The Lenkurt® Demodulator

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THE NEW MICROWAVE

Part 2

The third-generation microwave equipment now appearing reflects the growing demand for very high channel capacity and increased reliability. One way that reliability is sought is by substituting transistors for electron tubes. Transistors, however, may introduce new problems which require skillful engineering to solve satisfactorily — as described in last month's article.

This article discusses additional design problems which stem from increased bandwidth and transistor characteristics — the problems of nonlinearity in the transmitting klystron and the receiver discriminator.

Although heavy-duty microwave equipment of extremely high quality has been in service for over ten years carrying television and long-distance telephone circuits from coast to coast, this equipment is too costly for most of the newly-emerging industrial and other medium-length applications such as educational television. The early equipment was forced to obtain the necessary performance by complex circuits and elaborate modulation methods.

Simpler ways of doing much the same job are now available, but the intense desire to achieve greater reliability through the use of transistors provides additional complications. Transistors aren't *worse* than electron tubes — they are just *different*. Transistors and transistor techniques are advancing rapidly, and only now have reached the point where they can be applied to high-quality microwave equipment with assurance.

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As bandwidth is increased, extremely careful design is required to preserve linearity, not just in transistor circuits, but throughout the system. Noise, the bane of communication, finds more opportunities to creep into the system when the bandwidth is increased. Ironically, noise thrives and grows whenever the techniques used for overcoming it are misused. For instance, thermal or background noise may be reduced by increasing the modulation index (and frequency deviation) of an FM radio system. If this is carried beyond a certain limit set by the equipment, non-linear or intermodulation distortion provides far more noise than is eliminated.

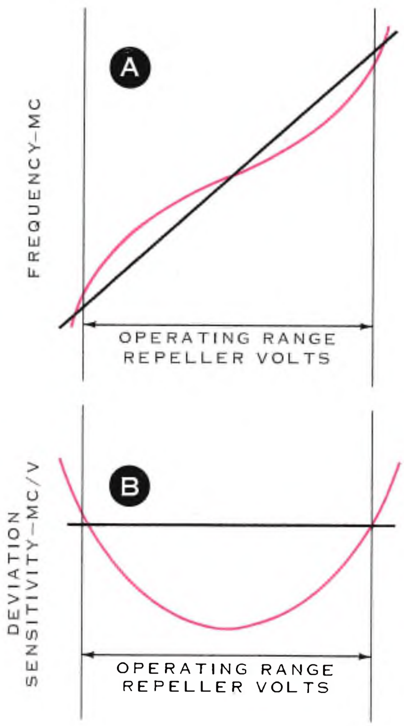

Figure 1. Non-linear modulation characteristic of reflex klystron operating into a matched load is shown by red curve in A. Resulting non-uniform modulation sensitivity is shown in B. Black curves represent ideal linear performance.

When additional channels must be accommodated, the required extra bandwidth "uses up" some of the frequency deviation capability of the equipment and limits its ability to fight the ever-present background noise.

Klystron Linearity

In ordinary amplifiers, intermodulation distortion can be overcome by negative feedback — which causes non-linearities to cancel themselves out. Such a technique, although possible, is not economically practical where the microwave signal is obtained from a modulated klystron — as is the case in virtually all commercial microwave systems operating at frequencies of 6000 mc or higher.

Unfortunately, these klystrons are inherently non-linear in their modulation characteristics, and this non-linearity increases as the frequency deviation becomes greater. The reason for this is that klystron output frequency is controlled both by the modulating voltage applied to the klystron repeller, and by the impedance of the klystron load. The tuning of the klystron to a given output frequency is essentially an impedance-matching process. Now, as the modulating signal alters the output frequency of the klystron, an impedance mismatch is created which changes with the instantaneous frequency deviation, and this mismatch has a de-tuning effect which either opposes or aids the effect of the modulating signal. The result is non-linear distortion which becomes greater as the deviation is increased. Figure 1*A* diagrams a typical klystron modulation characteristic in terms of repeller voltage versus frequency. Figure 1*B* shows how *deflection sensitivity* —

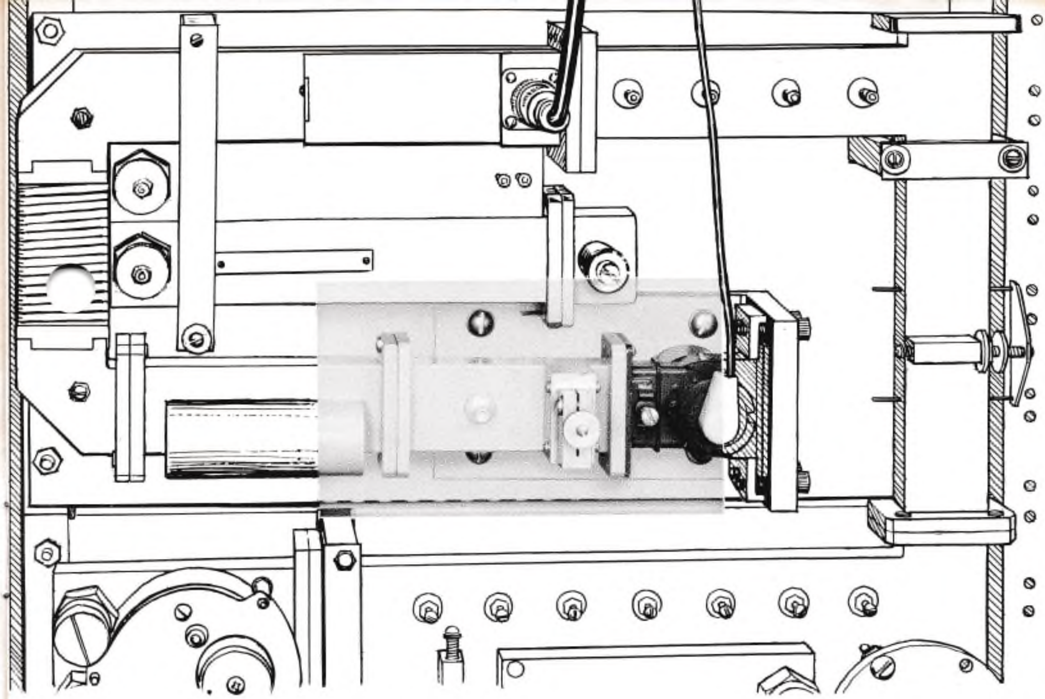

Figure. 2. Klystron linearizer (shown in photo insert) is attached directly to the transmit klystron. Unit is completely passive, may even improve power output from individual klystrons. Attaching device to left of linearizer is a ferrite isolator to eliminate effects of possible impedance mismatch with load.

the amount of frequency *change* for a given change in repeller voltage—varies with frequency.

This non-linear klystron frequency response is the principle cause of intermodulation distortion in a microwave transmitter, and thus a very important source of system noise at times of peak load. The greater the frequency deviation, the more distortion that occurs. Obviously, the distortion problem becomes much worse when additional channels must be accommodated by the klystron, as in 600-channel systems. If the overall frequency deviation is not increased to match the increased channel load, each channel's share of the frequency deviation is proportionately lessened, thus reducing the FM noise advantage. Conversely, if per-channel deviation remains the same as in smaller systems, the increased total deviation may cause intolerable intermodulation distortion.

The problem was overcome nicely in the high-capacity Bell TD-2 microwave system by the use of a so-called klystron linearizer. This is a device that causes a portion of the outgoing wave to be reflected back to the klystron so as to cancel the impedance-mismatch caused by frequency deviation. The exact phase and amplitude of the reflected wave are extremely important, and in the Bell linearizer, the phase is controlled by the location of a plunger or short circuit in a long (three to eight foot) section of waveguide or coaxial cable; amplitude of the reflected wave is controlled by a variable attenuator. Although a substantial portion of the klystron output is lost in the attenuator, this is of little importance in the TD-2 system, since the signal undergoes further conversions and amplification before it is transmitted.

A related device is used in the Lenkurt *Type 76* 600-channel microwave transmitter. Figure 2 shows the linearizer attached to the transmit klystron. Although much smaller and of a different design than the TD-2 linearizer, it performs exactly the same function. In the Lenkurt design, a portion of the transmitted energy is reflected from a wide-band filter section in the linearizer waveguide, the phase of the reflected signal being controlled by an adjustable stub in the cavity. The amplitude of the reflected signal is determined by an adjustable waveguide transformer, located near the klystron end of the linearizer. By adjusting both the transformation ratio of the transformer, and the phase of the reflected signal, it is possible to obtain any desired degree of linearity for the transmit klystron. Figure 3 compares the deflection sensitivity of a klystron operating with and without the linearizer. The presentation shown in the photographs is comparable to Figure 1*B,* and is directly related to the linearity of the klystron; the greater the curvature, the greater the intermodulation noise added to the signal.

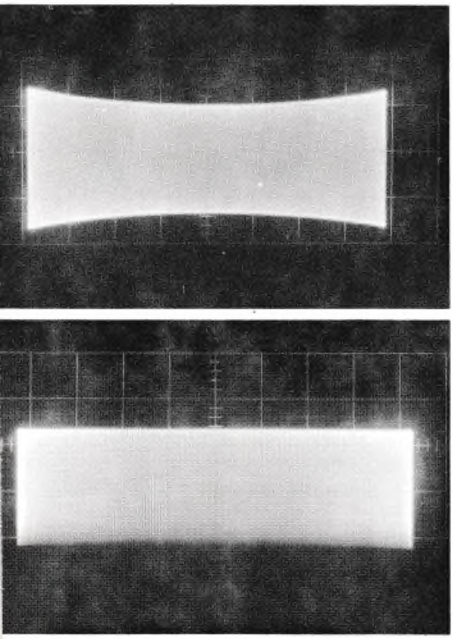

Figure 3. Actual unretouched photographs of effect of linearizer. Top photo shows variation in klystron sensitivity across a 20-mc bandwidth. Same klystron with linearizer shows no measurable variation across identical deviation range. Difference in width of the two displays is caused by oscilloscope adjustment.

Transistorized Discriminators

At the receiver, a similar problem exists. After passing through a series of IF amplifiers and limiters, the signal must be restored to its original form and range of frequencies. This is usually accomplished by a phase discriminator, the most popular kind of which is named after its inventors, Foster and Seeley.

The discriminator has the ability of detecting the *frequency rate of change* of the FM signal, and converting this to a signal voltage identical to the original modulating signal. In the discriminator, as in the klystron, any departure from perfect linearity in this conversion process results in intermodulation distortion much more serious than that generated elsewhere in the receiver.

One way of achieving discriminator action is to apply the IF signal to two resonant circuits, each tuned to a frequency near one end of the band of interest. For instance, one could be tuned to 58 mc, the other to 82 mc, as shown by the gray curves in Figure 4. If the circuit is well-designed and properly adjusted, the two characteristics will combine to yield the characteristic

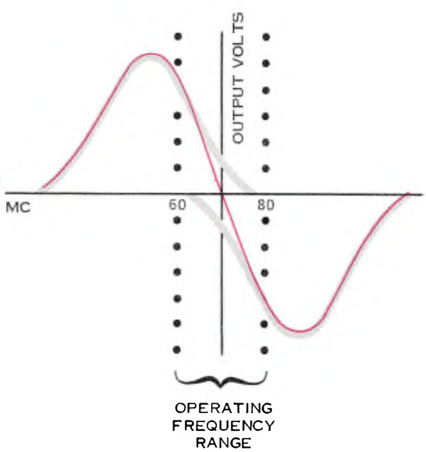

Figure 4. Typical discriminator characteristic (red) is sum of gray curves, which represent response of tuned circuits or phase shift of two sections of discriminator. Linearity becomes increasingly difficult to maintain as bandwidth increases.

shown in red. Note that curvature in one of the resonance curves just offsets that from the other so that the over-all response is a straight line from 60 to 80 mc. Obviously, if the circuit is not precisely balanced, or if one resonant circuit differs slightly from its companion, the resulting characteristic will exhibit irregularities which cause distortion. The phase discriminator accomplishes exactly the same function in a somewhat different manner, but is still subject to the same need for maintaining exact balance between the two symmetrical halves of the circuit.

As bandwidth becomes greater, it becomes increasingly difficult to match the two halves of the circuit exactly and maintain linearity. The most direct way is to lower the circuit Q so that there is less curvature to the resonance characteristic, and thus reducing the variation from the desired straight-line discriminator characteristic. However, this reduces the output level obtained from the discriminator.

Low output from the discriminator produces two distinct problems; semiconductor diodes, which replace electron tubes in the so-called "solid-state" equipment, have a characteristic similar to that diagrammed in Figure 5. Note that forward conduction does not begin until there is a potential of several tenths of a volt across the diode, and that in this region, diode conduction is extremely non-linear. At low signal levels, therefore, there is a likelihood of increased distortion. In order to avoid this type of distortion, it is very desirable to drive the discriminator at as high a signal level as possible.

A second difficulty arising from low signal output from the discriminator relates to the introduction of excessive noise in the demodulated baseband signal. Although it is more convenient in

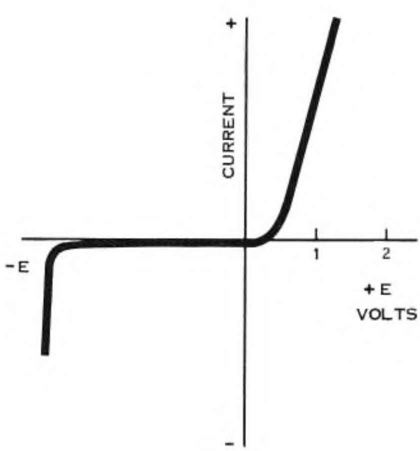

Figure 5. Typical semiconductor diode voltage-current characteristic. Nonlinearity at very low signal voltage can cause serious distortion. High-level driving signal minimizes this effect.

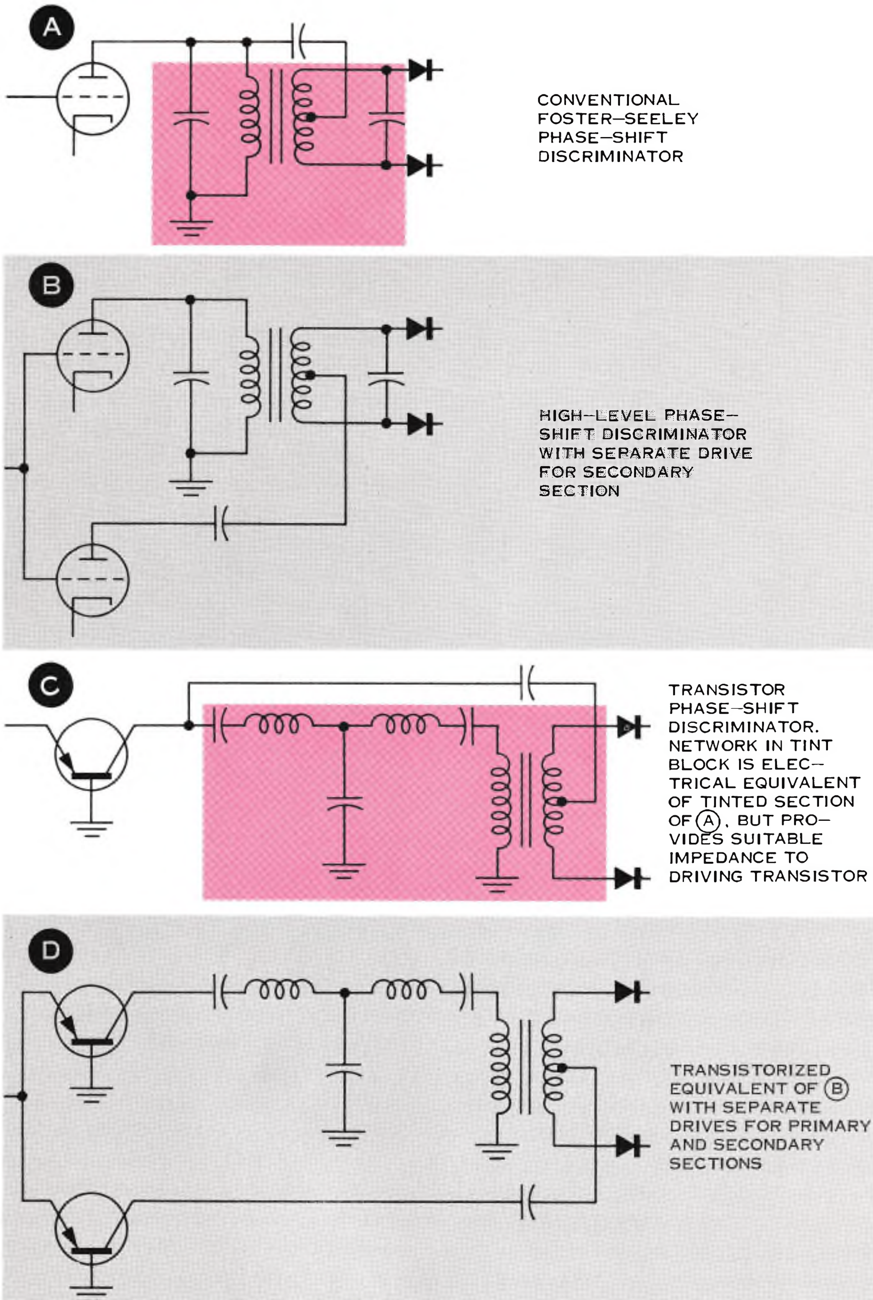

Figure 6. Evolution of a high-level, transistorized discriminator from a conventional Foster-Seeley phase discriminator using electron tubes.

conventional practice to obtain amplification at the baseband frequency, rather than the IF frequency, this can drop the signal level dangerously near the noise level of the diodes.

Several other factors complicate the design of a discriminator for transistorized equipment. At 80 mc, conventional transformers introduce too much loss and non-linearity. If air-core inductances are used, efficiency drops sharply, making it difficult to obtain an adequate output level from the discriminator. In the Lenkurt 76 discriminator, this problem was overcome by using the same high-frequency toroidal transformer technique as used in the IF amplifier sections for interstage coupling and reactance feedback (see DEMODULATOR, *September,* 1961) in constructing the discriminator hybrid circuit. These transformers provide efficient coupling and highly linear frequency response to frequencies above 200 mc, and thus prove to be highly satisfactory in the wide-band discriminator.

Another problem in designing a transistorized discriminator is that of achieving a suitable impedance match between the load, the hybrid, and the driving amplifier. In the 76 receiver it was considered very desirable to use the same common-base configuration for the driving amplifier as was used in the IF amplifiers, in order to maintain utmost stability and freedom from impedance variations which would tend to unbalance the discriminator and introduce distortion.

A special discriminator circuit was developed to match the output impedance of the transistor to that of the transformer hybrid. This circuit and a conventional discriminator arrangement are contrasted in Figure 6, which shows the "evolution" of the high-level discriminator used in the 76 receiver. The circuits shown within the pink-tinted areas are essentially equal in their electrical function, but are adapted to the particular circuits with which they are used. The T-network shown in Parts *C* and *D* of the illustration has the property of providing a suitable match between the transistor and the hybrid, and also achieving the desired phase shift required for discriminator action.

The net result of this technique is a discriminator of unusual efficiency, and which provides an unusually high output for its bandwidth. Separate driving amplifiers for the two branches of the hybrid permit an input level of +15 dbm, and thus allowing a very high output. An indication of the improvement is provided by the 0.15 volt-per-megacycle output obtained from the 76 discriminator, as contrasted with the 0.03 volt-per-megacycle more typically obtained from other discriminators operating across the same bandwidth.

Conclusions

Despite the widespread appeal of transistors, they are no panacea, and their use can result in degraded performance under some conditions, if suitable engineering skill is not employed in overcoming their present limitations. Radio bandwidth requirements are increasing, and this trend can be expected to grow, thus making it more difficult to maintain high standards of performance in communications equipment. Increased channel capacity and increasing circuit lengths for light and medium radio systems make it imperative that performance standards be *improved* rather than relaxed in the face of technical difficulties. Performance and reliability will improve continuously under the pressure of diligent research so long as the users of microwave equipment continue to appreciate the long-term values so obtained. ●

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