The Lenkurt® Demodulator

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HETERODYNE REPEATERS
For Microwave

Among the most vital elements of a microwave system are the repeaters which amplify and redirect the signal. As more stringent performance demands are made on the system, repeater quality becomes even more important. However, such qualities as low noise and distortion cannot be easily achieved without sacrificing such other factors as flexibility. This article considers the advantages and disadvantages of the so-called "heterodyne" repeater, and compares it to the widely used demodulating, or baseband, repeater.

The nature of microwave radio transmission requires that all but the shortest systems use intermediate repeating stations to provide gain and direction for the signal. Since each repeater consists essentially of a receiver and a transmitter through which the signal must pass, the repeaters are just as important to system performance as is the terminal equipment.

Because a perfect repeater has never been built, the signal is degraded somewhat each time it is retransmitted. Each repeater distorts the signal to some degree while retransmitting the distortions introduced by the preceding ones. This cumulative effect is so important that the length of a system is usually limited by the number of repeaters through which the signal passes. If the repeaters used in a particular system were replaced with ones providing better performance, the system could be extended while maintaining the same end-to end performance. Conversely, a shorter system could tolerate repeaters with higher distortion.

But other factors also affect the choice of repeaters. Chief among these is flexibility. Some communication systems require that groups of channels, or even a single channel, be dropped or inserted at the various repeater points. This means that the baseband must be available to permit the various channels to be separated.

Other systems, however, may require little or no drop and insert capability. The signal is simply applied at one end, amplified several times en route, and taken off at the other end.

The choice of repeaters for a microwave system, therefore, is somewhat more complex than a simple cost-versus-performance comparison. Before making such a choice it is necessary to define the qualities required of a repeater for use in a specific application.

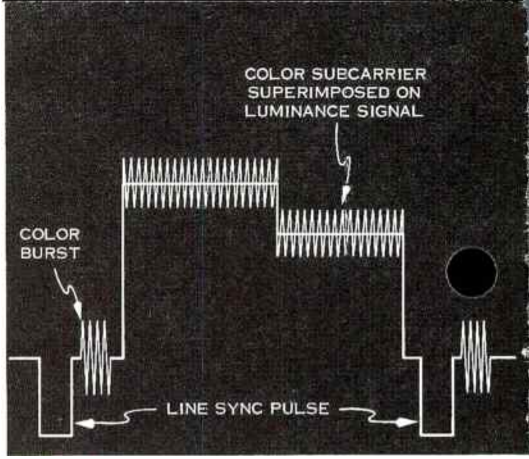

Figure 1. In the American and Canadian (NTSC) color system, "color burst" is transmitted as phase reference for color subcarrier superimposed on luminance signal. Any change in phase or amplitude of subcarrier causes color change in picture. This is called "differential phase" or "differential gain" when caused by change in luminance signal.

Performance Criteria

One of the major factors which must be considered in defining the performance of a microwave system is noise. Noise may come from a number of different sources, and it may appear in various ways. As far as the repeater is concerned, however, noise is generally of two types — thermally generated random (or "white") noise, and intermodulation products. The repeater itself generates both types of noise, adding its contribution to that already present. Thermal noise is picked up by the antenna and generated in the electronic circuitry, while intermodulation noise is produced by every non-linearity through which the signal passes.

Thermal noise is independent of system loading, but intermodulation noise increases as the loading increases. Thus, a repeater adequate for 120 channels might produce unacceptably high noise when loaded with 600 channels.

Another factor which is becoming increasingly important in defining the performance of a microwave system is its ability to carry a video signal. While a number of criteria apply here, among the more sensitive are differential gain and differential phase (see "Performance Testing of Television Channels," *The Lenkurt Demodulator*, October and November, 1963). *Differential gain* is the variation in the *gain* of the transmission system as the luminance or brightness signal varies between the values for "black" and "white." Any variation in *phase* of the color subcarrier as a result of changing luminance level is called *differential phase*. Ideally, variations in the *luminance* signal voltage should produce no changes in either the amplitude or the phase of the color subcarrier.

Both of these parameters are directly concerned with color information. In the American and Canadian system, a color subcarrier at a frequency of about 3.58 Mc is superimposed on the luminance signal. Different colors or *hues* are indicated by shifting the phase of the color subcarrier. The *saturation* or richness of the color is transmitted by varying the amplitude of the color subcarrier. In an ideal system, which would have no differential gain or differential phase, changing brightness values in the picture would have no effect on the phase or amplitude of the subcarrier.

However, when differential phase is present, a change in the brightness of the scene could change skin color from pink to purple, while differential gain could change the color saturation from, say, pink to red.

While differential gain and differential phase significantly affect only color signals, such requirements are usually established for any system engineered to carry video signals, even though initially it will only carry black and white.

In addition to specific performance requirements which must be considered when choosing microwave repeaters, other factors concerned with system engineering, such as drop, insert, bridging, and branching requirements must also be evaluated. Furthermore, the contribution of the terminal to signal distortion is much more important in a short system, while repeater performance assumes increasing importance in longer systems. Thus, no one repeater type is likely to provide the best performance in all respects, and a compromise is often necessary.

Types of Repeaters

Every microwave repeater performs two essential functions. Obviously it must provide gain. The power output of a typical repeater is from 55 to 105 db higher than the received power. The other function is not quite so obvious, but it is just as important. Each repeater must also perform a frequency change, transmitting at a slightly different frequency from that at which it receives, to provide enough isolation to minimize interference between the hops. This frequency shift is usually 252 Mc in the common-carrier band, and may be somewhat less in other bands.

The necessary amplification can be accomplished at any convenient frequency. One widely used method is to connect two ordinary terminals "back-to-back." In this arrangement the signal is translated to an intermediate frequency, amplified, then demodulated and amplified again at the baseband frequency. Finally it is remodulated for transmission in the microwave frequency range. This type of repeater is often called a demodulating, a baseband, or a back-to-back repeater.

However, amplification can also be provided at the intermediate-frequency, or IF, stage without going through the demodulation and remodulation processes. This is what occurs in an IF heterodyne repeater. As in the baseband repeater, the signal is first "heterodyned" to the IF stage. Here it is amplified before passing through the up-converter to be translated to the microwave frequency. Since the desired power output of a heterodyne repeater is usually beyond the capability of present solid-state devices, the output stage is normally a traveling-wave tube operating at microwave frequency.

Still another type of repeater is the RF heterodyne. In this repeater the amplification is provided directly at the microwave frequencies. Typical block diagrams of the three types of repeaters are shown in Figure 2. There are inherent advantages and disadvantages to each of the three types, even if all are well designed and manufactured.

The RF heterodyne repeater is seldom used for several reasons. Perhaps the most important of these is the present cost of providing gain at microwave frequencies. Typically, gain is provided in three stages, using either traveling-wave tubes throughout, or a parametric amplifier followed by two traveling-wave tubes. Both traveling-wave tubes and parametric amplifiers are quite expensive when compared to the more conventional transistor amplifiers. Other problems, such as designing filters with the required selectivity at microwave frequencies, providing adequate limiting and automatic gain control, and cor-

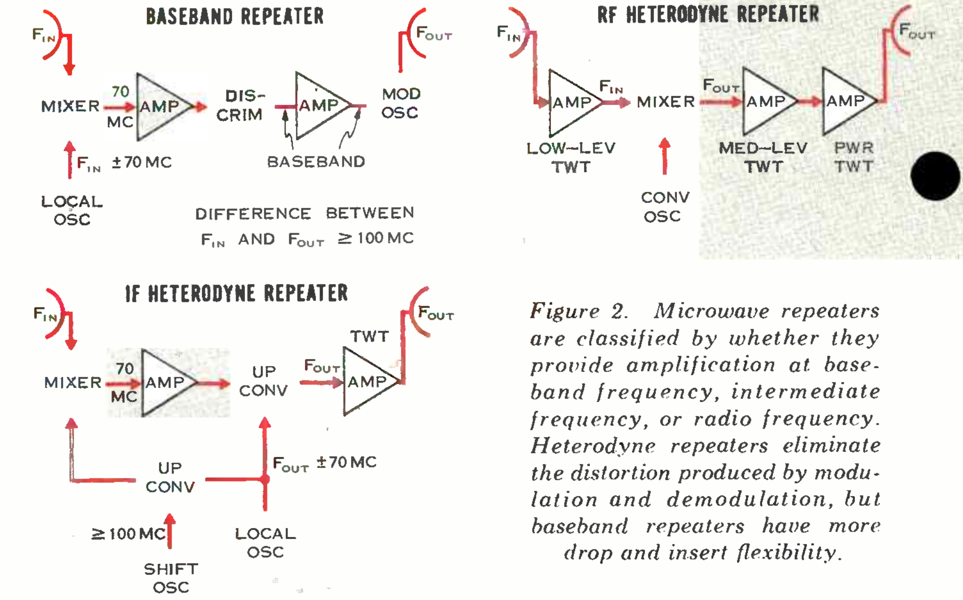

Figure 2. Microwave repeaters are classified by whether they provide amplification at baseband frequency, intermediate frequency, or radio frequency. Heterodyne repeaters eliminate the distortion produced by modulation and demodulation, but baseband repeaters have more drop and insert flexibility.

recting delay distortion, also arise. These problems are not unsolvable, but they are difficult — and hence expensive to overcome. In any case, a one-step frequency conversion must be made to separate the received signal from the transmitted signal.

Thus, the choice is usually between the IF heterodyne (often called simply the "heterodyne") and the baseband repeater. Both are widely used and the choice is dictated by the requirements of the specific system. Probably the most significant advantage of the heterodyne repeater is its improved noise-performance. Each time a signal is modulated or demodulated it picks up a certain amount of intermodulation noise. Since the heterodyne repeater "heterodynes" the signal down to the 70-Mc intermediate frequency and then heterodynes it back up to the microwave frequency without demodulating the FM signal, much of this intermodulation noise is avoided. In a typical case this means about a 3 to 4 db distortion noise improvement in favor of the heterodyne repeater.

Because this same modulation and demodulation process also introduces a large part of the differential gain, the heterodyne repeater has an inherent advantage for video transmission.

The heterodyne repeater also offers better baseband level stability than does the baseband repeater because level variations occur almost entirely in the modulation and demodulation processes. In a system of baseband repeaters these level variations tend to be cumulative, making it more diffcult to meet end-to-end objectives such as those required for drop level stability in Direct Distance Dialing.

Another significant advantage of the heterodyne repeater is its increased power output. A typical baseband repeater has a power output of about 1 watt, whereas the output power of the heterodyne repeater is normally 5 watts or more. This five-fold increase in power output means an additional 7 db to improve the signal-to-noise ratio, permitting longer hops or more channels.

But there are also advantages to the baseband repeater. The biggest of these is its flexibility. Since the full baseband is available at every repeater site, it is comparatively simple to drop or insert any desired number of message channels. Channels to be dropped are simply separated from the rest of the baseband by appropriate filters. Other channels can then be inserted into the "slot" left by the dropped channels.

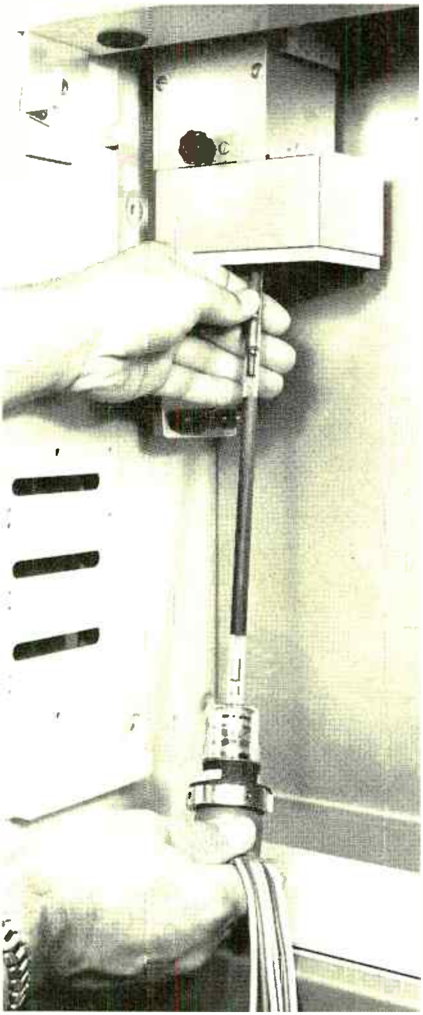

Figure 3. Traveling-wave tube (TWT), shown here being withdrawn from its mount, acts as output amplifier for heterodyne repeater.

The flexibility of the heterodyne repeater, on the other hand, is considerably restricted by the fact that the baseband is usually available only at the end terminals. Since demodulation does not normally occur at intermediate points, channels cannot be dropped as is done in the baseband repeater. Access to the baseband can be provided at repeater sites by bridging in the IF system and then demodulating the portion of the signal which is bridged off. But even so the full FM spectrum appears at each station, with no portion blocked. This means that if channels are to be inserted, idle frequencies must be available in the baseband spectrum. In other words, a number of channels cannot be dropped at some point and a similar number inserted in their place.

The baseband repeater also has the advantage in price — at least when only initial cost is considered. Because of its traveling-wave tube and the required power supply associated with the tube, the heterodyne repeater is usually somewhat more expensive than the baseband repeater.

Thus, the comparison between the baseband and the heterodyne repeaters becomes partly one of cost versus performance, but the choice is usually dictated by the particular requirements of the specific system under consideration.

Applications

In some cases, the choice of repeater type is clear-cut. For a video system 1000 miles long, heterodyne repeaters would be used almost without question. Con-

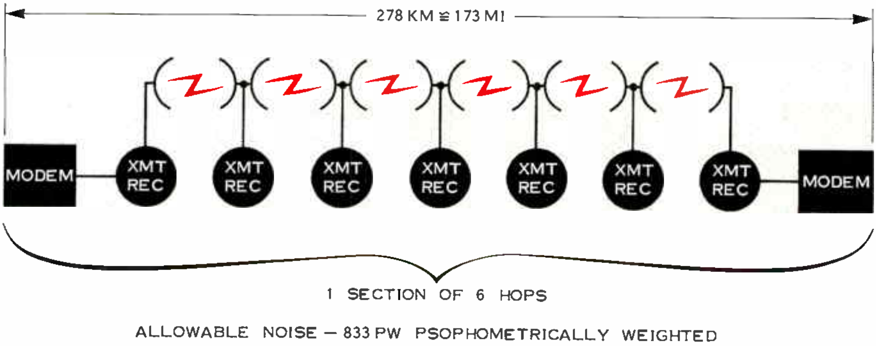

Figure 4. CCIR hypothetical reference circuit consists of nine sections of six hops each, with the sections interconnected at baseband frequency.

versely, for a 120-channel message system 100 miles long, with channels to be dropped and inserted at the repeaters, baseband repeaters would be used — again, almost without question. It is in the middle area between these extremes, where the guidelines are less firm, that questions often arise.

One logical place to start in making a comparison of different systems is the hypothetical reference circuit established by the CCIR (International Radio Consultative Committee). This reference circuit provides a common meeting ground for systems engineers and equipment designers. This 2500-kilometer (1550-mile) circuit is divided into nine equal sections of six hops each. The sections are interconnected at baseband frequency, resulting in nine modulation-demodulation processes in 54 hops. The CCIR-recommended limitation for mean noise power in any hour is 7500 picowatts, psophometrically weighted — equal to 32.7 dba, F1A weighted. (This is the radio contribution only, and does not include noise contributed by the multiplex equipment.)

Breaking this down, each section is 173 miles long, consisting of six 28.8-mile hops, as shown in Figure 4. The allowable noise for the section is then 833 pw, or 23.2 dba. The six feeder sets introduce perhaps 150 pw; the group delay (equalized on a per-section basis) accounts for about 100 pw; and the modulator/demodulator contributes approximately 37 pw. Subtracting these leaves an allowable contribution for the repeaters of 546 pw — 91 pw (13.6 dba) per repeater.

While this hypothetical system does not match any "real-life" system, it does provide a basis for comparing equipment performance against CCIR recommendations and it sets up performance objectives for equipment designers. For example, Lenkurt's heterodyne system is designed to exceed all CCIR recommendations when carrying 960 message channels or a monochrome or color video signal.

While a typical baseband repeater system might be hard put to meet this CCIR objective, it should be remembered that the per-hop objective used here is for a long-haul system. A much higher noise figure might be tolerable for a shorter system. By way of comparison, a 960-channel system using baseband repeaters might have as much as 27 dba per section, considerably above CCIR's 23.2 dba. But this only means that this particular system could not meet the CCIR noise objective for *nine tandem sections* — 54 hops in all. For shorter systems it could provide perfectly acceptable service; or the same system might well meet CCIR recommendations when carrying only 600 channels.

The other major performance advantage of the heterodyne repeater, decreased differential gain and phase, is considerably more difficult to state quantitatively. Differential gain is inherently lower in the heterodyne repeater because there is no contribution from the modulation and demodulation processes. However, a portion of the differential phase and gain is contributed by other parts of the system, usually through phase and amplitude distortion. Thus, it can be reduced by equalization at the IF stage in either type of repeater. Since the heterodyne repeater is built with more precise delay equalization to combat the systematically accumulated delay distortion, it offers less differential phase—and more performance "margin." For example, suppose a six-hop system has a differential gain requirement of 1 db and a differential phase requirement of 1 degree. Initially, this could probably be met by either baseband or heterodyne repeaters. The difference would come in maintaining the system within these tolerances. On a system of several hops, the lower maintenance costs to keep the heterodyne system within the specifications might well offset the higher initial cost.

Conclusion

The heterodyne repeater is not a new development. It has been used in various applications almost since the advent of microwave communication systems. Until recently its use was confined primarily to long-haul "back-bone" routes, but two factors are combining to change this. One is the vastly increased need for communications of all types—voice, data, telegraph, facsimile, etc.—which is resulting in heavier-density systems. The other major factor is the tremendous increase in video transmission. This includes not only commercial broadcast television, but such other services as educational television and industrial applications.

The heterodyne repeater is not a replacement for the baseband repeater. The baseband repeater will long be an important part of many microwave systems — particularly where drop and insert capabilities at intermediate points are important. The two types of repeaters are, of course, complementary, not competitive. Often both types are used in the same system to take full advantage of the best features of each. For example, a long-haul system may be composed primarily of heterodyne repeaters, with baseband repeaters used where channels are to be dropped or inserted.

Thus, while the heterodyne repeater does not replace the baseband repeater, it does offer the systems engineer an important tool in planning heavy-density, long-haul, or video systems. Not every system needs its capabilities, but for those that do it is invaluable. •

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