PCM/FM+FM/FM BIT ERROR RATE DETERMINATION BY MODELING AND SIMULATION

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ABSTRACT

A composite PCM/FM+FM/FM system combines the spectral efficiency of the analog system with the accuracy of a PCM system when needed for specific sensors and allows the direct transmission of binary computer words if necessary. A PCM/FM+FM/FM system combines the bit sequence with the modulated subcarriers at baseband and the resultant modulates the carrier. In the design of the composite system it is of importance to determine the impact of the subcarriers on the bit error rate of the bit sequence and to determine the degradation of the output signal-to-noise ratio of the subcarrier channels caused by the bit sequence.

KEY WORDS

PCM/FM, PCM/FM+FM/FM SYSTEM

INTRODUCTION

The bit error rate for PCM/FM+FM/FM system is developed in terms of system parameters for telemetering systems by modeling and simulations. A block model and the associated mathematical model are developed for an end-to-end assessment of the performance of the PCM/FM portion of the PCM/FM+FM/FM system in terms of system parameters. Models are also developed for a single receiver to demodulate and separate the bit sequence and subcarriers. Computer models and mathematical representations of the telemetry system are developed and used to simulate the end-to-end system and establish bit error rates.

The impact of the pre-modulation filter and predetection filter on the power spectral density of the bit sequence is considered and used to predict the bit error rate. Then the subcarriers are added and the impact of the subcarriers, both their magnitude and their placement with respect to the spectrum of the bit sequence, on the bit error rate in terms of the bit power to subcarrier power interference ratio is given. This allows the bit error rate to be determined as a function of the deviation of the carrier by the lowest frequency subcarrier and the frequency of the subcarrier. It was found that the impact of the lowest frequency subcarrier can be made marginal by proper design of the overall spectrum. A design procedure is developed in terms of the system parameters, which includes various tradeoffs, that establishes the best bit error rate for a particular PCM/FM+FM/FM telemetering system.

PCM/FM+FM/FM SYSTEM

PCM/FM+FM/FM modulation is the result of adding a filtered PCM data stream and frequency modulated subcarriers at baseband prior to frequency modulation of the carrier. A Block diagram of the system is shown below.

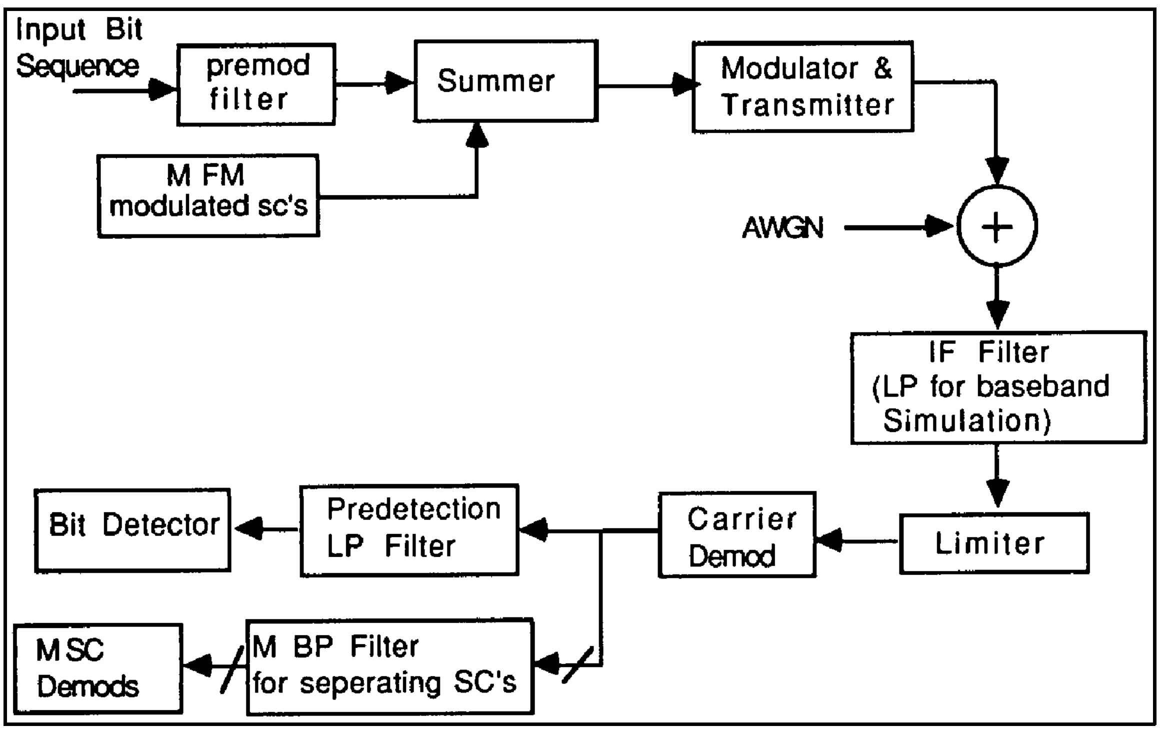

Figure 1. PCM/FM+FM/FM MULTIPLEX SYSTEM

The system uses one receiver, where the bandwidth of the IF filter is determined using Carson's Rule of bandwidth and set wide enough to pass both the subcarriers and the PCM data signals. FSK noncoherent detection is used since the hardware required for noncoherent detection is much simpler than that of coherent detection.

A PCM/FM receiver is composed of a IF filter, limiter, discriminator, integrate and dump filter. The composite system receiver has the predetection LP filter before the integrate and dump block to reduce the interference of the subcarrier.

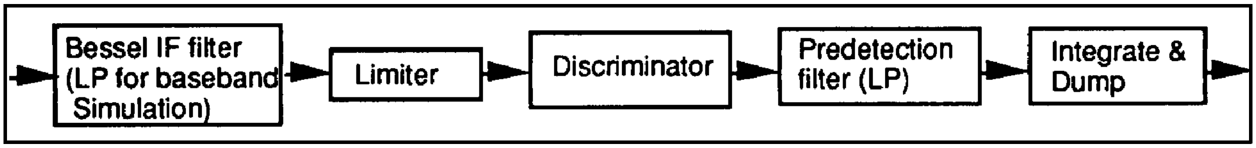

Figure 2. PCM/FM+ RECEIVER

SIMULATIONS

The Block Oriented System Simulator*, BOSS software is utilized to simulate the system and to find the premodulation filter order and it's 3 dB bandwidth, predetection filter order and it's 3 dB bandwidth, peak data deviation for a given IF bandwidth-for optimum BER. The system is also simulated to observe the BER of PCM/FM system with wider IF bandwidth and to find the impact of the subcarrier on the PCM data stream.

Random NRZ-L data, which is a basic BOSS module, used to simulate the PCM bit stream. The module outputs ±1 volt for a specified random data seed, with a specified probability of +1 volt and bit rate.

PREMODULATION FILTER SPECIFICATION

A typically premodulation filter for the PCM data of a PCM/FM system is a 1st order Bessel filter with 3 dB bandwidth=$0.5R_b$-$0.8R_b$. For a composite system the premodulation filter is 6-pole Bessel filter with 3 dB bandwidth=$0.5R_b$-$0.7R_b$. A higher order filter is used not only to limit the RF spectrum, but also to reduce the interference of the bit stream in the subcarrier channel.

It was observed that for a wide IF bandwidth, changing the premodulation filter order from 1 to 6 and varying it's 3 dB bandwidth from $0.5R_b$ to R_b does not have appreciable effect on the bit error rate (see Figure 3a and 3b).

PREDETECTION FILTER SPECIFICATION

A predetection filter is used to reduce the interference of the subcarrier on the bit stream. Using 1st or 2nd order Bessel filters as predetection filters and setting the 3 dB bandwidth=$0.5R_b$ to R_b does not change the BER significantly (see figure 4a and 4b).

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*Block Oriented System Simulator and BOSS are trademarks of Comdisco Systems Inc.

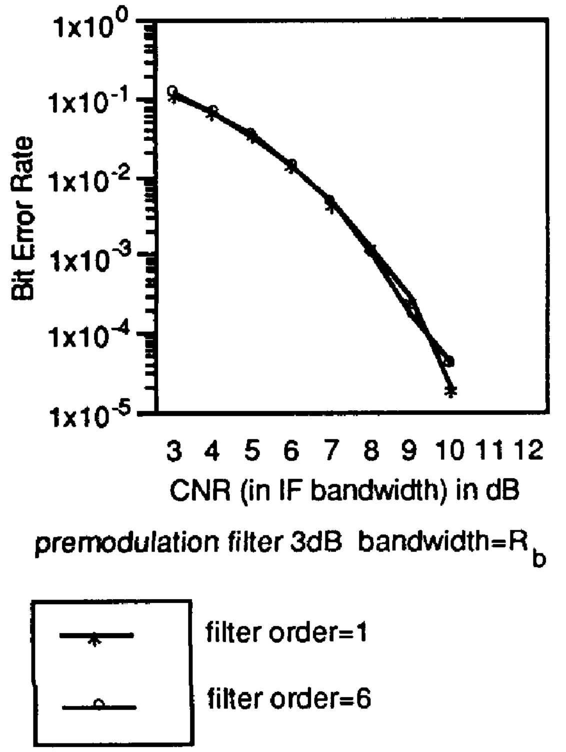

Figure 3a.

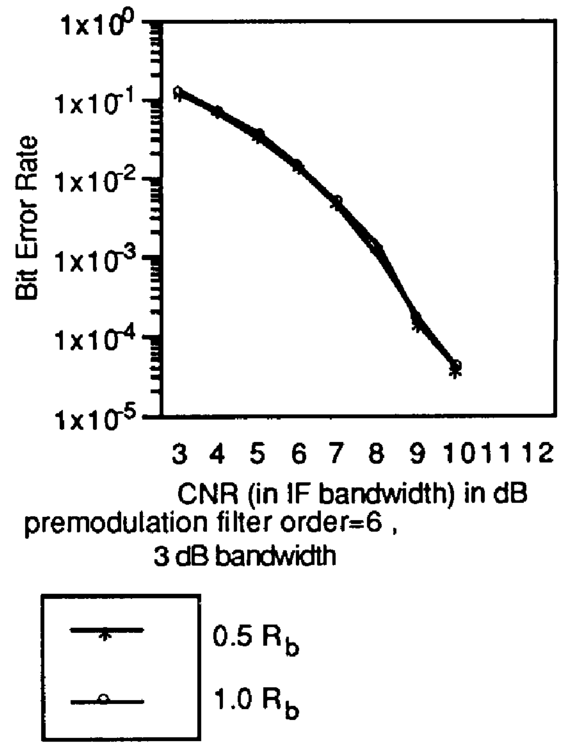

Figure 3b.

[for both the plots, predetection filter order= 1, 3 db bandwidth =0.7$_b$, Δf=0.35 R_b and BT=10]

OPTIMUM VALUE OF PCM DATA DEVIATION FOR A GIVEN IF BANDWIDTH

A PCM data deviation of the carrier by 0.35R_b to 0.4R_b for a IF bandwidth equal to R_b is found to be the optimum value. For a PCM/FM system a 1st order premodulation filter is used to constrain the RF spectrum (see figure 5).

In going from a PCM/FM system to a PCM/FM+FM/FM system, the IF bandwidth must be increased substantially in order to pass the subcarriers.

When the IF bandwidth is widened beyond 2R_b, 0.35R_b to 0.4R_b is not the optimum value for the peak data deviation. The following plots shows the BER for different values of peak data deviation, Δf, in a wide IF bandwidth.

In a PCM/FM system an estimate of the bandwidth is

$$B_{if} = 2(\Delta f + R_b)$$

or $$\Delta f < \frac{B_{if}}{2} - R_b$$

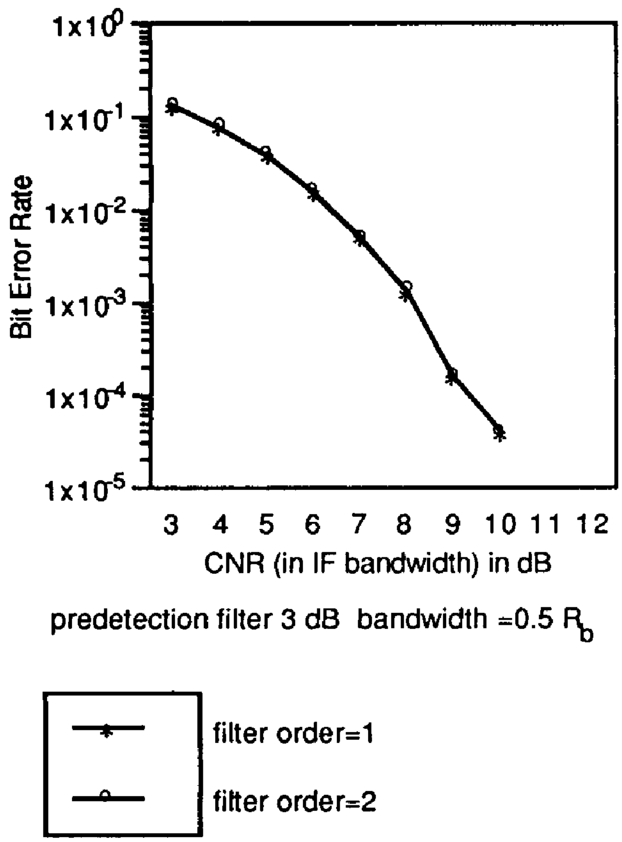

Figure 4a.

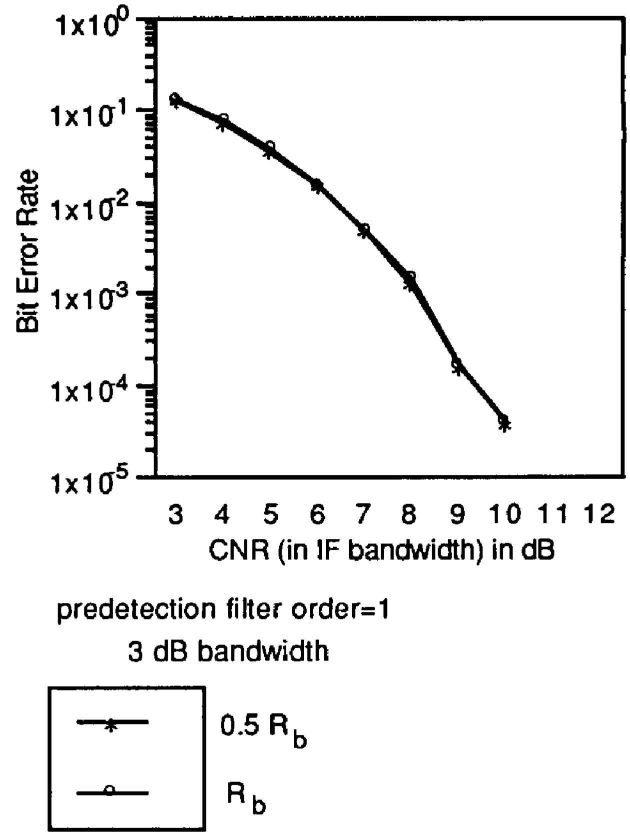

Figure 4b.

[for both the plots, premodulation filter order=6, 3 db bandwidth = $0.5R_b$, $\Delta f=0.35R_b$ and BT=10]

From figure 6 it can be seen that for a fixed B_{if}, the BER improves as Δf is increased until the inequality of equation 2 is violated. Therefore, in a PCM/FM system with a bandwidth in excess of $2R_b$, Δf should be made as large as the inequality of equation 2 will allow for the best BER. However, for a PCM/FM+FM/FM system both the deviation of the carrier by the bit sequence and the deviation of the carrier by the subcarriers will determine the required bandwidth.

IMPACT OF THE SUBCARRIER ON THE BIT STREAM

The PCM/FM+FM/FM system under study contains only one subcarrier which is the lowest frequency subcarrier since the lowest frequency subcarrier is the one having the significant impact on the BER. The spectrum at the input of the FM modulator is shown in figure 7.

The purpose of this study is to find how close to zero frequency the lowest frequency subcarrier can be placed without suffering appreciable degradation in the BER. The

BER for the composite system is compared with the BER of the PCM/FM system having same IF bandwidth, premodulation and predetection filter specifications.

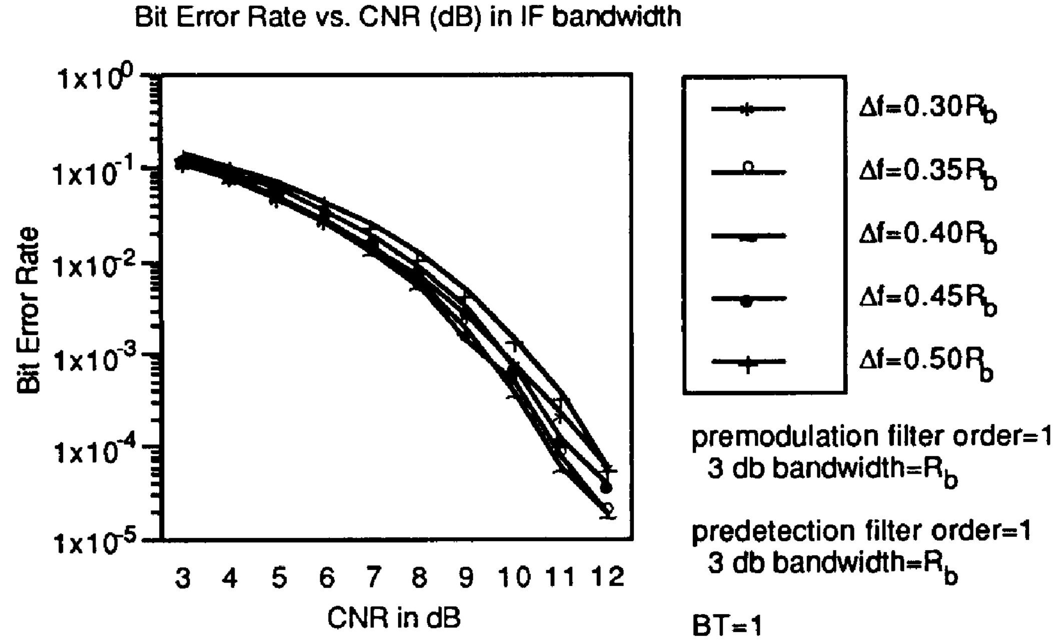

Figure 5.

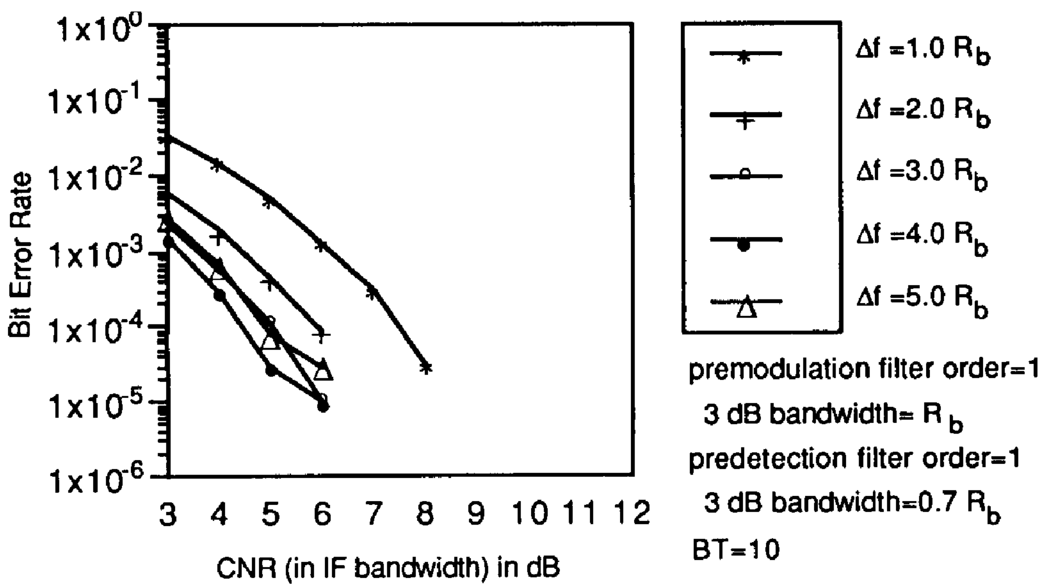

Figure 6.

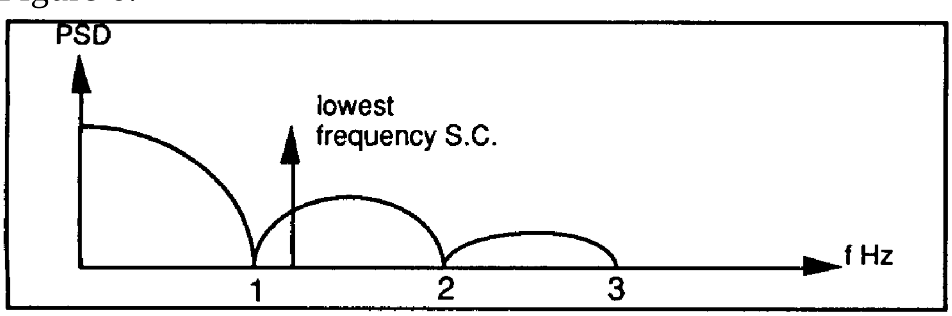

Figure 7.

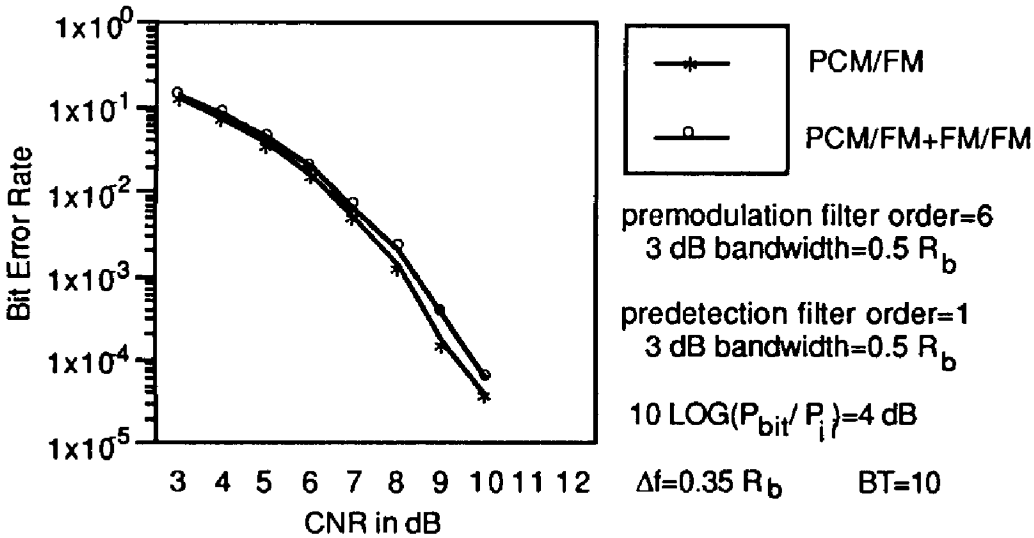

Figure 8.

For the composite system $10LOG(P_{bit}/P_i)$ should be maintained at or above 4 dB, where P_{bit} is the power per bit ($P_{bit} = E_b/T_b$, E_b is the bit energy and T_b is the bit period) and P_i is the interference power of the subcarrier. Both are measured at the predetection filter output. It is seen that for achieving a BER of 10^{-4}, the composite system needs only 0.5 dB more CNR in the IF bandwidth.

There are two ways for determining P_{bit} and P_i. One- using BOSS magnitude spectrum plot which shows total average power of the signal. The other method calculates the ratio using the following approach.

After carrier demodulation and predetection filtering, integration of the spectrum of the bit sequence gives the bit power

$$P_{bit} = K_d^2(\Delta f)^2 \int |H_{pm}(f)|^2 |H_{pd}(f)|^2 \mathrm{Sinc}^2(fT_b)df$$

where $\Delta f =$ deviation of the carrier by the bit sequence,
$K_d =$ FM discriminator constant, unit volts/hertz,
Hpm(f) is the transfer function of the premodulation filter,
Hpd(f) is the transfer function of the predetection filter.

The interference by the lowest frequency subcarrier is given by

$$P_i = K_d^2 \frac{(f_{dL})^2}{2} |H_{pd}(f_{sL})|^2$$

where f_{dL} is the deviation of the carrier by the lowest frequency subcarrier f_{sL}.
The ratio of P_{bit}/P_i is

$$\frac{P_{bit}}{P_i} = \frac{2(\Delta f)^2}{|H_{pd}(f_{sL})|^2 (f_{dL})^2} \int |H_{pm}(f)|^2 |H_{pd}(f)|^2 \mathrm{Sinc}^2(fT_b)df$$

DESIGN EQUATIONS

Although equation 3 is complex, it may be evaluated using numerical integration techniques. It may be used in designing the system to keep

$$10\mathrm{LOG}(P_{bit}/P_i) \geq 4\ \mathrm{dB}$$

In a FM/FM system an estimate of the bandwidth[1] is given by

$$B_{if} = 2(f_{dN} + f_{sh}) \qquad 5$$

where f_{sh} = highest frequency subcarrier and

$$f_{dN} = [f_{dc1}^2 + f_{dc2}^2 + \cdots + f_{dcn}^2]^{1/2}$$

= square root of the sum of the squares of the carrier deviations by the subcarriers and is referred to as the norm of the deviations.

For a PCM/FM+FM/FM system, where Δf is the deviation of the carrier by the bit sequence, an estimate of the IF bandwidth for the composite spectrum is

$$B_{ifc} = 2(f_{dNc} + f_{sh})$$

where $f_{dNc} = [(\Delta f)^2 + f_{dc1}^2 + f_{dc2}^2 + \cdots + f_{dcn}^2]^{1/2}$

and is referred to as the composite deviation norm. The composite norm may expressed as

$$f_{dNc} = [(\Delta f)^2 + f_{dN}^2]^{1/2}$$

In a PCM/FM+FM/FM system the ratio, R, of bit sequence interference to the power of lowest frequency subcarrier out of the bandpass filter separating the subcarrier is of concern and is given by[1]

$$R = 10\log(P_I/P_L)$$

$$= 20\log\frac{2\Delta f}{f_{dL}} + 20\log[(T_b)^{0.5}\mathrm{Sinc}(f_{sL}T_b)] + 20\log\left|H_{pm}(f_{sL})\right| + 10\log 2f_{ds_L}$$

where f_{sL} = frequency of the lowest frequency subcarrier,
f_{ds} = deviation of the subcarrier by the message

In order to avoid undue interference of the bit sequence in the lowest frequency subcarrier channel, a requirement on R is

$$R < -35\ \mathrm{dB} \qquad 9$$

In the design of a PCM/FM+FM/FM system, the preemphasis schedule should be designed first and modified such that the required bandwidth, B_{if} is 10% below the specified bandwidth. Set Δf equal to $0.5R_b$ to R_b. Use equation 6 to determine the new B_{ifc}. Because the IF bandwidth is primarily determined by the deviations of the higher frequency subcarriers, Δf will usually have a small effect on B_{ifc}. Since there is a conflicting requirement on Δf in the two channels, the next step is to use equations 4 and 9 to determine if the value chosen for Δf will satisfy the inequalities of these equations limiting the interference in the subcarrier channel and the degradation of the BER in the bit sequence channel.

SUMMARY

Design equations for PCM/FM+FM/FM systems were developed. The impact of a wide IF bandwidth on the PCM/FM BER was determined. It was found that the design procedure should insure that the ratio of P_{bit} to the interference P_i should be greater than 4 dB in order that the subcarrier have a negligible impact on the BER. For IF bandwidths larger than $2R_b$, Δf should be as large as the design equations allow. Both the interference of the bit sequence on the subcarrier channels and the impact of the subcarriers on the BER must be addressed in the design of PCM/FM+FM/FM systems.

REFERENCE

[1] Carden, F., and Moser, J., "PCM/FM+FM/FM Design Parameters for Telemetering Systems" ITC Proceedings Vol XXVIII. 1992, pp763-772.