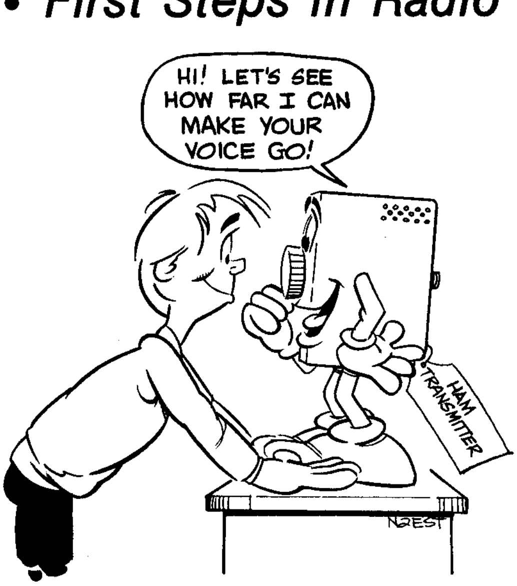
• *First Steps In Radio*



The Basics of Transmitters

Part 11: Last month we examined the fundamentals of receivers, so let's turn our attention toward the other half of a ham radio station — the transmitter, the amateur's on-the-air voice.

By Doug DeMaw,* W1FB

What is a transmitter? How much power must it generate to be effective? Must it be fancy in order to get the job done? Are transmitters expensive? Can I build my own transmitter? These are common questions asked by newcomers to Amateur Radio, and it is logical that the would-be ham feels a bit confused before obtaining answers to these important questions. Last month we learned the simple ins and outs of receiver circuits, so now we'll give similar treatment to transmitters.

The radio amateur has some options when acquiring a piece of transmitting gear. They include: (1) Purchase a new unit of commercial origin, (2) buy a used commercial transmitter, or (3) build a simple transmitter from a *QST* or *ARRL Handbook* description. The decision will be founded on how much money you can spare, whether or not you have the necessary faith in used equipment, or if you are sufficiently courageous to attempt home construction of your transmitter. I tend to favor the last choice, for as I recall my first years as a ham I recapture the thrill of talking around the world with a rig I built from scrounged and borrowed parts.

Whether you copy a design, modify one or start with your own design, there is a feeling of accomplishment that goes with the use of homemade equipment. The practicality of putting together a CW transmitter goes hand in hand with obtaining a Novice-class ham license, for CW transmitters are the least complicated and costly of the many types. Voice privileges are not available for Novices, so this makes things much simpler for the first-time builder. There are good circuits in back issues of *QST* and in the ARRL technical books.

Meet the Transmitter

In the early days of Amateur Radio, hams used what was known as a spark transmitter. By today's standards it is the most crude form of equipment for generating a Morse code radio signal. Voltage was fed to a mechanical interrupter that caused an arc when the telegraph key was closed. This wide-band energy was concentrated as much as possible in a narrow band of frequencies by means of a tuned circuit that was resonant at the desired operating frequency. The resultant note was broad and buzzy, but it could be copied. Such devices as a rotary spark gap, doorbell buzzer or Model-T Ford ignition (spark) coil were commonly used to cause the spark that became the radio signal. If we attempted to use that type of device today, our stations would interfere with every radio and TV set for blocks — or even miles! Furthermore, there would be room for only a few such signals in any of our CW bands!

After the spark transmitter was replaced by the vacuum-tube transmitter, things began to shape up in Amateur Radio. Greater distances were covered, and the ham bands could accommodate many signals at a given time. Early tube transmitters used a coil and a capacitor to control the operating frequency. This LC circuit was tuned to the desired operating frequency. Fig. 1 shows a simple version of this kind of transmitter. C1 and L1 are tuned to the operating frequency, and C1 is the main tuning control. C2 and L2 are also tuned to the operating frequency. L3 couples the output energy to the antenna system. This circuit is known as an oscillator or "LC oscillator." The key is inserted at J1. When the key is up, there

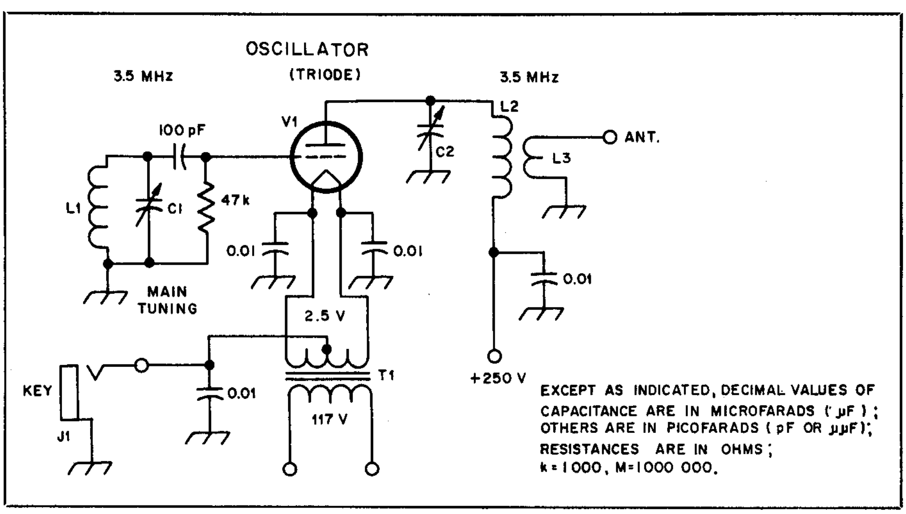


Fig. 1 — Circuit diagram of a vacuum-tube transmitter of the type used in the early days of Amateur Radio. C1 was used to change the operating frequency.

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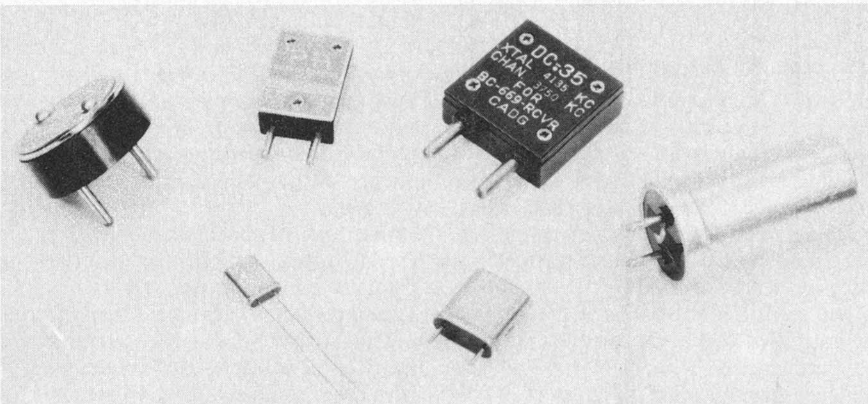

Fig. 2 — Photograph of various quartz crystals in their plug-in holders.

is no dc return to ground for the oscillator, V1, and no oscillation takes place. Key closure completes the dc circuit and causes power to be generated. Similar circuits are in use today, but not as transmitters. They may be used in some low-power part of a transmitter or receiver these days, but with semiconductors rather than tubes.

The most notable advance in transmitter technology during the early days of Amateur Radio came with the invention of the quartz crystal. It consists of a thin slab of rectangular quartz. The crystal is placed between two electrodes and enclosed in an insulating case or holder (see Fig. 2). When the crystal is excited electrically, as in an oscillator circuit, it vibrates. The operating frequency is determined by the number of times per second the quartz vibrates. For example, a 3.5-MHz crystal vibrates 3.5 million times per second. The crystal thickness determines the vibration rate. Hand grinding was the old method for crystal "tailoring," but an etching process is used today.

An example of a crystal-controlled oscillator is given in Fig. 3. It is an untuned oscillator because it has no adjustable coil and capacitor combination. It can operate only at the crystal (Y1) frequency. To change to a new frequency, we must plug in a different crystal at Y1. This circuit, like all oscillators, is basically an amplifier. But, part of the output power is routed back to the input of the amplifier to cause self-oscillation, or oscillation of the crystal.

Amplifiers should not oscillate when used strictly as amplifiers, but sometimes they do if careless design or layout permits output power to sneak back to the input side of the amplifier. This causes what is known as *instability*. So, a stage of that type becomes an oscillator, even though it is not meant to be one! The circuit in Fig. 3 is known as a Pierce oscillator — named after the man who invented it. There are many kinds of crystal oscillators, such as the Colpitts, tri-tet, Clapp, overtone and Butler. They all accomplish the same thing, but have different circuit hookups.

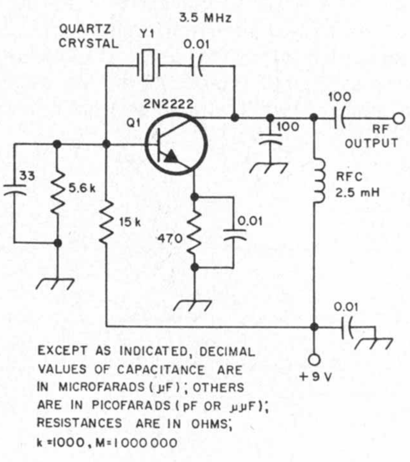

Fig. 3 — A crystal-controlled Pierce oscillator. This circuit may be used for a lab project, and can become a code-practice oscillator if used with a CW receiver.

You may wish to gather the parts for the circuit of Fig. 3 and assemble it. This will give you valuable first-hand experience concerning oscillator operation. You may hear the oscillator signal by tuning a shortwave receiver to the crystal frequency. If you open the ground connection for the 470-ohm resistor of Fig. 3 and insert a key, you may use the circuit for code practice. A CW receiver will be needed to hear the note well. Otherwise, you will hear only a thump when you key the circuit.

A Simple Transmitter

To illustrate the most simple of transmitters, let's look at Fig. 4. Here we have a one-transistor, crystal-controlled oscillator. With the parts specified in the diagram, we can expect approximately 0.25 watt (250 milliwatts) of output power. Although this may seem like too little power to communicate over anything but short distances, many hams specialize in talking around the world with QRP (low power) because it presents a challenge. This circuit, and a good antenna, can provide surprising results.

The crystal, Y1, determines the operating frequency. C1 and L1 are tuned to the operating frequency to ensure maximum power transfer to the antenna (maximize the signal output). The turns ratio on L1 and L2 is chosen to provide a proper impedance match between the collector of Q1 and the antenna feed line. Maximum power transfer can occur only when unlike impedances are matched. In other words, if the output of a transmitter has a characteristic impedance of 500 ohms and the antenna presents a 50-ohm characteristic, we would need to use some type of device (tuned circuit or transformer) to step the 500-ohm impedance down to 50 ohms.

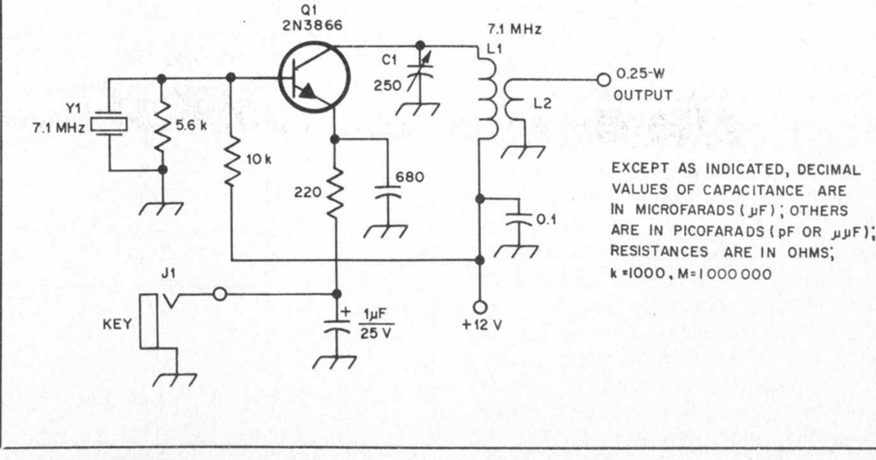

Fig. 4 — An example of a one-transistor, low-power CW transmitter. C1 and L1 are tuned to the operating frequency.

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For CW operation we need only to plug our key into J1 of Fig. 4. When the key is up (open), Q1 has no dc path to ground, and it can't oscillate. When the key is down (closed), the circuit oscillates and power is delivered to the antenna. If we desire more than 0.25 watt of power, we may add one or more amplifier stages after the oscillator. The power could be increased by this means to thousands of watts if that were our objective.

Voice Operation of Transmitters

There are three common voice modes for Amateur Radio — AM (amplitude modulation), SSB (single-sideband) and FM (frequency modulation). AM was the popular mode used in the early days of radio, and remains the method used in the standard broadcast band covering 540 to 1600 kHz. The amplitude of the transmitter carrier is varied in accordance with the voice energy, and a carrier plus two sidebands (upper and lower sideband, respective to the carrier frequency) result. SSB, on the other hand, provides only one sideband (upper or lower) and the carrier is suppressed. The resulting transmitter output power varies with the voice energy, much like AM. The advantage of SSB is that the transmitter is more efficient per watt in terms of overall power consumption, the signal occupies half the bandwidth of AM and power is not wasted in generating a carrier. The narrower bandwidth reduces congestion in crowded phone bands — a matter of great importance these days with so many hams on the air.

The FM technique is somewhat different than those of AM and SSB because the voice energy is used to shift or swing the operating frequency above and below the mean carrier frequency. This shift in frequency is called *deviation.* Voice energy may be applied directly to the transmitter oscillator to create FM. Another form of FM is PM (phase modulation). The end result of either system is the same. Fm receivers and transmitters will be discussed in more detail in a future installment of this series.

Representative Transmitter Arrangements

Whether a transmitter operates at VLF (very low frequency) or as a generator of microwave frequencies, the general scheme of things is the same. We must have a frequency source (local oscillator), subsequent frequency multipliers and/or amplifiers and resonant circuits. If voice operation is used, we need a *modulator*. It contains a speech amplifier and a circuit that applies the amplified audio data to the transmitter RF energy.

Fig. 5 shows a block diagram of a CW type of transmitter. We have included frequency doublers and amplifiers to provide a general idea of what might be found in a transmitter circuit. The frequency multipliers could be triplers or even quadruplers, if that would aid us in arriving at the desired transmitting frequency. On the other hand, we could design a transmitter that had no frequency multipliers: The transmitter output frequency would be the same as that of the oscillator. We might have one or two intermediate amplifiers to ensure the required excitation power to the final amplifier.

The oscillator in Fig. 5 need not be crystal controlled. Instead, we can use a VFO (variable-frequency oscillator), PLL (phase-locked loop) or a synthesizer to generate our operating or oscillator frequency. Most modern transmitters contain frequency synthesizers. They are very accurate and frequency-stable, and can be used to operate a digital frequency-readout display. In any event, all transmitters should contain a harmonic filter at the output in order to prevent the radiation of spurious frequencies that might interfere with other radio services, TV sets and FM radios.

The operating voltage for the power amplifier in Fig. 6 is processed by the modulator in order to provide amplitude modulation of the transmitter carrier. The remainder of the speech and RF stages are supplied with dc that contains no audio information. However, some transmitters use a small amount of modulated operating voltage on the stage immediately ahead of the power amplifier to ensure 100% modulation.

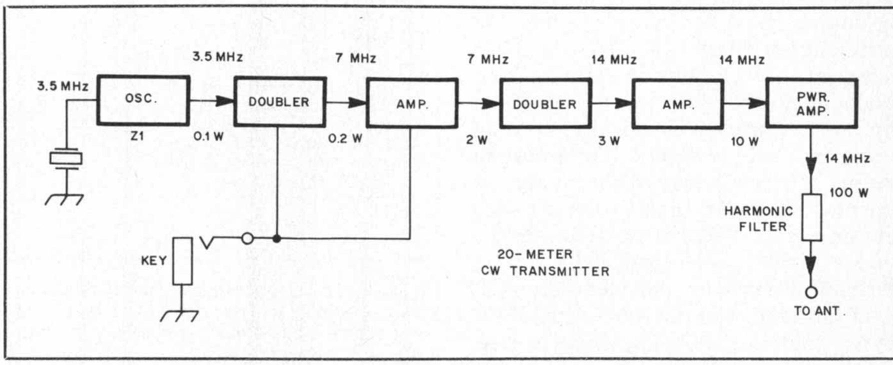


Fig. 5 — Block diagram of a simple CW transmitter with frequency doublers to increase the frequency from 3.5 to 14 MHz.

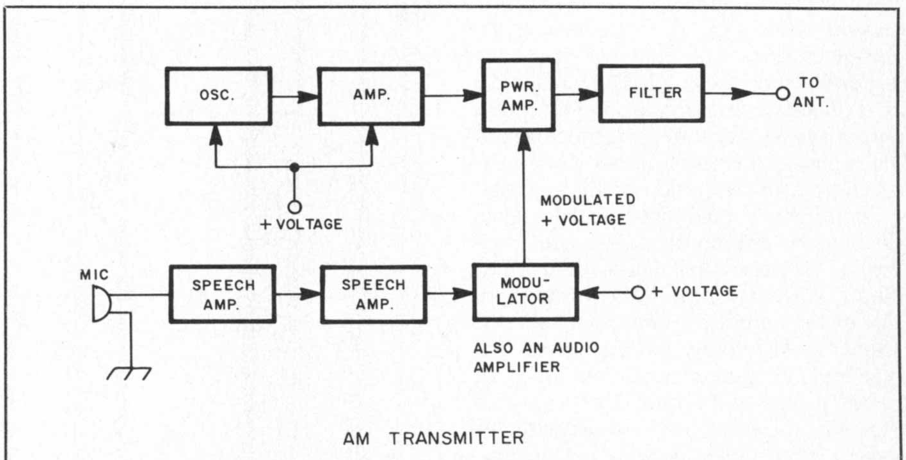
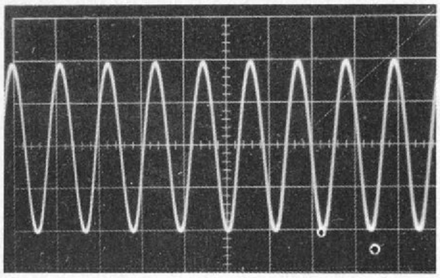
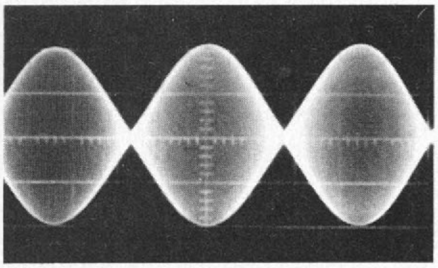


Fig. 6 — An AM transmitter is seen here in block-diagram form. The RF portion is the same as that of a CW transmitter. A modulator is used to provide AM voice output from the transmitter.



(A)



(B)

Fig. 7 — The photograph at A illustrates how an unmodulated RF wave form from an AM transmitter would appear on the face of an oscilloscope. Photograph B shows the wave form for a 100-percent-modulated carrier during AM operation.

Glossary

AM — amplitude modulation. A method of applying information to a carrier signal by superimposing the information-signal voltage on the carrier. The carrier amplitude is increased or decreased in proportion to the superimposed signal amplitude.

AMTOR — AMateur Teleprinting Over Radio. An RTTY communications method that employs error-checking procedures. Information is sent in groups of three characters (letters, numbers, punctuation, etc.). If the receiving station acknowledges correct receipt of a three-character group, the sending station transmits the next group. Should the receiving station not verify correct reception of the three-character group, the transmitting station retransmits the information. This form of RTTY overcomes the adverse effects of signal fading and interference, and ensures error-free information exchange.

ASCII — American National Standard Code for Information Interchange. A digital coding system that employs seven elements or *bits* to represent alphanumeric, punctuation and control characters. In Amateur Radio communications, the term is loosely applied to a form of RTTY communications in which ASCII is used to convey the desired information.

ATV — Amateur television. This term is usually applied to the fast-scan type of television, similar to that used by commercial TV stations. The video portion of the signal is amplitude modulated.

balanced modulator — a portion of an SSB transmitter that provides voice modulation of the carrier, then removes the carrier to leave only upper- and lower-sideband energy.

bandwidth — the amount of frequency occupied by a signal in terms of hertz or kilohertz.

carrier — the RF output from a transmitter, minus signal information.

deviation — the amount of frequency swing above and below the mean carrier frequency of an FM transmitter. The deviation is caused when audio-frequency voltage is applied to the oscillator.

discriminator — a type of detector in a receiver that has been designed for FM reception.

exciter/excitation — excitation is the RF voltage applied to an RF amplifier to cause it to amplify. An exciter is a circuit that provides excitation voltage.

FM — frequency modulation. A form of communication wherein the transmitted carrier frequency (rather than the carrier amplitude) is varied in accordance with the frequency of the modulating signal. The degree of modulation (the modulation index) is proportional to the amplitude of the modulating signal.

instability — an undesirable characteristic of an amplifier that self-oscillates.

modulator — the part of a transmitter circuit that applies modulation (audio-frequency intelligence) to one or more stages of the transmitter.

multiplier — a stage in a transmitter that doubles, triples, etc., the frequency that is applied to it.

PM — phase modulation. Another method for generating an FM signal.

ratio detector — a type of FM detector used in an FM receiver.

Repeater — A transmitter/receiver combination that receives and retransmits amateur or commercial signals at higher power levels and with a more effective antenna. This greatly increases the effective range of mobile, hand-held and/or low-power transmitters.

slope detection — a method of receiving FM signals with a standard AM receiver.

SSB — single sideband. A transmission method for creating a signal that has no carrier and just one sideband — upper or lower.

SSTV — slow-scan TV. A low-resolution, narrow-bandwidth method of picture transmission that uses audio tones applied to the modulator of a transmitter. Pictures may be transmitted in black and white or color.

synthesizer — a digital type of circuit for generating accurate, stable frequencies. Used in transmitters, receivers and test equipment. The frequencies are "synthesized" rather than generated directly by means of a crystal or LC oscillator.

Fig. 7A shows what we would see on an oscilloscope if we examined the output energy from the transmitter of Fig. 6, minus the modulation. In other words, the carrier would appear as a sine wave. But, when actuating the speech amplifier and modulator, the output wave form would appear as it is in Fig. 7B. In this example, the carrier is modulated 100% (ideal). If it is less than 100%, the signal sounds weaker in our receiver, and if the percentage is greater than 100, the signal is broad and distorted. Tubes or transistors can be used in the circuits of any of the transmitters discussed here.

Fig. 8 illustrates, in block-diagram form, the absolute basics of an SSB transmitter. The carrier is removed at the balanced modulator (balanced out, so to speak), which provides double-sideband, suppressed-carrier output to the sideband filter, FL1. Depending on the crystal used (Y1 or Y2), the output from FL1 will be upper- or lower-sideband energy, minus a carrier. The filter removes the unwanted sideband (AM transmitters transmit both sidebands, plus the carrier). The SSB energy is then routed to a mixer (as in a receiver) which is supplied in this example with 12.9-MHz energy from a local oscillator (VFO or synthesizer) to produce a sum frequency of 3.9 MHz.

Numerous other frequency schemes are popular. The one shown in Fig. 8 is but one of many combinations. The output waveform from a properly designed and operated SSB transmitter will look like that of Fig. 7B. Too high a level of modulation will cause distortion and broad signals, just as it does during AM-transmitter operation. Too little modulation will simply reduce the output power of the SSB transmitter. We should be aware that the carrier is never eliminated entirely by the balanced modulator, but it can be reduced to minus 50 dB or greater, which has the practical effect of eliminating it.

There are two methods commonly used for generating SSB signals. One is known as the filter method (Fig. 8), wherein a filter made from quartz or piezo crystals is used. In the other technique, known as the "phasing method," the unwanted sideband is removed by complex resistive and capacitive audio-phasing networks. Phasing types of transmitters have fallen out of popularity in recent years.

Other Amateur Transmission Modes

I would be remiss if I did not mention the additional transmission modes of ATV (amateur television), SSTV (slow-scan TV), RTTY (radioteletype), ASCII and AMTOR. For all practical purposes, the transmitters used for these more exotic communication modes follow the CW, AM or SSB formats described here. A proper treatment of how these modes differ from those we have already discussed would require more pages than we can devote to this article. But, you may find detailed information about these techniques, and those we have treated here, by referring to the *ARRL Handbook* and many past issues of *QST*. The ARRL technical department can provide a list of appropriate bibliographies from which to select suitable reference material. Please include an s.a.s.e. with your request.

Some Closing Thoughts

It is the intent of this article to familiarize you with the cornerstones of transmitter principles. Modern-day circuits are far more complex than the examples provided here, but the concepts are the same with regard to how the signal is generated. The schematic diagram of a typical modern

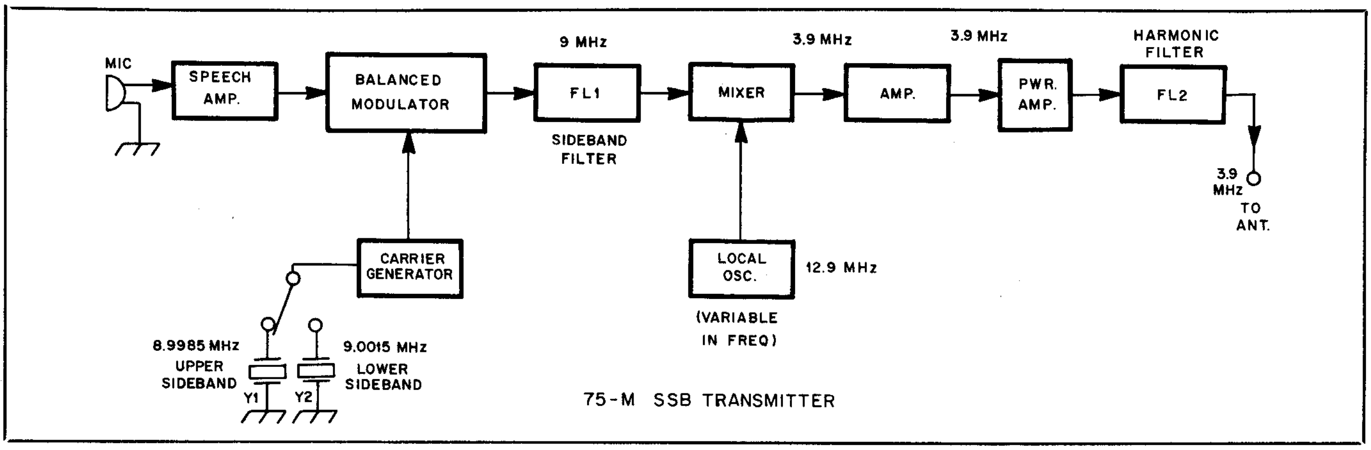


Fig. 8 — Block diagram of a single-sideband transmitter.

ham transceiver is so complicated that even *seasoned* engineers experience frustration when attempting to follow a single branch of a circuit. It would be absurd to force that kind of material on beginners, so we have followed a simplified "yellow brick road" in this installment. I want to encourage you to go beyond this treatment by reading more about these principles in the *ARRL Handbook*. A few practical experiments with the oscillator circuits from this article will be beneficial, too. Good luck!

(Continued from page 18)

'Talking to other hams is more important than your problems.'

"Instead," said Harris, "we made ourselves available to the managers for whatever appropriate help they might need. Not only did that approach give us a lot of satisfaction, but it also gained us tremendous respect from the Stanford LAOOC. People got to know that we were there, and available. We had a real advantage because, unlike ushers or security guards, we didn't have a specific assignment. We could be flexible."

The wide variety of talents among Harris's crew led to some other intriguing assignments. Sy Stein, M.D., WA6ROM, acted as net control for Red Cross medical efforts, which included 10 roving first-aid teams and two fixed stations. Then there were the 30 Crown Zellerbach Corporation buses arriving each evening with 1200 handicapped and underprivileged children from around the Bay Area. Barbara Mardesich, LAOOC Youth Services Manager for Stanford, asked for communications help at a managers meeting, and Ted Harris promptly volunteered his crew. Harris assigned Bob Tarone, WA6ZBX, to work with Mardesich on the problem. For the duration of the Games, Tarone and several other hams made sure the buses got through traffic to the correct parking area before the game, then helped get the kids back to the buses safely through post-game traffic. There was always one ham with Mardesich to relay information between her and the other traffic coordinators or local police.

To solve a communications problem at the venue administration offices, the Communications Crew installed packet radio systems at the stadium and at the LAOOC office in downtown Palo Alto. The goal was to overcome the problem of busy or unanswered phones ringing through to receptionists downtown. Before the packet system was installed, the receptionists had no easy way of getting the messages back to the managers, two miles away at Stanford. The packet system allowed them to send hardcopy messages back to the venue for easy retrieval by the administrators.

Aside from one board substitution, the two packet stations ran flawlessly 24 hours a day for 11 days, handling some 1300 messages in all. Harris, who is implementing packet systems for Red Cross disaster relief work, feels it was an important contribution to the Games. "Amateurs have to be innovative," he said. "We've got to take advantage of the latest technology if we're really going to be useful to the agencies we're trying to serve."

Team Finds Time for Radio

Amateur Radio participation in the Olympics wouldn't have been quite complete, of course, without every ham's favorite pastime — *playing* radio. Fortunately, if everything is well planned and luck is with you, even a major "disaster simulation" like the Olympics can leave some time free for that activity.

In Harris's original communications plan for the Olympics, spare time looked scarce, so he asked Ron Chiappari, N6AUV, to set up phone and CW stations outside the venue area and staff them with local hams. There was reason to believe that these (W23OG and W84OG) might be the only special-event stations operating from the Stanford Olympics.

But once the soccer activities were going smoothly, the possibility of running a special-event station from the Red Cross van looked more promising. By that time, a few days into the Games, W84OG and W23OG were going gangbusters, and Harris realized how many hams around the world wanted to make an Olympics contact. "I sat everyone down and said, 'Let's do as much as we can with this — it's hot.' "

Being warm-blooded hams, Harris' team leapt at the chance. They kept K84OG (K-84-Olympic Games) on the air most mornings and evenings thereafter, logging more than 4000 contacts with 71 countries.

Participation Brings Rich Rewards

The success of K84OG was the final touch on an already highly successful enterprise. Ted Harris and his entire crew received rave reviews from Olympics staff for their efforts. Technology Manager Chris Veal called their help "invaluable," and Youth Services Manager Mardesich said they were "super, just super." As visible evidence of this esteem, each of the 11 volunteers received a gold medallion from the LAOOC.

But Harris prefers to stress the internal rewards from his team's participation in this unique event — rewards that he feels are available to anyone willing to take an active role in public events or disasters. "You'll come out feeling like you've really made a difference," he said.

Indeed, despite the hectic pace and sometimes grueling hours, all of Harris's volunteers say they'd do it all over again. And, in fact, destiny has generously stepped in to give them an opportunity: This January, the Super Bowl comes to Palo Alto — and Stanford officials have already asked Ted Harris and his team to be there to help!