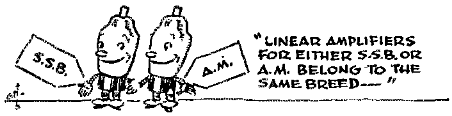
• Technical Topics —

Linear Amplifiers for A.M.

One of the by-products of single sideband is a revival of interest in linear amplifiers for amplitude modulation, particularly on the part of a.m. users who don't understand the limitations of the linear. Linear amplifiers for either s.s.b. or a.m. belong to the same breed and operate in exactly the same way. The difference between



the two is in the kind of signal they have to handle, not in the amplifiers themselves.

A single-sideband signal is essentially one whose amplitude is proportional to the instantaneous amplitude of the modulating waveform, so when there is no modulation there is no signal. Usually, this means that there is comparatively little d.c. input to the amplifier during those periods when there is no modulation or low-amplitude modulation — periods that represent a large percentage of the total time in voice communication. This is quite similar to the operation of a Class B modulator — which in fact is simply a linear amplifier operated at audio rather than radio frequencies.

In contrast, in a proper a.m. signal the *average* amplitude stays the same whether or not there is modulation. Merely generating an unmodulated carrier demands just as much d.c. input as generating a fully-modulated signal. This is the key to the difference in ratings on a linear amplifier for a.m. as compared with s.s.b.

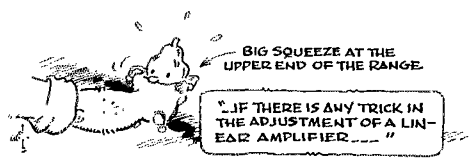
What Is Linearity?

The word "linear" in this connection implies that there is a fixed ratio between the amplitude of the r.f. signal applied to the grid and the amplitude of the r.f. output voltage in the plate circuit. In other words, any change in the r.f. voltage applied to the grid is accompanied by a proportionate change in the amplifier's r.f. output voltage. So long as this simple relationship holds true the amplifier's output faithfully reproduces the variations in — that is, the modulation on — the signal applied to the grid.

One operating requirement that will be recognized immediately is that any r.f. voltage, no matter how small, applied to the grid must cause *some* output to be delivered by the plate, and this in turn requires that some plate current must flow even with the smallest possible grid signal. That is, the grid bias cannot be greater than the plate-current cut-off value (although smaller bias is permissible); any larger value would "clip" the signal. This bias requirement establishes a ceiling on the tube plate efficiency.

At the other extreme, the r.f. grid voltage must not be allowed to become so large that a further increase in it will not be accompanied by a corresponding increase in the r.f. output amplitude. If increasing the r.f. grid voltage does not increase the output the amplifier is said to be "saturating," and the modulation is clipped on the up-peak in much the same way that biasing beyond cut-off would clip it on the down-peak. Both types of clipping distort the output signal and the amplifier is no longer linear. The no-saturation requirement establishes the operating range.

What you can get out of a linear amplifier depends principally on how much power can be squeezed out at the upper (large-signal) end of the



linear range. If there is any trick in the adjustment of a linear amplifier, this is it.

Plate Efficiency

What makes a linear amplifier linear? With the plate modulation customarily used in a.m., the plate voltage on the Class C amplifier is varied above and below the d.c. supply voltage at the modulation rate. The amplifier's plate current varies right along with the plate voltage, and so when the plate voltage is instantaneously doubled at the modulation up-peak the plate current likewise is doubled. Similarly, when the plate voltage is instantaneously zero the plate current likewise is zero. (These variations occur at audio frequency and so do not register on d.c. meters.) Since the plate voltage and plate current vary together, the Class C plate circuit "acts like" an ordinary resistor, in which the current is proportional to the applied voltage and the power is proportional to the square of the voltage.

In a linear amplifier the supply voltage does not vary with the modulation. The only thing in the plate circuit that can be varied is the plate current. The modulated r.f. grid voltage can cause corresponding variations in the plate current, and without attempting to dig into the technicalities of tube operation, it can be said that these plate-current variations can, within the operating limits mentioned above, be responsible for a fundamental-frequency r.f. output current whose modulated amplitude faithfully follows the amplitude variations in the modulated r.f. grid voltage. To a fair approximation, as most tubes are operated, the *d.c.* plate current is proportional to the amplitude of the r.f. grid voltage. Thus we have a circuit in which the plate voltage does not vary at an audio-frequency rate during modulation but the plate current does. This means that at a modulation up-peak the plate current is twice the carrier-only value while the plate voltage remains the same; that is, the power input is doubled. Compare this with plate modulation where the voltage and current are both doubled and the power is four times.

Now it is *necessary* to reach four times the carrier power on a modulation up-peak if the amplifier is to operate without distortion. The fact that the r.f. output current and r.f. grid voltage go hand in hand does guarantee that the output power will meet this condition, because on the modulation up-peak the r.f. output current is doubled as compared with the carrier value. Twice as much current in a constant value of resistance — and the load resistance for the tube, as represented by the load coupled to the plate through the tank circuit, *is* constant — means four times as much power, by Ohm's Law. Thus even though the power input is only twice as great at the peak, the power output is four times as great. How is the difference accounted for?

This can be made clear by citing an example. Suppose that at the up-peak the instantaneous plate current is 200 ma. and the plate voltage is 1000, an input of 200 watts. If the plate efficiency is 70 per cent, a not-unreasonable value, the output will be 140 watts. If the r.f. grid voltage is now dropped to one half its former value, corresponding to the unmodulated carrier figure, the plate current will drop to 100 ma., and since the plate voltage remains the same the input is 100 watts. The r.f. output current also drops to

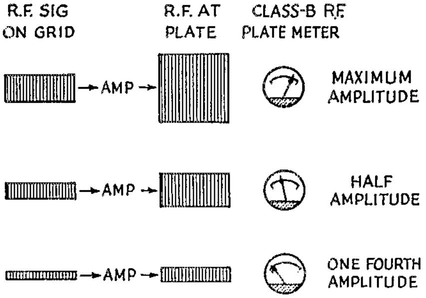


Fig. 1 — Three levels of operation in a linear amplifier when the grid is driven by a steady (unmodulated) signal whose amplitude can be adjusted within the limits of linear operation.

If the maximum amplitude within the linear range is as shown at the top, a half-amplitude signal on the grid will be followed by a drop to one-half in the output amplitude. The d.c. plate current likewise will drop to one-half the value it had with the maximum-amplitude signal. Similarly, decreasing the grid drive to one-fourth amplitude will be followed by corresponding decreases in output amplitude and plate current.

Strictly speaking, the plate meter will behave as shown only when the amplifier is operated true Class B; that is, biased to cut-off. With Class AB operation, where the no-signal plate current is appreciable, the d.c. plate current will not follow the grid driving voltage amplitude at low levels. Class AB operation is usually preferable to straight Class B because the AB amplifier is more truly linear at low levels.

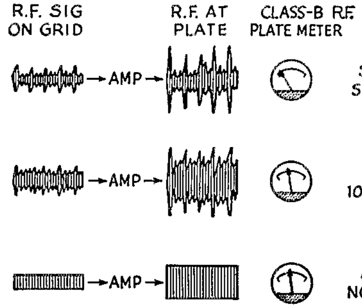


Fig. 2 — Behavior of the linear amplifier with a modulated signal. These drawings are to the same scale as Fig. 1, so the peaks in the s.s.b. and 100 per cent a.m. cases have the same height as the maximum-signal condition in Fig. 1.

With s.s.b., the plate current will vary at a syllabic rate according to the signal amplitude, as suggested in the upper drawing. In most cases, the d.c. meter will just "kick," on peaks, to about half the value shown in the maximum-signal drawing of Fig. 1. The a.m. signal will show the same plate-current reading whether or not the carrier is modulated, as shown by the two lower drawings above. The carrier amplitude and plate-meter reading are just half the maximum value shown in Fig. 1.

Note that the a.m. modulation drawings show a greater area than the s.s.b. drawing even though both signals have the same instantaneous amplitude on modulation peaks. This means that the a.m. signal has more average power than the s.s.b. signal, and since the power is handled by the amplifier at about half its maximum possible efficiency, the power used in heating the plate is considerably greater. Of the greater average power put out in the a.m. signal, over two-thirds is carrier and less than one-third is voice modulation.

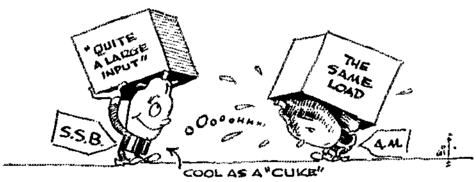
half its peak value and so the output is one-fourth its peak value, or 35 watts. The plate efficiency is now 35/100 or 35 per cent instead of its peak value of 70 per cent.

At other values of r.f. grid voltage the plate current and plate efficiency are proportional. The smaller the r.f. grid voltage, the smaller the plate current, plate power input, and efficiency. This is simply a consequence of the fact that while the d.c. input is directly proportional to the r.f. grid voltage, because the plate voltage is constant, the r.f. output is proportional to the *square* of the r.f. grid voltage.

Handling the Carrier

These relationships hold regardless of the type of signal being amplified — i.e., whether it is a.m. or s.s.b. In either case the power output, power input, and plate efficiency vary with the amplitude of the modulated grid signal. The loss in the plate of the tube, which is what determines how much power the tube can handle, likewise varies with the modulation. Thus in the example above, where the input on a modulation peak is 200 watts and the output is 140 watts, the power left on the plate is the difference, 60 watts. At the half-amplitude point the power input is 100 watts and the output is 35 watts, leaving 65 watts on the plate. Note that although the input is halved, the plate loss actually is a little higher than under peak output conditions. The fact is that the plate loss does not vary much with the grid signal level except at low levels where the input likewise is low.

Now in both s.s.b. and a.m. the grid signal amplitude, the plate input and the power output all are varying at an audio-frequency rate. The s.s.b. signal starts from zero with no modulation, just like the Class B modulator, and when the amplifier is biased near cut-off the power input and plate loss are substantial only when the modulation is fairly high. This means that the plate of the tube is heating only part of the time. Add to this the fact that voice waveforms commonly have only about half the energy content of a sine wave and you have the condition where the amplifier is delivering its full output on modulation peaks with an *average* input of only about half the power that would be required to sustain the peak. Both these things mean that the *average* power loss in the plate is fairly low with an s.s.b. signal — in the neighborhood of one-fourth the loss under peak conditions. The tube can handle quite a large peak input without getting hot.



The a.m. signal, however, does not start from zero with no modulation. It works up and down about the carrier level, which is just one-half the modulation up-peak level. When there is no modulation the tube is still called upon to deliver the unmodulated carrier, and since the carrier is at half level the output is one-fourth the modulation-peak output and the plate efficiency is one-half the modulation-peak efficiency. Actually, the efficiency increases with modulation, but since there are times when a speaker has to stop to catch his breath, the amplifier has to be designed to handle the unmodulated carrier safely. The tube gets hotter with no modulation than with it — quite in contrast with the s.s.b. case.

To resume the example above, on a.m. the tube would have to be able to dissipate 65 watts safely on its plate in order to give a carrier output of 35 watts. On s.s.b. the same tube with the same output on the modulation peak would have an average plate loss of around one-fourth the peak loss, or about 15 watts. Putting it another way, if the rated plate dissipation of the tube is the limiting factor in design, the a.m. amplifier would require a tube having a rated plate dissipation of 65 watts, but the same tube as an s.s.b. amplifier could give a peak output 65/15 or about four times as great as the peak output on a.m., the plate heating being the same in both cases.

Actually, the 70 per cent modulation-peak efficiency assumed in the example is a little optimistic in many cases, and for estimating purposes it is convenient to assume that the maximum efficiency will be 66⅔ per cent. This leads to the rule of thumb that on a.m. the carrier power output that can be obtained from a linear amplifier is equal to half the rated plate dissipation of the tube. It is easy to see why a linear amplifier is not worth while unless it uses a fairly big tube.

Where the Linear Might Be Useful

Altogether, it would seem as though the linear for a.m. would offer few attractions. This is especially so where it is being considered for following a plate-modulated transmitter running 75 to 150 watts input. The possible power gain, in most cases, is too small to be interesting.

It is possible to visualize cases, however, where there might be some advantages in the linear amplifier. Most such amplifiers need very little driving power for fairly substantial power output. By using any of several tetrodes in Class AB_1, or zero-bias triodes such as the 811A, there is no need to provide extra driving power simply for the sake of throwing it away to get good regulation — i.e., low distortion — in the amplifier's grid circuit. Hence the driver need supply — only a few watts of modulated output. Also — and this is a point seldom appreciated — the *total* d.c. power required by the complete transmitter is just about the same, when a low-power driver followed by a linear amplifier is compared with a plate-modulated amplifier with its higher-power driver, Class B modulator, and more elaborate speech amplifier. The total amount of equipment is considerably less, for the same carrier output, with the linear amplifier, and in most cases the total cost is lower. The catch is, of course, that the most carrier output that can be hoped for with a kilowatt input is around 350 watts as against 700 or 750 with plate modulation. But if your requirements are not for more than 300 to 350 watts carrier and you're starting the complete transmitter from scratch, it might be interesting to work up the comparative costs of the two systems.

One of the nice features of such a rig is the ease with which an s.s.b. exciter can be substituted when you reach that stage. — *G.G.*

Strays

"For sustaining service to amateur radio, and administrative leadership," the Institute of Radio Engineers conferred the grade of Fellow upon George H. Bailey, W2KH, its executive secretary.

The Association for Applied Solar Energy is retaining permanently in Phoenix, Arizona, the Solar Powered Amateur Radio Station (September *QST*). The exhibit will be kept in a group for display with appropriate credit to ARRL and W1CUT, the exhibitor. In connection with the exhibit a new $700,000 solar research laboratory will be opened by the Stanford Research Institute, also in Phoenix.