BENDING YOUR SYSTEM INTO SHAPE - HINGING

by R. Dattner and J. Shekel
Jerrold Electronic Corp.
Horsham, Pa.

Abstract - This paper discusses a new technique, called "hinging", for calculating system design levels to meet a specification while minimizing cost. The condition of a signal is treated as a normalized noise and distortion pair in a specialized coordinate space. This leads to a discussion of amplifier vectors, signal quality and system margin, which is related to tolerance. This approach is an expansion of some early work by D. Carson. (See Ref. 1)

This paper addresses the following question:

Give system and amplifier specifications, at what levels should the amplifiers be operated to minimize system cost?

It is generally accepted that the cost of a cable system is reduced by increasing the feeder-to-trunk ratio. The length of the feeder is a function of the output levels of the bridger and line-extenders, and the minimum acceptable subscriber level. For a given minimum subscriber level, the greater the output levels of the bridger and line-extenders, the longer the feeder, the better the feeder--to-trunk ratio, and the lower the cost.

Feeder systems are, therefore, normally operated at the highest possible levels within the allowable distortion specification. This is accomplished by reducing the distortion in other parts of the system, lowering their levels. These levels in turn are limitted by the carrier-to-noise specification. Because the feeder will contribute to the overall system noise, and the low-level sections of the system will still contribute distortion, care must be taken to insure that the system is still within specifications - as the feeder levels are increased. One major advantage of the approach discussed in this paper is that this problem can be handled directly.

Noise - Distortion Coordinates

The technique uses a coordinate system based on the two quantities which normally limit the operating levels of a CATV amplifier:

(1) Carrier-to-Noise
(2) Carrier-to-Distortion

These are normally specified in deciBels. (dB)

The distortion is assumed to be third order in nature, varying 2 dB for each 1 dB variation of amplifier level, and accumulate by voltage addition. It is usually cross-modulation or triple-beat, relative to the carrier level. Carrier-to-noise, as defined by the NCTA, varies 1 dB for each dB change in amplifier level and accumulates by power addition.

Unfortunately, neither of the two quantities mentioned above adds conveniently in deciBels when cascades are considered. It was therefore found more useful to consider them as inverse ratios:

(1) Noise-to-Carrier as a power ratio adds in cascade. Therefore, the output signal of a cascade of M amplifiers has a noise-to-carrier M times the noise-to-carrier of the same signal passed through only one amplifier. (Assuming a unity-gain system, identical amplifiers)

(2) Distortion-to-Carrier as a voltage ratio also adds in cascade.

It is further convenient to express these quantities in a normalized form, dividing them by their system specification. Thus, the condition of a signal is specified by the ordered pair (n,x) where,

n = Normalized noise-to-carrier ratio
x = Normalized distortion-to-carrier ratio

If $(N/C)_o$ is the noise-to-carrier of the signal,

and $(N/C)_{sp}$ is the system noise specification

then, $$n = \frac{(N/C)_o}{(N/C)_{sp}}$$

Similarly, if $(X/C)_o$ is the distortion-to-carrier ratio for the signal and $(X/C)_{sp}$ is the specification,

$$x = \frac{(X/C)_o}{(X/C)_{sp}}$$

Figure 1 shows the representation of the condition of a signal by a point in a n-x coordinate system. Note that the dotted lines represent the boundaries of the region of permissible signals, a signal on the boundary having "used-up" either of the specifications.

At (1, 1) the signal has used-up both the noise (n = 1) and distortion (x = 1) specifications. A "clean" signal is represented by the origin (0, 0).

Quality and Margin

Consider a signal which has a normalized noise-to-carrier of 0.3 and a normalized distortion-to-carrier of 0.7. It can be represented by the point (0.3, 0.7) of Figure 2. Another signal represented by the point (0.7, 0.3) in the coordinate system might be said to be equivalently degraded. This is expressed by a mathematical quantity Q - the quality of the signal --

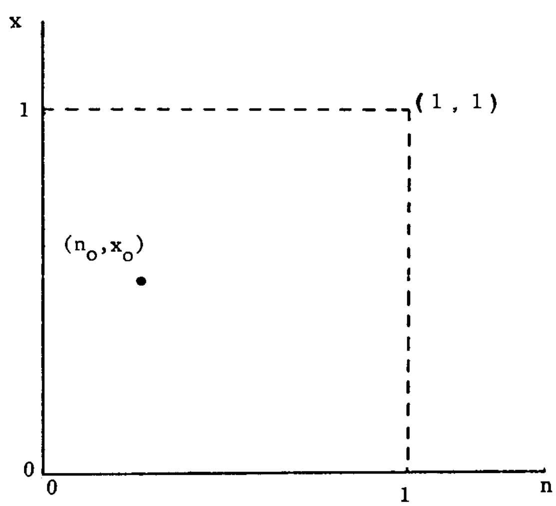

FIGURE 1
NOISE-DISTORTION
COORDINATE SPACE

n_o - normalized noise-to-carrier

x_o - normalized distortion-to-carrier

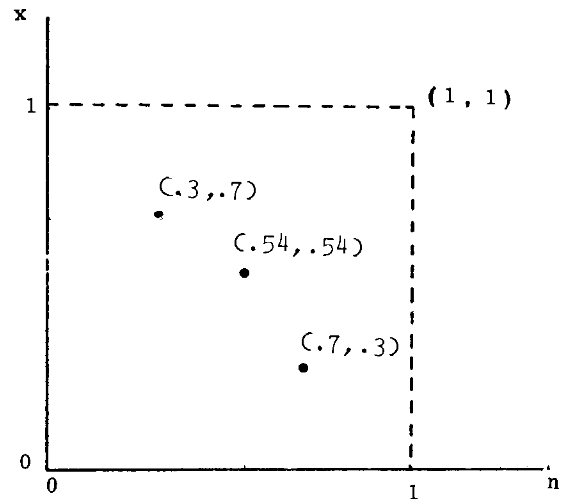

FIGURE 2
EQUAL Q (QUALITY) POINTS

$$Q = \sqrt{(1-n)\ (1-x)}$$

Note that both of the points above have a Q of 0.46. Other points having a quality of 0.46 are: (.54, .54), (.1, .76), (.76, .1).

The quality of a signal has the following properties:

1. If the signal is clean, n = 0, x = 0, Q = 1.

2. If either of the system specifications is used up,

n = 1 or x = 1, Q = 0.

3. Q has real values only when the signal is within specifications, and Q is always between 1 and 0.

Another term is also useful: The quality of the lowest-Q signal in a system is called the "margin" of the system and is usually expressed in percent. This signal normally occurs at the extremity of the longest cascade. Appendix I shows that this quantity is closely related to system tolerance as described in the Technical Handbook for CATV Systems by Ken Simons. (3rd Edition, Chapter VII, pg. 46)

Amplifiers, Cascades

If points q_1 and q_2 represent, respectively, the input and output signals of a given amplifier, then an arrow or vector drawn from q_1 to q_2 can represent that amplifier.

Figure 3 shows such a vector and demonstrates the effects of raising or lowering the output level of the amplifier.

(All other parameters: Gain, Noise Figure, Output Capability are, of course, assumed fixed). As the level of the signal at the output of the amplifier is varied, the vector, connecting the pair of points representing its input and output signals, changes in direction and length. The arc drawn through the points of all possible output signals is a hyperbola.

If a signal has equal n and x coordinates, i.e. n = x, it is said to be "midway" between the distortion and noise specifications. If such a signal is the input to an amplifier, the shortest length vector and the vector which causes the minimum change in Q, falls on a line which contains all of the "midway" points. The output signal of such an amplifier is "midway" and the amplifier is said to be operated at its "midway level".

The Handbook for CATV Systems shows that the maximum cascade can be achieved by operating an amplifier at midway level. At this level both specifications are used-up at equal rates. The shortest amplifier vector also results, and all the vectors lie on a straight line. Thus, the longest cascade from a point on the midway line is also on the midway line; and the longest cascade between two points is a straight line.

An amplifier vector has the following equivalent properties:

(1) It points from a signal of quality Q to another signal whose quality is always less than Q.

(2) Its angle with respect to the n - axis is between 0^o and 90^o.

(3) For a midway input signal, the shortest length amplifier vector occurs when the noise and distortion specifications are "used-up" at equal rates and the change in Q is minimized.

System Design

A cascade of amplifiers can be represented by placing their vectors heel-to-toe as in Figure 4. Amplifiers can be lumped together into a single vector by observing the input and output signal Q's and varying all the amplifier levels together. Figure 5 shows a two-vector cascade representing the trunk and feeder of a given system.

A cascade of identical amplifiers with a clean input signal and operated midway can be represented by the vectors in Figure 6. This type of system results in the highest possible margin and is optimum with respect to performance.

Rarely, if ever, is a system operated midway.

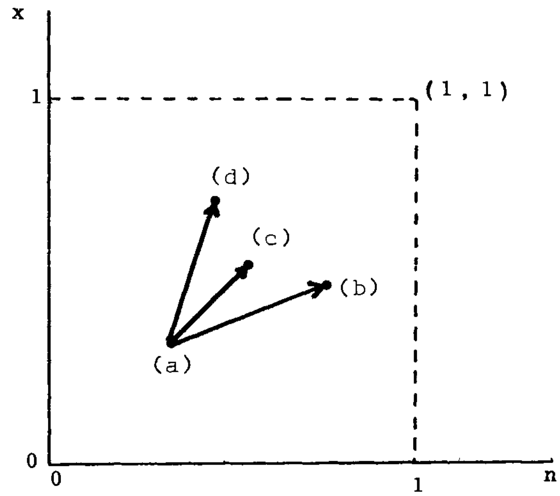

FIGURE 3
AMPLIFIER VECTORS

(a) input signal
(b) low level output signal
(c) midway output signal
(d) high level output

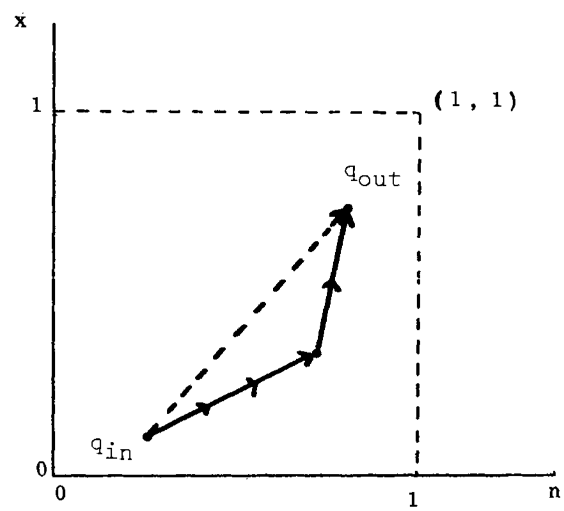

FIGURE 4
AMPLIFIER CASCADES

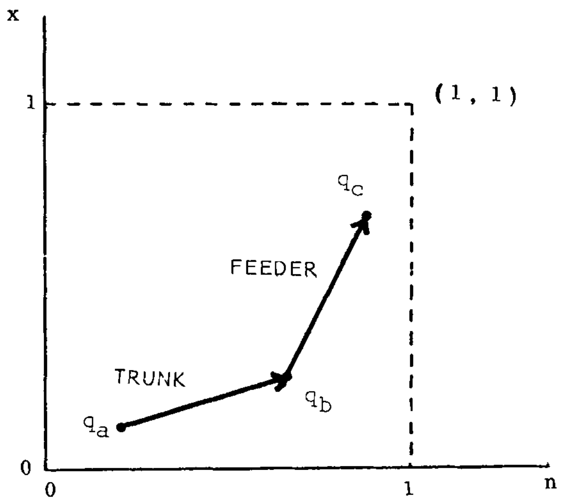

FIGURE 5
TRUNK AND FEEDER
VECTORS

q_a - signal into trunk
q_b - signal out of trunk, and into feeder
q_c - signal out of feeder

The levels are usually very low, resulting in a low feeder-to-trunk ratio and high cost. Fortunately a cascade much shorter than the maximum cascade is usually required, and the excess margin of the cascade is "used-up" to obtain better levels.

Operated midway, the system margin is maximized in Figure 7a. This margin is reallocated to reduce cost by increasing the feeder levels and reducing the other levels in the system. This results in the diagram of Figure 7b which suggests the name "hinging".

The maximum feeder levels occur when,

(1) All of the available specifications have been used, and the margin is zero.

(2) The distortion and noise specifications are simultaneously used-up, i.e. the last vector ends at (1, 1).

(3) The hinge point is such that the trunk vector has the lowest possible level.

The system which fulfills (1) - (3) is the solution to the problem of minimum cost.

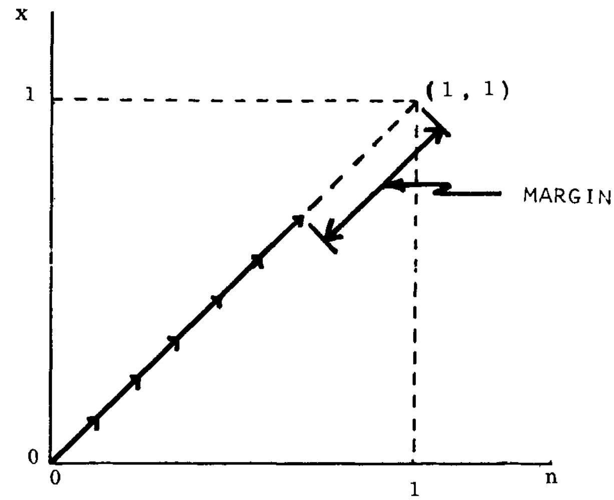

FIGURE 6
"MIDWAY" LEVEL SYSTEM

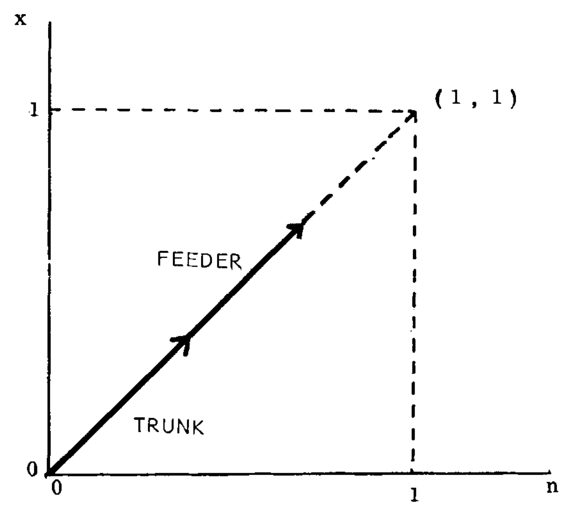

FIGURE 7A

OPTIMUM PERFORMANCE
SYSTEM
(HIGH COST)

The hinging technique has been used successfully at Jerrold for one-way and two-way systems. In a one-way system the terminating bridger of the longest cascade and the line-extenders are treated as the feeder vector. The trunk amplifiers are lumped together into another vector. The two vectors are then hinged. In a two-way system the return trunk, return feeder, and any hub-to-hub trunks, are included in the trunk vector to take full advantage of all excess margin.

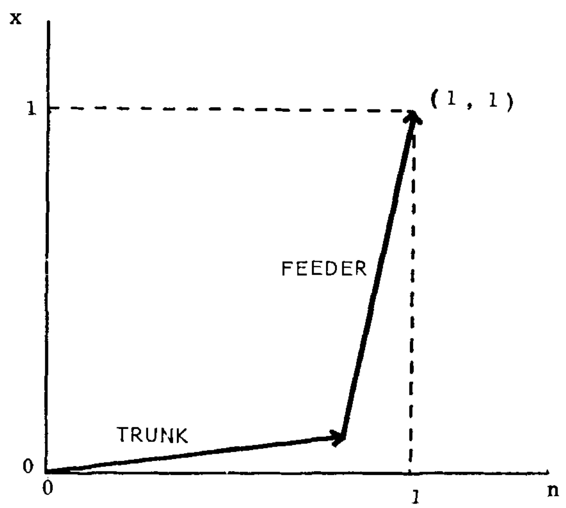

FIGURE 7B

OPTIMUM COST SYSTEM
(WITHIN SPECIFICATIONS)

Appendix I
Margin and Tolerance

The tolerance of a single amplifier, for a given set of system specifications is defined in the Handbook for CATV Systems as

$$T_1 = E_{max} - E_{min}$$

where E_{max} and E_{min} are, respectively, the maximum and minimum output levels, expressed in dBmV, allowed by the system noise and distortion specifications. In a unity-gain cascade of identical amplifiers the system tolerance is

$$T_s = T_1 - 20 \log m$$

in deciBels, where m is the length of the cascade. System tolerance is also called reserve tolerance.

Margin, as defined in this paper, can be shown to be related to system tolerance when margin is computed based on a midway system.

Given the system tolerance T_s, the midway level E_o is,

$$E_o = E_{xm} - T_s/2$$

$$T_s = 2\ (E_{xm} - E_o) \qquad (1)$$

where all levels are in dBmV and tolerance is in dB. E_{xm} is the maximum output level for each amplifier such that an m amplifier cascade just meets the distortion specification.

Operating midway, the resulting distortion from each amplifier is

$$X_o = X_s + 2\ (E_{xm} - E_o) \qquad (2)$$

in deciBels. X_s is the system distortion specification.

Since the distortion and noise are used up at equal rates, the normalized noise and distortion ratios are equal,

$n = x$ (n is the normalized noise; x, the normalized distortion)

and the margin M is,

$$M = \sqrt{(1 - n)\ (1 - x)} = 1 - x$$

$$x = 1 - M = 10^{-X_o/20} \Big/ 10^{-X_s/20}$$

where x and M are ratios and X_o and X_s are the deciBel values of signal distortion and system distortion respectively.

Therefore,

$$1 - M = 10^{(X_s - X_o)/20}$$

$$X_s - X_o = 20 \log (1 - M) \qquad (3)$$

and from (1) and (2) above,

$$-T_s = -2\ (E_{xn} - E_o) = X_s - X_o \qquad (4)$$

so that, from (3) and (4),

$$T_s = -20 \log (1 - M)$$

References

1. D.N. Carson, "CATV Amplifiers: Figure of Merit and the Coefficient System", IEEE Transactions on Communication Technology, vol. COM-14, pp. 512-520.
2. K.A. Simons, Technical Handbook for CATV Systems, Jerrold Electronics Corporation, Phila. PA, Third Edition, 1968.
3. K.A. Simons, "The Optimum Gain for a CATV Line Amplifier", Proc. IEEE, vol. 58, pp. 1055-1056, July 1970.
4. J. Shekel, "The Design of Cascaded-Amplifier Transmission Systems", to be published.