MUTUAL INTERFERENCE EFFECTS IN DATA/CATV SYSTEMS

Charles E. Sampson

Ross Telecommunications
Engineering Corporation
Washington, D.C.

ABSTRACT

The addition of data channels to CATV systems raises several problems for system designers. Among these are the determination of the best frequency slots and the proper signal levels for the data channels.

From a general intermodulation and distortion analysis this paper presents an evaluation of the mutual interference between data and TV channels. Undesired signal levels are presented for various frequency schemes and as a function of relative signal levels. By coupling this analysis with the susceptibility to interference of TV and data channels, suggestions are made regarding the design of the composite signal spectrum.

1.0 INTRODUCTION

With the increasing prominance of CATV systems, new services are being proposed that require data transmission on CATV systems. To engineer systems that accomodate data it is necessary to understand the mutual interference properties of data and TV channels which propagate over a common amplifier chain. In general, DATA/CATV system performance will be limited by the effects of noise and distortion components. The performance of television channels and data channels in the presence of noise is well understood and predictable. On the other hand, little work has been done which directly investigates the performance of television and data channels when contaminated by complex distortion products, i.e., it would be difficult to determine the effect on either a data or television channel by a DXT component (the intermodulation product produced from a data channel intermodulating with a television channel). Depending on the contributing components of the distortion product (D.P.) the product can have a wide range of characteristics and in this paper all interfering signals are given equal weight in terms of their relative effects.

Section 2 presents a general treatment of the distortion problem including the frequency distribution of DXT components within a 6 MHz band and the approximate expressions for distortion levels which are used in the system analysis presented in Section 3. In Section 3 an approach is presented for determining allowable amplitude levels for data channels in a CATV system. The approach for determining allowable levels is based on the strategy that a certain percentage of the allowable TV channel, interference (noise and distortion) budget be allotted to effects resulting directly from the addition of data channels. This approach appears viscerally sound and has the further advantage of related precedent.

With the advent of the communication satellite, tolerable flux density levels were based on a percentage of allowable noise levels in a reference telephone circuit. This was appropriate since the satellites shared the 4 and 6 GHz bands with terrestrial microwave facilities and were a source of interference. It should be noted that this sharing arrangement resulted in certain standards for the terrestrial facilities which were the first to occupy the band. An example is the limitation on radiation towards points on the synchronous belt. Similarly it is reasonable to expect certain requirements for TV related equipment to allow dependable data transmission.

2.0 DISTORTION COMPONENTS

A basic procedure for characterizing amplifier operation is to represent its transfer characteristic with a power series expansion and the amplifier can then be characterized by the coefficients (a_j) of the terms of the power series, i.e.,

$$e_o = \sum_j a_j e_i^j \qquad [1$$

where e_o is the set of output signals and

e_i is the set of input signals. Expressions for each component of e_o, both desired and undesired, can be obtained by substituting for e_i its frequency components, expanding the terms of the power series and collecting coefficients which contribute to a particular output signal. In summary, each term, in the power series representation of the transfer characteristic, whose order is equal to, or exceeds by a multiple of two, the order of a D.P. contributes to the level of the D.P. For near linear operation only the lower order terms contribute significantly with the higher order terms contributing for highly non-linear operation.

It can safely be assumed that lower order terms predominate for CATV systems and approximate expressions for second order—DP(2)—and third order—DP(3)—distortion components will be

$$DP(2) = \gamma_2 A_1 A_2$$
$$DP(3) = \gamma_3 A_1^2 A_2 \qquad [2$$

γ_2 and γ_3 characterize the amplifier and A_1 and A_2 are input signal levels in volts-RMS. Expressions for signal harmonies are similar with $A_1 = A_2$.

In a cable system which is operating properly in a relatively linear mode, D.P.'s of order greater than three should be minor relative to second and third order products. Further analysis in this section will therefore deal with the second and third order products. Push-pull amplifier operation results in cancellation of even order products and for this class of systems third order D.P.'s may be the dominant consideration.

Figure 1 illustrates the general shape of the D.P. resulting from broadband signals. As can be seen, second order D.P.'s bandwidth would be twice that of the bandwidth of the basic signal for the case where the products are due solely to one signal and are the sum of individual signal bandwidths when the D.P. is due to the interaction of two separate signals. Similarly, third order products are triple the bandwidth of the contributing signals.

The distribution of D.P.'s for two separate frequency schemes on a cable system is illustrated in Figures 2 and 3. Figure 2 considers a basic twelve channel TV complement and two data channels spaced between 24 and 36 MHz. The location of second and third order products is shown together with a very rough distribution of the composite distortion. Figure 3 presents the distortion components for a broadband system in which the midband also has TV channels. It is observed generally from these two figures that distortion results in broad spectrum interference and that it is impossible to locate the data channels such that they are completely free of TV channel related distortion products.

In addition to the general disposition of the envelope of distortion products over the total system frequency band it is helpful to understand the position of individual products within a given 6 MHz TV channel since the basic frequency scheme for placing data on broadband cable systems will follow an arrangement of channels related to 6 MHz frequency blocks. Figures 4 and 5 illustrate the distribution of distortion components resulting from various portions of the TV signal and an anticipated data signal. The TV signal is considered for this analysis to consist of three basic components: (1) the luminance carrier at 1.25 MHz, (2) the chrominance carrier at 4.83 MHz, and (3) the sound carrier at 5.75 MHz. A TV channel consists of frequency components across the 6MHz band; however, for periods of low information content signal energy will be concentrated at the above three frequencies and they can be considered as most important for the analysis of D.P. products. When two TV channels interact, intermodulation products are produced from all combinations of the above carriers. That is, the video from Channel 1 can mix with the sound carrier of Channel 2 to create either a second or third order D.P. The frequencies within a 6 MHz band at which the D.P.'s will occur is predictable and independent of the actual channels involved. Figure 4 presents a spectrum for all second and third order distortion products resulting from TV channels alone. The amplitudes of the individual components are established via an ordering procedure. The ranking of component amplitudes is considered relative to the largest anticipated intermodulation product which is the second order product achieved from two luminance carriers. Reductions in ranking reflect the carriers involved and the order of the D.P. The sound carrier is one order less than the luminance carrier and the chrominance carrier is one order less than the sound carrier. Third order products are two orders less than second order products. For the case of a sound carrier mixed with a chrominance carrier and creating a third order product, a ranking of 6 is achieved. This qualitative ordering procedure is used in lieu of a detailed analysis for which system specifications must be assumed and which would only serve to limit the amplitude spectrum to that system.

Further analysis assumed the inclusion of data channels and the data cross TV components are shown for second and third order products in Figure 5 for the case of a data channel at 2.0 MHz. Similar results were achieved for locations of the data channel 2.0, 3.0 and 4.0 MHz.

If the data channel is such that it will not include a full 6 MHz band Figure 4 illustrates desirable locations within the channel for minimal interference to the data channels from TV channel D.P.'s.

3.0 SYSTEM PERFORMANCE

The question of interest is, "How do data channel design parameters relate to TV channel interference and is sufficient latitude available in the selection of data system design parameters?" Figure 6 presents performance curves for data channels contaminated by noise and by noise plus a number of carriers. The latter is appropriate since it has application to the noise plus distortion analysis which follows. It is apparent that basic data channels are far more rugged than TV channels and that this fact can be used to advantage in structuring the spectrum of a DATA/CATV system.

It is useful at this point to investigate the levels of noise and distortion and the following definitions will apply in this analysis.

N_D = Number of data channels

N_T = Number of TV channels

V_D = R.M.S. voltage of data signal at amplifier output (volts)

V_T = R.M.S. voltage of TV signal at amplifier output (volts)

γ_2 = Second order intermodulation coefficient (volts^{-1})

γ_3 = Third order intermodulation coefficient (volts^{-2})

η = Signal-to-noise plus distortion ratio

K = Boltzman's constant

F_e = Amplifier noise figure

T = 290° Kelvin

B = Channel bandwidth (Hz)

G = Amplifier voltage gain

R = System Impedance=75Ω

α = That portion of the total distortion component power which is assumed to fall in a 6 MHz band $\approx 10^{-2}$

The second order distortion products from a single data channel are at a voltage level that can be represented by

$$V_2(DxD) = \gamma_2 V_D^2 \qquad [3$$

For η_D data channels, there are η_D^2 components which are effectively non-coherent

$$V_2'(DxD) = \gamma_2 V_D^2 \eta_D \qquad [4$$

The contributions to a specific product from each amplifier are assumed coherent, therefore, the total distortion measured over the system bandwidth is

$$V_2''(DxD) = \gamma_2 V^2 \eta_D m \qquad [5$$

Similarly for TV channels

$$V_2''(TxT) = \gamma_2 V_T^2 \eta_T m \qquad [6$$

For data and TV cross products, we have

$$V_2''(TxD) = 2\gamma_2 V_T V_D \sqrt{\eta_D \eta_T}\ m \qquad [7$$

and the noise power at the output of the last amplifier of a string of m amplifiers is

$$N_p = G^2 KTBF_e m \qquad [8$$

From these expressions for the noise and distortion components and the fact that their powers add, an expression can be written for the signal-to-noise ratio in a data channel

$$\eta_D = \frac{V_D^2}{\alpha\gamma_2^2 m^2 (V_D^2\eta_D + V_T^2\eta_T)^2 + N_p R} \qquad [9$$

Equation 9 is plotted on Figure 7 for parameters typical of CATV operation, 10 data channels, a data channel level of 20 dBmV and bandwidth of 6 MHz. Comparison of Figures 6 and 7 indicates that signal-to-noise is sufficient after a long string of amplifiers to allow good data channel performance at an operating level well below that of the TV channels.

If is further interesting to define the interference ratio—K_2—by the following equation.

$$K_2 = \frac{(V_D^2\eta_D)^2 + (V_D V_T)^2 \eta_D\eta_T}{(V_T^2\eta_T)^2 + N_p R/\gamma_2^2 m^2} \qquad [10$$

K_2 is the ratio of the second order distortion created by the presence of η_D data channels to the total noise plus distortion existing for TV only. Considering the most significant distortion products, the ratio for third order distortion effects can be written as

$$K_3 = \frac{(V_D^2\eta_D)^3 + (V_D V_T)^3 \eta_D\eta_T^2}{(V_T^2\eta_T)^3 + N_p R/\gamma_3^2 m^2} \qquad [11$$

Figures 8 and 9 present K_2 and K_3 plotted with the major data channel parameters—η_p,V_D—as independent variables and with the other parameters fixed at values reflecting CATV system operation.

4.0 RESULTS AND CONCLUSIONS

The interference ratio suggested in this paper provides a flexible procedure for investigating the effects of additional channels in a broadband cable system. Proper frequency allocations and level control must be based on distortion considerations and distortion analysis of complex signal structures is not tractable. This has necessitated several simplifying assumptions which restrict the results to general guidelines with more specific analysis required for specific problems.

Basically, data channels are far more rugged than TV channels and as a result the most favorable frequency bands should be reserved for TV with the data channels allocated to those positions which are least favorable from a noise and distortion point of view. Also the distribution of individual distortion components within 6 MHz channels does not form a pattern which indicates preferable positions for data channels unless the channels are very narrow band. Care should be taken, however, with the positioning of key signals within the data band such as synchronizing signals and order wire channels.

The selection of operating levels for data channels is based on a trade-off of

- Additional overall system distortion to TV channels
- Design flexibility for the data modem.

From the data presented here, it appears that an operating level 10-15 dB below that for TV would be appropriate since the added distortion would be approximately 1% and satisfactory data channel performance can be achieved with unsophisticated modems.

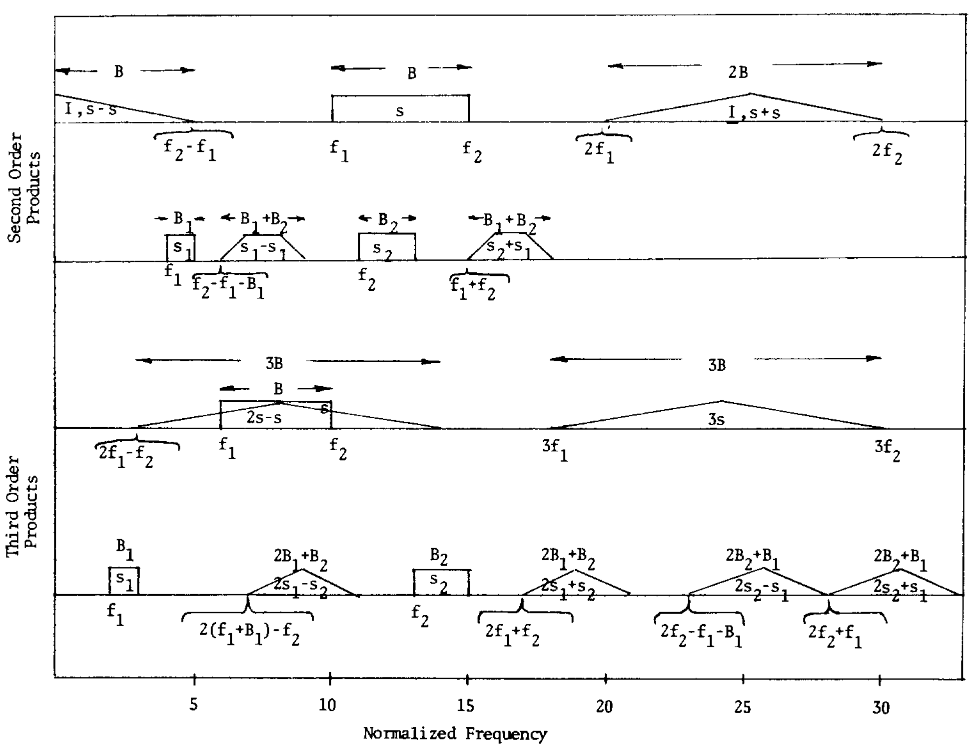


Figure 1. DISTRIBUTION OF SECOND AND THIRD ORDER INTERMODULATION PRODUCTS OF BROADBAND SIGNALS

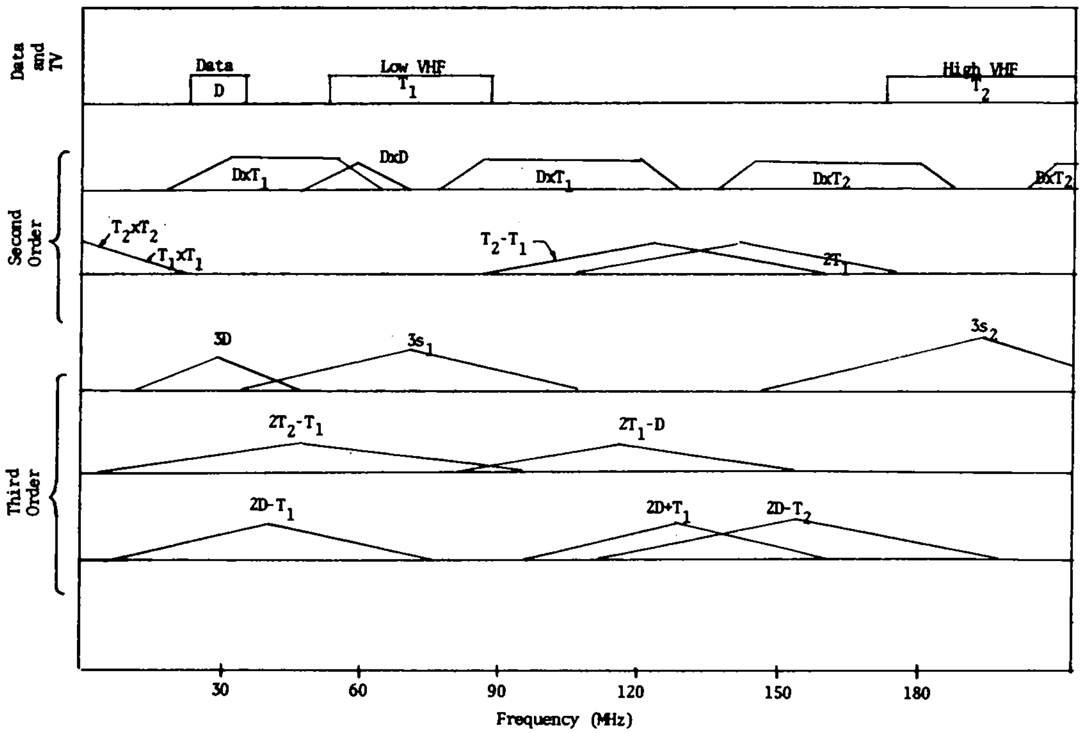


Figure 2. APPROXIMATE D.P. DISTRIBUTION FOR DATA AND 12 CHANNEL TV

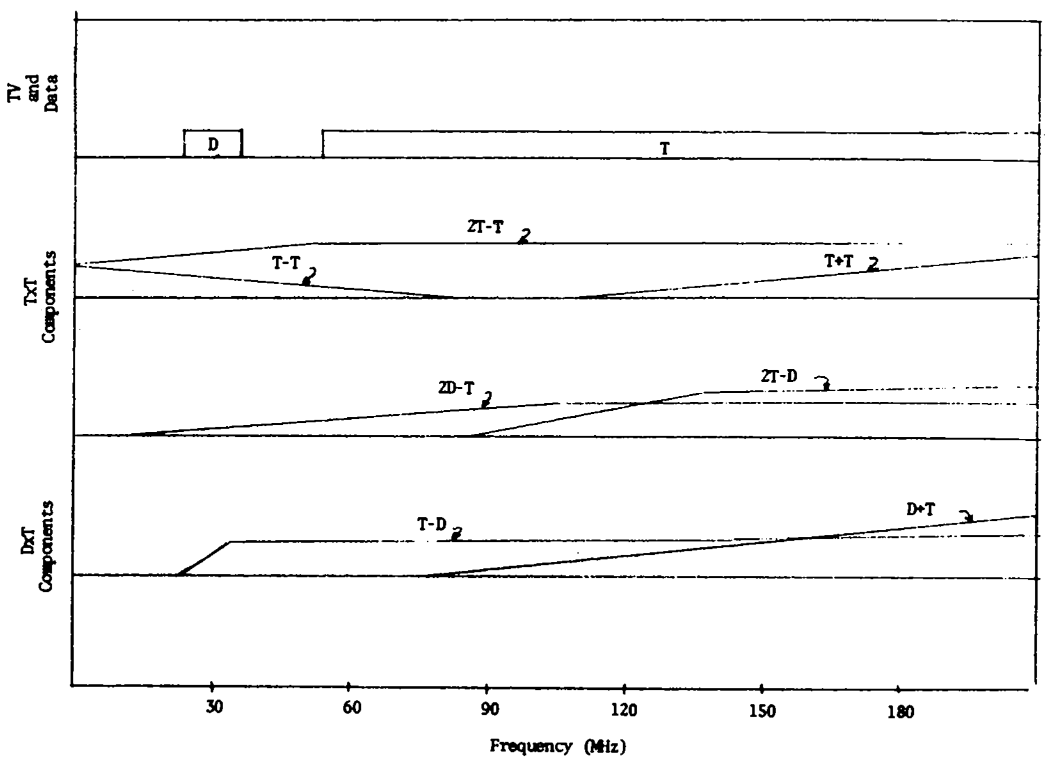


Figure 3. APPROXIMATE D.P. DISTRIBUTION FOR DATA AND 18 CHANNEL TV

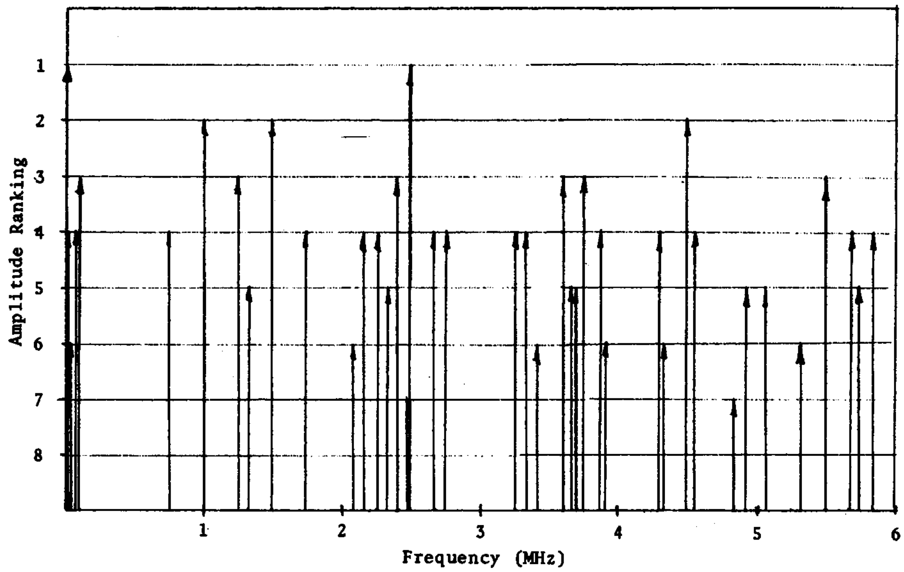


Figure 4. DISTRIBUTION OF SECOND AND THIRD ORDER D.P.'s WITHIN A 6 MHz BAND FOR TVxTV

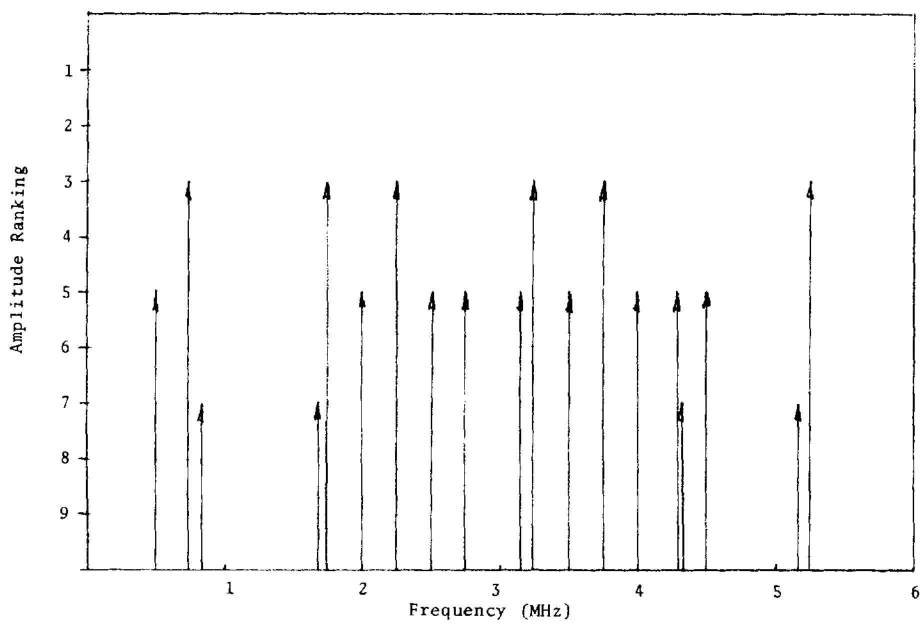
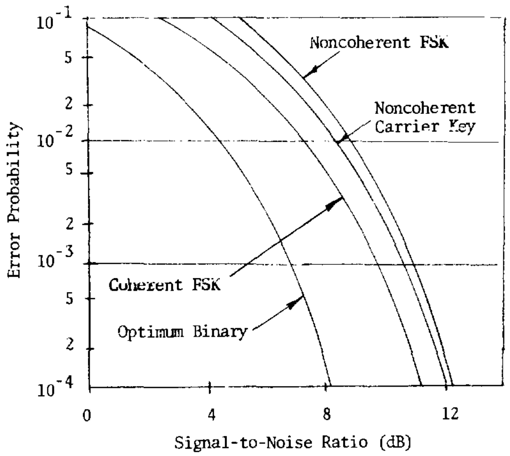
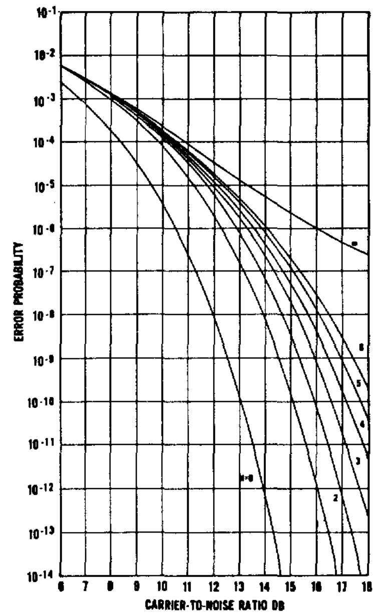


Figure 5. DISTRIBUTION OF SECOND AND THIRD ORDER D.P.'s WITHIN A 6 MHz BAND FOR DxTV AND DxD, DATA CHANNEL AT 2.0 MHz



a. Performance of Data Channels
In the Presence of Noise



b. DPSK Channel Performance in the Presence of Noise and Multiple Tones, Carrier-to-Interference=12dB

Figure 6. DATA CHANNEL PERFORMANCE

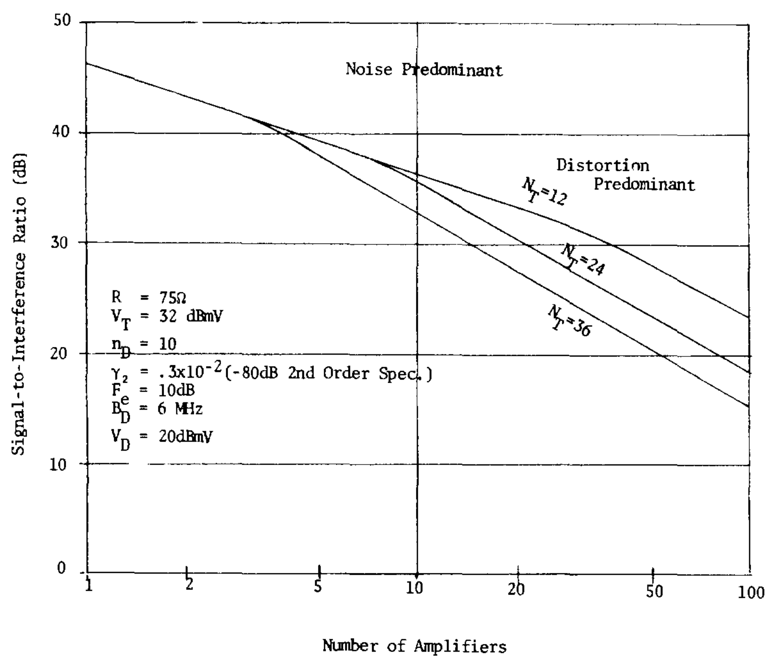


Figure 7. PERFORMANCE OF DATA CHANNELS

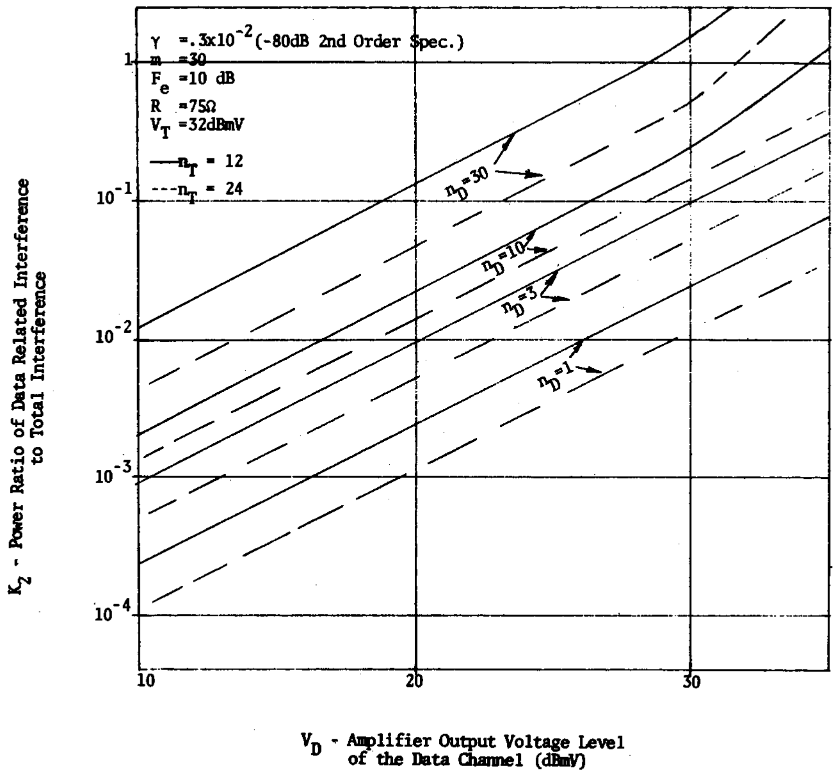


Figure 8. DATA RELATED INTERFERENCE EFFECTS VERSUS DATA CHANNEL PARAMETERS, SECOND ORDER DISTORTION

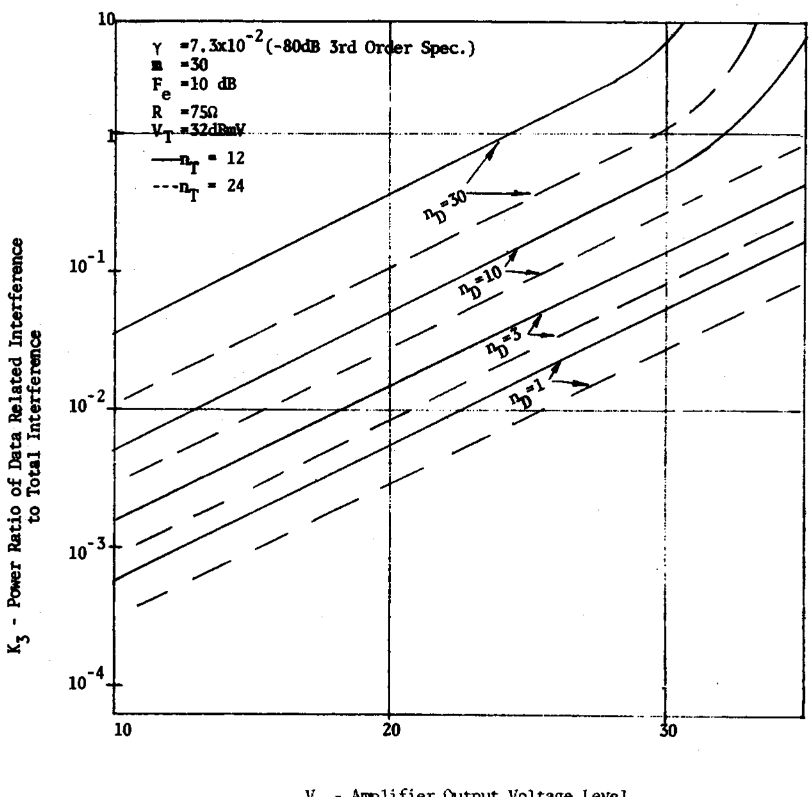


Figure 9. DATA RELATED INTERFERENCE EFFECTS VERSUS DATA CHANNEL PARAMETERS, THIRD ORDER DISTORTION