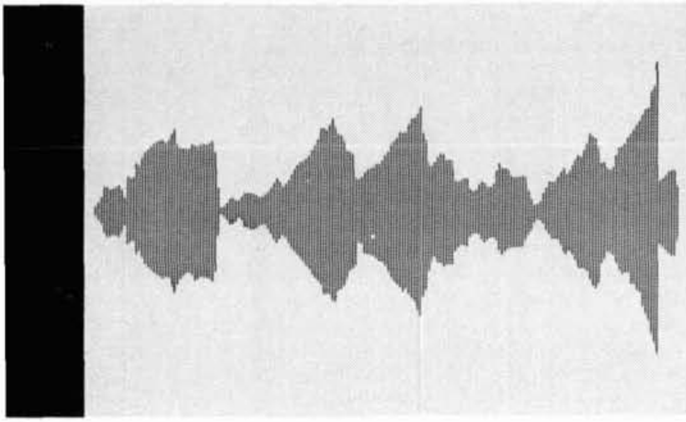


generating ssb signals with suppressed carriers

The inside story of the balanced modulator

Forest H. Belt, 119 Baker Avenue, South Plainfield, New Jersey 07080

The first step in forming a single-sideband signal is the generation of what is called a double-sideband suppressed-carrier or **dsbsc** signal. Some form of filter then removes one sideband completely. It takes a special kind of modulator to create the sidebands and eliminate the carrier, and the one used most is called a **balanced modulator.**

balanced modulators

A modulator is nothing more than a special mixer for mixing the voice signal with the carrier. With ordinary amplitude modulation, the mixing creates sideband frequencies equal to the sums of and differences between the voice modulation and the carrier–and, of course, both original signals remain in the output, too. The circuit that produces a suppressed-carrier signal must form the sidebands exactly the same as an ordinary a-m modulator and yet eliminate, as completely as possible, the carrier against which the voice modulation beats to create the sidebands.

First, then, to make it easy to understand the principles of carrier-suppressed modulation, let me explain a way to feed a carrier signal into a modulator circuit in such a way that the circuit is controlled by it and yet the carrier itself does not appear in the output. **Fig. 1** shows how this works.

Look at **fig. 1A** first. In this arrangement, the *rf signal is fed to V1 and V2 in parallel.* In other words, when the grid of one is on its positive rf half-cycle, so is the grid of the other. As is usual in amplifiers, each tube inverts the signal.

Look what happens when the outputs of the two tubes are connected in push-pull. The output of V1 is a negative half-cycle, and is applied in one direction through the transformer. The output of V2 is also negative-going, but it is applied in the opposite direction through the transformer.

The result is cancellation in the transformer of the effects of either signal. If the amplification of the two tubes is exactly equal, and the transformer itself is well balanced, there is total cancellation of whatever signal is applied to the grids of the two tubes.

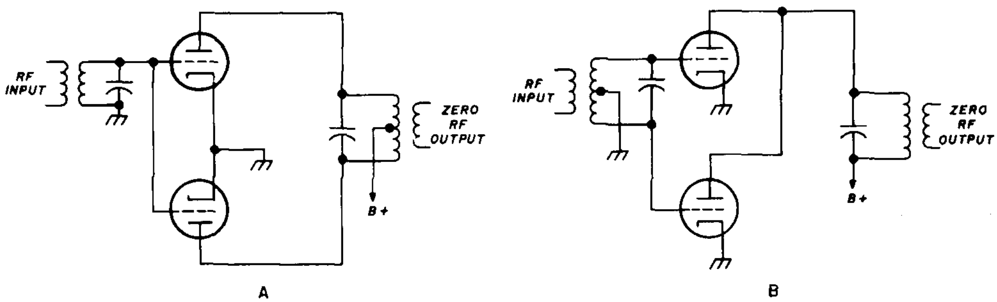
Next, look at **fig. 1B.** If a signal is fed to this stage in push-pull, the half-cycles of rf sine wave drive one tube in one direction and the other tube in another. However, if the outputs of both tubes are connected in parallel, the positive excursion of one always cancels the negative excursion of the other.

For example, suppose the signal at the grid of VI is on its positive excursion; the signal at the grid of V2, then, is on its negative excursion. As usual, each tube inverts the signal. The output of V1 is a negative half-cycle, and the output of V2 is a positive half-cycle. Since these are mixed in the same load, they cancel each other. Thus, push-pull in and parallel out also means cancellation of the input signal.

If you're wondering why any purpose is served by feeding an rf signal into the stage only to have it canceled in the output, think about what happens whenever the tubes become unbalanced. Imagine that V1 in **fig. 1B** amplifies less while V2 amplifies more. One of the signals that appears in the parallel output will dominate the other, because it is stronger.

If the situation were reversed, with V2 amplifying more than V1, the unbalance would create a dominance of the opposite polarity. If something switches the amplification of the two tubes alternately up and down quite rapidly, the output signal varies back and forth at the same rate. The result is an output that is a rapidly fluctuating rf signal of first one polarity and then another.

fig. 1. Cancelling the carrier signal: input in parallel, output push-pull (A); input push-pull, output parallel (B).



Consider the same action in **fig. 1A.** With V1 conducting more than V2, the opposite signal components in the transformer are no longer equal, and a certain amount of rf output is coupled to the secondary. If V2 conducts more than V1, the unbalance is in the opposite direction. Again, if something switches this unbalance back and forth between the two tubes at a rapid rate, the output varies at that same rate.

Fig 2A shows a convenient method of varying the gain of the two tubes. What you see is the same cricuit you saw in **fig. 1A,** but with a speech input *transformer added in* **push-pull.** It is easy to see that the push-pull speech signal can swing the amplification of the two tubes back and forth at an audio rate.

The tubes become *alternately unbalanced* at an audio rate, and rf shows up in the output—swinging back and forth from positive-going to negative-going output at the same rate. The effect is that the rf and speech signals are "mixed" and sidebands are created, yet the rf carrier signal itself does not appear in the output. The instant the speech modulation is removed, there is zero output from this balanced modulator.

Fig. 2B shows the principle applied to the circuit of **fig. 1B.** In this one, as you can guess if you now see the underlying principle of the balanced modulator, the speech signal is sent to both tubes *in parallel.* Since the tubes conduct alternately as far as rf is concerned, varying the gain of both tubes with the speech signal results in the same kind of amplification unbalance at an audio rate that was described in **fig. 2A.**

The result in the output is exactly the same. The carrièr itself does not appear in the output; in fact, with no speech input, there is no output. When there is speech modulation, however, the output consists solely of sidebands created by mixing the speech signal with the rf carrier.

The pattern of operation here should be clear. *In the balanced modulator,* the rf signal is applied in one mode and coupled out in the other. That is, if rf is fed into the stage in parallel, it is taken out in push-pull. If fed in in push-pull, it is taken out in parallel. This is true of all balanced modulators; that's why they suppress the rf carrier. The speech signal, on the other hand, is always applied in the same mode as the output is removed.

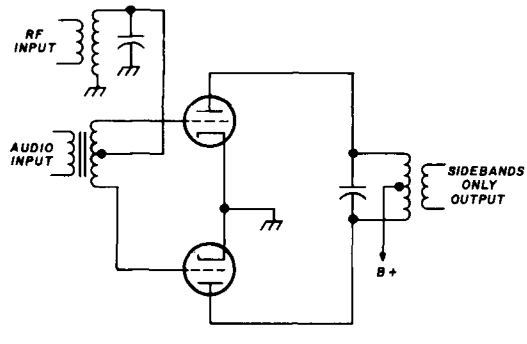
Balance is important. If either tube becomes slightly unbalanced, the carrier is then amplified constantly, even though slightly, by that tube. Many balanced modulators include a balancing adjustment which is set for minimum rf output with zero audio modulation.

Now that you are aware of the principles involved, let's examine some actual circuits. With your new understanding, you'll find the circuits themselves are easy to figure out.

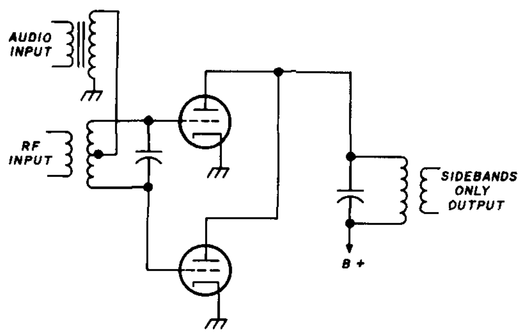
diode balanced modulators

The simplest and least expensive balanced modulators generally use semiconductor diodes. They seem to be more stable than tube-type balanced modulators, and are not prone to change characteristics over periods of time. Well designed diode balanced modulators provide about 40 dB of carrier suppression–more than tube types do (with the exception of the special beam-deflection-tube balanced modulator, which will be explained

fig. 2. Adding audio input for moduation: rf parallel, audio push-pull (A), rf push-pull, audio parallel (B).



A

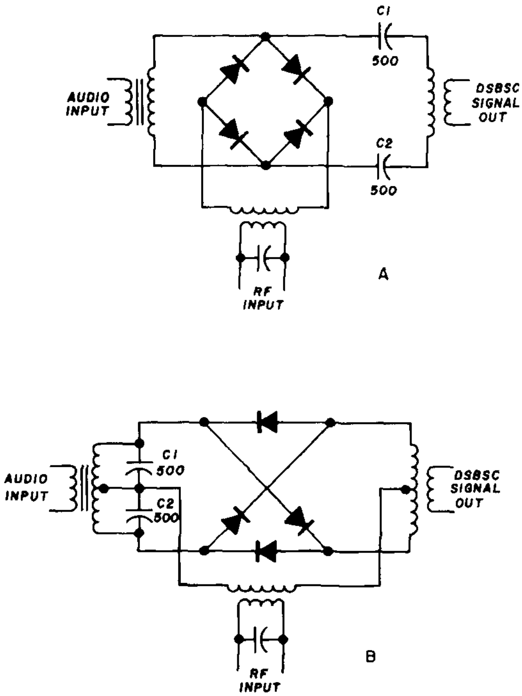


B

later). That means the power in the sidebands, at 100% modulation, will be at least 40 dB stronger than whatever carrier power slips through.

Two easy-to-understand diode balanced modulators are shown in **fig. 3.** At **3A,** you see the **bridge** type. In it, the rf and the speech signals are mixed in a four-diode bridge. Notice that, effectively, the principle of balanced modulators is adhered to. The speech signal is applied to the stage in the same mode in which the output signal is taken out.

fig. 3. Basic diode balanced modulators: bridge (A), ring (B).



The rf signal, on the other hand, is applied to the "balanced" corners of the bridge. One end of the rf input transformer is connected to the cathode of two of the diodes, and the other end is connected to the anodes of the other two. The result, of course, is that the rf signal is "shorted" to ground by the diodes except when there is speech modulation to unbalance their conduction. When that happens, the output becomes a double-sideband suppressed-carrier signal.

ring modulators

An improved version is shown in **fig. 3B.** It, too, uses four diodes–in a circuit called a **ring.** Better sideband signals are produced in the ring modulator than in the bridge-type. Again, the speech input is in the same mode as the output. The rf signal is fed into transformer center taps, so it is balanced with respect to the output.

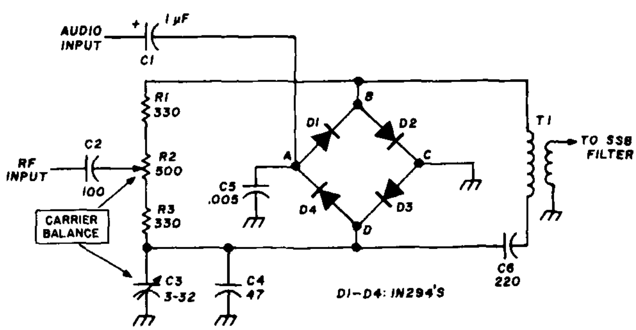
Efficiency in the ring modulator is high, and the four diodes should be carefully matched. One way to check them is with an ohmmeter, by measuring their forward and backward resistances. All four should match within 2%–even better, if possible. If they aren't matched, a certain amount of the rf carrier will slip through. Furthermore, the sidebands themselves will be unbalanced, which will create distortion when you try to recover them at the receiver.

The purpose of the 500-pF capacitors in both modulators is to keep audio and rf separated except in the mixer diodes. The capacitors pass rf energy quite easily, but present a fairly high impedance to the speech signal. In **fig. 3A,** the sideband output transformer would act pretty much as a short circuit for the speech signals; instead, the capacitors keep them out and they are forced to go into the bridge.

In **fig. 3B,** the two capacitors merely assure a low-impedance path for the rf signal in both directions to the ring circuit. The capacitors hardly affect the speech input signal at all, because of their low value.

About the most popular balanced modulator for ham equipment is the one shown in **fig. 4.** It is a variation on the ring circuit already described. Don't be confused by the

fig. 4. The most popular diode modulator used in ham transmitters.



way it's drawn, because it isn't a bridge. You can tell it's a ring by the fact that the diodes all are in series with one another; in a bridge, there are always two cathodes together and two anodes together.

This circuit has some other peculiarities, because it is designed to eliminate the expensive input transformers. Furthermore, both the speech and the rf signals are fed into the ring diode circuit from stages in which one side is grounded. The thing to do, to understand this particular balanced modulator best, is to analyze the action on the rf carrier alone first, and then study the effects of unbalance created by the speech input signal.

Next consider what happens when a speech signal is applied at point A. The capacitor there has little effect on the speech frequencies. Therefore, the path to ground for positive half-cycles of the speech signal is through D1 and D2. For negative half-cycles, it is through D3 and D4. The speech signal thus "turns on" these diode pairs alternately, at the speech-signal rate. You can see that the speech signal determines which diodes are conducting and which not conducting during a given half-cycle period.

As an example of the effect: when the speech signal is causing D1 and D2 to conduct, it has reverse-biased D3 and D4. Con-

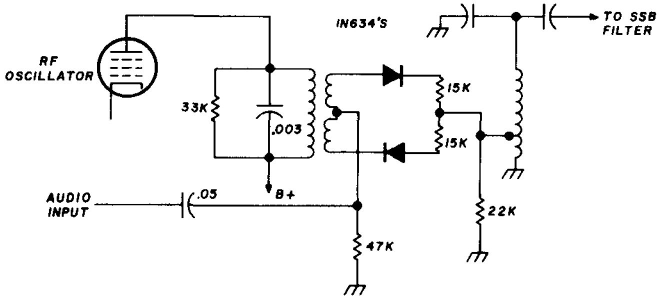


fig. 5. Two-diode balanced modulator is one form of the ring-type.

The first thing to notice is that two corners of the ring are grounded as far as rf is concerned. Capacitor C5 keeps point A at rf ground; point C is grounded directly. That being the case, the rf signal is applied to the ring effectively in parallel. It goes in both directions through R1 and R3, from balancing potentiometer R2. When it reaches B and D it splits up, with both segments being shunted to ground through whichever diode happens to be conducting on that particular half-cycle or excursion.

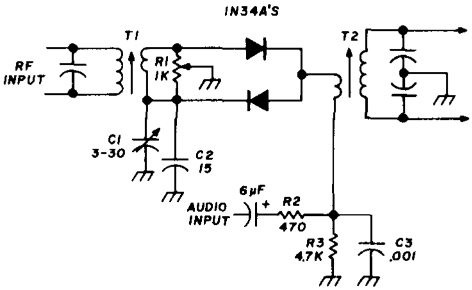
The important thing is that, because of the way the diodes are connected in the ring, the rf signal is behaving **inside the ring circuit** almost as if it were in push-pull. From point B, it goes through D1 on one half-cycle, then through D2 on the next, seeking ground. From point D, it alternates going through D3 and D4. With zero input from the speech circuit, the rf signal is continually shunted to ground on both excursions by one or another of the diodes. The result is that no rf reaches the primary of transformer T1 and consequently there is no carrier output.

sider positive excursions of the rf signal (**many** rf excursions occur during each audio half-cycle). Their only possible paths to ground at that instant are through D2, which is made conductive by both the rf and the speech signal, and through D4 which is made conductive only by the rf signal. Obviously, the greater rf current flows through R1 and D2. Much less flows in R3 and D4, because conduction in that diode is opposed by the speech-signal excursion. For negative excursions of the rf signal, the path aided by the speech-signal excursion is through R1 and D1; the R3-D3 path is opposed because D3 is still reverse biased.

If you carry through the reasoning for both positive and negative speech-signal excursions, you'll see that the path for all rf signals is through R1 on positive half-cycles of the speech signal, and through R3 on negative ones. This unbalancing means that some of the rf is not canceled and causes rf current to flow in T1–first predominantly in one direction, then in the other. Since, during modulation, this unbalance is varying at the speech-signal frequencies, the output is a pair of sidebands resulting from mixing the carrier and the speech frequencies; there is no carrier.

Capactitor C6 serves the same purpose it serves in the other circuits–to make sure only sideband signals reach T1; its value is such that it virtually blocks speech signals. C3 and C4 are balancing capacitors that make up for any stray capacitance in the stage; C3 is adjusted for minimum carrier output with zero modulation.

fig. 6. Simple two-diode balanced modulator is also ring-type.



two-diode modulators

An exceptionally simple variation of the diode-ring balanced modulator is used in one transmitter. If you examine its circuit carefully (**fig.** 5), you'll see that all the requisites of a balanced modulator are there. The diodes are in series with each other, as in a ring circuit. The rf signal is fed to the modulator circuit in push-pull by the secondary of the input transformer, and the resulting sidebands are taken out in parallel via a tap between the two balancing resistors. The speech signal is fed in parallel, being applied to the center tap between the two secondary windings of the input transformer.

With no modulation, each excursion of rf is applied to the diodes, but only the ones that make the top of the transformer secondary positive and the bottom negative can make the diodes conduct. Current then flows through the two balanced resistors. However, the output is taken off **between** the two resistors, so the voltages across the two resistors are in opposite phase with respect to ground, and they cancel. The result: no output. During the other excursion, there is no output because the diodes aren't even conducting.

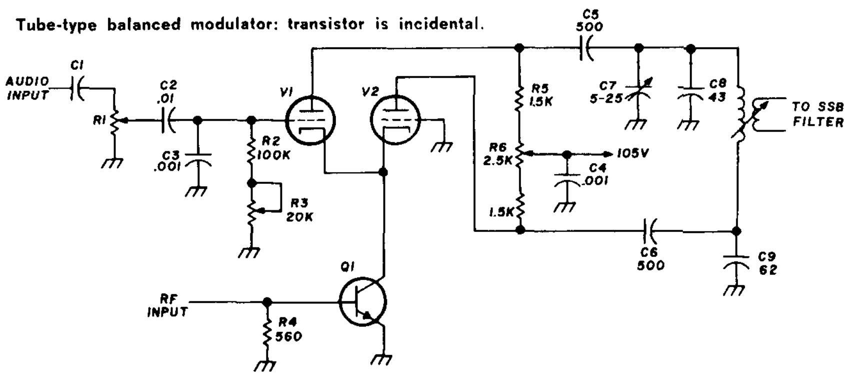
As the speech signal switches first one and then the other diode "on," the rf signal that is trying to flow in both diodes is either opposed or aided. The constantly shifting unbalance at the speech frequencies produces the sidebands at the junction of the two resistors, with the carrier suppressed.

Don't let the tap on the output coil confuse you. This one is strictly for matching the low impedance of this modulator to the higher impedance of the filter that follows.

There are other relatively simple two-diode ring circuits. One that has been popular in some home-brew rigs is shown in **fig. 6.** You don't need much explanation of this one; you can figure out its operation from your knowledge of this type of balanced modulator.

The rf is applied to the two-diode ring in push-pull. R1 can be adjusted for a "center-tap" ground that allows the speech to be fed in at a tap between the two diodes–therefore in parallel. The output is taken in parallel at the same point, through a coil which couples

fig. 7. Tube-type balanced modulator: transistor is incidental.



the sideband signals through a tuned secondary to the sideband filter.

C1 and C2 are the capacitance-equalizing part of the carrier-balancing network. Sometimes C1 is moved to the opposite end of the coil. R1 is of course the carrier-balancing potentiometer.

tube-type balanced modulators

In **fig.** 7 is a tube-type balanced modulator used in at least one commercial ham transmitter. A transistor is used, too, but it is primarily an impedance-matching input device. The balanced modulator has the usual configuration. The rf is fed to the stage in parallel, to the two cathodes, and the output is taken out in push-pull.

R5, R6, and R7 make up a balancing network to equalize conduction of the two tubes. The speech signal must be applied in push-pull, which is accomplished by grounding the grid of one tube and feeding the signal to the grid of the other. This is, in effect, push-pull.

Operation of this circuit is very much like the one in **fig 2A.** The two 500-pF capacitors keep speech signals out of the output circuit. C7, C8, and C9 are the capacitance-balancing capacitors. C7, the adjustable one, may be at either end of the output transformer winding, depending on which position does the best job of suppressing the carrier. Capacitor C4 keeps the carrier-balance control slider at rf ground, providing the rf "center-tap" ground necessary to make the output circuit push-pull.

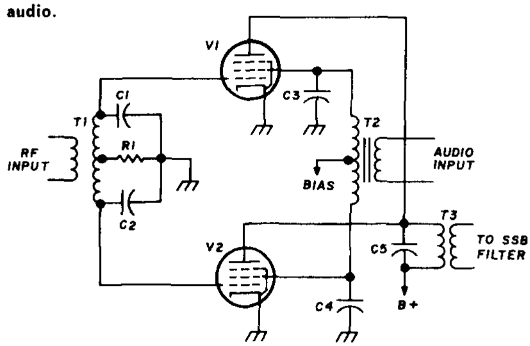
Pentodes may be used in place of triodes for this circuit. When pentodes are used, the rf signals may be fed to the control grids while the speech signal is fed to the screens. Speech and rf are in push-pull, and the outputs are paralleled. **Fig. 8** shows an example of this particular hookup. The schematic is simplified to show merely how it works; the system is seldom used in commercial ham transmitters.

deflected-beam-tube modulator

RCA has a tube, the 7360, that is designed especially for balanced modulators and balanced detectors. Its cathode gives off electrons that form a beam which travels between two deflection plates toward two output plates. The schematic diagram detailed in **fig. 9** looks pretty complicated, but it isn't if you keep the fundamentals you have already learned about balanced modulator operation in mind.

One big difference in this particular circuit is that it is self-oscillating. The carrier is generated internally. An external oscillator can be used, but there is little need, unless a separate oscillator is already part of another circuit. This one is a crystal-controlled Colpitts.

fig. 8. Pentode system uses screen grids to accept the audio.



The structure of the tube is such that the internally generated rf signal modulates the beam, but the beam doesn't strike either output plate. It goes right between them. So, you have that old familiar balanced-modulator characteristic: no rf-carrier output signal. You can call this type of carrier-signal injection parallel, since it has the capability of reaching either plate, as you will shortly see. The output, of course, is in push-pull.

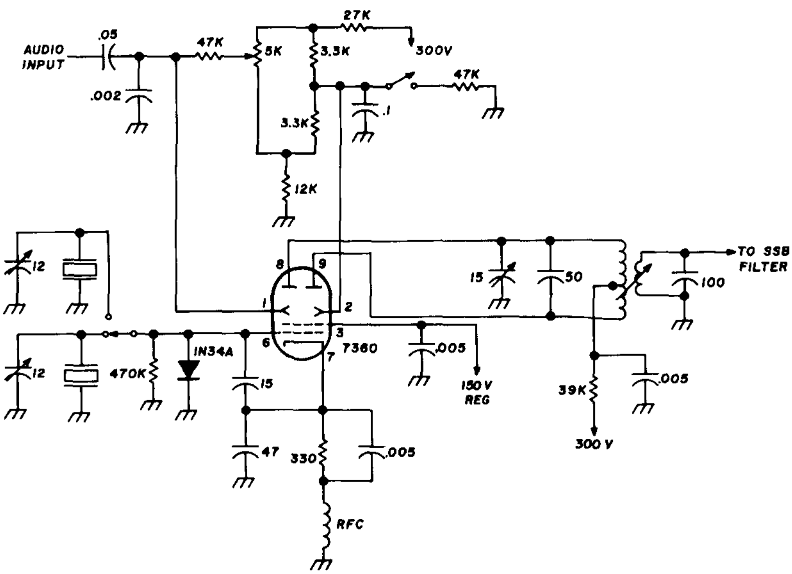
The speech signal is applied to the deflection plates of the tube, **effectively** in push-pull. One of the deflection plates is at ground potential for audio signals—the 0.1-μF capacitor does that job. The speech signal is fed to the other deflection plate.

The dc voltages on the two deflection plates must be equal when there is no speech input, so the rf beam misses both plates. That is done by a voltage-divider network across the 300-volt supply line, and the 5k potentiometer. Then, when speech modulation is applied to the deflection plates, the beam is pulled back and forth so it strikes the output plates, first one and then the other, at an audio rate. The speech signal thus produces an output that contains only the sidebands.

The beam-deflection balanced modulator has several advantages. It is easy to adjust and doesn't require a lot of tricky balance adjustments–just one potentiometer. A regulated supply is a good idea for the screen grid, which acts as a sort of plate for the oscillator. The circuit is capable of at least 60 dB of carrier suppression. This is beyond the most stringent requirements.

There you have the story of balanced modulators. Keep in mind the basics: the output mode is the opposite of the rf input mode, so the output will be devoid of the carrier frequency. The speech signal is fed to the stage so it can control gain, switch diodes, or deflect a beam that already contains the rf. The result of this mixing of signals is an output that contains the sidebands produced by the mixing process, without the carrier.

fig. 9. Beam-deflection balanced modulator; tube is a RCA 7360.



ham radio

two-year novice licenses

A number of rumors have been circulating around to the effect that Novice licensees who held a one-year Novice license which expired 22 November or thereafter, would receive a one-year extension to their license term. This is not true. According to the Federal Communications Commission in Washington, D. C., no extensions will be granted to Novice licensees because of the new two-year Novice-license term.

If you know any Novices whose licenses expired on or after 22 November 1967, check to make sure that they are not under the mistaken impression that their license has been extended for one year. If you hear other amateurs spreading this rumor, please tell them that there are no one-year extensions to Novice licenses. If they have any questions, have them check with their local FCC office.

ham radio