AMATEUR FM and REPEATERS

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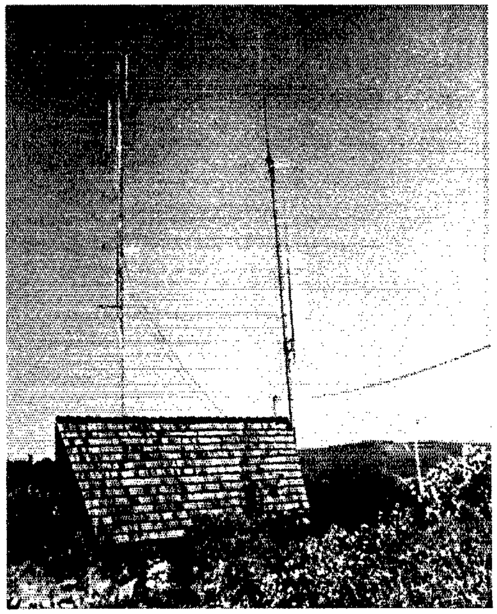

This is a view of the Mt. Vaca Radio Club repeater site on Wolf Mountain (2600 ft), 40 miles NE of Sacramento, Ca. The equipment is installed in a "vault." Several antennas are seen above the building, but only one antenna system is used by WA6UGS for its repeater.

Although amateur fm has been the subject of a number of theory and construction articles in *QST* and other publications since before WWII, it didn't get off the ground until recently. The claimed advantages of fm couldn't outweigh the additional receiver complexity required to fully obtain these improved results. The picture was changed, however, as large quantities of used commercial fm mobile equipment became available to the amateur.

This older equipment, some of it made obsolete for commercial service by changes in FCC requirements and by newer solid-state equipment, has become the new "surplus" equipment for hams. The ham tinkering instinct, long fueled by military surplus equipment, has been frustrated recently by the lack of such equipment suitable for modern amateur communications. Fmers, however, have rediscovered the old fun associated with adaptation and modification of inexpensive equipment. But it should not be inferred that fm equipment normally requires extensive conversion for amateur use. With many units, slight padding of certain tuned circuits and retuning to the amateur band is all that is required. Once the rig is on the air, though, much innovation is possible.

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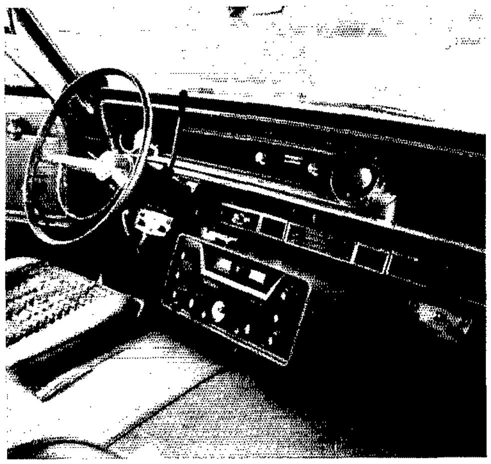
The recent upsurge in fm activity in amateur operating has brought with it new techniques, procedures and standards that provide a perpetual source of questions for the fm newcomer. This article discusses fm operating practices and the closely related subject of amateur repeaters.

Fm Characteristics

What are the technical advantages of fm? Many misconceptions exist on this subject due to popular oversimplification of fm theory. Fm has a noise advantage over a-m as long as the received signal is above the threshold of receiver sensitivity. The amount of fm noise improvement is proportional to the deviation or bandwidth occupied by the signal. A wide-band fm signal will have a greater quieting effect than a narrow-band fm signal of the same strength. As the deviation is lowered (assuming the receiver bandwidth is narrowed at the same time) the signal characteristics will become more like a-m. An fm signal with ±3-kHz deviation (nbfm) and an nbfm receiver will have a signal-to-noise ratio and threshold similar to a-m. The point usually missed is that the quieting effect of the wide-band signal is at the expense of receiver threshold. In other words, a-m has a greater range in weak-signal work, but fm will provide greater noise suppression in local work.

If this is true, why do amateur fm mobiles have a greater range than the average a-m mobile? The answer to that is simple. Typical 2-meter fm mobile transmitters, for example, are rated at 30 to 60 watts rf output power (50-100 watts input), or about 10 dB more output than most 2-meter a-m mobile rigs. Some writers have also claimed better receiver sensitivity for fm equipment. This is not exactly true, as the pentode rf stage in many vintage fm rigs can



Most fm mobile work is done with trunk-mounted equipment. This means that only the control head, speaker, and tone-signaling box (if used) are mounted in the driver's compartment. In this view of the W6TEE mobile installation one can see the fm controls, plus an hf transceiver for use on other amateur bands.

stand some improvement in noise figure. But, in general, the least sensitive fm receivers are still better than many of the simpler a-m receivers in common use.

Part of the unique nature of amateur fm operating is due to the effect of the equipment capabilities on operating practices. Fm equipment, as obtained from commercial users, is designed for fixed-frequency operation (but not necessarily single-frequency operation) with both the transmitter and receiver crystal controlled. When first faced with this unfamiliar configuration, the early fmers, rather than trying to modify the equipment to fit a preconceived mold of tunable receivers and random frequency operation, developed new techniques to better use the equipment and the mode. They found that channelized operation with squelched receivers permitted continuous monitoring of the active frequencies. They found that long, time-consuming calls and CQs were no longer necessary to establish communications, as all receivers on the channel came alive with their first word. Mobile operation became possible for those with only a short time to spend.

Fm Operating

What operating procedures are followed on an fm channel? Only one generalization can be made. Long transmissions are out. Natural, short transmissions, such as practiced by the better sideband operators, are usually encouraged. The old monopoly switch routine, where the operator gabs to himself for 10 minutes at a time, should have disappeared from ham radio with the antenna knife switch, but still clutters up the vhf bands on a-m. Other than that, operating procedures are a matter to be determined by the local channel users. Some channels are calling channels on which extended rag-chewing is discouraged, whereas other channels, or the same channel in another area, may be alive with chit-chat. This is a matter of local determination, influenced by the amount of activity, and should be respected by the new operator and the transient mobile operator alike.

One question that always comes up in connection with amateur fm involves the use of the "10 code". Some groups, having members who are in the two-way radio repair or law enforcement business, have carried the use of this code over into their amateur operating. However, many feel that this code offers little or no communications enhancement to amateur operating and that its use is an affectation. Plain language in many cases is as fast and requires no clarification or explanation to anyone.

Fm, more than a-m, requires precise frequency netting and high-quality crystals for best results. An off-frequency signal will be received with distortion and will not have full noise rejection. For this reason, fm transmitters and receivers have oscillator adjustments to permit an exact setting of the crystal in each.

Standard channel frequencies have been agreed upon to permit orderly growth and to permit communications from one area to another. On 2 meters, it has been agreed that any frequency used will fall on increments of 60 kHz, beginning at 146.040 MHz. The national calling frequency is 146.940 MHz (or "nine-four"). On 6 meters, the national calling frequency is 52.525 MHz, with other channels having 40-kHz spacing beginning at 52.560 MHz. Ten-meter fm activity can be found on 29.600 MHz. Recommendations for 10 meters and 220 MHz are for 40-kHz channel spacing starting at 29.040 and 220.020 MHz. Usage of the 420-MHz band varies from area to area, as it is used for control channels, repeaters, and remote bases, as will be discussed later. As an example, in California activity begins at 449.950 MHz and progresses down to below 435 MHz in 50-kHz increments.

Deviation

Now that you have read all of these facts about fm, you should know that it is not strictly fm that we have been talking about, but actually pm or phase modulation. The equipment available for amateur use, originally used on commercial vhf "fm" uses pm, not fm. Both fm and pm are forms of angular modulation, but through usage, fm has become the generic term covering both. Since both are easily generated, our only real concern is in the difference in signal characteristics. A phase-modulated signal will have a rising audio response at the higher frequencies when detected by an fm discriminator. For this reason, a simple *RC* circuit is placed on the discriminator output to roll off the higher frequencies to achieve a flat response. A true fm-generated signal must then have a high frequency boost to sound natural on a receiver designed to receive pm. It should be noted that this frequency slope is completely across the audio bandpass (at least 300 to 3000 Hz) and should not be confused with pre-emphasis in broadcast fm which applies only to a portion of the audio range.

Commercial equipment frequently has speech clipping in the transmitted audio. This not only permits the commercial user to meet FCC deviation requirements, it also permits the amateur to maintain a high audio level without deviating outside the receiver passband. When deviation is excessive, the receiver will actually lose the signal on modulation peaks and the squelch will close. Complementary *RC* circuits are employed before and after the clipper to overcome the rising modulation characteristic of pm to produce a constant peak frequency deviation without altering the basic frequency response. When the audio level is lower than the preset maximum, the clipper and its associated *RC* circuits will have no net effect.

Two deviation standards are commonly found. The older standard — "wide-band" — calls for a maximum deviation of 15 kHz. The newer standard — "narrow-band" — imposed on commercial users by the splitting of their assigned channels, is 5 kHz. The deviation to be employed by amateurs on frequencies where fm (other than nbfm) is permitted is not limited to a specific value by the FCC, but it is limited by the excellent bandpass filters found in fm receivers. In general, a receiver with a filter for 5-kHz deviation will not intelligibly copy a signal with 15-kHz deviation. Although some work is being done with 5-kHz deviation, most amateur work is with 15-kHz deviation. In some areas, a compromise deviation of 7 or 8 kHz is used with some success with both wide and narrow receivers. When necessary, receiver filters can be exchanged to change the bandpass.

Repeaters

A repeater is a device which retransmits received signals in order to provide improved communications range and coverage. This communications enhancement is possible because the repeater can be located at an elevated site which has coverage superior to that obtained by most stations. A major improvement is usually found when a repeater is used between vhf mobile stations, which normally are severely limited by their low antenna heights and resulting short communications range.

Although a-m repeaters are in use in some parts of the country, the recent upsurge in repeater interest was brought about by amateur fm. Proximity effects encountered between a repeater receiver and transmitter are quite troublesome with a-m, but are present to a much lesser degree with fm. Also, a-m repeater performance is degraded by off-frequency operation by some users through the use of inexpensive crystals in oscillators having widely varying characteristics. Fm equipment, however, is designed for spot-frequency operation, minimizing this problem. Although some of the following information will apply to a-m repeaters, much of it is based directly on fm techniques.

The simplest repeater consists of a receiver with its audio output directly connected to the audio input of an associated transmitter tuned to a second frequency. In this way, everything received on the first frequency is retransmitted on the second frequency. As a practical matter, certain additional features will be required to produce a workable repeater. These are shown in Fig. 1A. The COR or carrier-operated relay is a device connected to the receiver squelch circuit which provides a relay-contact closure to key the transmitter, when an input signal of adequate strength is present. As all amateur transmissions require a licensed operator to control the emissions, a "control" switch is provided in the keying path so that the operator may exercise his duties. This repeater, as shown, is suitable for installation where an operator is present, such as the home of a local amateur with a superior location, and would require no special licensing under existing rules.

Unfortunately, most groups intending to install a repeater do not have a suitable location that has a licensed operator on hand. In this instance, a special license for remote-control operation must be obtained and provisions made to control the equipment over a telephone line, or a radio circuit, 220 MHz or higher. The licensed operator must then be on hand at an authorized control point. Fig. 1B shows the simplest system of this type. The control decoder may be variously designed to respond to simple audio tones, dial-pulsed tones, or even "touch-tone" signals. If a leased telephone line is so specified, dc control voltages may be sent directly, requiring no decoder. A 3-minute timer to disable the repeater transmitter is provided for

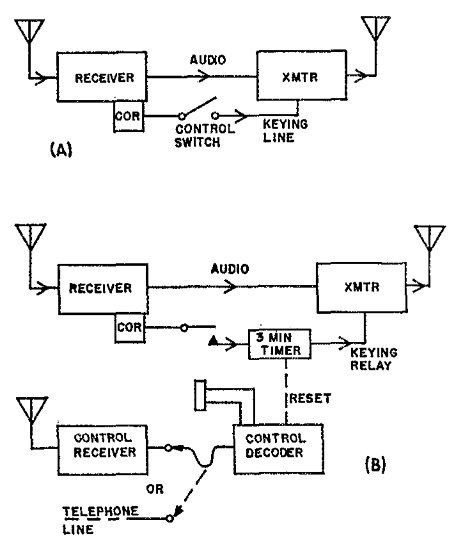


Fig. 1—Simple repeaters. The system shown at (A) is for local control. Remote control is shown at (B).

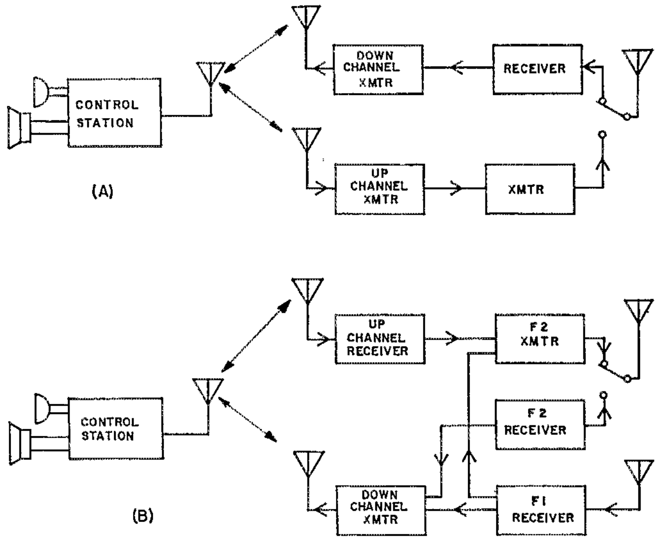


Fig. 2—A remote base is shown at (A). A repeater with remote base operating capability is shown at (B). Control and keying circuits are not shown. Telephone line control may be substituted for the radio control channels shown.

fail-safe operation. This timer resets during pauses between transmissions and does not interfere with normal communications. The system just outlined is suitable where all operation is to be through the repeater and where the frequencies to be used have no other activity.

Remote Base

Before we can discuss more sophisticated repeaters, we must explain the "remote-base" type of operation. The remote base, like the repeater, utilizes a superior location for transmission and reception, but it is basically a simplex device. That is, it transmits and receives on a single frequency in order to communicate with other stations also operating on that frequency. The operator of the remote base listens to his hilltop receiver and keys his hilltop transmitter over his 220-MHz or higher control channels (or telephone line). Fig. 2A shows such a system. Control and keying features have been omitted for clarity. In some areas of high activity, notably Los Angeles, repeaters have all but disappeared in favor of remote base, due to the interference to simplex activity caused by repeaters unable to monitor their output frequency from the transmitter location.

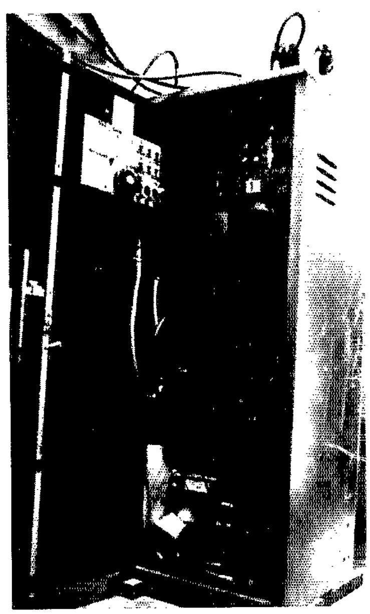


Fig. 2B shows a repeater that combines the best features of the simple repeater and the remote base. Again, necessary control and keying features have not been shown, in order to simplify the drawing. This repeater is compatible with simplex operation on the output frequency because the operator in control monitors the output frequency from a receiver at the repeater site between transmissions. The control operator may also operate the system as a remote base. This type of system is almost mandatory for operation on one of the national calling frequencies, such as 146.940 MHz, because it minimizes interference to simplex operation and permits simplex communications through the system with passing mobiles who may not have facilities for the repeater input frequency.

This photo shows the Wolf Mountain repeater equipment which is rack mounted and neatly placed inside the shared vault. This equipment is a complete working system of the type described in the text. The local control and test panel is mounted on the open door.

The audio interface between the repeater transmitter and receiver can, with some equipment, consist of a direct connection bridging the transmitter mike input across the receiver speaker output. This is not recommended, however, due to the degradation of the audio quality in the receiver output stage. A cathode follower connected to the discriminator after the *RC* compensator provides the best results. A repeater should maintain a flat response across its audio passband to maintain the repeater intelligibility at the same level as direct transmissions. The intelligibility of some repeaters suffers because of improper level settings which cause excessive clipping distortion. The clipper in the repeater transmitter should be set for the maximum system deviation — for example, 10 kHz. Then the receiver level driving the transmitter should be set by applying an input signal of known deviation below the maximum, such as 5 kHz, and adjusting the receiver audio gain to produce the same deviation at the repeater output. Signals will then be repeated linearly up to the maximum desired deviation. The only incoming signal that should be clipped in a properly adjusted repeater is an over-deviated signal.

Channel Frequencies

The choice of repeater input and output frequencies must be made carefully. On 2 meters, 600-kHz spacing between the input and output frequencies is common. Closer spacing makes possible interference problems between the repeater transmitter and receiver more severe. Greater spacing is not recommended if the user's transmitters must be switched between the two frequencies, as happens when the output frequency is also used for simplex operation, either for short range communications, or to maintain communications when the repeater is not functioning. Careful consideration of other activity in the area should be made to prevent interference to or from the repeater. Many "open" or general-use repeaters have been installed on one of the national calling frequencies. On two meters, a 146.940-MHz output is usually paired with a 146.340-MHz input, and many travelers have made good use of this combination where it is found. Where 146.940 MHz simplex activity has not permitted a repeater on this frequency, 146.760 MHz has been used as an alternative. On 6 meters, several choices of input frequency have been paired with 52.525 MHz and no real standard has emerged. Again, the choice and usage is a matter for local agreement. All that can be done here is to report general trends.

In some cases where there is overlapping geographical coverage of repeaters using the same frequencies, special methods for selecting the desired repeater have been employed. One of the most common techniques requires the user to automatically transmit a ½-second burst of a specific audio tone at the start of each transmission. Different tones are used to select different repeaters. Standard tone frequencies are 1800, 1950, 2100, 2250, and 2400 Hz.

Where there is to be much repeater activity in a given geographical area, a coordinating committee or council may be established to resolve problems of common interest. An example is the California Amateur Relay Council (CARC) which originated in the San Francisoco area and now has 32 repeater and remote-base operators in California, Nevada, and Hawaii as members. The CARC, as one of its functions, coordinates frequencies for council members and other users. As an example, the CARC has listed 137 440-MHz control and repeater frequencies in use in Northern California.

Although it is impossible to cover specific details of each subject that has been mentioned here without writing a book on the subject, it is hoped that the organization of the material presented here will help to put relationships in perspective so that a better overall picture of amateur fm and repeater operation can be obtained. We would like to thank the other members of the Mt. Vaca Radio Club that made this article possible, notably W6FRE and WA6DBL. QST

FM JARGON

Duplex — Simultaneous transmission and reception between two stations using two frequencies.

Simplex — Alternating transmission and reception between two or more stations using one frequency.

Low-band — 30 to 50 MHz. Also, the 6-meter amateur band.

High band — 148 to 174 MHz. Also, the 2-meter amateur band.

Remote base — A remotely-controlled station, usually simplex. See text.

Machine — Either a repeater or a remote base. Also called a "box".

Vault — Building that houses the machine.

COR — Carrier-operated relay. See text.

CTCSS — Continuous tone controlled squelch system. Continuous subaudible tone (250 Hz or lower) transmitted along with the audio to allow actuation of a repeater or receiver only by transmitters so equipped. More frequently referred to by various trade names such as Private Line, Channel Guard, and Quiet Channel.

Down channel — Communications circuit from the machine to the control point.

Up channel — Communications and/or control circuit from the control point to the machine.

Open repeater — A machine where transient operators are welcome.

Closed repeater — A machine where use by non-members is not encouraged. (When heavy expenditures are involved, free-loaders are not popular.)