

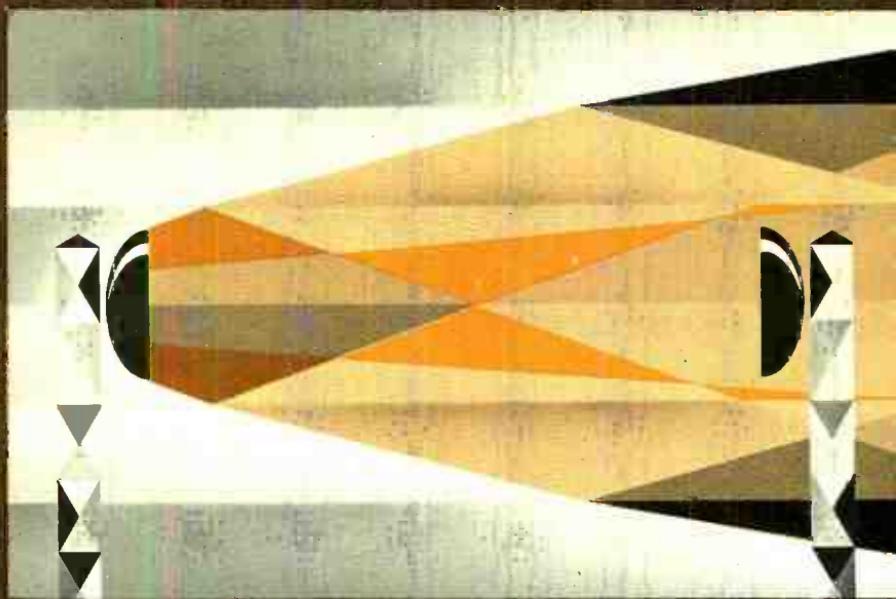
GTE

Communications
Transmission Systems

DEMODULATOR

SEPTEMBER/OCTOBER 1981

Adaptive Equalization



Large capacity, digital microwave links are susceptible to high-level, short-delayed, multipath rays. Echoes delayed a few nanoseconds, and with sufficient amplitude to reduce the Carrier to Interference (C/I) ratio to less than about 10 dB, will cause intersymbol interference, which is manifested by high bit error rate (BER) bursts.

Since most longer microwave paths routinely exhibit this kind of fading, digital systems rely on equipment fixes and diversity schemes to resolve intersymbol interference problems. In the environment described, the interference results from a rapidly changing slope and parabolic characteristic of the IF/RF pass bands. So, one way to overcome the problem is to equip the receiver with an adaptive equalizer to provide a flat IF amplitude response characteristic. After a brief discussion of the multipath phenomena, this article describes an adaptive equalizer developed by GTE Lenkurt.

The multipath fading geometry we are discussing is illustrated in Figure 1. L₁ is the length of the direct ray and L₂ is the length of the multipath ray. The time difference Δt is:

$$\Delta t = \frac{L_2 - L_1}{c} \text{ where } c \text{ is the speed of light}$$

A fading null occurs when the multipath ray is 180 degrees out of phase with the direct ray. As the time difference between rays increases, the fading null becomes more selective (occupies less bandwidth) and the amplitude and associated group delay slopes become greater. These relationships are shown in Figure 2.

The effect on the digital spectrum is illustrated by Figure 3 which shows the distortion caused by a

multipath signal with a Δt equal to 7.2 nanoseconds and a C/I equal to 1.94 dB. When the null is 180 degrees from f_o, an up fade occurs, with positive rounding of the spectrum.

With a 90° from f_o null, the signal level is equal to the unfaded condition but slope is becoming apparent in the passband. When the null is 45° away from f_o, the carrier is depressed 7 dB and there is 11 dB slope over f_o ±12 MHz. When the null is on f_o, the carrier is depressed 14 dB and the spectrum is quite flat.

Adaptive IF Equalizer

The following discussion refers to Figure 4. The adaptive IF equalizer developed by GTE Lenkurt generates complementary distortions to cancel the path distortions. Path distortions are detected by a spectral

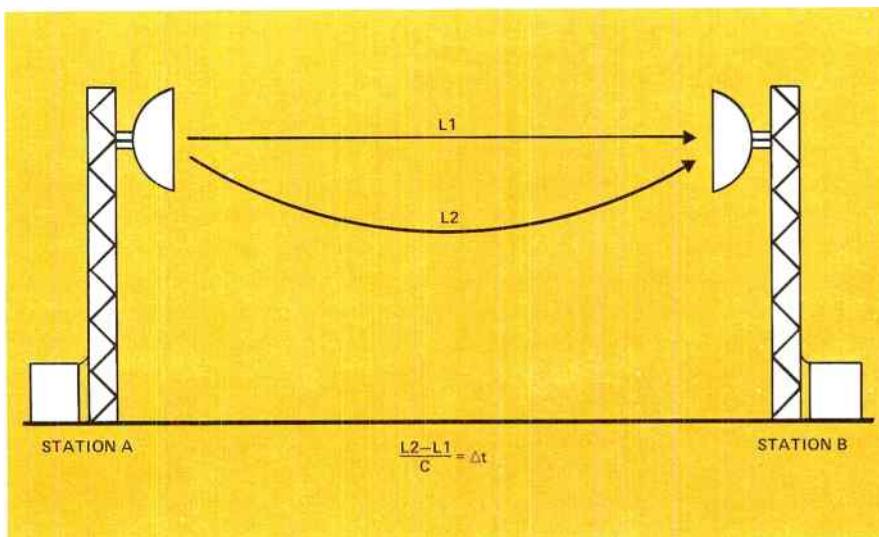


Figure 1. Multipath Fading Geometry

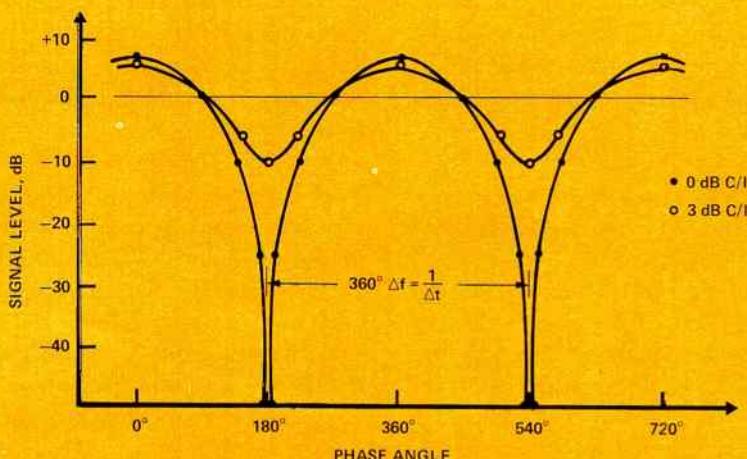


Figure 2. Two Ray Multipath

comparator which samples the digital radio signal at five frequencies and compares the samples with the undistorted values. The derivation of the undistorted values is discussed in the description of Spectrum Filters.

The error at the output of the spectral comparator is measured by an analog computer which activates the specific equalizer sections required to correct the distortion. The equalizer sections are driven until the spectral comparator output is zero. Feedback loops are used to accelerate the corrections.

The amplitude shapes generated have an associated group delay which is in phase with the amplitude and has a fixed relationship in magnitude. The group delay corresponds to multipath distortion caus-

ed by a delayed ray of lesser magnitude than the direct ray. This amplitude/delay relationship is the one that is most likely to occur on a well engineered microwave path.

Spectrum Filters

The equalizer output signal is sampled by five bandpass filters. Each filter has a 5 MHz, 3 dB bandwidth. Their center frequencies are 58, 64, 70, 76 and 82 MHz. With a normal, undistorted signal at the input, the circuit gain for each filter is adjusted to provide equal outputs from each of the five detectors following the filters. The detector outputs provide the undistorted reference values previously discussed.

The detectors are biased, hot-carrier diodes. They are balanced against a reference diode for thermal

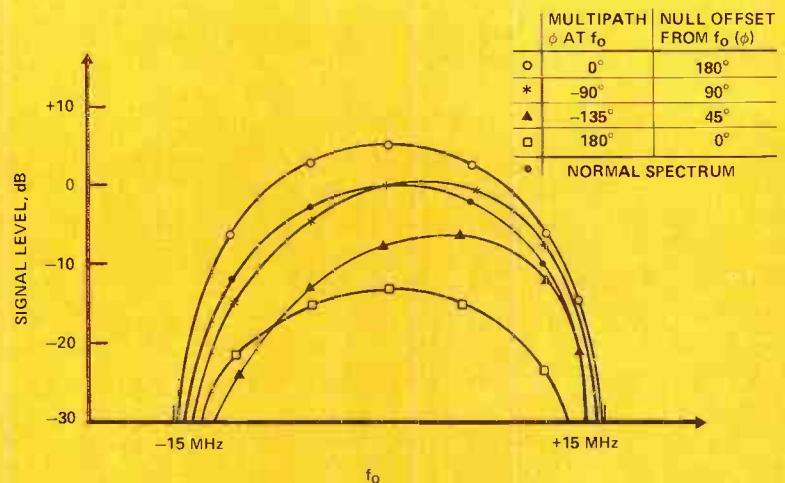


Figure 3. Digital Spectrum With Multipath Distortion

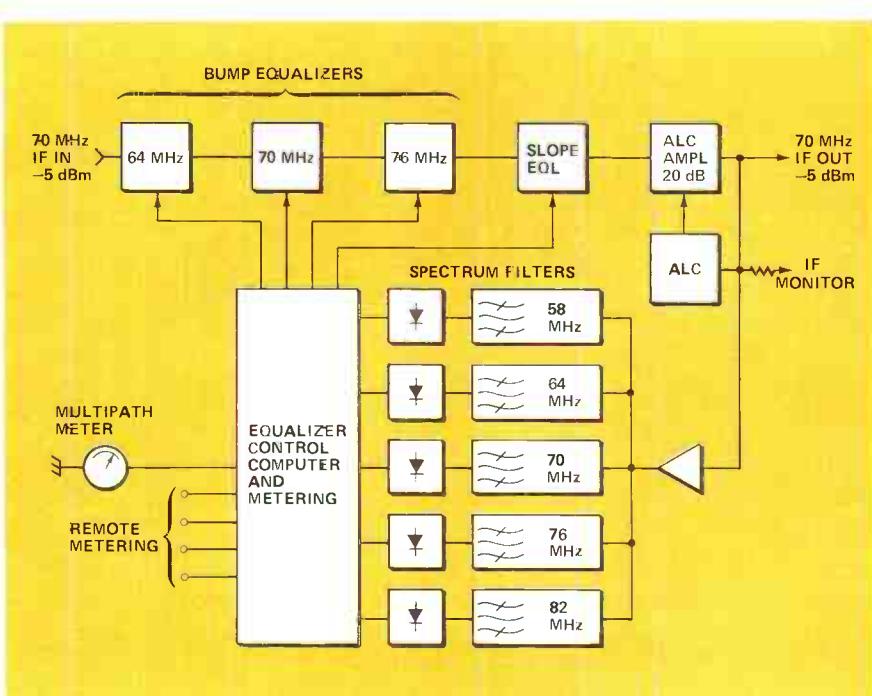


Figure 4. Block Diagram, Adaptive IF Equalizer

stability. The output of each detector is buffered by an operational amplifier.

Slope Equalizer

The slope equalizer section consists of four equalizer stages. Four stages are used because the response of each stage is cosine shaped but a linear slope is required. This requirement is met by using only the linear slope range of each stage. The result is a voltage controlled slope equalizer producing 20 dB of positive or negative slope across a 30 MHz wide channel. The slope control voltage is determined by computing the difference between the outputs of the 58 and 82 MHz detectors.

Three of the stages produce amplitude and slope delay of the same

sense. That is, increasing amplitude corresponds to increasing group delay. The remaining stage can be strapped to produce group delay of either sense. If strapped for opposite sense, its group delay will cancel the delay produced by one of the other stages leaving a net delay of two stages. When the stage is strapped for the same sense as the other three, the net delay of all four is present. This 2:1 change in delay allows the equalization to be adjusted for short or long multipath delays. Figure 5 shows the slope equalizer amplitude response.

Circuit Description

Figure 6 is a block diagram of a slope equalizer stage; Figure 7 is a schematic. IF signals enter the unit through a buffer amplifier with a

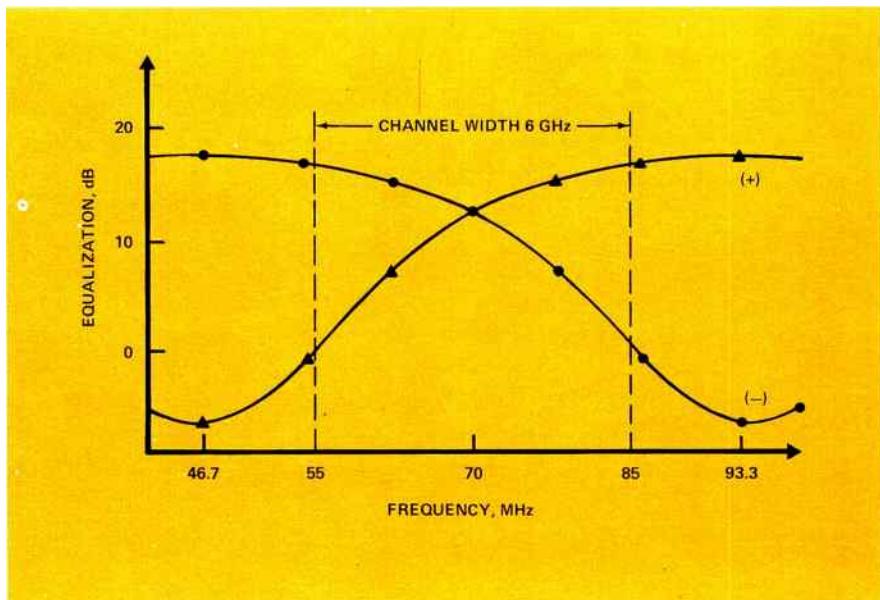


Figure 5. Slope Equalizer Amplitude Response, Four Tandem Sections

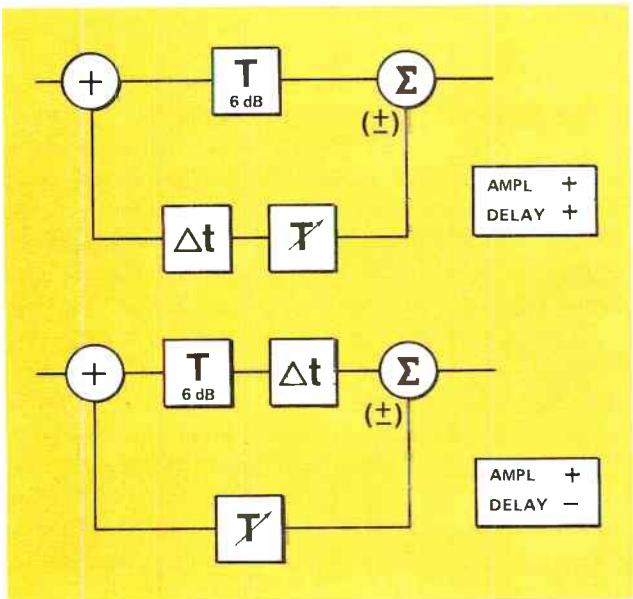


Figure 6. Slope Equalizer

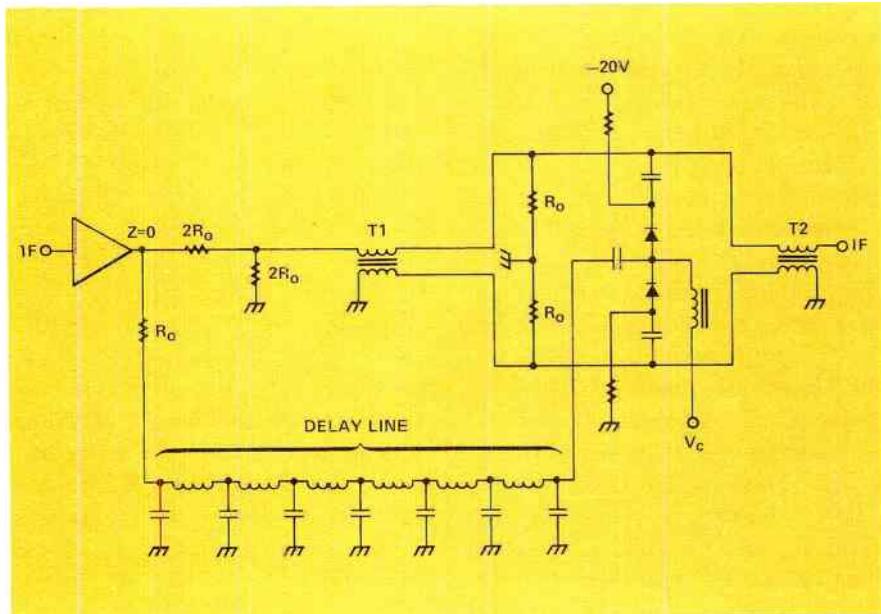


Figure 7. Slope Equalizer Schematic

low impedance output for signal splitting.

The main signal is attenuated 6 dB by a voltage divider and connected to the input of a summing junction. A balun converts the unbalanced path to a balanced configuration.

Two 75 ohm resistors connected in series are shunted across the balanced line and form half of a bridge circuit. The other half of the bridge is formed by a pair of series connected PIN diodes.

Both diodes are biased-on to about 500 ohms. A DC control voltage is connected to the node between the diodes. This voltage is used to provide a differential variation in the resistance of the diodes. This allows a signal coupled to the node to be added to both sides of the balanced line but in differential amounts. A second balun, connected across the bridge output, responds to balanced or differential currents but rejects common mode currents. This balun returns the output path to an unbalanced configuration.

Returning to the split path at the buffer amplifier output — the secondary signal is connected to the input of a 10.7 nanosecond delay line. At 70 MHz, this delay corresponds to a 90 degree phase difference between the main and secondary signals.

When the secondary signal is added in phase, a null occurs at 46.7 MHz and a peak at 93.3 MHz. The result is a positive slope in the passband. If the secondary signal is added out-of-phase, the peak occurs at 46.7 MHz and the null at 93.3 MHz.

The slope in the passband is negative.

The second of the four equalizer stages can be strapped to operate as described or so that the main signal is delayed with respect to the secondary signal. As a result, the delayed signal will be of greater amplitude than the undelayed signal. This causes the group delay of this stage to be out of phase with the other three. The delay of one of these three is cancelled by the out of phase signal so only two stages are effective in contributing to the group delay slope. When it is strapped for this minimum delay, the equalizer is suitable for use on shorter microwave paths.

Multiple Bump Equalizers

The Multiple Bump Equalizer has three equalizer stages. Each stage is tuned to a frequency in the passband. These frequencies are 64, 70 and 76 MHz. Each section can produce a peak or dip at its resonant frequency and is controlled by a DC voltage from the analog computer.

Figure 8 is a block diagram and Figure 9 is a schematic of a bump equalizer stage. Signals enter through a buffer amplifier with a low impedance output for signal splitting. The signal on the main path is attenuated 6 dB by a voltage divider and is connected to the input of a balanced, differential, summing junction. At this point a balun is used to convert the path to 75 ohms balanced.

Two sets of PIN diodes are connected across the balanced line.

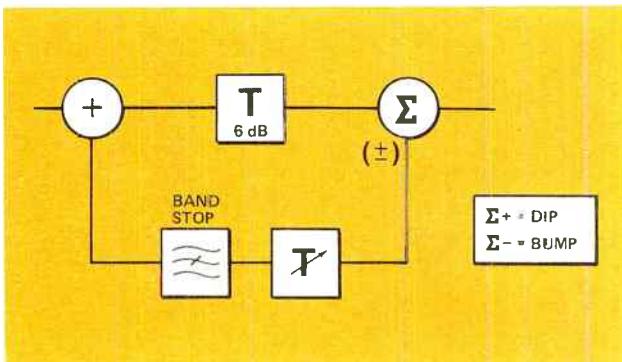


Figure 8. Bump Equalizer

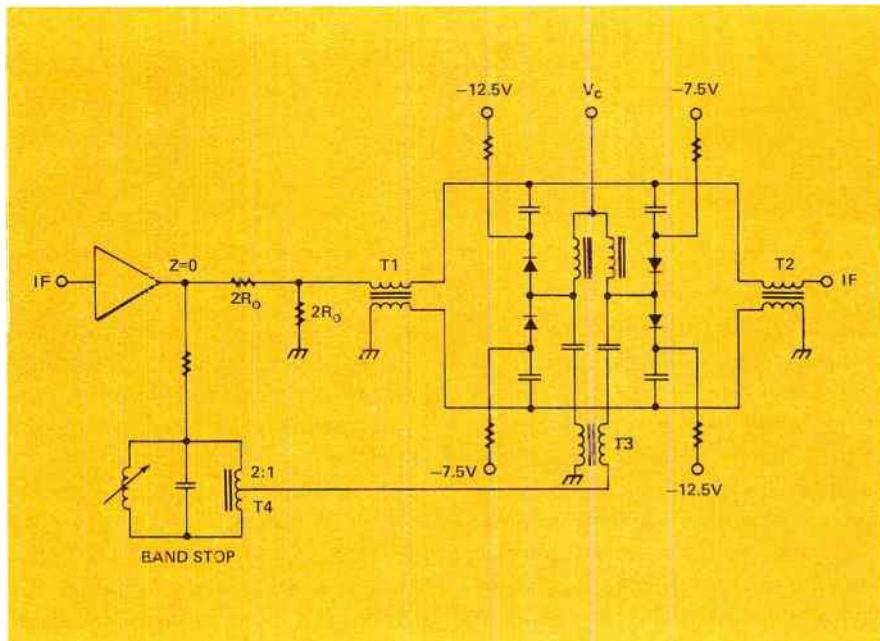


Figure 9. Bump Equalizer Schematic

These diodes act as a bridge of four variable resistors controlled by a single control voltage (Vc Figure 9) from the computer. As a result, a secondary signal of varying amplitude can be added to the main

signal. The secondary signal may be in or out of phase with the main signal.

Returning to the split output of the buffer amplifier, the secondary signal is passed through a high-Q

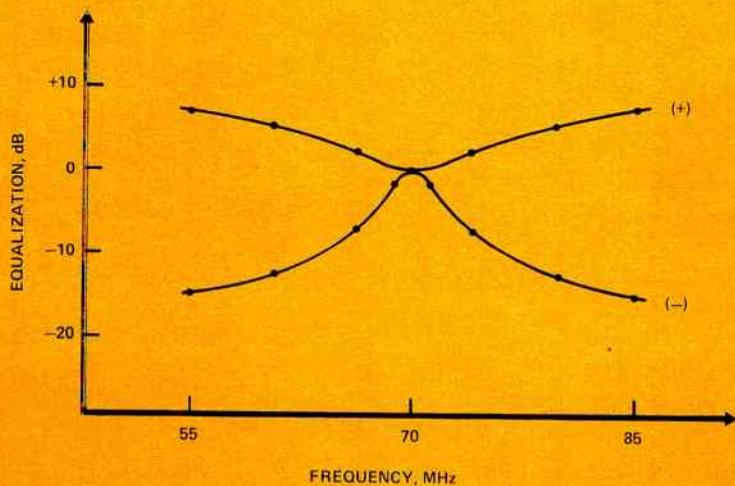


Figure 10. Bump Equalizer Amplitude Response, One of Three Sections

parallel resonant circuit tuned to the bump frequency. The circuit acts as a bandstop filter to attenuate signals at the bump frequency. The output of this filter is connected through a balun to the diode nodes. In addition to providing a balanced signal to the nodes, this balun assures that both the main and secondary paths have equal time delay to the summing point.

When this secondary signal is added out of phase to the main signal, cancellation occurs above and below the bump frequency, causing a bump in the amplitude response. When the secondary signal is added in phase, addition occurs above and below the bump frequency, causing a dip in the amplitude

response. The size of the dips and bumps is determined by the amplitude of the secondary signal. Figure 10 shows the amplitude response of a single bump equalizer stage.

A third balun is used to restore the output to unbalanced transmission. The outputs of the first two bump equalizer stages are shunted by choke coils for amplitude slope correction. The output of the third stage has a shunt capacitor for 75 ohm impedance matching.

Automatic Level Control

The last section in the Adaptive IF equalizer unit is an automatic level control, IF amplifier. This amplifier provides a constant level output from the unit.

Features

The Adaptive IF Equalizer has several features which enhance its usefulness in the field. It is equipped for internal and remote metering of all four equalizer control voltages. The remote metering provision can also be used to provide signals for

recording or telemetering multipath conditions.

A front panel meter and selector switch can measure 12 internal voltages. The meter is used for alignment, for observation of multipath conditions and for verification of active component operations.

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