EXPERIMENTAL COMPARISON OF PCM/FM, PCM/PM and PSK

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ABSTRACT

This paper compares the experimental bit error rate (BER) performance of PCM/FM, PCM/PM, and PSK. The data are presented as BERs versus signal-to-noise ratio (SNR) in a bandwidth equal to the bit rate. The effects of premodulation filtering and receiver IF bandwidth are discussed. The necessary RF bandwidths for these modulation methods are also discussed. Two methods of generating PSK signals were used: ±90° linear phase modulation and mulitplication of the RF carrier by ±1 using a double balanced mixer. The first method will be referred to as PCM/PM (±90°) in this paper.

INTRODUCTION

Many modulation techniques exist for the transmission of telemetry data. This paper discusses three of the main methods for the transmission of digital data: PCM/FM, PCM/PM and PSK. Most PCM telemetry data transmitted on the National Ranges currently use PCM/FM, PCM/PM, or PCM/FM/FM as the modulaton method. The Telemetry Group of the Range Commanders Council has sponsored this study to compare the performance of PSK with PCM/FM and PCM/PM under the real-world conditions of range telemetry. This study will include the effects of premodulation filtering, receiver IF bandwidths, multipath, and predetection recording on the bit error rate performance of these modulation methods. The RF spectra of the codes will also be compared. The results presented in this paper will include the effects of premodulation filtering and receiver IF bandwidths.

EXPERIMENT

Laboratory tests were performed to measure the BER versus SNR performance of the modulation methods under study. The test setup is shown in figure 1. Some of the test parameters are listed below:

PCM code: NRZ-L

Test sequence: 2047 bit pseudo random

Premodulation filter: 5-pole linear phase

RF frequency: ≈ 2250 MHz

Receiver IF filter type: linear phase

PSK demodulator type: Costas loop

PSK demodulator low pass filter bandwidth: 2 MHz

PSK demodulator loop bandwidth: 10 kHz

PCM/FM peak deviation: ≈ 0.35 times bit rate

The tests will be expanded to include other premodulation filters and BIØ-L coding later in the study.

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The SNR was measured using the receiver linear 10 MHz output with an unmodulated carrier. The actual IF bandpass frequency response was measured and the equivalent noise power bandwidth calculated. This bandwidth was used to compute the SNR in a bandwidth equal to the bit rate. When the double balanced mixer was used to generate PSK, the unmodulated carrier amplitude was adjusted with a DC voltage applied to the mixer IF input to be the same level as the mid-bit level with modulation. The average RF power with modulation was ≈ 0.4 dB below the unmodulated power.

TEST RESULTS

The experimental results with PCM/PM (±90°) and PSK (double balanced mixer) agreed quite closely. The SNR for a given BER with PCM/PM (±90°) with premodulation filtering at three times the bit rate was slightly lower (≈ 0.2 dB) than the SNR for the same BER with PSK when the SNR was defined as above. If the SNR was redefined to compensate for the power loss of PSK during bit transitions, the PSK performance was

≈0.2 dB better than the PCM/PM (±90°) performance. The author believes that the correct method is to use the SNR as described in the previous section. Therefore, PCM/PM (±90°) appears to be slightly better than PSK (double balanced mixer). If the insertion loss of the mixer is included the advantage of PCM/PM (±90°) is much larger (greater than 4 dB for the mixer used in this study). Since the transmitter power is limited by the available missile or battery power in most missile telemeters that the author is familiar with, the insertion loss of the double balanced mixer causes a corresponding decrease in transmitted power (assuming linear amplifiers are used). Therefore, the following discussion will include only PCM/PM (±90°) and PCM/FM.

The effects of premodulation and receiver IF filtering are shown in figure 2 and table 1. The PCM/PM (±90°) data (300 kb/s) was only 0.7 dB worse than theoretical PSK[1] at a 10^{-5} BER with a premodulation filter bandwidth (-3 dB) of 3 times the bit rate and a receiver IF bandwidth of 11 times the bit rate. An additional 0.7 dB of degradation was measured when the premodulation filter bandwidth was equal to the bit rate. The data with a premodulation filter bandwidth equal to the bit rate for 300 kb/s and 900 kb/s are nearly the same. Increasing the bit rate to 1.5 Mb/s and keeping the filter bandwidths fixed caused 2.3 dB of degradation from the 300 kb/s data.

Tests were also conducted to compare PCM/FM and PCM/PM (±90°) under identical conditions. The results of these tests are presented in figure 3 and table 1. The data in figure 3 show that PCM/FM and PCM/PM (±90°) require approximately the same SNR for a 10^{-5} BER (11.9 dB and 11.6 dB respectively) when the receiver IF bandwidth is equal to the bit rate for PCM/FM and equal to twice the bit rate for PCM/PM (±90°). Interestingly, the SNR for a 10^{-5} BER is also approximately the same (13.1 dB and 12.9 dB respectively) when the IF bandwidth is equal to twice the bit rate for PCM/FM and the bit rate for PCM/PM (±90°). At a 10^{-3} BER the BER performance of PCM/PM (±90°) is significantly better than that of PCM/FM. At an 8 dB IF SNR with a 1.5 MHz IF bandwidth, PCM/PM (+90°) and PCM/FM perform about the same while PCM/FM is 1 dB better, under the same conditions, at a 10^{-5} BER. The PCM/FM data agree well with the results of Tjhung and Wittke[2] who show an SNR of 10.74 dB for a 10^{-4} BER with a Gaussian bandpass filter with bandwidth equal to the bit rate while figure 3 shows approximately 10.65 dB. The premodulation filter bandwidth was approximately 1.6 MHz for all the data shown in figure 3. The BER versus SNR performance of optimum PCM/FM is not affected significantly by premodulation filter bandwidth as long as the bandwidth is greater than the bit rate for NRZ-L[3].

Two bit detectors were available in the PCM bit synchronizer used in this test. The best bit detector for all PCM/FM data and PCM/PM (±90°) with the receiver IF bandwidth equal to the bit rate was the filter at one-half the bit rate and sample detector. The best bit detector for the other PCM/PM (±90°) signals was the filter which was matched to rectangular PCM signals. The definition of best bit detector is the detector which yielded the lowest BER.

The bit error rate of PCM/FM is determined by the actual SNR in the bandwidth that the FM demodulator sees. The reason for this is that most bit errors are caused by noise “pops” which occur when the FM demodulater is captured by noise. As the SNR is decreased the number of “pops” increases and so does the BER. The optimum IF bandwidth for NRZ-L PCM/FM with the optimum deviation[2,3] is approximately equal to the bit rate (also a function of filter type and rolloff rate). The reason is that the signal energy is concentrated in a bandwidth equal to the bit rate[2,4,5]. Widening the bandwidth increases the noise power faster than the signal power and narrowing the bandwidth decreases the signal power faster than the noise power.

The bit error rate of PCM/PM (±90°) is determined by the ratio of signal energy per bit to the noise power spectral density because of the coherent demodulator. Narrowing the premodulation or receiver IF bandwidths decreases the signal energy per bit (especially of single bits of one polarity) without changing the noise power spectral density. (The receiver IF filter does reduce the noise power spectral density at frequencies above one-half the receiver IF bandwidth)

The optimum peak deviation for unfiltered PCM/PM is 90° because at this deviation the signals for a “one” and a “zero” are antipodal (i.e., exact opposites of each other). The RF carrier is also at a null for this deviation. When the PCM signal is premodulation filtered, the carrier null occurs at a higher peak deviation than 90°. However, the lowest bit error rate occurs with a peak deviation quite close to 90° even with premodulation filtering.

A test was also conducted using a non-random test sequence. This test sequence was generated using a 6-bit ramp generator with each 6-bit word repeated 4 times before the value was incremented by one. The BER results were the same as with the pseudo-random sequence.

Another property of the PSK demodulator that is important to the telemetry system designers is that the demodulator output has an equal probability of outputting binary “ones” as a high level or a low level because the demodulator has no way of telling the two phases apart. When the demodulator loses lock because of a signal- dropout the output polarity, when lock is reacquired, can be either the same as before loss of lock or inverted. Therefore, PCM frame synchronizers should be operated in the “auto polarity” mode to prevent the data from being inverted after loss of lock. Polarity insensitive codes such as NRZ-M and NRZ-S can also be used to solve this problem with a doubling of the bit error rate.

The necessary RF bandwidths for a 500 kb/s NRZ-L signal with a 5-pole linear phase premodulation filter equal to the bit rate are:

1. PCM/FM ≈ 1.7 MHz

2. PSK ≈ 2.6 MHz

3. PCM/PM (±90°) ≈ 3.7 MHz

The necessary RF bandwidth is defined to be the bandwidth beyond which all signals are 50 dB below the unmodulated carrier when measured in a 30 kHz bandwidth.

CONCLUSIONS

1. PCM/PM (±90°) appears to be superior to PCM/FM under static conditions if the premodulation filter and receiver IF filter are both much larger than the bit rate. The difference in performance is a function of the total filtering of the PCM/PM (±90°) signal.

2. PCM/FM is superior to PCM/PM (±90°) at a 10^5 BER if the overall effective system data bandwidth is less than approximately 0.75 times the bit rate for NRZ-L.

3. The RF bandwidths required for PCM/FM are significantly less than the bandwidths required for PSK and PCM/PM (±90°).

REFERENCES

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Table 1

IF SNR in a Bandwidth equal to the Bit Rate for Bit Error Rates of 10^{-5} and 10^{-3}

Modulation Type	Bit Rate (kb/s)	RF Deviation	Premod. Filter Bandwidth (kHz)	IF Bandwidth (kHz)	IF SNR (dB) in Bandwidth = Bit Rate 10^{-5} BER	10^{-3} BER
PCM/PM	300	±90°	300	3300	11.0	8.0
PCM/PM	300	±90°	900	3300	10.3	7.5
PCM/PM	900	±90°	900	3300	11.2	8.1
PCM/PM	1500	±90°	900	3300	12.6	9.0
PCM/PM	1500	±90°	1600	3300	11.6	8.4
PCM/PM	1500	±90°	1600	1500	12.9	9.5
PCM/FM	1500	±533 kHz	1600	1500	11.9	9.2
PCM/FM	1500	±533 kHz	1600	3300	13.1	10.6

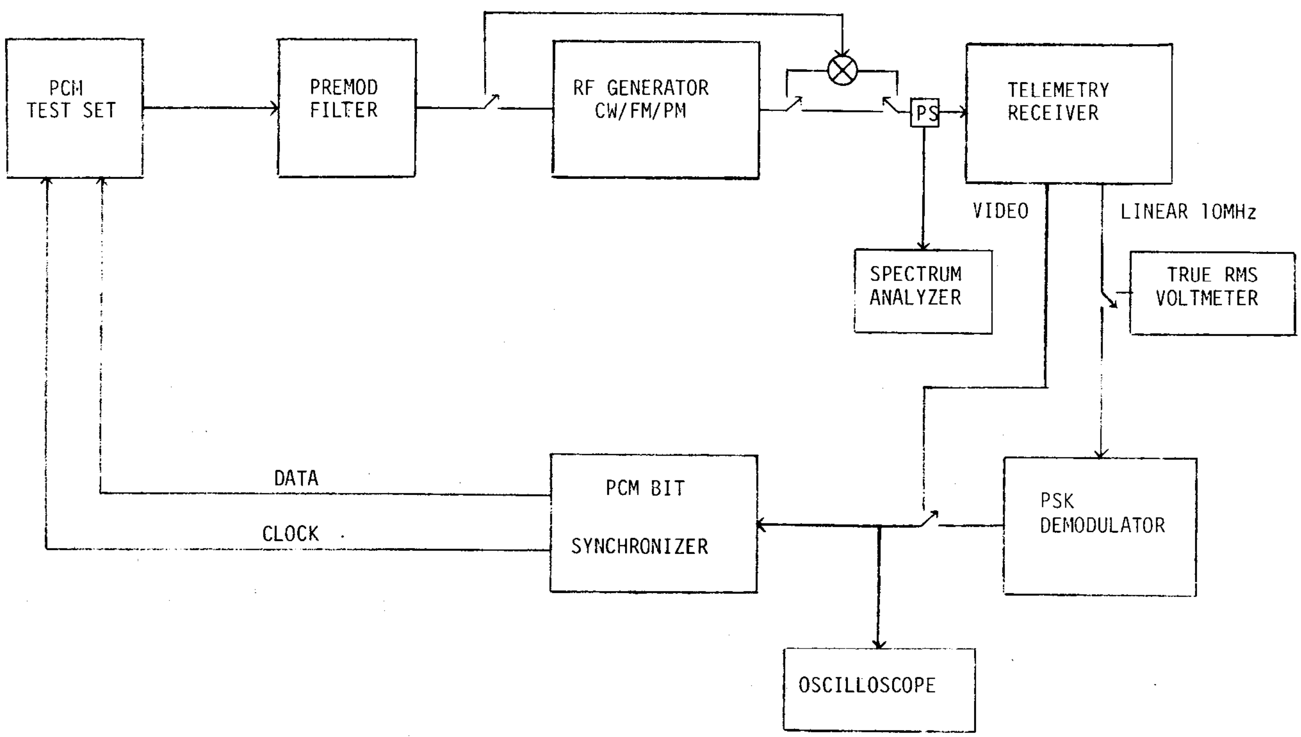

Figure 1. Test Setup

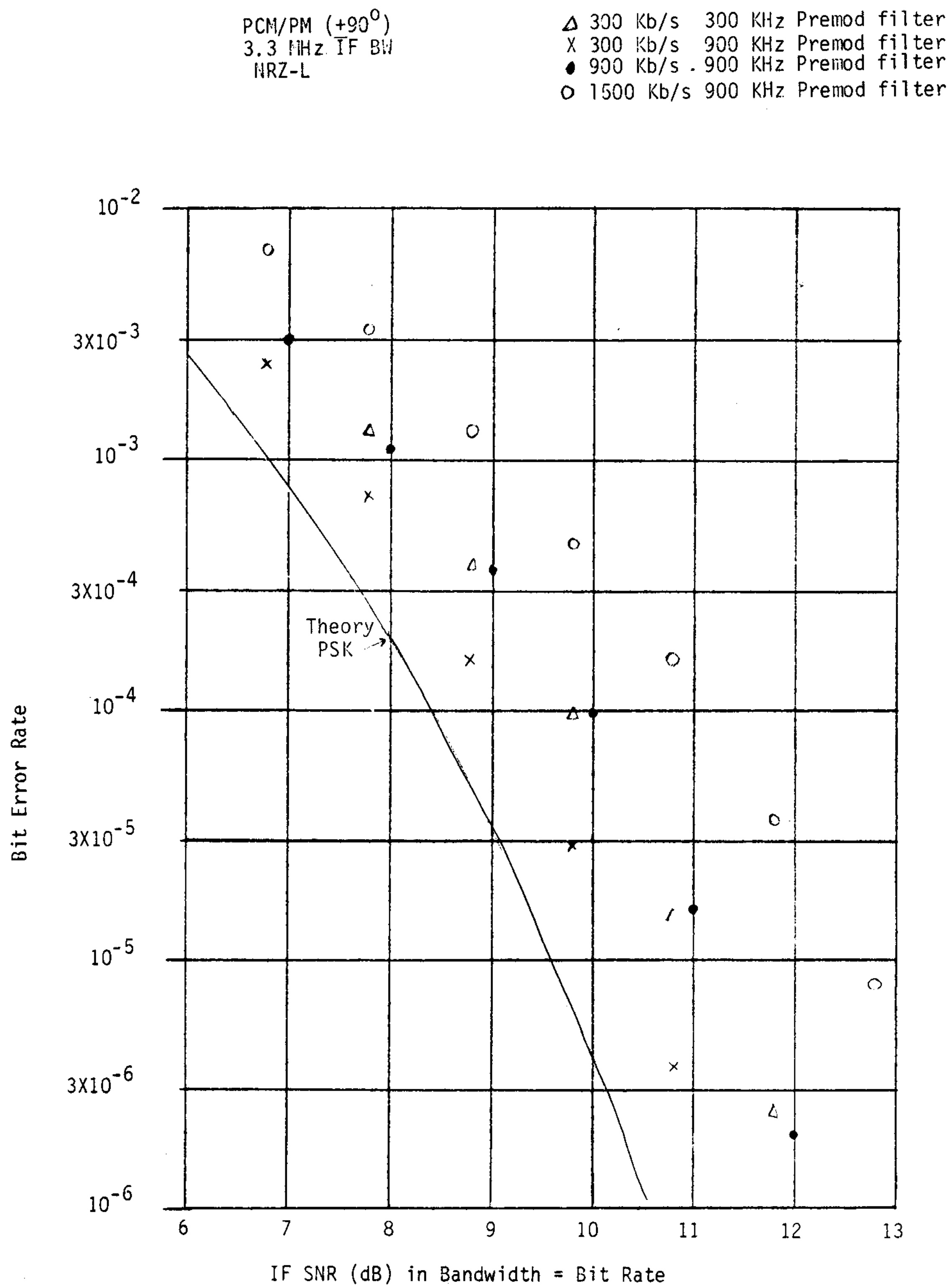

Figure 2. Bit error rate versus IF SNR in bandwidth equal to bit rate for PCM/PM (±90°).

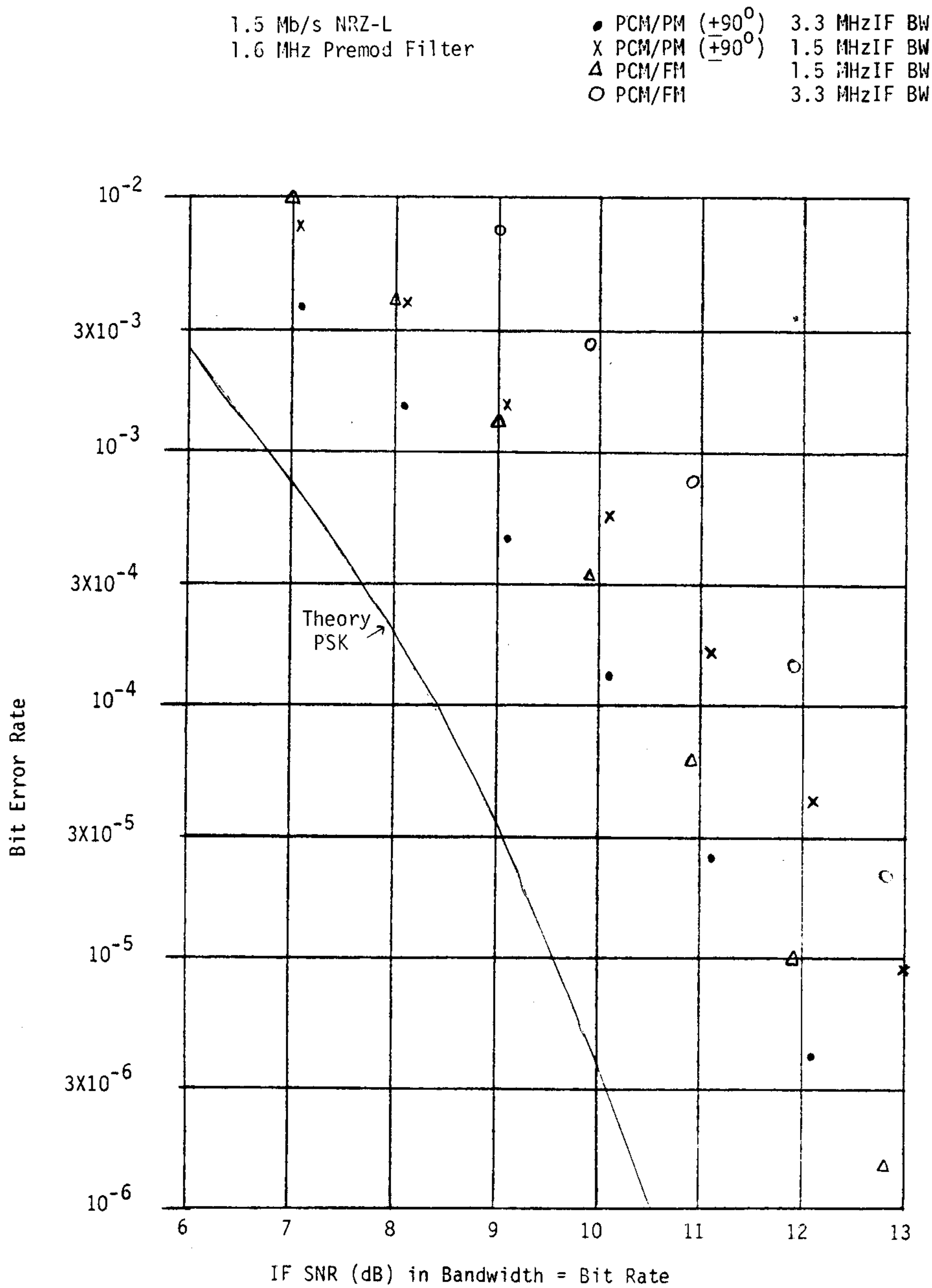

Figure 3. Bit error rate versus IF S1JR in bandwidth equal to bit rate for PCM/PM (±90°) and PCM/FM.