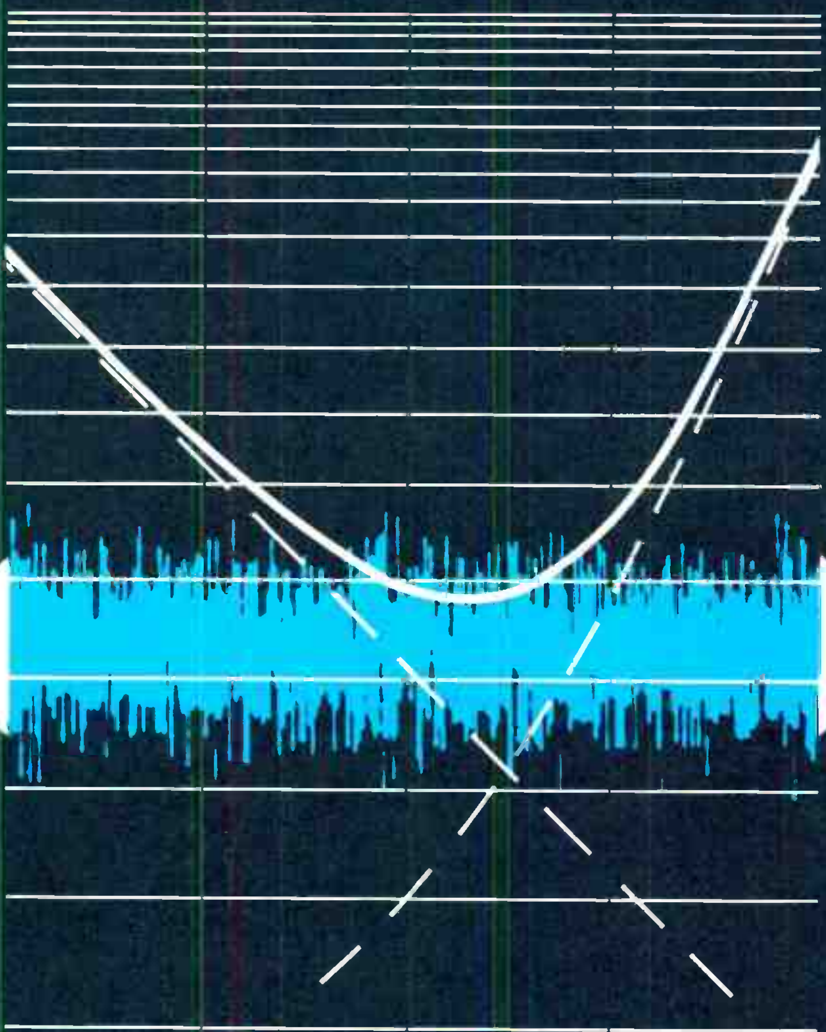
GTE LENKURT

DEMODULATOR

MARCH/APRIL 1976



Bucket Curves

parts 1 and 2

Bucket Curves
part 1

The bucket curve, otherwise known as a noise load, noise performance, NPR, "V", or trough curve, is the most important and easy-to-use noise diagnostic tool readily available to most microwave communications systems engineering and maintenance departments.

Reliability and noise contribution are the most significant considerations influencing the design and maintenance of a microwave communications link or route.

This article will deal mainly with the influence of noise on a system. The total busy-hour noise in any operating microwave system baseband-derived channel is the sum of several categories of noise—including thermal, basic, interference, and rfi, which are all idle contributions—plus equipment intermodulation, path and feeder echo distortions that are present only with modulation. Such noise impairments, whether internal or external to the microwave system, can be readily identified by a simple but thorough interpretation of an accurately plotted bucket curve, thus enabling the rapid implementation of necessary corrective measures.

The bucket curve is a graphical presentation of noise within a microwave system, displayed in a form that permits separation and identification of the individual idle and intermodulation (IM, or cross-modulation) impairments. Analysis of a bucket curve can provide important information as to type and amplitude of the noise contributor within a matter of minutes, rather than the hours or days often spent on resolving the more difficult noise problems. The only test instrument required to generate such a curve is the common white-noise load test set which, with its calibration and impedance matching units, is already available along with the necessary expertise to the engineering and maintenance section of most communications departments.

As the term indicates, idle noise is unwanted, random electrical energy present in a transmission system under unmodulated conditions. The noise impairments related to baseband modulation are intermodulation and echo distortion.

Intermodulation Distortion

A single frequency tone passing through a non-linear device—such as an amplifier—will emerge at the output not as a single fundamental frequency, but as a fundamental frequency (f) along with the harmonics of that fundamental (2f, 3f. . .nf). Similarly, if more than one frequency is passed through the non-linear amplifier, harmonics of each of the fundamental frequencies appear at the output. Harmonics are the result of distortion caused by the amplifier's non-linearity. The more non-linear the amplifier, the greater the signal power that is converted to distortion products.

Most analysts refer to the single-frequency products as "harmonic distortion," and consider them separately from the products formed by the mixing of several frequencies. These additional frequencies, or intermodulation (IM) products, represent not only the sum and difference of the original input frequencies, but also the sum and difference of the various harmonics and the intermodulation products themselves. For example, if frequencies A, B, C, etc. appear at the input of an amplifier, the harmonics appearing in the amplifier output will be 2A, 3A, 4A... ; 2B, 3B, 4B... ; 2C, 3C, 4C... ; etc. While there are an infinite number of harmonics of each fundamental, the magnitude of these harmonics diminishes very rapidly with higher order, so that only the first few harmonics of each frequency have significant importance.

Second order intermodulation products consist of such frequencies as (A+B), (A–B), (A+C), and so forth. Third order products are much more complex and will typically consist of such frequencies as (A+B+C), (2A+B), (A+B–C), (2A–B), etc., although most products (A+B+C and 2A+B, for example) fall out of the passband and therefore do not influence the noise performance of the system.

Second and third order distortion products have different distributions across the frequency band. The differences result from the way in which the various intermodulation products form. Second order intermodulation can only appear as (A±B), (B±C), and the like. Third order IM products, however, are formed from a more complex combination of many frequencies, both above and below the fundamentals.

Echo Distortion

Like intermodulation distortion, echo distortion is a modulation-related impairment. It is created when one or more delayed echo signals introduce a phase-sensitive delay ripple across the fm portion of the system. The amplitude of this distortion is a complex function involving the relative magnitude and delay time of the echo signal with respect to the main signal, the level of baseband loading present, and the relative position of the channel in the baseband. Echo distortion is more significant in the upper reaches of the baseband, with greater echo and delay times, and is directly proportional to echo amplitude (a 1-dB increase in echo amplitude causes a 1-dB increase in echo distortion). In broadband radio links or systems with long waveguide or IF cable runs, it is necessary to maintain close control of return loss by ensuring low VSWR of antennas, equipment, waveguide and coaxial cable runs, and of all junctions; in this way, echo distortion can be kept at acceptably low levels. With the trend toward higher channel capacities, quieter radios, and longer feeders, echo distortion can easily become the dominant noise contributor.

Path reflections can, in some unusual cases, also produce echo signals with sufficiently long delay as to cause significant distortion. Such a condition could occur on a path with a relatively strong reflection and an abnormally large amount of clearance, as a result of a double bounce off one building to another and then to the antenna, or by near-field reflections behind an antenna or passive reflector. With proper system routing and antenna configurations, this type of distortion can be kept to the very low levels needed to meet overall noise objectives.

In-Service Noise Testing

In-service noise measurement schemes have been devised over the years by an ever-increasing number of microwave system users not permitted the luxury of frequency diversity. Out-of-band slots are provided for monitoring the in-service noise during idle and busy-hour periods. The baseband load is either generated by actual traffic or simulated with discrete high-level tones. There are indications that the in-service monitoring of the intermodulation products of two or more tones may provide a more sensitive measurement of second, and perhaps higher order, IM than does white noise testing. While it is a very useful technique, especially for identifying general system degradation without disruption of service, such multiple-tone testing does not closely simulate normal multiplex loading on a broadband radio system, leading to some misinterpretation and inconsistency in the test results. For example, multitone techniques appear particularly vulnerable to large phasing errors when attempting to isolate the phase-sensitive ripple of long-delayed echo distortion and multiple noise contributions. Out-of-service white-noise testing, however, very nearly approximates the busy-hour spectrum, and its results are not as affected by the same shortcomings as multitone procedures.

Unlike multitone testing, the white-noise technique requires that the system under test be removed from service. The speed with which bucket curves can be prepared, however, reduces the outage to only a few minutes in most cases. If downtime is impossible, the traffic can be routed onto an emergency restoration path which bypasses the link being tested.

White-Noise Load Testing

The baseband spectrum of a multichannel microwave system most often employs frequency division multiplexing with 4-kHz channel spacing. During busy-hour periods, this multiplex spectrum contains so many signals that it takes on the appearance of white noise. When impressed upon a quiet, non-distorting transmission system, these innumerable, randomly varying signals are reproduced at the receiving end, with no degradation. The transmission system, however, is never perfectly quiet nor is it perfectly linear in amplitude or delay. Noise, harmonics, and IM products are, therefore, introduced into the baseband spectrum. When demodulated, this noise and unwanted IM products are heard by the telephone user as interference.

Because of its appearance, the busy-hour spectrum of the microwave baseband signal can be simulated with white (random) noise of the proper amplitude and bandwidth. Analysis of a bucket curve produced under the simulated busy-hour condition can reveal the amount of noise and distortion present within the system so that corrective action can be taken, if necessary. The amplitude of the white noise used to simulate a busy-hour spectrum with reference to a zero dBm test tone level (0TTL) is usually based upon an assumed 25% activity factor (one-fourth of the spectrum in use) for system densities exceeding 239 voice channels, and a larger activity factor (approaching 50%) for a smaller number of voice channels.

A typical distribution of busy-hour rms powers in a 600-channel message system, under actual operating conditions (shown in Figure 1), reflects the fact that the mean speech power is less than 50% of the total, although it does dominate during short-term level peaking periods. The busy-hour rms wideband multiplex load for this 600-channel system is +12.8 dBm0; that is, the total busy-hour power is 12.8 dB above the test tone level. With white-noise load testing, this total power figure is referred to as the noise load ratio (NLR), or the baseband rms power level. The NLR for any capacity radio is computed as follows:

12-59 chan: 2.6 + 2 log N, dBm0
60-239 chan: –1 + 4 log N, dBm0
240 or more channels: –15 + 10 log N, dBm0
where N = number of channels.

VF, TONE, OR PILOT CHANNEL	QTY	UNIT POWER dBm0	UNIT POWER μW	ACTIVITY %	TOTAL OTTL POWER, mW	% OF TOTAL
VF	588	−12	63	25	9.3	48.9
RADIO PILOT	1	−3	500	100	0.5	2.6
SG PILOT	10	−20	10	100	0.1	0.5
GP PILOT	50	−20	10	100	0.5	2.6
SG CARRIER LEAKS	9	−20	10	100	0.1	.5
GP CARRIER LEAKS	50	−20	10	100	0.5	2.6
CH CARRIER LEAKS	600	−27	2	100	1.2	6.3
SIG TONES	588	−9	125	2	1.5	5.26
VF TELEGRAPH TONES (12 CH @ 24 T/CH)	288	−20	10	80	2.3	12.0
MISCELLANEOUS	–	–	–	–	3.0	15.8
		TOTAL:			19.0 mW (0TTL) (+12.8 dBm0)	

Figure 1. Distribution of powers in a 600-channel system during busy-hour periods. The most modern multiplex systems, such as the GTE Lenkurt 46A3, have carrier leaks substantially lower (10 to 20 dB) than those shown here.

NLR's for 60 vf channels and up are established internationally by CCIR recommendations. The NLR for 12-59 channels was set by FCC docket, and the NLR for 3-11 channels is established by each microwave systems manufacturer: the GTE Lenkurt NLR formula is 1.5 + 1.5 log N, which assumes a 100% activity factor and channels used by a larger proportion of high-level (loud) talkers and data.

White-noise loading is a widely accepted term for out-of-service measurement of noise in a microwave system using the simulated busy-hour traffic technique; for determining the rf spectrum of a microwave transmitter for interstation interference calculations; and for establishing compliance with FCC occupied-bandwidth and necessary-bandwidth limitations.

A typical white-noise measurement test setup is shown in Figure 2. The white-noise, generated by a noisy diode or resistor, is amplified and band limited by high-pass/low-pass filters to simulate the multiplex spectrum. Notch filters vacate selected portions of this simulated spectrum before transmission. At the receiver, these noise slots are examined to determine how much noise, and what types of interference, are introduced by the system. The noise slot measurement frequencies, standardized throughout the world, are positioned at the low, middle, and high reaches of the baseband. The most common noise measurement parameters are shown in Figure 3, although other slot frequencies and bandwidths are also used.

Crosstalk, the often-intelligible spillover of adjacent channel energy resulting from inadequate filtering, excessive coupling or overmodulation, should be excluded from the measured noise since it could mask the idle and IM contributions. In the test setup shown in Figure 2, crosstalk is eliminated by assigning a noise transmitter bandstop filter width some 8 to 60 times wider than the 1-3-kHz noise receiver bandpass filter width.

Noise Contributors

The following specific noise contributors (with a few influencing mechanisms) may be identified through bucket curve analysis:

(1) Internal idle noise contributors.

Thermal (noise figure, rf input level, deviation)

Basic or intrinsic (component or power supply noise)

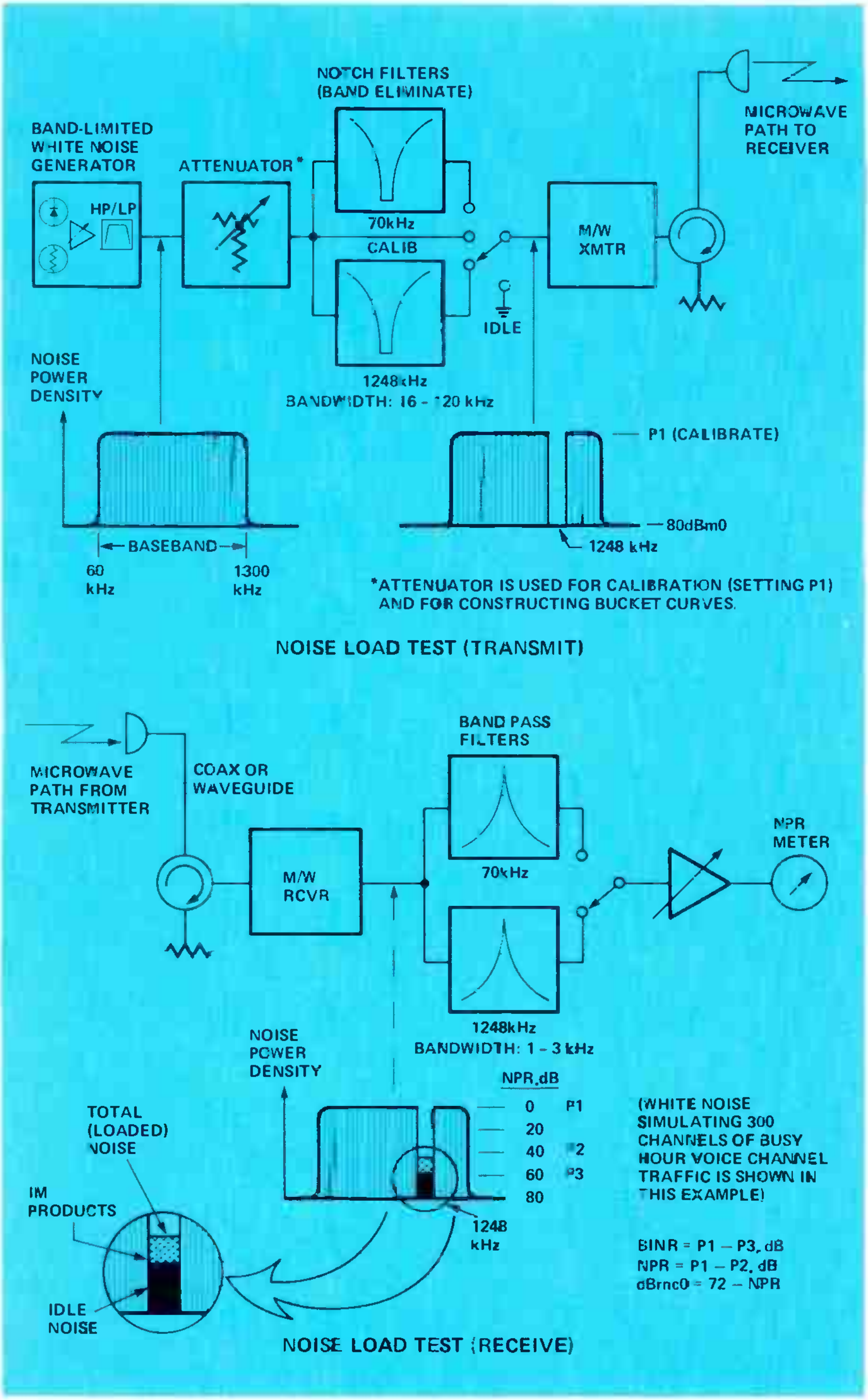


Figure 2. A typical white noise load measurement test setup.

NUMBER OF CHANNELS	NOISE BANDWIDTH (HP-LP) kHz	NOISE SLOTS kHz	REFERENCE NLR dBm0
12	12-60	14,40,56	+4.8
24	12-108	14,70,105	+5.4
36	12-156	14,70,152	+5.7
48	12-204	14,105,185	+6.0
60	60-300	70,185,245	+6.1
120	60-552	70,270,534	+7.3
132	12-552	40,270,534	+7.5
240	60-1052	70,534,1002	+8.8
252	12-1052	40,534,1002	+9.0
300	60-1300	70,534,1248	+9.8
420	60-1796	70,534,1730	+11.2
600	60-2660	70,1248,2438	+12.8
960	60-4028	70,2438,3886	+14.8
1200	316-5564	534,3886,5340	+15.8
1500	316-7284	534,3886,6900	+16.8
1800	316-8204	534,3886,8002	+17.5
2100	316-10162	534,5340,9624	+18.2
2400	316-11404	534,5340,9624	+18.8
2700	316-12360	534,5340,10700	+19.3

Figure 3. Noise load parameters.

(2) External idle noise contributors.
- Rf and IF interference
- Rfi and ground loops (at baseband)
- Feeder conversion (2A–B spurious products)

(3) Internal intermodulation contributors.
- Linearity slope (modulator-demodulator match)
- Hard clipping (amplifier amplitude overload)
- Spectrum truncation (discriminator)
- Group delay slope (filter flanking, etc)
- Parabolic group delay
- Spectrum truncation (rf filter)
- Pre-amp overload (differential gain slope)
- Linearity or group delay glitches

(4) External intermodulation contributors.
- Waveguide or coax feeder echo distortion
- Waveguide moding (differential delay)
- Path intermodulation contribution
- Group delay slope (caused by a very short echo)

(5) Multihop idle and loaded noise additions.

(6) Improper transmitter deviation.

Most important, the actual amplitude of most of these contributors may be separated from the measured or total system noise, identified, and compared with levels allocated by the microwave systems engineer. Periodic bucket curve analysis will pinpoint sources of path or system degradation, such as waveguide corrosion or damage, or receiver component drift which could upset the linearity of the system. In most cases, an impairment isolated by bucket curve analysis can be corrected without the sophisticated delay, linearity, or sweep test equipment (usually in the form of a microwave link analyzer) which is rarely available (with the necessary expertise) to short-haul, and even some heavy route, microwave communications systems users.

Baseband Levels

The baseband levels into and out of any active device, whether a simple baseband amplifier or a heavy route microwave system, are assigned by the systems engineer for optimum noise performance with some allowance for

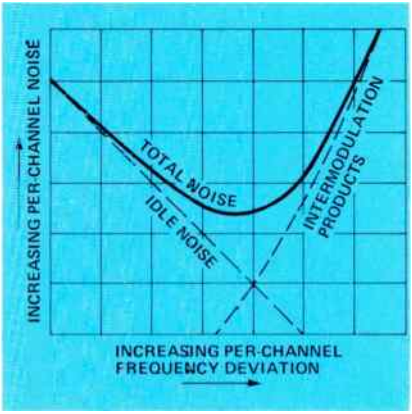


Figure 4. An optimum balance between idle and IM noise contributions is desired in a microwave system.

peaking. In fm radio systems, baseband amplitude variations are translated into rf carrier frequency deviations, controlled in width by the deviation setting on the transmitter. Again, an optimum balance between idle and IM contributions is desired, as shown in Figure 4. As the transmitter deviation is increased, the output at the radio or multiplex receive end of the system is reduced to maintain proper drop levels. This causes a reduction in idle noise, but as the transmitter is deviated into non-linear or unequalized spectra, IM products become rapidly dominant.

Noise Overload Curves

Noise overload, or signal-to-noise ratio (SNR), curves are constructed by plotting noise as a function of noise load without drop level correction (see Figure 5). While SNR curves are seldom used for evaluating the noise performance of a microwave link, they are useful in determining the "break" point, where a small increase in noise load results in a very large increase in slot noise. SNR and other noise parameters, such as dBrnc0 or dBm0, are not adjusted for the level of the noise load applied to the system.

A popular and more easily prepared and analyzed version of the Figure 4

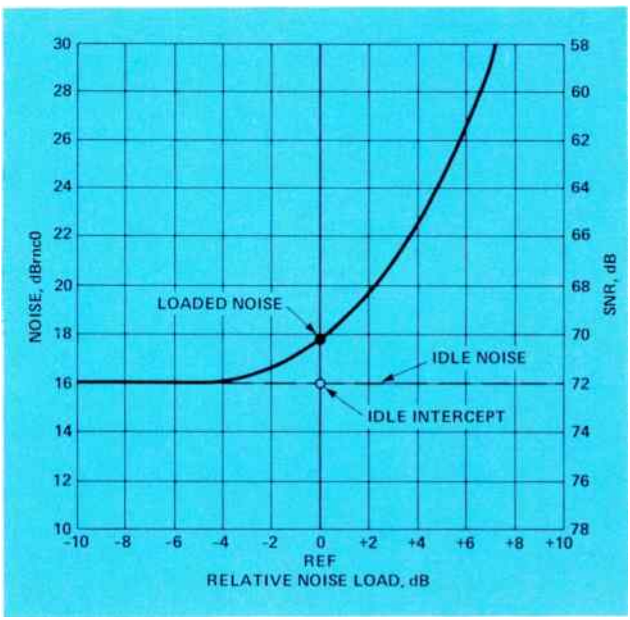


Figure 5. Noise overload or SNR curve. The dBrnc0-SNR relationship is approximate.

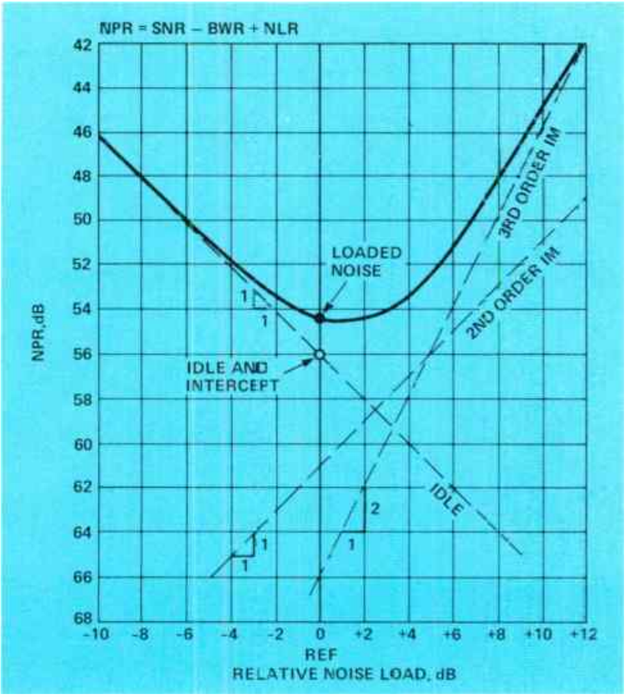


Figure 6. The NPR (bucket) curve, with radio-only noise or distortion elements.

and 5 curves is the NPR, or bucket, curve.

Noise Load (Bucket or NPR) Curves

Noise power ratio (NPR) is related to signal-to-noise ratio (SNR) and dBrnc0 as follows:

NPR = SNR (flat, 3.1 kHz) – BWR + NLR, dB

and

NPR = 88.3 – dBrnc0 – BWR + NLR, dB

where the bandwidth ratio (BWR) is the ratio of the baseband noise spectrum to the 3.1-kHz vf channel noise measurement bandwidth, i.e. 10 log (low pass – high pass)/3.1, dB. From Figure 3 it can be seen that the BWR for a 300 channel system, for example, is 10 log (1300 – 60)/3.1 = 26 dB.

NPR is associated with NLR (noise load ratio), the level of the noise load. If the NLR at the noise generator is increased by 1 dB, one dB must be added to the SNR reading (or subtracted from the dBrnc0 reading), at the noise receiver prior to converting these noise levels to NPR. It is the correction (in accordance with the NPR = SNR – BWR + NLR formula) that converts the SNR curve (Figure 5) into the bucket-shaped NPR curve (Figure 6). This correction is most often done arithmetically—one dB is added to the noise reading for each dB decrease in noise load from reference; one dB is subtracted from the noise reading for each dB increase in noise load from reference.

It is important to recognize that readings on a noise receiver already calibrated to measure NPR's are valid only at reference noise loads (+9.8 dBm0, for example, for a 300-channel system, as shown in Figure 3). Any change in noise load (perhaps to con-

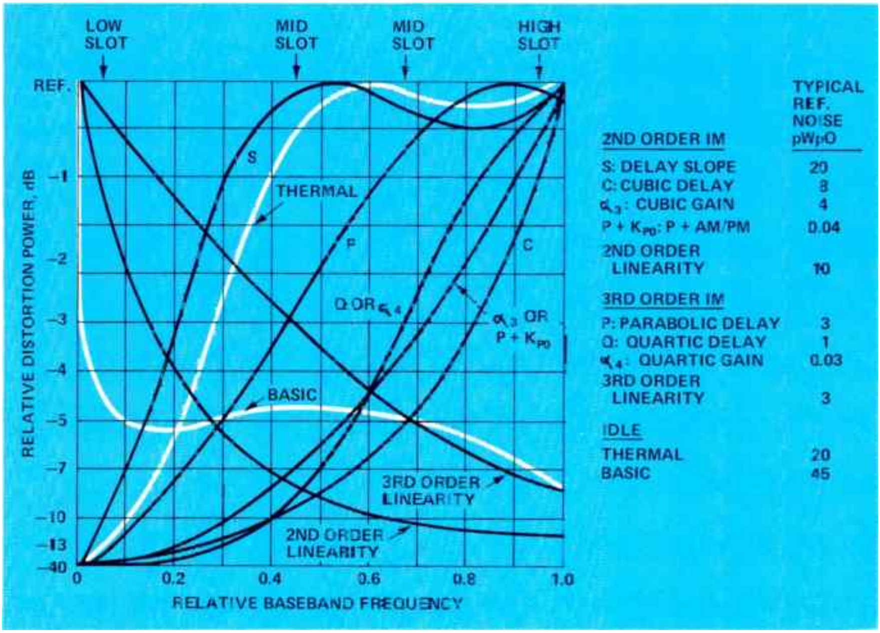


Figure 7. Distribution of distortion power in a typical baseband microwave link (with emphasis).

struct a bucket curve) must be accompanied by an associated correction in the NPR reading at the receiver.

Distribution of Distortion Powers

The noise distribution over the baseband spectrum of the numerous idle and IM contributors is widely varied, which makes possible an identification of the impairment by careful analysis of the relative amplitudes of the 2nd and 3rd order line reference crossings in the low, mid and high noise-slot bucket curves. Figure 7 shows a typical spectral distribution of idle and IM distortion products for a number of microwave transmission irregularities. The two equipment idle noise contributors, basic and thermal, are typically distributed unequally across the baseband, with thermal noise negligible, but basic noise maximum, in the low slot and their magnitudes reversed in the high slot. Some of the IM impairments shown in Figure 7 are negligible in lower density microwave systems.

The low-slot idle and loaded noise result from markedly different noise-generating mechanisms than in the upper slots, as shown in Figure 7. Further, as the noise load is varied in amplitude from nearly idle conditions (perhaps 10 to 12 dB below the reference NLR) to the point where 3rd or higher order intermodulation distortion becomes dominant, the dominant noise measured in each slot changes from idle noise to 2nd order to 3rd order to higher order IM products with an increase in NLR. These two fundamental characteristics form the foundation for bucket curve noise analysis.

Noise Conversions

Figure 8 provides exact conversion data between NPR (at reference noise load) and dBrnc0, assuming that FCC

NUMBER OF CHANNELS	BWR, dB	dBrnc0
12	11.9	81.2-NPR
24	14.9	78.8-NPR
36	16.7	77.3-NPR
48	17.9	76.4-NPR
60	18.9	75.5-NPR
120	22.0	73.6-NPR
132	22.4	73.4-NPR
240	25.0	72.1-NPR
252	25.3	72.0-NPR
300	26.0	72.1-NPR
420	27.5	72.0-NPR
600	29.8	71.9-NPR
960	31.1	72.0-NPR
1200	32.3	71.8-NPR
1500	33.5	71.6-NPR
1800	34.0	71.9-NPR
2100	35.0	71.5-NPR
2400	35.5	71.6-NPR
2700	35.9	71.7-NPR

Figure 8. Conversion data between NPR and dBrnc0.

rather than CCIR NLR's are used below 60 channels.

From Figure 8, it can be seen that the relationship dBrnc0 = 72−NPR is sufficiently accurate for most high-density (240 vf channel capacity and above) link measurements.

Other noise measurement terms are not related to channel capacity, BWR or NLR, but are identified only with a weighting factor or measurement bandwidth (usually a 300-3400 Hz vf channel).

Some of these terms can be defined using the following:

$$\mathrm{dBrnc0}\begin{cases} = 88.3 - \mathrm{SNR} \\ = 88.3 + \mathrm{dBm0} \\ = 90.8 + \mathrm{dBm0p} \\ = 10 \log \mathrm{pWp0} + 0.8 \\ = \mathrm{dBa0} + 6.8 \end{cases}$$

$$\mathrm{dBa0}\begin{cases} = 10 \log \mathrm{pWp0} - 6.0 \\ = 84.0 + \mathrm{dBm0p} \end{cases}$$

$$\mathrm{pWp0}\begin{cases} = \log^{-1} (90.0 + \mathrm{dBm0p}) \\ = \log^{-1} (87.5 + \mathrm{dBm0}) \\ = \log^{-1} (87.5 - \mathrm{SNR}) \end{cases}$$

Most noise measurement equipment used in the U.S. reads in NPR or dBrnc0, but some provides pWp0 or dBm0p readings. The obsolete dBa0 measurement unit is still used occasionally, so this term has been included. SNR and dBm0 assume flat noise measured over the 3.1-kHz vf channel bandwidth, and "0" indicates that the noise levels are referenced to a 0TTL point. The weighting factors used for pWp and dBrnc (from flat noise) are 2.5 dB and 1.7 dB respectively, although the latter has been variously assigned between 1.5 and 2 dB.

Bucket Curve Plotting

Before plotting a bucket curve, the loaded and idle noise points are carefully located on the reference line, as shown in Figure 6. Idle noise is measured with the noise generator disconnected or disabled. The bucket curve is then constructed (in the high and low slots) over a range of at least ±10 dB from the reference noise load in 1-dB or (if the measured noise is sufficiently stable) 2-dB steps. For each dB the NLR is decreased, one dB is arithmetically added to the slot noise reading (or subtracted from the NPR reading). For each dB the NLR is increased from reference, one dB is subtracted from the noise reading (or added to the NPR reading). These corrected values are plotted on rectangular graph paper having equal dB/inch vertical and horizontal scales. The NLR should be decreased until idle conditions are reached (some 16 dB of increased attenuation may be necessary if high-amplitude echo distortion is present), and increased until the right side of the plotted curve becomes a straight line with 2:1, 4:1, or other tangent slope (see Figure 6).

The noise load test should be conducted during quiet propagation, non-faded periods when the idle noise and path intermodulation contribution, if any, remain stable and the measurements at various NLR's are repeatable.

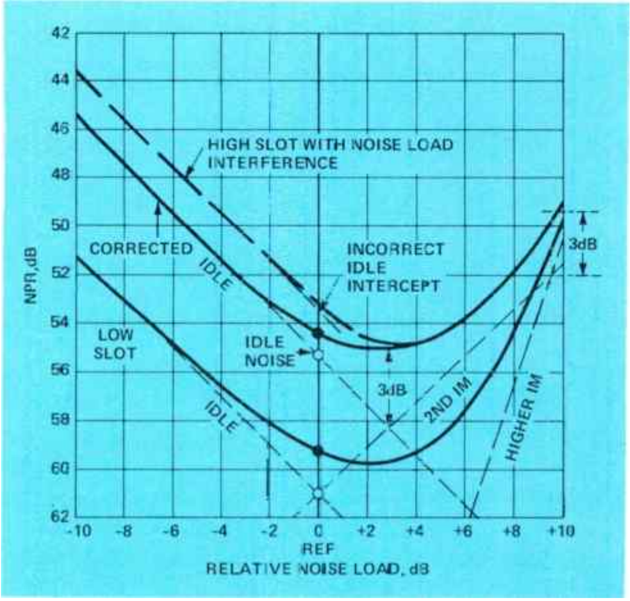


Figure 9. An incorrect high-slot bucket curve showing noise load interference.

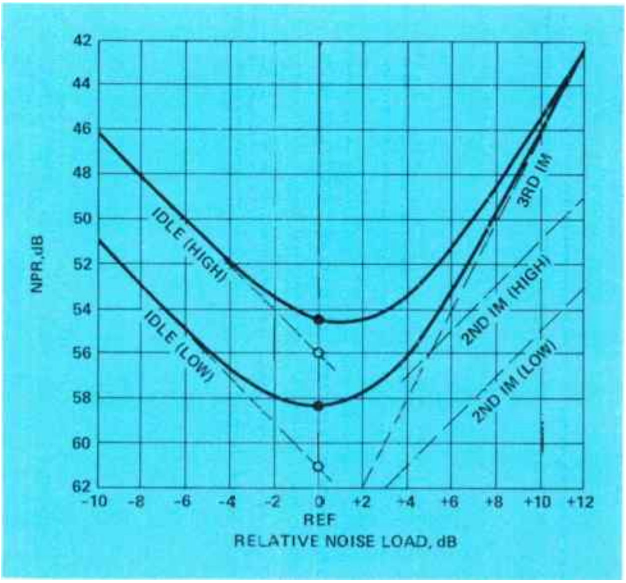


Figure 10. Bucket curves showing the idle and 3rd order tangent lines.

If this precaution is taken, an idle line drawn at 45° from the upper left to the lower right tangential to the bucket curve should intercept the idle noise point. The interception of this idle line with the reference noise load line is the "idle intercept point," and it must fall very near (within ±0.5 dB) the idle noise reading initially taken, or the test (or arithmetic corrections) must be redone. If the idle intercept line and idle noise point do not coincide, the measurements are invalid for one of the following reasons:

(1) Noise load interference has occurred, which is common in intrastation, loop or back-to-back radio tests with the noise generator and receiver in the same room. In this case, the idle intercept point always falls above (is higher than) the idle noise, as shown in Figure 9. Physical isolation of the test units and cords, and grounding are useful.
(2) A high-amplitude interference tone has fallen into the receive baseband; it may be located with a selective VTVM or spectrum analyzer.
(3) Rfi or ground loops have occurred in the radio, baseband, or test units.
(4) The measurements or arithmetic corrections were erroneous.

Typical Bucket Curves

Figures 9 through 11 show typical "radio-only" bucket curves. These curves depict only the radio noise impairments, excluding path IM and feeder (waveguide or coax) echo distortion. The curves are usually prepared for the low and high frequency slots only, although in an emphasized system the mid-slot is more sensitive to certain upper baseband noise impairments, and may therefore be used for a more detailed noise analysis.

The curves in Figures 9 through 11 show the important idle and 3rd (or 5th) order IM lines drawn tangentially at the far left and far right, respectively, of each bucket curve. The idle line is always a 45° (1:1) slope, while the higher order IM line will usually have a 2:1 slope, indicating predominate 3rd order IM (see Figure 10). Some narrowband (or truncated) radios break into 5th order IM (4:1 slope) with increased noise load (Figure 11).

Bucket Curve Graphical Analysis

With a valid high- or low-slot bucket curve, the four key noise contributors in a microwave line or system can now be isolated. These are:
(1) The idle noise line
(2) The 2nd order IM line
(3) The 3rd (or higher) order IM line
(4) The echo distortion inverse parabola.

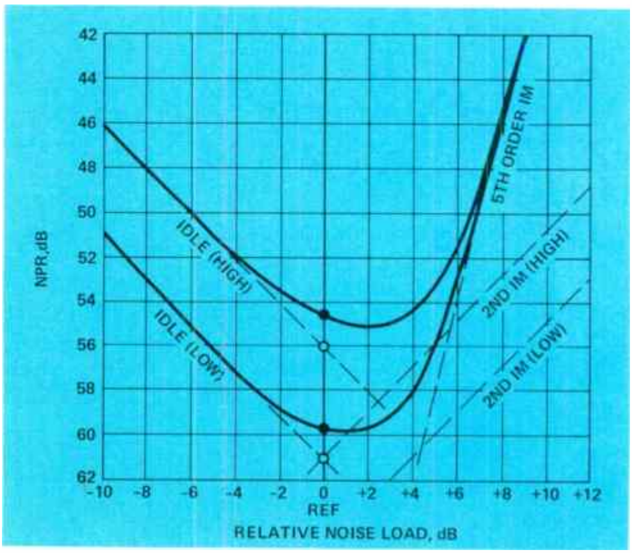


Figure 11. Same as Figure 10, but with 5th order IM establishing the higher order tangent line.

P_s = SUM OF POWERS P_a & P_b (P_a IS LARGER THAN P_b)

$P_a - P_b$, dB	$P_s - P_a$, dB	$P_s - P_b$, dB
0	3.0	3.0
0.5	2.8	3.3
1.0	2.5	3.5
1.5	2.3	3.8
2.0	2.1	4.1
2.5	1.9	4.4
3.0	1.8	4.8
3.5	1.6	5.1
4.0	1.5	5.5
4.5	1.3	5.8
5.0	1.2	6.2
5.5	1.1	6.6
6.0	1.0	7.0
6.5	0.9	7.4
7.0	0.8	7.8
7.5	0.7	8.2
8.0	0.6	8.6
9.0	0.5	9.5
10.0	0.4	10.4
12.0	0.3	12.3
14.0	0.2	14.2
16.0	0.1	16.1

Figure 12. Power addition and subtraction.

The idle noise and 3rd (or higher) order IM lines are simply drawn tangentially to the straight left and right side, respectively, of the bucket curve. If the right side of the curve has not become a straight line, it is preferable that the noise load be increased until the line is straight (see Figure 11). However, the higher order tangential line may be carefully drawn at an estimated location (see (Figure 9). The 3rd (or higher order) lines for the high- and low-frequency slots may merge into a single line as shown in Figures 10 and 11. After the idle and higher order IM lines are drawn and the idle intercept point falls within 1/2 dB of the idle noise, the 2nd order line is either located with computer-generated graphical overlays (often not available to the analyst) or computed. It has a 1:1 slope (45° up and to the right), as does the idle line (45° up and to the left). A 2nd order line NLR crossing is best determined at the far right of the bucket curve, away from any echo distortion contributions.

Computing and plotting the 2nd order IM line requires some familiarity with power addition and subtraction, best accomplished with the aid of

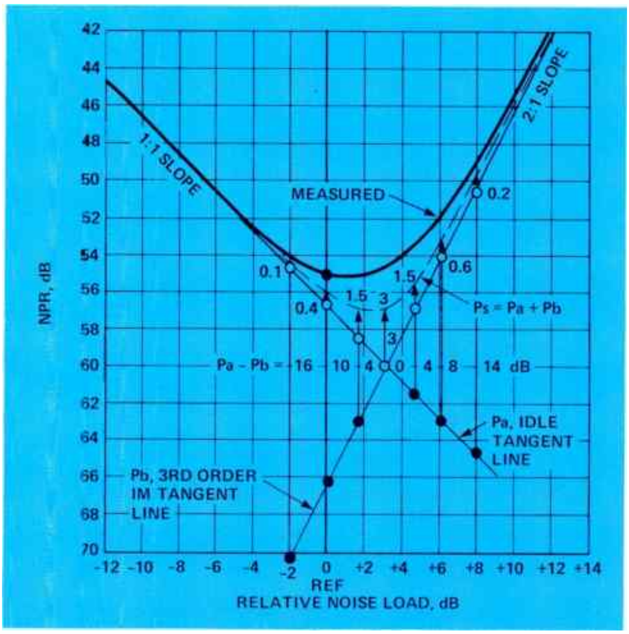


Figure 13. The first step in computing the 2nd order IM line is to add the idle and higher order tangents.

Figure 12. Given any two of the three powers (P_s, the total power, P_a, the larger of the components, and P_b, the smaller of the components), the third can be determined. If $P_a = P_b$, then $P_a - P_b = 0$ and the sum (P_s) is 3 dB above either P_a or P_b. If P_b is 4 dB below P_a, ($P_a - P_b$ = 4 dB), P_s is 1.5 dB above P_a. If P_b is 7 dB below P_s, P_a is 1 dB below P_s. Columns 1 + 2 = column 3 ($P_a - P_b + P_s - P_a = P_s - P_b$).

Figure 13 details the first step in locating the 2nd order IM line by calculation. The known idle and 3rd (or 5th) order IM tangent lines are added with the aid of columns 1 and 2 in Figure 12 to find a curve showing idle plus 3rd (or 5th) order IM. The second step is to subtract this curve from the measured curve, as shown in Figure 14, using columns 2 and 3 in Figure 12. In the absence of echo distortion, this should derive a straight 2nd order IM line with a 1:1 slope.

Echo distortion, if not severe, rarely influences the measured noise with noise loads exceeding 6 dB above reference (except occasionally in radios of 1200 channel or higher capacity). The 2nd order IM line position is most accurately located, therefore, by carefully determining where the 3rd order tangential line (P_a) separates from the measured noise curve (P_s) by exactly 1 dB (11 dB above reference noise load in Figure 15). From Figure 12, if $P_s - P_a$ = 1 dB, then P_b (the 2nd order contribution) is 6 dB below P_a (the 3rd order contribution). A 45-degree line drawn down and to the left through this point establishes the 2nd order IM line. With some practice, the 2nd order IM line can be located almost immediately by inspection.

In the absence of echo distortion, the measured bucket reflects only radio contributions (with rfi and interference); that is, the sum of the idle, 2nd, and 3rd order IM lines as added with the use of Figure 12. Figures 9 and 16 show a few of the points added. If two lines cross, the sum is 3 dB. The sum of two points 6 dB apart is 1 dB above the larger power, while powers 4 dB apart produce a sum 1.5 dB above the larger.

A radio-only bucket curve is plotted in this manner. Any departure of

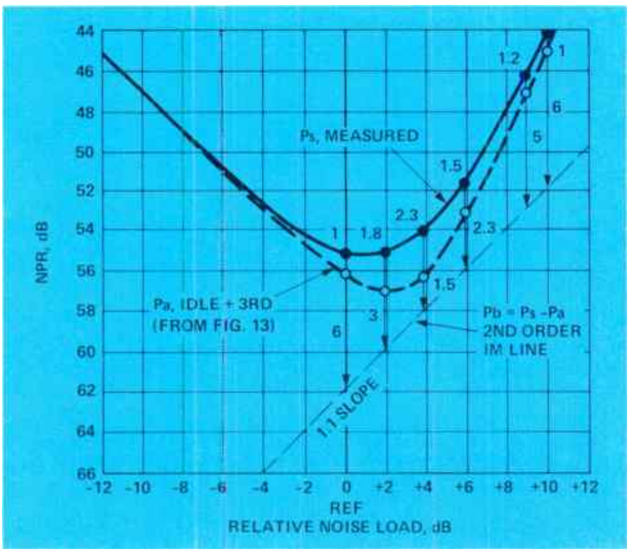


Figure 14. The second step in computing the 2nd order IM line is to subtract the sum of the tangents from the measured (total) noise (no echo distortion).

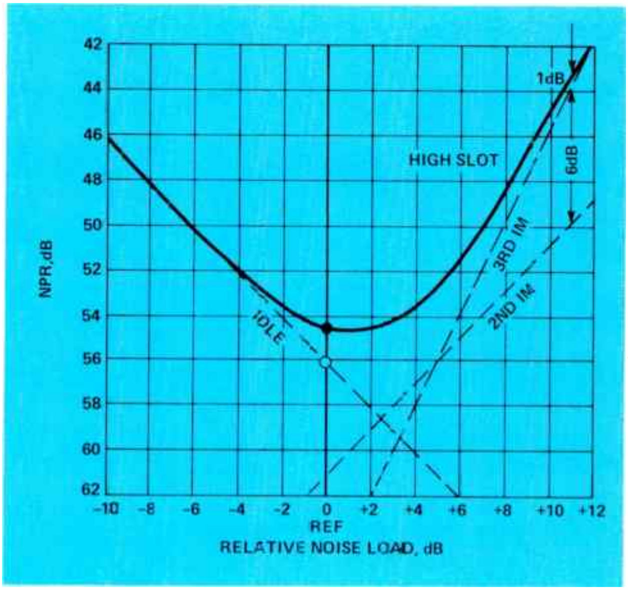


Figure 15. Computation of the 2nd order IM line at an NLR removed from the influence of echo distortion.

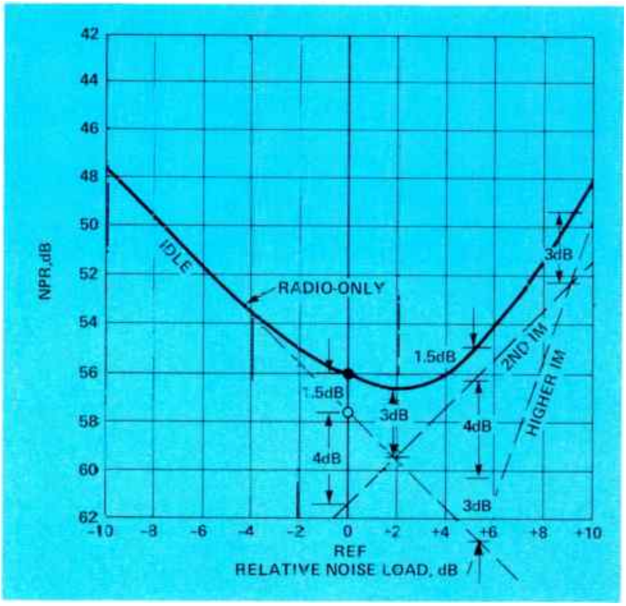


Figure 16. The radio-only bucket curve is computed by adding its three component lines.

this bucket from a carefully measured total noise curve probably results from echo distortion. When the radio-only curve is subtracted from the measured noise curve, the echo has the appearance of an inverse parabolically-shaped curve.

The Idle Noise Line

As a general rule, the idle intercept point should fall 2-3 dB below the loaded noise requirement for the hop or system (15-16 dBrnc0 if the requirement is 18 dBrnc0, for example). If the separation is less than this, the link or system is said to be idle-noise limited. This usually results from low radio deviations, low rf received signal levels, poor noise figure (such as with the loss of a mixer diode), unusually low IM contribution (such as in a well-equalized heterodyne radio link), or (in the top slot) lack of emphasis. If the margin is much greater than 3 dB, radio intermodulation or echo distortion is the controlling factor, possibly requiring that corrective measures be taken if the total noise is excessive.

Idle noise is the sum of the following contributors:

(1) Thermal (front end or variable) noise, computed (in a vf channel) as follows:

Thermal, dBrnc0 =

$$-C - 47.8 + N_f - 20 \log D/f_b - E$$

where

C = rf input level to the receiver (at the point where the noise figure is measured), dBm

N_f = the receiver noise figure, dB

f_b = noise slot frequency, kHz

D = peak sine wave per-chan deviation, 1.414 x rms deviation, kHz

E = emphasis advantage (or disadvantage), if any, at f_b (usually +3.7 dB in the top slot, 0 dB in the mid slot, −4 dB in the bottom slot).

For example, reference thermal noise in the top frequency slot (1248 kHz) in a 300-channel emphasized system deviated 200 kHz rms/channel, with a 9-dB receiver noise figure and a −40 dBm rf input, is 10.4 dBrnc0 (9.1 pWp0). Degradation of any parameter (rf input level, noise figure, deviation setting, omission of emphasis) will increase thermal (and, therefore, idle) noise accordingly (see Figure 17). Low rf input signal levels are easily verified by comparing the agc reading with the computed median, or by fading the path (by partially closing the receive waveguide shutter, for example) and observing the increase in idle noise; a dB-for-dB increase indicates excessive thermal noise contributed by a low received signal level. If the transmitter deviation is improperly set, the high- and low-slot bucket curves will look normal, but both will be shifted either to the right (low deviation, with high

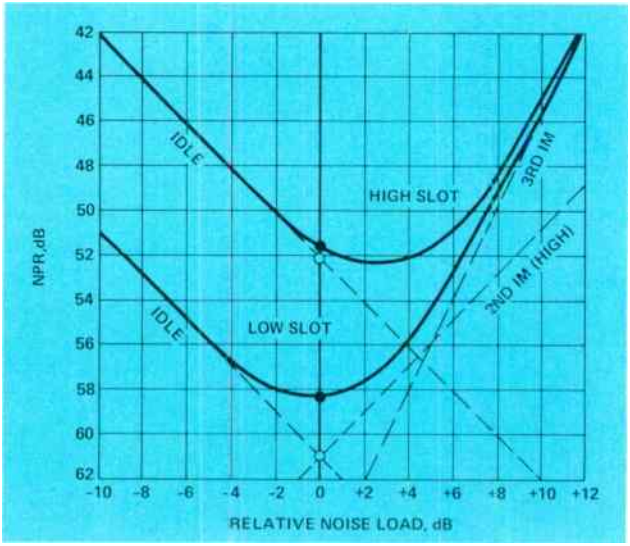


Figure 17. Excessive high-slot idle noise with a depressed rf input signal level.

idle) or to the left (high deviation, with low idle) of reference. A poor noise figure or low deviation is also reflected quite accurately as a degraded (high) radio threshold (mute point). The low-slot thermal noise contribution is negligible at normal rf input levels.

(2) The basic (fixed or intrinsic) noise of the radio is not influenced by rf input levels, and usually has greatest effect on the low slot (see Figure 18). It is contributed by noisy active components (usually klystrons, transistors, or varactors) in the baseband or rf chain, or by poor dc supply filtering, and is best isolated by switching between on-line and standby units.

(3) External interference. Except for threshold degradation and the aforementioned high-level single tone interference that affects the idle intercept point, the noise contribution levels of most interference mechanisms (co-channel intercarrier beat, co- and adjacent-channel sideband coupling, etc.) depend upon the carrier-to-interference (C/I) ratio, not upon the actual level of interference. If the wanted signal is high, the interference signal level may also be high for a low noise contribution. The partial closing of the receive shutter reduces the received signal level and interference arriving via the antenna by an equal amount, so the ratio and noise (until thermal dominates) remain constant. The best way to find interference of a magnitude influencing single-hop noise is to disable the distant transmitter, search for foreign agc by moving the receive frequency (afc off), and check for a proper receive mute.

(4) Internal interference, rfi, and ground loops. If the high-slot idle line remains constant with changing rf receive signal levels, internal (intrastation) interference, rfi, a ground loop in the radio or test setup, or a 2A–B or A+B–C waveguide conversion product is probably responsible, as follows:

(a) Internal interference. This may occur either near the rf or the IF frequency. If a circulator is faulty or a waveguide flange internal or external to the radio is loose, adjacent local oscillators, transmitters, or foreign signals close to the receive frequency may cause high interference. Vhf radios (especially between 35 MHz and 80 MHz, or at a wavelength almost equal to the T/R spacing) may introduce interference into the baseband or IF circuitry which is usually intermittent, since most of these radios are keyed. Shielding, grounding, filtering, and flange tightening are helpful.

(b) Rfi or electromagnetic interference (baseband interference). High-powered hf and vhf radios, TV and broadcast transmitters, and other radiating devices may introduce interference (directly or by IM mixing) into receivers or modems, either by detection into the active baseband elements (transistors) or by direct modulation of the transmitter through the fmo (frequency modulated oscillator). Rfi is best tracked down with a spectrum analyzer and cured by shielding, grounding, trapping, filtering, isolating, rf bypassing, etc. Each case is different, and no effort is made here to define all of the solutions, some of which are quite complex.

(c) Ground loops. This results from some radio components

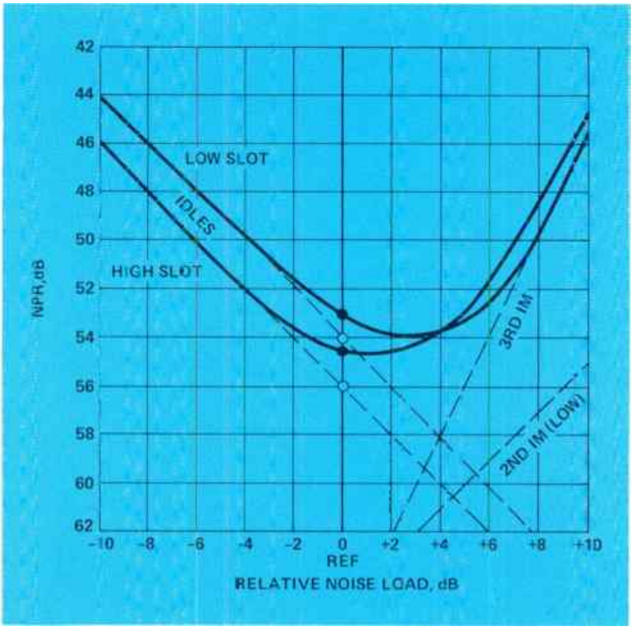


Figure 18. Excessive low-slot idle noise caused by a noisy amplifier or waveguide conversion product.

being at a different potential from others, such as radio modems, multiplex units, or test equipment. All units should be at a common ground and tied with ground straps or wire.

(5) Waveguide conversion. With two or more transmit frequencies sharing a common feeder with one or more receive frequencies, the transmitted signals may mix in a corrosive or point-contact element and generate a stable interfering 2A−B or A+B−C IM signal falling within the receiver passband, with most effect in the low slot (see Figure 18). The test for conversion is to disable one transmitter at a time, until the interference disappears. Waveguide joints must be tight and the interior of the waveguide clean. The exact location of the conversion element is pinpointed by lowering a load into the waveguide with the transmitters on until the product vanishes.

The April issue of the *Demodulator* will continue the discussion of bucket curves. Specifically, it will cover the analysis of intermodulation products and echo distortion through the use of bucket curves.

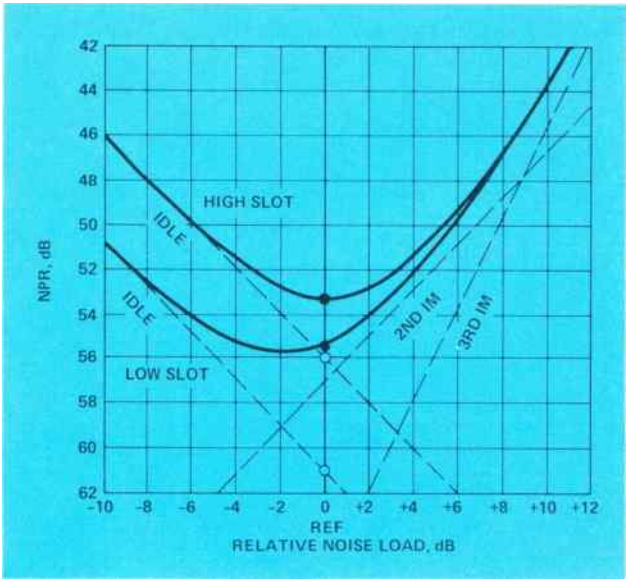
Bucket Curves
part 2

Part 1 of the bucket-curve series dealt with the various types of idle noise that affect a microwave system, as well as with the basics of bucket curve construction and analysis. This issue continues the discussion of bucket curves, with emphasis on the analysis of IM (intermodulation) distortion products generated by transmission impairments which may be either internal or external to the radio.

The 2nd Order IM Line

The 2nd order IM intercept point (at reference drive) should be below the idle intercept by 3 dB or more, unless the idle is very quiet because of high rf signal levels. Excessive low-slot 2nd order IM usually indicates a linearity mismatch between the transmitter and the receiver (see Figure 1), and is resolved in most radio systems by discriminator adjustment. Excessive high-slot 2nd order IM distortion (see Figure 2) is often corrected by delay slope adjustment in the receiver IF filter equalizer (if the low-slot 2nd order IM line is acceptable). Rf filter flanking is a common contributor of excessive 2nd order IM, indicating a mistuned filter, a bad circulator, or excessively close T-R (transmitter-to-receiver), T-T (transmitter-to-transmitter), or R-R (receiver-to-receiver) frequency spacing. Assignment of the local oscillator frequency on only one side (high or low, rather than staggering) of the receive frequencies will generate excessive delay slope (unless

Figure 1. Excessive low-slot 2nd order IM distortion can be corrected by linearity adjustment.



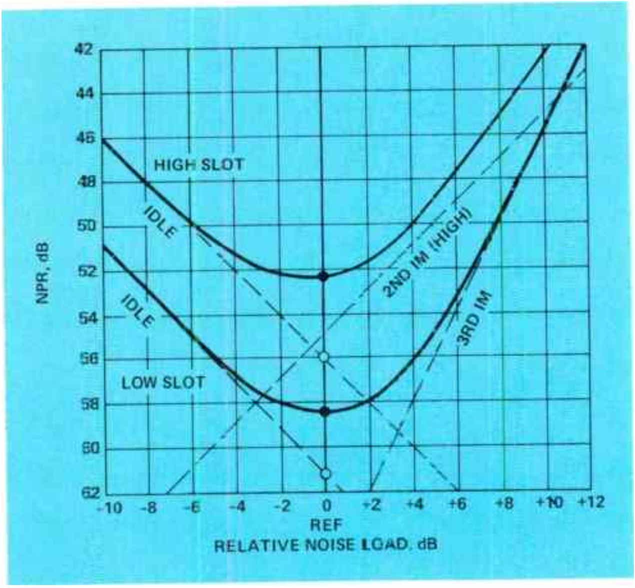


Figure 2. Excessive high-slot 2nd order IM distortion requiring delay slope equalization.

there is per-hop equalization) in a multihop system, since the per-hop slopes are correlated and, therefore, voltage additive. A very short (less than 10 nsec) waveguide or coax echo, or stable multipath (secondary) rf signal could also generate a delay slope influencing the 2nd order IM line. However, for this to occur, the secondary rf signal amplitude must be unusually high (often nearly equal to the desired signal), which in itself causes fading, with consequent increases in thermal noise that could mask the IM contribution.

An overloaded 70-MHz pre-amp or other active component (delay equalizer, IF amplifier, etc.) is indicated if the high-slot 2nd order IM line moves with changes in rf received signal input.

3rd (Or Higher) Order IM Line

The 3rd (or higher) order IM line should intercept (at reference NLR) below about 66 dB NPR (about 4 pWp0) per hop in both the low and high slots if the link is part of a multihop system (rather than a single hop or spur). These higher order contributions are indicative of amplitude clipping with amplifier overload, limiting, or of bandwidth constriction with rf or IF filtering. The low- and high-slot bucket curves may break into the same higher order tangential line. A low-slot higher order IM slope, very different than that of the high-slot, is often indicative of two separate mechanisms, such as a narrow, mistuned, or off-frequency discriminator influencing the low slot, and a narrow, mistuned, off-frequency or parabolically unequalized rf filter introducing higher order IM into the high slot. If the higher order line is steep (4:1 or greater slope), hard amplitude clipping or bandwidth truncation is evident (see Figure 3). This is most often seen in narrowband radio systems.

Even if excessive (perhaps 3 to 6 dB high), higher order IM distortion seldom influences the busy-hour noise performance of a single radio hop. But higher order products on two or more tandem hops are correlated and, unlike most other contributions, increase on

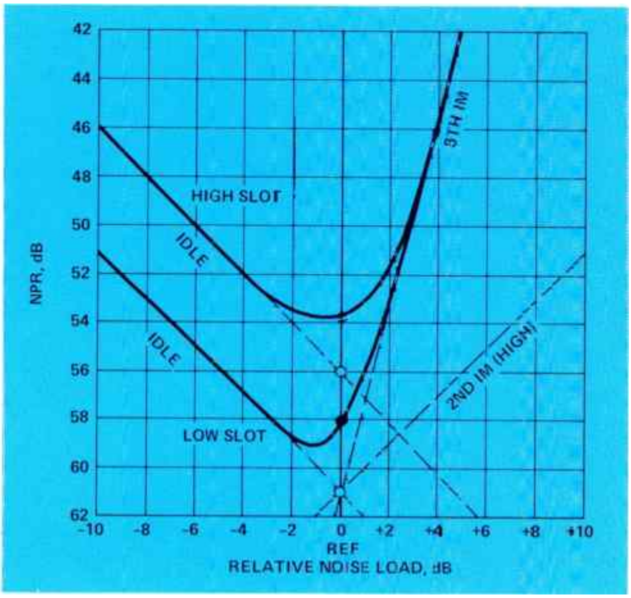


Figure 3. Excessive higher order IM distortion resulting from amplifier overload (hard clipping).

a voltage, rather than linear power or quadratic (rss) addition, basis.* If each hop contributes only 8 pWp0 of 3rd order IM distortion during busy-hour periods, 10 tandem hops contribute $(8)\ (10)^2 = 800$ pWp0. This could easily dominate the noise budget for a multihop microwave system, and must be carefully controlled. If this line is shifted up in the low slot of the bucket curve, it usually indicates an overloaded baseband amplifier resulting from improper level assignments or settings (Figure 3).

If the higher order contribution is excessive in the high slot but the low slot is acceptable, parabolic (or higher order) delay distortion revealing rf filter skirts may be the contributor. Most receivers have multisection parabolic delay equalizers which compensate for this distortion over the designed bandwidth of the system.

The Echo Distortion Inverse Parabola

Figures 4 through 6 show radio-only curves, which reveal the total measured noise for a microwave system – in this case, a 300-channel system. Any departure of the total measured noise from the radio-only curves is probably caused by one of the following echo distortion contributors, which generate delay ripples rather than slope, parabolic, or other group delay shapes across the IF passband:

(1) Internal feeder system or IF cable echoes. "Kinks" or "glitches" in the IF delay pattern can introduce random bumps in a bucket curve, which are unrelated to echo distortion.

(2) Long-delayed, far-field secondary ("sneak") reflection paths between the antennas (path IM).

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*Linear summation (10 hops @ 20 pWp0/hop) = (10) (20) = 200 pWp0
Quadratic or rss (10 hops @ 20 pWp0/hop) = $[(10)(20)2]^{1/2}$= 63 pWp0
(rss = root sum square)
Voltage (coherent) addition (10 hops @ 4 pWp0/hop) = $4\ (10)^2 = 400$ pWp0

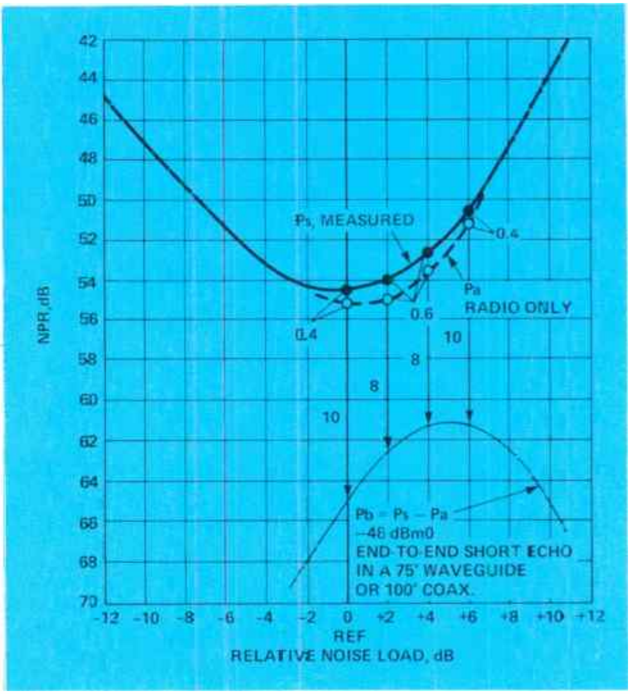


Figure 4. The radio-only bucket is subtracted from the measured total system noise curve to derive the echo distortion contribution.

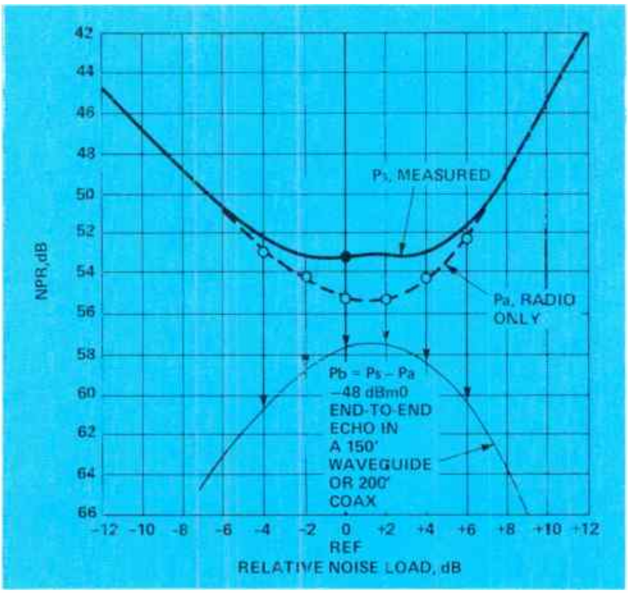


Figure 5. Same as Figure 4, but with a 150-foot waveguide echo.

(3) Secondary paths in periscope antenna systems, or other near-field reflecting surfaces.

(4) Differential delay distortion with spurious mode conversion in circular or elliptical waveguide.

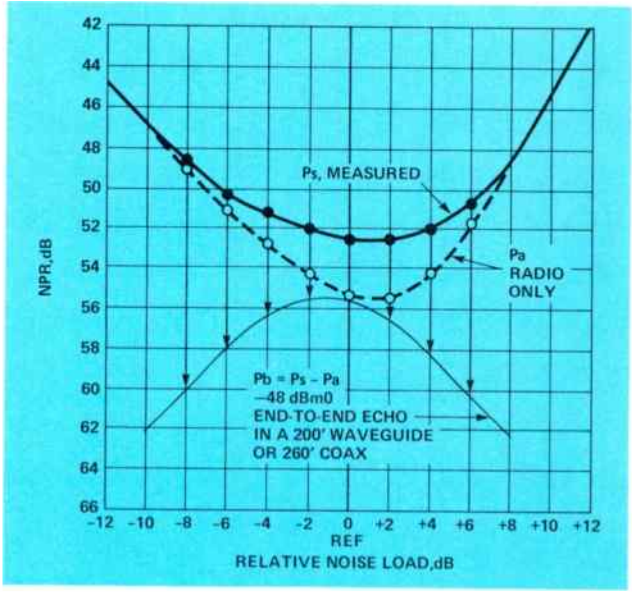


Figure 6. Same as Figure 4, but with a 200-foot waveguide echo.

The inverse parabola, plotted by subtracting the radio-only noise (the sum of the idle, 2nd order, and higher order lines) from the measured bucket curve, does not differentiate between the four echo distortion contributors listed above, except in that far-field path IM will cause loaded noise readings to fluctuate rapidly over a wide range (1-10 dB or more).

Although a bucket curve will always reveal the presence of measurable echo distortion in a slot, it lacks such fine-grain detail as precise distance or delay time (ripple period) that the microwave link analyzer provides, nor does it precisely pinpoint the location of a damaged piece of waveguide, or isolate certain types of spurious mode conversion, as does a reflectometer. But it does separate echo distortion from the radio contribution, reveals if it is generated in the antenna feeder system or path, and furnishes such other information about it as:

(1) Approximate delay time, which may be converted into delay or echo distance.
(2) Exact echo distortion level.
(3) Echo amplitude.
(4) The number of echos (sometimes).

The Figure 4 high-slot bucket curve reveals the presence of a 75-foot waveguide (or 100-foot coax*) echo. The echo contribution curve has been derived by subtracting the radio bucket from the measured or total noise curve. Only the top slot is affected; no indication of echo distortion is evident in the bottom slot. The echo distortion level is 65 dB NPR at reference. The total noise is 54.5 dB NPR, and the radio-only noise is about 55 dB NPR, all taken from the curve at reference drive (also known as reference noise load and NLR).

A long-delayed echo is analyzed as a co-channel interfering signal, with a C/I (desired carrier-to-interference) ratio computed from the following formula:

C/I, dB = NPR − 3 dB − echo amplitude/distortion ratio − emphasis.

*Microwaves travel 20-30% slower in rectangular or elliptical waveguide than in free space, coaxial, or larger diameter circular waveguide.

The 3-dB correction assumes that long-delayed echo is uncorrelated with the desired signal. The echo amplitude-to-distortion factor is shown in Figure 7 and is best explained by example. The horizontal scale of Figure 7 is the ratio of the busy-hour rms deviation of the radio to the noise slot frequency. For the 300-channel system (1248-kHz slot) measured in Figure 4, this ratio (at the reference +9.8 dBm0 noise load and 200-kHz rms/ch deviation) is:

$$(200)\ (\log^{-1}\ 9.8/20)/1248 = 0.50.$$

The reference deviation line is drawn vertically at this point (see Figure 7). As the noise load is varied (from −12 to +12 dB from reference), the rms deviation of the radio changes accordingly. Radio deviation is a voltage function; a 6-dB increase in noise load doubles the radio rms deviation and, therefore, the ratio of the rms deviation to slot frequency.

In Figure 4, echo distortion peaked 5 dB above reference noise load. The intersection of the peak distortion ridge line with a line drawn vertically 5 dB to the right of the 1248-kHz reference load occurs at $f_b T = 0.25$ (point a on Figure 7) on a −7-dB echo amplitude-to-distortion contour. Since we know the peak echo distortion from Figure 4 (61 dB NPR) and the slot frequency (1248 kHz), the echo amplitude (C/I) and delay time (T), convertible to delay distance, may now be determined by:

C/I = NPR − 3 dB − echo amplitude/distortion radio − emphasis
$= 61-3-7-3$
$= 48$ dB

and

$T = 0.25/1248 \times 10^3\ \text{Hz} = 2\times10^{-7}$ sec
$= 200$ nsec.

This equates to an echo 48 dB below the desired transmitted or received signal level, with a delay of about 200 feet in free space, coax or large circular waveguide, or about (0.75) (200) = 150 feet delay in rectangular or elliptical waveguide. The echo distance is 1/2 of the delay distance (100 feet in free space or coax, and 75 feet in waveguide).

This relatively short echo had little influence upon reference noise in this 300-channel system (only 0.4 dB as shown in Figure 4). If either the channelization or the echo distance was increased, the distortion at reference noise load would have become much larger. This is seen in Figures 5 and 6, with radio and echo parameters similar to Figure 4, but with increasing echo distances (for waveguide, from 75 feet in Figure 4 to 150 and 200 feet in Figures 5 and 6, respectively). In accordance with Figure 7, the echo distortion approaches a peak as the echo delay time (T) increases in this 300-channel system (points b and c, respectively, for the 150-foot and 200-foot waveguide). By plotting other reference deviation lines on Figure 7, echo distortion in radio systems of any capacity can be analyzed from the bucket curve.

Long Delayed Path IM

Reflections from buildings and other on-path surfaces can generate echos with such long delay times (from hundreds to thousands of feet) as to influence even the low baseband slots in a microwave system, as shown in Figure 8. These secondary paths often occur in the far field of the antenna systems, and are therefore subject to fading characteristics independent of the desired signal. This causes the C/I ratio (and echo phasing in shorter delayed paths) to continuously change, causing wide fluctuations in loaded noise. This characteristic is contrary to the stable distortion levels measured with feeder or near-field external echoes. Again, Figure 7 and the bucket curve are used for analysis.

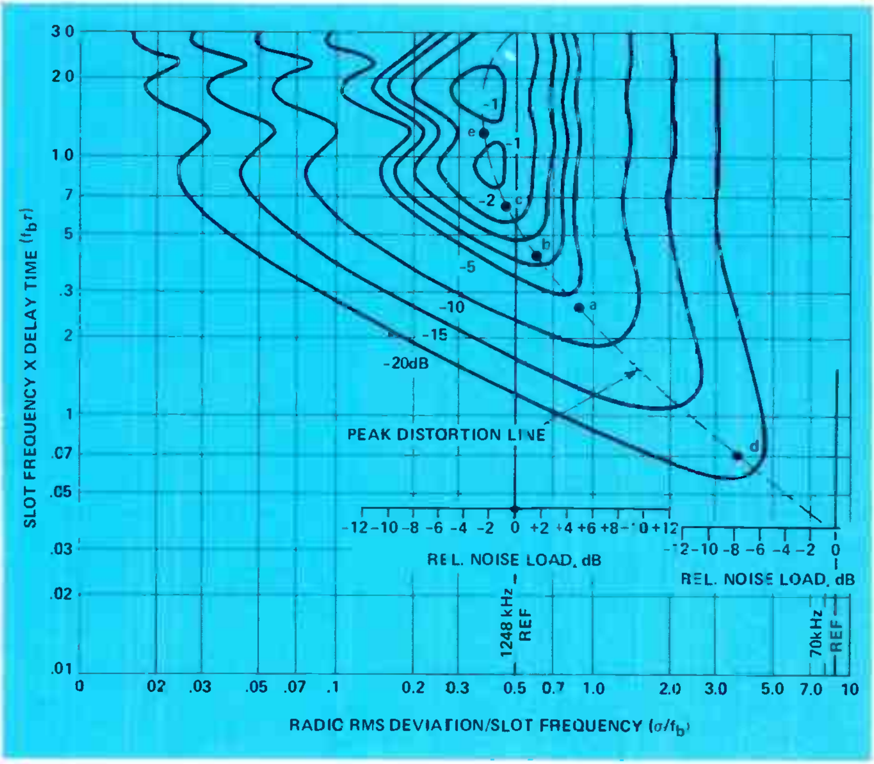
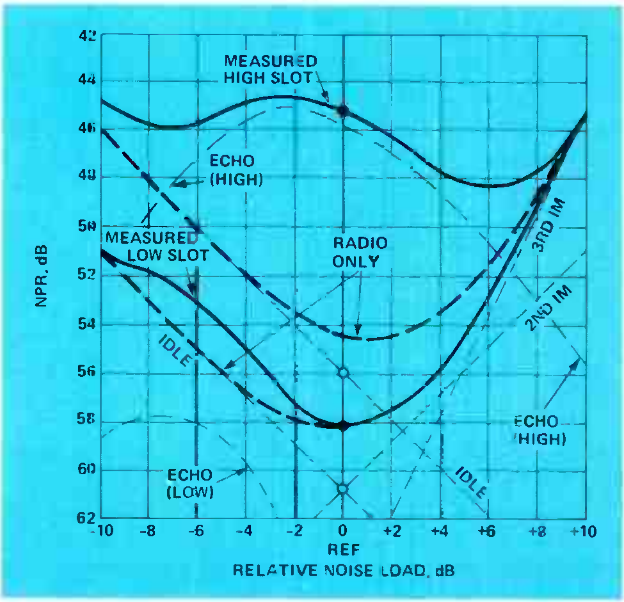


Figure 7. Contours of constant echo amplitude-to-echo distortion ratio.

Figure 8. Bucket curves showing path IM and the influence of a single long-delayed (1000 feet), high-amplitude (−38 dBm0) multipath reflection.



The 70-kHz reference σ/f_b (rms deviation/slot frequency) ratio for a 300-channel system is:

$$(200)(\log^{-1} 9.8/20)/70 = 8.8,$$

which is plotted far to the right on Figure 7. The low-slot echo distortion peaks 8 dB below reference noise load in the bucket curve of Figure 8. The intersection of the peak distortion ridge line with the vertical σ/f_b line reduced 8 dB below (to the left of) reference plots at $f_bT = 0.07$ (point d in Figure 7).

The echo delay time is found to be:

$$T = 0.07/70 \times 10^3 = 10^{-6} \text{sec} (1000 \text{nsec}),$$

or slightly less than 1000 feet in free space. Since there are no feeders of half this length (500 feet) in the system, and since the loaded noise fluctuates, path IM must be the contributor. The f_bT in the high (1248 kHz) slot computes to 1.25, with peak distortion occurring about 3 dB below (to the left of) the reference deviation line (at point e, Figure 7). This corresponds with the high-slot bucket plotted in Figure 8.

According to Figure 7, the distortion level difference between the high and low slots should have been about 16 dB without emphasis or 9 dB with emphasis; the Figure 8 bucket curves show about 13 dB, but with the fluctuating noise measured with a path IM product (perhaps ±6 dB), this degree of inaccuracy can be expected. The echo amplitude is best computed from the high-slot peak echo distortion (45 dB NPR):

$$C/I = 45-3-1-3 = 38 \text{ dB}$$

The secondary noise-generating multipath signal is therefore arriving 38 dB below the desired signal (−78 dBm if the rf input level is −40 dBm). For simplification of analysis, and to increase the sensitivity of the radio to echo distortion, the path IM should be investigated without emphasis.

Path IM is corrected by increasing the C/I ratio through the use of larger, more directive antennas, shrouding, antenna orientation on a minimum loaded noise, rather than best rf input, level and other more costly measures. It occurs most often when using electrically small passive reflectors (at 2 GHz, for example) and when attempting to thread a microwave path between or near downtown buildings or other reflecting surfaces.

Multiple long-delayed path reflections cannot be separated in the top slot curve, but may generate several small bumps in the bottom slot bucket curve, as shown in Figure 9. Low-slot echo distortion is very sensitive to delay time (T), and several echoes of long but differing delays may be isolated with the use of Figure 7. In contrast, multiple long-delayed echoes tend to blend into a single line in the high-slot bucket curve.

Correction of Noise Problems

As the slot frequency and noise load are varied, differing noise contributors become dominant. Once the noise source is identified, the slot frequency and noise load should be set to the values most sensitive to the mechanism. For example, low-slot linearity, a 2nd order impairment, is best adjusted 3 dB above reference load in the low slot.

Multihop System Analysis

An example of a high-slot bucket curve for a 6-hop, 600-channel microwave system is shown in Figure 10. The analysis of this noise load curve is similar to that of a single-hop curve. The major difference between a single hop bucket curve and one for a multihop system is that the latter appears much narrower, a characteristic resulting from the buildup of 3rd (or higher) order distortion on a voltage (n^2) basis

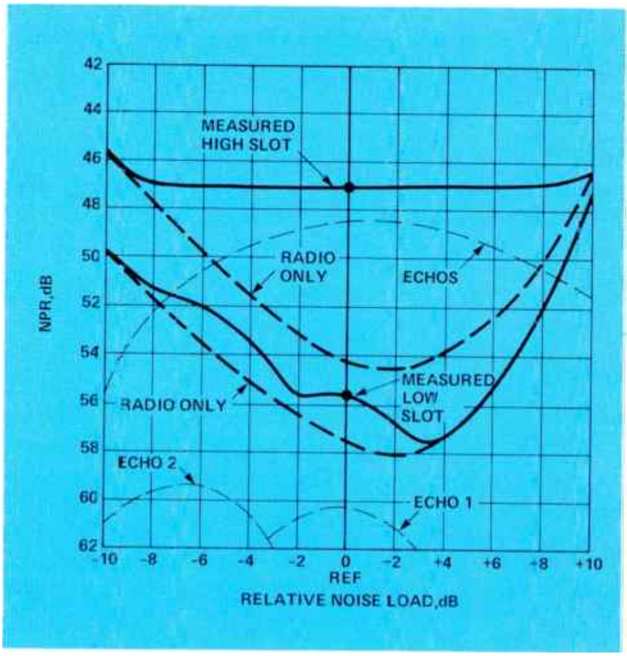


Figure 9. Path IM generated by two reflections.

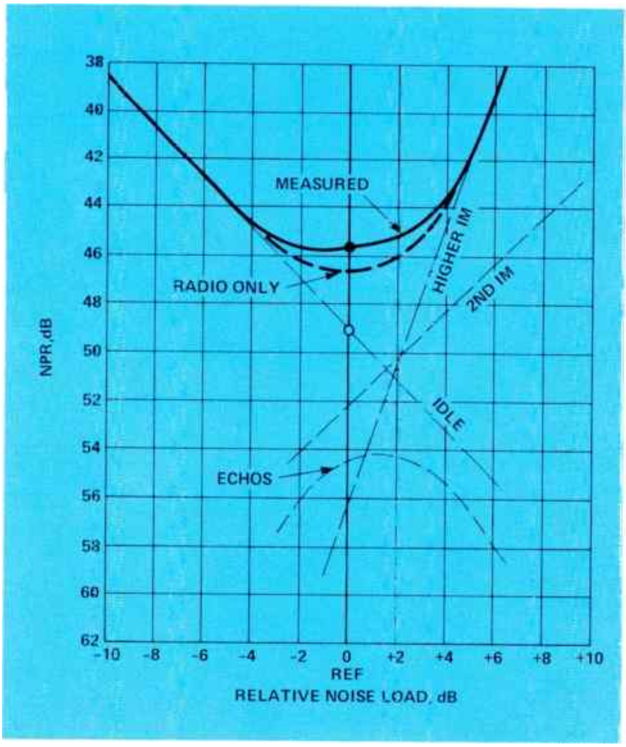


Figure 10. Typical high-slot noise load curve for a 6-hop baseband microwave system.

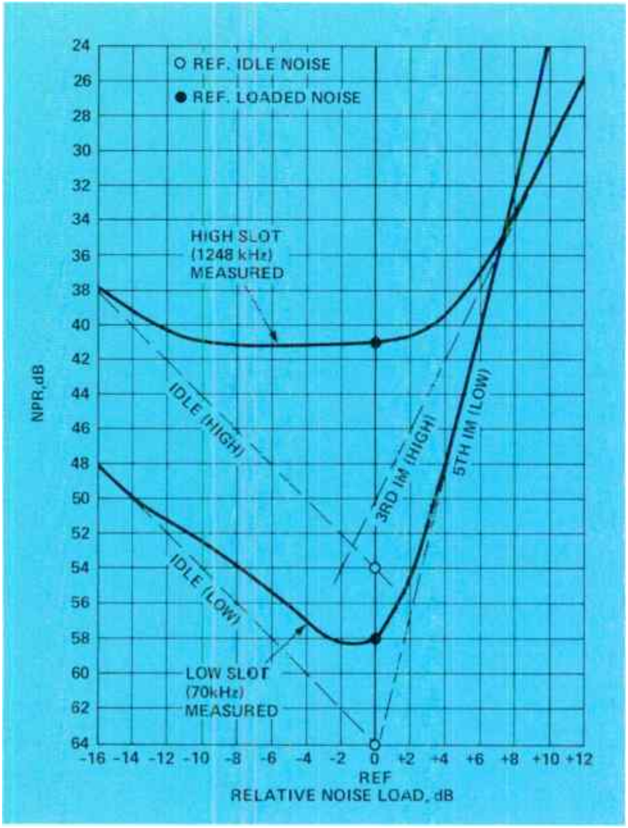


Figure 11. Bucket curves for a microwave link with excessive high-slot noise.

as compared to most other noise contributions, which add on a straight power or rss addition. Individual per-hop noise levels are determined by the intersection of the contributor with the reference noise load line, and divided by n (number of hops) or n^2 (higher order IM) to establish the average per-hop levels, as follows (for Figure 10):

Contributor	Total Noise dB NPR	Total Noise pWp0	Per-hop Noise, pWp0
Idle Noise	49	166	28
2nd Order IM	52	83	14
Higher Order IM	56	40	1.2
Echo Distortion	54.5	47	8
Total	45.9	336	51.2

This total per-hop noise contribution converts to about 54 dB NPR or 18 dBrnc0, which appears to be about right for a properly designed and equalized baseband microwave system. In this case, the higher order IM distortion is somewhat better than predicted, due to the trade-off with the slightly excessive idle contributions caused by fading in one or more paths at the time the measurement was made. Excellent per-hop parabolic delay equalization is evident, however, which is an essential ingredient to obtain the low busy-hour noise performance of this multihop microwave system. The echo distortion is probably contributed from a single damaged feeder rather than distributed equally among the 12 feeders.

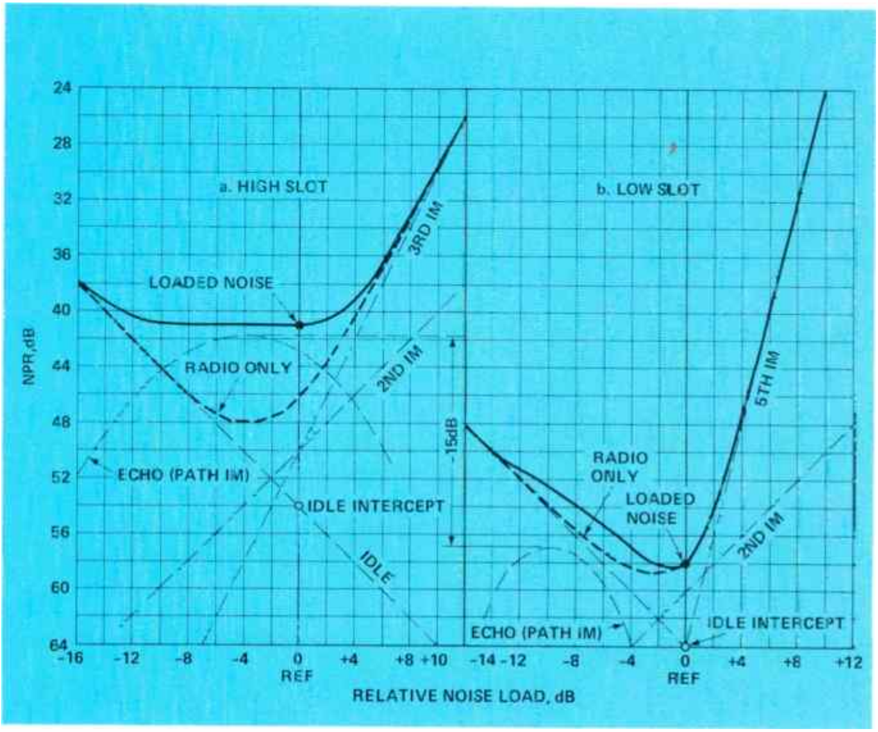


Figure 12. Analysis of the Figure 11 curves.

Bucket Curve Analysis Example

An example of a single 300-channel microwave link with considerable problems is shown in Figure 11. Without the bucket curve, all that would be known about this path is that its low-slot idle (64 dB NPR) and loaded (58 dB NPR) noise levels appear acceptable, but that the high-slot idle noise is perhaps 2 dB high (54 dB NPR), and the high-slot loaded noise is excessive (41 dB NPR) and fluctuating. The following conclusions are immediately extracted from Figure 11 without computation.

1. The idle intercept point and idle noise coincide, reflecting proper bucket curve construction.
2. The high-slot idle noise is excessive, traceable to a low (−48 dBm) rf input signal level, subsequently corrected by antenna alignment.
3. The high-slot 3rd order IM intercept (50 dB NPR) is about 16 dB high, corrected by adjustment of the parabolic delay equalizer internal to the receiver.
4. The higher order IM lines for the high and low slots have different slopes, indicating separate distortion mechanisms.
5. The steep low-slot higher order line was corrected by discriminator changeout. This higher order IM, very near reference noise load on the bucket curve, would have been controlling on a multihop system.

Figure 12 shows complete noise analyses for the low and high slots. The low-slot 2nd order IM (60 dB NPR) is satisfactory, indicating excellent linearity. The low-slot echo contribution peaks 10 dB to the left of reference noise load, at 57 dB NPR, which is about 15 dB below the high-slot echo (42 dB NPR). From Figure 7, f_bT is about 0.09, and the delay is $(0.09/70 \times 10^3) \times 10^9$ = 1285 nsec, or about 1200 feet. High-slot f_bT computes, therefore, to $(1248 \times 10^3)(1285 \times 10^{-9})$ = 1.6. The peak distortion thus occurs 2-3 dB to the left of the high-slot reference noise load. The echo amplitude is:

$$42 \text{ dB NPR} - 3 - 1 - 3 = 35 \text{ dB C/I},$$

or only 35 dB below the desired rf signal level. This secondary path was isolated to a hillside to the rear of the passive reflector, and corrected by increasing antenna directivity (larger near-end antenna size) and by careful antenna orientation for best loaded noise, rather than for maximum rf input. The last impairment is excessive high-slot 2nd order IM (Figure 12), which was corrected by delay slope mopup equalization at the receiver.

Other Uses

From its beginnings as a rudimentary laboratory experiment more than two decades ago, the use of the bucket curve to solve difficult microwave noise problems has now gained acceptance as an efficient troubleshooting procedure. And, although this article was directed mainly toward analysis of microwave systems carrying telephone traffic, bucket-curve testing and troubleshooting also can be applied as well to fm radio systems carrying video and data. Once the investigator has gained expertise in the efficient use of this valuable tool, its main deficiency (the requirement that the test be conducted with the system out of service) is minimized.

The increasing acceptance of the bucket-curve for use in even the more routine test procedures will enhance the reliability and maintainability of a microwave communication system.

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