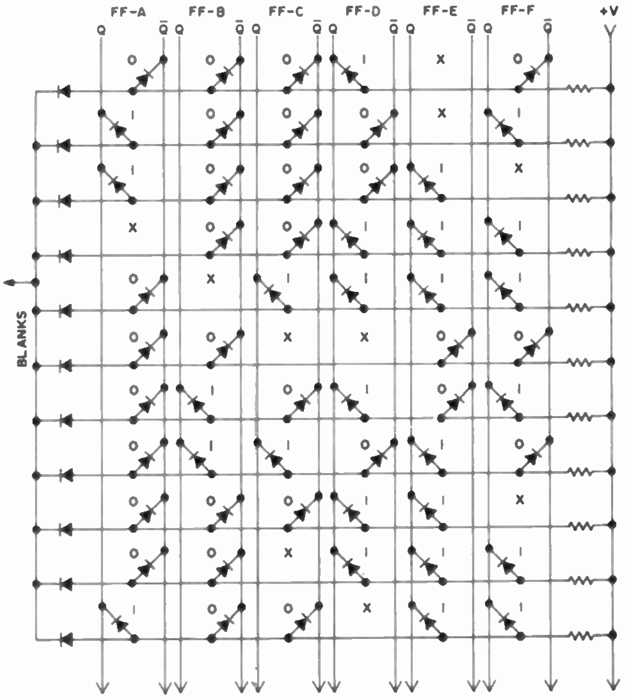


Fig. 2-29. Wiring map for blanks.

a wiring map is useful when you start to construct your decoder. Figure 2-29 shows the map with the diode wiring schematic superimposed to help you see the map's usefulness for wiring the blanks decoder.

The Curtis CW Identifier

When repeaters started getting very popular and manufacturers began to tool up their assembly lines for production of 2m FM transceivers, a representative of Curtis Electro Devices called me to ask what the potential might be for a repeater ID unit. Curtis has been manufacturing electronic keyers for some time, and the switchover to an automatic ID unit seemed logical enough. It seemed to me that the market could certainly afford at least one manufacturer in the identifier field, provided that the manufacturer could afford to produce the unit at a cost that was within the budget of the average repeater group.

The Curtis people were not too involved with repeater operation, but they wanted to make their identifier solve all the problems associated with automatically identifying repeaters; so the representative listened while I listed all the desirable features such a unit would have – which were considerable. Within two months, I opened a package that came in the mail and found what I consider to be the ideal identifier. Curtis had taken the ideas I'd given and combined them with some of their own, and the result was a working production ID unit that can be easily installed into any repeater within minutes. What's more, the Curtis identifier contains in its one small package all the control circuitry, tone oscillator, and relay contacts required to make the unit immediately operational.

When properly connected into a repeater, the identifier will send out a modulated CW signal when the first carrier appears on the repeater input. From that point on, it will identify at three-minute intervals as long as the repeater is being used. When all the carriers drop out and the repeater is no longer being accessed, the Curtis identifier will send out one more ID at the end of 3 minutes, then it will keep quiet; and it will remain quiet until someone else comes along and uses the repeater.

The unit has a built-in speaker so that you can hear the ident when you are testing or installing the system. And an inside-mounted switch allows you to cut off the speaker when you're through making checks. The unit has a set of relay contacts built in, too. These contacts stay closed during the time the identifier is generating its signal; they are used to lock the repeater transmitter on during an ident so the identification signal won't get cut off in mid-sentence.

Other features include a volume control to adjust the level of the modulated CW signal into the repeater transmitter, a speed control to adjust the rate of the automatic identification signal, and various terminals to change the mode of operation from "automatic" to "manual" – or from periodic keying to keying each time a carrier appears.

The Curtis automatic identification unit should be compatible with most repeaters, because it uses a negative dc voltage (12–28V) for control. A ground signal, as from the carrier-operated relay, keys the identifier, but does not cause triggering of the ID until the required time period has elapsed.

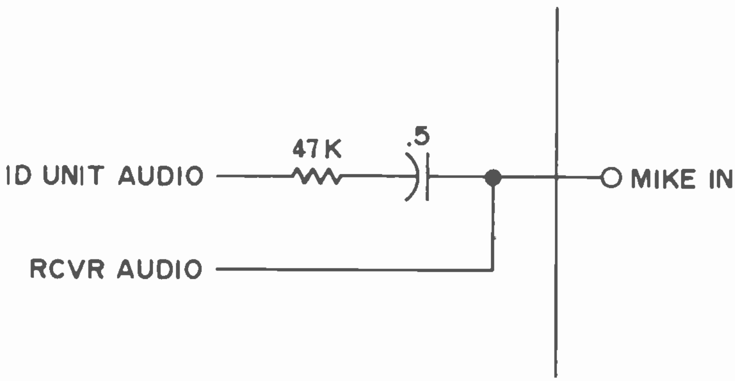


Fig. 2-30. A series resistor/capacitor netwrok in effect increases the impedance of the ID unit's audio output, and prevents circuit loading.

When I connected the identifier into the WA1KGO repeater, I noticed that the audio from the Curtis unit tended to swamp the audio arriving from the receiver. This situation resulted in repeater users being jammed out by the identifier. I placed a 47 kΩ resistor and a 0.5 μF capacitor in series with the audio lead from the identification unit (Fig. 1), and that solved the problem.

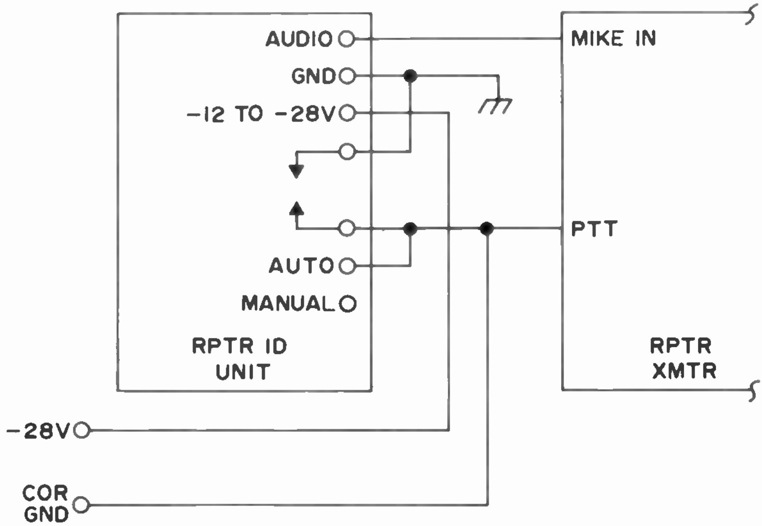


Fig. 2-31. This interconnect scheme allows identification only when repeater is in use.

I didn't do a great deal of thinking or planning before I connected the ID unit initially, and I ended up paralleling the ID unit's contacts with those of the transmitter PTT. This is an acceptable scheme, but it resulted in an automatic identification every three minutes, day and night, even when the repeater was not in use. This was because of the small bias voltage on the PTT line. If you like to sleep with your monitor receiver on, you'd be driven quite mad with this sort of hookup. I know I was. So I raced up to the hilltop and made a few small control-circuit changes; the final interconnect circuit is shown in Fig. 2-31. This latter arrangement keeps the unit from generating an ID signal unless the repeater is actually being keyed, but it does not keep the unit from finishing its ID once it's started, even if the incoming carrier drops out.

Technical Aspects

The block diagram (Fig. 2-32) can be used to follow this operational description. When a signal from the carrier-operated relay in the repeater grounds the "automatic cycle" input a latch is set indicating the closure regardless of duration. For the first closure after the repeater has been at rest, the clock control starts the clock which is fed into a +128 counter. This counter is fed to two 1 of 8 decoders and one 1 of 8 multiplexer. The decoders ground the horizontal matrix lines in sequence starting at the top and proceeding downward. Each line is held low for eight clock cycles.

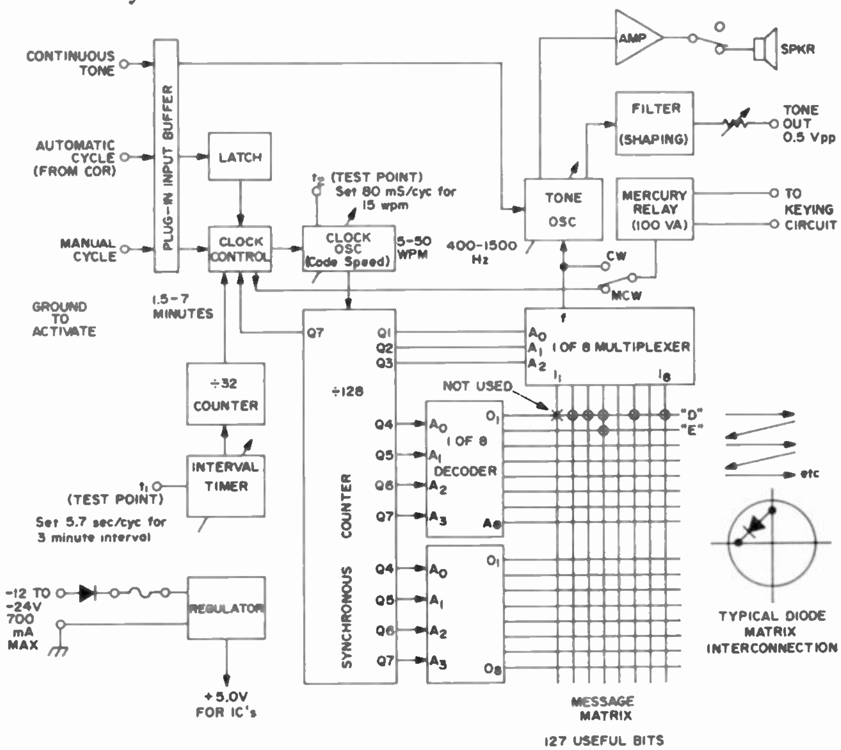
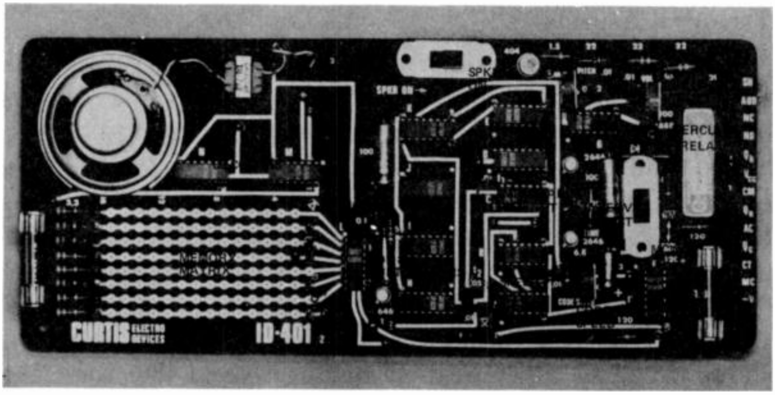


Fig. 2-32. Block diagram of Curtis ID-401 identification unit.

At the same time, the 1 of 8 multiplexer is scanning the vertical lines – acting in effect like a single-pole, eight-position switch. In this manner the matrix is scanned bit by bit from the upper left down to the lower right.



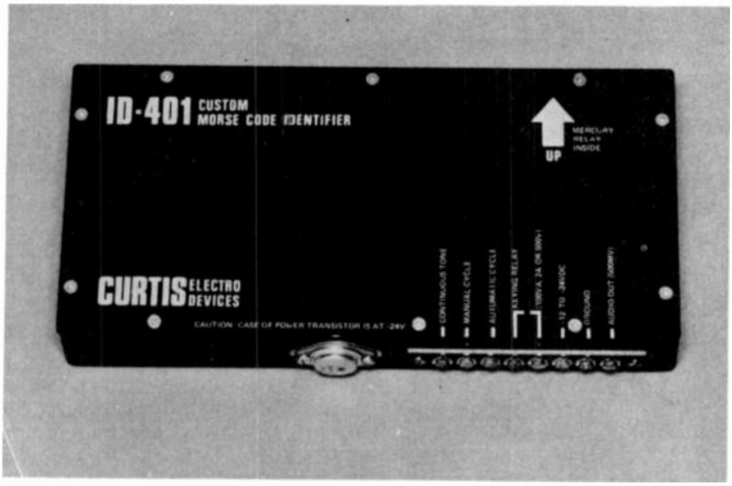
Inside the Curtis ID-401. A PC-mounted speaker (upper left) allows monitoring of the audio signal even before the ID unit is connected to the repeater. The memory matrix (below speaker) can be programmed or reprogrammed by amateurs in the field. The matrix shown is programmed for "DE" only, as indicated by the diode placement.

Each intersection between the vertical and horizontal lines which is connected by a diode pulls the input of the multiplexer low. Each "low" is interpreted as a dot; three in a row is a dash. Where a diode is not connected, the output represents a space. In effect, the memory plays out just like a paper tape. You can read the message by examining the diodes. Programming or reprogramming requires only a knowledge of Morse code and no knowledge of Karnaugh maps.

The memory plays out one time and stops until the interval counter counts out the set interval at which time the program will play out once more. If the repeater has been activated during the waiting period the timer will again count out a set interval and cause the unit to identify once more. Only when an interval passes without repeater activation will the unit cease identifying. And at the same time, the unit will not ID *more often* than the set interval regardless of what is happening at the repeater.

The interval timer is a unijunction oscillator followed by a ÷32 counter to obtain reliable long time intervals over temperature and independent of line frequency (in case the unit uses batteries for standby).

Activation of the "manual cycle" input causes continuous IDing. Activation of the "continuous tone" input



The Curtis ID package. The terminal strip gives access to all control, voltage and ground points needed for fully automatic operation.

gives a continuous audio output. These three controls are all buffered by a plug-in IC since improper hookup may damage the input ICs. The IC is easily changed in the field. The unit is protected against reverse polarity. A fuse (and a spare) is also provided.

The output of the multiplexer drives both the MCW oscillator and a mercury reed output relay. The relay may be switched to either a CW (keys the Morse) or MCW (key down during whole program) position.

The audio drives both a switchable internal speaker and is filtered and level controlled for directly modulating the repeater carrier.

The interval timer is variable between 1.7 and 7 minutes, the speed from 5 to 50 wpm and pitch from 400 to 1500 Hz.

The regulated power supply allows operation from –12 to –28V dc and draws about 700 mA.

The unit employs 14 ICs, three of which are MSI types.

PART III

The Autopatch

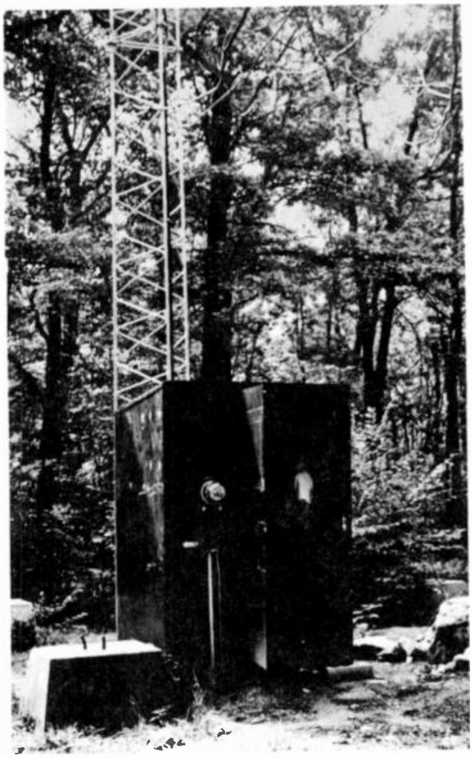
K6MVH Autopatch

A great many amateurs seem to think it is illegal to interconnect a telephone with a repeater for automatic patching; but this is simply not true. The legality of a remotely operated telephone system depends on its ability to meet the requirements of FCC Rules and Regulations. The principal requirement is that incoming calls must not be capable of keying the transmitter when no licensed operator is monitoring from the control point.

Another area of questionable legality is that of controlling a remote station from a mobile unit. The FCC says that a remote station must be controlled from a fixed site. To many, this automatically precludes the possibility of setting up a control station in the mobile. But close scrutiny of Part 97.43 of the Rules reveals no prohibition of mobile control. The currently popular interpretation of the Rules is that control can be accomplished from anywhere as long as fixed control is maintained.

Some amateurs even go further, and do not maintain a fixed control *per se*. They say they get their authority to control exclusively from a vehicle because of the permission to do so given by the conditions on the back of the amateur license. According to the statement on the reverse of General and Technician class licenses, the remote control point is considered "fixed" even though it may be actually mobile or portable. (Take a good look at the back of your license; it pays to read the small print.)

Not all individual officers of the FCC go along with the wording on the back of the license, I hasten to add. James Barr, FCC Chief of Safety and Special Services, says the control station must be fixed – the disclaimer on the license notwithstanding. But Barr might have a rough time making his opinion stick when the official documentation plainly counters it.



Most autopatches are simply phone patch panels installed at a remote repeater site where telephone service is available. Often, owners of commercial remote installations such as the one pictured here will permit amateurs to install an autopatch-equipped repeater. The key word is service, and no facility fills the bill more perfectly than a ham repeater whose users are prepared to act fast in an emergency. (Photo by Motorola News Bureau.)

In spite of all those hair-splittings, no one within the FCC has ever been known to deny the legality of mobile control *as long as a licensed fixed station is manned by an operator authorized to turn the remote system off should the need arise.*

Understanding the Telephone

The conventional telephone uses but two wires to accomplish what may amount to a multitude of different functions. There is typically a low voltage dc level across the line to drive the carbon microphone element. When the telephone rings, however, a higher voltage ac signal is superimposed on the line pair to energize the bell in the instrument.

A telephone with its receiver on the hook is an open circuit. The circuit closes when the receiver is lifted, introducing a moderately low-resistance load (several hundred ohms). The dial is a rather complex switching device that has the capability of opening the circuit briefly for a number of times that correspond to the number dialed. The circuit stays closed as the finger hole is brought around to the stop. Then, circuit "opens" are pulsed out sequentially as the dial returns to its "home" position.

Thus, the dialing function could be simulated by rapid manipulation of the hang-up button, provided that the required speed of 10 switching operations per second could be maintained manually. And hang-up could be effected (temporarily) by controlled positioning of the dial.

The Autopatch

The block diagram of Fig. 3-1 shows the method by which an automatic patch such as the one described in this article is interconnected into a repeater. The broken lines represent control signals and the solid connecting lines represent audio signals. As can be seen, the telephone needs no modification, and is interconnected with the system by

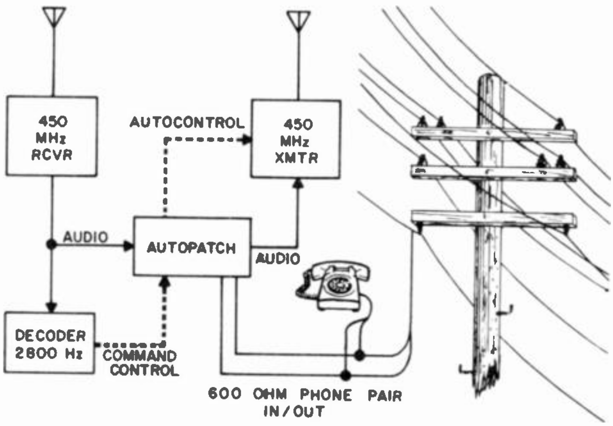


Fig. 3-1. The autopatch's interconnection with the phone line has no effect at all on an existing telephone connection since it is wired in parallel with the instrument. The block diagram shows how a fully duplexed autopatch system is set up with a UHF repeater.

merely tapping into the two wires that are already part of the existing telephone circuit. It should be noted that the autopatch can be integrated just as easily into a UHF or

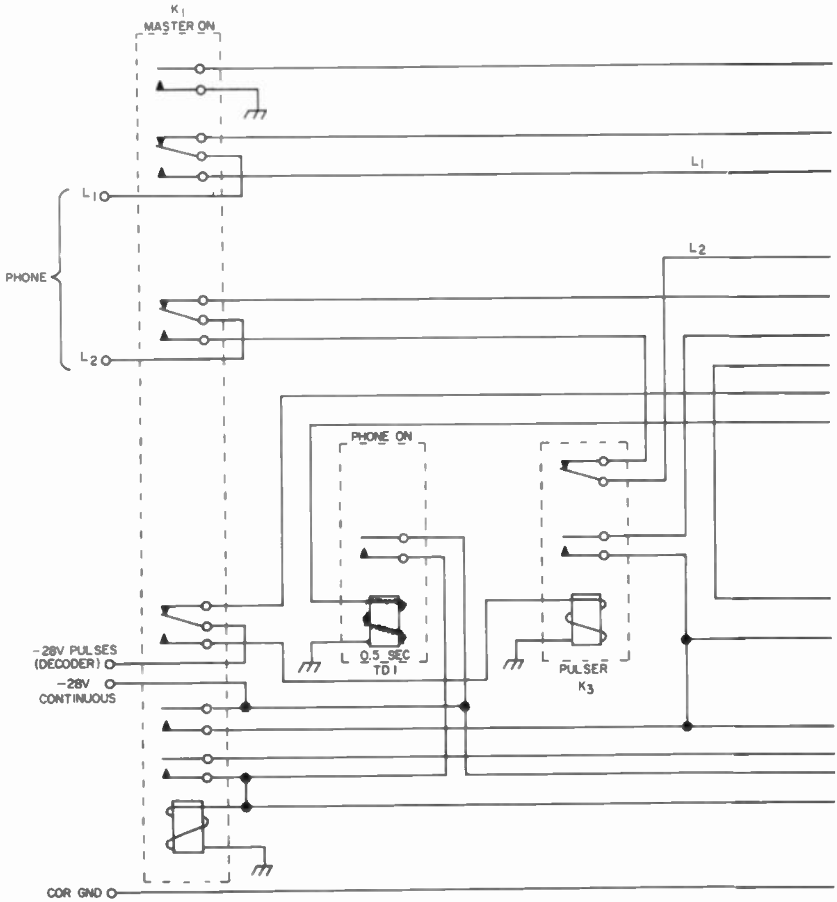
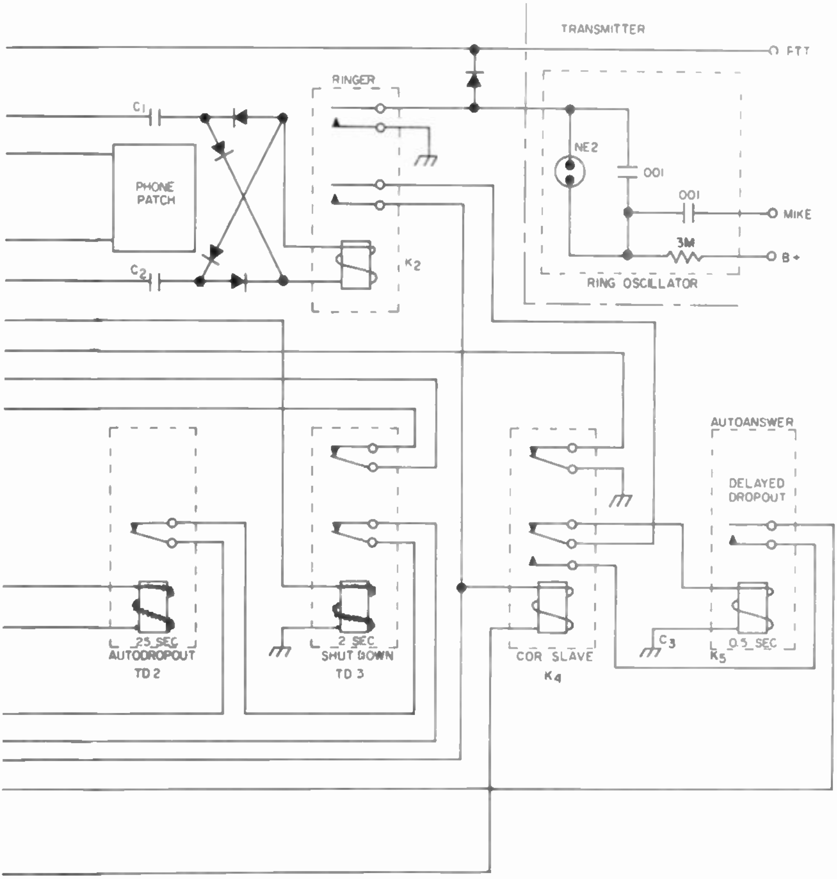


Fig. 3-2. This autopatch circuit has everything: timed on, timed off, autoanswer from units that are not tone equipped, and a number of built-in "failsafe" features to assure control even if you lose control.

VHF repeater, though duplex operation with VHF would be next to impossible to achieve for the user mobiles because of frequency proximity and attenuation problems.

As shown in Fig. 3-2, the circuit contains all the elements necessary to make it the "cadillac" of automatic patching devices. It does just about everything. In response to timed control tones transmitted by the control operator, it can "lift the receiver from the hook" and interconnect the phone patch with the repeater; or it can "replace the phone on the hook" and disengage the repeater. When the phone rings, the control operator knows he has an

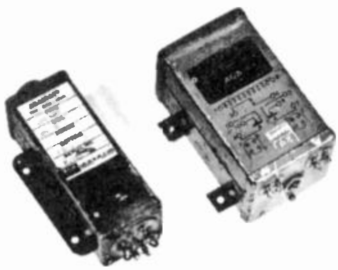


incoming call: the autopatch generates its own tone and turns on the repeater transmitter with each ring.

Without the need for tones, the control operator has the capability of allowing the phone patch to be engaged or not, as determined by the sequence by which he activates the carrier of the control point transmitter. And, as a final safety measure, the autopatch disengages from the repeater when there is no control signal immediately apparent. If, after the control operator engages the phone patch, he loses control or his transmitter drops off the air, the patch disengages itself in seconds, shutting off the repeater transmitter until control can be reestablished.

Ring Indication. Since the autopatch is likely to be incorporated into an already existing repeater setup, the circuit has been designed for full compatibility. The phone line at the repeater site can be continuously monitored for incoming landline calls without disrupting the normal operation and control functions of the repeater. During normal repeater use, the phone line is sensed for the presence of an ac voltage (which would indicate that the phone is ringing). The two lines of the twisted pair are fed through a set of normally closed contacts on the main relay (K1) to a bridge rectifier circuit. The dc component of the line is isolated by placing 0.5 μF capacitors in series with the conductors. A sensitive plate relay on the output of the bridge pulls in when the telephone rings and keys the repeater transmitter for the duration of the ring. This momentary closure of the relay triggers a signaling device so that when the transmitter is thus keyed, a ring signal is generated also.

Agastat pneumatic timers are perfect for autopatch applications because they can switch plenty of current, they are instantly resettable, and they offer a high degree of reliability. The unit at left is a standard adjustable time delay relay (TD1, TD2, TD3 in schematic of Fig. 3-2); at right is a delayed dropout. Units are available surplus for $3 to $5 each.



The ringer shown in the upper right corner of Fig. 3-2 is nothing more than a simple relaxation oscillator; it can be constructed in a few minutes with a couple of capacitors, a resistor, and a neon lamp. The device shown generates an unstable tone that is easily identifiable at the receiving end.

Timers. The K6MVH autopatch makes extensive use of timers for effective active and passive control. The timers are Agastat pneumatic delay devices made by Elastic Stop Nut Corporation (ESNA), of Elizabeth, N.J. If purchased new, these delays can be quite expensive. They are available surplus, however, from any of a number of reputable military-surplus dealers.

All-transistor timing and switching circuits work quite well, but their incorporation does make the schematic a bit more complicated because of the various polarity requirements. The cheapest way to miniaturize would be to compromise a bit by using hybrid timer circuits that employ miniature relays for switching in combination and unijunction timer circuits.

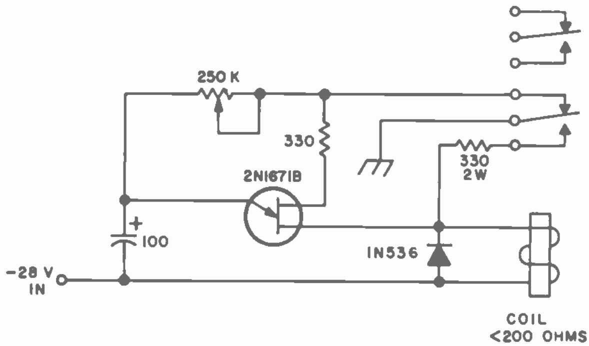


Fig. 3-3. This unijunction timer circuit offers a broad range of delay periods, from less than 0.5 second to more than 3 minutes. The delay is set by the 250 kΩ pot; each 10 kΩ of resistance gives a second or so of delay. In practice, of course, the pot would be replaced by the proper fixed resistor, because there would be no need for a variable time delay.

Figure 3-3 is an adaptation of a timer circuit that was published in GE's "Transistor Manual, Seventh Edition." This circuit is particularly versatile because it employs a low-cost semiconductor, relatively few parts, and an easy-to-find relay with a coil resistance of 150–200Ω.

The Phone Patch. The phone patch itself is an item that warrants some attention, but a great deal has been written on this subject in the past so I won't go into it in detail here. As references, I will cite the FM Repeater Handbook (Editors and Engineers, Ltd., Indianapolis, Indiana), FM Magazine (July 1968 and December 1968), FM Anthology, Volume II (73 Bookshop), and 73 Magazine ("VHF Operation by Remote Control," August 1968).

The most important point to remember when connecting a phone patch into an autopatch system is to leave a dc path through the patch primary. If a series capacitor is placed in the circuit, it should be shorted; otherwise telephone ringing and dialing cannot be effected automatically for remote operation.

"Desirable" characteristics for commercial phone patches are: (1) a high degree of signal isolation, (2) automatic compression circuitry, and (3) built-in preamplification for phone signals.

Autopatch Decoder Control

In the system described here, a high-frequency tone decoder is used to switch a −28V signal for control of the autopatch when a call is to be initiated. The decoder shown in Fig. 3-4 is ideal for this purpose, having stood the test of time and use. This unit, by the way, is a simplified version of Motorola's transistorized decoder (Part 9-SP022563).

The original Motorola circuit is not satisfactory for dial pulsing because it is slow-responding. The Motorola version is used as a "single-tone" controller, where a stable, continuous tone is needed. Removal of a few circuit elements, however, makes the Motorola decoder a natural for phone pulsing applications. (The circuit of Fig. 3-4 is a quick-pulsing decoder that responds easily to tone pulses of a 10 per second repetition rate.)

Tone Frequency. The decoder is set to respond to tone signals in the frequency range of 2200 to 2900 Hz. Adjustment of the frequency-sensitive elements permits the pinpointing of any 50–75 Hz bandwidth within that range.

Of course, any frequency between 600 and 3000 Hz can be used, but the lower frequencies have serious disadvantages in practical applications. At frequencies between 600 and 1000 Hz, for example, ordinary conversation causes decoder triggering, and the result is errant and inadvertent operation of the functions to be controlled. Frequencies from 1 to 1.5 kHz can also be triggered by occasional voice signals; and a playful repeater user can toy with the phone by simply whistling.

Things begin to get more secure as the frequency goes up. But at 3 kHz, the audio processing capability of the transmitting and receiving equipment may be exceeded, particularly if there is inherent audio distortion in the system. The range from 2.25 to 2.85 kHz should prove ideal: it's difficult to voice-trip, it resists whistle-on attempts, and it is well within the frequency-response limits of most commercial FM units.

Decoder Alignment. Since impedances are critical when making voltage measurements at the decoder input terminals, an electronic ac voltmeter (vtvm) will be required. With the voltmeter connected across the receiver's audio output leads, have one of the repeater users transmit a tone. With the tone on the incoming signal, adjust the 500Ω pot on the decoder input for a reading of 400 mV. If this is not obtainable, set the 50C Ω pot to midposition and adjust the receiver audio gain control. (If the receiver "speaker" audio connects directly to the transmitter, repeater levels will have to be readjusted.)

Next, connect the voltmeter (ac range) from the wiper arm of the 500Ω pot to point A of the 50–100 mH inductor, then adjust the inductor for a peak indication on the meter.

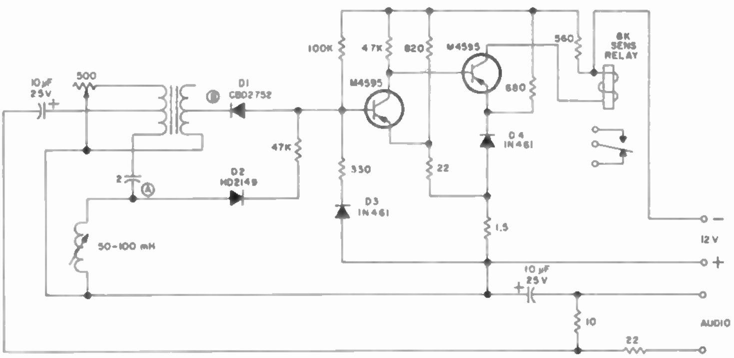


Fig. 3-4. This audio decoder responds to signals in the frequency range of 2200–2900 Hz. Precise setting is explained in the text. Although Motorola part numbers are shown, equivalent values may be substituted.

Move the voltmeter lead at point A to the cathode of diode D1 (point B), then *slightly* adjust the 50–100 mH inductor for a *dip* indication.

Autopatch Operation

In operation, when the ham operator sends a note of the proper frequency from the remote control point, the decoder switch closes, applying a −28V signal to the phone patch "master on" relay (K1). Look now at Fig. 3-2, to see where the −28 decoder-pulse terminal is on the autopatch unit. During the time the operator sends a tone, the negative-voltage signal is applied through the normally closed contacts of K1 and the normally closed contacts of shutdown timer TD3 to the coil of "phone on" timer TD1. At the end of the period of TD1, exactly one-half second, the coil energizes to supply power to the coil of the "master on" relay, which latches in the energized position.

When K1 is latched on, the phone patch is in the circuit and the decoder output is connected to pulser K3. If the operator's tone generator is connected to a telephone dial so that tone pulses can be transmitted, K3 can be used to dial any number. Pulser K3 interrupts the dc circuit of the phone line to accomplish this. At the end of the phone conversation, transmittal by the operator of a continuous tone will hold pulser K3 in. A second set of contacts on K3 feeds the coil of a shutdown timer, which will pull in after a 2-second period to completely disengage the autopatch.

Malfunction Protection. An autopatch is a borderline thing with respect to official sanctions; it thus behooves the builder to take every precaution possible to see that failsafe measures of every kind are included. The schematic of the autopatch shown here includes a feature that shuts down the patch if the remote operator does not transmit at least one brief signal every 25 seconds or less. If more than 25 seconds go by without an incoming radio signal, the shutdown timer (TD3), supplied through the normally closed contacts of the carrier-operated relay, will break the circuit supplying the latching voltage to the "master on" relay.

Most repeaters already are equipped with timers that shut down the repeater if a signal stays on too long, so none was included in this patch. The two schemes are perfectly compatible, and they do complement each other in such a way that when an operator cannot demonstrate that he has control, the phone patch will turn itself off automatically. To effectively demonstrate control, the operator must not talk – during any single transmission – longer than the safety time of the repeater, and he must transmit a signal at intervals of 25 seconds or less.

Control Without Tones. To answer the phone quickly when it is ringing, the operator can engage the phone patch with the tone as described earlier. Or he can do it, without tones, by transmitting a carrier at a precise time. If he transmits the carrier too soon or too late, the phone will keep on ringing and will not be answered. The autoanswer feature is performed with ringer K2, the COR slave (K4), and autoanswer relay K5 (a delayed dropout relay with a period of 0.5 second).

When the phone rings, ringer K2 energizes only during the period of the ring. The closed contacts of K2 during the ring apply a −28V signal to the delayed dropout relay (K5) through the normally closed contacts of the carrier-operated relay. Thus, K5 is energized for one-half second beyond the ring (or beyond actuation of the carrier-operated relay). If, during the ring, a carrier is placed on the repeater input, a −28V signal is routed to the "master on" relay. The signal must go through the contacts of the ringer, the COR, and the delayed dropout relay; if all three are not energized at the same time, the telephone cannot be turned on without tone control.

If a repeater user is transmitting at the time the telephone starts to ring, the autopatch will not be engaged because the COR cannot feed voltage to the delayed-dropout relay. If he waits until after the ring to transmit,

Twin antennas mounted on the rear cowls keep the author's installation from looking junky. Inside the car, the only visible evidence of a rig is the "Princess" telephone, mounted to the console and modified to serve as a "control head."

the phone won't answer because the ringer contacts will be open. To answer, the operator must press his transmit key after the phone has started a ring but before the ring has stopped. This concept serves to prevent inadvertent telephone energization yet gives control of the phone to such non-tone-equipped units as handie-talkies.

WØDKU Autopatch

This chapter describes the automatic telephone patch system developed for the two Wichita 2 meter repeaters. The features include mobile dial control, giving the mobile radio amateur access to the landline telephone system, as well as making other functions available to him. Many methods of remote control have been developed; most use one or more tones transmitted simultaneously or sequentially, but the method used at Wichita is a modified "Secode" type, or interrupted "single tone."

Secode systems transmit a tone of fixed frequency, interrupting the tone with no-tone pulses, created by the contacts of a standard rotary telephone dial. The decoding units sense the presence of tone and count number of "holes." When the proper sequence of pulses (holes) are received, the decoder unit will make a set of contacts for a short period (momentary make). A single decoder unit can be set to select from one to five functions at the remote location. We use separate functions to turn the telephone patch on and off.

The Encoder

The diagrams shown in Figs. 3-5 and 3-6 are almost self-explanatory. The output link is wound on the 88 mH toroid, using as many turns as needed. (See Fig. 3-7.) For high-impedance microphone circuits, 10–15 will be required; for low-impedance microphone circuits, 30 turns should be about right. The dial can be almost any type, but must have a set of open contacts that "make" when the dial is rotated "off-normal." The dials from "Trimline" telephones are small and pretty, but they do not have the "off-normal" points and cannot be used. The dial pulses *must* have the correct speed and make–break ratio.

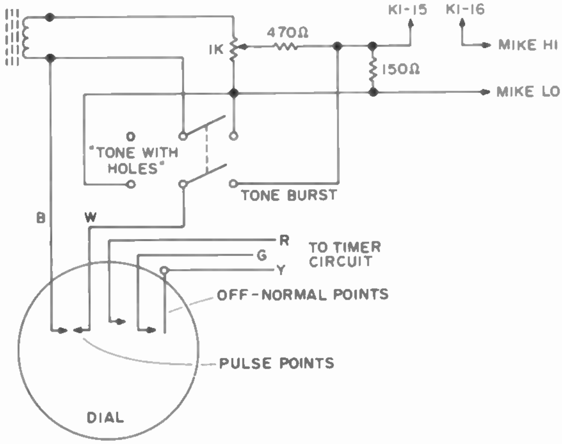


Fig. 3-5. Schematic showing output portion of dial encoder.

Checking dial speed and make–break ratio is not difficult; one of the easiest ways is a 15 ips tape recorder with editing facilities. First, make a recording of WWV and the time ticks. At 15 ips the time ticks should be spaced 15 in. apart. This verifies your tape speed. Next, record the output of your tone encoder transmitting the digit "zero."

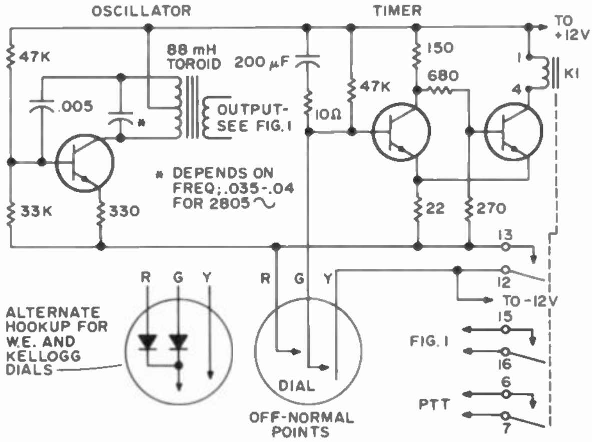


Fig. 3-6. Schematic showing oscillator and timer portions of tone encoder.

Careful use of a grease pencil or nylon point pen to mark the on and off spaces will show you the speed of the dial and the make–break ratio. Ten pulses should take 15 in.

and of the 1½ in., the pulse points on the dial should be open about 9/10 in.

Once you have one or more encoders checked out, transmit the tone through the decoder to test the pulsing relay. Adjust spring tensions, air gaps, and residual screws as necessary to obtain the same make–break ratio as transmitted by the encoder. The timer circuit holds the transmitter energized during the "interdigit" time. The 200 μF value is nominal, and can be varied. The relay shown in the diagram is a common item, but not critical. To hold the tone frequency to ±5 Hz, use of Mylar capacitors is recommended.

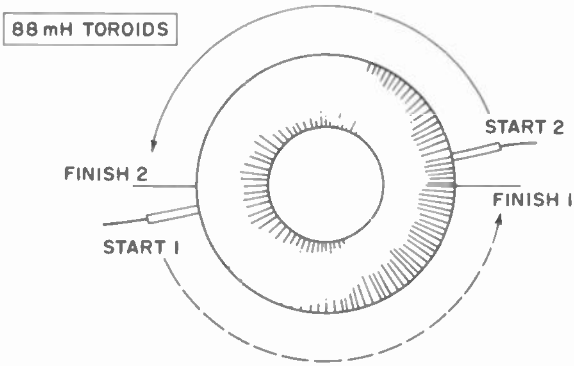


Fig. 3-7 Sketch shows construction of 88 mH toroids. Connect start 1 and finish 2 together (or start 2 and finish 1); this gives center tap.

The Decoder

The equipment used in Wichita's channel A repeater (146.34 to 146.94 MHz, WØDKU) is a modified Secode RPD-612 with ac power supply (Fig. 3-8). An additional stage (Fig. 3-9) is "tapped in" at the transformer lead feeding the neon bulb. This additional stage consists of one NE-48 lamp, a pair of diodes, capacitors, resistors, a tube, and a relay with a set of normally closed contacts. This set of contacts is used to pulse the telephone network and should be tested and adjusted to give the 60% break when used with the encoder in the "tone burst" mode. Due to the difference of tone on and tone off times in the two modes of encoder operation, the stepper unit in the selector will not operate when "tone burst" is being used.

The equipment used in the channel B repeater (146.22 to 146.82 MHz, operated by Don Pryor (WØIPB) uses the same principles but consists of a modified RPD-650 Secode decoder (transistors and mechanical selector). The Schmitt trigger stage collector load resistor (R22), 4.7K, was replaced by a relay, and the emitter resistor was reduced in value from 180Ω to 100Ω. The model 708 selector was

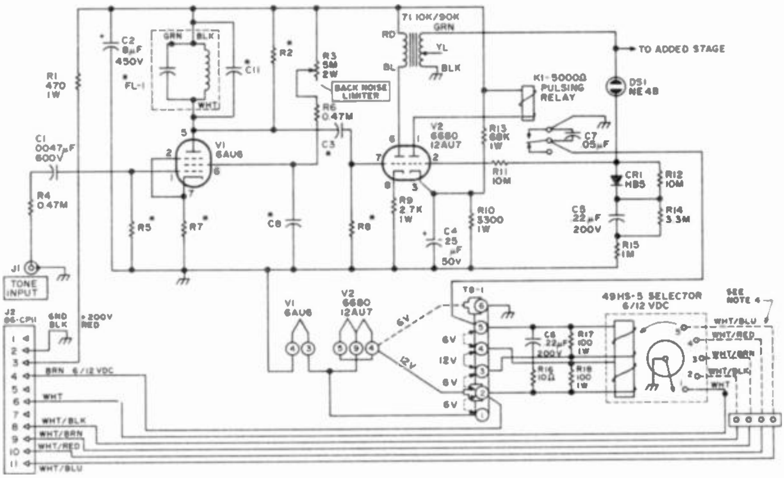


Fig. 3-8. RPD-612 schematic, digital decoder type 1859.

modified by adding the five-function kit and the operation is the same as the other repeater.

Some "tinkering" was necessary to adjust spring tensions in the selector. This tightened the tolerance on the make–break ratio to prevent stepper action during "tone burst." In the RPD-612, the sensing of the make–break ratio is in the electronic circuittry. In the RPD-650 and RPD-650A, the spring tensions of the model 70 selector must be altered to obtain this effect. (The RPD-650 and RPD-650A are made to operate with 75–25 or 25–75 make–break ratio and all variations in between.)

The Telephone Patch

The first reaction of radio amateurs when they see the circuit diagram (Fig. 3-10) is usually "where is your hybrid balance adjustment?" Quite simple, since the patch doesn't use hybrid circuitry and is not intended for simultaneous

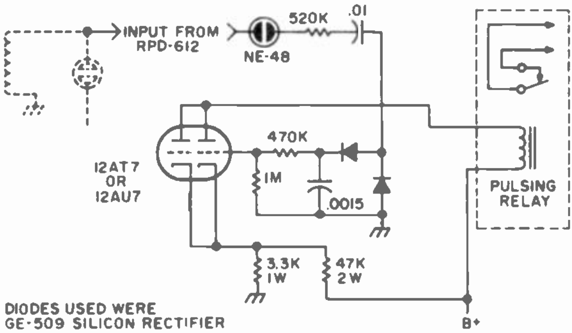


Fig. 3-9. Secode unit is "customized" for the Wichita repeaters by adding a separate stage for dial pulsing of the phone line.

duplex operation. Since any repeater must have some type of carrier-operated switch, we use the carrier switch to change from transmit to receive. This has a "bonus" – if the radio amateur wishes to interrupt the person on the landline, he simply pushes his microphone button and the landline is no longer transmitting. Very useful to prevent outbursts of unbecoming language from being transmitted. After all, how many two-meter mobiles are equipped for simultaneous duplex operation?

An examination of the schematic diagram shows a pulsing relay, a switching relay, the patch-on relay and the patch-off relay, plus the call-length timer. The pulsing relay is controlled by the presence or absence of tone. The points are closed unless tone is received by the decoder. The call-length timer, a motor-driven unit, opens a set of normally closed points after a preset time interval. The timer begins operation when the patch-on relay is operated; it is returned to zero when the patch-on relay is deenergized. The patch-on relay is held on by a set of points on its own point stack. In the event of power failure the patch-on relay drops out and releases the telephone line. The call-length timer and the patch-off relay momentarily interrupt the power to the patch-on relay, again deenergizing the relay. The switching relay is operated by the carrier-operated relay in the receiver.

When no carrier is coming into the repeater, one set of contacts holds the transmitter keyed on while a second set of contacts connects the audio from the telephone line to the transmitter. A transmission by a mobile unit operates

Parts List

1 – Dial, Stromberg Carlson or equiv., or W.E. or Kellogg dial, alternate.
1 – 88 mH Toroid, w/added winding, 20–50 turns.
1 – Dpdt Switch
1 – Relay, 4pdt, allied control LT-154 Series CC-CC, 12V, 185Ω Coil
1 – 1 kΩ potentiometer (output lever)
3 – NPN transistors (2N2712)
1 – 200 μF 15V capacitor
1 – .005 μF Mylar capacitor
1 – Capacitor, vary to place on freq., (.035.04 for 2805 Hz)
2 – 47 kΩ
1 – 33 kΩ
1 – 680Ω
1 – 470Ω
1 – 330Ω
1 – 270Ω
2 – 150Ω
1 – 22Ω
1 – 10Ω

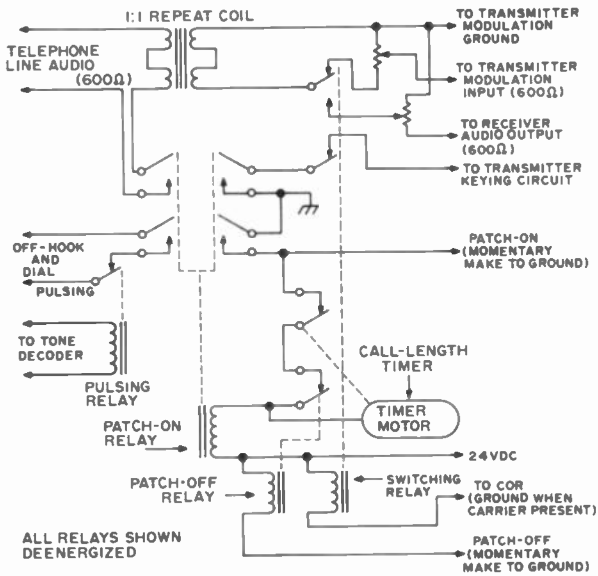


Fig. 3-10. Schematic diagram of Wichita autopatch radio/telephone interface.

the carrier-operated relay in the repeater, which in turn operates the switching relay in the patch. When the switching relay operates, the telephone line is switched from the transmitter input to the receiver output. The contacts used to hold the transmitter on are opened and allow the telephone patch to be used in two ways.

If the patch-on relay is wired to disable the normal repeater keying circuit, the telephone patch operates in a semiprivate mode. The conversation from the telephone to the mobile goes on the channel, but when the mobile transmits, the repeater transmitter goes off the air (not shown on the diagram). The way we normally use the patch, the carrier-operated relay keys the transmitter in the normal way and both sides of the telephone conversation are transmitted over the repeater channel. Since the "pulsing relay" is open at any time tone is being transmitted, practically no tone is ever transmitted over the telephone line.

Both the channel A and channel B repeaters are General Electric Progress Line repeaters, and are equipped for 600Ω audio input and output. The phone patch transformer is a salvaged telephone company one-to-one repeat coil, available on the surplus market.

System Levels

Overall system performance will depend on how carefully everything is set up in the first place. Keep in mind that hard limiting or volume compression will degrade the performance of the decoders. It is extremely helpful if a signal generator with external FM capability is available for testing the system.

The Touchtone Autopatch

Much of the information in this chapter was provided by Ray Pichulo (W1IRH), whose article, *Even More on Touchtone*, was published in 73 Magazine, April 1971.

Touchtone has become very popular lately for a variety of signaling applications. FM repeater users, for example, have found this to be a particularly useful means for controlling a variety of repeater functions as well as for "dialing" through an autopatch.

Encoders

The basic sending units, or pads, as they are commonly called, are available not only through surplus channels, but can be purchased new at prices which are reasonable for most hams' pocketbooks. One source of new pads is Automatic Electric Co. of Northbrook, Illinois. Their Touchtone pads are available in single lots for approximately $25. Touchtone signaling is also used for many computer and data transmission applications, and already some equipment from these fields is becoming available through the surplus channels.

Once you get a Touchtone pad, however, either new or surplus, the next problem is how to hook it up. The majority of pads available have been designed for telephone use, and have an overabundance of lead wires. Depending on the type you get, there may be 7 to 11 leads coming out of it. The number of leads, incidentally, has no relation to the number of buttons on the pad. Some of these leads are used in a telephone set to short out or attenuate signals to and from the handset through a set of switch contacts on the pad. Also, since the induction coil in the telephone set is sometimes used as part of the connection, there are even more leads to contend with.

It is possible to make a pad work with only two leads, plus and minus. The schematic of Fig. 3-11 shows one such connection scheme. When connected as shown, the pad will work with as little as 3V applied. The leads shown are the only ones of importance, and if your pad has other leads which are not shown on the schematic, they can be ignored. One exception would be if you have a violet lead and a green-white lead on an 11-lead pad; these are connected to an internal set of normally open contacts which close whenever any button is depressed. These leads can be used to key a push-to-talk, battery, or other line. With the hookup of Fig. 3-11, the Touchtone pad can be

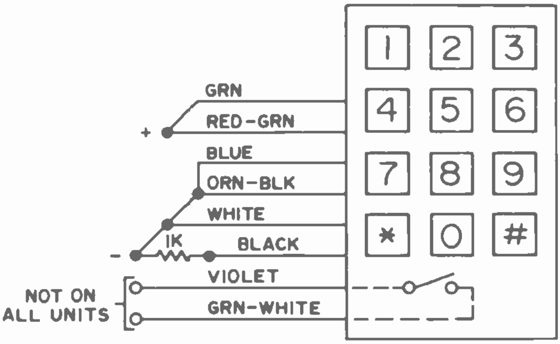


Fig. 3-11. Two-wire conversion.

plugged directly into a carbon mike input circuit, and it will work without any other power requirement, since the microphone current source will usually be sufficient to power the pad. With a dynamic mike or crystal mike input, however, an external power source, load resistor, and blocking capacitor must be used, as shown in Fig. 3-12.

Testing Encoders. How about testing one of these pads, now that you have it working? Well, if you happen to live in an area where the phone company offers Touchtone service (even if you don't have this service yourself), then your local phone company probably has a device available that you can use. First, hook the leads on the pad together per Fig. 3-11. Then dial up the ringback number of your phone. In many parts of the country, this number is 981- or 982- plus the last four digits of your own phone number. For example; your phone number is 234-5678 – the ringback would be either 981-5678 or 982-5678. You will get either a busy signal (in which case try the other prefix) or a second dial tone. If you get the second dial tone you have been successful in reaching the Touchtone tester.

Being sure to observe the proper polarity, connect the pad directly across the phone line (red and green wires) and depress 1 through 0 in sequence. If the frequency and level of the tones reaching the central office are within acceptable limits, you will be rewarded with two short bursts of tone. If they are incorrect, or you missed any one of the buttons, after 15 seconds you will hear one short tone burst. With a twelve-button pad, the test sequence is still the same. The # and * character buttons may be depressed, but they will not affect the outcome of the test.

The dial tone will remain on during the entire test, so don't be misled by the fact that it does not go away after you press the first digit button.

Be sure to disconnect the pad from across the line *before* you hang the phone up as the line voltage will rise to 48V with the phone on the hook and could damage the pad.

This ringback number is also used by telephone installers to make a phone ring back. If you should press the hookswitch momentarily or dial a 1, a second dial tone will change to a 1000 Hz tone, and another dialed 1 or hookswitch depression will cause the phone to ring when it is hung up. In case the 981- or 982- prefixes do not work in your area, a call to repair service or a talk with an amiable telephone installer could probably get you the information required in order to access the ringback and test number.

It is not strictly necessary to use a Touchtone-type decoder at the repeater receiver to get a Touchtone autopatch in service. One of the characteristics of the Touchtone pad is the fact that it generates a precise single-frequency tone when two of the encoder buttons are pressed simultaneously. This allows you to use an ordinary precision single-tone decoder for control of the telephone functions, while maintaining the ability of sending conven-

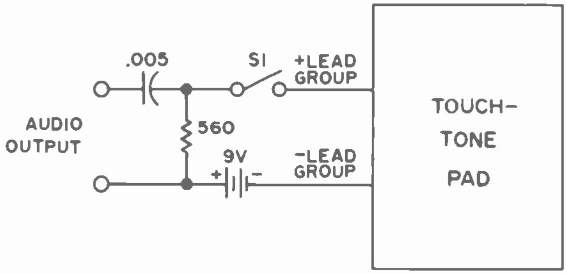


Fig. 3-12. Connections for use with non-powered mike inputs. S1 may be internal switch through violet/grn-wht leads if provided. Otherwise S1 is external SPST power switch.

tional two-tone Touchtone signals over the telephone circuit. The decoder should respond only to single tones of the frequency of your choice (depending on the two digits you select for controlling the "phone on" function). If the decoder responds when two-tone signals are transmitted (as when a single key is pressed on the pad), the telephone "dialing" process should be as quick as possible, pressing each number button for no more than one-half second as the telephone number is dialed.

The K6MVH digital autopatch circuit shown in chapter 13 is perfectly compatible for Touchtone dialing applications. The one single modification would be to jumper the top set of contacts on pulsing relay K3.

PART IV

Tips and Circuits for Repeater Users

Setting up a Mobile Station

Much of the information contained in this chapter was taken from the FM Magazine article, *How to Get the Most From Your Mobile,* by Bill Harris (K9FOV).

In making a mobile FM installation, the first item of note is the crystals you intend to use for transmitting and receiving. *Don't try to save a buck or two on crystals!* What you may have saved in dollars will not buy back what you will have lost in performance through the use of substandard crystals.

Twelve or fourteen dollars for a set of Sentry or International crystals may seem high, but bear in mind that it will be a one-time investment; they'll last the lifetime of the rig, and the frequency will be the same the day your radio dies of old age as it was on the day of its birth. The rule is: Get the crystals made for the unit and you will never have frequency stability and drift and "bad rock" problems that might otherwise cripple the rig. And *never* try to "fake" the crystal with one you just happen to have lying around the shop. With conventional ham radio, such tactics are clever; with FM, they're crude. Quite understandably, it's the most common mistake FM newcomers make.

The mobile rig should be checked completely before installation, and all noticeable defects corrected at that time. In this way, you can spot such problems as broken cables, loose connections, and the like while you can still get at them. This can prove to be a pretty handy tip if there's no one within 80 miles of you who has the necessary jig and cables to fire up your unit on the bench. Troubleshooting in the trunk of a car tends to be a time- and gas-consuming headache, especially when the difficulty is serious and the light is poor.

You can help to overcome the potential problem of inadequate lighting by taking the time to install a simple light on the inside of the deck lid. Most auto parts stores sell mercury-switch lights that can be installed in minutes; such lights go on when the lid goes up and go off when the lid is shut.

Antenna Location

Give some consideration to mounting the antenna in the roof if at all possible. Contrary to popular opinion, the small hole in the roof does not depreciate the value of the car these days. If it's the effects of the hole that bother you, take heart: A good make of antenna properly installed will not leak. Unless you use a car-top carrier a good part of the time, the space up there is going to waste. So use it – you won't regret it.

Never use a bumper mount, particularly on 6m. A bumper-mounted whip puts the antenna close to the ground (which is a noise source in itself) where signals find it difficult to compete with road garbage; and it hides the antenna behind the mass of the car. On any other rear-mounted type of installation, the car mass reinforces the signal by lending it gain and directivity off the front (at the sacrifice of side coverage, of course); but this is not so with the bumper mount.

Other types of antenna installations to stay away from if you're making it a permanent hookup are gutter clamps, jiffy mounts, trunk-groove and magnet-base mounts and their ilk. For the most part, they give misleading vswr indications and result in high radiation angles due to their self-resonance and inherent inductance in the ground return. Also, they tend to leave the transmission line and coaxial termination out in the open where eventual deterioration is inevitable. To top it all off, the kink in the cable where the door, window or trunk lid closes will ruin it in short order.

And while we are discussing the cable aspect: Upon installation and periodically thereafter, carefully check the transmission line; replace it if it shows signs of degradation, crushing, or right-angle bends. It may not show up on a vswr meter, but weather contamination or center-conductor migration will wipe out a lot of performance.

Surplus Commercial Installations

When installing a surplus unit, fasten it firmly to the floor. In the case of a front mount, get some heavy trunnion brackets made and use them to bolt the case to the dashboard (and to the floor or fire wall, if possible). There are several sound reasons for mounting the rig securely: For one, the same amount of rf current that goes to the antenna must flow through the car body, and it does not generally prefer the dynamotor ground lead or the coax braid for its path to ground. The battery current will, however, tend to return through the coax braid for its ground path, particularly if the negative cable connection happens to loosen a bit. This will tend to affect the receiver sensitivity due to increased vibrator hash pickup along the lead.

The last reason I wish to expound in favor of fastening a surplus FM rig securely is one that has probably never entered your mind: Say you are involved in a wreck and you hit something head-on or roll the car a time or two. What will you have accomplished if you are kept intact by the seat belts only to be decapitated by your faithful old 80D (which weighs something like 1400 lb at 60 mph).

Mount the speaker where you can look directly into it when you're sitting in the driver's seat. It's usually better not to give the preferential location to the control head, and stash the speaker way up under the dash panel where it can talk to all the defroster ducts and wiper cables. Since the control head is a set-and-forget device, it should be the item mounted in the more remote spot. In any case, intelligibility of signals will be greatly improved by judicious situation of the speaker; and likewise, intelligibility will be seriously degraded if the speaker is not mounted reasonably close to the listener, and positioned toward the listener's ear.

If the speaker has a warped or torn cone, replace it. It's an inexpensive item to buy, but it is still one of the weakest links in your radio system. In addition to affecting the readability of signals, a speaker with a rubbing voice coil will actually increase the apparent noise in the audio.

Transistorized Amateur FM Units

The commercially available transceivers now being marketed for amateur use specifically have special requirements. At first glance, it might seem that the suggestions that apply to control heads in general might also apply equally to these transceivers. But such is not the case. A control head can be mounted out of the way because there is little need to keep reaching for it once the rig is placed in operation; a transceiver, on the other hand, is likely to require fairly frequent manipulating. Most come ready to operate on at least a half dozen channels, for example, so the operator will find himself constantly reaching for the rig to shift from one frequency set to another.

The transceiver also differs from the control head in that it will invariably contain a speaker. If you move the transceiver out of easy reach, chances are you'll be moving the speaker out of easy earshot as well.

So. The important things to consider when mounting a multichannel transceiver are: (1) The rig should be easy to remove and replace; (2) the front panel should be easily reachable and viewable without undue leaning on the part of the driver; (3) the mike cord should not interfere with the steering wheel while the transmitter is in use; and (4) the speaker should be oriented for the most advantageous listening.

The limitations offered by individual makes of automobile, coupled with the space requirements and control placement of particular makes of transceiver, may make impossible the fulfillment of all the four main objectives. The user can only be admonished to use good judgment when making his own installation, and seek to accomplish as many of the "desirables" as he can. Remember, a little thought goes a long way in terms of safety, comfort, and convenience.

Sit in the driver's seat and close your eyes; angle your right arm straight out and lay your palm on the dash. That's the spot where the mike bracket should be mounted. Unfortunately, in 98% of the newer cars, this spot is infeasible, so try to find one that is not. In any event locate it where you can grasp it without taking your eyes off the road.

Power Source

Here's a helpful hint on battery cables: Remove the cables from the battery and carefully clean the connectors and the battery posts with soapy steel wool and warm water. At the same time, it's a good idea to clean off all foreign matter from the top of the battery. Rinse the area well, then dry it off and reconnect the cables to the battery. When the reconnection is completed, spread a thin coat of silicone grease over the connection; chances are you'll never have to wade through the oxidation again (and neither will the current to the battery from the generator or from the battery to the radio or starter).

Noise

Don't forget an ignition tuneup or any other noise suppression that may be necessary. (There are many articles and books available on this subject.) Of course, FM is not as susceptible to noise as some of the other modes, but it is by no means immune; it's just that you don't notice noise presence so much because of the squelched receiver.

If you hear a 2m signal better with the engine off than you do with the car running, double-check your ground connections from the car battery to the vehicle chassis. Use heavy braided copper wire and ground the battery to the engine. From the terminal point of the copper braid, run a similar length of strap to the car body itself. To be sure the connections are sound electrically, scrape the areas clean, exposing the bare metal, before the ground strap is bonded to the frame and body.

Operational Check

After the unit is installed and peaked to the antenna, check with someone to make sure you are transmitting on frequency. If warranted, make any necessary adjustments. The closer you get to frequency, the stronger your transmitted signal will seem. At this time, zero the receiver oscillator onto channel by monitoring a known signal with a discriminator meter. Get a few modulation reports, and adjust the transmitter deviation as necessary.

This should find you all set to go FM mobile. Just remember, you'll only get out of your unit what you have put into it!

Encoders for Subaudible, Tone-Burst, or Whistle-On Use

When two or more repeaters operate with overlapping coverage on the same input or output frequency, mobile operators occasionally find themselves triggering more than one repeater. The mobile operator who does so may thus cause interference by his unintentional keying of the repeater in a neighboring community.

As a rule, shifting the frequencies of one of the repeaters is no solution, because both relay stations will want to be on the nationally accepted standard (146.34 MHz input, 146.94 MHz output). Such standardization is a boon to the mobileer who has a limited supply of crystals and must travel across the country or from one area to another once in a while.

But there are workable solutions. More and more, repeaters in highly congest areas are going to a "tone-burst entry" approach or a "whistle-on" system of keying. With a whistle-on system, the control circuits are all at the repeater site. The repeater is never operative unless specifically activated by one of the users.

A broad whistle on the input frequency energizes a decoder at the repeater site, which in turn activates the automatic signal-relaying system. Typically, the repeater stays on, once activated, retransmitting the signals of all carriers on the input. When the traffic dies down a bit – that is, after a short period of no signals – the repeater shuts down again, and cannot be used unless someone deliberately calls for it by whistling on the input.

When multiple-repeater conditions are more severe, the tone-burst keying system is the more satisfactory solution. Here, a specific tone frequency – usually 1700 to 2000 Hz – must be present briefly at the outset of every transmission before a signal can be automatically relayed.

In practice, all who intend to use the repeater will install simple audio oscillators into their transmitters, connecting them in such a way that the tone comes on briefly each time the transmitter is keyed. The tone, decoded at the receiver of the relay station, is used to activate the repeater – but only for the duration of a single carrier.

The FCC sanctions the use of semicontrol techniques such as continuous-tone carrier squelch systems (very low frequency tones accompanying all carriers) and single-tone (tone-burst entry or whistle-on access) in applications where limited access to a remote station or a repeater is desirable. The W6FNO repeater in Southern California went one step further, and the result is a repeater that is fully compatible with two-way nonrepeater operation taking place on the input channel.

Whistle-On Encoder

In many ways, the W6FNO repeater at Radio Ranch could serve as a model installation: The repeater stands ready for use 24 hours a day and is never shut down where it cannot be accessed by a station on the input frequency. On the other hand, the repeater will shut itself off if a three-minute period elapses with no signals on the input. Sounds a little contradictory, but it isn't – not really. The W6FNO repeater was an experiment to test the concept of subcontrol, i.e., limited control of the repeater from the actual frequency of operation.

The repeater is equipped with two timers. The first timer is a transmission-limiting device: when the input carrier exceeds three minues duration, B+ is removed from the transmitter final; and it can only be reapplied after the input carrier drops out momentarily. The second timer removes the transmitter B+ also. But in this case, the timer is activated by the absence of an input signal. Since the shutdown is only B+ removal, the repeater is ready to be activated immediately upon application of the proper signal, which in this case is nothing more than a shrill whistle.

The W6FNO repeater is a "talkback" type, as opposed to a "prime" repeater. A talkback repeater uses a national

FM channel as the input frequency and a nonactive channel as the output. A prime repeater uses a nonactive channel as the input and an active, popular frequency as the output. the popular 146.34-to-146.94 repeaters across the country are primes. If the frequencies were reversed, they would be talkbacks.

The active FM channel for direct nonrepeater operation in the W6FNO territory is 146.82 MHz, which also serves as the repeater input. The repeater output frequency is not used at all except by stations who want to hear what's going through the repeater. When two stations are conversing on the FM channel, the repeater is not even a part of the operation unless one of the operators wants it to be (as for instance when the copy gets rough).

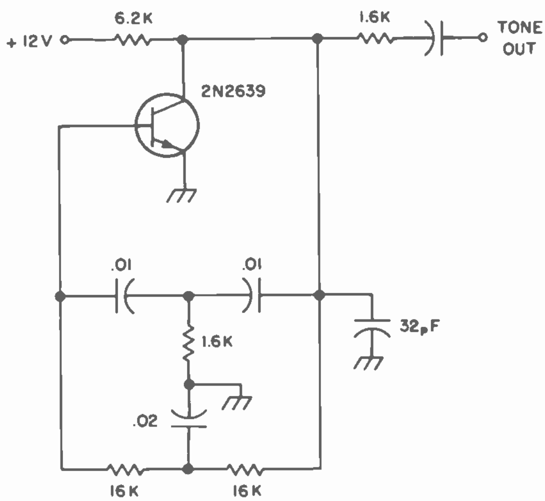
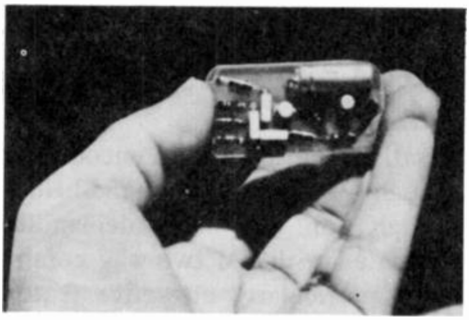


Fig. 4-1. Single-transistor tone oscillator for tone-burst or whistle-on use produces 1750 Hz at sufficient amplitude for most transmitters.

When a user wants to monitor the active 146.82 channel, but he is too far away from the area of activity to hear the stations, he merely puts a carrier on the channel and whistles into the microphone. Instantly the repeater comes on, regardless of the time of day or night, and the user finds himself right in the middle of the action. The only difference is that he hears the 146.82 action on some other channel.

The decoder at the repeater site that provides the turn-on function is nothing more than a simple frequency-to-dc converter such as the decoders shown in Part I of this book.

The circuit shown here was designed by John Gallegos (W6ZCL), and is the epitome of simplicity. A single-transistor oscillator using a twin-tee feedback network. As can be seen from the circuit of Fig. 4-1, a few minutes and a good junkbox are all that is required.



Barely more than a thumb's width, the W6ZCL phase-shift oscillator is small enough to be packaged within the case of almost any commercially available held-held transceiver. Photo shows three separate packaging schemes: printed-circuit layout; "cordwood" technique, and the "crystal-can" method, using a conventional Pomona Electronics miniature mounting box.

Don't connect the whistler so that it comes on with each transmission. Not only will this defeat the purpose of a repeater's automatic-off function, but it will give your signal the unpleasant characteristic of a squeal at the outset of each transmission. Instead, connect the device into the transmitter so that it is energized by pressing a momentary-contact switch on the control head. Figure 4-2 shows how the oscillator may be interconnected into a typical mobile unit.

The oscillator circuit shown in Fig. 4-1 works for tone-burst entry applications, too, where the tone frequency tolerances are not particularly critical. But the interconnection would have to be a little different from that shown in Fig. 4-2. For tone-burst operation, remember, the audio note must appear for a short period every time the transmitter is keyed.

Tone-Burst and PL Encoders

Where the tone frequency is critically set, decoder instability is intolerable and whistling won't quite cut the mustard. For such applications, the encoder requirements become quite stringent. But it is possible to build a highly stable encoder unit with a minimum of parts. The circuit described below, also designed by W6ZCL, represents a very

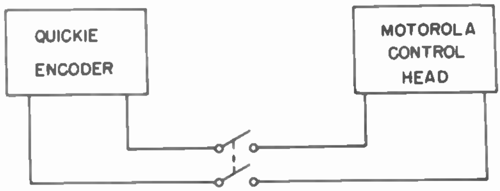


Fig. 4-2. A momentrary-contact switch can be used as shown to interconnect the encoder audio into the mike line at the control head for whistle-on applications.

versatile transistorized encoder that can be built small enough to use with hand-held transceivers, yet stable enough for the most demanding applications normally associated with FM two-way communications.

A particularly attractive feature of the encoder is the fact that it can be used for either continuous-tone squelch (commonly known in these parts as PL, or Private Line), or for tone-burst entry. (A continuous-tone squelch scheme utilizes a subaudible very low-frequency note, whereas the single-tone method depends on generation of a fairly

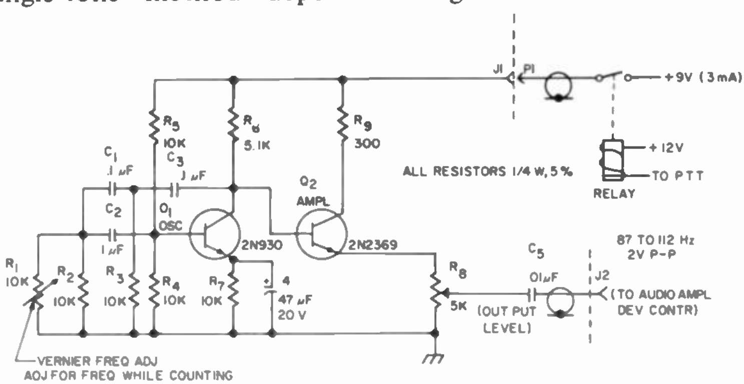


Fig. 4-3. Schematic diagram shows basic circuit as used in a continuous-tone-squelch repeater access system. Parts values shown are not applicable to single-tone encoder applications (see text).

high-frequency note.) Most low-frequency encoders require vibrating reeds for stability; the one described here is a notable exception.

Figure 4-3 is the schematic diagram for the unit, which is essentially a phase-shift oscillator coupled into an emitter follower. Since the power consumption of the oscillator circuit is so low, a standard 9V transistor-radio battery will provide an ideal power source. At full output, the oscillator draws no more than about 3 mA.

Table IV shows two complete parts lists. The application of the encoder (continuous-tone squelch or tone-burst entry) will determine the parts selection for your particular use.

The very small size and the apparent simplicity of the encoder might logically lead you to suspect its performance. But these factors not withstanding, the device can produce a very healthy looking sine wave, as can be seen from the photo of Fig. 4-4. Laboratory temperature cycling tests on the three units that were built by W6ZCL indicate

Table IV. Parts Lists for CTS and Single-Tone Systems

Component	87-112 Hz range	1750 Hz
R1	10 pot (multiturn)	50 kΩ pot (multiturn)
R2, 3, 5	10 kΩ	47 kΩ
R4	10 kΩ	22 kΩ
R5	10 kΩ	47 kΩ
R6	5.1 kΩ	5.1 kΩ
R7	5 kΩ pot (multiturn)	4.7 kΩ (multiturn)
R8	300Ω	300Ω
R9	0.1 μF	0.001 μF
C1, 2, 3	47 μF, 20V tantalum	47 μF, 20V tantalum
C4		1 μF tantalum
C5	0.01 μF	
Q1	2N930	2N930
Q2	2N2369	2N2369

that the tone output will remain stable and will not drift more than 0.5 Hz over the range of 25–60° C. His units were built using disk ceramic capacitors, incidentally; substitution of Mylar capacitors for C1, C2, and C3 will result in even better temperature stability.

The schematic shows transistor Q1 to be a 2N930, but this type was chosen arbitrarily. Actually, any good NPN will suffice, as long as it is a type with a *beta* of 100 or so. The transistor used for the emitter follower is even less critical, and can be effectively duplicated with just about anything in the junkbox that has the same polarity.

Fig. 4-5 is a circuit board layout shown actual size. Figure 4-5 is for those of you who intend to do the job up first class with printed-circuit wiring. The printed-circuit version looks sharper, of course, and it has the added advantage of ending up with a slimmer overall profile. The layout shown in Fig. 4-6, however, is perfectly satisfactory for "brass-board" models. This version requires nothing more than a few holes and some standoff terminals on a flat piece of almost anything.

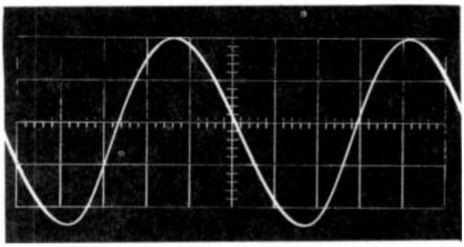


Fig. 4-4. Scope trace shows the sine wave obtained with W6ZCL's encoder unit. Increments shown are 2 msec per centimeter for the horizontal scan and 500 mV per centimeter for the vertical scale.

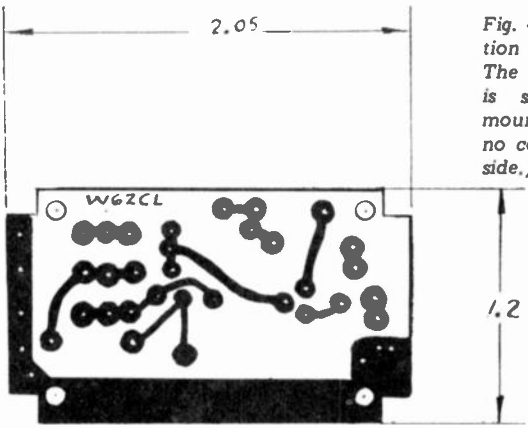


Fig. 4-5. Actual-size reproduction of printed-circuit layout. The copper side of the board is shown; components all mount from far side. (There is no copper on the component side.)

The dimensions of the boards are suitable for mounting the completed unit inside a Pomona Electronics Model 2417 shielded box ($1.50 at practically any self-respecting electronics sales outlet). Miniature coax can be used to apply the dc supply voltage (9V) and to carry the signal to the deviation control potentiometer through a 500 kΩ resistor, as shown in Fig. 4-7. If space is not available in the radio to mount the Pomona box, the printed-circuit board itself can be mounted in any available underchassis spot. The two variable resistors can be replaced without detriment by fixed resistors after the proper values have been determined for your particular frequency and output-voltage level. But potentiometers are handy if you have the space. If you *can* use them, I suggest the use of the miniature multirun devices (Bourns *Trimpots*), because of the vernier tuning they afford.

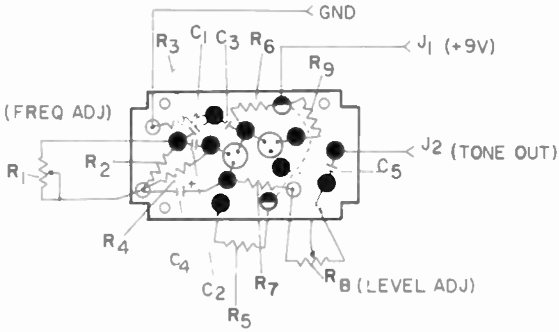


Fig. 4-6. Wired-board layout was designed for use with Sealectro push-in Teflon standoffs and ground terminals. Transistors can be held in place by TO-18 heatsinks. (Heatsinking is actually unnecessary. The cases of the transistors are hot and must be insulated from ground; the heatsinks perform this job by virtue of their anodized finish.)

The parts lists shown in Table IV cover the continuous-tone-squelch range of 87–112 Hz and the single-tone frequency of 1750 Hz. For those whose requirements are not met by either of these sets of values, the frequency of the encoder may be calculated from the equation:

$$f = \frac{1}{2\pi\sqrt{6}RC} = \frac{0.085}{RC}$$

If the tone-burst version is used rather than the continuous-tone squelch version, the audio need not be coupled to the transmitter as shown in Fig. 4-7. At these higher frequencies, it is practicable and convenient to simply mount the encoder unit inside the control head and connect the audio output lead from the oscillator directly onto the mike line. If you choose to adopt this method,

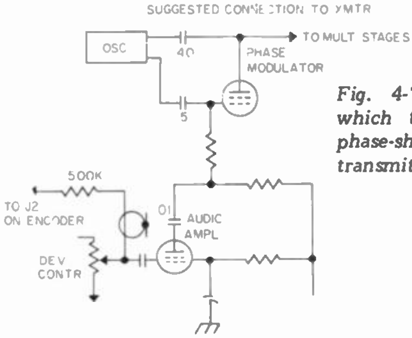


Fig. 4-7. Schematic showing manner in which the low-frequency version of the phase-shift oscillator can be tied into the transmitter.

just connect a 200Ω resistor in series with the tone oscillator output lead before attaching it to the carbon mike pin on the control head connector.

If the local repeater is the whistle-on variety (rather than tone-burst entry), you might also find it convenient to turn the audio lead through a single-pole switch mounted on the control head. In this way, you can switch the tone on whenever you want it, and keep it out of the circuit the rest of the time.

Another good encoder is the unit designed by Bob Kertesz (VE2BZK). His unit is a standard LC feedback type, and is as stable and accurate as the quality of the components used in the collector circuit. Kertesz used a standard 88 mH toroid for the inductance in his circuit (Fig. 4-8), and then calculated C1 and C2 from

$$f = \frac{1}{2\pi\sqrt{LC}}$$

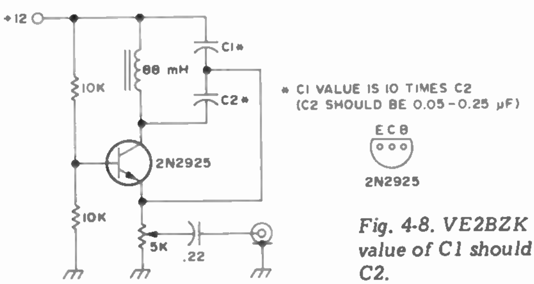


Fig. 4-8. VE2BZK encoder schematic. The value of C1 should be 10 times the value of C2.

Where f, L, and C are, respectively: hertz, henrys, and farads. His capacitors are in a ratio of 1:1 to get a high Q; so, after arriving at the value of C1, he simply multiplied the result by 10 to determine C2. Values of 88 mH, 2 μF, and 0.22 μF·will produce a tone output of 1 kHz.

To prevent instability, mica capacitors of 10% tolerance or error should be used for C1 and C2. The transistor can be any general-purpose NPN type.

A circuit board for the finished board can be obtained from Stafford Electronics, Inc., 427 S. Benbow Rd., Greensboro, NC 27402. The PC board, model ST4-71A sells for $2.50 drilled, or for $1.25 undrilled.

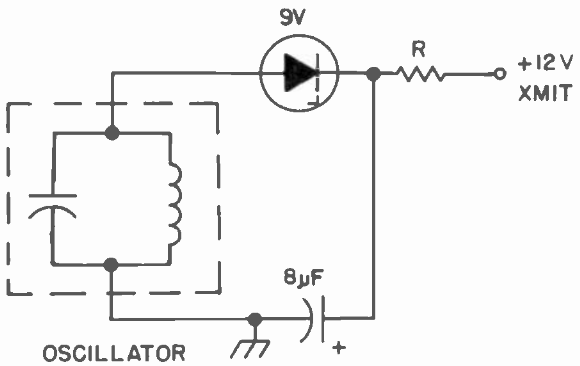


Fig. 4-9. K6GUC tone-burst timer.

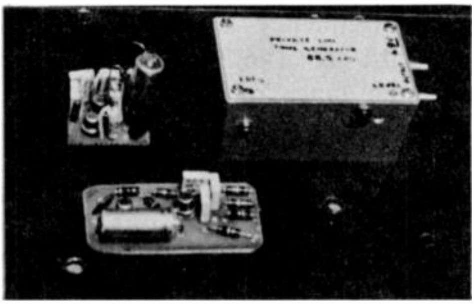


Photo shows three separate packaging schemes: printed-circuit layout; "cordwood" technique, and the "crystal-can" method, using a conventional Pomona Electronics miniature mounting box.

Interconnection

When a tone-burst encoder is used, some means must be employed to limit the oscillator's output to no more than a half-second or so with each keying of the transmitter. To accomplish this, the timing circuit shown in Fig. 4-9 was developed by K6GUC. In his approach, the 12V supply for the encoder must be keyed on and off with the transmitter.

Multichannel Scanning

The circuits and much of the text in this chapter were taken from a 73 Magazine article by Gary Hendrickson (W3DTN). The article, *A 2-Channel Search-Lock for FM Receivers*, appeared in the July 1970 issue.

Until recently, the popular repeater frequency of 146.94 MHz was restricted to "direct" operation. In many communities, this frequency has continued to survive as a point-to-point channel, with the repeater frequency being assigned to some other standard channel. In such cases, FM operators with two-channel units can have the capability of monitoring both the repeater output and the local direct frequency. A scanning circuit, which is used to sample two frequencies alternately and rapidly, does the job.

Even repeaters have occasional applications for scanning circuits. A good example would be a repeater situated close to the Canadian border: In Canada, the standard repeater input frequency is 146.46 MHz, while in the U.S., the standard is 146.34 MHz. A repeater installed within working range of units from both countries could make good use of a two-frequency scanner to monitor for incoming signals on either of the two standard input channels.

Gary Hendrickson (W3DTN) designed a two-channel "search-lock" scanner, which very rapidly monitors two frequencies sequentially, the locks onto whichever of the two channels that bears an incoming signal. Included in Hendrickson's circuit is an optional active-channel indicator that will light up to show which channel is being used.

The W3DTN scanner can be used with any tube-type receiver such as those normally employed for repeater applications.

The search-lock unit (Fig. 4-10) consists basically of a flip-flop (Q2 and Q3) with the outputs connected to the cathodes of the two crystal oscillator tubes. As the flip-flop operates, it alternately grounds the cathode of each crystal oscillator for a short time, thus sampling each frequency. The flip-flop is triggered by pulses generated by unijunction transistor Q1, at about a 10 pulse-per-second rate. Therefore, each channel is sampled five times per second, for 100 ms each time. This sampling rate is fast enough that no information is lost at the beginning of any received transmission, yet slow enough to permit the crystal oscilla-

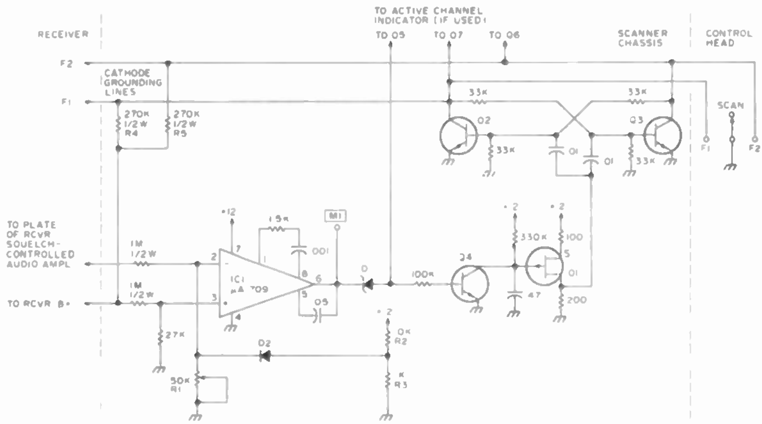


Fig. 4-10. Two-channel search-lock for FM receivers. For mobile installations, the switch is mounted on the control head; everytying else may be mounted inside the radio cabinet.

tors to turn on completely and come up to full output. It is also long enough to allow the squelch to open if a signal is present on one channel.

When a signal appears at the receiver input and the squelch opens, the gate circuit will turn off the unijunction transistor pulse generator, and the receiver will stay locked on that channel as long as the signal is received. In this respect, the circuit is similar to that of a carrier-operated relay. The gating circuit consists of a squelch detector (IC1), and gate amplifier (Q4). IC1 is a type 709 operational amplifier wired as a differential switch. This circuit effectively prevents drift of the gate trigger level with changes in battery voltage when used in a mobile installation.

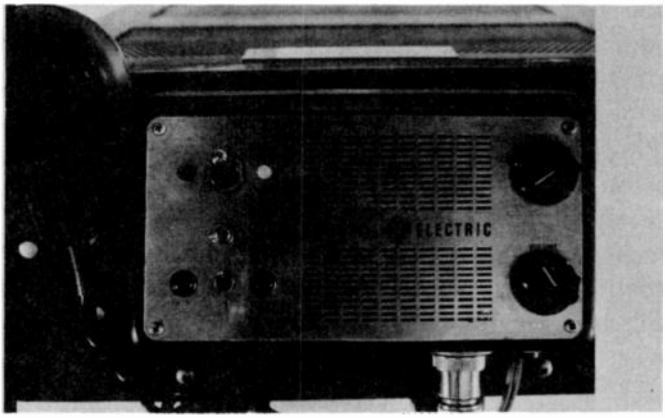


Fig. 4-11. Search-lock controls mounted on a GE Progress Line front-mount control head. Separate transmitter and receiver channel switches are used. The scan switch is the toggle mounted just under the main power switch. In the extreme left position, the receiver locks on frequency 1, and in the extreme right position, it locks on frequency 2. The center position allows the receiver to scan, thus locking itself on whichever channel becomes active first. The two lamps mounted adjacent to the lower toggle switch provide an indication as to which channel is being used.

The positive input of the differential switch (IC1) is connected to receiver B+, and is the reference voltage. The negative input is connected to the plate of the squelch controlled audio amplifier tube.

When no signal is being received, the dc voltage on this plate is the same as B+. When a signal appears and the squelch opens, the dc voltage at this plate will drop. This

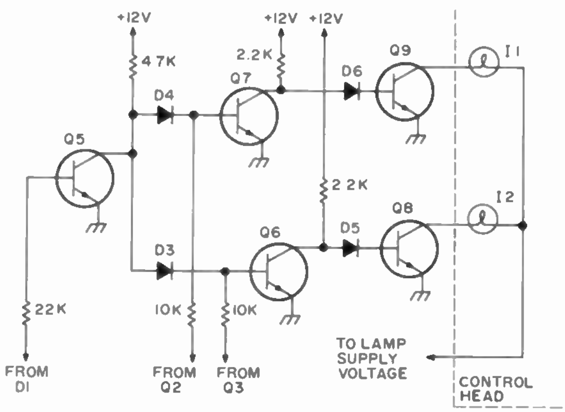


Fig. 4-12. Optional active channel lamp indicator circuit. The lamps are mounted on the control head.

voltage change is detected by the differential switch (IC1), is amplified by Q4, and switches pulse generator Q1 off.

Potentiometer R1 is the differential switch threshold adjustment. If B+ varies up or down due to a change in battery or line voltage, the differential switch will not operate because it is only sensitive to changes in the ratio of the two input voltages (and not to changes in the absolute values of these two voltages).

Resistors R4 and R5 provide a pull-up voltage on the cathodes of each oscillator (switching point in the receiver) to make certain that they go completely off when not

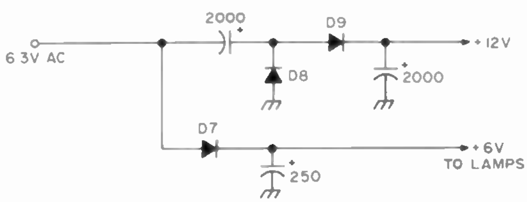


Fig. 4-13. The ac filament voltage typically available in a tube-type base station can be used to power the search-lock device if this simple rectifier circuit is built.

grounded through their associated transistor in the flip-flop. They also absorb any leakage currents through either flip-flop transistor.

A switch on the control head is the only operating control needed. It is a three-position type (up, down, and center), and the center position is "on." In the center position. The search-lock operates normally. In either extreme position the associated cathode is grounded directly, and the search-lock is disabled (see Fig. 4-11).

The active channel lamp indicator circuit (Fig. 4-12) is an optional operating convenience that may or may not be included. Transistor pairs Q6 and Q8, and Q7 and Q9, are the lamp drivers. They are controlled by squelch gate amplifier Q5 and inputs from the flip-flop (Q2 and Q3).

When there is no signal present, the lamp drivers are gated off, and neither lamp lights. This was done to eliminate any flashing lights which might be a distracting safety hazard while driving at night. When a signal appears, gate amplifier Q5 turns on, the appropriate lamp driver circuit is turned on, and the lamp lights. As soon as the signal disappears, the lamp goes out, and the search-lock resumes operation. Resistors R2 and R3 and diode D2 serve to keep the squelch gate circuit turned off when transmitting so the channel indicator lamps don't light.

If used in a mobile installation, the entire unit can be powered directly from the 12V battery line. If used in a fixed station, the rectifier power supply in Fig. 4-13 can be used to supply dc voltage from the filament line. In this case, 6V lamps should be used. (For mobile operation, 12V lamps should be used.)

Parts layout is not critical. Small quarter-watt resistors may be used except where noted, and low-voltage capacitors are also satisfactory. Diode D1 is a 1N747, Motorola HEP-102, or similar low-power zener diode of 3–5V. Diodes D2 through D6 are low-power silicon computer diodes such as 1N645, 1N2069, or Motorola HEP-154. All components can be mounted on a plug-in Vector board, as shown in Fig. 4-14.

Unijunction transistor Q1 can be a 2N2160, 2N1671, GE X-10, or Motorola HEP-310. Integrated circuit IC1 is a type 709 operational amplifier. All the semiconductors can be purchased for about $10, including IC1, from Poly Paks in South Lynnfield, Mass. Transistors Q2, Q3, Q5, and Q6 can be 2N3641, 2N706, GE-17, Motorola HEP-50, or any similar type. Transistors Q4 through Q7 can be 2N3565,

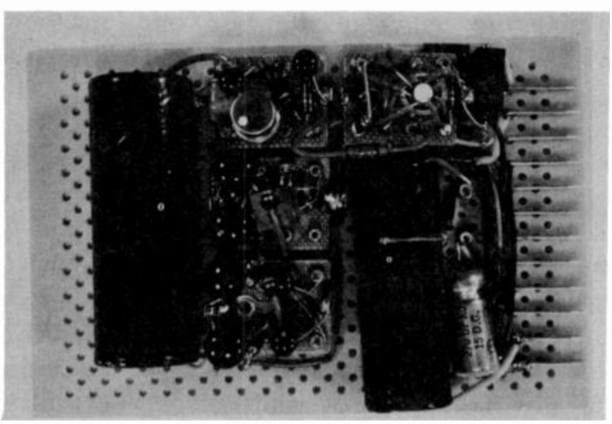


Fig. 4-14. Components for the search-lock can be mounted on a plug-in Vector board.

2N3860, GE-17, Motorola MPS-6520 or HEP-55, or any similar type. The lamps should be low-power types that do not draw over 150 mA.

The chassis can be installed inside the case of a mobile unit or anywhere in a fixed station. The only modifications necessary are to separate the receiver channel switching lines from the transmitter lines. Separate switches for transmitter and receiver should be mounted on the control head. The transmitter switch can be any type with the proper number of positions required for the particular installation.

If you elect to include the active channel indicator lamp circuit, the two lamps will have to be mounted on the control head, and lines run to the search-lock chassis. If the existing control cable doesn't have enough conductors to handle the separate receive and transmit channel switching, plus the indicator lamps, another multiconductor cable can be run to accommodate these wires.

The only adjustment necessary is to set the squelch gate threshold pot (R1). This is done by reading the voltage at metering point M1, the output of IC1. With no signal at the input and with the squelch fully closed, adjust R1 until this voltage drops to just under 2V. Check to see that this voltage rises almost to the supply voltage when you open the squelch.

When operating normally, with no signal, metering point M1 should be under 2V, pulse generator Q1 should be generating short pulses at about 10 pps, the flip-flop should be operating, and the lamps, if used, should be out. When the squelch is opened, either manually or by a signal, metering point M1 should rise to near the supply voltage, pulse generator Q1 should not be operating, the flip-flop should be stopped with one side turned on and the other off, and one lamp should be lighted.

RF Preamplifiers for Repeater Applications

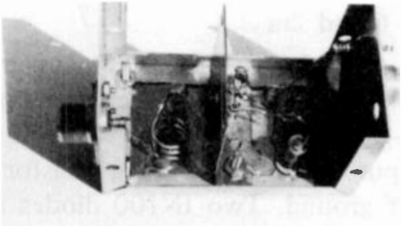
The single most important requirement for a receiver preamp to be used in a repeater is selectivity – or a healthy resistance to blocking from nearby rf fields. Repeaters are situated, by necessity, at locations that are inherently high in stray radiation. A broadband preamp installed in the presence of high electromagnetic fields will do nothing more than degrade the performance of the repeater because it will increase receiver desensitization by an amount usually equal to or more than the gain offered.

The preamps selected for inclusion in this manual have been tested in repeater service and have proved themselves effective for installation in high-field-strength areas. Clifford Klinert (WB6BIH) designed the first preamp, construction details of which first appeared in 73 Magazine, May, 1971. Klinert's preamp offers a high degree of selectivity and up to 20 dB of gain.

The second circuit was designed by Ernest Franke (WA4WDK) for operation in either 6 or 2 meter receive applications.

WB6BIH Preamp

Figure 4-15 shows the schematic of the amplifier. A common-source unneutralized Motorola MFE 3007 is used. The input signal is applied to one gate, and the other gate is used for biasing. An rf choke and feedthrough bypass capacitor are used to improve isolation from the power supply. Experimentally tapped coils are used for input and output coupling.



WB6BIH dual-gate rf preamplifer.

The amplifier was built in a small aluminum box. The top was cut out and replaced with a copper plate, and a copper partition was soldered in the center as a shield. Both L1 and L2 are made with 3½ turns of 18-gage wire stretched to about ¾ in. long. The coils are ½ in. diameter. MC 603 trimmer capacitors are used for C1 and C2. They are 1–28 pF, but a variety of small variable types could have been used. L1 and L2 are mounted perpendicular to each other to minimize electromagnetic coupling. Since the MFE 3007 is susceptible to gate breakdown, all leads of the transistor should be shorted together with a short piece of wire until soldering is complete.

The first step in tuning is to set the tuned circuits approximately on frequency with a grid dip meter, then see that they tune fairly sharp on the desired frequency.

After the tuned circuits are set up with zero bias, the 100 kΩ can be turned slightly to increase the bias. This will cause a decrease in output, but retuning the tuned circuits, mostly C2, will bring the output back up.

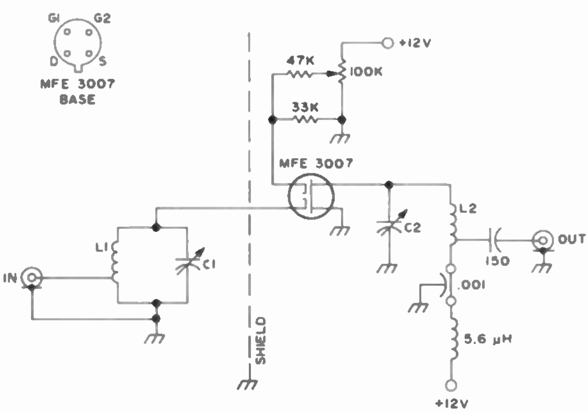


Fig. 4-15. 146 MHz rf amplifier.

The WA4WDK Preamp for 6 and 2m

The schematic of Fig. 4-16 shows WA4WDK's preamp, which uses a 2N3823 (or TIS 34) field-effect transistor cascaded in the common-gate configuration. A simple rf choke provides the rf input load. The biasing resistor is bypassed to provide the rf ground. Two IN100 diodes are placed back-to-back at the input connector to prevent possible overload damage: Poor isolation, especially in the antenna relay, could easily destroy the input transistor.

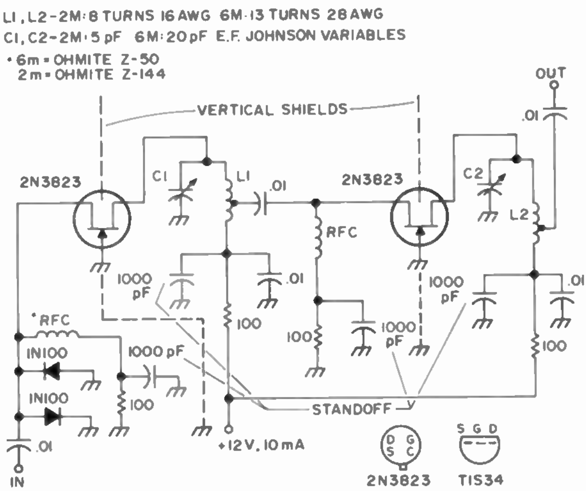


Fig. 4-16. Cascade preamp circuit, using two grounded-gate FETS, provides plenty of rf gain on 6 or 2 meters. Frequency-sensitive values are listed at the upper left portion of the diagram.

The amplifier can be mounted on a piece of copper-clad printed circuit board. The board, with the copper on but one side, is cut to length and drilled as shown in Fig. 4-17. The general layout may be increased if parts appear too cramped. Notches must be cut in the vertical shields for the transistor sockets. The boards and component leads are then cleaned with steel wool tos prepare a good soldering surface. After the sockets are mounted, the vertical shields can be soldered in place neatly and evenly using a small soldering iron. The standoff button bypass capacitors are soldered firmly to the board. All ground connections are made by directly soldering the part down on the copper.

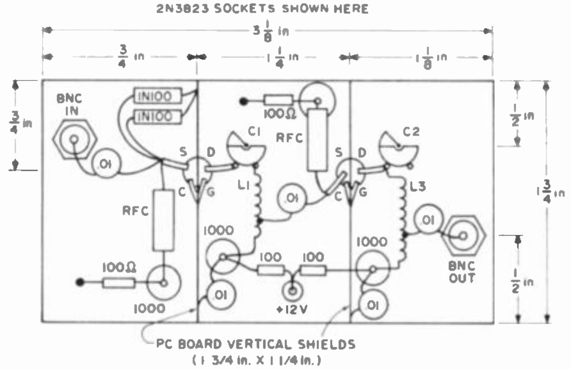


Fig. 4-17. Sketch shows layout of FET preamp. Note use of shield walls between stages.

The 2 meter coils are wound on a ¼ in. diameter rod using 8 turns of 16 AWG enamel-coated copper wire. The coils are spread to ¾ in. long and tapped 2 turns from the supply voltage end. Each 6 meter coil is wound on a 3/8 in. diameter rod using 13 turns of 28 AWG wire, tightly spaced and tapped 2½ turns from the cold end. Care must be taken when soldering the leads to the Johnson capacitors. The stator plates are held in position by solder during manufacture and may fall apart when heated. Maximum capacitance values of 5 pF for 2 meters and 20 pF for 6 meters were chosen for the variables so that they would be in their mid-position at resonance. The output tap may be varied to determine bandwidth and gain.

A CU-2101 A Minibox is drilled to allow passage of the connectors, sockets, and capacitor shafts. The printed

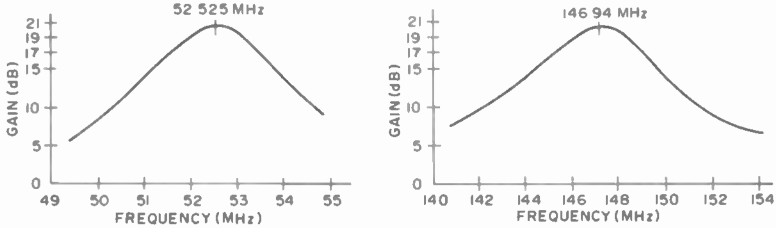


Fig. 4-18. Gain-bandwidth curves for 2 and 6 meter versions of the FET preamps. Note that gain peaks at about 20 dB in both instances. Bandwidth can be reduced by selection of coil tap points.

circuit board chassis is then bolted to the Minibox top and labeled with dry transfers or decals.

With a 12V supply, the preamp draws about 10 mA total current. The two capacitors are tuned to resonance simply by peaking on noise. Figure 4-18 shows the response characteristics of each preamp.

PART V

Ideal Antennas for 2m FM

Collinear Gain Antenna for VHF-UHF Repeaters

. . .Quadruples your repeater output power and will bring in solid those marginal mobiles in the fringe areas.

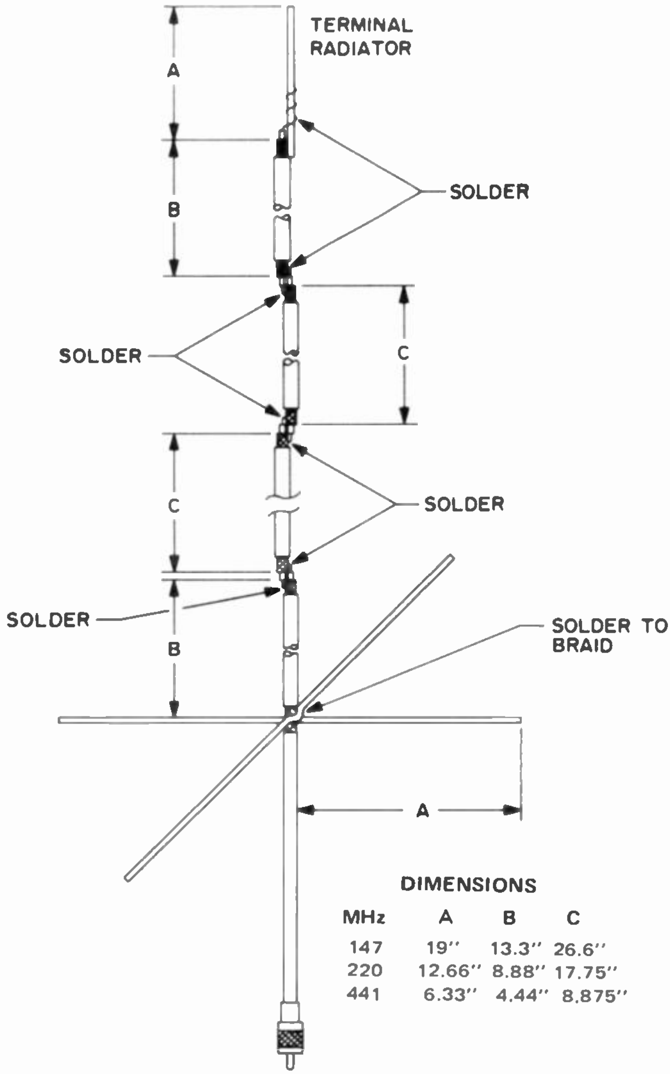
Probably the most popular antenna in the amateur repeater world is the omnidirectional collinear coaxial stack, although it is seldom calledsby that name. Versions of this antenna are manufactured by such companies as Prodelin, Phelps Dodge (Communications Products), and several other firms that build antennas specifically for the commercial bands.

Two of the reasons the collinear antenna is so popular are that it can be made to exhibit a great deal of omnidirectional gain at a very low anglė of radiation and it takes up very little space. In its manufactured form, it resembles a long fishing pole with a pair of crossed fins at the base.

In spite of the fact that a great deal of painstaking effort is required to make the antenna and get it just right, the operation is surprisingly simple. And what makes it even more attractive to the amateur, it is remarkably inexpensive. About all you need is a good-sized hunk of 50Ω foam-dielectric coaxial cable and some polyvinyl-chloride (PVC) pipe. For 2 meters, the pipe should be between 20 and 21 ft in length; for 450 MHz, an 8 ft length will do fine. The total omnidirectional gain (as compared with a reference dipole) will be 6 dB (actually 5.8 dB, but who's counting?).

Building the Antenna

Ignoring the structural aspects, the antenna itself is nothing more than a series of precise lengths of coaxial cable soldered in an alternate phase-reversal configuration as shown in Fig. 5-1. A quarter-wave whip at the antenna's tip shorts the inner and outer conductors of the coax and becomes the terminal radiating element. At the lower end



DIMENSIONS

MHz	A	B	C
147	19"	13.3"	26.6"
220	12.66"	8.88"	17.75"
441	6.33"	4.44"	8.875"

Fig. 5-1. The collinear gain antenna is made up of coaxial sections connected in a phase-reversal configuration. The bottom section (from the radials to the first joint) and the upper section (which joins the antenna to the shorted radiator) are half the size of all other sections.

of the antenna, the last coax section actually becomes the feedline itself, whose length, incidentally, is not critical as long as the dimensions are followed with religious fanaticism.

A number of amateurs have managed to build antennas of this type, and diagrams have never been scarce. Getting the antenna together is no big deal. The problems start to happen when it's time to turn the soldered-together pieces of coax into a structurally sound antenna. Applying wet epoxy, as in a fiber-glassing scheme, doesn't work out. I have yet to determine whether the problems are attributable to some chemical interaction between the wet epoxy and the coax dielectric (changing the dielectric constant of the line) or because the hardened epoxy doesn't allow any flexing of the coax braid. In any event, sealing the antenna with epoxy is ultrabad news. When the antenna is rigid and looks great, you'll measure a very disappointingly high standing wave ratio and you'll discover with much lament that your old groundplane worked better.

The commercial antenna people use fiber glass, but they do not use it to seal the antenna. Instead, they use an inert and flexible sealer, then encase the whole business within a preformed fiber-glass tubular envelope. At least one of the commercial suppliers uses beeswax as the inert sealer. Actually, there is no real need to immobilize the antenna once it has been placed inside the PVC pipe. The most important point in the construction process is to make the thing water-tight. Water drops inside a hunk of coax do bad things to antennas and feedlines; and once the water gets inside, you're better off changing antennas than trying to ignore the problems.

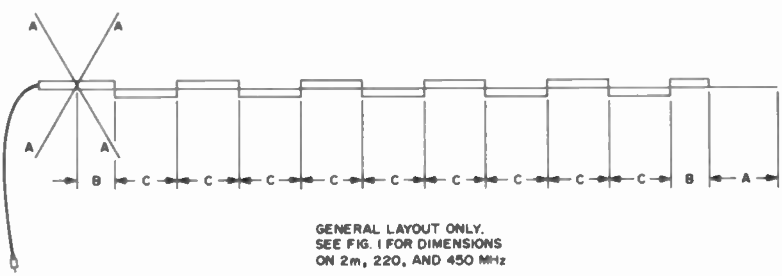


Fig. 5-2. Layout and dimensions of collinear gain antenna. The 2 meter dimensions are for a frequency of 147 MHz; the 450 MHz dimensions are for 441 MHz exactly. The 220 dimensions are for 220.5, just half the 450 frequency. The antenna is broadbanded enough to yield a low vswr on any frequency within a megahertz of that shown.

The dimensional details of the antenna are shown in Fig. 5-2. Lengths have been calculated in the decimal system to the nearest hundredth of an inch. Of course, you'll not be able to maintain this accuracy, but the system did simplify the computations. The 2 meter figures are based on an operating frequency of 147 MHz. The antenna is broadbanded enough to give an swr of close to unity regardless of the FM channel of operation. The 450 MHz frequency of operation is 441 MHz, exactly three times the frequency of the 2 meter version. You'll note the 450

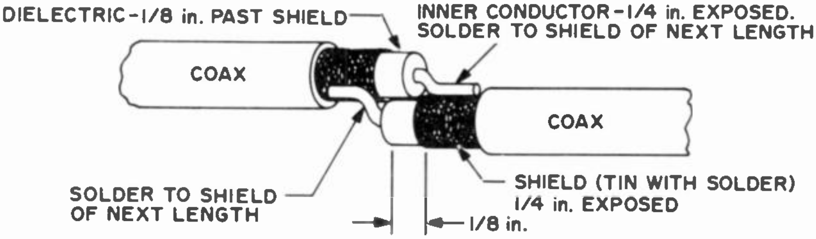


Fig. 5-3. The coaxial lengths should be soldered as shown. Keep the braid trimmed evenly all the way around and make sure the braid from one section doesn't make contact with the braid of the next section. If conductors are well tinned, problems will be minimized. Coax lengths are measured individually from braid end to braid end.

dimensions are just one-third those shown for the 2 meter version. If you build both antennas, don't select those two exact frequencies for repeater channels or you'll likely end up with your 2 meter system triggering your 450 receiver – it *has* happened. The 220 dimensions are calculated for 220.5 MHz (half the 450 frequency). I haven't built the antenna for 220 because I've never had the occasion to use that band. But if 450 continues its trend of increasing population, there should be a general turning to 220 MHz for repeater control in the not-too-distant offing.

To begin construction, cut eight lengths of coax from the reel. Each piece should be cut about an inch oversize, then trimmed down later so that all pieces are of exactly the same length. The dimensions given are end-of-braid to end-of-braid for any given length. (See closeup detail in Fig. 5-3.) The braid-to-braid distance should be approximately the same as the distance between the inner and the outer conductor of the coax you're using, or approximately 1/8 in. This dimension is the only one that does not change with operating frequency or band.

When all the lengths have been cut and trimmed to the precise lengths, and you are sure they will fit together as shown, study Fig. 5-3 carefully, then tin all exposed braid and conductors. This tinning process is an important step and should be done as completely as you can manage it.

As you solder the lengths together, use care to avoid handling the soldered pieces any more than is absolutely necessary. The braid can pull loose without much encouragement – and when that happens your only recourse is to replace the section with the loose braid. Winding each joint with electrical tape has always worked out well for me, but I always wonder if everything is okay under that tape. Once the tape is applied, you'll just have to guess about the condition of the hidden joint. The best approach would probably be to make all joints first, then inspect the whole antenna. If everything looks shipshape, then go ahead and wrap the joints with tape. Just be very careful in the handling until the antenna is safely stuffed into its plastic pipe.

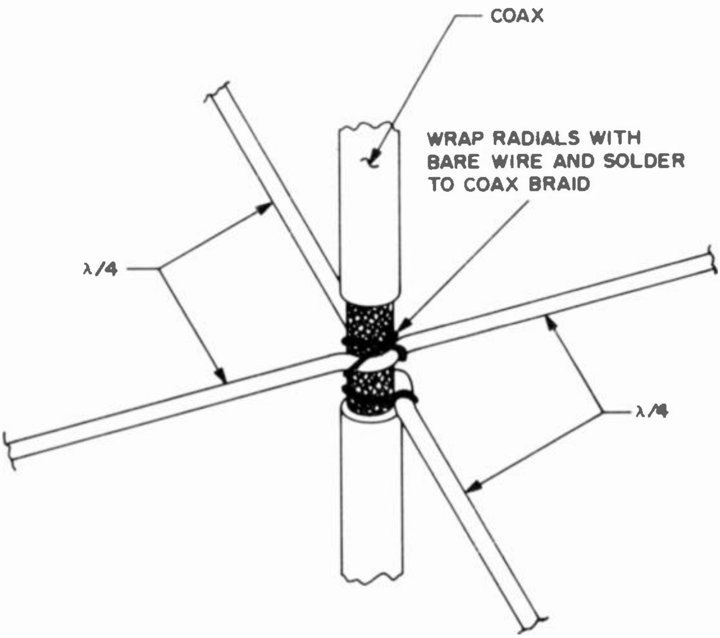


Fig. 5-4. Radials, of narrow-diameter copper tubing, should be cut to slightly longer than a half wavelength. The center should be bent to conform to the rounded shape of the coax braid so that on each radial a quarter-wave length extends outward from the coaxial braid. Tin the braid first. After wire-wrapping and soldering, wrap the joint well with electrical tape.

The quarter-wave radiator that goes at the top can be any good conductor, but copper is best. And the easiest way to get a good, stiff copper conductor is to buy some narrow-diameter (1/8 in. is ideal) copper tubing. The same material can be used for the radials at the base of the antenna. I *have* used type TW soft-drawn copper wire (10-gage), but it has proved too flexible for applications involving remote mounting – such as at distant repeater

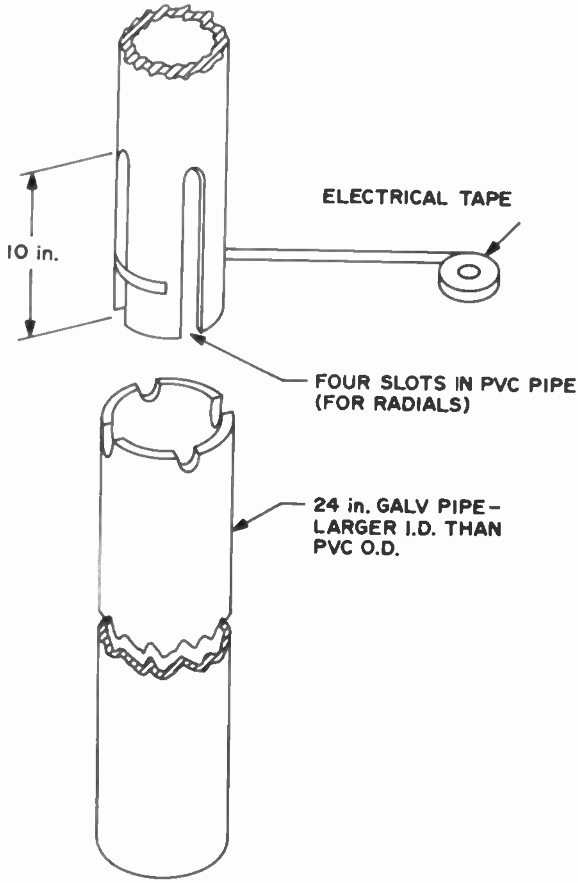


Fig. 5-5. Long slots in the PVC pipe will hold the radials in place with the antenna inserted. Wrap the bottom well with electrical tape after the antenna is installed in the fiber tube. Notch four matching places on a 2 ft length of galvanized pipe to seat, and try for a snug fit.

sites. The tubing offers a great deal better stability. If you have a heavy-wattage soldering iron or gun, you'll have excellent results soldering the tubing, too – even though you'll probably have to file or scrape the parts where solder is to be applied.

Ground Radials

There is nothing sacred about the manner in which the radials are attached to the antenna. Figure 5-4 shows the system I used, which worked, but had a rather ugh look about it. K6VBT built one and used an arrangement of his own that looked much more professional – but his required a lot more work and some rather precision drill work in the PVC pipe. The idea is to get four 19 in. radials extending equilaterally away from the antenna while maintaining some structural integrity. If the concept of Fig. 5-4 is adopted, the slot arrangement of Fig. 5-5 will hold things together satisfactorily.

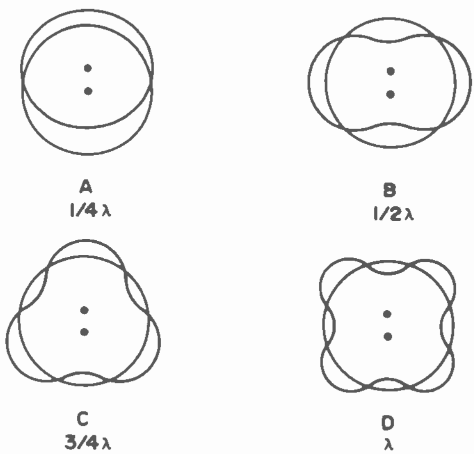


Fig. 5-6. By spacing the antenna the proper number of quarter wavelengths, some interesting radiation patterns can be obtained. In the patterns shown, the circles represent the 5.8 dB omnidirectional gain achieved by top-mounting. The asymmetrical overlays represent the patterns obtained by side-mounting. Note that even though signal loss occurs in some directions, significant gain improvement is realized in other areas.

The slots (Fig. 5-5) are cut lengthwise into the bottom of the PVC pipe so that the radials can be held in place when the PVC is inserted into the mounting pipe (made of heavy metal). The metal pipe is notched gently to seat the radials. Before inserting the PVC into the larger pipe, the slots on the PVC should be taped up (after the antenna is installed in the PVC sheath, of course).

Building your own gain antenna *is* a lot of trouble, as you can readily see. But it looks pretty attractive when you start pricing the commercial equivalents. And there is an almost indescribable satisfaction that comes with putting out a good "commercial quality" signal from a homebrew antenna.

The lengths used for the collinear half-wave sections were determined using the formula:

$$\frac{5904V}{f}$$

where V is the velocity factor of the coax cable used and f is the frequency in MHz. We used the velocity factor of .66 for this antenna as that is the most commonly found constant for solid dielectric coaxial cable. Amphenol polyfoam, however, is an example of a coax with a different velocity factor – .8. Check your coax's velocity factor in a good handbook before construction.

One Last Note

If your repeater doesn't give omnidirectional coverage, or if you'd rather have a definite preplanned radiation pattern, you can get considerably more gain than the 5.8 dB already promised by merely spacing the antenna a prescribed number of quarter wavelengths from the tower. Of course this means that your antenna will have to be side-mounted rather than top-mounted. If you space the antenna one quarter-wave from the tower, you'll get a major lobe in the same direction as the antenna is from the tower mass, as shown in Fig. 5-6. Each additional quarter-wave essentially adds a lobe that exceeds the 5.8 dB omnidirectional reference point.

The Welding-Rod Groundplane

For UHF and VHF applications in particular, the groundplane is perhaps the most utilitarian of all antenna types. It is simple to build and offers effective performance for both receiving and transmitting. The most economical of the groundplanes is the "coathanger" type, where the elements are cut from some stiff conductor such as 10 AWG type TW copper wire or, even better, brass welding rod. With a little imagination on the part of the builder, this groundplane can be made into a very professional-looking antenna.

Fig. 5-7. Construction of the welding-rod groundplane.

To build up a quickie 2 meter groundplane (Fig. 5-7), you'll need five welding rods, five toy plastic beads, a chassis-mounting UHF connector, and some silicone grease.

The first step is cutting. Refer to the cutting chart (Fig. 5-8), to determine the lengths of the radials and the radiator, then cut accordingly.

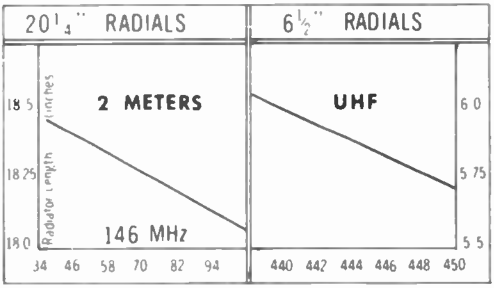


Fig. 5-8. VHF/UHF cutting chart.

When the elements have all been cut to length, sand the the wires for ¾ in. at one end of each piece. The sanding will remove any surface coating or corrosion and prepare the wire to accept solder.

The beads will be affixed to the unsanded ends of the elements. The beads offer an added measure of safety and give a professional appearance to the antenna. To attach the beads, heat the unsanded end of a wire on the kitchen stove for a few seconds; then, while the conductor is still very hot, press the bead down firmly over the wire end. The heat melts the plastic of the bead so that the stiff wire bores its own hole. Now, as the wire and bead cool, the plastic bead hardens and becomes securely attached to the end of the element.

The four screw holes in the chassis UHF connector will be the "solder lugs" for the radials. Using a pair of long-nose pliers, bend a "U" in the sanded end of each of the four longer pieces. (The shorter piece is the upright radiator, and requires no bend.) Allow no more than ½ in. for each bend, and be sure to keep each piece the same length.

Hook each bend into the UHF connector as shown in the sketch of Fig. 5-7, then compress the joints with pliers. Try to keep each radial positioned so that it maintains a 90-degree interval from adjacent elements.

Before soldering, adjust the positions of the radials precisely so that a symmetrical cross is formed by looking directly down onto the antenna from the top. Then solder all connections with a heavy iron or gun. The chassis connector requires a considerable amount of heat to keep the solder flowing, and insufficient heat will mean cold solder joints.

When the radials have been soldered, insert the shorter upright piece into the "center conductor" soldering point of the chassis connector. Twirl the radiator in the tube as you solder to make sure it is tinned completely, but don't allow excess solder to build up to the point where it exudes onto the dielectric. The characteristic impedance of the connector is determined by the dielectric material as well as the radial distance from the center conductor to the shield. If this distance is shortened in any way – as from a blob of solder – the characteristic impedance will be lowered and a mismatch will result.

When the joints have cooled, carefully bend the radials downward about 30^0 from the horizontal. This will lower the radiation angle of the antenna and will result in a better match for a 50Ω input impedance. Spread a generous amount of silicone grease over all connections to prevent corrosion and minimize the chance for water entry.

That's all there is to it; the antenna is ready to use. And in appearance, it's "just like downtown."

If you're thinking of building up this antenna to use in conjunction with a repeater or remote installation, there's one other trick of interest: Mount the thing upside down! Of course, this type of an installation would not be beneficial at all in run-of-the-mill applications, but it could mean the difference between "hearing" and "hearing nothing" on a mountaintop.

The ground plane characteristically has a very high angle of radiation. This problem is not too evident when the antenna is put into service in the lowlands; but when it is part of a mountaintop station, a high angle of radiation gets less and less tolerable. By mounting the groundplane so that the vertical radiator is suspended, the angle of radiation can be put to work *for* you.

High-Gain Mobile Antenna for 2m FM

For years amateurs have been pretty well limited to the quarter-wave vertical or the 5/8-wave vertical antenna for mobile installations, from a do-it-yourself standpoint. Then, in April 1970, Gil Boelke (W2EUP) described an improved version of the antenna (7/8-Wave Mobile Antenna for 2m FM, 73 Magazine, April 1970) that offers a lengthened whip for added capture area. His version, when tested, showed a consistent performance improvement over previous 5/8-wave mobile verticals.

The material in this chapter, most of which appears in Boelke's own words, describes the antenna and the tests made for comparing the performance with other mobile antennas.

Horizontal vs Vertical Polarization

As long as antenna polarization is matched at opposite ends of a path, there is little to choose between horizontal and vertical propagation. Although man-made noise pickup is higher on a vertically polarized receiving antenna, the inherent noise rejection afforded by FM tends to offset this disadvantage. The big advantage in going vertical for mobile operation is that antennas with substantial gain can be built with reasonable size and neat appearance. Fortunately, vertical polarization has been standardized for channelized FM communication.

Table V shows relative antenna gain, referenced against a dipole, illustrating the gain advantage. Gain figures were obtained in the literature cited in the first four references

Table V. Mobile Antenna Comparative Data

TYPE	POLARIZATION	GAIN[1]	GAIN[2]	COMPARATIVE POWER
1/2λ dipole	horizontal	0 dB	0 dB	100W
1/4λ whip	vertical	0	0	100
1/2λ whip	vertical	+1.8	+3.6	44
5/8λ whip	vertical	+3	+6	25
3/4λ whip	vertical	-1	-2	160
Big Wheel	horizontal	0	0	100
Turnstile	horizontal	-3	-6	400
Halo	horizontal	-2 to -4	-4 to -8	250 to 630W
7/8λ phased	vertical	+4.2	+8.4	14.5W

[1] Test antenna at one end of path.
[2] Test antenna at both ends of path.

at the end of this chapter, except for the 7/8-wave phased vertical, which was measured against a 5/8-wave antenna. Just to emphasize the effect on mobile-to-mobile operation, the fourth column in Table V shows the relative performance when both stations use the same antenna type. The last column converts the relative gain figures to power levels, indicating the power each station would need to realize the same signal-to-noise ratio for the different antennas, referenced to 100W using dipoles.

It must be recognized that there are gain variations – depending upon the shape of the car body, the position in which the antenna is mounted, and the direction of measurement. Tests tended to verify the handbook figures except in the case of the 3/4-wave whip. Theoretically, the gain of this antenna at the horizon should be about 1 dB below a 1/4-wave whip, but in the tests it proved to be almost the equal of the 5/8-wave whip. This anomaly is attributed to the fact that the car body is not really a flat infinitely conducting ground plane.

Tested were 1/4-, 5/8, and 3/4-wave whips, two phased collinears of different types, and the 7/8-wave phased antenna to be described. In the listening tests, two antennas were mounted on the same car on opposite sides or on cowl and roof, etc. A coaxial relay was used to switch between them. Testing operators would switch antennas while in motion, saying "antenna A," then switching to the other antenna, saying "antenna B" many times in rapid succession. On the average, a clear difference could be discerned between antennas, despite the fact that for each individual comparison either antenna might have shown up better.

The cars were driven in all directions relative to the receiving sites in average terrain in western New York.

Receiving stations were not told what antennas they were hearing or which was which. Even on the same pair of antennas, the letter designations were sometimes scrambled to prevent any possibility of prejudiced responses due to psychological fixation. It was most impressive to find that the reporting station operators could not find any difference between two identical antennas tested as a control.

Each antenna was carefully matched for a 1:1 swr, and the feedlines were cut to the same length, except in the roof-mounted installations. In this case 5 additional feet of RG-58/U cable were deliberately included, since the extra line is needed anyway in a practical installation. A 5 ft length of RG-58/U coax exhibits a loss of about ½ dB (depending upon age) at 147 MHz. This difference could account for the fact that the 5/8-wave antenna behaved identically on the roof and the cowl.

Table VI lists the tests and the results. It was concluded that the 5/8-wave antenna offered the best performance. It is also one of the easiest antennas to build. The other collinears had the same performance, so only one collinear is mentioned. In one case it turned out that the power loss in the collinear partly offset its gain, since it heated up when appreciable power was applied.

Table VI. Mobile Antenna Performance Record

ANTENNA TYPES COMPARED AND MOUNTING LOCATIONS	TEST CRITERION	RESULTS
7/8λ phased on cowl vs 5/8 on same mount	Measurement	7/8λ shows 1.2 dB more gain
5/8λ on one cowl vs 5/8 other cowl	Listening test	No difference
5/8λ cowl vs 5/8 on roof	Listening test	No difference
5/8λ on one cowl vs 3/4 on other cowl	Listening test	5/8λ has slight edge
5/8λ on cowl vs 1/4 on roof	Listening test	5/8λ superior
1/4λ on roof vs 1/4 on cowl	Listening test	Roof mount superior
5/8λ on cowl vs 3 el. collinear on other cowl	Listening test	5/8λ better
3 el. collinear vs 1/4λ on roof	Listening test	Collinear better

The 7/8 wave phased antenna came about as an attempt to improve on the 5/8. It was reasoned that the 5/8-wave antenna was not the maximum length that could be tolerated on a car, and that making it longer must make it better, if only the current flow could be maintained in the same direction throughout its length. Current distributions are shown in Fig. 5-9 for a 5/8 wave, a continuous 7/8-wave whip, and the modified current distribution resulting from the insertion of a series capacitance at a point 3/8 wavelength from the top. The capacitor method of phasing meets the conditions of simplicity and efficiency.

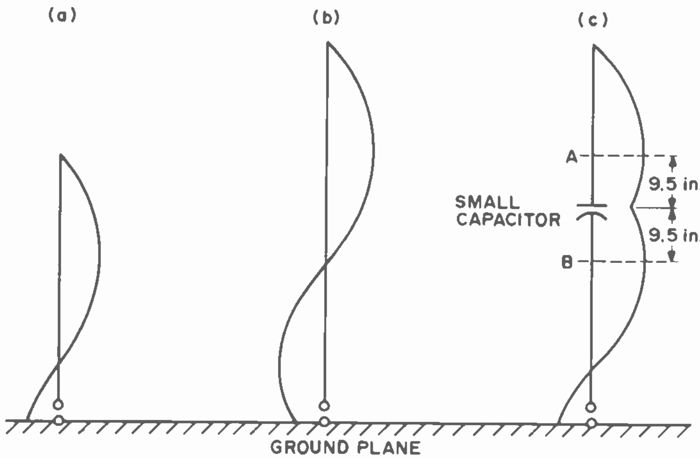


Fig. 5-9. Current distributions of 5/8-wave whip (a), and 7/8-wave whip (b). A series capacitance 3/8 wavelength from the top changes the current distribution as shown in (c).

An antenna of this type was constructed ad adjused to exhibit the current distribution shown. It was found that the feedpoint impedance was little changed from the standard 5/8-wave antenna. Because of this similarity, a different test method was used to evaluate it in an effort to obtain a quantitative comparison.

A 5/8-wave whip was installed in the test position on the car. The matching L section was adjusted to null out any reflected power and the power level to the antenna was adjusted to exactly 20W. Signal strength was noted on a meter at a station about 7 miles away. The 5/8-wave antenna was removed and the 7/8-wave antenna was substituted. The L network was then trimmed to null out some slight reflected power. Received signal strength was reported to be higher! Power was then reduced in small steps until the received signal strength was exactly the same as it was with the 5/8-wave antenna with 20W. The power then read 15.1W – for a difference of 1.2 dB. This procedure was repeated with the car moved to another spot. This time the power had come down to 14.8W, for a difference of 1.3 dB.

Other tests were made to determine whether the capacitance value was optimum, vertifying that it was. If it is assumed that the published value for a 5/8-wave antenna (3 dB gain) is valid, the gain of the 7/8-wave job must be at least 4 dB!

Construction

The Boelke 7/8-wave antenna consists of a 39 in. length of 1/4 in. diameter Dural rod for the base section, and a 29 in. length of 3/16 in. Dural rod as a top section. The two sections are joined with a piece of 3/8 in. diameter epoxy – fiberglass rod as shown in Fig. 5-10. A small metal tab is fastened under the screw connecting to the bottom section, and is trimmed to obtain the proper amount of capacitance between the top and bottom sections. Epoxy is used to hold the parts together rigidly and permanently.

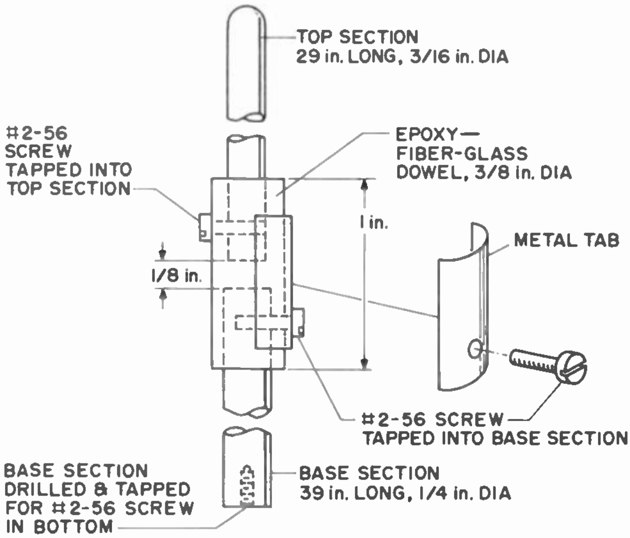
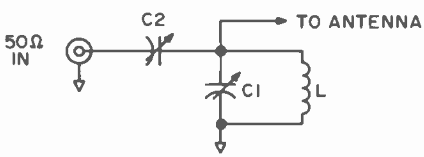


Fig. 5-10. Construction details, 7/8-wave mobile vertical.

The base mount consists of a high-voltage potentiometer-insulating fitting, made of epoxy-fiberglass with a 1/4 in. shaft bushing on one end and a shaft lock on the other. Clamping the shaft lock on the base section holds the base of the antenna in place. Removal is quick and easy by loosening the shaft lock. Connection to the base section is accomplished by attaching a short Teflon-insulated wire to the end of the base section by means of a #2–56 screw tapped into the end. This wire is stripped and tinned on the bottom and a small alligator clip is used to connect into the matching network.

Due to the similarity to the 5/8-wave antenna, this antenna can be matched with a coil at the base. However, for the most accurate match, an adjustable matching network at the base of the antenna inside the car offers three advantages: (1) Extra selectivity is added to the antenna system, minimizing interference problems on both receive and transmit; (2) other antennas may be substituted on the same mount and brought to a match with little trouble; (3) the system can be accurately matched to 1:1 swr.

A schematic and a sketch showing a suggested construction and mounting method are shown in Figs. 5-11 and 5-12. Each trimmer is adjusted for a minimum swr alternately until an exact match is obtained. If C1 reaches minimum capacitance before a match is achieved, reduce the inductance of L1 slightly. If more than half the capacitance of C1 is used at null point, increase L until it tunes near minimum capacitance. This procedure assures maximum coupling efficiency.



C1 – 20 pF MAX APC-TYPE AIR VARIABLE

C2 – 20 pF MAX APC-TYPE AIR VARIABLE

L – 2T, 14 AWG, 1/2 in. DIA SPACED DIA OF WIRE

Fig. 5-11. Schematic of matching section.

Adjustment of Current Distributions

Feed at least 20 or 30W of rf to the antenna, adjusting for an impedance match as outlined. Hold a neon bulb

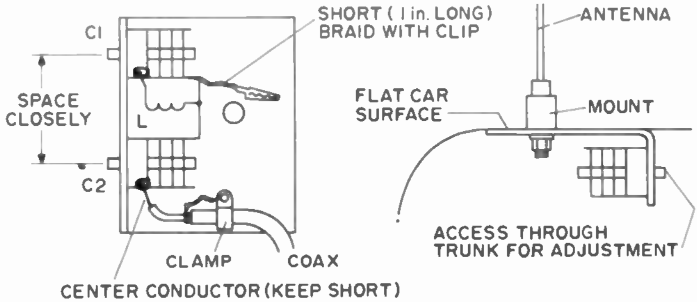


Fig. 5-12. Mounting details. A base mount was fashioned using a high voltage potentiometer mount from an old oscilloscope.

against the tip of the antenna until it fires, then slowly slide it down the top section. Exactly 1/4 wave from the top (19 in.) it should go dim or out. Continuing on down, it gets brighter at the top of the capacitor. Below the capacitor another null should be found. The position of this null moves up if the capacitance is increased and down if it is decreased. Point B (Fig. 5-9) is the proper position for this null. If it is too high, reduce the capacitance in small steps by trimming the metal tab on the insulator with a pair of tin snips. As the null moves down it tends to get broader and less distinct. If doubt exists about its position, attach a paper clip to the tab to move it up to where you can see it. Then reduce capacitance slowly, observing the null carefully as you go. When the proper adjustment is found, epoxy the rods, the tab, and tape up the insulator.

References:
1. Williams, "Radiating Characteristics of Short-Wave Loop Aerials," I.R.E. Proceedings, Oct. 1940.
2. Kandoian, A.G., "New Antenna Types and Their Applications," I.R.E. Proceedings 70W–75W, Feb. 1946.
3. Foster, D., "Loop Antennas with Uniform Current," I.R.E. Proceedings, Oct. 1944.
4. I.T.T. Handbook.
5. Brier, "A 5/8 Wave Vertical for 2," CQ, Feb. 1964.

Part VI.

FM Test Equipment Circuits

The Poor Man's Frequency Meter

While the FM'ers may be the only hams around who make a religion out of being precisely on frequency, virtually *all* active amateurs have a need for a frequency meter periodically. Well, this may come as something of a shock to some, but there *is* a way to measure frequency accurately without the use of expensive equipment. With a handful of parts and a few items found commonly around the radio shop, you can build the *poor man's frequency meter*, the design of which was provided by Donald Milbury (W6YAN).

This is *not* a substitute for a good frequency meter for commercial use, but if you have a limited number of frequencies that you want to be "dead on," this may be the answer. And it ought to be a must for the group of fellows who maintain the local FM repeater.

A nice feature of the *poor man's frequency meter* is the fact that it puts to use that old surplus military communications receiver which has undoubtedly been sitting around in a dark corner of your basement under piles of old magazines and discarded dynamotors. It also uses any old commonly available surplus wideband FM receiver.

The idea is not new; hams in the two-way business will recognize it as the system that has been used for many years for the Motorola station monitor and various other common applications. Basically, it is composed of four major units:

- Receiver converter with calibration oscillator constructed on a high-band front-end deck from an old Motorola Sensicon A receiver chassis.

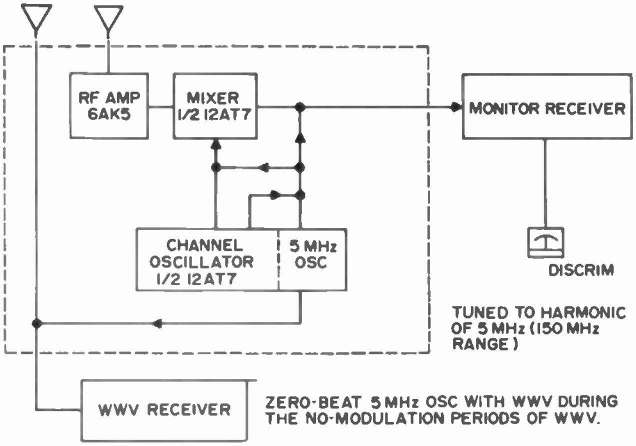


Fig. 6-1. This system block diagram shows how equipment should be interconnected to make the frequency meter setup.

- Monitor receiver (any 150 MHz wideband receiver); a low i-f of 455 kHz is best.
- WWV receiver (here is where the surplus communications receiver comes in).
- Accessory items (hang a modulation meter on it).

Principle of Operation

The frequency converter operates on the heterodyne principle. A station frequency is monitored by heterodyning its carrier with the output frequency of the crystal oscillator and then feeding the resultant frequency of these two signals into the calibrated monitor receiver. If the beat frequency between the crystal oscillator signal and the monitored carrier is exactly equal to the frequency to which the receiver is aligned, the discriminator meter will indicate zero. If the beat frequency is lower or higher in frequency than the one to which the receiver is aligned, a direct indication of carrier frequency error in the monitored transmitter will be given on the meter.

The monitor receiver is aligned to a predetermined frequency. The specific frequency used will depend upon the spurious harmonics emitted by the channel crystals which will be required to monitor the specific carrier channels in consideration, plus the operating frequency to be measured.

The beat frequency fed to the control receiver may be either the sum or difference frequency of the channel crystal frequency and the monitored carrier frequency. Channel crystals for operation in the range from approximately 1.6 to 12.5 MHz may be used.

Calibration Oscillator

The calibrating oscillator consists basically of an rf amplifier stage, a mixer, and an oscillator. The calibrating crystal, shunted by a trimmer capacitor for any minor adjustment of oscillator frequency, is used for calibrating the monitor receiver.

Although the crystal is temperature controlled, a *greater degree of accuracy is obtainable without the use of the heater*. The trimmer capacitor provides *exact* calibration of the crystal frequency at any temperature by zero-beating the oscillator against the WWV signal.

The crystal heater should be used *only* when a quick check is necessary; such as where it is desired to quickly bring the crystal to a temperature that would eventually be reached due to the heat dissipation of the equipment.

The control receiver may operate in the 145–160 MHz range; therefore, when using a 5 MHz calibration crystal, the 29th, 30th, 31st, or 32nd harmonic of the 5 MHz crystal frequency is used to calibrate the receiver to 145, 150, 155, or 160 MHz.

The selector switch operates in conjunction with the calibrating oscillator. This switch may be used to select any one of several crystals as the frequency controlling element of the oscillator. These crystals include the 5 MHz calibration crystal and the five channel crystals.

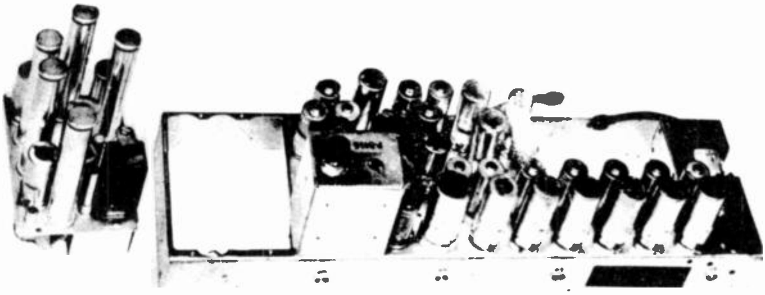


Fig. 6-2. The front end of a Motorola Sensicon A receiver is shown next to the receiver itself. Removal of the deck is a simple matter.

One half of a 12AT7 tube is used as the oscillator while the other half of the tube functions as the mixer. The carrier frequency to be monitored is picked up by the VHF antenna, amplified by the 6AK5 amplifier, and then mixed with the selected channel crystal frequency. The output of the mixer is fed to the calibrated monitor receiver where it is determined if the tranmitted carrier is on frequency.

Assume that it is desired to monitor the output of the transmitter which is operating on 146.94 MHz and that the control receiver has been calibrated at 150 MHz. The necessary channel crystal frequency will be the difference between 146.94 MHz and 150 MHz, or 3.06 MHz. If the transmitter is on frequency, the 146.94 MHz signal will mix with the 3.06 MHz channel crystal frequency to produce an input signal of 150 MHz at the control receiver. In this case, no indication will be given by the discriminator meter. If the monitored transmitter carrier is above or below its designated frequency, the input signal to the monitor receiver will be above or below 150 MHz, causing the discriminator to produce an output voltage. This voltage is fed to the meter, which is calibrated in kilohertz to give a direct reading of carrier frequency error.

When monitoring transmitters which operate in the 420–450 MHz band, the monitor must be placed so that the monitor antenna is within a few feet of the transmitter. For this application, the frequency of the stage preceding the final tripler is monitored. This is done by selecting a different frequency crystal for the monitor which, when beat against the frequency of the transmitter stage preceding the tripler, produces the frequency at which the control receiver is tuned.

Say that it is desired to monitor the output of a transmitter operating on 443.75 and that the monitor receiver is calibrated at 150 MHz. The channel crystal frequency is determined as follows:

443.70 ÷ 3 (tripler) = 147.90
(frequency actually monitored)
150 – 147.90 = 2.1 MHz
(channel frequency crystal)

If the transmitter is on frequency, the frequency of the stage preceding the final tripler will mix with the 2.1 MHz channel crystal frequency to produce an input signal of 150 MHz at the monitor receiver. In this case, no indication will be given by the discriminator meter. If the monitored transmitter carrier is above or below its designated frequency, the input signal to the monitor receiver will be above or below 150 MHz, causing the discriminator to produce a positive or negative output voltage. This voltage is fed to the discriminator meter *which can be calibrated to give a direct reading of carrier frequency error.*

Any error in carrier frequency indicated on the discriminator meter is an error in the frequency of the stage preceding the tripler; therefore, the error in the transmitter signal from the final amplifier will be three times as great. When using this method of monitoring, check the output (420–450) of the transmitter with a reliable wavemeter to ascertain that proper frequency multiplication is made.

Channel Crystal Accuracy

Since the fundamental frequency of the channel crystals is used, any error in crystal frequency is not multiplied. Therefore, the error in monitoring a frequency by this method is very small. Crystals are held to within 0.002% of the specified frequency over the ambient temperature range of -30° C to $+60^{\circ}$ C. Therefore, with the previous 2 meter example, the maximum frequency error of the 3.06 MHz crystal would be 3.06 x 0.0020%. At the frequency being monitored, the percentage error would not be discernible on the meter.

The "improvement factor" of possible percentage accuracy at the channel crystal frequency over the percentage accuracy at the carrier frequency is approximately the same ratio as the monitored carrier frequency over the channel crystal frequency, or 146.94/3.06 equals 48. This is another way of stating that the channel crystal is more than 48 times as good percentage-wise at the monitored frequency than at its fundamental frequency.

The improvment factor may be checked on any channel by the above method. It will always remain reasonably high; therefore, the possible error of the channel crystal frequency is negligible.

The front end deck of a Motorola Sensicon A receiver provides an ideal converter for the *poor man's frequency* *meter.* Figure 6-2 shows this assembly as a separate unit as well as in its original form installed in a Motorola Sensicon A receiver. The part numbers referred to in the modification procedures described here are those part numbers called out in the Motorola manual for the Sensicon A 150 MHz receiver. The procedure is quite simple, too. Here is all you do:

1. Replace R102 (2.2MΩ) with 3.3 MΩ and ground low side.
2. Remove C104.
3. Replace R103 (33 kΩ) with (470 kΩ).
4. Replace L101 with a 100 kΩ resistor.
5. Remove R112 (3.9 kΩ), completed B+ circuit.
6. Replace X102 with 9-pin socket (with shield).

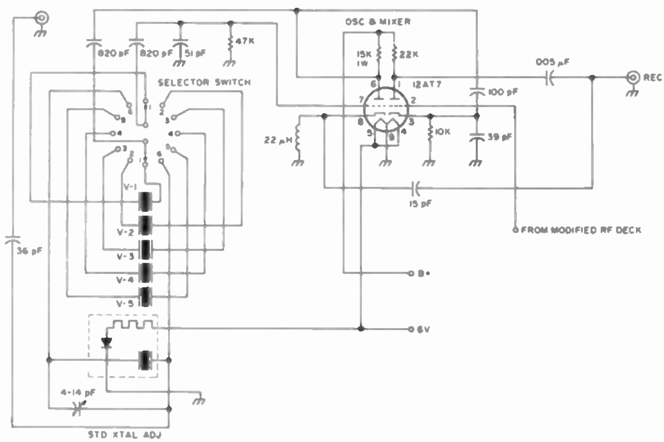


Fig. 6-3. Circuit of the oscillator/mixer to be built into the existing front-end deck.

7. Remove wire from pin 1 and connect to pin 2.
8. Connect 1 MΩ resistor from pin 2 to ground.
9. Wire 12AT7 socket for 6V filaments. (Connect 6V to pins 4 and 5, and ground pin 9).

This completes the modification of the rf amplifier. To construct the oscillator/mixer, remove the balance of the circuitry on the deck with the exception of the crystal socket. Then build the circuit as shown in Fig. 6-3 around the new X102. Be sure to use silver mica capacitors in the crystal circuits. The crystals themselves are Motorola SEMT-2 (R11, 5 MHz), and they may be obtained from Sentry or International.

The Sensicon A receiver is found in a number of the older, less expensive Motorola FM units, such as the 40V, the early 41V, and all Model series bearing the AAV and AAD suffix. These are available from Newsome (Detroit), Mann (Tarzana, Calif.), C & H (Long Beach, Calif.), and Gregory (Saddlebrook, N.J.).

Signal Generator Circuits

The W3JKL Signal Generator

In the May 1970 issue of 73 Magazine, Ed Goldsby (W3JKL) presented an interesting circuit for aligning FM receivers. Since his circuit was quite stable and the signal output from the completed unit was strong, the author, who himself maintains a two-way commercial service facility, stated that the "aligner" can be used for setting transmitter units on frequency (using the heterodyne principle) as well as tuning up receivers.

Goldsby's signal generator starts off with a crystal oscillator and multiplier, which is coupled into a diode mixer/detector stage followed by an audio amplifier. The circuit is shown in Fig. 6-4.

The VE3GFW Signal Generator

The Toronto FM Communications Association members got together and worked up a circuit for aligning FM receivers that went a step further than most circuits that had been published previously. Their unit, which was said to be "patterned after" the popular Measurements Model 80 in terms of actual features, was written up in the form of an article and published in the April 1971 issue of 73 Magazine. The author was Howard White (VE3GFW).

According to White, the one-transistor generator provides a variable output from 80 mV to 50 mV of rf power; it has a frequency range from 1.8 to 450 MHz; and it incorporates a safety feature to protect the circuit in the event of inadvertent keying of a transmitter while the generator is connected to a transceiver.

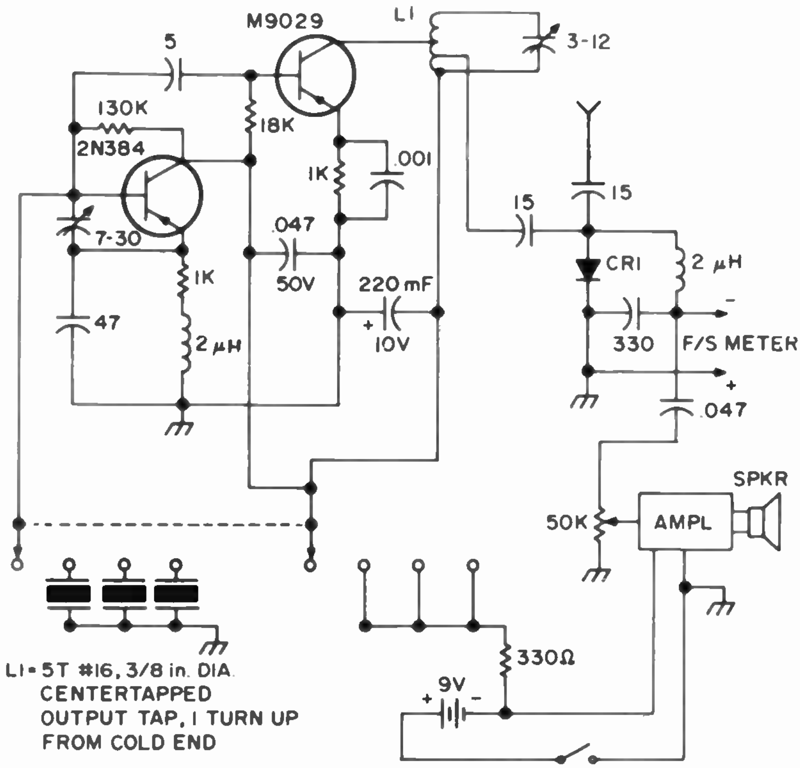


Fig. 6-4. Signal generator/amplifier.

The unit is built on a PC board. The parts layout is almost exactly the same as that of the schematic shown in Fig. 6-5. The electronic components are placed on the copper side of the board. The on-off switch-level control, frequency adjustment, output jack, and crystal socket are on the other side (Fig. 6-6). The unit can be packaged in a minibox.

Almost any crystal in the 1.8–12 MHz will oscillate in this unit. The output is rich in harmonics to 450 MHz, so you can tune up any receiver from 160 to ¾ meters.

The output impedance of the signal source is 51Ω, a value which simulates a perfect antenna load to the receiver. This is the manner in which this is accomplished: A 51Ω, ½W resistor is connected across the terminals of an RCA phono jack. No physical connection is made to the circuit except through the common ground of the PC board. The maximum output level depends on the lead lengths of the resistor. (The

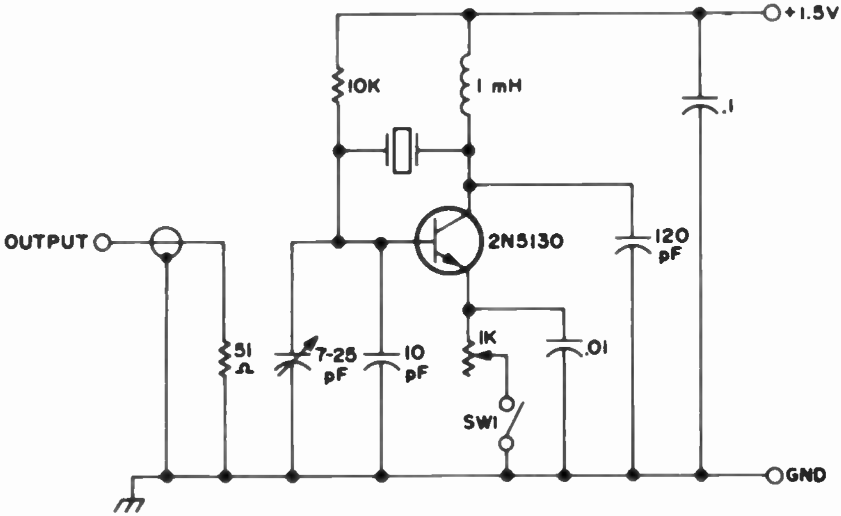


Fig. 6-5. Schematic diagram of the VE3GFW signal source, designed by club memebers of the Toronto FM Communications Association.

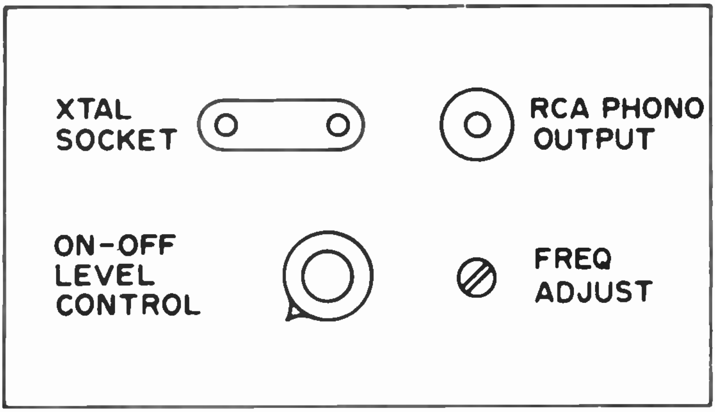


Fig. 6-6. Minibox layout of the VE3GFW signal source panel.

unit has plenty of output when the lengths are added about ½ in long.)

The Toronto group has on hand a limited quantity of assembled, tested, and guaranteed signal sources. These will be mailed postpaid for $8 each. Order from Toronto FM Communications Association, Box 427, Willowdale, Ontario, Canada.

The K1CLL Signal Generator

The K1CLL signal generator described here is a bit more complicated than those described previously in this chapter, but it does offer features that should tend to make the extra effort well worth the trouble. Among the features: stability and quality equal to commercial two-way standards, and a precison attenuator arrangement that, once calibrated, will allow accurate determination of receiver performance in terms of microvolts of signal per decibels of receiver quieting.

The K1CLL unit is built inside a well-shielded "waveguide" assembly to minimize radiation other than through an interconnecting coaxial cable. Positioning of the generator, by sliding along the waveguide, provides a variable strength stable signal of from several hundred millivolts down to absolute zero. It does this in a smooth and continuous fashion rather than in discrete steps, so that every fraction of a decibel in reducing band noise immediately shows on the slide dial. Calibration of the attenuator, of course, must be accomplished by the builder after construction of the unit.

The waveguide *must not* have any holes in it and should be reasonably smooth inside; otherwise your dial would not read smoothly in attenuation. You *could* use copper or aluminum drain pipe or soldered pieces of copper-clad PC board.

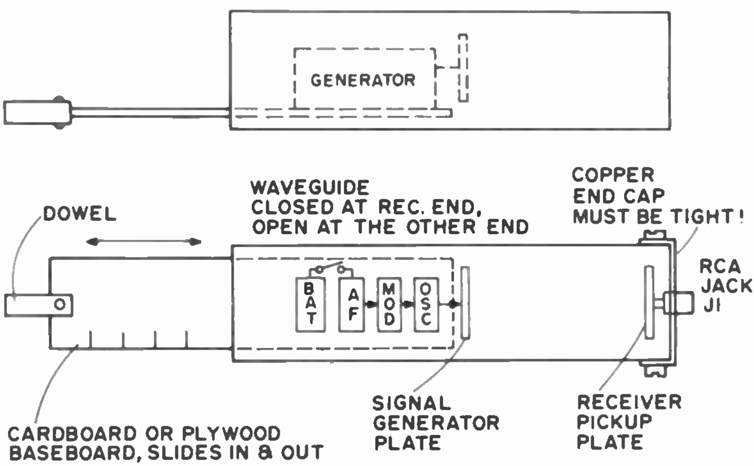


Fig. 6-7. Sketch shows plan-view layout of unit inside waveguide attenuator. The oscillator unit is mounted on a flat wood or cardboard strip that can be calibrated to give accurate indications of output signal.

Figure 6-7 shows the basic idea. When the signal generator plate is close to the receiver pickup plate, you can get about 100 mV of signal into the receiver. When the two plates are about 8 in. apart, the signal is just detectable on a good receiver.

As you go up in frequency you may have to make smaller and smaller oscillators in order to fit in smaller waveguides to get the cutoff effect.

A crystal oscillator, an af oscillator, and a simple class A modulator do an excellent job to start with. Figure 6-8 shows the unit as used on 6 meters. It must be stressed again that no wire or other piece of metal may be allowed to reach the outside from this assembly.

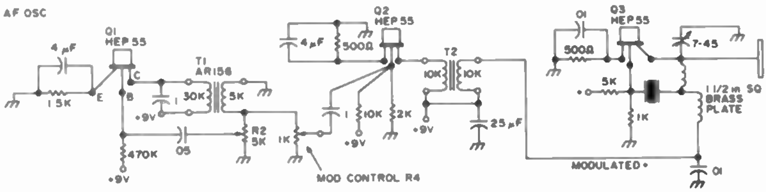


Fig. 6-8. Schematic of generator. This entire assembly about 3 x 4 in. including small 9V battery and switch must be entirely inside the waveguide. No wire or metal of any kind can be brought outside.

A controlled-feedback transformer-coupled af oscillator does a good job in furnishing a sine wave. A Motorola HEP55 is used for the oscillator, with feedback to the base from the collector through transformer T1, controlled by resistor R2. Audio output is taken off the 5 kΩ winding of T1, is fed through R4 the modulation control, and then to the base of af modulator Q2. Transistor Q2 is set up for low-power class A operation because not much modulation is needed for the signal generator. Transformer T2 is an old 5W unit from "tube-type portable" days. The secondary of T2 feeds a modulated +9V signal to Q3, the crystal-controlled 50 MHz oscillator.

A 1½ in. square plate is tied onto the collector, radiating energy to the receiver pickup plate facing it inside the waveguide. This energy is rapidly attenuated as you move the plates apart, and should be impossible to detect after some 9 or 10 in. of separation.

Once again, do *not* bring any wires or any other metal or conductor out from the oscillator assembly. If you want an outside controlled switch or other control, bring it out as a wooden dowel handle.

To calibrate the signal generator, you must compare its performance with a known standard, such as the Measurements Model 80 signal generator, which is widely used in commercial service of two-way radio equipment.

Calibration is a fairly simple process if a signal generator "standard" and a voltmeter (with a decibel scale) are available. Connect the ac voltmeter across the speaker terminals of the receiver, open the squelch on the receiver with no signal coming in, and adjust the volume control on the receiver for a voltmeter indication of +20 dB.

Connect the *standard* signal generator to the antenna input terminal on the receiver, making sure that the signal is exactly on frequency as measured by a discriminator meter on the receiver. Adjust the signal generator for an output of 100 mV, which should completely quiet the noise on the speaker as well as deflect the voltmeter to the no-voltage position.

Detune the receiver front end stage until some squelch noise appears, and try to detune it sufficiently to bring the meter reading up to 0 dB. When the ac voltmeter indicates 0 dB, disconnect the standard signal generator and connect the K1CLL generator. Make certain that the output from the K1CLL generator also gives a zero discriminator reading, then adjust the slider bar until the ac voltmeter reads 0 dB. At this point, mark the slider bar and label it "100 mV." Then reconnect the *standard* generator, reduce the output to 50 mV, and tune the receiver front end slightly so that 0 dB is again indicated on the ac voltmeter.

You can compare and mark all the way down the slider until you can no longer get an indication of 0 dB by adjusting the receiver front end, at which point the last slider marking will be on the order of 1μV or less. But you can calibrate past that point by injecting a signal (from the standard) that will deflect the ac voltmeter to the +10 dB point, +15 dB, etc., noting the signal levels on the slider with each comparison.

RF Power Measurement Circuits

The amateur world has been getting along handsomely for years without wattmeters. But now, with the advent of FM, this venerable instrument has finally found a place where it is almost a real necessity.

FM units are not typically set up with meters for monitoring plate current, grid drive, and so forth. Commercial units, of course, are generally equipped with test points so that an ordinary voltohmmeter can be used for checking the various stages, but amateur gear as a rule is provided with nothing more than a single panel meter to indicate relative output power. Thus, a wattmeter can find a very happy home in the shack of the amateur who wants to keep his FM transmitters in a state of fairly good repair.

As long as the standing-wave ratio on the antenna is low, and the wattmeter provides the same impedance load to the transmitter as does the antenna to be used, the wattmeter will give a true and accurate accounting of how well the transmitter will perform in actual service.

By their nature, wattmeters are difficult creatures to build with accuracy; the chief problem is getting a meter to indicate with any degree of precision over the entire logarithmic scale. There are ways to circumvent this problem, though. One way is to construct a "comparative" wattmeter, where a known power is fed into a light bulb and compared with the rf power fed into a similar lamp. Another is to measure rf on a conventional linear-scale meter, then plot the reading on a conversion graph. This chapter describes methods for building wattmeters of both types.

Low-Cost Comparative Wattmeter

The comparitive wattmeter described here (designed by Bill Hoisington, K1CLL) is effective for measuring power levels in the range of 10 mV to about 5W. If output power levels beyond this range are to be measured, the method described in the next section of this chapter should be built. The most attractive feature of the comparative wattmeter is its price, which should total less than $4.

In the comparative wattmeter, you use two lamps mounted side by side. You first light one of the pilot lamps as a dummy load, then switch in the second lamp to match the brilliancy of the first. A calibrated wirewound potentiometer will permit you to adjust the power into the second lamp to precisely match the rf power into the first.

The potentiometer circuit is shown in Fig. 6-9. Calibrating the dial of this pot is simple: Just measure the resistance of the pot at various settings and calculate power based on input voltage. Put a current-measuring meter in series with the battery or power supply initially, then multiply current times voltage to get power. (If you measure current in millivolts, you can use that figure to get power in milliwatts.)

Figure 6-10 tells almost the whole story at a glance. You can, of course, put as much calibration on the dial as you like. It is quite important to orient the bulb filaments in the same relation to your eyes for best matching. There isn't much in back of the panel except one 6V battery which can be obtained in any hardware store.

If you're planning on using this system for UHF, be sure and note the need for a large range of series capacitors

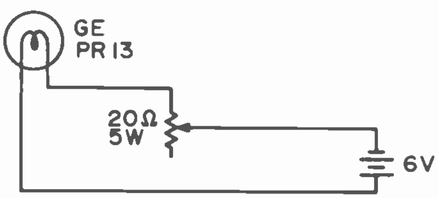


Fig. 6-9. The circuit supplies the brilliance "standard" for comparison. When the "standard" lamp is mounted adjacent to the dummy load, the pot permits variation of the standard to match the load. If the resistance is panel-marked in watts, a good power indication is achieved.

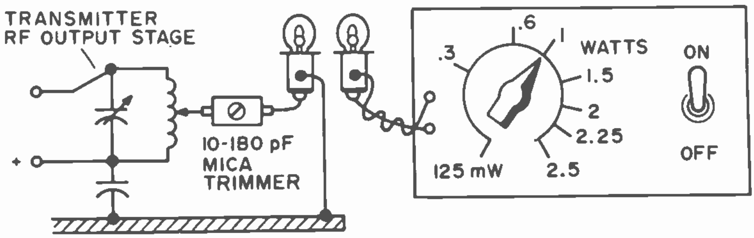


Fig. 6-10. A series capacitance loads the rf indicator for comparison. The capacitance value will decrease inversely with frequency increases.

for the rf pilot lights as you go up in frequency. This can be seen clearly in Figs. 6-10 and 6-11. The block diagram, Fig. 6-10, shows a 6 meter setup. As you go up in frequency the series capacitance drops. A good matched load on 450 MHz can be obtained as shown in Fig. 6-11. You can remove the tin base from the bulbs, but this is not an absolute necessity. It is important to vary the amount of coupling, and thus the series capacity, by spacing the tab capacitor closer or further away from the ground plane, as detailed in Fig. 6-11.

The number 48 or 49 bulb, listed at 2V and 60 mA, is rated at 120 mW, and glows dim at about 12 to 15 mV; so it can be used for low-power receiver oscillators, etc. With two other bulbs found in hardware stores, connected and matched to the rf inductor, such as the PR13 (5V at 500

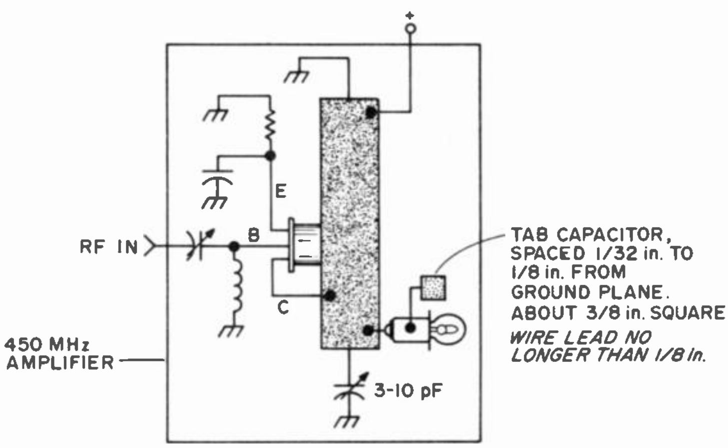


Fig. 6-11. Matched pilot light load for the UHF version.

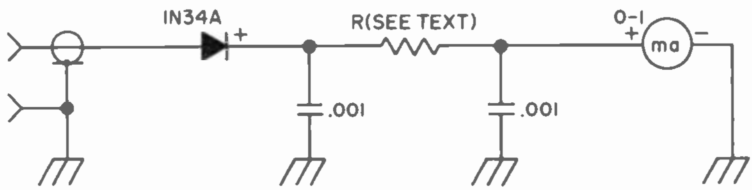


Fig. 6-12. Schematic diagram of simple, accurate, and easy-to-build rf wattmeter.

mA), you can read correctly up to 5W. From there on up you're on your own, although a good variable 115V dc supply can be made up to work around 50 to 100W.

Conversion Wattmeter

The meter described here is as accurate as components allow, and it's easy to build. The calibration is logarithmic, which means that a simple graph is possible, and easier than changing the meter scale. This unit was designed by Marc Leavey (WA3AJR) and described in the November 1970 issue of 73 Magazine.

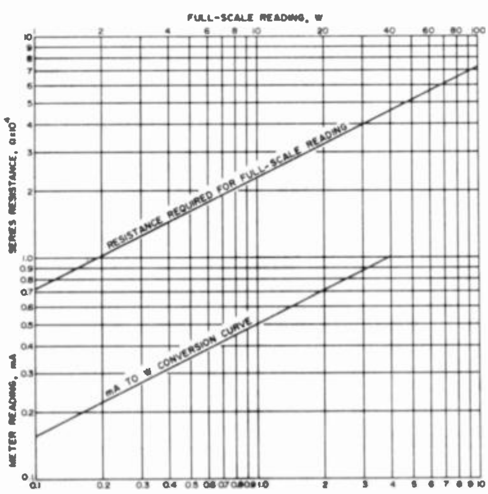


Fig. 6-13. Logarithmic plots for determining power. The upper curve gives resistance values for determining what the full-scale meter deflection will be (remember to multiply the series resistance value shown on the chart by 12 kΩ). The lower curve will allow you to determine your precise power out if you use a 0–1 mA meter.

As the schematic (Fig. 6-12) shows, the circuit uses a basic rectifying-type rf voltmeter. The prototype was built in a small can of the plug-in-module variety. About the only critical part is the series resistor. The capacitors are mica, but ceramic disks would work as well. The diode can be a 1N34A, 1N270, 1N52, 1N38A, or just about anything else.

If the series resistor is accurate, the meter will be self-calibrating to a log scale. Figure 6-13 shows a graph for conversion of indicated current to rf power.

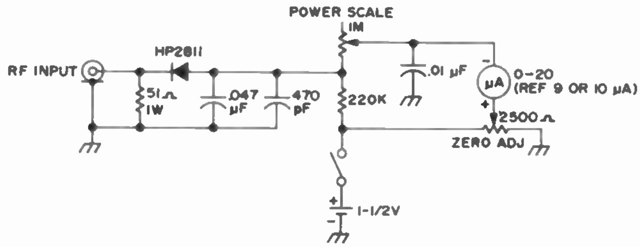


Fig. 6-14. Schematic diagram of Frank Jones' 0.05–500 mW wattmeter.

Install the meter through a coaxial tee at your antenna connector, or through some other predetermined means, and terminate with a dummy load. A suitable dummy load would be three 150Ω resistors in parallel, dipped in epoxy, shielded with a copper braid, and installed on a BNC plug. The meter can be used with an antenna if your swr is below about 1.2:1.

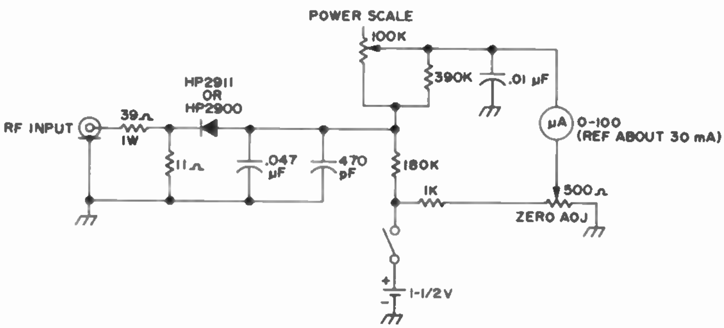


Fig. 6-15. Schematic of Jones' milliwattmeter for measuring rf power levels of 1–1000 mW.

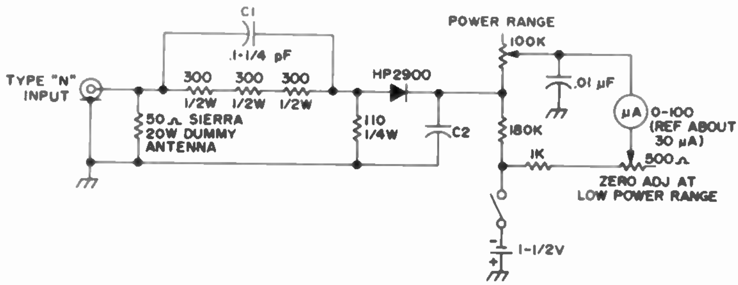


Fig. 6-16. .025 to 10 watt rf wattmeter.

Wide-Range Wattmeters

The advent of hot carrier diodes has had a significant effect on amateur radio, making possible the homebrew construction of wattmeters with a very wide operational range (from the audio region to UHF). Frank Jones (W6AJF), one of 73's most talented authors, submitted design criteria for several highly accurate wattmeters that can be used to measure power levels ranging from fractions of a milliwatt to as much as 300W.

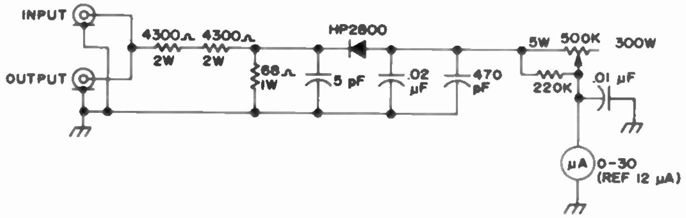


Fig. 6-17. 5 to 300 watt rf wattmeter merting circuit. (External 300 or 400 watt dummy antenna load.)

Figure 6-14 is a schematic diagram for Jones' wattmeter covering the 0.05–500 mW range; Fig. 6-15 shows the circuit for measuring power in the range from 1 mW to 1W. The higher-power circuits are shown in Figs. 6-16 and 6-17; the first is excellent for measuring the range from 25 mW to 10W, and the latter is ideal for the 5–300W range.

All circuits are designed for use with microammeters with full-scale deflections of 20 to 100 mA. Since the meters will be linear-scale reading while rf power increases logarithmically, the scale of the meter must be calibrated against a known standard. If the meter can be taken apart without too much difficulty, you can make accurate marks directly on the linear scale.

For calibration, a Bird Thruline wattmeter is extremely handy. Insert the Bird wattmeter in series with the coaxial line from an rf source that feeds the wattmeter you've built. All you need to do is detune the rf source to get a desired indication on the Bird wattmeter, then mark the scale of the microammeter to identify that power level. Increase the power as often as you like, and make incremental marks over the whole microammeter scale.

Adjusting FM Deviation

While a deviation measuring device is a very desirable piece of test equipment to have, it is not one of the most important items the amateur FM'er can accumulate. Nonetheless, if full benefits of the FM mode are to be realized, some means of setting all the individual transmitters in a communications system to a common deviation level must be adopted. When deviation of one transmitter is too high, voice peaks from that unit are not heard by the receivers in the system; when deviation is set too low, noise will swamp the signal from that transmitter in repeater "fringe" areas.

If a communications system – that is, the repeater and all the user stations – contains both wideband and narrowband units (a worst-case condition), use a narrowband receiver to adjust the deviation initially. Make certain the discriminator and low i-f stages of the receiver are in good symmetrical alignment. Position this "standard" receiver some distance away from the transmitter to be adjusted and have the transmitter operator gradually increase his deviation level as he whistles loudly into the microphone. This will insure that the transmitter's limiter will be set to the maximum deviation level that can be copied.

When the signal at the receiver just begins to "break up," or "squelch out," the deviation control of the transmitter should be backed off slightly. At this point, if the receiver doesn't squelch out on loud whistles it will accept anything the adjusted transmitter can dish out in terms of audio level. For optimum system performance, of course, all transmitters should be similarly adjusted.

All FM operators should bear in mind that reducing a wideband transmitter's deviation to make it compatible with a narrowband receiver is an unfortunate compromise. The performance of the wideband receivers in the system will be degraded substantially. Signal-to-noise ratios will deteriorate, reducing the apparent sensitivity of the wideband receivers, and increasing ignition interference susceptibility.

As you adjust deviation in the manner described above, remember to keep a fully limiting (very loud volume) audio signal going into the transmitter at all times; unless this is done the whole process is a waste of time.

Part VII

Build-it-Yourself FM Rigs

Pocket-Size VHF Transmitter and Receiver

All you have to do is look once at the price of commercial walkie-talkies to see how the effort of building your own can be justified. But there's a satisfaction that comes with operating something you've put together yourself, which goes well beyond the knowledge that you've beaten the manufacturers at their own game. I won't be foolish enough to tell you that building up a portable FM transceiver is a snap, because it frankly isn't quite that simple. But it really isn't particularly difficult either; and the time you spend will be amply rewarded by a good solid working knowledge of what's in those little radios you hold in your hand. Besides, it can be fun!

The construction process is described here in its entirety – first, the receiver, then the transmitter. But since the project is to be a miniaturization job as well as simple construction, there are certain specifics involving components that must also be considered. In the main, these are dealt with individually.

The units described here were built by Bill Hoisington (K1CLL). A construction article for them was presented in the April 1971 edition of 73 Magazine.

Miniature Components

Capacitors. Bypass units can be the Lafayette thin units (see page 294 of 1970 catalog) where a 0.01 μF job can be found which is only 5/16 in. square by 5/64 in. thick. And the 1000 pF ones are only 11/64 in. square. For the lower values used in coupling and for fixed tuning capacitors, Elmenco dipped silver-mica jobs were used in the original model.

Resistors. Resistors can be the Ohmite ¼ watters, but for the sake of miniaturization, you'll be better off if you get a selection of Allen Bradley 1/8 or 1/10 watt midgets. They're *really* small!

Crystals. The crystals should be the small plug-in kind, about 400 by 175 mils because repeater input channel frequencies do vary across the country. The most prevalent in the U.S. is 146.34, with 146.46 being Canada's prime choice.

Coils. The 8 and 24 MHz coils are the 9050 units from J. W. Miller, and are very handy for modifying to suit transistor input impedances, as well as having good, stable, mechanical tuning of the cores.

There isn't much else on the strip except thin copper-clad, 1/16 in. linen-base Bakelite or fiber glass strips, four Motorola HEP 55s, and two Motorola HEP 75s (2N2866).

Various colors of subminiature wire will help also.

Special Tools

Don't worry about particular tools; they're not too special, as you will see, but you should prepare a little in order to do a good job. You must have the usual set of good small tools and it helps to thin down by grinding the already thin needlenose pliers to get into those really narrow places you will find in the back of the mounting strip. Use the same treatment on some small side-cutters also, because you will be cutting off a lot of small wires in even smaller places.

A collection of small low-cost screwdrivers will be handy, too – file them sharp and very small for special places. Sharp-pointed tweezers are handy as well.

Various fiber TV tuning tools are useful for the trimmer capacitors, and several lengths of ¼ in. Lucite and Bakelite rods make good insulated screwdrivers also.

A slightly unusual aid is a "coffee stick" with an arrowhead-shaped lump of coil wax stuck on the end. When you're winding small coils with small wire it is very handy to put a drop of wax on the coil and let it sink in and cool. You can do this with the tip of your small iron; it does help hold all that tiny wire in place. All the filter chokes shown use this method. Good for a lot of receiver coils to come later, too, and for holding the extra turns wound on the Miller coils for base impedance matching.

Be sure to have plenty of subminiature clip leads with flexible wire of various lengths from 1 in. up to 1 ft.

Have a good selection of Arco midget trimmers on hand also, such as the 400 series, which are just ½ in. long.

No. 48 or 49 bulbs are good for checking rf as you go along the multiplier chain from stage to stage. You should always be able to light one of these, which glow red (dull) at 20 mW. Use a matching series trimmer, as little as 5 pF for 147 MHz and less than 1 pF on 450.

Have a roll of plain masking tape to hold down strips and things while working on them. A small drill vise or the "third hand" bench vise helps, too.

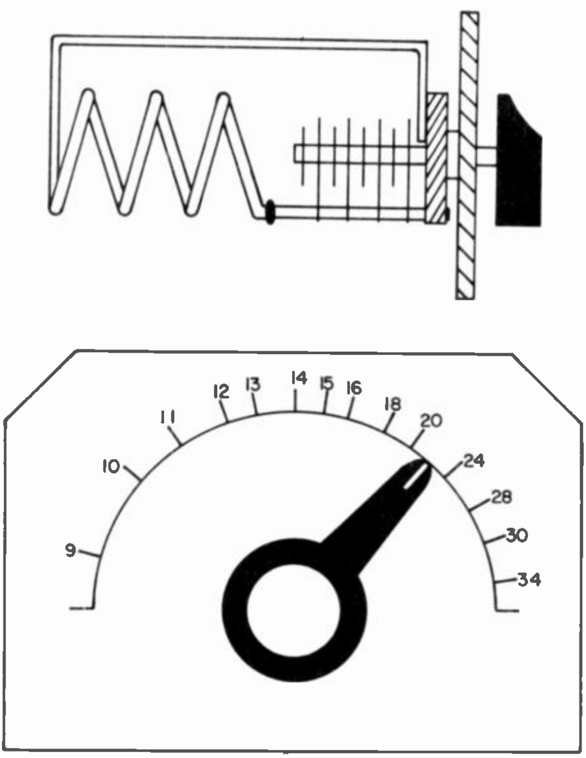


Fig. 7-1. Typical absorption wavemeter.

Do's and Don'ts. These hints apply especially to a multiplier chain including a straight-through amplifier used as a phase modulator, which is the circuit being described in this chapter. It has an 8 MHz crystal oscillator and ends up on 147 MHz, so you must be *sure* of the frequency of each stage as it operates. Do *not* rely on your receiver or on grid-dipping the inductors first.

Using an absorption wavemeter (Fig. 7-1), any circuit under test can be checked for the real and exact frequency at which it is resonating or oscillating, by lighting a bulb on rf or using a diode detector with a meter. When the absorpotion meter resonates with the rf in the collector circuit which is lighting the bulb or actuating the meter, a dip in the light or on the meter will show. This indicates the *real* frequency of the main body of the rf present. Some transistor collector circuits not tapped down on coils are especially notorious for this, and may exhibit two frequencies at the same time. For example, there may be energy at 72 and 96 MHz present. This is an indication of mistuning, or overloading, or both. Tap the collector down on the coil, don't load it so heavily to the next stage, check it carefully with the diode meter, and don't worry about a small remnant of off-frequency energy. After all, a multiplier is bound to have some of this present. Just get the *main* amount of frequency and be happy. And be sure the *next* stage also peaks on *its* desired frequency.

A grid-dipper in the *diode* position can also be used for this work. A one-turn link around the low end of the grid-dipper coil and a cable will get you into small places in a rig where you cannot insert the whole dipper.

The diode detector. Figure 7-2 shows the schematic of one of these useful pieces of equipment which allow you to listen to your transmitter multiplier stage as you built it, and check the actual frequency at the same time. With a good variable capacitor you can generally run over three to one in frequency range – up to the UHF region at least. From there on up things get a little more difficult.

These "receivers," because that's what they really are, although of low sensitivity, are especially helpful in transferring known frequencies on a signal generator to a homemade set of wavemeters.

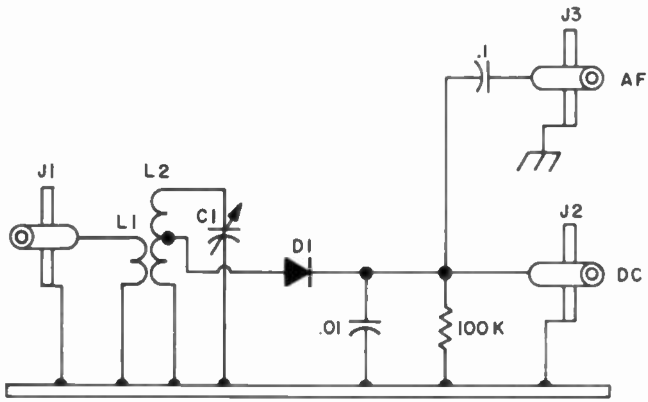


Fig. 7-2. Tuned diode detector.

The meter. This should be as sensitive as possible. Lafayette has good ones down to 50 μA. Use a tap switch to put resistors in series to bring the voltage range up to 10V or so for use with an active portion of the rig such as the 1W final circuit.

The AF Amplifier. This item should not be neglected as it is at times a great aid to getting a trouble-free, *noiseless* carrier, which you can then modulate and be proud of. The valuable RCA handbook, "Transistors, Thyristors, and Diode Manual," has a lot to say about "discontinuous jumps in amplitude or frequency as various levels of drive are encountered." These little termites can be seen on the meter or *heard* on the af amplifier or can show up on both. Figure 7-3 shows a mounted version of the af amplifier

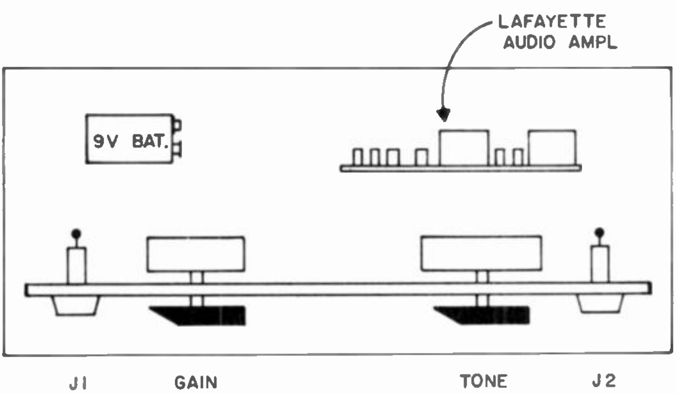


Fig. 7-3. Handy af assembly, top view.

used here for this purpose. It is a worthwhile and handy little piece of equipment to have in a lot of situations, in both receiver tests and transmitter tuneup. Just plug it into J3 of the diode detector in Fig. 7-2 and hear those unwanted clicks, whistles, rushing noises, squeals, etc., coming from what you may have wishfully thought was good clean rf in your multiplier drive!

Overdrive is especially to be avoided in multiplier chains with transistors. Superregeneration is one of the indications.

Diode dectector cable probes. Have a collection of these on hand as in Fig. 7-4. You can use them also to feed rf into a pilot light, connect up to your lab receiver, etc.

Handy meter jacks. Figure 7-5 shows an elementary but flexible and useful metering method for checking stage current.

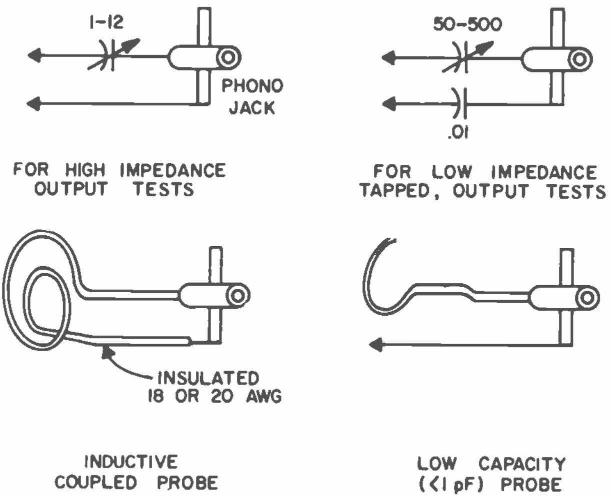


Fig. 7-4. Coupling methods.

FOUNDATION RECEIVER

The basic design shown here is for a low-cost single-conversion utility receiver for 2 meter FM; particular attention is given to easy-to-build i-f and discriminator modules for the 10.7 MHz section. The rf is tunable from 144 to 148 MHz, with a switch for AM use. This is a complete portable receiver, *not* tied down to a large ac communications receiver.

The schematic of Fig. 7-6 shows how easy it can be. Remember, this is just a basic receiver which, without double-conversion, is a relatively broadband, easy-to-tune job, but it sure pulls in those interesting repeaters!

Front End

Simplicity is the word in this module. You can check different transistors for low noise, coils for rf, or add a low-noise stage; and the tunable oscillator is easy to change to a crystal oscillator for repeater operation. All three stages are tunable from 144 to 148 for coil, sensitivity, and selectivity experimentation, and to allow you to check the

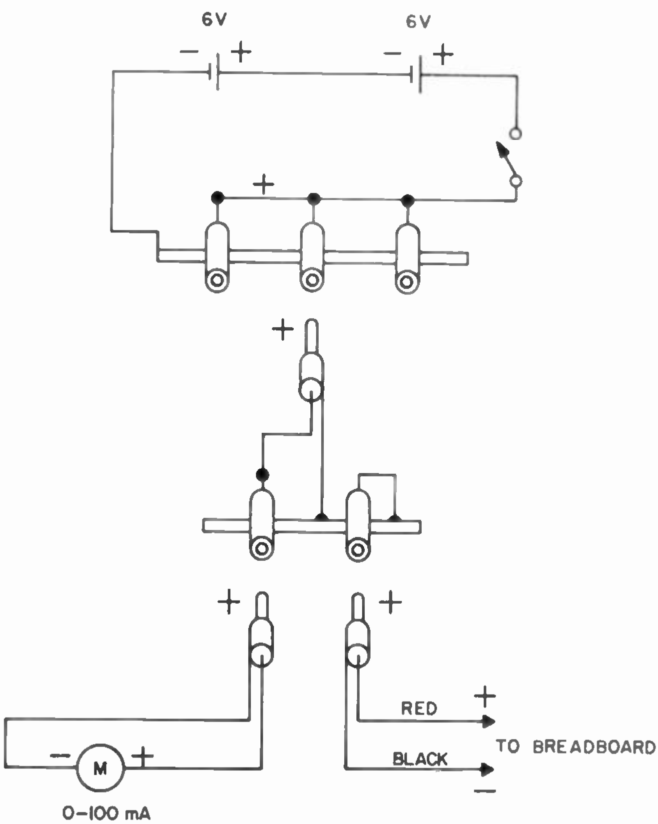


Fig. 7-5. Handy metering jacks and plugs.

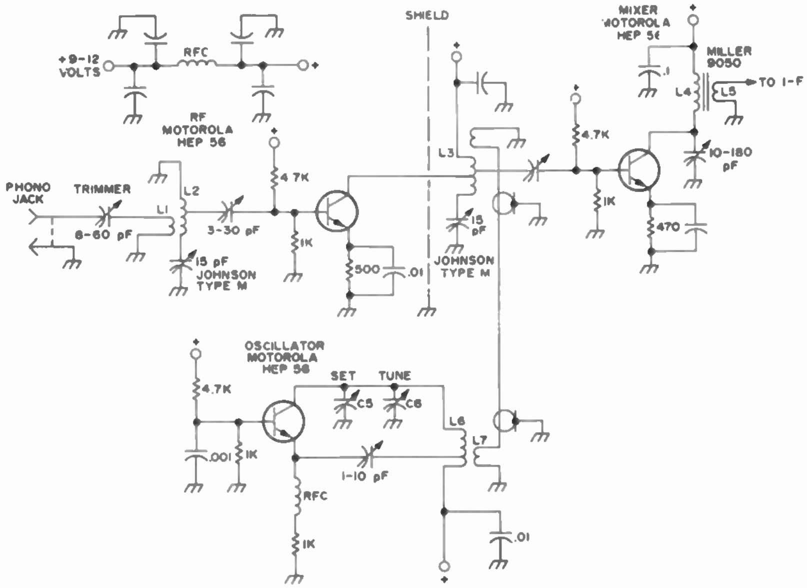


Fig. 7-6. Schematic of basic 2m FM receiver.

AM section of the band as well as repeater work in your neighborhood.

The oscillator tuning dial also relaxes preliminary oscillator crystal frequency requirements by allowing you to find out what crystals you will want later, and order them without rushing the deal. The link coupling at low impedance permits easy switching from tuned to crystal control, if you wish to retain the tunable feature.

The rf and mixer stages are tuned by small variable capacitors mounted on the baseboard with small brackets made from copper-clad. Small pointer knobs allow peaking of these circuits. The rf stage has a trimmer capacitor feeding the base which is quite useful, resulting in a welcome balance between gain and self-oscillation. The mixer also has a trimmer for its base input, which permits a selectivity adjustment for this circuit.

The tunable oscillator was mounted on the Miller slide-rule dial for mechanical stability as shown in Fig. 7-7, and works quite well – with the broadband i-f of course.

The 2m band can be spread out from 10 to 90 on the

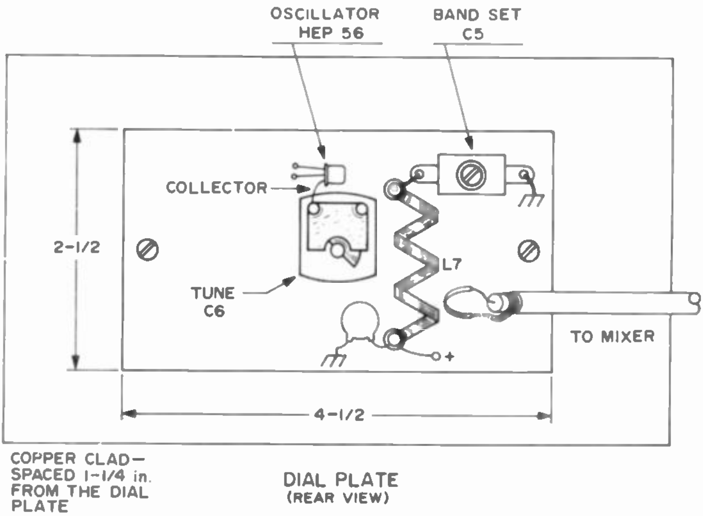


Fig. 7-7. Dial-mounted local oscillator.

dial by trimming L7, increasing C5, and using a smaller C6.

Oscillator coupling can easily be adjusted for maximum conversion efficiency via L4 and L7. To start up, adjust L7, C5, and C6 for the range 133 to 127.5 MHz as a local oscillator for the i-f of 10.7 MHz to be used later. Tune up the whole front end using the diode detector of Fig. 7-2 tuned to 10.7 for the i-f section.

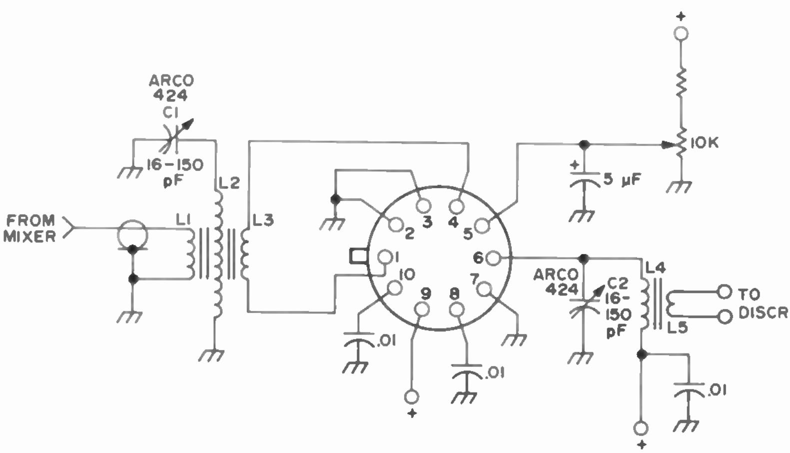


Fig. 7-8. 10.7 MHz i-f, bottom view of IC.

10.7 MHz I-F Stage

The reliable and sure-fire Motorola HEP 590 IC was used here – 25 dB gain, no self-oscillation. Figure 7-8 shows the circuit, using Miller half-inch shielded coils both on the input and output. Note that the 590 is simply turned leads-up and soldered onto a few resistor supports, with a shield, as in Fig. 7-9. A gain control is used, which may or may not be kept in later as you wish. With the limiters that can be added, the gain control is *not* needed.

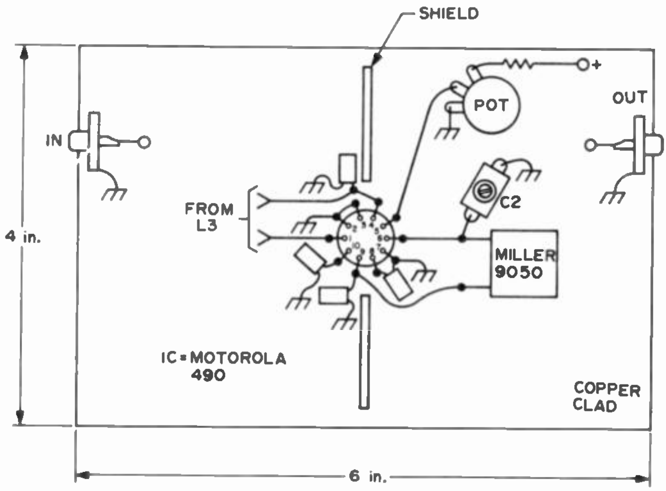


Fig. 7-9. I-f shielding as seen from top side of board (bottom view of IC).

A B+ filter is included in each module, and a 100Ω resistor with a 10 μF capacitor may be needed also to cut out motor-boating when more stages are added later, if you go to double conversion. Be sure *not* to return L3 to *ground* dc-wise, as the needed bias is supplied internally through pin 4. Pin 9 is the main B+, along with the cold end of L3. Gain control can be obtained through a pot in the pin 5 lead, where maximum gain is reached with pin 5 at *ground* potential.

The internal and external circuit of the Motorola IC590 is shown in Fig. 7-10. This IC, which is very useful for frequencies up to at least 6 meters, has extremely interesting features, among which can be noted the absence of internal feedback (even at 50 MHz), the high gain, and the

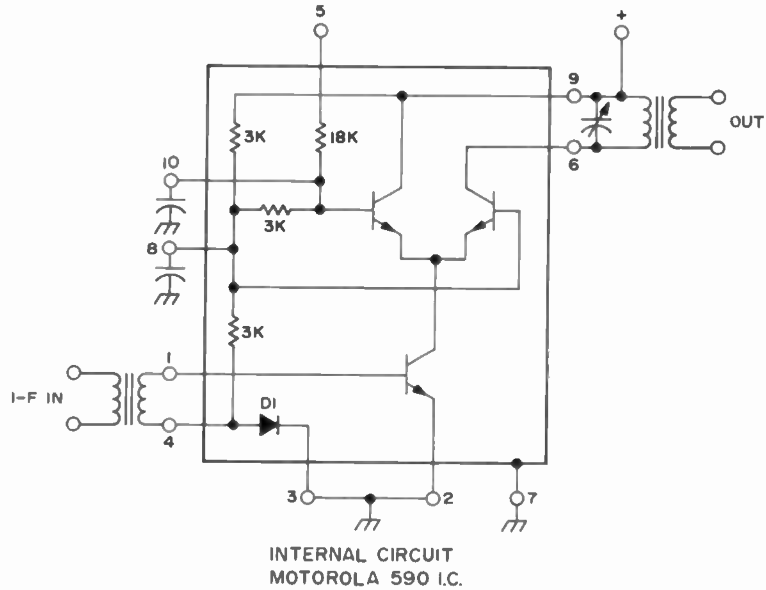


Fig. 7-10. Internal circuit of Motorola's HEP 590 IC.

excellence of the gain control at pin 5, either manual or automatic. For this receiver, mainly intended for experimental FM use, no avc is used. Later, if you add double conversion, the limiter section module will eliminate the need for avc.

Trimmers are shown for C1 and C2, but fixed capacitors of the proper value may be used to allow tuning of the i-f coils at 10.7 MHz by the variable tuning slug cores in L2 and L3. Note that these Miller half-inch gems have very good electromagnetic as well as electrostatic shielding, due to the cup-core type of construction, and are available for

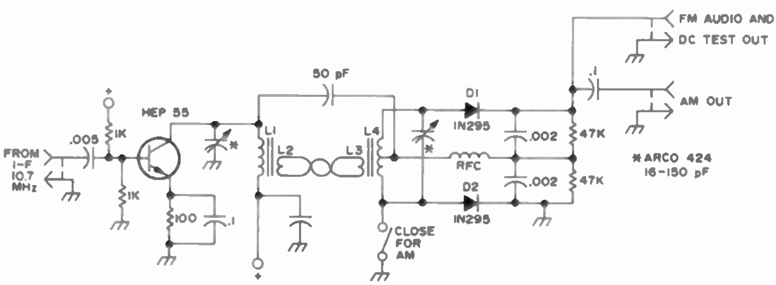


Fig. 7-11. Discriminator circuit.

use from 30 MHz down to 135 kHz. They can also be easily opened for the addition of primary or secondary low-impedance windings.

Discriminator

The discriminator circuit works from 10.7 MHz down to about 135 kHz, and at the same time is easy for the homebrewer to build because of the link coupling. Figure 7-11 shows the circuit where L1 is a simple tuned coil in the collector circuit, with *no* coupling requirements other than a one- or two-turn link. When the primary of a discriminator transformer has to be coupled just right to the centertapped secondary it is not a job for the usual experimenter at his bench. With the link you can't go wrong. Just tune L1 to 10.7 MHz, put a turn or two around it and another turn on L4. Figure 7-12 shows the discriminator dc output curve, which handles about 25 kHz for 2-0-2V.

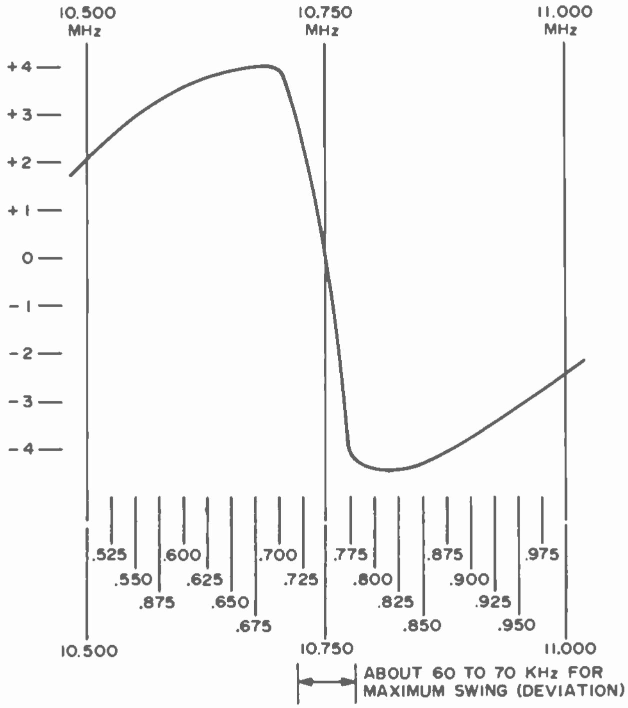


Fig. 7-12. Discriminator dc output curve.

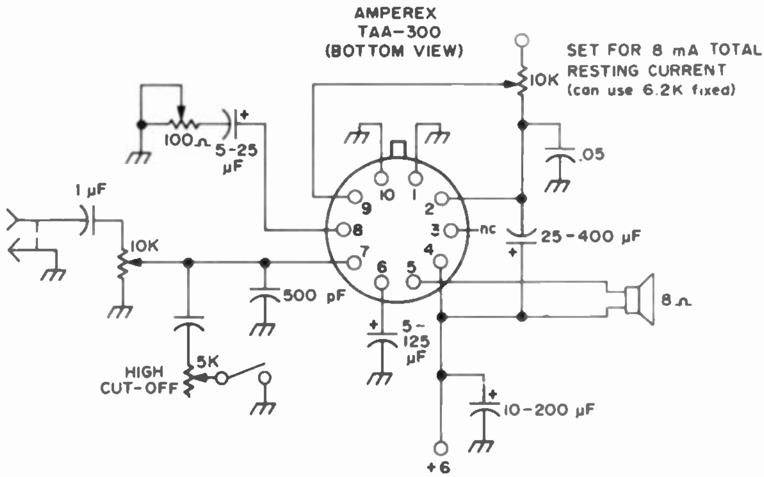


Fig. 7-13. Audio amplifier IC.

Audio Amplification. The audio section is an Amperex TAA-300 1W "baby-hi-fi" IC. There are about 11 transistors in that one little can, and it is flat to 1 dB from 25 Hz to 25 kHz! Get a halfway decent 8Ω speaker to go with it, because it's worth it. Figure 7-13 shows how to connect it up.

FM TRANSMITTER STRIP

The transmitter section measures 1 in. wide by 8 in. long, and it puts out over a watt on 146–147 MHz, with low-cost components. This miniaturized transmitter is a logical step toward design and ultimate construction of a "shirt pocket" portable transceiver. The parts for that one jump up a little in cost, because it takes a lot more tools to make subminiatures, such as stereo microscopes, special materials and skills, jewlers tools, and so on.

Shape Factor, and Assembly Method.

These are important features, as you will see, allowing the homebrewer to build a complete FM rig in a minibox and still have room enough left over to change components for repairs or design improvements if needed. You can also substitute slightly different components if you have to.

Figure 7-14 shows the method, using a copper-clad baseboard on which is mounted a drilled ½-in.-high strip of

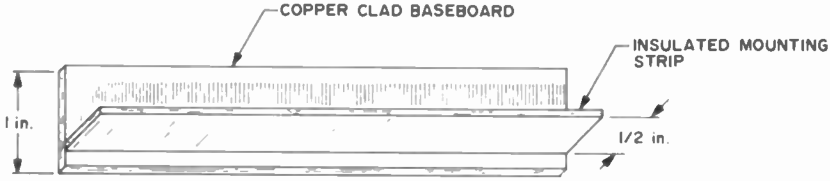


Fig. 7-14. Baseboard/mounting strip configuration.

insulating material holding all the components. Bypass capacitor leads to ground are no longer than ¼ in., shielded coils are used, and all tuning is done from one side.

The photos show the happy results of placing the parts to best advantage on such an assembly. Notice that the components are also all on one side, and their leads and connections are on the other side. On the wiring side, every connection is spread out in front of you, with room

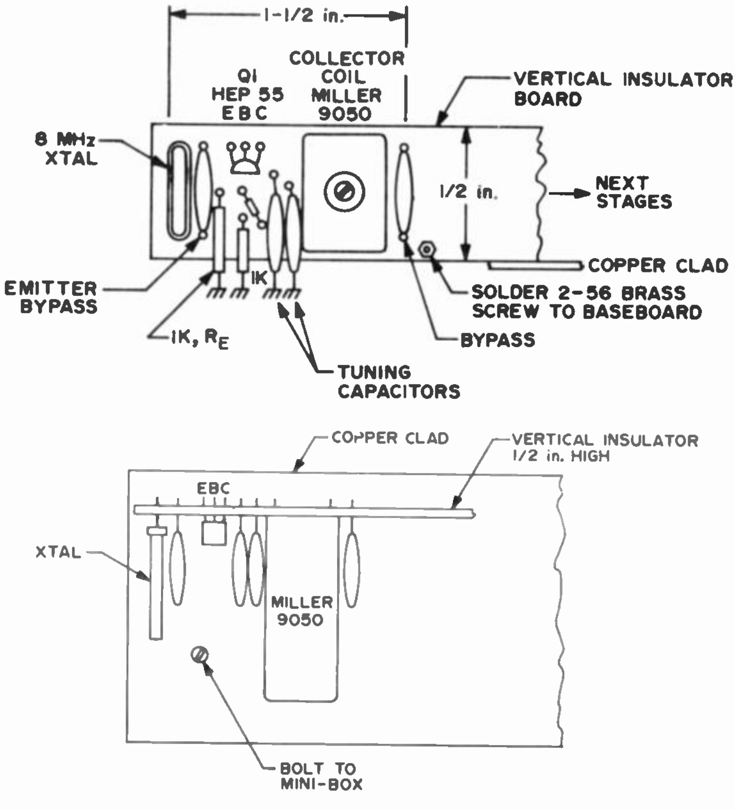


Fig. 7-15. Component layout, top and side.

between each one for good soldering; no resistor supports or other metal tie points are needed.

The B+ lead is red subminiature wire and goes from filter to filter along the strip. The rf lead is green and goes from the coil output tap of each stage to the next base coupling capacitor; the rest of the connections practically fall in place for soldering together. As you can see, there is still room left over!

The detailed planning of the holes to be drilled becomes a large portion of the work. Figure 7-15, component side and top views, shows how to start this off. The next step is to make a life-size drilling template using the

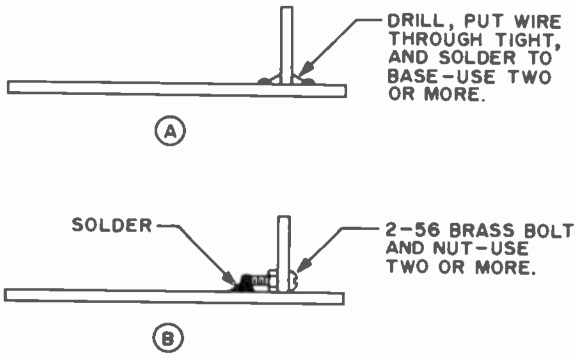


Fig. 7-16. Methods for fastening insulated strips to baseboard.

components you have or intend to use. I mention this because most of these are not critical and you may substitute without trouble providing you keep thinking "little." Even here, you can go bigger with the components if you want to, but your overall package size may expand. You can also go smaller if you plan carefully and cram everything together a little tighter. The reason for this will be evident if you study the circuit, where you will see that no critical wires cross over each other, and that the power amplifier is well away from the oscillator.

Ultimate size is actually up to you, and you can judge for yourself after laying out the parts on hand. If you send for a selection of Lafayette Radio very thin and small capacitors, you will have an easier task to get it down in size.

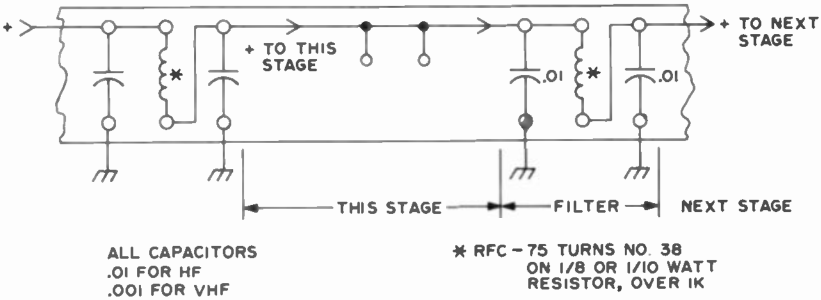


Fig. 7-17. Miniature filters, interstage.

Figure 7-16 shows two methods of preliminary fastening of the vertical strip to the copper-clad baseboard. This will start off the assembly, and after the wiring you could hardly tear them apart with your fingers.

You can also make strip modules of any length you want such as modulator af, receiver sections, etc., as shown in the receiver plans. This makes the task of repairs or improvement changes easier later on. These shorter strips can be fastened end on to each other and fastened down to the baseboard as shown.

Miniature Filters.

Do *not* try to make up frequency multipliers *without* rf filters in the dc line to each stage. You can make up "dime" filters without much difficulty if you follow thy simple directions below. Materials needed are tiny resistors (any value over 1 kΩ), some 36 or 38 AWG wire (double silk covered), coil wax (you can use paraffin wax if you can't get coil wax), and small capacitors, such as the Lafayette types. Use 0.01 for HF and 0.001 (1000 pF) for

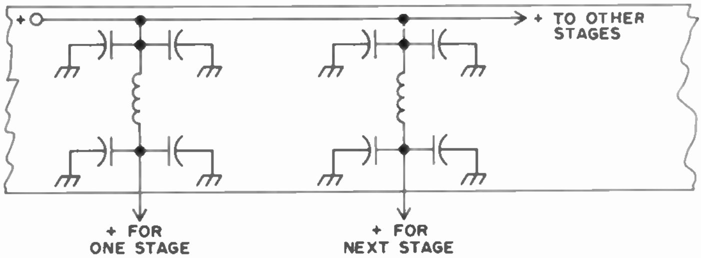


Fig. 7-18. UHF filters for interstage coupling.

VHF. Figure 7-17 shows the circuit. The main thing is to interpose an rf trap in the plus lead between each stage and any other.

The series method shown in Fig. 7-17 is best for high-gain amplifiers because it puts *several* filters between the high-power output stage and the sensitive first stage. However, if the filters are very good you can bring the battery leads from each stage to a common point, but this must be checked carefully if you have to do it.

Clean and tin carefully each resistor form lead close to the body, then melt a thin layer of wax onto the resistor to hold the wire from slipping when you wind it on. Solder one end of the wire onto one lead and then random wind 75 to 100 turns of 38-gage wire onto it, and wrap the end around the other lead ready to solder. Put a drop of wax on the coil before soldering to hold the wire turns in place. The wax should penetrate the whole coil. Most types of insulation on 38-gage wire will disappear as soon as solder and heat are applied, so you don't have to bare the wire first. Now you have an rf choke, and if you keep the capacitor leads real short to ground, the filter will do the job for you.

It works fine even up to 450 MHz if you use four capacitors, each to different point on the ground plane of copper-clad, as in Fig. 7-18.

Phase Modulator

Phase modulation results in a type of frequency modulation of the carrier at the rf output jack which the usual FM receiver cannot distinguish from true FM. Being crystal-controlled it is used by practically all of the FM mobile and base stations in the U.S. And of course with the crystals in there, you *will* be on the amateur FM channels, providing you buy them right. You have to pay around $7 for these but it seems well worth it.

Certain designs of the af section of the phase modulator, its tuneup, and the connections to the phase modulator can be troublesome for the homebrewer, so considerable time was spent to make it as simplified and easy to adjust as possible. It also can be used in the receiver section as the af amplifier because the frequency correction is done *outside.* The use of an 8 or 16Ω output connection into the phase modulator emitter circuit helps to stiffen the af drive and keep it clean.

Phase modulation af sections in commercial rigs are often qualified as "audio conditioning," or "processing" circuits, which they are of course, but don't let that bother you. Excellent FM quality can be obtained by the use of an inductance of large value, placed outside of the af amplifier, in the noncritical low-impedance output circuit. The inductance cuts down the extra high audio modulating frequencies caused by the phase modulator's tendency to

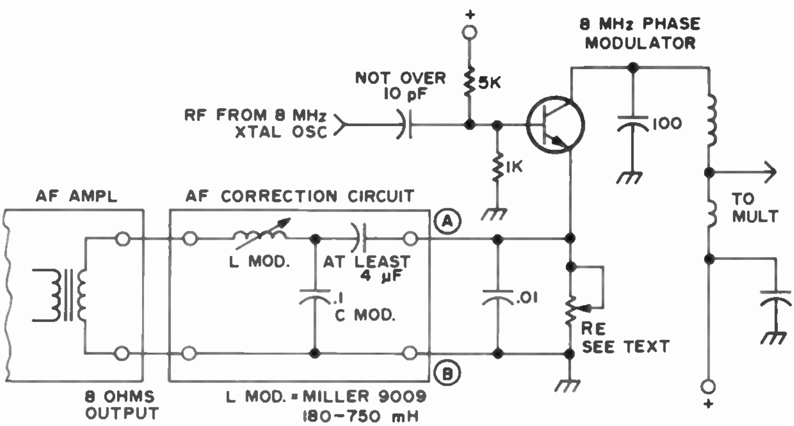


Fig. 7-19. Phase modulator interconnect circuitry.

make the FM deviation directly proportional to the modulating frequency, which emphasizes the highs too much unless corrected. Being outside of the af amplifier, you can now use almost any good low-cost job and use it in the receiver also.

Figure 7-19 shows the simplicity of the method used.

The af output needed to drive the phase modulator emitter is several hundred millivolts, and the low impedance allows the usual rf bypass capacitor of 10,000 pF to act simply as an additional af filter, which is does.

As a result, the entire tuneup is done by adjusting the value of the emitter resistor and the phase modulator tank tuning coil. Neither are actually critical but should be adjusted while listening to the 146 MHz carrier on a good

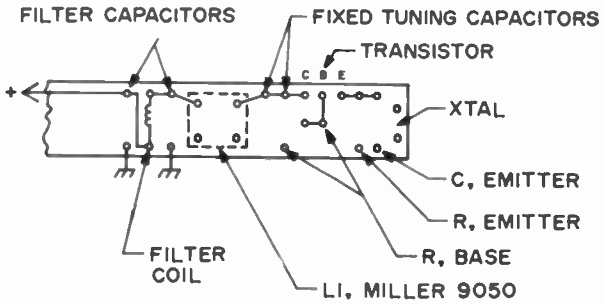


Fig. 7-20. Drilling layout (wiring side).

amateur narrowband FM receiver. The emitter resistor will be heard to kill the modulation when going much below 2 kΩ and to bring in distortion on large amounts of audio when going a lot more than 2 kΩ. This latter condition also causes a drop in the rf output. You may hit it right the first time with the 2 kΩ value.

The actual phase modulation resulting from varying the emitter voltage with audio is adjusted by tuning, which is also smooth and noncritical. I used the tried-and-true method of listening to my own voice with plenty of audio on the receiver and a set of well-padded earphones (you can get a very useful set for under $10 at Lafayette) which keep your voice from reaching your ears directly through the air. It also cuts down audio feedback.

Tuning with af going into the phase modulator as per

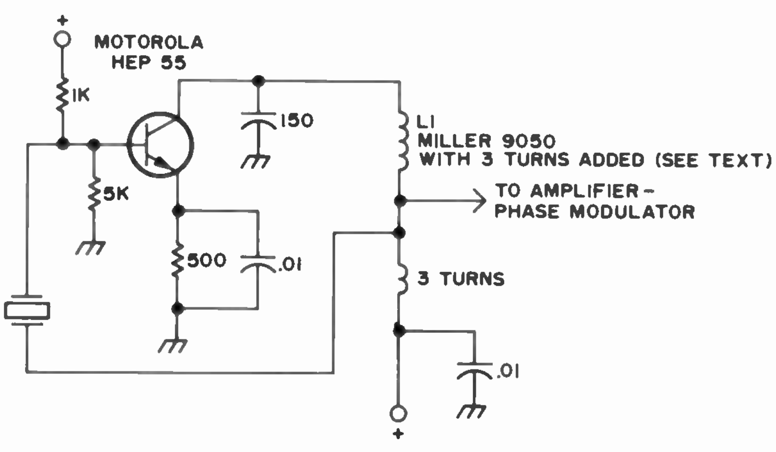


Fig. 7-21. 8 MHz oscillator schematic.

Fig. 7-19, you will notice good strong clean FM on either side of the peak tuning. These points occur *before* the 146 MHz carrier output starts to drop from detuning the phase modulator tank, so don't worry about that part. In any case, you are supposed to be following the phase modulator with enough saturated class C multipliers and amplifiers to prevent any variation in amplitude (otherwise known as AM!). You have to watch *very* carefully when using ICs for modulators, they tend to pick up rf and generate feedback with their wideband audio circuits and sometimes as many as 11 or even more transistors in one little can. Also, don't put more than the specified voltage on IC amps. You can easily drop down with a resistor and a *large* bypass capacitor.

Almost any desired amount of highs and lows can be obtained or suppressed by the manipulation of the LC values in the modulator. If you use a Miller 9009 wide-range adjustable inductor, 180–750 mH, you can hear the difference as you adjust the core in and out.

A layout is shown in Fig. 7-20. To make the life-size drilling template, lay out the components one after the other, "standing up" on a ½ in. strip of good-grade white cardboard and mark the component lead holes, which should result in something similar to Fig. 7-20. A nice feature of the cardboard method is the easy punching of the holes and the way it holds the drill as you go through the strip. Tape the template in place onto the insulating vertical strip. Do not use anything that melts under heat, though. Even if you ruin part of the strip, or want to make a large change of one stage you can just saw that out and make up another section and go ahead.

The 8 MHz Oscillator

Figure 7-21 shows the schematic of the crystal oscillator stage. Note the apparent use of negative feedback with the base return through the crystal to a tap on the inductance. It is only apparent, though, as the crystal reverses the feedback phase, making it positive.

The tap on the coil also provides a good low-impedance match for the next base input. The coil itself is made from a Miller 9050 shielded coil which has magnetic as well as

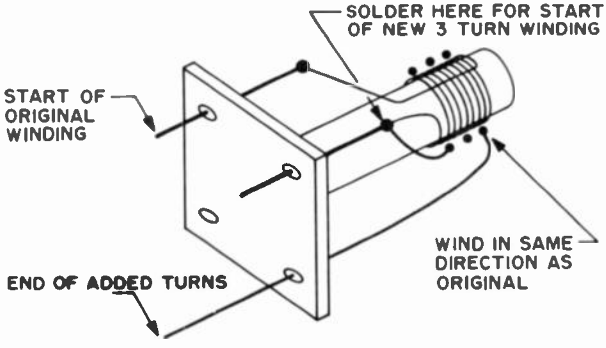


Fig. 7-22. Miller 9050 coil with added turns.

electrostatic shielding, and a good adjustable core that works good mechanically (which is more than you can say for some of those types of cores).

Remove the aluminum can by bending back the four holding tabs and wind on three turns of 30- or 32-gage silk-covered wire onto the existing winding of the coil. Be sure and wind them in the same direction as the turns that are already there. The oscillator coil will then look like Fig. 7-22, and is ready to mount on the strip.

The wiring on the lead side of the strip is shown in Fig. 7-23, where most of the leads are seen to fall in place quite well.

Insert the component leads through the strip and bend

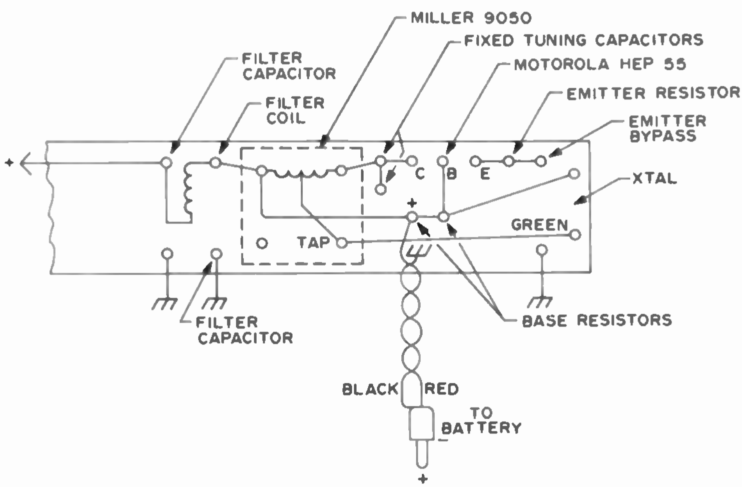


Fig. 7-23. Oscillator wiring diagram (lead side of strip).

them slightly in the direction they will go, such as the two base resistor leads which are bent towards the base lead, as shown clearly in Fig. 7-23. When all the leads to be soldered in one place are all touching each other, a final dressing can be done followed by soldering. In the example mentioned, the base lead has three other wires soldered to it, a wire from the crystal, the 1 kΩ resistor, and the 5 kΩ resistor.

The can of the 9050 coil has a tab which should be soldered to ground. The ground lead of some resistors (or all of them) is not routed through the strip but is soldered to the baseboard on the component side of the strip.

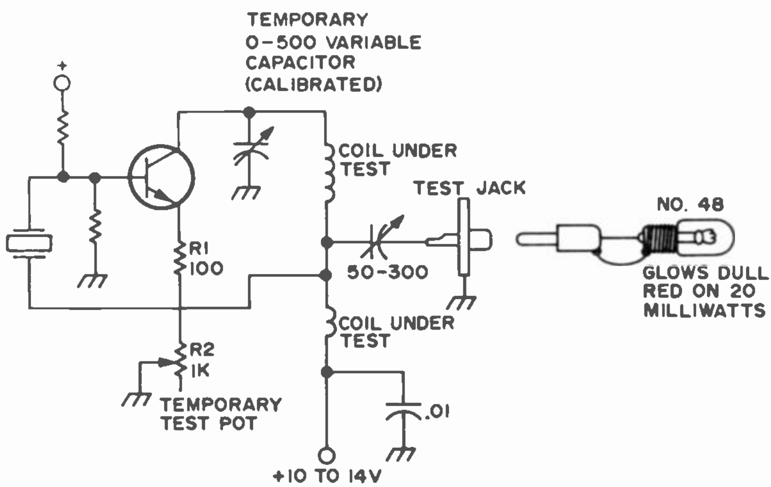


Fig. 7-24. Oscillator test setup.

When the oscillator is assembled and wired, B+ can be brought in and the unit tested for rf. Some 5–10 mA of current should register and as soon as the oscillator coil is resonated to the crystal frequency, the oscillator should show rf output to the 8 MHz tuned diode test set connected to the output tap lead.

Check the oscillator carefully on a sharp receiver for its frequency-holding ability while tuning the slug in and out of resonance at 8 MHz. Actually this will be near 8.130 MHz. (With a multiplication of X18, this should land on whatever 2 meter FM channel you're aiming for). It should come into resonance on one side with a good "plop" and gradually build up on the other side as you tune.

Start with a large calibrated variable capacity at C3 (some 500 or 1000 pF, made from an old BC set three-ganger) and then put in fixed values so that the iron core tuning slug in the 9050 coil tunes properly about ½ in. under the winding of the coil.

Power can be adjusted by the emitter resistor, and feedback by the number of turns between ground and the oscillator-coil tap. (These are of course the number of turns added to the Miller 9050.)

A 48 or 49 bulb, rated at 2V and 60 mA, should light up with about 50 to 100 mW worth of rf with a 50–300 pF trimmer in series, as in Fig. 7-24. When the oscillator is properly tuned and under good power control via the test pot (in Fig. 7-24) and the plus voltage is checked for the voltages you expect to see, the next stage can be assembled. Of course if you wish, you can mark out the whole strip template, drill all the holes, and mount and solder all components except the coupling capacitor and B+ to the next stage. This allows you to test the oscillator by itself.

The 8 MHz Amplifer–Phase Modulator

This stage (Fig. 7-25) is not critical, other than to keep the input base coupling capacitor at a low value to avoid self-oscillation. The only requirement is that the tuning should be correct for phase modulation.

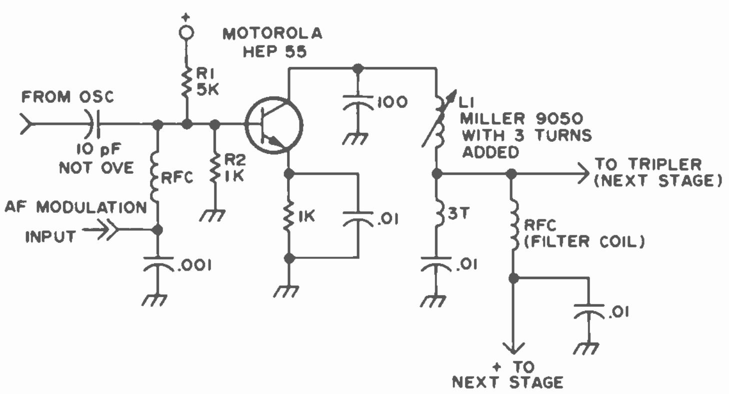


Fig. 7-25. Schematic of phase modulator/amplifier.

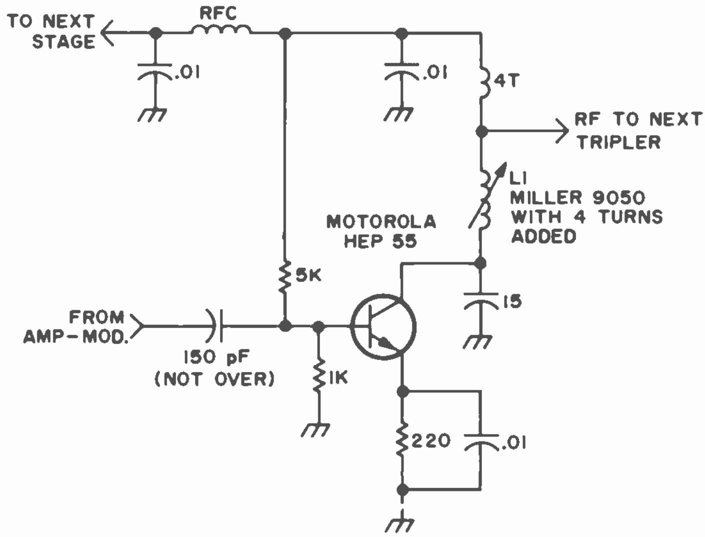


Fig. 7-26. 8 MHz tripler schematic.

Use the same methods of assembly, wiring, and tuneup for power output as with the oscillator stage. You do not need much gain, if any, in this stage.

The 8–24 MHz Tripler Stage

A frequency multiplier has the advantage that generally (though not always) it is free from self-oscillation, due mainly to the output and input circuits being on different frequencies. The bias requirements are different in a tripler from those of a doubler or class C straight-through amplifier, but this can be adjusted simply by varying the emitter resistor during tuneup for maximum output on the desired frequency. Figure 7-26 shows the schematic of this stage, where the base input coupling capacitor is seen to be much larger than in the preceding stage. However, in spite of a small tap winding and low impedance in the preceding stage it is easy to cause superregeneration in the base circuit if the coupling capacitor is too large; 150 pF or slightly less is a good value.

The wiring side layout for this stage, which is typical of the multiplier circuits, is shown in Fig. 7-27. A logical wiring system is seen to prevail, especially as regards the emitter, base, and collector wiring and their components. Two extra wires are used, one red for the B+ and one green for the base input rf circuits, with a filter coil separating the plus of each stage.

A 24 MHz diode detector is clipped onto the rf output tap on the inductor (Fig. 7-27), as was done in the preceding stages. Be very *sure* you're on 24 MHz, and not on 16 or 32. Here again you should be able to light a 48 bulb with rf with a 5–180 pF trimmer in series for matching. The collector tuning and power output curve with emitter resistor lowering should be clean and smooth.

As mentioned in the test equipment section, it is a real *must* to *listen* to the carrier as you build it up in frequency. Do this with a little af amplifier continually connected to the diode detector output because the carrier has to be free of all spurious noise, squeals, frequency and power jumps, etc.

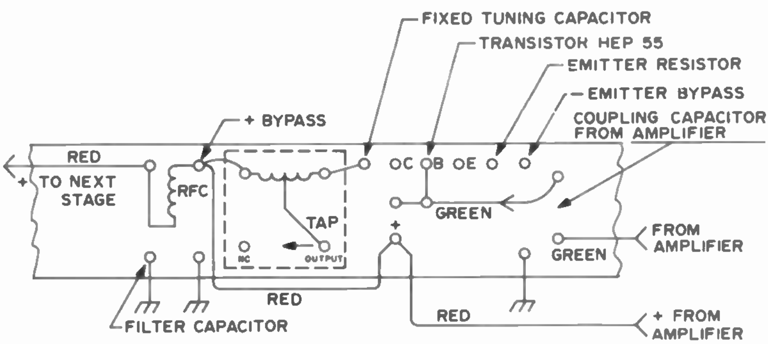


Fig. 7-27. Wiring diagram, 8 MHz tripler.

The Tripler to 73 MHz

This one proceeds in a similar fashion to the previous stage, except that now you begin to use capacitor tuning of the collector coils. The iron-core coils of the Miller 9050 series do not do a good job here, so you have to wind your own.

Figure 7-28 shows the circuit and values obtained by tests here. Do not exceed the value of 50 pF for the base input capacitor. In case of any spurious noise, this is the first place to look; in fact, start off with a trimmer at that

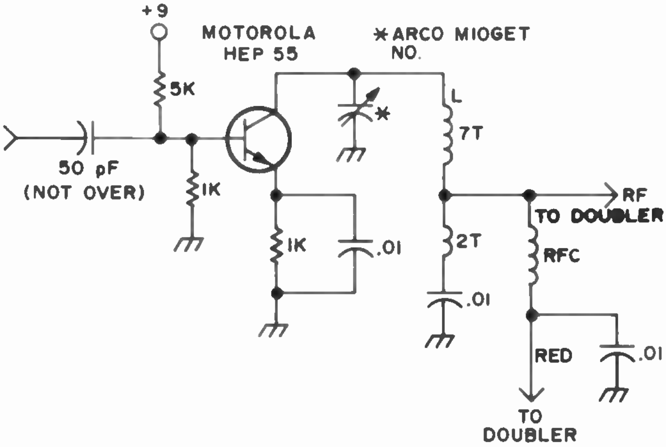


Fig. 7-28. 24 MHz tripler schematic.

point to make sure and get the maximum drive possible *without* noise.

When the stage is assembled and wired and under test as done with the previous stages, once again, look out for those *undesired* harmonics, especially the 64 MHz one in this case.

The inductor may be fastened to the mounting strip with a nylon screw (Fig. 7-29) for ruggedness. The variable capacitor does all right standing up on end with the fixed plates soldered to the baseboard, and the movable plates brought out through the strip with a piece of 16- or 18-gage wire, where it is joined up with the collector, as can be seen in Fig. 7-29.

Clip on your diode detector for power checks and

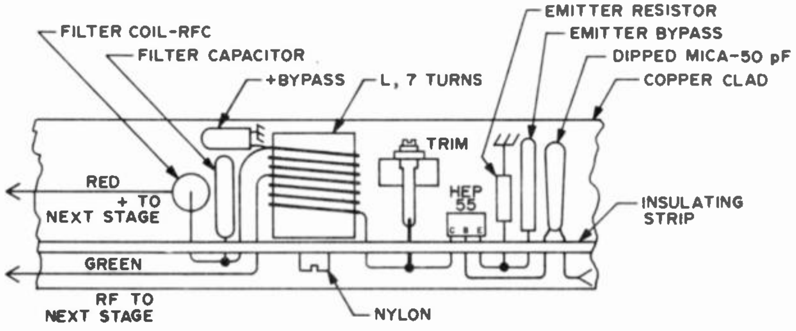


Fig. 7-29. 24 MHz tripler wiring diagram.

frequency. After testing for power control and noise, you are ready for the next stage, a doubler.

The Doubler to 146 MHz

This stage uses a Motorola HEP 75 (2N3866), always a lively powerful one for VHF. The schematic, shown in Fig. 7-30, is similar to the others except for the different transistor and another coil tap. The base input capacitor worked out at 25 pF maximum, with a 39Ω emitter resistor to keep the power up for maximum input into the final stage. The collector lead is cut off and the collector connection is made by soldering a 1/8-in.-wide soft and thin copper strap, which increases the heatsinking as well as rf conduction, directly to the HEP 75 case.

Clean the case well by scraping at the place to be soldered. Use small solder, a small iron, rub the iron gently on the case two or three times for about one second only

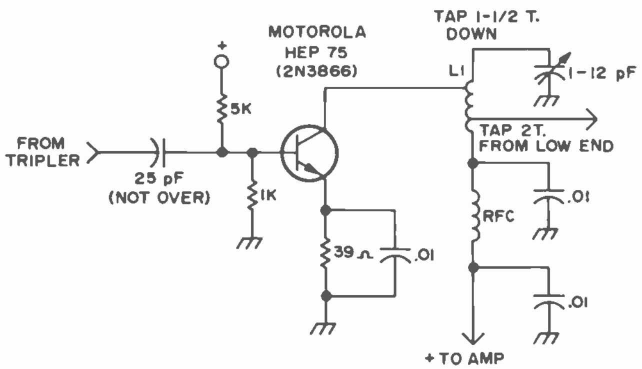


Fig. 7-30. 73 MHz doubler schematic.

to effect a good joint for the collector strap over to the coil. The inductance is not actually critical but should be correctly tuned up and tapped for the collector as well as the output tap.

You could use a little larger emitter resistor, for a little less current, but here again power is a point to watch. I find about 50 to 120 mW of rf at 146 MHz at the output tap, depending on the plus voltage also. Of course, you can play around with up to 18V if you want to push out a bigger signal. Before buttoning up this stage, check it once more for frequency.

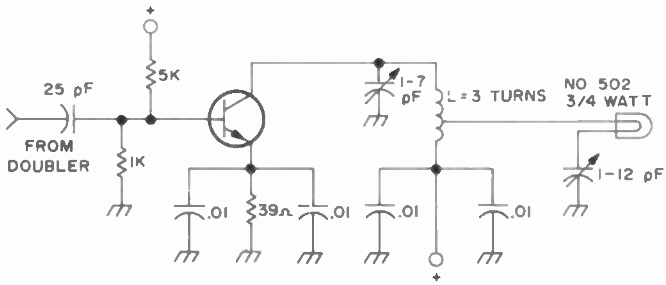
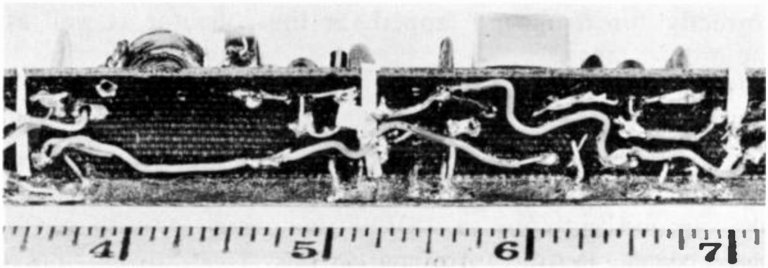


Fig. 7-31. 146 MHz amplifier schematic.

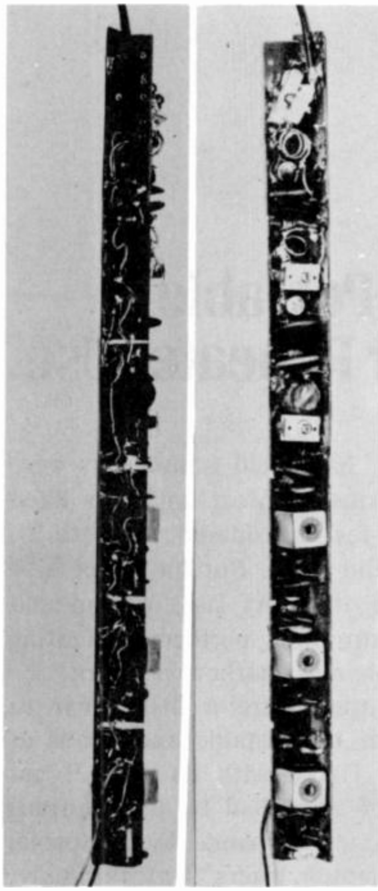
Power Amplifier

Refer to Fig. 7-31. Everything went along nicely with this one also, as in the previous stage. You will note a nice feature, true of most electronic circuits that are good and foolproof, that when everything is tuned up correctly and matched properly the whole stage becomes less critical all around. That is, the tuning is not touchy, the power goes up and down nicely, and even the output tap is not too critical. Note that with small emitter resistors of under 50Ω the collector current can get pretty high, so always keep at least 10Ω in series, as you test for the best emitter resistor value. Don't forget that 1W is 100 mA at 10V. And for a watt out you will need more than 100 mW even at 15V. "Big" transmitters (50 watters) use as low as 0.1Ω at times in this place, and in some of the new heat-sunk jobs (out of our price range) the emitter goes directly to ground.

Currents of not over 100 mA should be used for this stage. The arrangement shown uses about 50 to 60 mA, depending on drive from the tripler, B+ voltage, and output loading.



Closeup of wiring side of insulated strip.



Complete receiver strip. Size: 3/4 x 9 in.

Blowup view shows degree of miniaturization.

Two bypass capacitors are used in the collector circuit. A test bulb (5V at 150 mA), in series with a 1–12 pF trimmer to ground, indicates rf output and loads the collector circuit. Without the test bulb or any antenna loading you can expect self-oscillation as the HEP 75 gives plenty of action on 146 MHz. The output tap can be led into the small but good and very useful 50Ω cable (RG-174/U). This cable will then go to your changeover switch or relay for the final assembly.

As a final note on the transmitter, each tuned circuit of the multipliers and finals should also be adjusted while listening to the carrier modulation.

Low-Cost Portable Transmitter for Repeater Use

Until the "age of repeaters" hand-held transceivers were more or less items of curiosity. Most amateurs liked the idea of owning one, but few considered them to be worth the effort required to build them. But the propensity of VHF repeaters changed all that. At last, a hand-held low-power transmitter could turn in a performance rating just like the big jobs. So a whole new market was born.

The commercial manufacturers were a little slow to develop tiny transceivers – with the notable exceptions of Varitronics with its HT-2 and Drake with its TR-22; and the vacuum in this new market was filled by used surplus hand units made for the commercial bands by Motorola, GE, and a handful of other manufacturers. Unfortunately, the demand exceeded the supply, with the result that hand-held two-way units are a great deal more expensive than they should be. But the amateur is not bound to the surplus counter. He can, without a great deal of trouble and expense, build his own units.

For around $20, a fairly sensitive and very small receiver can be purchased new (Allied Radio Shack, Lafayette, and other sources). But transmitters are not so readily available. This chapter describes the construction of a miniature transmitter that should be an ideal companion to one of the low-cost tunable VHF receivers mentioned above. And it should prove its real worth when used with a local repeater facility.

The unit described here was designed by Cliff Klinert (WB6BIH), whose article, *A 2m Minitransmitter for Re-*

peater Use, appeared in the December 1970 edition of 73 Magazine. Figure 7-32 shows the schematic of Klinert's transmitter, which is as straightforward as a homebrew construction man could ask for.

For operation on 146.94 MHz, the transmitter oscillator uses a crystal of 18.29250 MHz. This fundamental frequency is multiplied by a factor of eight to produce an output on the repeater input channel.

A Motorola Varicap is used to modulate the oscillator, giving true FM rather than the phase modulation typical of most available two-way units. There will be no detectable difference, by the way, between frequency modulation and phase modulation.

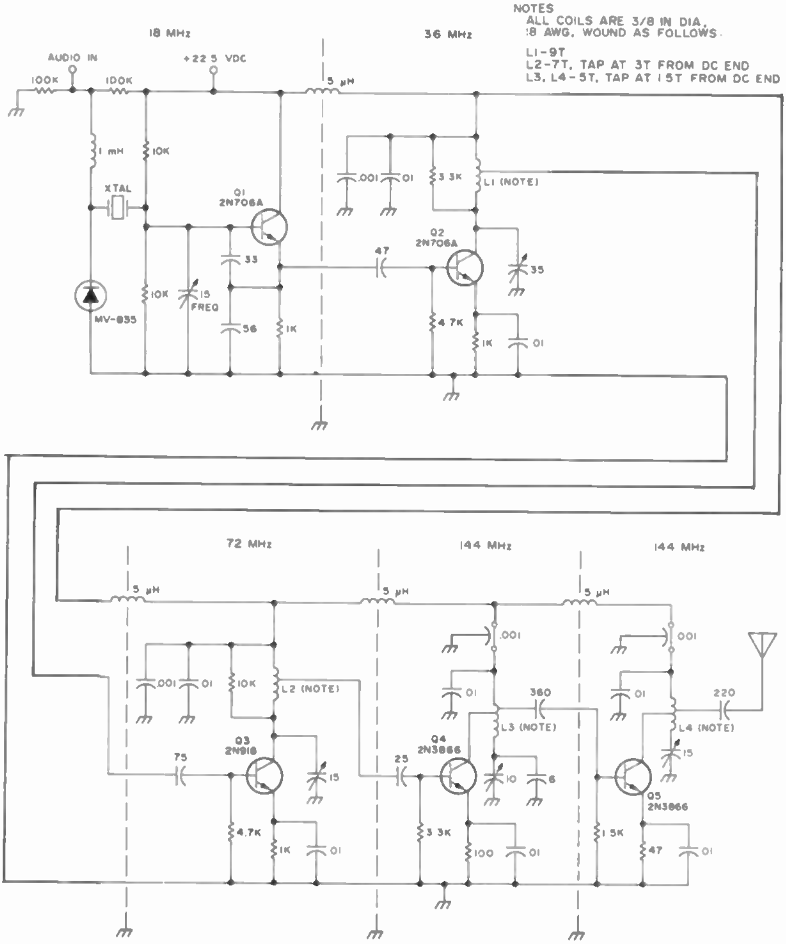


Fig. 7-32. Schematic.

With an audio input of about 22.5V peak-to-peak (maximum bias on the diode from the power supply), the deviation is a little more than the 5 kHz at the output frequency.

A few notes about the crystal should be made: The crystal must be a "fundamental" cut to work in this circuit. An overtone crystal will oscillate on its fundamental frequency, and will be different from its marked frequency. The crystal load capacitance in this circuit is about 20 pF and this should be noted in the crystal order. A general-purpose type crystal (0.01% error) might be satisfactory, but a commercial-standard 0.001% crystal was ordered by mail, and quickly tweaked down on frequency with the 15 pF trimmer.

The three stages following the oscillator are all conventional common-emitter, LC-coupled doublers. While operating, they are driven into class C. Interstage matching is accomplished by trial-and-error tapping of the coils.

The use of ordinary resistors in the base bias circuit was found to be most successful. This avoids the resonance problems when chokes are used. Large capacitance (0.01 μF) bypass capacitors were used to minimize the chances of low-frequency oscillation. Since the gain of the transistors increases at lower frequencies, it is possible to have low-frequency feedback paths that have been overlooked while concentrating on the VHF circuitry.

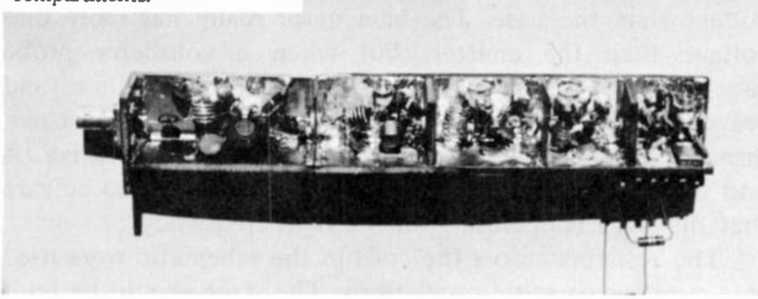
Using the coil in each stage for the dc return to the collector not only simplifies design, but provides a low-impedance collector return for lower frequencies that would not be possible if choke-and-capacitor coupling were used.

The final transistor can be driven to as much as 2W dc input in this circuit, but was held to one watt to reduce heat. Power can be adjusted by changing the value of the emitter resistors in the multiplier stages, and changing interstage coupling.

Construction and Tuning

Simply having a schematic available does not mean that it will be easy to build a transmitter. Construction is very simple, but making it work will occupy the majority of the time. Since all transistors are different and any two transistors with the same number can have widely different impedance and gain parameters, the tuned and coupling circuits will require extensive adjustment. Many of the values in the schematic will probably be a little different in different transmitters.

Considerable experience as well as appropriate test equipment is required for the tuning and tweaking. A grid dip oscillator is a must, and a general-coverage receiver that can cover all the frequencies between the oscillator and final output is always handy. An swr bridge or power meter that works at VHF is necessary for tuning for output power, as well as all the other tools and test equipment that are usually available in the average shack.



Photograph of the complete minitransmitter strip. Note how stages are shielded into "compartments."

The circuit was laid out on a double clad printed circuit board that makes a very simple arrangement. Small Teflon standoffs were glued to the board with epoxy to provide a place to solder the transistors. Details of the construction and parts to be used will mostly be left to the individual builder.

Small dipped mica capacitors are used for interstage coupling. Other than the feedthrough bypasses, disk ceramic capacitors are used for bypassing.

The transmitter should be built one stage at a time, starting with the oscillator. Each stage should be checked and tuned as it is built. The oscillator will be easy because there is nothing to tune but frequency adjustments, and the circuit is very easy to get working. Check for output while listening to a receiver tuned to the crystal frequency. Adjust the two resistors that provide the bias to the varicap to put the diode voltage at about 10V measured at the diode–crystal connection with a VTVM or oscilloscope.

An audio signal voltage can be applied at the "audio in" point in the schematic. Make sure that the audio source is isolated with a series capacitor to prevent affecting the diode bias. A maximum of about 20V peak-to-peak can be applied here. A preassembled imported audio amplifier can be used for modulation, or an amplifier can be built to fit individual requirments.

Tuning the multiplier stages can be accomplished by measuring the emitter voltage of the following stage while tuning the preceding one. Voltage across the emitter resistor measures emitter current, which is a measure of rf drive. To determine that the stage is operating class C, compare the emitter and base voltage. The emitter should show more voltage than the base. The base never really has more bias voltage than the emitter, but when a voltmeter probe touches the base, it partially shorts out the rf there and reduces or eliminates drive. Since the emitter is bypassed, measuring emitter voltage has no effect on the rf drive. A grid dip meter must be used for the final tuning to be sure that the stage is operating on the right frequency.

The resistors across the coils in the schematic were used as a cure for parasitic oscillations. The stage should be built without the resistor first, and then resistors can be added when instability occurs. A grid dip meter can be used to detect parasitics and oscillation, but an AM general-coverage receiver is much more sensitive.

Adjusting the output stages is just a matter of changing taps on the coils while watching for transistor overheating, checking for parasitics and oscillation, and retuning each time for resonance. Also be sure to check that the right harmonic is being tuned for on the grid dip meter used as a wavemeter.

Leave a TV set turned on; it will let you know when oscillation breaks out. Watch channel 8; the 36 MHz signal tends to come through the 72 MHz doubler, and multiply five times in the 144 MHz doubler to cause TVI on this TV channel. A 36 MHz series-tuned trap might be used at the collector of Q3 as a last resort, but with proper tuning this should not be necessary.

Conclusions

This transmitter has provided good results in the final analysis, but there are problems and changes that could be worked out. The thing is quite difficult to tune and clean up, and some kind of standard chassis, housing, shield, board, or whatever should be designed to provide ease of mechanical construction and duplication, rf shielding, and mechanical strength. Double-tuned, inductively coupled interstage circuits might be used to provide better selectivity.

UHF Transmitter

The information in this chapter was contributed by Wilfred Collier (WA1HVG), whose article, *450 MHz Remote Site Transmitter*, was published in 73 Magazine, May 1971.

Many of the repeaters now being built are using 450 MHz for control or auxiliary inputs. Unfortunately, most of the gear available for use on 450 is either antiquated or expensive.

Both Motorola and GE use tubes in the power amplifier stages of these transmitters – tubes that cost many dollars each, and need replacement about once a year – or even more frequently, depending on use and power output.

The 450 band is looking more and more attractive for ordinary repeater operation nowadays, anyway – particularly in view of the heavy crowding in the 2 meter spectrum. Probably if more people were aware of the good coverage achievable on UHF, there would be a stampede for the 450 band by those closed repeater groups so active on VHF.

Path Loss

One factor that adds up quickly in the UHF spectrum is path loss. On 450 MHz, the ability to use a repeater 40 miles away just may be governed by how many trees your signal

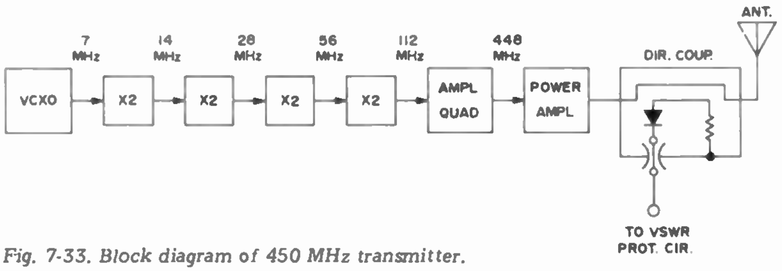


Fig. 7-33. Block diagram of 450 MHz transmitter.

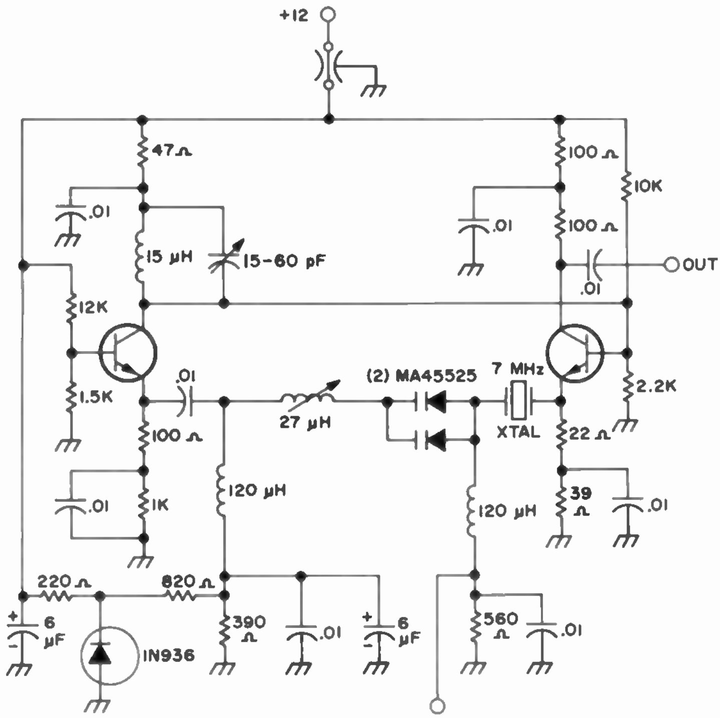


Fig. 7-34. Variable crystal-controlled oscillator circuit.

must pass through to reach the repeater site. The path loss on 450 is not greatly higher than that of the 2 meter band over average terrain for a given distance. To maintain a 99% reliability factor, the system must be set up for a 30+ dB fade margin.

Example: If the 450 receiver has a −115 dBm (0.4 µV) sensitivity for 20 dB of quieting and the transmitter is 40 miles away running 10W output (neglecting feedline losses and antenna gains, which ultimately must be added in), the fade margin is:

10W	= +40 dBm
rec. sens.	= −115 dBm
difference	= 155 dB
path loss	= 160 dB
difference	= 155 dB
fade margin	= −5 dB

In other words you may *just* be able to use the system, but only occasionally will your signal be full quieting; most of the time you will be noisy into the 450 receiver.

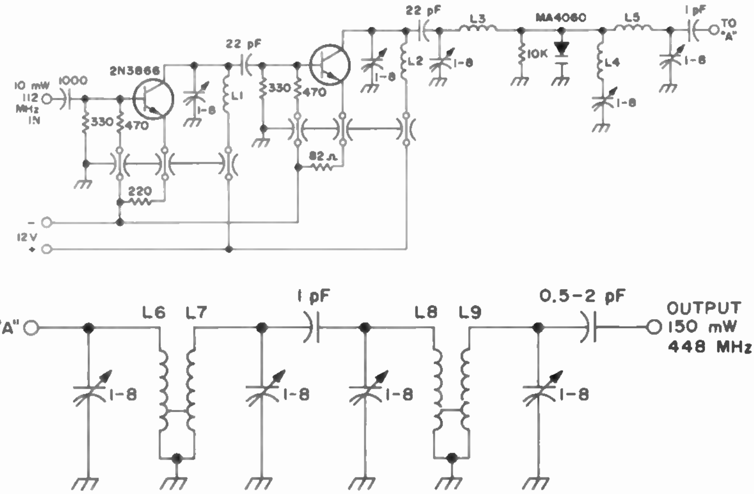


Fig. 7-35. Multipler stages of UHF transmitter. A 10 mW input signal is quadrupled to 448 MHz, at a power level of 150 mW.

Now let's look at an accurate case.

5W out	= +37 dB
feedline loss	= 3 dB
ant. gain	= 17 dB
total	= +51 dBm = 125W radiated power
Rx sens/20 dB	= –115 dBm
feedline loss	= 3 dB
antenna gain	= 17 dB
total sens	= –129 dBm

Fade margin = 51 + (–129) = 180 – 160 = 20 dB margin.

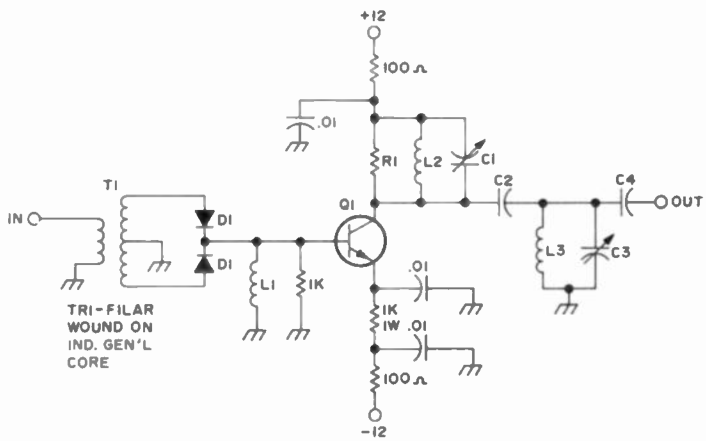
This means that 99% of the time your signal will be full quieting at the 450 receiver.

Transmitter

As shown in the block diagram of Fig. 7-33, the design of this transmitter is straightforward; and it is easy to build and tune. Deviations from values upwards of 10% will not affect the operation; however, it is recommended that no changes be made in the transistor or diode types shown.

The oscillator (Fig. 7-34) uses a 2N3866 and a 2N3904 in an emitter-feedback configuration. The inductor in series with the crystal is used to match the output signal to the system receiver. The crystal should be ordered to operate in the "series resonance" mode. The oscillator puts out 10 mW.

The multipliers (Fig.7-35) are push-push doublers, and need be tuned only for maximum output. Spurious responses measured better than 37 dB down from the signal in all cases when the multipliers were tuned for maximum output. Each stage is designed for a gain of unity so that the 10mW power level is maintained throughout.



INPUT FREQ	T1 *	D1	L1	L2	R1	C1	C2	L3	C3	C4	Q1
7 MHz	6t-Q1 CORE	1N914	150 μH	15 μH	2.0K	33 pF FIXED	3 pF	6.8 μH	5-18	5 pF	2N3904
14 MHz	6t-Q2 CORE	HP2800	47 μH	2.2 μH	2.2K	10 pF FIXED	3 pF	1.8 μH	5-18	5 pF	2N3904
28 MHz	6t-Q3 CORE	HP2800	6.8 μH	0.47 μH	OMIT	8-25	1 pF	1.0 μH	2-8	3 pF	MPS918
56 MHz	6t-Q3 CORE	HP2800	3.3 μH	0.33 μH	OMIT	2-8	1 pF	0.15 μH	5-18	3 pF	MPS918

* INDIANA GENERAL CORE MATERIALS SHOWN

Fig. 7-36. Basic UHF transmitter doubler block.

The power-amplifier quadrupler stage (Fig. 7-36) consists of two 2N3866s as amplifiers, a varactor multiplier, and a bandpass filter. The output of this stage is at the 100 mW level, and can be monitored on an FM receiver.

The final amplifier (Fig. 7-37) uses a 2N3866 and a pair of 2N3375s to achieve 5W output. A vswr protect circuit (Fig. 7-28) is included to add to the life of the output stage. The unit will not be damaged if the antenna is accidentally open or short-circuited.

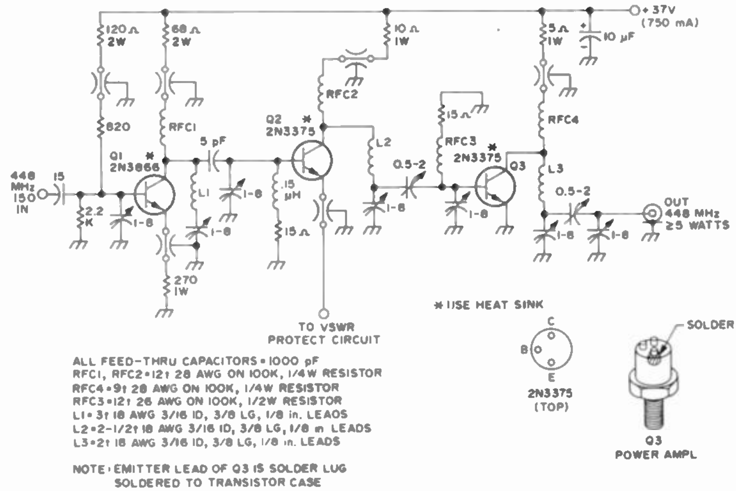
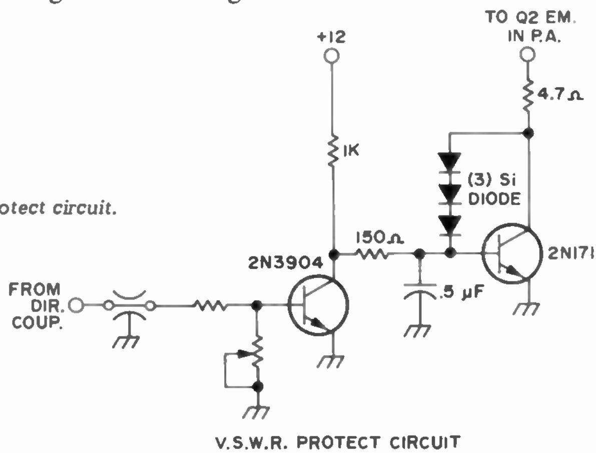


Fig. 7-37. RF power amplifier stages. With a 150 mW input, a signal of at least 5W is produced.

Layout

All leads in both the quadrupler and the power amplifier must be *short*. A ½ in. piece of 20-gage wire makes a reasonable choke at this frequency! Also, all of the transistors in these stages *must* have good heatsinks.

Fig. 7-38. Vswr protect circuit.



Tuneup

Apply power to the oscillator only and check the frequency with a good stable receiver. The note produced with the bfo on should be pure and stable.

Apply power to each succeeding stage, tuning each for maximum power output. Output frequency should be checked after each stage is tuned. Each stage should be checked for stability after it has been tuned by removing the crystal from the oscillator. All output should disappear in all stages. If by chance it does not, isolate the problem stage and decrease the value of the collector resistance until it becomes stable.

The power amplifier should be tuned with only 20V applied at first. Tuning in these stages is affected by both supply voltage and drive level; 2–3W output should be seen with a 20V supply and 100 mW drive.

The only really critical part of the coupler is that it have sufficient directivity, or the transmitter will shut off. The coupler can be checked by using a 450 source such as a signal generator and a good load. Reversing the coupler should make an order of magnitude change in the voltage as shown in the diagram of Fig. 7-39.

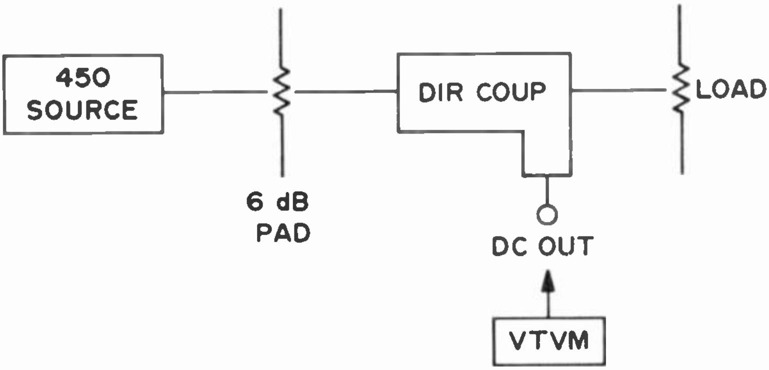


Fig. 7-39. Reversing the coupler should make an order of magnitude change in the voltage.

Loads

If you don't have a good load for 450, then use 200 ft of RG-58/U and terminate it with a 2W 51Ω carbon resistor. This load will handle up to 60W input at 450 MHz!

The power supply (Fig. 7-40) has proved quite adequate for the 450 transmitter, but it does require effective heatsinking.

If built as described, this transmitter will maintain 5W output (continuous operation) for a long, long time. It should outlast any tube-type transmitter by a wide margin.

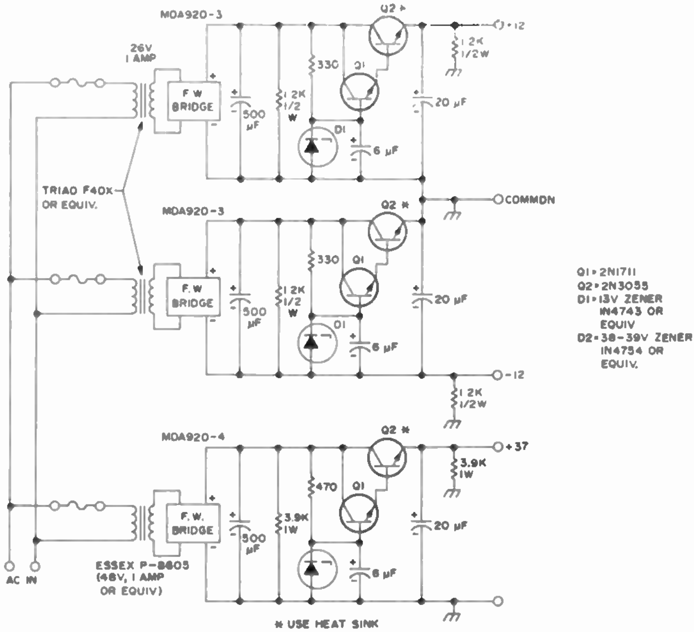


Fig. 7-40. Solid state power supply for 450 MHz transmitter.

UHF Superregen Receiver

The circuits and much of the text
in this chapter were abstracted from a
July 1970 73 article by E. R. Davvison:
450 MHz Mighty Mite.

This chapter describes a simple transistorized UHF super-regenerative receiver which works nicely at 420–450 MHz. This circuit (Fig. 7-41) provides exceptional sensitivity. If your hearing is good, you may connect a pair of earphones directly to the circuit, although the level of audio is quite low. The more ambitious may, or course, build up a small audio amplifier, borrow one from an old transistor radio, or use an RCA CA3020 integrated circuit audio amplifier.

The transistor used is a Fairchild 2N4916, which costs less than a dollar. This transistor is an excellent low-cost device featuring a beta of over 150 at 450 MHz.

No special parts have been used and the only problem area may be the choke in the audio output lead (RFC2). You can use the secondary of a driver transformer from an old transistor radio for this, but a choke closer to 30 mH would probably be better.

A "gimmick" capacitor (twisted leads) can be used to tune the circuit to a specific frequency. This will also eliminate the work involved in providing an insulated shaft for a small variable capacitor. Other means are available for tuning this simple circuit, such as by shading L2. This would provide a means of covering a spread of frequencies but would make the receiver more complex mechanically.

Figure 7-42 shows the foil side of the printed circuit board and Fig. 7-43 shows the component side. The tank coil L2, was made from printed circuit board; its size and shape is shown in Fig. 7-44.

Again to keep the circuit simple, L1 and L2 are both

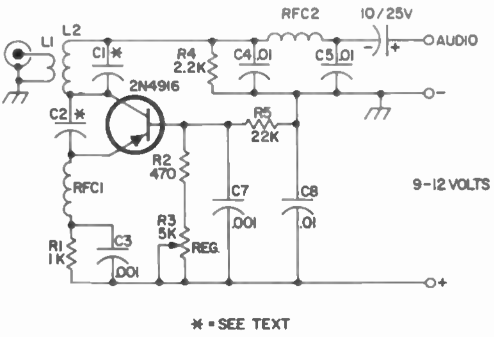


Fig. 7-41. Schematic diagram of the superregenerative receiver for the ¾ meter band.

soldered to the foil side of the board. The more ambitious builder could make slots in his main board to accept L2, so that it would be on the parts side of the board. L2 is soldered perpendicular to the main board with the foil side facing L1.

L1 consists of 1½ turns of hookup wire (3/16 in. ID) spaced approximately ¼ in. from L2 and parralel with it.

C1 is a gimmick capacitor made from two ¾ in. lengths of hookup wire and twisted together. This provides sufficient capacity for oscillation, but is still small enough not to lower the frequency of the tank too far.

C2, also a gimmick capacitor, consists of two 3½ in. lengths of hookup wire twisted to achieve the frequency of interest. If you take this approach, you might try shorter lengths (such as ½ in.) and try various fixed capacitors, starting at about 1 pF. The total capacity required depends on such factors as output capacity of the transistor used, feedback capacity, and closeness of L2 to the chassis.

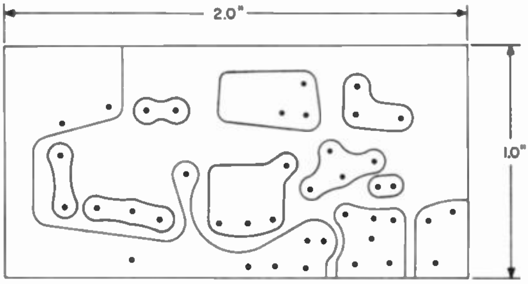


Fig. 7-42. PC board, foil side.

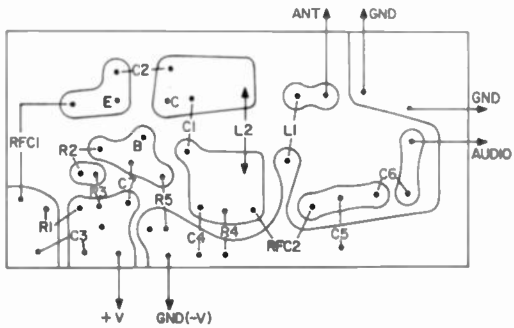


Fig. 7-43. Suggested PC board layout for the receiver.

RFC1 consists of 4½ turns of 16-gage enamel wire wound on a ¼ in. slug using an AM oscillator coil from an old transistor radio.

After the circuit is built, connect a pair of earphones or an audio amplifier and apply power. If no hiss is heard, slowly adjust the potentiometer until the hiss is heard. The most sensitive position is where oscillations just occur. Try adjusting the spacing of L1 and L2 for sensitivity as well.

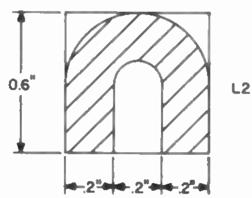


Fig. 7-44. The tank coil (L2) is made from PC material.

PART VIII

Special Repeater Circuits

Repeater Zero Beater

by Paul Hoffman W1ELU and Ray Pichulo W1IRH

One of the biggest problems with an FM repeater is getting everyone's transmitters exactly on frequency. It is even more important with a narrowband input; yet, since most hams do not have ready access to a frequency meter or counter, it is rather difficult to do. This article describes a device that uses the repeater's receiver as a reference and makes it both convenient and easy for everyone to get on frequency. It is as accessible as the repeater, and in effect, is the same as having someone always monitoring the repeater receiver's discriminator voltage and giving back the reading after each transmission (but without the basic personnel problem). Since it is always there, it allows anybody using the repeater to see how well his rig is staying on frequency.

The device is called a zero beater because it produces an audio tone which behaves in exactly the same way as a heterodyne (although it is not). The zero beater operates by monitoring the repeater receiver's discriminator voltage during a transmission and storing a representative voltage in a capacitor. When the transmission is completed, this voltage is converted to a tone, which is transmitted during the repeater's tail period (approx. 1 second). All it takes then, is two seconds to check frequency; a one-second transmission to establish the frequency, and one second to listen to the tone. If the frequency is less than 1 kHz off, no tone will be heard. Each time the repeater is keyed, the process repeats, up to 15 seconds of repeater use. Then the zero beater is disabled until the repeater is idle for 15 seconds or more. (The disabling feature was added after the zero beater was installed because the squeaks and squawks tend to become objectionable with excessive use.)

Operation

The zero beater is built on a 4 in. square plug-in board and requires ±15V for operation. Referring to Fig. 8-1, which is a schematic of the completed device, the receiver's discriminator voltage is applied through a resistance of 100 kΩ to the noninverting input of opamp A1. The operation of A1 is bipolar so that the polarity of the output voltage will swing positive or negative to follow the polarity of the input voltage. The output of A1 is applied simultaneously to the inverting input of A2 and to D2. The output of A2 is applied to D1. When the output voltage of A1 is positive, D2 conducts and the output voltage is applied across C2 (when Q3 is normally cut off).

When the output of A1 is negative, D2 is back-biased and therefore disconnected, while the output of inverter A2 now swings positive, forward-biasing D1, and voltage appears across C2. Because of the operation of D1 and D2, the voltage appearing across C2 is always positive regardless of the input polarity.

The output of A3 drives Q1, which in turn drives a CK1122 "Raysistor." The Raysistor consists of a tungsten

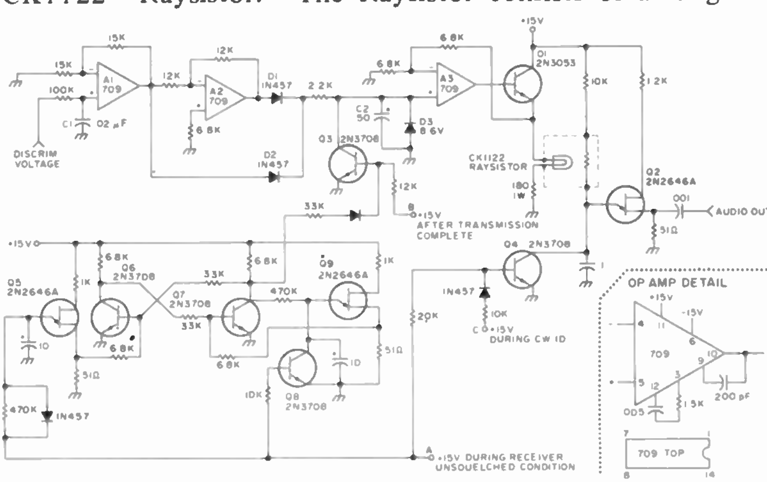


Fig. 8-1. Off-frequency tone generator.

filament lamp and a cadmium-sulphide photoresistor in the same package, with the lamp illuminating the photoresistor. The 8.6V zener (D3) across C2 prevents the voltage across the lamp from becoming too high. The photoresistor portion of the Raysistor is used as a frequency determining component in a unijunction oscillator circuit (Q2).

The dark resistance of the photoresistor is high enough to prevent Q2 from oscillating. As its resistance decreases, the frequency of Q2 increases up to about 2 kHz. While a signal is being received, the frequency error seen at the discriminator is stored by C2 and, through A3 and Q1, illuminates the Raysistor lamp. At the same time, the positive voltage (A) applied to the base of Q4 causes it to conduct, shorting the emitter of unijunction Q2 to ground and preventing it from oscillating. As soon as the receiver no longer hears a signal, Q4 shuts off and allows Q2 to oscillate. During the repeater tail period, then, the tone is transmitted back. As soon as the repeater transmitter is unkeyed, a positive voltage (B) applied to Q3 causes it to conduct, discharging C2. C2 must be discharged in this way because of the high input resistance of A3.

The remaining circuitry comprising Q5 through Q9 is a "timeout" control circuit which disables the zero beater after 15 seconds of repeater use and reenables it after the repeater has been idle for 15 seconds or more. Q6 and Q7 form a flip-flop which is set or reset by Q5 and Q9. Both Q5 and Q9 are 15-second timer circuits.

Steering control for the flip-flop is accomplished by Q8, which shorts out the timing capacitor of Q9 when the repeater is in use. After the repeater has been in use for 15 seconds or more, Q5 completes its timing cycle and discharges the 10 μF timing capacitor into Q6, setting the flip-flop. Then the collector of Q7 goes positive, and the positive voltage coupled to the base of Q3 causes it to conduct, shorting the input of A3 to ground and disabling the zero beater.

When the repeater is inactive, point A goes to ground, Q8 is turned off, unshorting Q9's timing capacitor, and Q9 begins its timing cycle. After 15 seconds, Q9 discharges into Q7, resetting the flip-flop and enabling the zero beater.

External Connections

As shown in Fig. 8-1, the external connections required are power, discriminator voltage, audio output, and three control voltages. The control voltages are connected to points

A, B, and C on the schematic, with the conditions shown. The inactive state of all three signals is ground. In the WA1KFY repeater, the CW identification function is self-completing; in other words, the repeater stays on until the ident has completed. It is necessary to inhibit the zero beat during the ID; otherwise both will play at once. This repeater uses solid-state logic for its control functions; however, the required signals (A, B, and C) may be derived from the COR of a relay-controlled repeater.

Summary

The zero beater provides everyone using the repeater with a continued frequency check. It has proved to be a very effective and useful device. The tone reaches its highest frequency when the input error is approximately 3 kHz or greater. If the error is less than 1 kHz, no output is generated. Since the device uses the receiver's discriminator output, it is important that the repeater receiver's frequency be accurate and stable.

Other uses for the device readily suggest themselves; for example, limiter voltage could be monitored, and the tone would then indicate signal strength. It could also be used as an alarm. In either case, A2 could be eliminated along with D1 and D2, since the input polarity would not change.

Repeater Controller

by W.B.Kincaid WA4YND

The myriads of mechanical contrivances that repeaters inevitably wind up with can be replaced with transistor equivalents . . . with a resulting increase in system reliability and decreases in headaches for the repairman.

After operating an amateur repeater for several years it became quite apparent that the majority of our repeater failures were caused not by a malfunction of either the receiver or the transmitter, but by a failure of the carrier-operated relay (COR), the three-minute mechanical timer, or the *hang-in timer*.

We have been using the standard Motorola tube-type COR with a Telechron drive three-minute timer and an Agastat dash-pot timer for hang-in. We often had trouble with the Agastat mechanically shaking things loose in the repeater and middle-of-the-night wife-type complaints about the noise, particularly when a mobile was putting in a "picket fence" signal at 2 a.m. It's like waking up to a machine-gun.

In an attempt to eliminate the problem associated with these mechanical devices we began to work toward a solid-state system. Our objective was to reliably key the transmitter on both weak and strong signals, without any buckshot, and to provide carrier hang-in, automatic tone CW identification and a three-minute timer. We accomplished this with a Schmitt trigger operating from the change in plate voltage of the first audio amplifier in our GE Progress Line receiver.

The Schmitt trigger requires only a 2V change in a negative direction to switch on properly, due to the regenerative feedback of the direct emitter coupling. (Refer to Fig. 8-2.) Once it has switched, Q3 sees the 8V change on the collector of Q2 and turns on, causing series-connected relays K1 and K2 to close. This circuit and the relays have

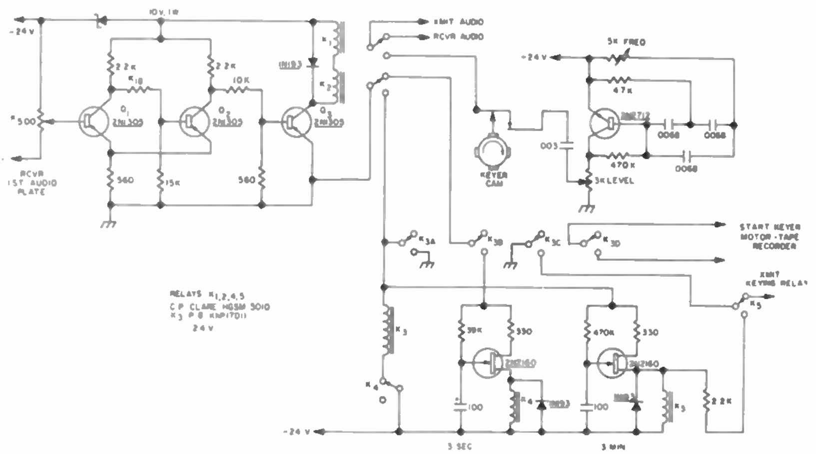


Fig. 8-2. Schematic diagram of repeater controller circuit.

the capability of switching at speeds up to 20 kHz. Once K2 has closed, K3 latches itself closed through contacts K3A. When this occurs, the transmitter is keyed via K5 and K3C.

Since relay K3 is latched closed, when the received carrier drops out it cannot open and let the transmitter turn off; however, when relay K2 opens, voltage is applied to the three-second timer via K3B and K2, which causes the 100 μF capacitor to charge through the 39K resistor. When the capacitor charges to the breakover voltage of the 2N2160 unijunction transistor, it then discharges into the coil of relay K4 causing its normally closed contacts to open momentarily and allow relay K3 to reset.

In the interim period after K2 opens, K1 has switched the transmitter audio input from the receiver to the CW keyed tone for identification purposes. This provides an automatic "ident" every time a mobile releases his microphone. It also eliminates the squelch-tail noise burst from the receiver since the Schmitt trigger will reset faster than the receiver squelch.

In the event an input signal is present in the receiver for longer than three minutes, another unijunction transistor timer – which starts its timing cycle as soon as the transmitter is keyed – will time out and latch relay K5 closed. This shuts down the transmitter until such time as the input signal is removed and the three-second timer times out and resets relay K3. When relay K3 opens, both timers are instantly reset (no waiting for the gears to unwind in a mechanical timer).

The tone oscillator frequency is set to 1800 Hz to allow its use for actuating other devices in the control link system on 450 MHz. A potentiometer can be bridged from the tone oscillator output to the transmitter audio input to provide a 1 Hz deviation of the transmitter on top of the receiver audio. This tone can then be used to key a 450 MHz link to another site.

In our system we utilize a 2 meter receiver feeding a 450 MHz transmitter (which keys a second 450-MHz-to-2-meter transmitter at a remote site). The tone gives us tone control of the remote transmitter as well as automatic identification of both transmitters. We can also control the remote site by use of 450 mHz from our control points; in fact, we occasionally operate crossband to 450 MHz mobiles.

Our repeaters were built by using old, wide-drawer, GE MTS units and replacing the vibrator transformers with ac transformers. The controller mounts where the Secode was installed originally. It makes a nice compact repeater that can be carried in one hand.

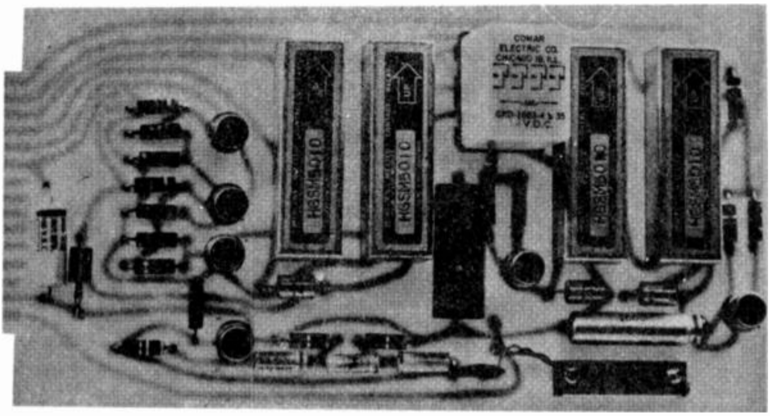


Fig. 8-3. A single circuit board holds all relays and other components of repeater controller.

Construction

The PC board can be laid out by first cutting the board to size and then drilling the required holes at the proper locations. Then, using the *rub-on* PC board decals, the proper circuit layout can be made easily right on the copper. If you

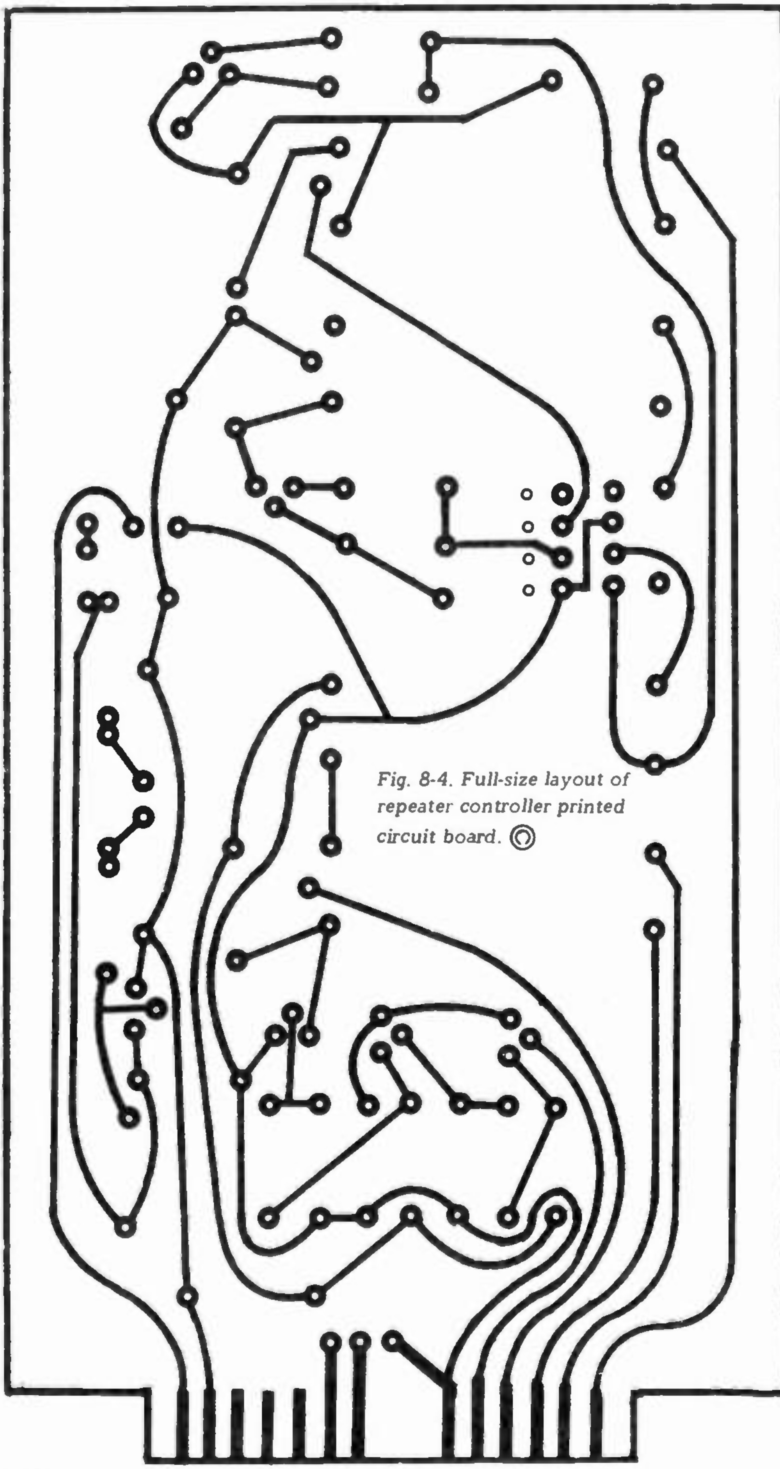


Fig. 8-4. Full-size layout of repeater controller printed circuit board. ©

have relays which are electrically similar to the photo of Fig. 8-3, simply drill holes and position the layout to fit your parts.

After laying the board out, wipe the board with a cotton sponge soaked in mineral spirits to remove the excess adhesive (which tends to ooze out from around the rub-on decals. This will give much sharper lines after etching in ferric chloride. To remove the decals after completion of the etching, we used a piece of steel wool (which also cleans the copper and makes soldering easy).

The board layout (shown full-size in Fig. 8-4) was made to fit an Amphenol 143-015-04 edge connector; however, the wires to the repeater can be soldered directly to the circuit board if desired. It does facilitate servicing and testing the unit if a connector is used. Figure 8-5 is a reduced drawing of the component side of the board.

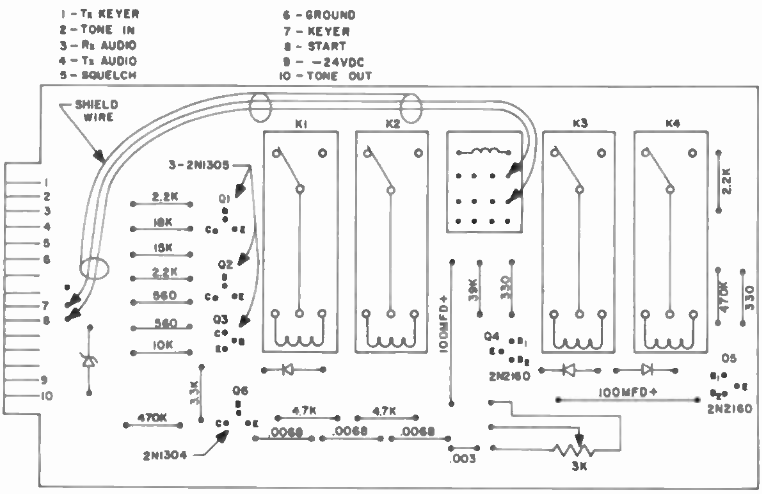


Fig. 8-5. Proportionately reduced sketch of board shows coding for components and wiring interconnects.

The circuit diagram shows a 5K potentiometer in the tone oscillator to adjust the frequency; this is really not necessary unless you are going to use a tone decoder in the system that requires a specific frequency. In our system, we used a fixed resistor selected to produce 1800 Hz. Also, you will note that there are no connections from section D of relay K3 to the edge of the PC board. Since this set of contacts switches commercial 115V power, we found it necessary to use a two-conductor shielded wire directly from the relay to the edge connector to eliminate hum pickup in the transmitter audio.

The controller can also be used in continuous-tone-squelch (CTS, Private Line), repeater systems where it is desired to key the repeater with the continuous tone transmitted by the

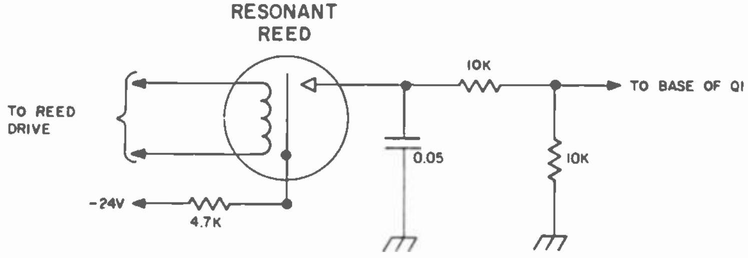


Fig. 8-6. PL-reed interconnections for use with continuous-tone carrier-squelch systems.

mobiles, by using the circuit shown in Fig. 8-6. In this operation, when the reed contacts close, the 0.05 μF capacitor charges to the 24V supply, which is then applied to the base of input transistor Q1. This transistor then operates the controller and keys the transmitter. The time constant of the *RC* network is long enough to prevent the controller from following the momentary-contact closure of the reed. Since some reeds have a tendency to remain vibrating longer than others after removal of the input signal, you may wish to vary the value of the 0.05 μF capacitor as well as the input drive to the reed coil so that the repeater audio will be switched to the tone oscillator input in as short a time as possible after the tone input is removed from the reed. This will prevent receiver squelch noise from being transmitted momentarily at the end of each mobile transmission. This problem is minimized if your mobiles are equipped with a squelch-tail eliminator circuit, which provides a short burst of tone 180 degrees out of phase with the normal transmitted tone at the end of each mobile transmission, thus providing a damping action on the reed relay to stop its vibrations.

A Solid-State 10-Minute Timer

by Walt Pinner WB4MYL

This 10-minute solid-state station timer is a simple economical, one-evening project whose application is only governed by your imagination. An indicator is illuminated by a *set* button and burns for 10 minutes before extinguishing, thereby reminding you longwinded ragchewers or break-in operators to identify as required by the FCC. The unit, made up of 11 components, is installed inside my SB-100 transceiver with the indicator lamp located behind the main tuning dial, where it is readily visible (eliminating the need for hole drilling).

As shown in the circuit diagram (Fig. 8-7), the heart of the unit is a MOSFET which gates an inexpensive SCR to turn on

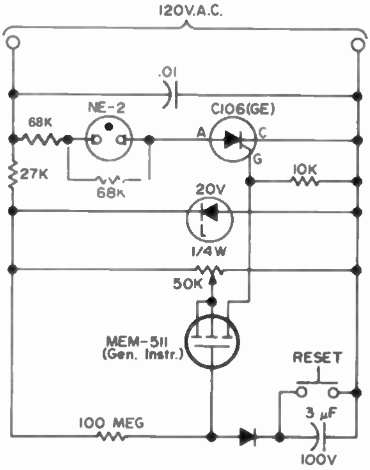


Fig. 8-7. Schematic diagram of the MOSFET 10-minute timer.

an indicator lamp (or, if you prefer, energize a relay). Voltage pulses are applied to the transistor and the RC timing circuit, 100 MΩ low-leakage diode, and a 3 μF 100V capacitor.

When 6V appears at the capacitor, the FET is turned off, turning off the SCR and the indicator lamp. Pressing the *set* switch discharges the capacitor, recycling the circuit for an additional 10 minutes.

Because the circuit is line-operated, all components should be isolated from the chassis. In view of the high impedances involved do not attempt to measure voltages, as any but the most sophisticated test equipment will load the circuit.

Caution . . . The FET is supplied with a shorting wire around its leads; this should remain in place until the transistor is soldered in the circuit.

Precise timing is adjusted with the 50 kΩ pot, which will compensate for component tolerances. Any neon panel

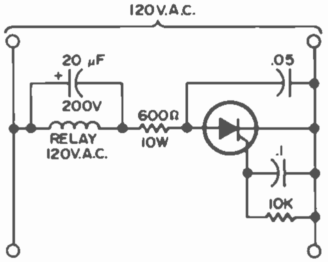


Fig. 8-8. A relay and associated filter network may be used as shown for switching loads in excess of 2A.

indicator with a built-in resistor can be used in place of the NE-2 and 68 kΩ resistor. Color the bulb to contrast with existing panel lighting. Should you wish to power other dc loads up to 2A merely substitute your choice for the lamp. For loads in excess of 2A, the NE-2 may be replaced by a 115V ac relay with a series 600Ω 10W resistor and filter (Fig. 8-8).

The 600Ω resistor limits the direct current through the ac relay to a safe level, and the 20 μF capacitor insures that the relay will remain on during the half-cycle the SCR is off. The reset switch may be any unused contacts on your rig, such as spare positions on your 100 kHz calibrator switch. It may also be convenient to replace a control with one having a pull switch, thus eliminating the need for hole-drilling should you wish to preserve the original appearance of your equipment.

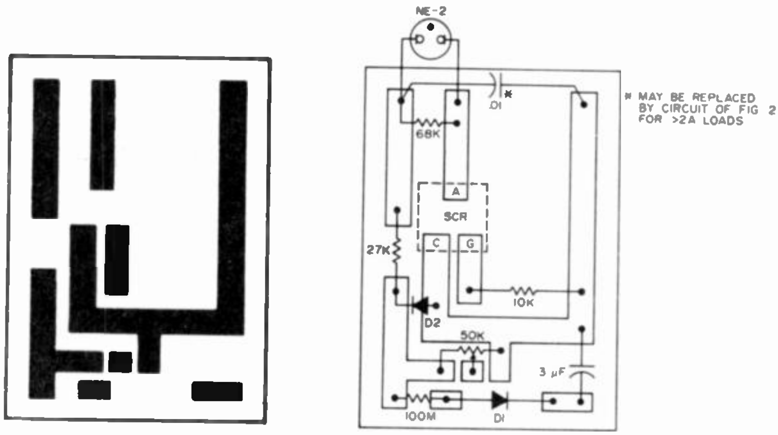


Fig. 8-9. Layout is shown actual-size alongside a composite view which gives component placement data.

Wiring is not critical and a circuit board (full size) is shown in Fig. 8-9. After soldering, it is suggested that all connections on the board be cleaned with a solvent such as nail polish remover to eliminate leakage via flux, etc. The zener and low-leakage diode were obtained from surplus boards. The SCR is not critical, and any type with 120V ratings that will trigger at 0.8V is acceptable.

Repeater Audio Mixer

by Paul Hoffman W1ELU and Ray Pichulo W1IRH

The audio mixer described, although designed primarily for repeater use, can be used anywhere it is desired to mix a number of audio inputs with a high degree of isolation between inputs. The mixer is adaptable to almost any configuration which may be required to suit the individual's requirements. The number of inputs can be increased by a factor of two or three to suit the user's needs. The isolation between individual inputs of over 40 dB makes it possible in repeater operation to have tone command information on one channel not be affected by another input. The mixer shown is the one designed for use in the WA1KFY repeater. It has eight inputs – three of them squelched, the other five continuously on.

Operation

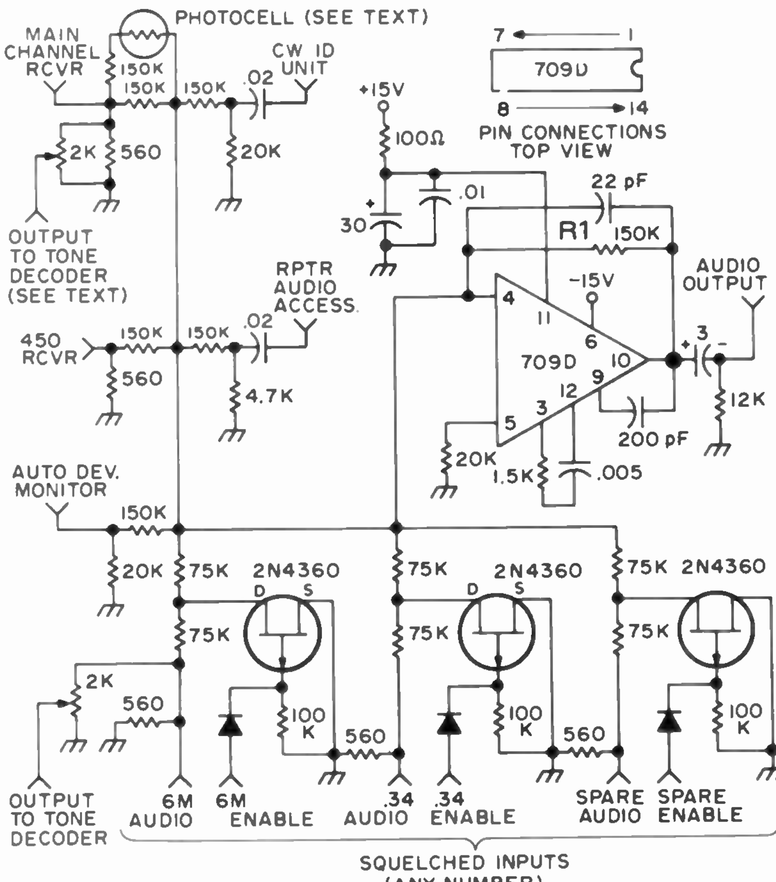
The amplifier uses a single 709D opamp plus one FET for each squelched input. The audio inputs as shown in Fig. 8-10 are applied to the opamp's inverting input. The output is fed back through 150 kΩ resistor R1. Notice that the signal from each input is applied through 150 kΩ also. The resultant voltage at the input terminal of the opamp is the combination of the input signal plus the out-of-phase feedback voltage. Since both are applied through equal series resistances, the resultant voltage is zero. This condition results in the opamp's having an extremely low (almost zero) input impedance. This resultant low impedance, together with the high series resistance on each input, accounts for the high degree of isolation between inputs. The squelched inputs use a FET across each input as a switch. With zero volts on the gate, the FET exhibits a drain-to-source resistance of about 350 Ω effectively shorting its associated input to ground. When +15V is applied to the gate, the FET switches off, enabling the input channel. The 75 kΩ resistors between each FET and the input bus prevent the input bus from being shorted by the FETs.

The gain of the opamp is determined by the ratio of the feedback resistance to the input series resistance. In this case, the gain on all the inputs is unity. If more gain is desired on a particular channel, the input resistance can be lowered to change the ratio (and therefore the gain). For example, it was found necessary to increase the gain from the main channel receiver when the phone patch was connected in order to increase the level into the phone line. (The phone patch does not load down the output; rather, the gain had to be raised in order to properly drive the line.) The gain change is accomplished by a photocell–lamp assembly, with the photocell in series with a second 150 kΩ.

The frequency response of the amplifier is essentially flat from dc up to about 8 kHz. Beyond that point, it rolls off. The 22 pF capacitor across the feedback resistor determines the rolloff frequency characteristic. The audio output voltage swing can go as much as ±10V. This is more than ample to drive 10 or more high-impedance inputs. The audio amplifier in WA1KFY is presently used to drive three transmitters, a phone patch, and a monitor earpiece. The number of inputs can be expanded to suit individual requirements. The unsquelched inputs require only an additional 150 kΩ series resistor and load resistor for each leg. The squelched inputs each require an additional FET switch in addition the load resistor and series resistors.

The opamp requries 15V (positive as well as negative) to operate it. The current requirements are approximately 30 mA. The components shown in the detail schematic (1.5 kΩ 0.005 mF, and 200 pF) are used to compensate the amplifier against instability. The 100Ω resistor, 30 μF capacitor and 0.1 μF capacitor on the +15V line form a decoupling network.

Two trimpots at the top edge of the board (see photo) are used to provide audio outputs for tone-operated command functions. They are connected across the load resistors of the six meter receiver and the main-channel two-meter receiver as shown in Fig. 8-10. The arms of both pots connect to pins on the edge connector and go off the board to their associated tone decoders on another board. These pots are mounted on the audio mixer board as a matter of conven-



Notes:

1. Resistance values in ohms, capacitance values in microfarads unless otherwise noted.
2. Diodes are IN457'S.

Fig. 8-10. Audio summing amplifier.

ience and would not be used if it is not required to bring audio to another point in the system for tone command or other functions. The photocell–lamp assembly for gain changing on the main channel input is on the right side of the board. Similarly, it could be deleted if this feature is not required.

Summary

This audio mixer provides the repeater owner a high-quality audio mixer system which has minimal space and power requirements. It is especially attractive for use in more sophisticated repeater systems where several receiver/transmitter combinations are used. However, if the same construction techniques as those described in this article are used, it is just as good to use with a simpler repeater system because there is more than adequate room for expansion at a later time.

PART IX

What The FM Market Holds

The Amateur FM Market

One of the most important elements of amateur growth in recent years has been the advent of the VHF FM repeater. The result of this development has been nothing less than a vital shot in the arm of amateur radio, even though not quite of the magnitude required to sustain the whole industry. American manufacturers, by experience wary of "fads," stood by while Japanese imports snatched a huge chunk of the FM equipment market, which was being shared only with the purveyors of used commercial surplus equipment. But as the surplus market dried up and the demand for more FM gear continued, American manufacturers began responding.

Keenly watching the unprecedented success of Varitronics, Incorporated, the U.S. industry was determined to gain a foothold. Varitronics offers a line of Japanese imports at prices that are typically American, so the profit margin was wide enough to warrant a few cautious incursions into the apparently lucrative field. Besides, according to some of the recent manufacturing newcomers, there was nothing to lose – because VHF FM is virtually the only aspect of ham radio that is exhibiting any growth at all.

The first of the American firms to try for the FM market was International Communications and Electronics Company, a small Texas corporation. But ICE dropped out of the running within a few months due to design problems, inadequate servicing facilities, and premature release of production models that had not been debugged fully. But the imports kept coming and were being accepted by anxious amateurs hungry to get going in this rapidly expanding field. Varitronics retained its lead, though other distributors made attempts to challenge the leader with Japanese imports of varying degrees of quality and price.

In the face of ICE's disaster and the phenomenal success of Varitronics' import line, another American firm made its debut against bets within the industry that this new upstart, World Radio Labs, would be heading for an early failure. But the line – Galaxy – made it. Finally an American made unit was successfully selling against the hot Varitronics line, and even though its early models couldn't match the Varitronics unit in performance, it sold at a price well below that of the import.

As other manufacturers kept their eye on Galaxy with the intent of emulating its success, Hy-Gain took over the Galaxy line and began making product and price improvements. It managed to grab the lion's share of the market and Hy-Gain was determined to hold it.

The eyebrows of other American manufacturers were raised as Galaxy continued its erosion into the market that most experts said was spoiled by "low-priced used gear and Jap imports." And before long other U.S. makers jumped in, each with improvements and innovations that commanded the attention of the VHF FM enthusiast.

There was Regency, with plenty of channels, lots of power, and virtually no "frills or fancy stuff." The Regency unit was priced plainly to encroach on Galaxy's increasing share of the market – it bore a modest retail tag of $229 and set new standards of performance within the American radio manufacturing industry.

Then Clegg, who was determined to market a transceiver that provided all the advantages of crystal control for the transmitter, but the flexibility of tunable control for the receiver, introduced its unit – with a whole new set of standards. It had a tunable receiver that was as hot as a stovetop and a transmitter that combined tubes and transistors to pump out more power than any of the competition.

Another entry, Drake's "Marker," is a hybrid of sorts. It is a Japanese import, but it is being marketed by an American manufacturer as a compromise between Japanese production capability and American expertise in peripheral servicing and marketing.

In spite of the growing involvement of American makers in the traditionally Japanese-dominated field, the inward flow of the import continues, each unit touting new concepts or features.

Telecomm, for example, imports not only a conventional 2 meter FM transceiver but a complete line of receiver, transmitter, and power amplifier circuit-board "modules" as well.

Henry Radio, who had been quietly distributing a Japanese VHF FM transceiver import (the Model FM-V), noted that sales of the unit began to increase appreciably even though no advertising had been placed for the units in the national amateur magazines. So Henry began to talk about its unit and had to step up its import operations.

And the market shows no signs of losing any activity in the near future either, even though it should get progressively more difficult to show a profit in view of the increasing competition. Each month, several more firms announce new VHF FM-gear to be made available. And even those manufacturers who looked once at the market and turned away are reportedly making a more thorough reexamination of it now. In this latter category are companies like Heath, Hallicrafters, and Johnson. The going won't be easy for any of them, though. Swan is already on the market with a 2 meter FM transceiver, for example, and so is Simpson. And the Standard import, at one time strictly "marine," turned to the ham market and is making a great deal of headway with its own expanding line. So the competition will get tougher and tougher, even though most of the manufacturers can hardly keep their delivery apace with new-unit orders.

The impact of all this in-fighting could have a dramatic and beneficial influence to the ham in terms of total value per dollar of investment. But most important of all is the fact that this flurry of activity on our VHF bands has already begun to draw more people into the ranks of ham radio. And many of the inactive oldtimers have already come out of hiding to join the swelling ranks of the FM'ers.

In 1969, there were an estimated 10,000 active FM'ers. Today, there are easily more than 2½ times that number, and an estimated additional thousand operators appear each month.

Also, despite the increase in the total number of open repeaters, owners of repeaters tend to report a substantial increase in the number of user stations. These factors, and others, point to a VHF FM population that is very closely approaching the 30,000 mark.

To the great relief of manufacturers and dealers in the ham radio field, the current VHF FM boom has had little if any negative effect on the conventional amateur market. Indications are that a large number of the new FM'ers are indeed from the dyed-in-the-wool low-band SSB crowd, but there is no indication that the newcoming FM'ers are deserting their old modes. Wayne Green, publisher of 73 Magazine, says he makes it a point to delve into the question at conventions, club meetings, and at every opportunity. "It appears," he said, "that VHF FM is more or less universally taken up by the sidebander as a supplement to his hobby rather than as a replacement. Amateurs who operated on other bands before trying 2 meter FM continue to operate on the other bands. They use FM as something of an intercom among themselves to keep each other apprised of DX conditions such as rare station appearances and band openings, to maintain car-to-car communications at transmitter hunts, to pass traffic, or to participate in public service functions."

At no time in the history of ham radio has this current expansion of FM interest been paralleled. Even the development of sideband in the late fifties and early sixties was incomparable in terms of adding new faces to the existing ranks. And there appears to be no end in sight!

Comparing FM Equipment

. . .A detailed rundown
on current models of
2m FM transceivers.

FM's fantastic rise in popularity has brought about a revolution in the ham market, with manufacturers young and old competing for a share of the business. New equipment continues to make the FM scene at a clip far too furious for complete and comprehensive reviews to keep pace. As an alternative, here are "capsule reviews," where the available 2m FM transceivers are listed together and described in one sequence of pages; this will permit you to compare price, performance, features, and appearance.

To prepare this data, 73 Magazine requested evaluation models of all rigs currently being manufactured. Then, as the units came in, they were systematically checked out and photographed. The specifications were listed and comprehensive descriptions prepared. The following paragraphs represent the results of the lengthy evaluation effort. The 2m FM units pictured and described herein are: Clegg, Drake, Galaxy, Regency, Simpson, Standard, Swan, Telecomm, Tempo, and Varitronics. The reviews also include two portable units – one by Varitronics, the other by Drake.

STANDARD

Standard's SR-C826M is a 12-channel transceiver that runs 10W of rf output power, has a receiver sensitivity of 0.4 μF for 20 dB of quieting, and sports an illuminated selector switch and S-RF meter. The transceiver comes from the supplier with 4 frequency positions installed:

Standard's new SR-C826M uses a beefed-up receiver borrowed from the company's type-accepted line of marine units. Among other improvements over the early Standards: more rf amplification stages and increased selectivity.

146.94 direct, 146.34/146.76, 146.34/146.94, and 146.76 direct. The Standard unit comes from the factory equipped with microphone, mobile mounting bracket, power cable and cord.

The transmitter frequency deviation is preadjusted to ±7 kHz, a good figure for most of the repeaters in the country; an internal adjustment will vary the level from 0 to 10 kHz. A front panel switch allows selection of rf output power to conserve drain when operating off an uncharged battery. The high-power position is 10W out; the low-power position drops the output to slightly below a watt. In the low-power position, battery drain is about a quarter-amp during transmit. Under normal weather conditions (−10 to +60° C), the frequency drift of the unit is less than 0.001% – depending, of course, on the quality of crystals you use. The SR-C826M is reportedly a drastic improvement over the earlier model (SR-C806M) in terms of selectivity. One of these units was functioning at SAROC as an in-band repeater. Sales price: $339.95. *Standard Communication Corp., Box 325, Wilmington CA 90744.*

VARITRONICS

The Inoue IC-2F, distributed exclusively by Varitronics, Inc., has 6 transmit and 6 receive channels. Even though the rig is packed with compact circuitry, the unit is remarkably serviceable, owing to the "swingaway" construction of the subchassis elements. The receiver is rated for 0.4 μV for 20 dB quieting, which has proved realistic. The selectivity is adequate for amateur mobile and base operation, but you won't likely be able to use the transceiver as a functioning repeater.

The transmitter uses 18 MHz crystals; the receiver uses 45 MHz rocks. Construction and layout are exceptionally clean. A 5-prong receptacle on the rear of the chassis simplifies interconnection of tone accessories and allows discriminator frequency monitoring via a remote meter. A plug for this is provided with the unit.

The unit comes complete with mike, mobile mounting bracket, power connector/cable, spare fuses, and a mike hanger. Connect 12V and a good antenna and you're on

The Varitronics IC-2F has about the highest packaging density of any transceiver on the market, with more circuits per square inch of volume and less dead-air space inside the cabinet. The large panel meter lights up red during transmit. Unprecedented sales volume has allowed the distributor to drop the sales price recently to $299.

the air with a good 10W of rf. A built-in protection circuit senses high standing-wave ratios and will cut off the transmitter when the value climbs too high, thus saving expensive power transistors. Indirect illumination of the built-in S-RF meter serves as "power" and "transmit" indicators: When the power is on, the meter is lit with an ordinary low-drain incandescent lamp: on transmit, a brilliant ruby lamp illuminates the meter. Provided with comprehensive maintenance/operation manual, 1 year guarantee. Comes with crystals for 146.34/146.94 and 146.94 simplex. Sales price: $299.95. *Varitronics, Inc., 2321 E. University Dr., Phoenix AZ.*

TEMPO

Henry Radio's Tempo FM-V transceiver is one of the more compact of the imported units. Housed in a sturdy one-piece metal case, the unit comes with power cable, microphone, and one set of crystals – 146.94 (transmit and receive).

There are 8 positions on the channel selector switch and sufficient crystal sockets for 8 transmit and 8 receive

The Tempo FM-V import offers an unusual buy in terms of performance-per-dollar-of-investment. At $249, the unit will produce up to 15W of rf, and offers sensitivity, selectivity, and noise immunity comparable to the highest priced transceivers. Though the FM-V has no panel meter, it does contain an internal meter socket that allows monitoring of all stages, including discriminator.

crystals. Cross-wiring for accessing one crystal in several positions is a simple process.

The transmitter section is rated at 10W output, though the 73 test unit actually pumped out 15W into a 50Ω antenna (13.8V input). The receiver sensitivity is rated at 1.0 μV for 20 dB of quieting, but 73's test unit did much better (0.6 μV). The selectivity is better than average. Noise immunity is definitely superior.

The transceiver chassis contains a metering socket for monitoring all the transmiter and receiver stages. A 0–50 μA meter can be used for monitoring these functions (including discriminator current), or you can purchase a low-cost test set from Henry that is designed to plug in.

With its 29 transistors, 2 integrated circuits, and 15 diodes, the unit is surprisingly compact; and with all of its compactness, the unit is surprisingly accessible for service. It comes with a complete instruction manual that describes tuneup and alignment procedure, photos of the transceiver, theory of operation, parts lists, schematics, and a warranty. Sales price of the Temp FM-V: $249.00 *Henry Radio, Inc., 11240 W. Olympic Blvd., Los Angeles CA 90064.*

SWAN

The FM-2X by Swan Electronics is a 12-channel transceiver with a rated rf output power of 12W. According to Swan, the unit comes factory-equipped for crystals on 146.34/146.94 and 146.94 simplex. 73 has not yet had the opportunity to check out this unit, but the specs are as follows: Harmonics and spurious radiation better than –60 dB; frequency deviation is factory adjusted to ± 12 kHz, *Swan's FM-2X import boasts a series of 12's: 12W, 12 channels, and factory deviation adjusted to 12 kHz. A large illuminated panel meter and a back-lighted frequency selector make mobile operation an easy chore even at night. The unit operates either direct from the car battery or from 115V ac (for base station operation). Power cords are supplied for ac and dc operation.*

but may be increased or decreased with an integral pot.

The receiver is rated at better than 0.6 μV sensitivity at 20 dB of quieting. With a dual-conversion superheterodyne circuit, the unit is certain to give adequate selectivity for amateur mobile or base station use.

The unit sports an easy-to-read, illuminated panel meter for indicating relative power during transmit and relative signal strength during receive. With 28 transistors, 12 diodes, and an integrated circuit, the FM-2X comes complete with power cable (and connector), operating manual, and standard Swan guarantee. Sales price: $229. *Swan Electronics, 305 Airport Rd., Oceanside CA 91054.*

GALAXY

Hy-Gain's Galaxy FM-210 transceiver is all-American. Manufactured in the U.S. with U.S. parts, the unit offers conservative design with plenty of room inside the chassis for mounting tone units or other circuits. With independently controllable transmit and receive frequencies, a great

The FM-210 by Galaxy offers 9 channels (3 x 3), easy access for service, and traditional U.S. quality. A power-booster accessory, available at extra cost, increases the value of the FM-210 by upping its output to 35W. This unit has the distinction of being the "American Classic." Like the Ford automboile, Galaxy pioneered the American penetration into an all-import market with this sensibly priced transceiver.

deal of flexibility is offered in terms of selection of operating frequencies (9 possible, with 3 crystal positions for transmitter and 3 for receive). FETs in the front end serve to enhance sensitivity with a minimum of active devices. Receiver is rated at 1.0 μV for 20 dB quieting. The basic transmitter runs about 3.0W out, but this can be doubled with the optional "power booster" accessory. Crystals for transmit and receive on 146.94 MHz are provided. The receiver audio output is very high quality and the level is sufficient for the noisiest of environments. The microphone input is designed to accept any high-impedance audio input. The transmitter deviation level can be adjusted to any point from 0 to 15 kHz. Plug-in transistors and easy-access circuit boards simplify servicing. Provided with operation manual, full guarantee. Sales price: $229.50 . *Hy-Gain Electronics Corp., Box 5407-GL, Lincoln NB 68505.*

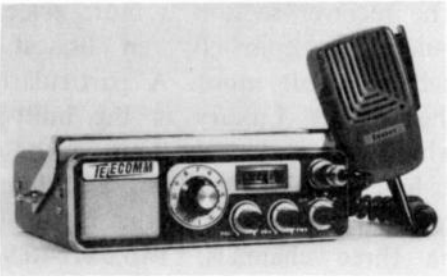
TELECOMM

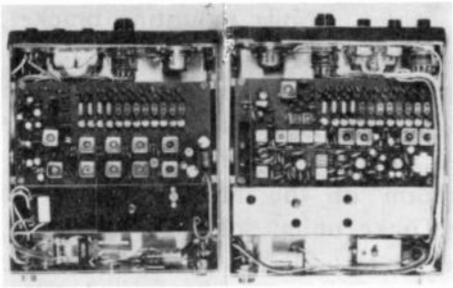
The Telecomm import is a 12-channel transceiver with a rounded two-piece housing, front mounted speaker, produced 15W with 13.8V dc input. The front panel sports a unique multipower switch, which changes the output power to 2.5W (medium-power position) or 10 mW (low-power position). The audio quality is particularly clean.

The unit comes equipped with two sets of crystals (146.34/146.94 and 146.94 direct), and has provisions for accepting power amplifier, tone encoders, remote control circuitry.

The receiver section is rated for 0.6 μV for 20 dB of quieting. Selectivity and noise immunity seem to be on a par with other imports – plenty adequate for amateur mobile or base station operation. Transmitter and receiver oscillators are equipped with trimmers for rubbering crystals to precise channel variations. To ease servicing, the transceiver circuit boards are modular; the transmitter is accessible from the underside, the receiver from the top. The transmitter uses 12 MHz crystals (12X); the receiver, 45 MHz crystals. The i-f lineup is the standard 10.7 MHz/455 kHz arrangement. Comes with schematics and

Telecomm, a California company, imports the 10W unit pictured here, but stocks the integral modules as well. The module boards include the receiver, transmitter, and rf power amplifier. The Telecomm has 12 transmit and receive crystal positions, a front-mounted speaker, and three switch-controlled power output levels.





The Telecomm transmit board (left) is accessible from the top of the rig's mobile housing. As shown, the 12-channel board is easily removable. The transmit board drives the rf power amplifier shown at the bottom of the photo at left. Note also the integral hash filter. The receiver portion (right) is accessible from the underside of the chassis.

simplified opeating instructions. Sales Price: $289.95. *Telecomm Electronics, Box 461, Cupertino CA 95014.*

DRAKE

The *MARKER Luxury* by Drake represents a sensible compromise in hybridization. Combining a tube-type final with solid-state oscillator, multiplier, and driver stages to give an output signal that exceeds 20W (with an input of 13.8V dc), the transceiver offers a total of 12 channels, compact construction, and excellent overall performance.

Drake's Marker Luxury is designed as a mobile/base station. An integral supply allows connection to 115V primary power; the supply is bypassed when the unit is connected to a car battery. The Drake unit has a back-lighted channel indicator and an illuminated meter. Crystal positions are provided for 12 each, transmit and receive. Each crystal has an adjacent micro timmer. Though rated at 15W output, typical Marker Luxury units approach the 20W mark.

The receiver section is more selective than most, and can quiet the noise by an honest 20 dB with only a half-microvolt input. A particularly interesting feature of the Marker Luxury is the built-in 115V power supply, which means that the unit can be operated in the car or as a base station with no additional appliances. The unit comes equipped from the factory to transmit and receive on three channels: 146.34/146.94, 146.34/146.76, and 146.94 simplex. Included in the purchase price are the mike, power cords and cables, mobile mounting bracket, coax, and a ¼ wave mobile antenna.

For some reason – probably known only to Drake – the Marker Luxury is extremely conservatively rated. The 73 test unit performed far in excess of the specifications.

The overall construction of the Marker Luxury is similar to that of other Drake units: solid, stable, classy. The design is like the specs – tasteful and conservative. The speaker is front-mounted, and a meter is provided for monitoring rf output during transmissions or signal strength during the receive mode. Sales price: $329.95. *R. L. Drake Co., 540 Richard St., Miamisburg OH 45342.*

REGENCY

Regency's HR-2 is a compact American-made economy model that uses a Motorola 10W transistor in the final amplifier stage. The channel selector is a 12-position switch that allows 6 each transmit and receive channels plus 6 cross-wired channel combinations. The extra-large speaker is mounted facing upward in the one-piece housing. Removal of the speaker gives easy access to all circuits.

The receiver section is rated for 0.35 μV for 20 dB quieting. 73's test unit did not quite meet this spec – though it did perform within the 0.5 μV figure that is fairly typical of most available transceivers. The transmitter put out 12W with an input of 13.8V when the channel selector was on the 146.94 MHz position, and the power dropped to 10W on the 146.34 position. The unit comes with high-impedance ceramic mike, power cable and plug, and transmit and receive crystals for 146.94 MHz. The transmitter crystals have frequency-adjust trimmers, but the

Regency's HR-2 is one of the few American-made 2m FM transceivers. Though not the smartest-looking of the units available, there's probably not a unit anywhere that is easier to service. When the extra-large speaker is moved aside, all parts of the HR-2 are easily accessed. The compact transceiver is characterized by design economy and adequacy of performance.

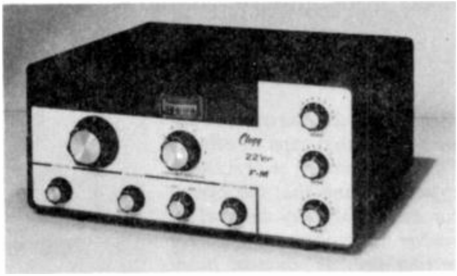
receiver does not. A built-in swr "mismatch protection" circuit prevents operation with improperly tuned, open, or shorted antennas. The receiver i-f's are 10.7 MHz and 455 kHz. Receive crystals are 45 MHz types. The transmitter stage uses 6 MHz crystals. Comes with 5½ x 8½ in. operating manual, 90-day warranty, necessary accessories. Sales price: $229. *Regency Electronics, Inc., 7900 Pendleton Pike, Indianapolis IN 46226.*

CLEGG

The Series 25 Clegg 22 FM'er is a radical departure from the traditional, and the manufacturer gambled against heavy bets within the FM fraternity that a tunable receiver wouldn't make it. Though the unit is designed primarily for base station applications, with its built-in ac supply, circuitry has been incorporated to allow use in the mobile by direct connection to the 12V battery.

Performancewise, the 22'er FM is almost incomparable. The receiver is remarkably sensitive (0.4 μV for 20 dB of

The Clegg 22'er uses vacuum tubes in the final to produce more power output than any of the available transistor rigs. The tunable receiver is calibrated to mark existing FM channels. The transmitter section is crystal-controlled, and runs approximately 35W out. The receiver section is highly selective and as sensitive as they come. Unit operates from 115V ac or 12V dc.



quieting), and surprisingly selective, with a rated adjacent-channel level of –80 dB. The transmitter is crystal-controlled and has crystal sockets for 9 channels. The Series 25 receiver dial is calibrated in standard-channel increments of 60 kHz, with minor markers at the 30 kHz channel points. Reports from users of the 22'er generally state that the dial accuracy is extremely close; silent channels can be selected with precision, and no tuning is required to make sure you're really monitoring the right frequency.

The transmitter runs about 30W output, though this figure varies from unit to unit. Some reports have indicated outputs of up to 40W. The receiver and most transmitter stages are fully solid-state; the transmitter final is a tube. Design is clean; the knobs have that "executive feel." Sales price: $384.95. *Clegg Associates, Inc., Littell Rd., East Hanover NJ 07936.*

CLEGG SYNTHESIS

One of the most important developments in the FM era – indeed, perhaps THE most important – is the successful manufacture and marketing by Clegg Associates of the FM 27, a transceiver that incorporates a fully frequency-synthesized receiver section. To monitor a specific frequency, the operator merely sets the two receiver controls to the numbers corresponding to the 146 MHz channel. To monitor .94, the operator sets the first control to. 9, the second one to 4. In the photo, the receiver is set to monitor .76. The beauty of this approach is that any one of 100 possible channels can be monitored with crystal accuracy – but without the need for crystals. And even such off-breed nonchannels as .80 and other sometimes used nonstandard frequencies can be monitored, as long as

Clegg's FM 27 has one fantastic feature that tops all others: The receiver is a synthesis type, meaning that the operator can "dial" any channel he wishes to monitor by merely setting up the channel numbers on the two controls.

the channels are multiples of 10 kHz between 146 and 147 MHz.

The transmitter portion of the transceiver is the 10-channel version from the company's 22'er model. The transmitter puts out about 30–35W of rf, and is said to be exceptionally stable. The design is clean, as it is with all Clegg units. As can be seen in the photo, accent is on simplicity and ease of operation.

The selectivity of the receiver is rated at 80 dB of adjacent-channel attenuation.

SIMPSON

Simpson's Model A FM transceiver steps into amateur radio from the nearby VHF FM marine band, where it has been – and still is – serving boat owners and yachtsmen. The Model A's rugged construction is probably attributable to this heritage; the rig is built like a battleship, and from first appearances one might guess that nothing could damage it.

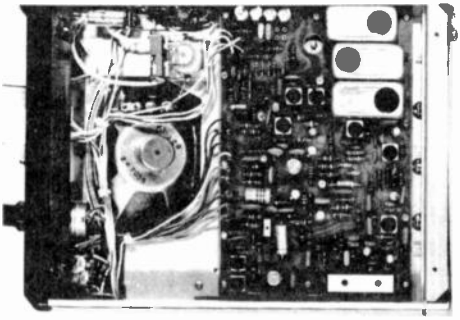
Although a smidgen larger than most of the other solid-state 2m FM units, the Model A's power output is

The Simpson Model A transceiver is one of the few that have received FCC type-acceptance for operation on the adjacent marine band. This durable FM unit has removable top and bottom cover plates that give easy access to internal circuitry. Sufficient volume exists inside the housing to mount tone units or other add-on circuits.

slightly less than average – about 7.5W at 13.2V dc input. This rig's big plus is its serviceability; the circuit boards are laid out in such a manner that virtually every stage of both the transmitter and the receiver sections are easily accessible for repair should the need arise.

Two channel-selector switches adorn the front panel of the Simpson Model A – one for the receiver, the other for the transmitter. With four channels transmit and four

As can be seen in this view of the Simpson, the tuned circuits are all enclosed in shielded metal housings, and the trimmers are all of the air-variable variety. A very large speaker, mounted in an acoustical chamber, is capable of coupling several watts of audio into the air. Active devices of the Model A include several integrated circuits.



channels receive, the total number of transmit/receive combinations are 16.

The Model A comes with crystals for operation on .94 (direct) and .34/.94. Other factory equipment includes power cable and connector, push-to-talk microphone, fuse, mike hanger, mounting hardware, and an operation/maintenance handbook.

The unit houses an extra-large speaker housed in a clever acoustical chamber that supplies very loud and crystal clear audio under adverse conditions of a noisy environment. Receiver sensitivity is about 0.5 μV for 20 dB of quieting, and the selectivity is –60 dB at 36 kHz. Sales price: $245. *Simpson Electronics, Inc., 2295 NW 14th St., Miami FL 33125.*

DRAKE TR-22 Hand-Held

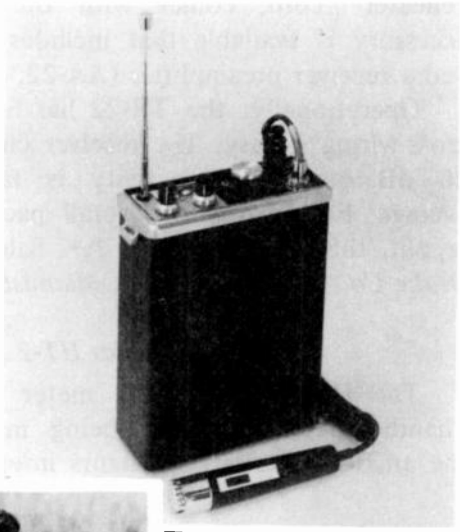
The TR-22 is a very compact transceiver that can only be classed as a "portable." With the general shape of a conventional mobile transceiver and the size of 1½ late--model hand-held units, the little rig runs a watt and a half of rf out into its own integral telescoping whip antenna. The rig is set up to do triple duty – as a handheld unit, a base station, and a mobile.

For hand operation, the unit sits in its leather carrying case with shoulder straps. The slim "pencil" microphone connects to the transceiver through a curly cord, and the telescoping whip extends from the face of the unit. An internal pack of "penlite" rechargeable Nicads supplies 12V to power the rig. The case is easily removable (without tools), but provides a splashproof housing for the transceiver and its speaker.

As a mobile, the unit can be connected under the dash. A standard UHF connector is provided on the rear panel of the chassis along with a connector for accepting battery voltage. A mating connector and power cable are furnished with the TR-22.

As a base station, the unit becomes operable by connecting a 115V power cord between the unit and

The TR-22 is about half the size of the smallest mobile units, and includes virtually all the performance features of the big rigs while retaining that elusive ingredient called portability. The unit has 6 channels, independent squelch and volume controls, and a panel meter to indicate the capacity of the integral batteries. The unit is powered from an internal battery pack, external auto battery, or 115V ac. In addition to the front-mounted telescopic whip, the unit has a conventional UHF connector on the rear to facilitate operation as a mobile or base station.



As a portable unit, the TR-22 operates from its own self-contained batteries. A carrying case and shoulder strap are provided with the unit, as is the pencil microphone with its curl cord. Power output is between 1.1 and 1.5W, depending on condition of batteries.

As a mobile unit, the TR-22 fits easily under the dash of even the most compact car. It connects directly to the car battery and an external antenna. The speaker is splash-proof, and the unit can be removed from the case without tools; two unique push clips hold the unit in its one-piece housing.

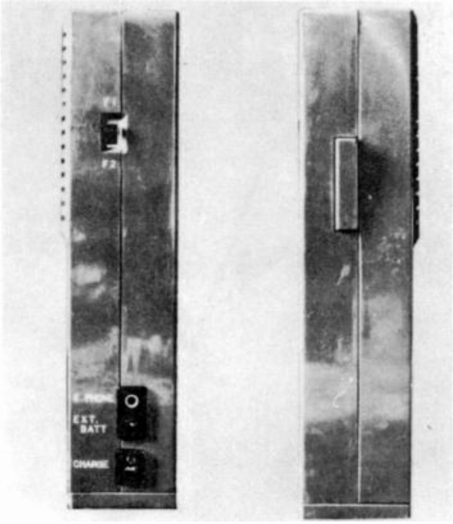
household power. The proper cable, resembling a TV "cheater" cord, comes with the transceiver. A unique accessory is available that includes an rf output amplifier and a receiver preamplifier (AA-22, $149.95, 25W).

Operationally, the TR-22 has 6-channel capability, and cross-wiring is easy. The receiver checks out at 0.5 μV for 20 dB quieting. Selectivity is fair; noise immunity is average. For quality of overall package, and construction/layout, the TR-22 rates an A+. Sales price: $199.95. *R. L. Drake Co., 540 Richard St., Miamisburg OH 45342.*

Varitronics HT-2 Hand-Held

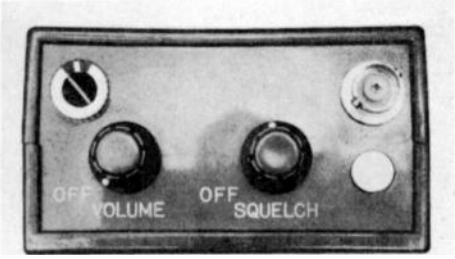
The HT-2 hand-held 2 meter transceiver is the only "handie-talkie" currently being marketed specifically for the amateur market. Amateurs interested in small packages

Varitronics' HT-2 is a 2-channel, 2W hand-held transceiver that comes with Nicad batteries, carrying case, battery charger, and crystals for .34/.94 and .94 direct. Sensitivity of the receiver section is 0.4 μV for 20 dB of quieting.

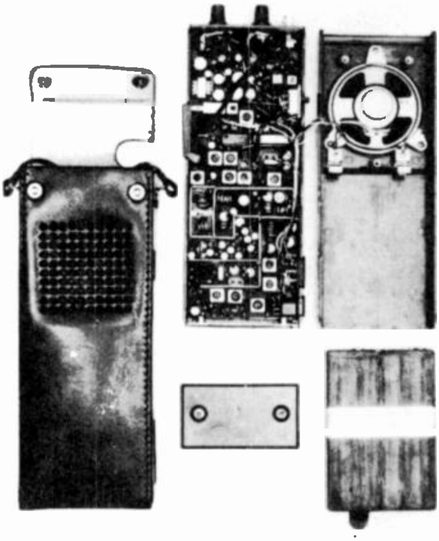


and big performance should not overlook this sleeper. This unit was tested more thoroughly by 73 staff than any other FM transceiver, because it seemed to be too good to be true. The transmitter pokes out 2W, and the signal is good, clean, and stable. Early units had bassy audio, but recent models sound almost hi-fi. Deviation level on the transmitter is factory adjusted to about 10 kHz, and can be easily set to any requirement by pot adjustment.

The selectivity of the receiver is adequate, nothing more. But the sensitivity is unbelievable – 0.4 μV or better for 20 dB of quieting. It's something you'll have to measure for yourself to fully appreciate.



The top of the HT-2 contains on-off and volume control, squelch control, a BNC antenna connector (which also mates to the antenna supplied with the transceiver), and a battery-level indicator.



The stages of the HT-2 are isolated from one another by thin shielded partitions. The "guts" can be removed easily from the transceiver housing for service in the unlikely event that such action might be necessary.

The package is definitely not Motorola quality even though the performance is. And even the plain packaging can be appreciated if you have to work on the unit. The whole thing comes apart to reveal well laid-out, easily serviceable stages, each well shielded from the other by metal barriers.

The unit comes with carrying case, leather strap, earphone, nickel-cadmium batteries, and a charger. A top-mounted meter tells the state of charge of the battery at all times the unit is turned on. The antenna (also supplied) mates with a BNC connector on top of the unit itself. Sales price: $149.95. *Varitronics, Inc., 2321 E. University Dr., Phoenix AZ.*

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