Some Principles of Radiotelephony

Part II — *Plain Talk About A.M. Fundamentals*

BY BYRON GOODMAN,* W1DX

• Part I appeared in the May issue. Although Part II is complete in itself, it is highly recommended that Part I (and Technical Topics in this issue) be read before the second installment. — ED.

Modulator Power

Apparently, one of the most confusing points about a.m. radiotelephony is the need for modulator power. Since the Year 1 amateurs (and commercials) have been looking for a means for feeding a low-powered audio signal into a big transmitter and getting out a husky 'phone signal. They're still looking.

We can think of only two general classes of modulation systems. One would be where *r.f.* power fed into the modulated stage is controlled, and the amount of r.f. appearing in the output is dependent upon the instantaneous value of the modulating signal. This could be represented as in Fig. 7A, and a typical example is a diode-modulator circuit. The modulated stage is not an amplifier of any kind — it is simply a point where r.f. power from another source can be controlled by a modulating signal.

The other general class of modulation system would be one where a modulated *amplifier* stage is involved. Here a relatively small r.f. signal is amplified by the stage to deliver a large r.f. power output. Any such device will, of course, have a d.c. power supply associated with it, since the increased power must come from somewhere, and the amplifier actually only transforms the d.c. power into r.f. It doesn't do this job completely — some of the d.c. power is used up by the stage in the process. A high-efficiency amplifier might transform 75 per cent of the d.c. power into r.f. power, while an inefficient one might deliver only 30 per cent. If the efficiency of the modulated stage is constant over a given range of d.c. input voltage, we can modulate the stage by using the modulating signal to control the *input voltage*. This is illustrated in Fig. 7B. If, however, the efficiency (and input current) of the stage can be varied by the modulating signal, then we can modulate the output by using the audio signal to control the *efficiency* (and input power) of the stage. This is illustrated in Fig. 7C.

The first example of a modulator, shown in Fig. 7A, is seldom used except at low power levels, and is of little more than academic interest in this discussion. The other two examples are the ones commonly used in transmitters.

*Assistant Technical Editor, *QST*.

Let's examine the example of Fig. 7B more closely. Since we know (even without showing an actual circuit) that the modulated amplifier is taking d.c. power from the d.c. voltage source, we can represent the amplifier by a resistance capable of dissipating that power. Further, we have agreed that the efficiency of the amplifier is constant, so we also know that this resistance is a constant one (not changing in some way with applied voltage), or else the control of the

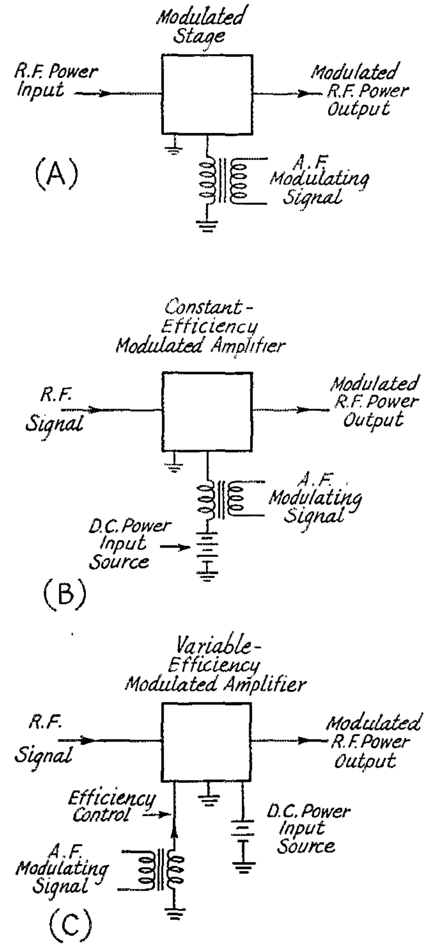
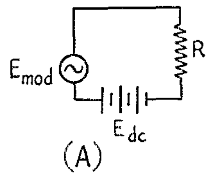


Fig. 7 — Three possible methods for modulating a radio signal.
(A) The modulating signal controls the passage of r.f. energy through the modulated stage. A diode modulator stage is an example of such a method.
(B) The modulating signal varies the power input to a constant-efficiency r.f. amplifier.
(C) The modulating signal varies the efficiency and input current of a variable-efficiency r.f. amplifier.

input voltage by the modulating signal must also vary in a similar manner. While this might be done, it would be an unnecessarily complicated system.

Thus we have a constant resistance, a d.c. source and an a.c. source connected in series, as in Fig. 8A. We have omitted any mention of r.f. now because we know that the r.f. output voltage is some constant percentage (the efficiency) of



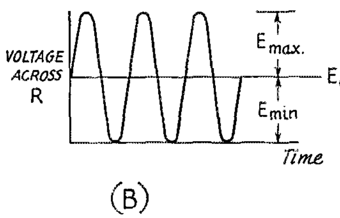


Fig. 8 — Fig. 7B looks like (A) above to the d.c. power source and the modulating-signal source.

(B) For 100 per cent modulation of the voltage applied to R in (A), the applied voltage will vary with time in this manner. E_{max} and E_{min} represent the voltage swings above and below the steady E_{dc}.

the input voltage. Our problem is to find what power, if any, must be furnished by the audio source, E_{mod}, for the maximum-permissible modulation percentage of 100.[1]

The d.c. source puts a voltage E_{dc} across the resistor R, and the audio source, E_{mod}, also develops its voltage across R. Maximum modulation will occur when the voltage across R is being swung up to a value equal to twice E_{dc} and back down to zero, as in Fig. 8B. This is obvious, of course, and it can be seen that the maximum and minimum peak swings, E_{max} and E_{min}, are equal in value to E_{dc}.

To see what all this means in the way of power in R, let's first review what we mean by power. In a d.c. circuit it is, of course, simply I^2R or $E^2 \div R$. I and E have steady values, so it's easy to know what numbers to use. In an a.c. circuit, it's a little more complicated, because the current or voltage is not constant but is changing rapidly, as in any of the sine-wave representations we have shown so far.

In scientific circles, "power" is called the "time rate of doing work." It might be considered a special kind of average. To illustrate this double-talk, let's look at Fig. 9.

In Fig. 9A, a resistor R is connected to a voltage source, E_{dc}. We know that the current through the resistor is $E_{dc} \div R$, and it will be constant with time unless we change E_{dc} or R.

[1] Why the maximum-permissible modulation percentage is 100 was explained in Part I. — Ed.

Fig. 9B shows a similar case with an alternating voltage source, E_{ac}, and the problem is to find what *peak* value of E_{ac} will do the same work as E_{dc} is doing. Now the only work that the current does in flowing through the resistor is to heat it, so here is our common factor. We recall that the power dissipated in the resistor for the d.c. case, and hence the power supplied by the d.c. source, is I^2R or $E^2 \div R$.

We can draw a curve for this as in Fig. 9C. When we try to do the same thing for the a.c. circuit, we're stumped. At least we are until we treat each little period of time separately. Then it isn't too difficult. All we have to do is to take the value of current *at that instant*, square it, and multiply by the resistance. When we do this we get a new curve that looks like Fig. 9D. This turns out to look like a sine wave of twice the frequency of the original. You could call this a graph of the "instantaneous power" (but be careful how you use that expression, "instantaneous power"). What we want to find is how the a.c. of Fig. 9B relates to the d.c. of Fig. 9A when they both have the same heating effect on R. It's obvious that if the frequency of the a.c. were very low, the heat changes in R could be detected if we were brave enough to touch the resistance, but any a.c. we would be working with would be of a frequency high enough so that the heat changes during a cycle wouldn't be apparent. So at any practical frequency it must reach an "average" of some kind. The mathematicians will tell you that the "average" of a curve like this can be obtained by taking the area under the curve (shown shaded) for a given time interval and dividing it by the time. The answer is a single value that, working over the same time interval, would give the same total area. But the value of our power for the d.c. case is just the same thing — it is a figure that, over a given time interval, gives the area under the curve (shaded portion of Fig. 9C). You can tell by just looking at the two power curves that the peak "instantaneous power" for the a.c. case is a high value compared with the d.c. case.

It all works out, if you dive into the mathematics of it, that an a.c. with a peak-to-peak swing of 2.828 amperes has the same heating effect as a d.c. of 1.0 amperes. With a peak-to-peak value of 2.828, the peak value is half of this, or 1.414. If the peak value is 1.0, the d.c. equivalent value is 0.707. This d.c. equivalent value is called the "effective" or "r.m.s." ("root-mean-squared") value — it's what an a.c. ammeter indicates for you. There are devices known as "peak meters" that can indicate peak values for you — they're useful for measuring a.c. that is made up of more than a pure single frequency, where the relationship between peak value and r.m.s. value is not known as it is in this case.

Now let's get back to that modulator-power requirement. Referring again to Fig. 8B, we can recall that in this 100-per-cent-modulation case, $E_{dc} = E_{max} = E_{min}$. With our new-found knowledge about a.c., we see now that the effective value of E_{mod} is 0.707 of the peak value, and since the peak value is E_{max} (or E_{min}), the effective value of $E_{mod} = 0.707\ E_{max}$. Without knowing about the a.c., we knew that the d.c. source E_{dc} was delivering power to the load R that can be computed by

$$\text{Power supplied by } E_{dc} = \frac{E_{dc}^2}{R}$$

$$= \text{d.c. power supplied.}$$

Independent of this, the source E_{mod} furnishes power computed by

$$\text{Power supplied by } E_{mod} = \frac{(0.707\ E_{max})^2}{R}$$

$$= \frac{0.5\ E_{max}^2}{R}$$

Since E_{max} has the same value as E_{dc}, we see that, in a constant-efficiency modulation circuit, *with 100 per cent sine-wave modulation, the modulator must furnish power equal to one-half the d.c. power supplied to the modulation circuit.*

There is one point you shouldn't overlook. We said nothing about the efficiency of the modulated stage except that it was constant. It might be only 40 per cent or it might be as high as 75 per cent, but we would still need the same amount of modulator power for 100 per cent modulation. We need *power* to swing the voltage around on the modulated stage, and there is no way around it. Of course, if the modulation percentage is less, we will require less power from the modulator. If the modulating signal is a complex one, like voice, in which the r.m.s. value is less than 0.707 of the peak value, then we will require less modulating power. But the modulating-power source should be capable of delivering the power necessary for 100 per cent modulation with a sine wave.

By now you're itching to ask about the other modulation system, the one in which the *efficiency* is varied by the modulating signal (Fig. 7C). This looks like pay-dirt territory, because conceivably the unnamed "efficiency-control" circuit has a high effective resistance, and it won't take much modulator power to swing it all over somebody's half acre. Quite true. Such circuits can be made in which the modulating voltage can be developed across a high resistance and the power involved is low (control-grid modulation is an example). But you still pay a price. For a starting point, remember that we must swing the efficiency up and down about a mean level. It is obvious that the maximum efficiency that we can swing up to is the maximum the tube is capable of (maybe 75 per cent, with your fingers crossed). So our mean level, or "operating" point, will be down to half of this, or 37 per cent, in the best possible case. And because the efficiency is low, and the tube itself is dissipating most of the input power, the input to the stage must be lower than what could be run with higher efficiency. Otherwise the tube would overheat. The net effect is that the *carrier output power* is about *one-fourth* what would be obtained from the same tube and a constant-efficiency modulation system.

So back to the "constant-efficiency" modulation systems. You probably have recognized by now that plate modulation falls under this heading. The plate-modulation case is clear-cut: The modulator swing applied to the plate circuit must have a peak swing equal to the d.c. plate voltage, and this means a modulator-power requirement of one-half the d.c. plate power source. The tube can run at its best efficiency of as high as 70 or 75 per cent, and we can get out a husky and fully-modulated carrier, if we will supply the necessary (and perhaps expensive) modulator power.

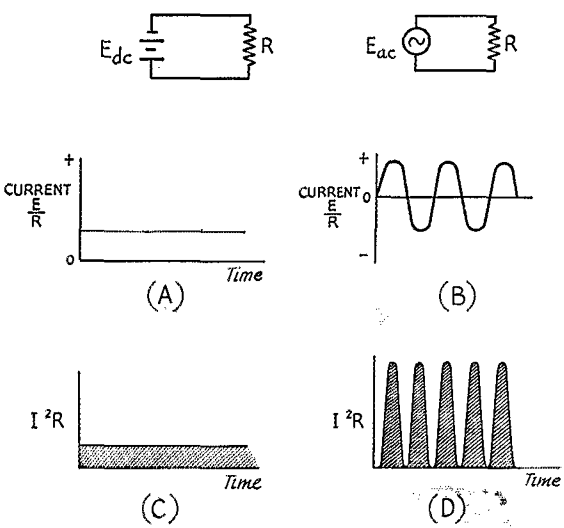


Fig. 9 — (A) A d.c. source and load R, with a plot of current *vs.* time.
(B) An a.c. source and load R, with a plot of current *vs.* time.
A plot of $I^2 R$ *vs.* time for the d.c. case (C) and for the a.c. case (D). Notice that each cycle in (B) gives *two* cycles in (D).

How about screen modulation? The screen circuit doesn't take much d.c. power, so the modulator power requirements are low. Quite correct. But how do you go about getting that necessary "operating point," about which the screen voltage will be varied? If we make it the normal screen voltage for the tube used as an r.f. amplifier, we're going to swing it up to twice this voltage on peaks. Two things can happen. The tube can burn up because it's being overloaded. Or the output can increase without hurting the tube, showing that we weren't getting as much out in the first place as we could have got.

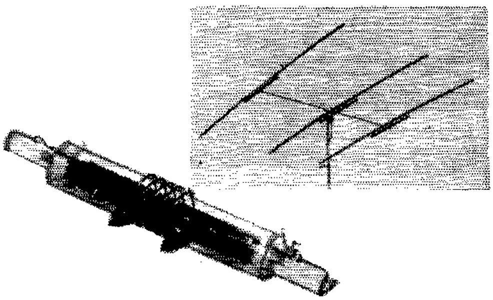
How, then, can we modulate this amplifier via the screen grid? The only way is first to find what the tube can do as a straight r.f. amplifier, and then cut the screen voltage back to about one-

(Continued on page 112)

NOW AVAILABLE!

Pre-Wound Coils for the VEST POCKET BEAM

as shown in QST, May, 1954



BELOW: Close-up — ABOVE: Installation

TUNED—READY TO INSTALL

Set consists of three coils (reflector, director and driven element) wound on ¾″ polystyrene bars complete with coil covers and end plates. Driven element coil includes 5-turn link for 52-ohm coax line.

All coils are wound and tuned by WØQFG and WØVZC, designers of the VEST POCKET BEAM. Coil assemblies are complete and ready to install.

SET OF 3 COIL ASSEMBLIES $24.95 Postage Paid

CONVERT YOUR 10 METER BEAM

Since the element lengths for the VP Beam are about the same as those for a 10-meter beam, it is a simple matter to convert to 20-meters provided the *inside* diameter of the center section is ¾″. Bring your 10-meter beam out of moth balls and start working on 20.

COMPLETE VP BEAM KITS AVAILABLE

VP BEAMS

Kits include pre-wound coils, elements, clamps, insulators, element panels, hardware, 12′ boom and mounting assembly. Full details on request.

VP BEAMS

VEST POCKET BEAM CO.

6635 Delmar Blvd., Room 324, St. Louis 5, Mo.

Radiotelephony

(Continued from page 16)

half. The plate current drops to one-half (approximately) of its previous value. If then we think of the screen circuit as the R of Fig. 8A, we see that we can swing the screen from this value up to a safe peak value or back down to zero, for 100 per cent modulation. But here's the unhappy part. When we modulate the screen, we have an *efficiency*-modulation system quite parallel to control-grid modulation, and the output obtainable with a screen-grid-modulated stage runs just about the same as it does for control-grid modulation of the same stage. Screen-grid modulation may be a little easier to apply and adjust in some cases, but it is no end-of-rainbow pot-of-gold deal. Clamp-tube modulation is simply a resistance-coupled version of screen-grid modulation.

You may run into "cathode modulation," which is a *combination* of grid and plate modulation. Here again you don't get something for nothing — the more modulator power you can supply, the more nearly the system approaches plate modulation and maximum output for a given r.f. amplifier tube.

Peak Power Input

Some time you're going to run into a sage who will mention that the "peak power input" to your 100 per cent plate-modulated 'phone rig is 4 times the unmodulated d.c. input, and as proof he will point out that on positive peaks the voltage is doubled on the modulated stage. (This is the same as the peak of E_{max} in Fig. 8B.) He will show that the doubled voltage is equal to 2 E_{dc} and that therefore the power is $(2\,E_{dc})^2 \div R = 4\;E_{dc}^2 \div R$. Then he'll try to confuse you by asking where this extra power comes from since your modulator and d.c. supply together only furnish a power equal to $1\frac{1}{2}\,E_{dc}^2 \div R$. Don't let him snow you — you just remember back to those earlier paragraphs about "instantaneous power" and ask him where the power is hiding on the negative peaks!

The power delivered by the a.c. source, E_{ac}, is an average figure as measured by any practical measuring equipment. In other words, the meter looks at the various "instantaneous powers" over a cycle, averages them (the values in Fig. 9D) and comes up with an answer. The a.c. source, E_{ac}, is working hard some of the time and coasting some of the time to come up with the figure indicated by the meter — your heckler is picking one small fraction of the time and trying to confuse you with it.

Linear Amplifiers

As a last resort in your search for power, you may wonder about modulating a low-powered stage and then building up the power level in a following (linear) amplifier. If the modulated stage is really low-powered (5 or 10 watts r.f. output), and the following linear amplifier has high sensitivity (requires little driving power), you can sometimes gain from this system in

(Continued on page 114)