The Lenkurt® Demodulator

NEWS FROM LENKURT ELECTRIC

VOL. 10 NO. 9 SEPTEMBER, 1961

# THE NEW MICROWAVE

## Part 1

*In the dozen years or so since the first commercial microwave systems went into service, microwave radio has undergone astonishing growth and change. To meet new demands, channel capacity has steadily increased, performance has been improved, and power consumption and physical size reduced.*

*Many desirable new features, however, tend to oppose each other. For instance, although the use of transistors is very appealing because of their structural characteristics and low power requirements, transistors usually introduce more noise and distortion than electron tubes. Greater bandwidth imposes a severe problem of linearity in all circuits, but particularly in modulated klystrons and in the receiver discriminator.*

*This article is the first of two which discuss some of the problems encountered in designing a new, high-capacity transistorized microwave system, and how they were solved.*

Just a very few years ago, it seemed unlikely that there would soon be any substantial need for microwave systems able to carry more than one or two hundred voice channels (except, of course, in the great transcontinental "backbone" routes). Today, however, there is a surprising demand for equipment capable of handling 600 channels or more. Even if some of the "need" may be premature, or stimulated by the glowing promises of newcomers to the field, there still remains a small but growing body of microwave users whose needs are very real and for whom the higher capacity means lower costs and greater efficiency.

Many different types of problems appear in designing a system to accommodate 600 voice channels or a wide-band video signal. Part of the difficulty is economic, part is technical. "Brute force" methods which have been used for very long toll circuits over high density routes are generally too expensive for use in equipment intended for a broader range of applications. One way out of this problem is to devise simpler, more sophisticated techniques which yield the same performance as the older methods. Actually, this approach is virtually mandatory since efforts to attain greater channel capacity by merely scaling up older designs, or to "transistorize" the equipment by substituting equivalent transistor circuits for their original electron tube counterparts, will prove disappointing.

## Transistor Problems

The basic nature of transistors introduces problems of a sort not usually encountered in electron tube equipment. One of the outstanding problems is the remarkable sensitivity of transistors to all sorts of outside influences. Very small changes in operating bias may cause rather large changes in the gain, stability, and frequency response of a transistor circuit, particularly in wideband circuits. Even the life expectancy of transistors seems to be greatly influenced by the way in which they are used and the temperature at which they operate.

Electron tubes are essentially "one-way" devices, maintaining almost perfect isolation between the output circuit and the input. Changes in load have little or no effect on the input. In transistors, however, small changes in load impedance may cause rather large variations in the total performance of the circuit. Numerous techniques have been developed to compensate for these transistor characteristics: temperature-sensitive resistors in the power source of the transistor circuit alter the operating bias to compensate for the temperature characteristics of the transistor. Similarly, voltage-sensitive diodes and varistors are employed to reduce the effect of power supply variations. Despite the availability of these techniques, the problem becomes exceedingly difficult as transistors are used in high frequency

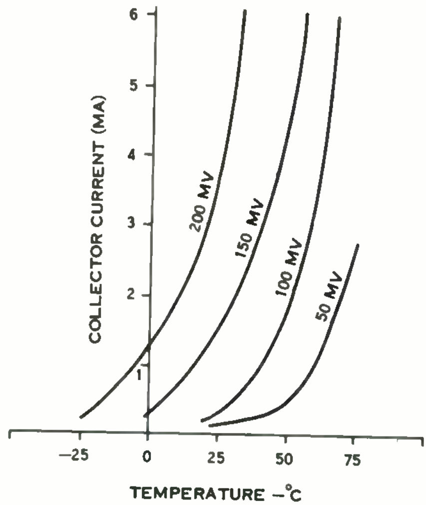



*Figure 1. Output current versus temperature in typical common-emitter transistor circuit for several values of collector bias.*

circuits with much greater bandwidths. Figure 1 illustrates how transistor characteristics may vary with temperature.

## Transistorized IF Amplifier Design

Problems of this type become most acute in the design of a wideband IF (intermediate frequency) amplifier for use in a microwave receiver. It is in this section of the microwave system that the signal is weakest, where the greatest amplification occurs, and where phase and amplitude distortion are most likely. In short, this is the portion of the system where skimpy or inadequate engineering can be most harmful.

In conventional design practice, each IF amplifier stage is tuned to achieve maximum gain over the desired band of frequencies. The overall bandpass and phase shift characteristics of the receiver are determined by the chain of tuned amplifiers, each of which is important to receiver performance.

At the standard 70-mc IF frequency, component values in the tuned circuits are quite small, and even the inter-electrode capacitances of electron tube amplifiers are an important part of the circuit tuning. Although these values don't change appreciably with the age of the tube, they do vary from tube to tube, and the phase and amplitude characteristics of the IF amplifier can be considerably altered merely by replacing an aging tube.

In transistor amplifiers, the problem may be worse. Here, replacement is less of a problem than maintaining the stability of the circuit in the face of changing conditions. Transistors introduce a considerable capacitive or inductive reactance, depending on the operating frequency and the way in which the transistor is used. To a much greater extent than in electron tubes, this reactance varies according to the bias applied to the transistor.

Normally, this wouldn't have much importance except that in a microwave system, wide variations in signal level exist because of fading, and these are normally compensated for in the IF amplifier. This is achieved by applying an AGC (automatic gain control) bias voltage to various stages of the amplifier.

When this technique is used in transistorized amplifiers, the desired gain control may be achieved by varying transistor bias, but the resulting changes in transistor reactance affect the tuning characteristics of the stage. The overall effect is to degrade the receiver bandpass and phase shift characteristics and introduce a subtle form of intermodulation distortion.

There are several ways of reducing this type of difficulty. One is to provide far more gain than is actually required for the signal, then use most of it for negative feedback and AGC. The negative feedback helps stabilize the individual stages, and the AGC controls the operating point of the amplifiers. This conventional approach encounters serious difficulties in transistorized equipment as the bandwidth is increased. The tuned transistor circuits tend to become more and more unstable. The common-emitter transistor connection (that will most likely be used in order to achieve the necessary gain) must be neutralized, and the tuning and line-up of the equipment becomes increasingly critical. In very broad-band circuits, feedback may not be very effective due to the difficulty of maintaining the required 180° phase shift over the entire bandwidth. Because of the critical tuning required, actual field perform-

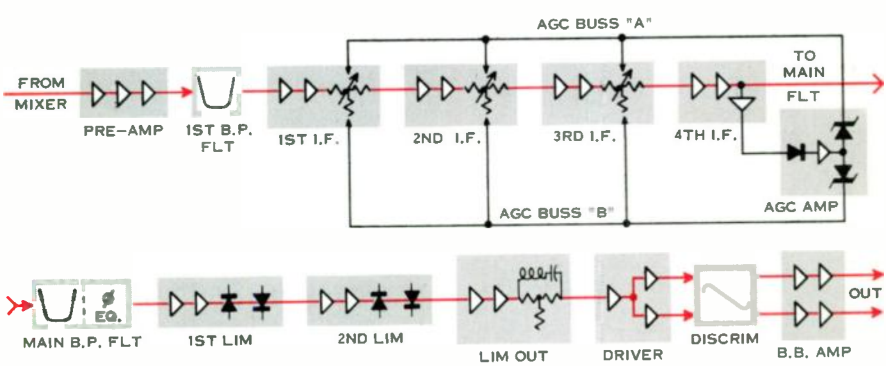
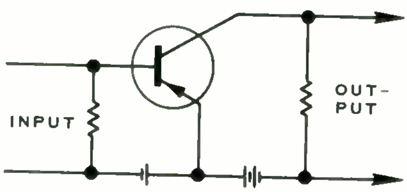



*Figure 2. Simplified block diagram of Type 76 receiver IF section. Separation of tuned circuits and transistor amplifiers provides more stable operation, better delay equalization.*

ance is likely to become degraded.

An entirely different approach was taken in Lenkurt's new *Type 76* microwave equipment. Rather than fight the complicated interaction of transistor behavior and tuned circuits, the two were entirely divorced from each other. As shown in Figure 2, all tuned circuits were removed from the amplifier stages and isolated in two bandpass filters. This provides several advantages: the bandpass characteristics of the receiver become independent of the amplifiers, the signal level, or the way in which the amplifiers are operated. Replacement of amplifier components no longer has any effect on the tuning characteristics of the receiver.

In addition, this arrangement makes it possible to include an envelope delay equalizer which exactly matches the characteristics of the IF bandpass filters, thus permitting much tighter control of envelope delay, a very important consideration in the transmission of color television and high-speed pulse or data signals.



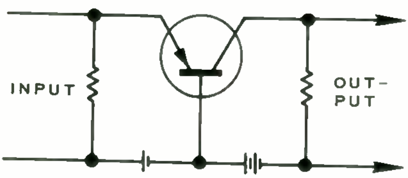




*Figure 3. Comparison of common-emitter and common-base transistor arrangements. CE provides high current gain, but may be unstable in wide-band circuit. CB is very stable but requires transformer output.*

With the tuning elements eliminated from the amplifier circuits, it became possible to take a fresh approach to the design of the transistorized IF amplifier circuits. The object was to improve circuit stability and frequency response, and to reduce the effects of temperature, time, and other external influences. Since most of the trouble in very wide-band transistor amplifiers comes from the variation in reactance within the transistors themselves, circuits were devised which overcame this effect, thus making the IF amplifier essentially a resistive, constant-impedance network. In this approach, three closely-related techniques were used: a stable transistor configuration, an improved inter-stage coupling technique, and transistor reactance cancellation.

## Transistor Characteristics

Throughout the IF amplifier section, a common-base transistor circuit was used, instead of the more typical common-emitter arrangement. The common-emitter configuration is the most widely used transistor circuit because it provides the greatest power gain of the three possible arrangements, and is easy to use because of biasing and impedance-matching considerations. By contrast, the common-base arrangement is little used because it has a current gain less than unity and therefore always requires some form of transformer for coupling it to following stages, thus increasing manufacturing cost.

Unfortunately, the popular common-emitter circuit is the least stable of the three from the viewpoint of temperature and bias variations. In addition, age shows its greatest effect in the common-emitter version. Figure 3 shows these basic arrangements.

The reason for this contrast in stability lies in the basic nature of transistors. The current gain or $\alpha$ of a transistor connected in the common base configuration is only slightly affected by age or

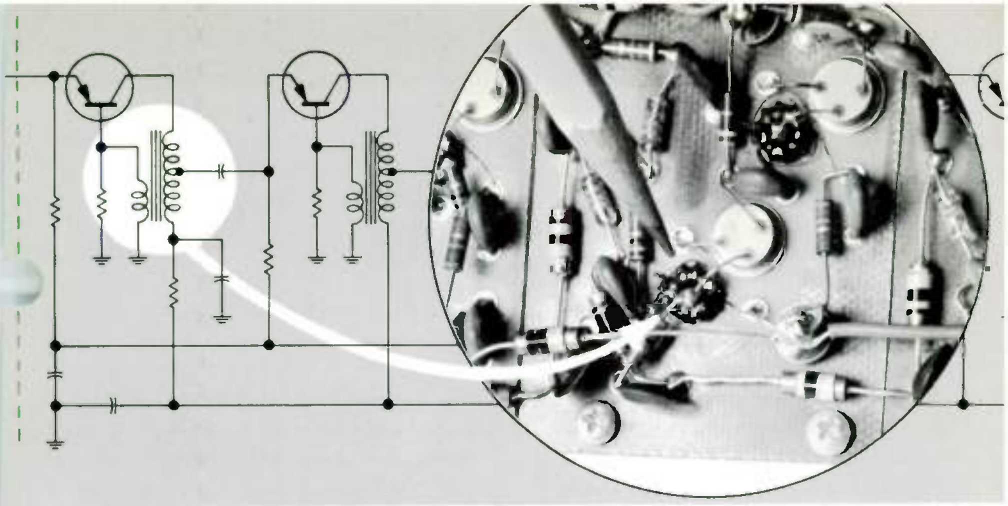


*Figure 4. Simplified schematic and photograph of typical 76 IF amplifier stage. Toroidal interstage transformer (at tip of pencil) provides flat frequency response to 200 mc, allows reactance feedback, thus stabilizing the transistor and extending its frequency response.*

such external factors as temperature and bias. In the common-emitter arrangement, however, gain is proportional to $\beta$ which is controlled by $\alpha$ according to the relationship

$$\beta = \frac{1}{1-\alpha}\ .$$

A quick bit of arithmetic shows that very small changes in $\alpha$ result in very large changes in the value of $\beta$. For instance, should the $\alpha$ of a transistor change from 0.995 to 0.994, the gain of the common-base configuration will only vary by 0.1%. In the common-emitter arrangement, however, the gain would drop from 200 to 166, a change of 17%. At lower frequencies, the problem of compensating for this change in gain is much less difficult and the greater economy of the common-emitter circuit usually recommends it over the common-base arrangement.

## Transformer Coupling

In order to take advantage of the superior stability of the common-base connection, it was necessary to provide an interstage coupling that would match the output impedance of one stage to the input impedance of the next and, at the same time, convert the voltage gain of the amplifier to useful current gain.

This requirement can be satisfied by a transformer, but conventional transformers cannot operate efficiently at 80 mc and still provide a good impedance match to the transistors.

In the 76 receiver, a novel interstage coupling transformer is used which satisfies all these requirements with remarkable efficiency. Not only does this device provide efficient coupling and excellent impedance-matching characteristics, it opens the way to sharply-improved transistor performance. Figure 4 shows a simplified schematic and a photograph of typical IF amplifier stages in the 76 receiver. Interstage coupling is achieved by autotransformer action in the main winding of the toroidal transformer. This produces a stepdown in voltage but an increase in signal current, thus correcting the low current gain of the common-base connection. The special transformer design used in the Lenkurt interstage coupling provides uniform frequency response out to at least 200 mc, so that IF frequency response is limited by transistor characteristics rather than by the coupling network. The black curve of figure 5 shows typical frequency response of the resulting IF amplifier.

## Transistor Reactance Cancellation

Although transformer coupling is unusual at these frequencies, this particular kind of transformer circuit provides still other benefits not yet attainable by more conventional techniques.

Transistors, like most components, unavoidably introduce reactance, and this limits the ultimate frequency response of the transistor. Because of the special nature of the Lenkurt interstage transformer it is possible to apply a special form of feedback to the transistor base which tends to neutralize the reactance appearing in the transistor itself. Unlike conventional negative feedback which corrects *amplitude* variations, this feedback arrangement tends to offset the changes in circuit *reactance* caused by the changing signal voltage across the transistor junction. The net result is an amplifier circuit that is essentially resistive and remarkably free of phase distortion.

## AGC Technique

One of the important characteristics of transistors is that variations in load resistance cause a corresponding change in input impedance. Similarly, variations in input impedance affect the transistor output impedance, and these changes may have an undesirable effect on the over-all performance of wide-band circuits. Even though these undesirable effects are largely overcome in the Lenkurt 76 IF strip, due to the interstage coupling and type of feedback used, an improved automatic gain control technique was developed to maintain the inherent stability of the IF amplifiers under all conditions.

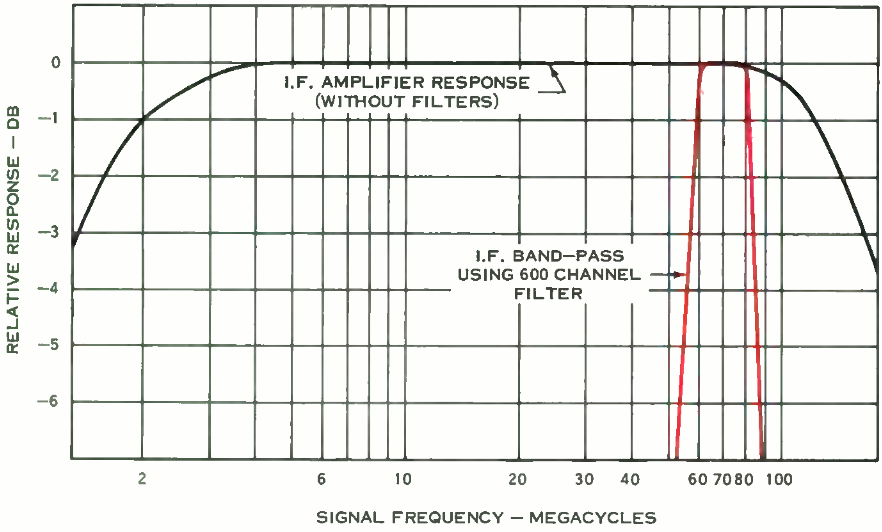



*Figure 5. Frequency response of Lenkurt 76 IF amplifier with (red curve) and without (black curve) lumped bandpass filters. Other filters and equalizers may be substituted in applications having different bandwidth requirements.*

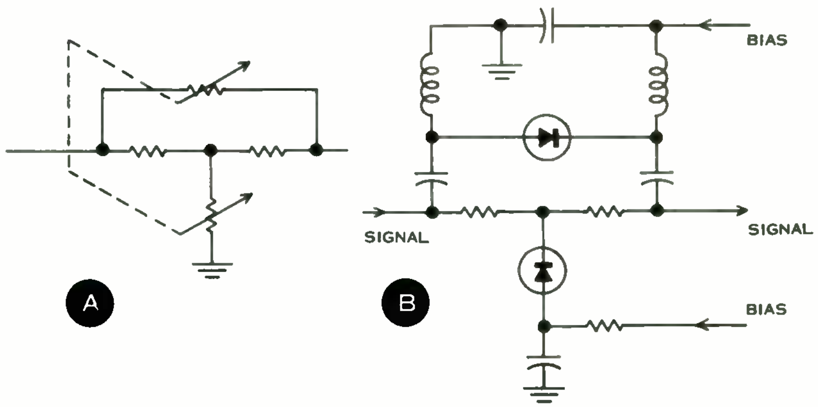



*Figure 6. Typical bridged-T attenuator shown in A maintains constant impedance in both directions as one variable resistance increases, and other decreases. Lenkurt circuit uses variable resistance of semiconductor diode at different current values to achieve same effect in AGC circuit. Additional components shown isolate dc bias and IF signal from each other.*

Instead of altering the gain of the controlled stages by changing transistor bias, a form of "variolosser" or variable-loss circuit was introduced to control the output level of the controlled stages. In this arrangement, an electronically-controlled variable attenuator is inserted in the signal path following each pair of transistor amplifiers. This permits the transistors to operate at a constant fixed point on their characteristic, with the benefit of improved performance and possible extended life.

In the Lenkurt circuit, the variolosser takes the form of a bridged-T attenuator with variable elements, as indicated in Figure 6. If both the series and shunt elements are varied inversely, input and output impedance of the network will remain constant over a wide (20 db) range of attenuation values. Two bias voltages are required, one to control the series resistance, and another opposite-going voltage to control the shunt resistance. By deriving these voltages from the same source, the two variable elements "track" very well and maintain the desired constant impedance over the operating range of the circuit.

## Conclusions

The design approaches described above for a particular piece of equipment illustrate the trend toward increasing sophistication and ingenuity that is required to achieve superior performance. As the number of channels transmitted over a microwave system increases, it becomes more important to preserve or improve performance quality because of the increased value of the resulting communication. The upsurge in high-speed data and wide-band video transmission increases the stringency of the required transmission standards, and makes it particularly important that state-of-the-art limitations of transistors and similar components not be allowed to determine performance capabilities. ●

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*Next month, the second article in this two-part series will discuss ways of overcoming intermodulation distortion in the critical modulation and demodulation circuits of a microwave system— the transmitting klystron and receiver discriminator.*

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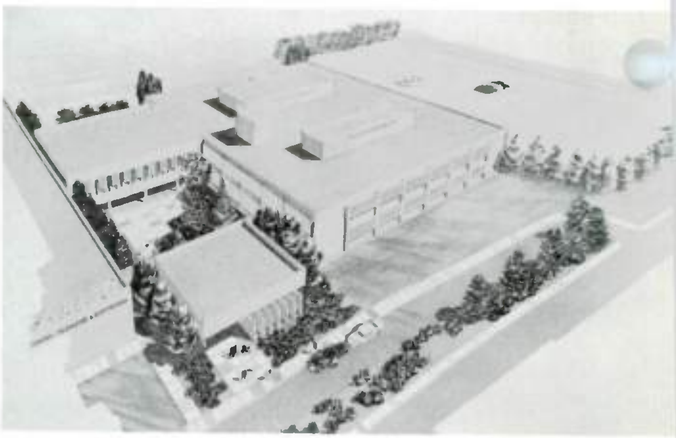
## New Lenkurt Development Laboratory Started

Lenkurt's rapidly expanding engineering program will be housed in a new, ultra-modern laboratory now under construction in San Carlos. Attractive offices and laboratories, plus many advanced test and computer facilities will enhance Lenkurt's drive for better communication techniques.



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