# APPENDIX B

## USE CRITERIA FOR FREQUENCY DIVISION MULTIPLEXING

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### 1.0 General

Successful application of frequency division multiplexing telemetry standards depends on recognition of performance limits and performance tradeoffs, which may be required in implementation of a system. The use criteria included in this Appendix are offered in this context as a guide for orderly application of the standards, which are presented in Chapter 3. It is the responsibility of the telemetry system designer to select the range of performance that will meet data measurement requirements and at the same time permit operation within the limits of the standards. A designer or user must also recognize the fact that even though the standards for FM/FM multiplexing encompass a broad range of performance limits, tradeoffs such as data accuracy for data bandwidth may be necessary. Nominal values for such parameters as frequency response and rise time are listed to indicate the majority of expected use and should not be interpreted as inflexible operational limits. It must be remembered that system performance is influenced by other considerations such as hardware performance capabilities. In summary, the scope of the standards together with the use criteria is intended to offer flexibility of operation and yet provide realistic limits.

### 2.0 FM Subcarrier Performance

The nominal and maximum frequency response of the subcarrier channels listed in Chapter 3 (Table 3-1A, Table 3-1B, Table 3-1C and Table 3-2) is 10 and 50 percent of the maximum allowable deviation bandwidth. The nominal frequency response of the channels employs a deviation ratio of five. The deviation ratio of a channel is one-half the defined deviation bandwidth divided by the cutoff frequency of the discriminator output filter.

2.1 The use of other deviation ratios for any of the subcarrier channels listed may be selected by the range users to conform with the specific data response requirements for the channel. As a rule, the rms signal-to-noise ratio (SNR) of a specific channel varies as the three-halves power of that subcarrier deviation ratio.

2.2 The nominal and minimum channel rise times indicated in Chapter 3 (Table 3-1A, Table 3-1B, Table 3-1C and Table 3-2) have been determined from the equation which states that rise time is equal to 0.35 divided by the frequency response for the nominal and maximum frequency response. The equation is normally employed to define 10 to 90 percent rise time for a step function of the channel input signal. However, deviations from these values may be encountered because of variations in subcarrier components in the system.

## 3.0 FM Subcarrier Performance Tradeoffs

The number of subcarrier channels that may be used simultaneously to modulate an RF carrier is limited by the RF channel bandwidth and by the output SNR that is acceptable for the application at hand. As channels are added, it is necessary to reduce the transmitter deviation allowed for each individual channel to keep the overall multiplex with the RF channel assignment. This reduction lowers the subcarrier-to-noise performance at the discriminator inputs. Thus, the system designer's problem is to determine acceptable tradeoffs between the number of subcarrier channels and acceptable subcarrier-to-noise ratios.

3.1 Background information relating to the level of performance and the tradeoffs that may be made is included in Telemetry FM/FM Baseband Structure Study, Volumes I and II; which were completed under a contract administered by the Telemetry Working Group of the IRIG in 1965. The results of the study show that proportional bandwidth channels with center frequencies up to 165 kHz and constant bandwidth channels with center frequencies up to 176 kHz may be used within the constraints of these standards. The test criteria included the adjustment of the system components for approximately equal SNRs at all of the discriminator outputs with the receiver input near RF threshold. Intermodulation, caused by the radio-link components carrying the composite multiplex signal, limits the channel's performance under large signal conditions.

3.2 With subcarrier deviation ratios of four, channel data errors on the order of 2 percent rms were observed. Data channel errors on the order of 5 percent rms of full-scale bandwidth were observed when subcarrier deviation ratios of two were employed. When deviation ratios of one were used, it was observed that channel-data errors exceeded 5 percent. Some channels showed peak-to-peak errors as high as 30 percent. It must be emphasized, however, that the results of the tests performed in this study are based on specific methods of measurement on one system sample and that this system sample represents a unique configuration of components. Systems having different performance characteristics may not yield the same system performance.

3.3 System performance may be improved, in terms of better data accuracy, by sacrificing system data bandwidth; that is, if the user is willing to limit the number of subcarrier channels in the multiplex, particularly the higher frequency channels, the input level to the transmitter can be increased. The SNR of each subcarrier is then improved through the increased per-channel transmitter deviation. For example, the baseband structure study indicated that when the 165-kHz channel and the 93-kHz channel were not included in the proportional-bandwidth multiplex, performance improvement can be expected in the remaining channels equivalent to approximately 12 dB increased transmitter power.

3.4 Likewise, elimination of the five highest frequency channels in the constant bandwidth multiplex allowed a 6-dB increase in performance.

3.5 A general formula,[1] which can be used to estimate the thermal noise performance of an FM/FM channel above threshold, is as follows:

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[1] K.M. Uglow,. *Noise and Bandwidth in FM/FM Radio Telemetry,* "IRE Transaction on Telemetry and Remote Control," (May 1957) pp 19-22.

$$\left(\frac{S}{N}\right)_d = \left(\frac{S}{N}\right)_c \left(\frac{3}{4}\right)^{1/2} \left[\frac{B_c}{F_{ud}}\right]^{1/2} \left(\frac{f_{dc}}{f_s}\right) \left(\frac{f_{ds}}{F_{ud}}\right) \quad \text{(B-1)}$$

where:

$\left(\frac{S}{N}\right)_d$ = discriminator output signal-to-noise ratio (rms voltage ratio)

$\left(\frac{S}{N}\right)_c$ = receiver carrier-to-noise ratio (rms voltage ratio)

$B_c$ = carrier bandwidth (receiver IF bandwidth)

$F_{ud}$ = subcarrier discriminator output filter: 3-dB frequency

$f_s$ = subcarrier center frequency

$f_{dc}$ = carrier peak deviation of the particular subcarrier of interest

$f_{ds}$ = subcarrier peak deviation

If the RF carrier power is such that the thermal noise is greater than the intermodulation noise, the above relation provides estimates accurate to within a few decibels. Additional information is contained in RCC Document 119, *Telemetry Applications Handbook.*

3.6 The FM/FM composite-multiplex signal used to modulate the RF carrier may be a proportional-bandwidth format, a constant-bandwidth format, or a combination of the two types provided only that guard bands allowed for channels used in a mixed format be equal to or greater than the guard band allowed for the same channel in an unmixed format.

## 4.0 FM System Component Considerations

System performance is dependent on all components in the system. Neglecting the effects of the RF and recording system, data channel accuracy is primarily a function of the linearity and frequency response of the subcarrier oscillators and discriminators employed. Systems designed to transmit data frequencies up to the nominal frequency responses shown in Chapter 3 (Table 3-1A, Table 3-1B, Table 3-1C and Table 3-2) have generally well-known response capabilities, and reasonable data accuracy estimates can be easily made. For data-channel requirements approaching the maximum frequency response shown in Chapter 3 (Table 3-1A, Table 3-1B, Table 3-1C and Table 3-2), oscillator and discriminator characteristics are less consistent and less well-defined, making data accuracy estimates less dependable.

4.1 The effect of the RF system on data accuracy is primarily in the form of noise because of intermodulation at high RF signal conditions well above threshold. Under low RF signal conditions, noise on the data channels is increased because of the degraded SNR existing in the receiver.

4.2 Intermodulation of the subcarriers in a system is caused by characteristics such as amplitude and phase nonlinearities of the transmitter, receiver, magnetic tape recorder/reproducer, or other system components required to handle the multiplex signal under the modulation conditions employed. In systems employing pre-emphasis of the upper subcarriers, the lower subcarriers may experience intermodulation interference because of the difference frequencies of the high-frequency and high-amplitude channels.

4.3 The use of magnetic tape recorders for recording a subcarrier multiplex may degrade the data channel accuracy because of the tape speed differences or variations between record and playback. These speed errors can normally be compensated for in present discriminator systems when the nominal response rating of the channels is employed and a reference frequency is recorded with the subcarrier multiplex.

## 5.0 Range Capability For FM Subcarrier Systems

The following subparagraphs outline additional range capabilities:

5.1 Receivers and Tape Recorders. The use of subcarrier frequencies greater than 2 MHz may require tape recorders of a greater capability than are in current use at some ranges. It is recommended that users, who anticipate employing any of the above channels at a range, check the range's capability at a sufficiently early date to allow procurement of necessary equipment.

5.2 Discriminator Channel Selection Filters. Inclusion of the higher frequency proportional-bandwidth channels and the constant-bandwidth channels may require the ranges to acquire additional band selection filters. In addition to referencing Chapter 3 (Table 3-1A, Table 3-1B, Table 3-1C and Table 3-2) for acquiring channel-selector filters, consideration should also be given to acquiring discriminators corresponding to the predetection carrier frequencies shown in Appendix D, Table D-9. In applications where minimum time delay variation within the filter is important, such as tape speed compensation or high-rate PAM or PCM, constant-delay filter designs are recommended.

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