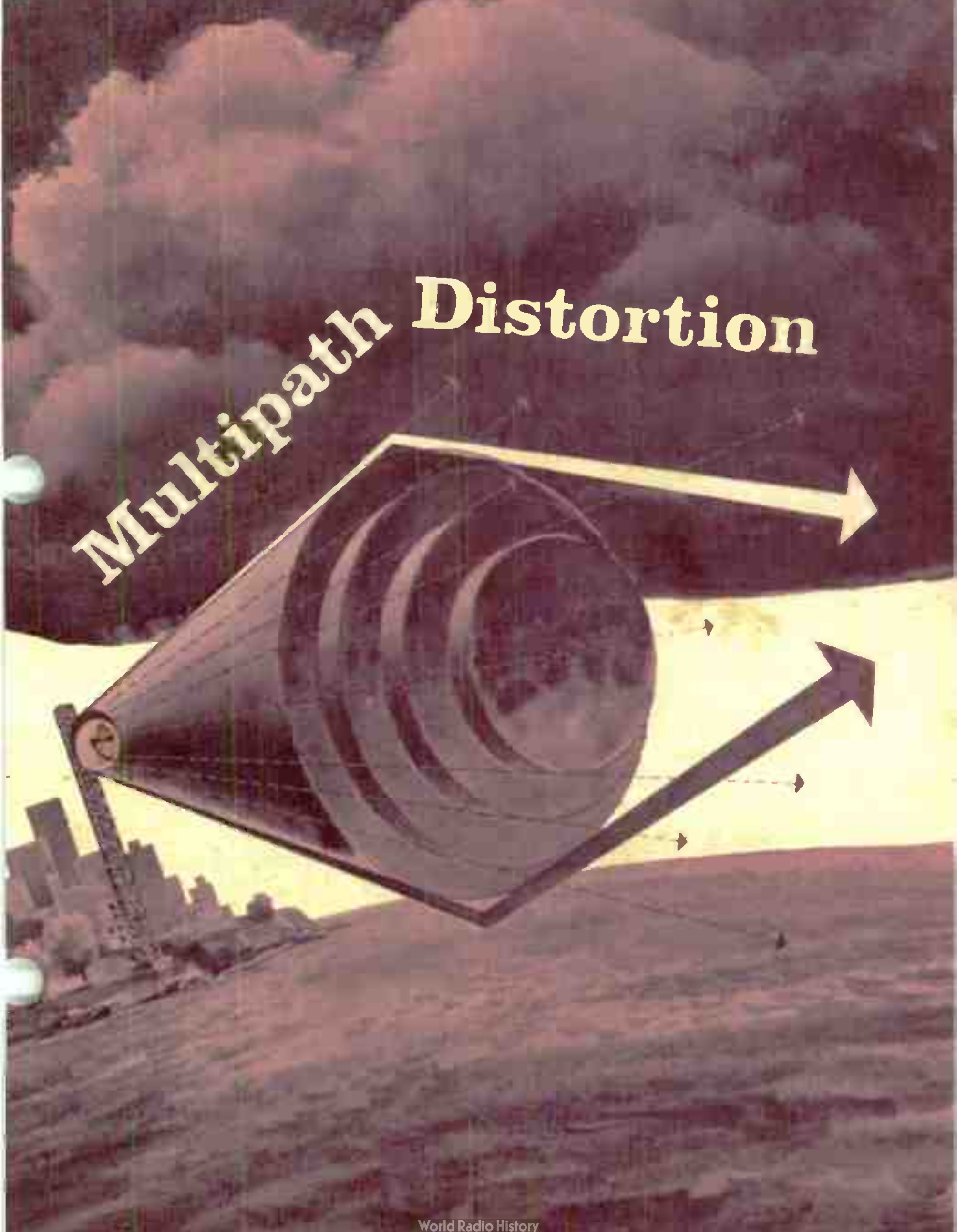
GTE Communications Transmission Systems

DEMODULATOR

NOVEMBER/DECEMBER 1990



Modern microwave equipment has been improved to a point where the back-to-back performance is not necessarily the principal factor in determining the noise performance of a microwave link. External sources such a radio frequency interference, electro-magnetic interference, feeder echoes and particularly, multipath distortion are sometimes the major noise contributors.

This issue of the Demodulator describes multipath distortion mechanisms and identifies various geometries that produce them. Methods for minimizing or eliminating multipath distortion are also discussed.

Today, most new, low-noise microwave systems are engineered and installed without prior over-the-path testing. This makes it virtually impossible to positively identify possible multipath routes and assess their probable impact on system performance. Under the circumstances, it is understandable that the incidence of multipath distortion in new microwave links is increasing.

Judging from recent performance test reports, for example, it appears as many as half of all new wideband, 2 GHz, analog microwave links traversing midwestern farmlands show some evidence of multipath distortion. Two reason for this are: A scarcity of tree foilage, particularly in the winter months, to provide some attenuation of 2 GHz secondary wavefronts, and an increasing number of tall, paired, metal silos, separated by a substantial distance.

An examination of the performance test data shows that the multipath distortion does not make most of the links unusable, nor does it always degrade system noise performance below an acceptable level. What is apparent is that technological improvements have reduced other radio noise contributors to a level where they no longer mask multipath distortion. Even acceptably low levels of this impairment are now readily identified and measurable.

However, multipath distortion does increase noise to an unacceptable level in some systems. Sometimes the distortion is evident only during busy-hour traffic periods. In more severe cases, even lightly loaded microwave links are made nearly unusable by very long-delayed multipath signals of such amplitude as to cause harmonics of multiplex, alarm, pilot and regulating tones to appear as interference in the upper supergroups.

Other systems, immune to multipath distortion during unfaded propagation periods, experience excessive degradation with even small (5-15 dB) fades, well within an acceptable fade margin for normal links.

Occasionally, multipath echoes have delays of such length as to invite comparison to an rf co-channel interference mechanism, wherein the desired and secondary signals are uncorrelated. However, multipath distortion more often masquerades as waveguide or coaxial feeder system echo distortion, as shown by the following similarities:

— Multipath distortion levels appear stable, if the echo occurs within the near field of the antenna system, and therefore may affect only a single radio channel.
— Multipath distortion levels increase with delay time (echo length) as this time approaches the period (2 π radians) of the top baseband frequency.
— Multipath distortion levels in the upper baseband are improved (decreased) with emphasis.
— Multipath distortion often results from a single echo.

As is true of feeder echoes, the amplitude and delay time of a multipath echo can be computed from microwave link analyzer (MLA) IF/RF delay and amplitude ripple presentations, or by bucket (NPR) curve analysis techniques. MLA presentations and bucket curve analysis are described later in this article. A detailed discussion of bucket curve analyses techniques is presented in the March/April 1976 issue of the Demodulator.

Significant differences between feeder and multipath echoes also exist and provide a basis for identifying and analyzing multipath distortion. Some differences are:

— Multipath echoes, originating in the far field of both antenna systems, often cause large fluctuations in the levels of test tones, pilots and distortion.
— Multipath echoes in the far field usually introduce distortion in all radio channels in both directions.
— Multipath delay times are often much greater than the delay times that could occur in either of the two waveguide or coaxial feeders.
— Multipath distortion is often sensitive to the orientation or repositioning of one or both antennas. Feeder system echo is not.
— Multipath signal fading characteristics are often uncorrelated with those of the direct path and cause wide fluctuation in multipath distortion during fading periods. Feeder echo distortion levels are stable in a fading environment.

Analog Vs Digital

Multipath signals have different effects on analog and digital radios. Increasing distortion is introduced into the upper baseband spectrum of an analog system by long-delayed, low amplitude multipath echoes. An echo even 50 dB (50 dB S/I ratio) below the desired signal can be the dominant distortion contributor in an analog system, if the echo delay time approaches the time period of one cycle at the top baseband frequency.

The period of the 2.54 MHz top frequency in a 600 channel analog baseband is 394 nanoseconds, equating to that delay an echo would encounter over 387 feet of free space. This also equates to the end-to-end echo delay in about 175 feet of air-dielectric coax or approximately 147 feet of waveguide.

The type of echo described above does not appear to adversely affect even high capacity digital radio systems. They remain essentially error free until the interference level increases about 25 dB compared to the analog interference level above. This eliminates normal, low-amplitude feeder system and long-delayed multipath echoes as a cause for digital system performance degradation.

However, large-capacity, digital microwave links are very often susceptible to high-level, short-delayed multipath rays. Echoes delayed less than about 3 nanoseconds, with sufficient amplitude to reduce the S/I to less than about 10 dB, will cause intersymbol interference in uncompensated, higher-capacity digital systems.

In the presence of two high-level signals, one direct and the other a multipath signal slightly delayed, intersymbol interference occurs as the result of a rapidly changing slope and parabolic characteristic in the IF/RF passbands. The interference is manifested by high bit error rate (BER) bursts. By way of contrast, this type of multipath causes only dispersive fading, without significant distortion, in analog systems.

To operate satisfactorily in a fading environment, some digital receivers are equipped with sophisticated adaptive equalizers. The equalizer maintains a flat IF amplitude response characteristic. Since some equalizers only partially improve performance, space diversity is often added when the path traverses a particularly difficult propagation area.

It is the nature of most longer microwave links to routinely exhibit varying degrees of dispersive and flat multipath fading. So, to resolve intersymbol interference problems, digital systems engineers must rely on equipment fixes or diversity protection schemes rather than path optimization techniques. The corrective measures used for digital systems are ineffective in combatting multipath distortion in analog systems so, the balance of our discussion describes multipath distortion only as it impacts analog radio systems.

Common Multipath Mechanisms

As previously stated, microwave links are seldom completely free from one or more low level secondary interference rays. These are propagated along reflection, refraction and diffraction routes. They travel by different paths and interfere with the direct ray at the receive antenna. Multipath interference is most easily categorized by its amplitude, delay-time and phase stability with respect to the direct signal. Common multipath mechanisms are described in the following paragraphs.

High amplitude multipath interference with a very short delay-time is common even in well engineered links with optimized path clearances. The S/I ratio approaches 0 dB and the delay-times fall between 0 and perhaps 3 nanoseconds. This kind of multipath causes moderate fading without measurable distortion.

High amplitude multipath interference, with short time delays of 5 to 20 nanoseconds, is a characteristic of microwave paths having excessive path clearances over reflective terrain or water. This kind of multipath not only causes rapid, deep fading but also fluctuating distortion in systems with capacities greater than perhaps 960 channels.

Low amplitude, short-delayed multipath interference rays which do not reduce the S/I ratio below 20 dB, have little effect on any analog microwave link.

Very low amplitude, long-delayed multipath signals with S/I ratios less than 50 dB and delay-times greater than 100 nanoseconds, do not cause fading. However, this interference introduces distortion in the upper baseband of systems with greater than 300-600 channels capacity. The distortion and baseband levels are stable, if the multipath echo occurs in the near field forward or to the rear of an antenna. They are usually unstable if the echo occurs in the far field, remote from both antennas.

Very low amplitude multipath signals, with time delays greater than 1,000 nanoseconds, do not cause fading. However, they can generate high levels of distortion across the entire baseband spectrum. Even systems with capacities under 300 channels are affected by this distortion. In a few rare cases, 36 channel, light route radio performance has been severely degraded by a multipath echo delayed over two miles.

Figures 1 through 10 show specific examples of geometric relationships among antenna systems, microwave paths, natural terrain and man-made structures, which can cause multipath distortion. Suggestions for corrective actions are included with the figures. Our discussion continues on page 9.

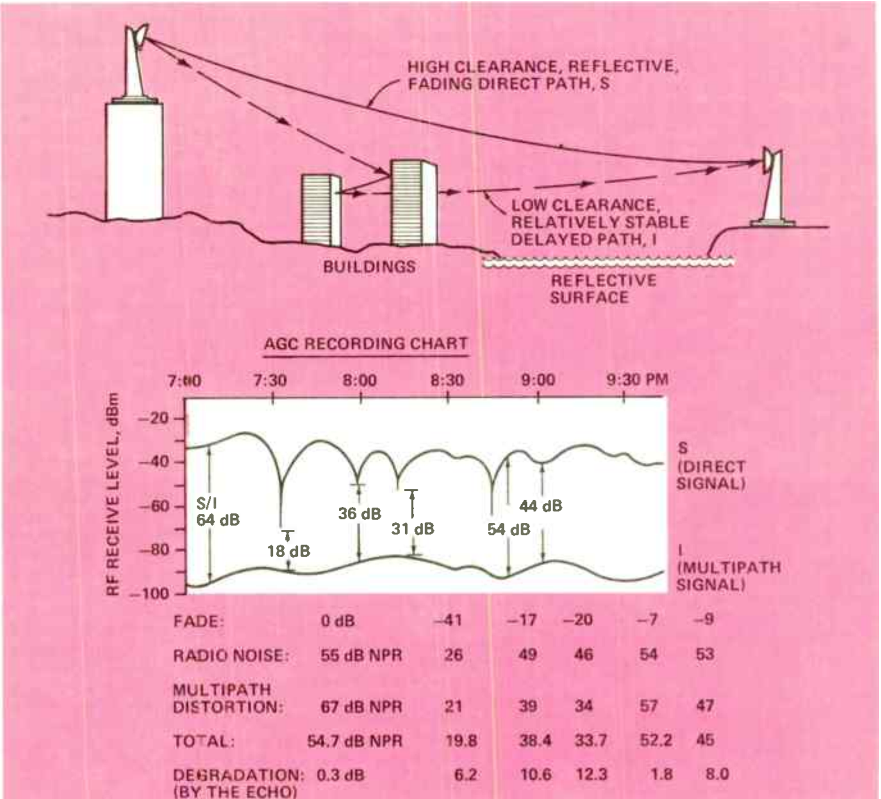


Figure 1. Multipath Distortion in a Fading Environment (Delayed multipath/direct signal fades are uncorrelated). Correct by minimizing direct path fading or by raising or increasing the size of the close-in antenna.

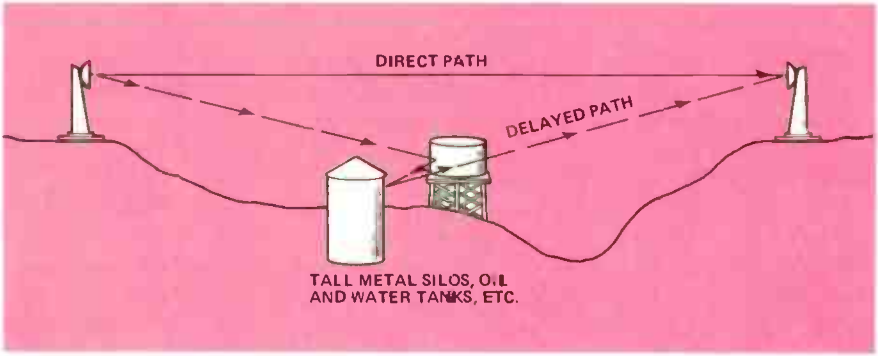


Figure 2. On-Path Double Reflection Mechanism (Often not correctable except to minimize direct path fading — see figure 1)

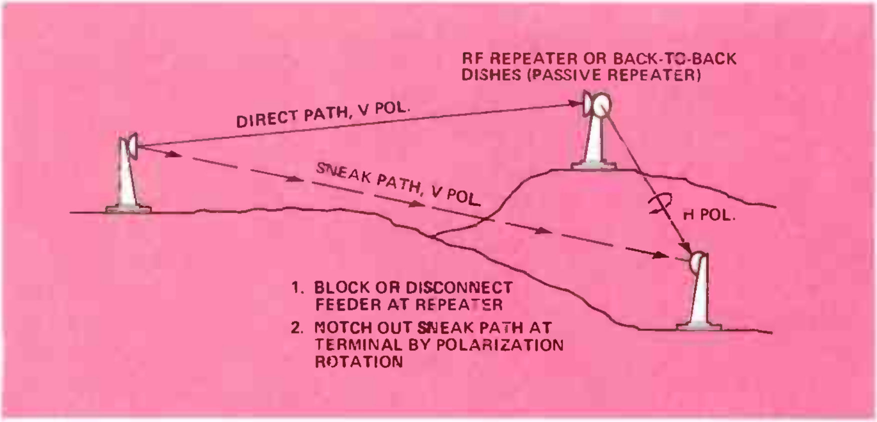


Figure 3. Multipath Distortion in Back-to-Back Passive or RF Repeaters.

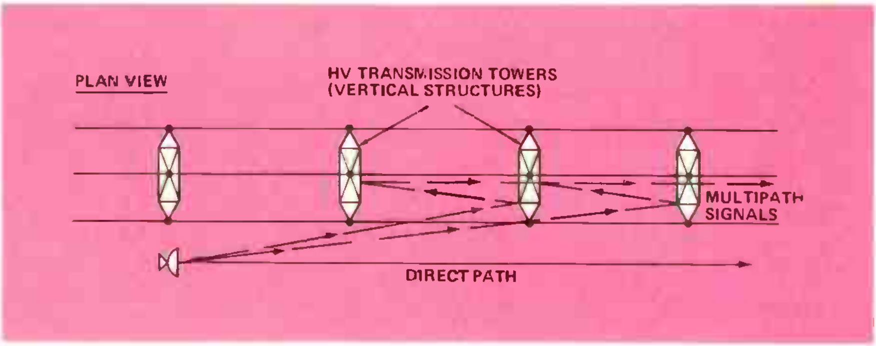


Figure 4. Multipath Generated When a Microwave Path Parallels (and is close to) A HV Transmission Line Supported by Vertically — Faced Towers. Correct by horizontal antenna notching or larger antenna.

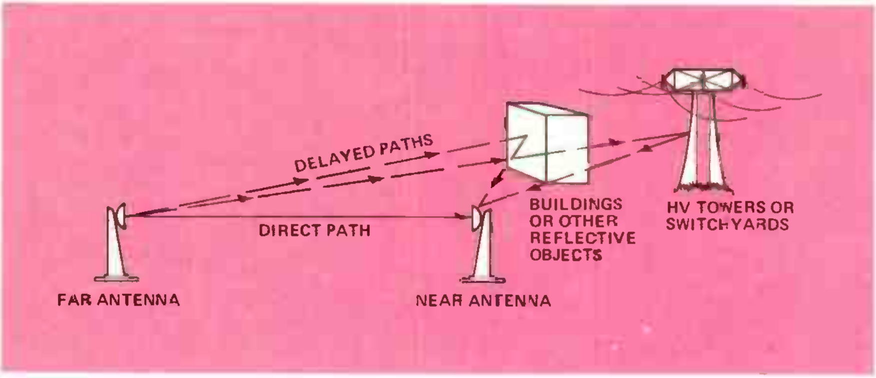


Figure 5. Rearward Multipath Distortion Mechanism (Correct by shrouding or raising the near antenna).

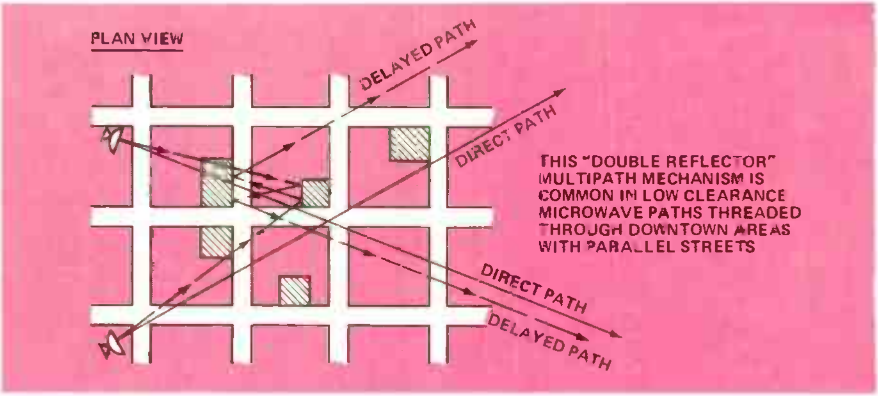


Figure 6. Metropolitan Area Multipath Mechanism. Parallel building walls generate an on-path echo signal irrespective of path azimuth.

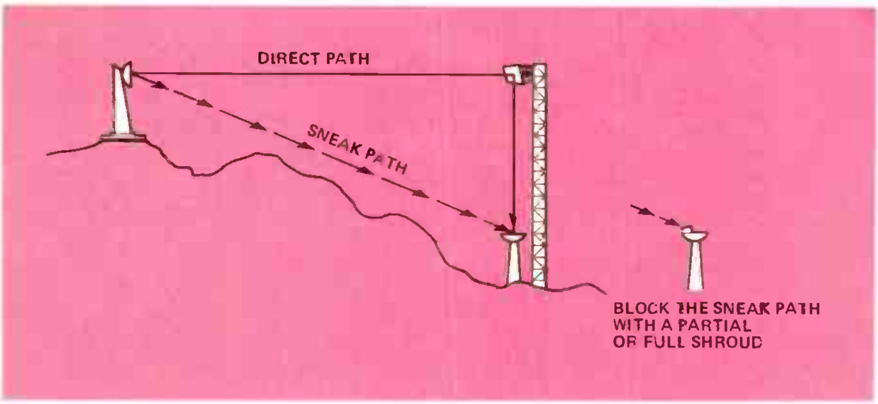


Figure 7. Periscope Antenna Multipath Distortion Mechanism.

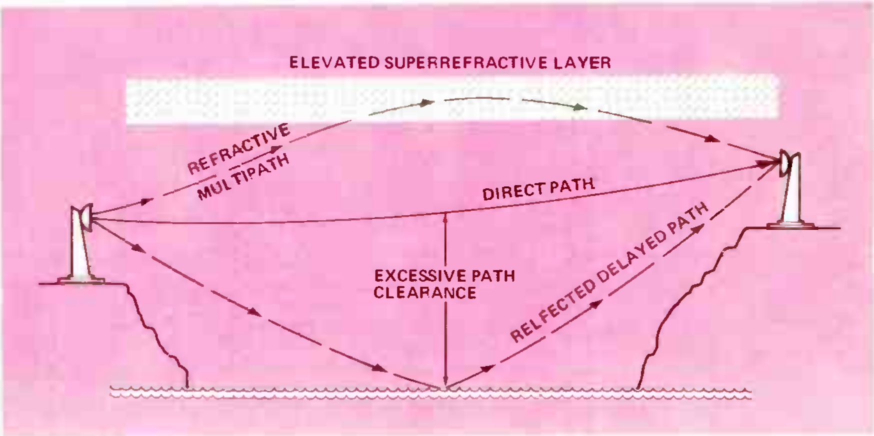


Figure 8. Multipath Distortion Caused by a Single Long-Delayed Reflected or Refracted Secondary Multipath Signal. Correct by Vertical Notching of the Lower Antenna For Minimum Distortion.

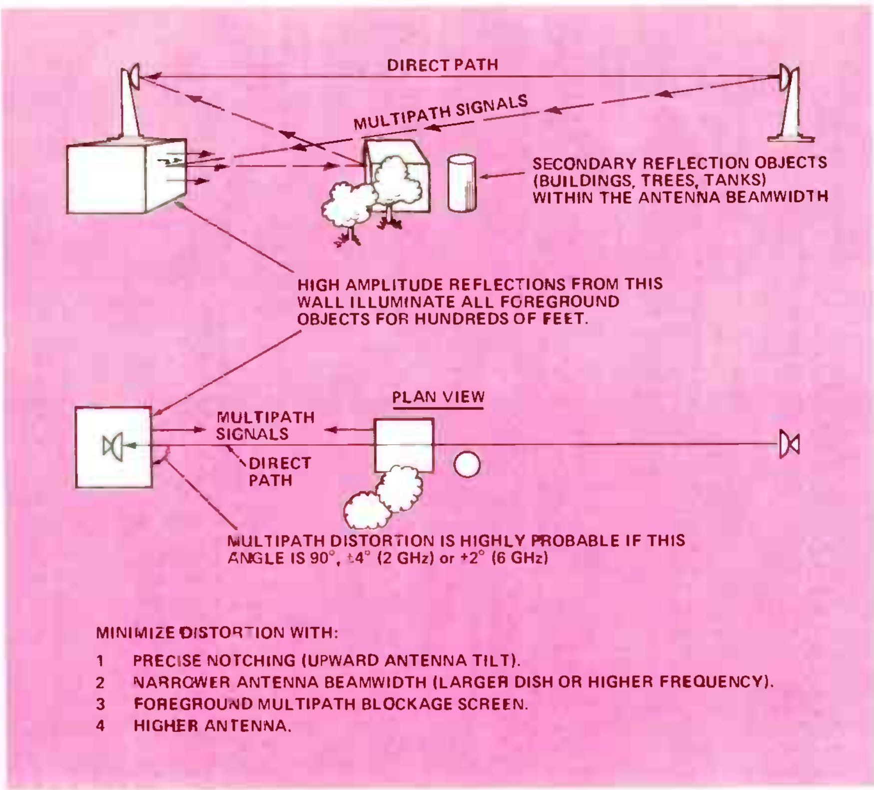


Figure 9. The "Floodlamp" Multipath Distortion Mechanism.

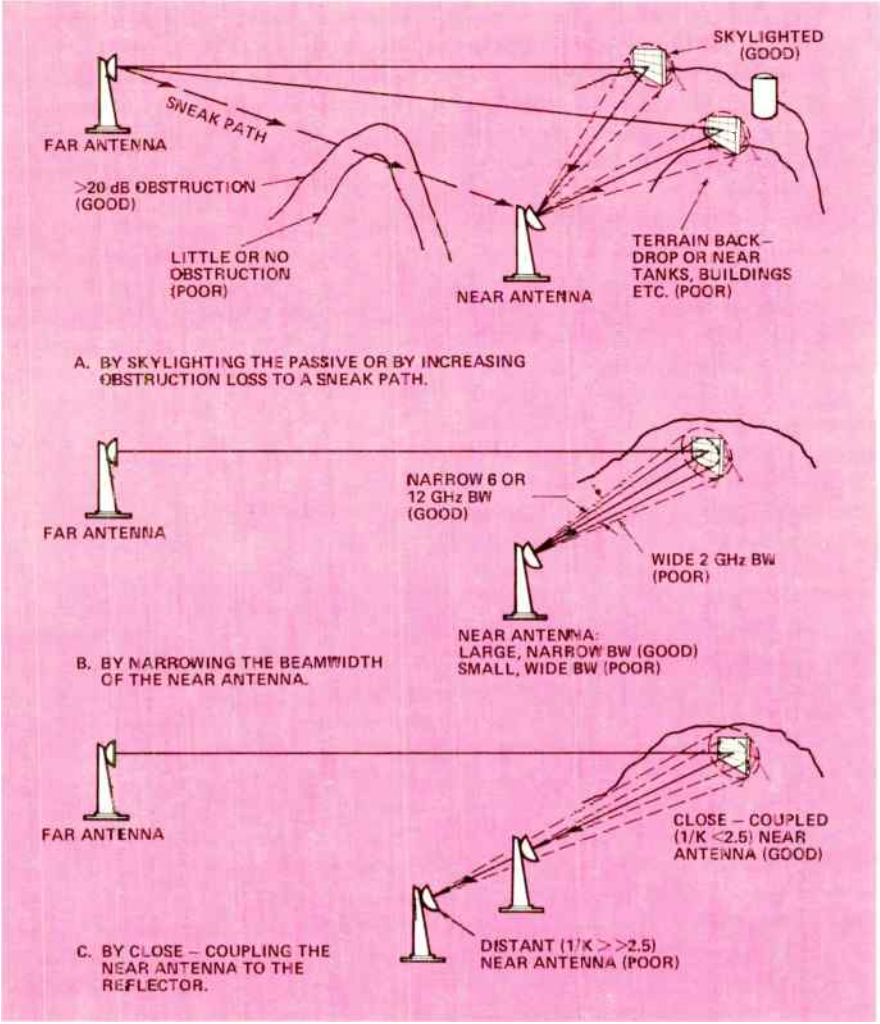


Figure 10. Methods of Reducing Multipath Distortion in Passive Reflector Systems (After near-end antenna notching).

Troubleshooting and Correction

Our troubleshooting discussion will use a hypothetical path for ease of explanation. Assume a 600 channel, 2 GHz analog microwave link with a configuration similar to that in Figure 10B. The stations are equipped with short, 40 foot, coaxial feeders and 8-foot parabolas directed to a small, 16x20 foot, passive reflector located about one mile from the near end dish.

This link is vulnerable to multipath echoes and distortion for the following reasons:

1— The reflector is positioned on the hillside rather than the peak so, a 2 GHz secondary wavefront is easily reflected from the surrounding trees and terrain.

2— The near-end parabola is located in the far-field (1/K = 2.5) of the passive reflector.

3— The beamwidth of the 8-foot, near-end dish is 4.2 degrees wide; illuminating a circular area nearly 400 feet in diameter around the 16x20 foot reflector.

After installation, busy-hour, baseband load tests showed excessive noise in both directions (44 dB NPR or 6 dB worse than the 50 dB NPR predicted). Measurements fluctuated almost ±3 dB although idle noise was stable. At this time a microwave link analyzer (MLA) was used to measure IF group delay and amplitude.

The MLA display (Figure 11) revealed unstable, 4 nanosecond, 0.17 dB peak-to-peak ripples having 5 MHz periods. From Table 1, this proves the presence of a 40 dB S/I rf echo, delayed 200 nanoseconds (ns) from the direct signal. Time in seconds is equal to the reciprocal of the frequency in Hertz so:

$$t = \frac{1}{f} = \frac{1}{5x10^6} = 0.2 \times 10^{-6} = 200 \text{ ns}$$

(One nanosecond = 10^{-9} seconds)

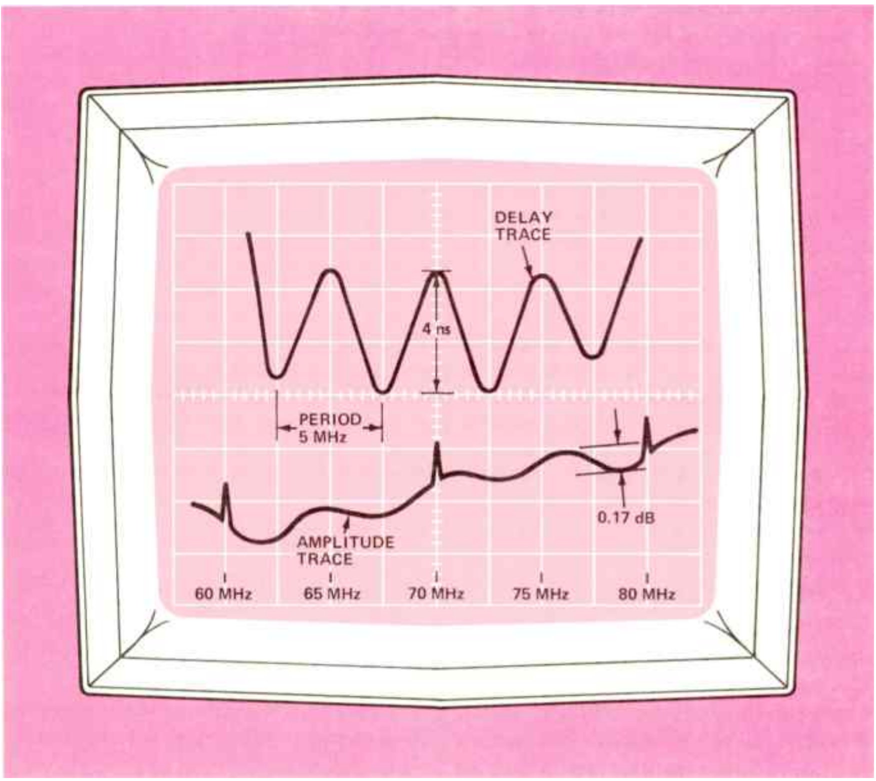


Figure 11. Artist's concept of a MLA IF Display showing a ripple caused by a multipath echo delayed 200 ns (196 ft. in free space) S/I = 40 dB.

ECHO AMPL (S/I), dB	RIPPLE AMPL, dB	RIPPLE DELAY, NS, FOR VARIOUS RIPPLE PERIODS, MHz								
		0.2 MHz	0.5 MHz	1.0 MHz	2.0 MHz	5.0 MHz	10 MHz	20 MHz	50 MHz	100 MHz
-20	1.74	1000	400	200	100	40	20	10	4.0	2.0
-22	1.38	794	318	159	79	32	16	8.0	3.2	1.6
-24	1.10	630	252	126	63	25	13	6.3	2.5	1.3
-26	0.87	501	200	100	50	20	10	5.0	2.0	1.0
-28	0.69	398	159	80	40	16	8.0	4.0	1.6	0.8
-30	0.55	3.6	126	63	32	13	6.3	3.2	1.6	0.6
-32	0.44	251	100	50	25	10	5.0	2.5	1.0	0.5
-34	0.35	200	80	40	20	8.0	4.0	2.0	0.8	0.4
-36	0.28	158	63	32	16	6.3	3.2	1.6	0.6	0.32
-38	0.22	126	50	25	13	5.0	2.5	1.3	0.5	0.25
-40	0.17	100	40	20	10	4.0	2.0	1.0	0.4	0.20
-42	0.14	79	32	16	7.9	3.2	1.6	0.8	0.32	0.16
-44	0.11	63	25	13	6.3	2.5	1.3	0.6	0.25	0.13
-46	0.09	50	20	10	5.0	2.0	1.0	0.5	0.20	0.10
-48	0.07	40	16	8.0	4.0	1.6	0.8	0.4	0.16	0.08
-50	0.05	32	13	6.3	3.2	1.3	0.6	0.32	0.13	0.06
-52	0.04	25	10	5.0	2.5	1.0	0.5	0.25	0.10	0.05
-54	0.03	20	8.0	4.0	2.0	0.8	0.4	0.20	0.08	0.04
-56	0.03	16	6.3	3.2	1.6	0.6	0.32	0.6	0.06	0.04
-58	0.02	13	5.0	2.5	1.3	0.5	0.25	0.13	0.05	0.09

Table 1. Relationships Among Echo S/I and Ripple Amplitude (dB Delay (ns) and Period (MHz) as observed on an MLA.

Since the velocity of radio waves in free space is 1.018 ns/ft, this delay could result from a 196 foot sneak path or within a 90 foot coax feeder having a 91% propagation constant.

A multipath signal rather than a feeder echo is assured because:

1— The fluctuating noise and pilot (test tone) levels and an unstable MLA display are characteristic of a far-field, multipath echo. Near field and feeder echoes are stable.

2— The computed secondary path length is much longer than twice the length of the longest feeder.

A top-slot bucket (NPR) curve was drawn and clearly shows the flattened or pushed-up bottom indicative of echo distortion (see the before curve, Figure 12). The amplitude and delay length were established through bucket curve analysis, which verified the 200 ns, 40 dB S/I multipath signal seen on the MLA.

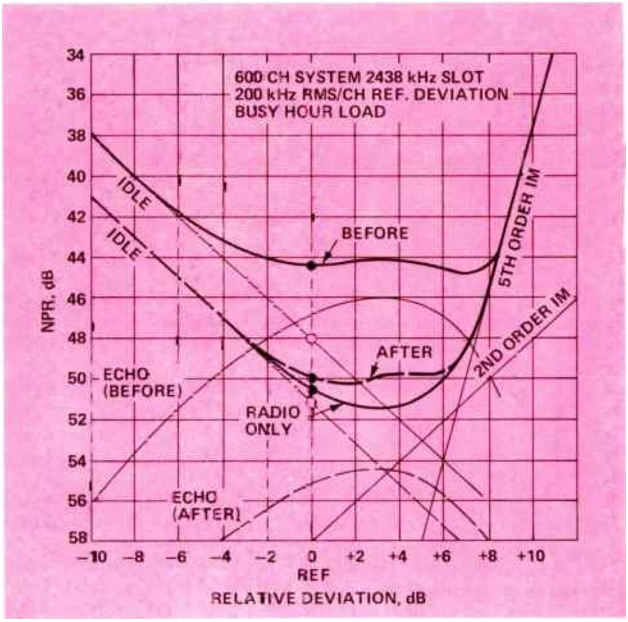
The bucket curve is an invaluable analytical device, available to all microwave test personnel. A standard noise-load test set is the only test equipment required.

Corrections

Multipath distortion is reduced only by improving (increasing) the desired signal-to-interference signal (S/I) ratio. Any corrective measures causing an equal change in amplitude of both S and I are ineffective in combatting multipath distortion. Among such ineffective measures are: increasing transmit power; lowering feeder system losses and realigning or increasing the size of a far-end antenna, distant from the multipath causing geometry.

The following options are available to the system tester, to resolve multipath distortion problems. The options apply to our hypothetical link and to most other types of path geometry as well. They are presented as a step-by-step procedure:

Figure 12. Bucket Curves showing distortion caused by a multipath echo (near the passive reflector) delayed 200 ns. S/I improved 8 dB from 40 to 48 dB with a larger near-end dish providing 3 dB higher gain and a 50% reduction in beamwidth.



Step 1: "Notching" or "Tweaking of a near end antenna, presuming the multipath signal arrives slightly off axis to the desired signal. Echo distortion is inversely proportional to rf S/I. Since the directivity and orientation of the near-end antenna affects S and I by unequal amounts, the precise "notching" of this dish for minimum multipath distortion (maximum S/I) is always the first corrective procedure. However, some small loss in receive signal and consequently fade margin may be expected. Orientation of a far-end antenna is seldom helpful, since the S and I signals are probably coaligned at that distant location.

Step 2: Increase the diameter of the near-end dish. This increases its gain to S and reduces its beamwidth, providing increased discrimination against the interference signal. Increasing the size of the far-end dish increases the gain equally for both S and I. So, the distortion remains constant.

Step 3: Increase the frequency to a higher band. This has the same effect as increasing the diameter of the near-end dish, Step 2.

Step 4: Rotate the path polarization. This is seldom effective because the multipath reflection point is rarely sensitive to polarization. Although, in those services where it is authorized, circular polarization provides a high degree of discrimination to multipath signals.

Step 5: Reduce the echo amplitude with hardware cloth or other screening. Partial or full antenna shrouding is effective in reducing rearward or wide-angle multipath reception.

Step 6: Increase the size of the passive reflector. This improves S only.

Step 7: Reposition the near-end dish into the near field of reflector.

Frequently nothing is done beyond the precise notching of the near-end antenna, since even a somewhat excessive single-hop, busy-hour distortion level is often negligible compared to the total noise contribution of the entire microwave system.

In our hypothetical link, assume that dish orientation was only minimally effective because of the wide beamwidth of the near-end antenna, the length of the path and the inappropriate position of the small reflector on the hillside. Increasing the near-end antenna size to a diameter of ten feet was an effective solution. This reduced multipath distortion 8 dB, with a similar improvement in S/I ratio. S increased 3 dB and I, now down the side of the narrowed main lobe, dropped 5 dB. Idle noise also decreased about 3 dB, with the higher receive signal level.

Some trace of multipath distortion was still present, as evidenced by the slight flattening at the bottom of the "after" curve, Figure 12. In many microwave links, multipath distortion can never be totally eliminated but can be reduced to an acceptable level.

One type of multipath distortion, which can be difficult to correct, is illustrated by the bucket curves in Figure 13. The figure shows degraded low and high slot NPR curves for a 300 channel link with a very long-delayed multipath echo. Multipath echoes seldom affect the low baseband slots of a radio system, unless delays in the thousands of nanoseconds are encountered.

Unfortunately, after-the-fact correction of severe multipath distortion is often very expensive. Microwave stations have been changed from repeater to spur configurations (with the degraded path turned down); sites have been relocated or abandoned and passive reflectors turned to active or rf repeaters, to alleviate severe multipath problems.

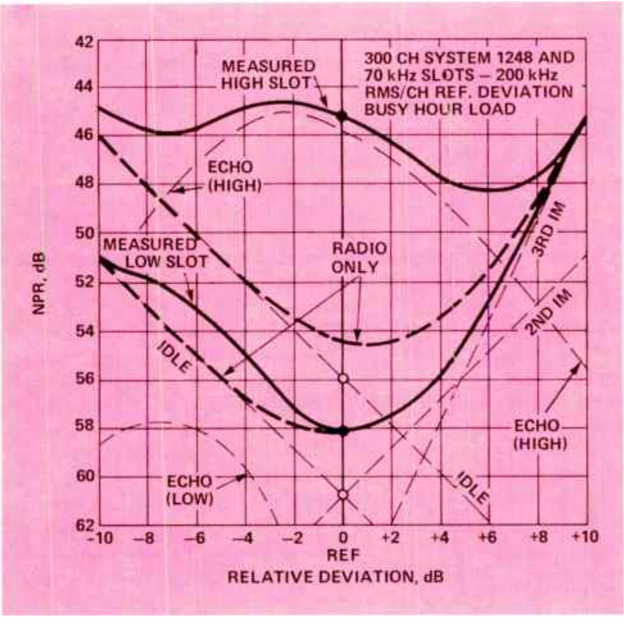


Figure 13. Bucket Curves showing high distortion due to a long-delayed (1000 ns) – 38 dBm0 multipath echo. Note its influence in the low slot.

Preventive measures are probably most economical in the long run. Such measures include: judicious site selection; a conservative engineering approach to repeater spacing; an educated eye, sensitive to identifying multipath distortion geometry on a proposed path; optimum radiating component selection and alignment, and path testing over proposed links, using portable microwave sets.

Comparison With Broadcast Reception

Multipath reflections from tall buildings and overflying aircraft often interfere with broadcast reception. Ghosting and color-shifting of television pictures are the result of multipath interference.

High fidelity audio equipment can also be affected by multipath distortion of fm broadcast signals. The effect on audio quality varies from barely perceptible to a severe breakup of the higher frequency notes.

There are a number of similarities between multipath distortion on broadcast and microwave paths. In both cases, the distortion reduces the clarity and intelligibility of the information. Furthermore the distortion is more severe with longer delay-times and smaller S/I ratios.

Broadcast multipath interference can often be minimized by careful orientation of the receiving antenna and/or increasing its gain. These same techniques are used to minimize microwave multipath interference. The techniques are effective because both mechanisms are related to S/I ratio, which generally varies with antenna orientation, gain and selectivity.

BIBLIOGRAPHY

1. Laine, R.U., *Multipath Distortion in Microwave Communication Links,* 1980 — GTE Lenkurt, Inc., San Carlos, Ca.

2. Hawker, P., *How Serious is Multipath Distortion?* Wireless World, April 1980, Electrical-Electronic Press Ltd., Dorset House Stamford Street, London, England.

3. *Bucket Curves,* GTE Lenkurt Demodulator March/April 1976, GTE Lenkurt Inc., San Carlos, Ca.

4. Worring, T.J., *Passive Repeater Engineering,* Microflect Manual Number 161A, Microflect Co., Inc., Salem, Oregon.

CORRECTION

The July/August 1980 issue of the Demodulator has two errors on page 5. The first error is in the definition of the term Z_t used in the Return Loss Equation. The definition should read:

Z_t = Terminating impedance.

The second error is in the paragraph immediately following the equation. This paragraph should read:

> Reflections manifest themselves as echoes in telephone circuits. For voice transmission the "talker echo" is most troublesome. For data signals "listener echo" is most troublesome, because the reflections are delayed in time and interfere with the desired receive signals, particularly at data speeds above 2400 bps. Telephone circuit reflection paths are shown in Figure 5.

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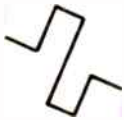

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