# STANDARDS RE-EVALUATION FOR WIDEBAND MAGNETIC TAPE RECORDING

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## EVOLUTION

With the expanding utilization of predetection techniques and serial PCM recording, there has become an acute need for standardization of wideband (1 mc and up) tape recorder specifications and parameters.

Recorder manufacturers have attempted to extrapolate methods for specification and testing from the existing terminology of standard magnetic recorders. Unfortunately, these standards were previously extrapolated from the audio recorder industry and were already stretched to the limit of their meaningfulness when applied to instrumentation recording. Generic Audio terms such as “flutter” no longer have a place in the sophisticated realm of wideband recording. The methods of measurement of such parameters offer no real basis for comparison of recorders, and newly encountered unspecified parameters may have more profound effects on system performance.

Existing test techniques are hopelessly inadequate for testing and comparing wideband machines. The industry should no longer rely solely on recorder manufacturers to recognize these problems since they are often far removed from the end use and usually have a strong proprietary interest which may distort the emphasis on critical systems requirements. Relief must therefore come from the systems designers who can see the whole problem objectively, and from the using agencies who can visualize the effects of forthcoming requirements.

In reviewing the traditional methods of recorder performance specification, one can trace the origin of nearly all currently used specification terms and test techniques back to early audio recording ... a natural type of evolution wherein methods used to define professional audio tape recorders have simply been extended and found their way into the instrumentation field. This natural application of existing terminology was not unreasonable when professional audio recorders were extended in frequency response to accommodate early frequency-multiplexed telemetry systems. They were somewhat stretched to cover the next generation of instrumentation recorders which consisted largely of those using one-half inch seven track or one-inch fourteen track formats. At this point, the IRIG standards and recommendations did much to improve the situation. However, the recent explosive increase of predetection recording and serial recording of PCM signals using recorders with responses in excess of I mc and speeds of 120 IPS, makes these traditional terms and test procedures inadequate to permit the systems engineer to evaluate his system performance in relationship to available recorder specifications.

## MEASUREMENT PROBLEMS

The measurement of specified parameters using existing IRIG techniques is not completely indicative of recorder quality. For example, IRIG standards call for flutter components to be measured to 10 kc. An evaluation of the spectral distribution of flutter in machines running at 120 IPS indicates that there may be appreciable velocity variation caused by “scrape” components and “violin string” effect above 10 kc which quite seriously effect the performance of the recorder in predection recording systems (Fig. 1). Additionally, there are specifications for signal-to-noise ratio which, when applied over the full bandpass of the recorder, may not be at all indicative of the excellence of that recorder’s performance. No reference is made in the standards to the spectral distribution of noise to be measured. It has been found in wideband instrumentation recorders using constant current recording techniques that the noise spectrum rises sharply at the high end of the recorder response (Fig. 2). This is due to partial erasure of short wavelengths and the resulting equalization curves necessary to yield flat frequency response. The shape of the noise spectrum is of great concern to the system designer in establishing FM center frequencies and determining bandwidth utilization.

There are also certain recorder specifications where optimization can be accomplished to favor the most important characteristics at the expense of other less important specifications. For example, the following parameters are related and interdependent:

Record Level
Bias Level and Frequency
Harmonic Distortion
Intermodulation Distortion
Signal-to-Noise Ratio
Frequency Response
Phase Response

When increasing the record current and decreasing bias to maintain a flat frequency response, harmonic distortion, intermodulation distortion and signal-to-noise ratio all increase. The relationship is complex and certain trade offs can be made to improve the performance in some areas at the expense of the others. It is difficult to completely specify a magnetic tape recorder in this performance area. Further, definitions of terms and methods of measurement vary considerably among manufacturers.

At present there are no universal standards for measuring these parameters in the magnetic recording industry. Each manufacturer measures and defines these parameters differently. It is most difficult to assess relative competitive merit solely on the basis of quoted specifications. The effects of slight differences in specifications are subtle and difficult to evaluate. As discussed above, one parameter which has a significant and easily identifiable effect is the non-uniform distribution of noise. System performance is often optimized by simply adjusting the various parameters for minimum noise and distortion over the region of interest. This then indicates that the systems' operating procedure may call for other-than-normal adjustment of record level, bias, equalization, etc. Some specifications therefore assume a greatly magnified importance in relation to others. A few, in fact, can even contribute to severe degradation of data.

The situation is further complicated by measurement methods. Signal-to-noise ratio may appear to be worse in a wideband measurement when the actual region of interest in reality exhibits less noise.

"Flutter", more accurately termed "velocity error", has a spectrum which in any well-designed transport is more or less of a random nature. There can be, however, strong components which exceed 10 kc and are not measured by obsolete "standard" methods. If, for example, a frequency of 225 kc is used to make this measurement, then the velocity error can be measured over a wider frequency range. This is due to the fact that the noise spectrum of the recorder electronics is such that 225 kc represents a region of exceptionally high signal-to-noise ratio. Signal-to-noise ratio is usually a limiting factor in flutter measurement. However, by using a record level near saturation and a midband frequency such as 225 kc, its effects are minimized. The standard" IRIG method calls for this measurement to be made at 52.5 kc over a 10 kc BW at 60 IPS only. In some cases, 52.5 kc is completely out of the recorder passband.

It is no longer feasible for the Systems Engineer to specify recorder performance at a single reference point (Fig. 3). Enough points must be specified to define the curve of each important characteristic; i.e., harmonic distortion varies over the passband due to tape, head, and electronic equalization characteristics and should be defined and measured at at least 3 key points in the passband of the recorder.

## SYSTEMS REQUIREMENTS

One outgrowth of old audio techniques is the establishment of 1% third harmonic distortion as normal record level. This particular figure has no relation to the requirements of instrumentation recording systems; yet in attempting to maintain this specification, other more important specifications must, of course, be compromised. This is not a very serious problem if one assumes that the various recorder parameters listed above are adjustable to the extent that any one can be optimized at the expense of others. However, there is a certain amount of variation in specifications brought about through production tolerances in the recorder heads and circuit configurations which cannot be easily changed. Unfortunately, the study work necessary to establish optimum recording parameters is not often provided for in system planning, and it can only be assumed that the recorder configuration which is specified will be close to optimum.

Another parameter which assumes a magnified importance with use of wideband recorders is bias frequency. Ordinarily a bias frequency of approximately five times the highest frequency to be recorded is chosen, and this is also the case with wideband recorders. In most previous systems, the exact frequency has not been important. However, when bias frequency is in the area of 7 or 8 mc, it then becomes a source for serious consideration insofar as RFI is concerned. The bias oscillator necessarily is a rather high powered device and difficult to contain at HF frequencies. Much more extensive precautions need be taken in wideband recorders to suppress the radiation of bias signals. The system designer is aware of the fact that telemetry receiver, IF frequencies, are usually 5 or 10 mc. Should the bias frequency for a wideband recorder fall within the passband of receiver IF, it could create a very difficult system integration problem. Fortunately, 7 mc bias falls nearly half way between the standard IF frequencies of 5 and 10 mc for telemetry receivers. This may not always be the case and therefore, allocation of bias frequencies and some special techniques for suppressing RFI need be considered when setting up performance specifications of magnetic recorders to be used for predetection telemetry purposes.

Probably the worst problem facing the system designer is one of making a good comparative evaluation Of advertised specifications (see Table). In some cases it has been a practice to quote a set of specifications for a magnetic recorder based on individual measurements optimizing such factors as equalization, record level, distortion, etc., independently, and it has been found that the recorders themselves are not capable of maintaining all published specifications simultaneously. Every manufacturer should be compelled to specify any instrumentation recorder in such a manner that all specifications can be achieved with a single setting of all controls and adjustments.

Input and output impedances are yet another problem area. In the field of telemetry, it has been common practice to use bridging techniques -- that is, most devices had been designed with high input impedances and low output impedances to enable driving a reasonable amount of cable capacity while maintaining good frequency response. However, when working with frequencies up to 1.5 mc, this is no longer feasible. It has become necessary in predetection systems and high bit rate PCM systems to use terminated lines. It therefore becomes important to standardize the input/output impedances of wideband magnetic recorders. Although all recorder manufacturers have recognized the need for lowering input impedance, no two have standardized on any given value.

## R&D NEEDED

The effects of "flutter" can contribute as much as 2% inaccuracy in certain types of predetection recordings such as FM/FM data. It is, of course, desirable to remove all identifiable sources of error from the recording process. Fluxuations in the velocity of the recording medium result in time-base modulation of the recorded signal. This process manifests itself as simultaneous frequency, phase, amplitude, and time displacement errors in the recording and the only known method for compensating <u>all</u> effects is through an inverse time-base modulation of the reproduced signal.

The type of compensation normally associated with early telemetry systems reduces only the frequency modulation effects which are the predominant effects of post-detection recording of FM/FM signals. In predetection recording of the same signals, however, there are primary and secondary order effects which contribute to inaccuracies. It has been shown that FM of the individual subcarriers is a significant effect and that compensation using the standard discriminator subtraction technique will somewhat improve the accuracy of an FM/FM signal. Manifestation of jitter on pulse type signals is a result of time-base modulation, however, and cannot be compensated using the discriminator technique. Several methods have been proposed for inverse time-base modulation of the reproduced data using electrical, mechanical, or ultrasonic variable delay devices. At first glance, this appears to be an adequate solution until a quantitative design analysis is attempted. It then becomes impractical to implement these approaches due to the fact that delay variations of several hundred microseconds are required at rates exceeding 10 kc. Mechanical devices are immediately ruled out due to the fact that physical displacements of inches are required at high rates. Ultrasonic devices fall into the same category and have the additional problems of achieving 1.5 me bandpass. It is theoretically possible to construct an electronic delay line with active isolation between sections. The number of sections required to realize several hundred microsecond variation makes this device also impractical.

One method that has considerable merit involves actual physical movement of the recorder reproduce heads through servo control. Once again, the rate of change is too great. The necessary time displacement may be reduced by the incorporation of a tape speed control servo with frequency response exceeding that normally supplied with the recorders which have response to only a few cycles/second. If this could be extended to several hundred cycles per second through use of a low-mass capstan arrangement, then the range of delay required for the variable delay line could be considerably reduced and some of the approaches discussed above could be more readily implemented. A variable delay utilizing cathode-ray technique which can theoretically meet all of the requirements for true flutter compensation is also under evaluation.

There are always some practical and economic factors to consider in that each track of the recorder must be individually compensated, and therefore requires its own reference discriminator and variable delay line. Even so, the overall improvement possible through total flutter compensation would not, in fact, be very significant due to other sources of system error which approach or exceed flutter effects in magnitude. Recorder noise alone can contribute as much as 5% error in wideband signals, while incidental FM in receiver and translator oscillators can contribute errors of the same magnitude for very narrow band signals. Translator spurious at -30db can contribute 3% error when they fall in the passband of a subcarrier channel.

Further difficulties are encountered in attempting to mix a reference signal with the predetection signal. When using the full (1.4 mc) available of recorder bandwidth, there is no convenient place in the recorded spectrum to place the reference tone, unless system bandpass is restricted by using a narrower recording IF amplifier.

Another area of considerable misunderstanding throughout the industry is that of envelope delay measurement. Since all recorders have a fixed time delay between the record and reproduce heads, the actual envelope delay variation cannot be measured with conventional test instrumentation and each recorder manufacturer has a different recommended method for measuring this parameter. In general, none of the recommended methods are very satisfactory due to the complicating effects of a fixed delay which is a great many times longer than the delay which is to be measured, and instantaneous velocity variations (flutter) which are of the same magnitude as those delay variations we are attempting to measure. No equipment exists for making this measurement over the full bandwidth.

## ACTION

It should therefore be evident that a great deal of standardization, evaluation, and investigation needs to be accomplished in the wideband longitudinal recorder field. The systems engineer has probably had more experience in the use of wideband recorders as applied to predetection recording of telemetry signals than the original manufacturer, and hence, is in the best position to recognize and compensate for the limitations imposed by the recorder characteristics on system performance.

A committee must be formed to make recommendations for formulating an approach to the specification and test of wideband instrumentation. This committee should include not only IRIG members and recorder manufacturers, but most importantly, cognizant engineering representatives of major system houses where integration problems are known and competitive prejudices minimized. Areas requiring intensive investigation are:

1. Redefine performance specifications to apply to full scope of WB recorder capabilities and to accurately describe true performance.

2. Standardize test methods to enable uniform comparison of competing instruments.

3. Establish descriptive specifications and test techniques for unprecedented performance characteristics such as phase response.

4. Establish standards for Reference Frequencies, Servo Carriers, FM Carriers, Predetection Frequencies, Bandwidths, Bias Frequency and Input/Output Impedances.

5. Develop the necessary specialized instrumentation to accurately measure each specified parameter.

6. Establish uniform time displacement error specification and test methods for low-mass capstan recorders.

The state-of-the-magnetic-recording art could then progress with direction, based on a solid foundation of measurement standards available to all researchers, manufacturers, and systems designers.

## TABLE I COMMON PERFORMANCE SPECIFICATIONS

| Specification | Remark |
| --- | --- |
| Harmonic Distortion | Use as reference point for other specifications questionable. Needs standard frequencies for various recorder speeds and needs definition of individual contributing components. May also require measurement at more than one point in a spectrum to fully define. |
| Intermodulation Distortion | Of great importance in predetection applications. Needs standard frequencies or standard frequency spacing and definition of individual products to be measured. |
| Frequency Response | Interrelated with other adjustable parameters. Needs firm limits, standardized reference points, etc. |
| Signal-to-Noise Ratio | Spectral distribution must be defined and controlled, possibly through use of narrow band samples at various reference points. Terminology (RMS, peak-to-peak, average, etc.), needs defining and standardizing, characteristics of band limiting filters should be established. |
| Phase Response | Reliable test equipment unavailable. No uniform definition in general use. This is a new parameter of interest. |
| Input & Output Characteristics | Uniform levels and impedance terminations must be set. |
| Bias | Frequency and RFI level must be designated. |
| Flutter | Terminology, measurement techniques, test equipment, all completely obsolete. Spectral characteristics must be included. Cumulative figures are meaningless. |
| Tape Speed Accuracy | Could be included in flutter measurement if DC response is available on test equipment. Controlled time interval and physical tape characteristics must be accounted for. |

| Specification | Remark |
|---|---|
| Time Displacement Error | The increasing use of low mass capstan machines requires that uniform standards of measurement and designation be applied to the spec on all machines. |
| Instantaneous Amplitude Stability | Never before specified but vital in many applications. It is a measure of constancy of tape-head contact "head bounce". |
| Dynamic Skew | Many applications require time correlation of multiple tracks. Skew definition should be expanded to include non-adjacent tracks, all speeds, and interstack skews. |
| Track Dimensions | IRIG standard dimensions were developed for low frequency machines and may not be optimum for minimum crosstalk, best time correlation, etc., on wideband machines. The state-of-the-art in head technology permits a higher density of head stacking than is currently used. The audio industry has made monaural and stereo track spacing mutually compatible and there is no reason why instrumentation track dimensions cannot have several standard configurations which are also mutually compatible. |
| Head Life | A uniform specification must make use of speed, type of tape, head contact time, etc. It may be desirable to develop a special controlled, abrasive medium for making this measurement. |
| Metering | Normal record level should be sensed by peak-to-peak reading device rather than RMS or average reading and should be defined in terms other than harmonic distortion level. Standardized time constants necessary. |
| Tape and Reel Dimensions | Well standardized but are they optimum considering available recording times, transport overall size, and dynamics of tape handling with high speed machines? |

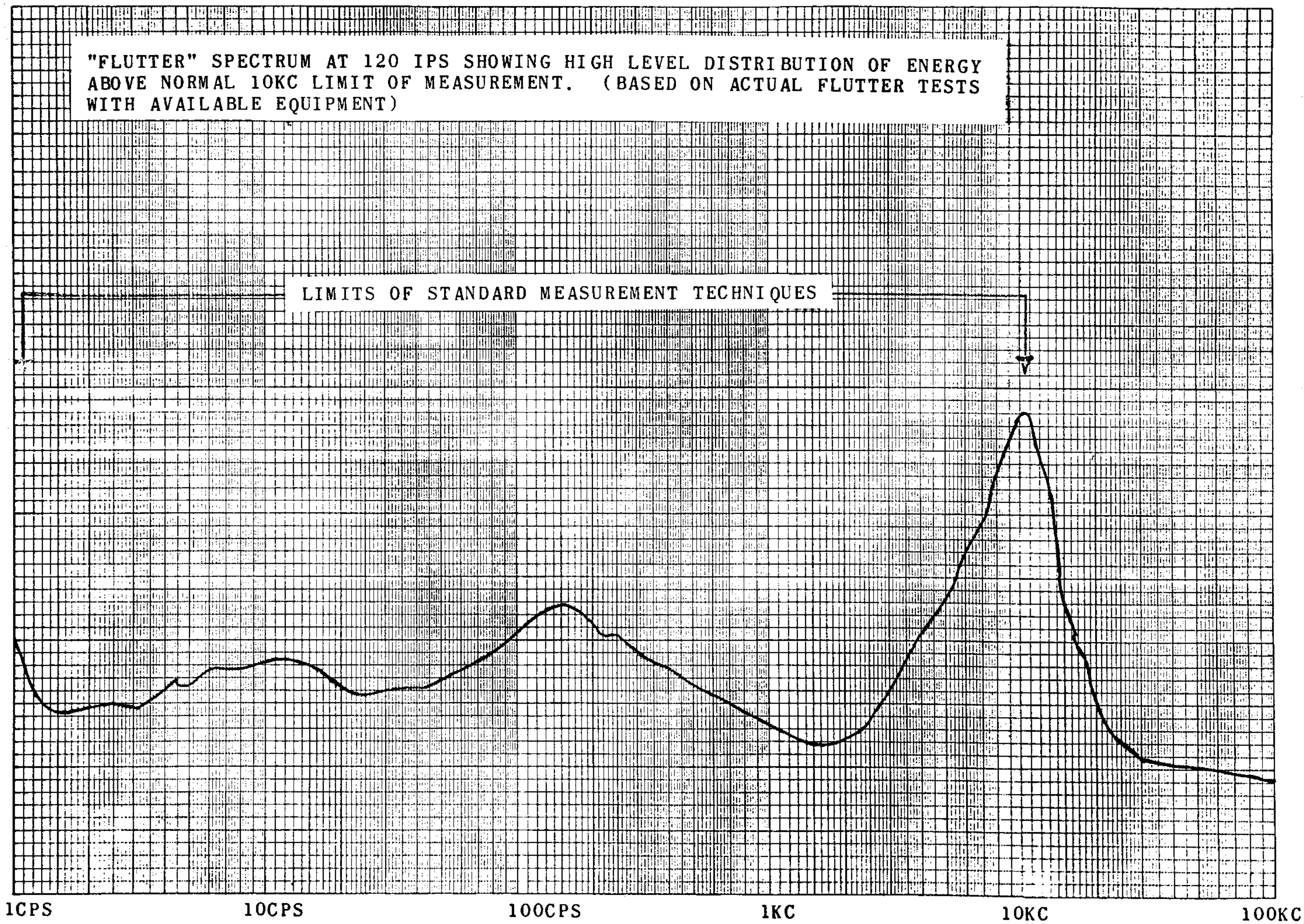
"FLUTTER" SPECTRUM AT 120 IPS SHOWING HIGH LEVEL DISTRIBUTION OF ENERGY ABOVE NORMAL 10KC LIMIT OF MEASUREMENT. (BASED ON ACTUAL FLUTTER TESTS WITH AVAILABLE EQUIPMENT)
LIMITS OF STANDARD MEASUREMENT TECHNIQUES
1CPS
10CPS
100CPS
1KC
10KC
100KC

**FIGURE 1**

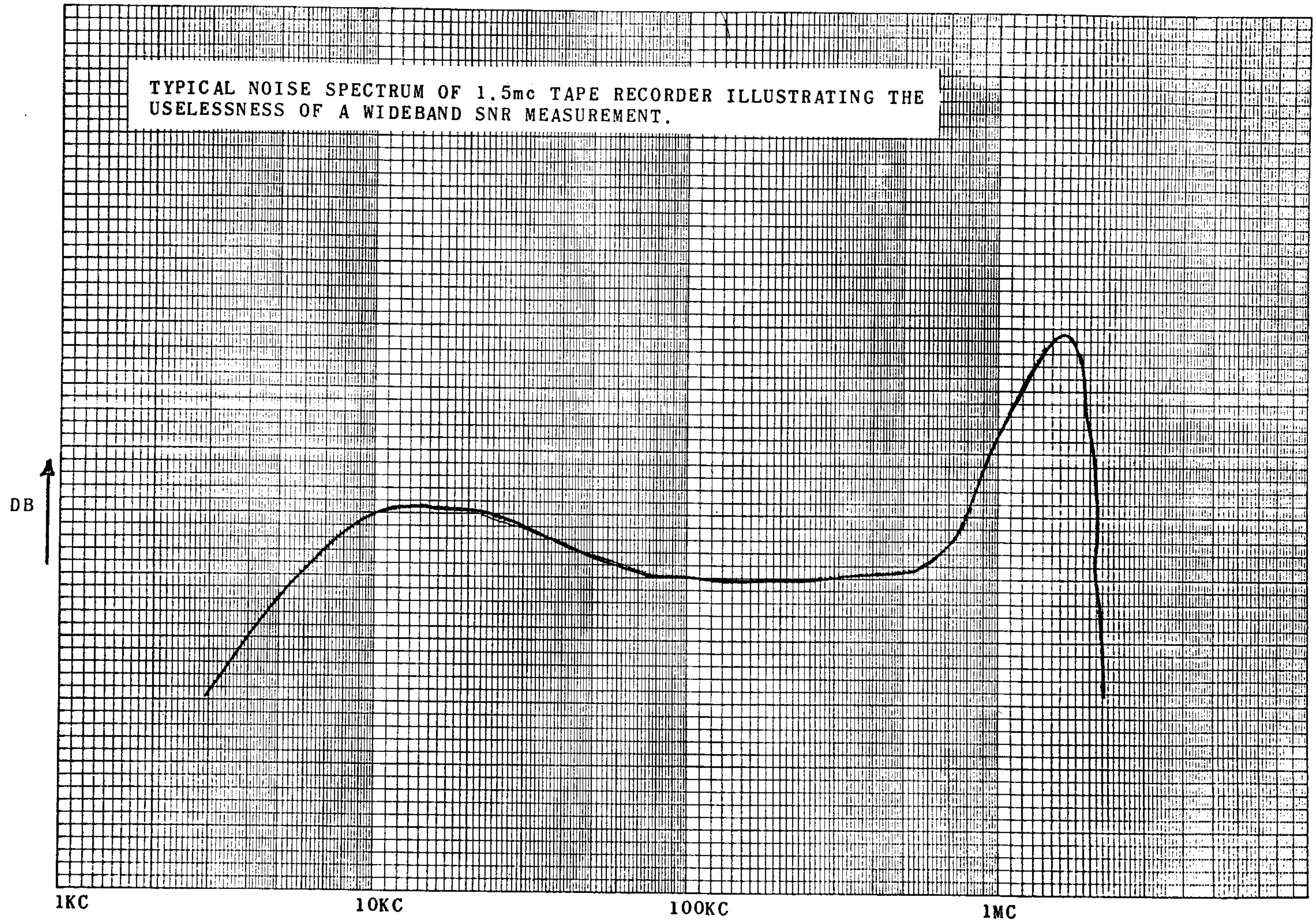
TYPICAL NOISE SPECTRUM OF 1.5mc TAPE RECORDER ILLUSTRATING THE USELESSNESS OF A WIDEBAND SNR MEASUREMENT.
DB
1KC
10KC
100KC
1MC

**FIGURE 2**

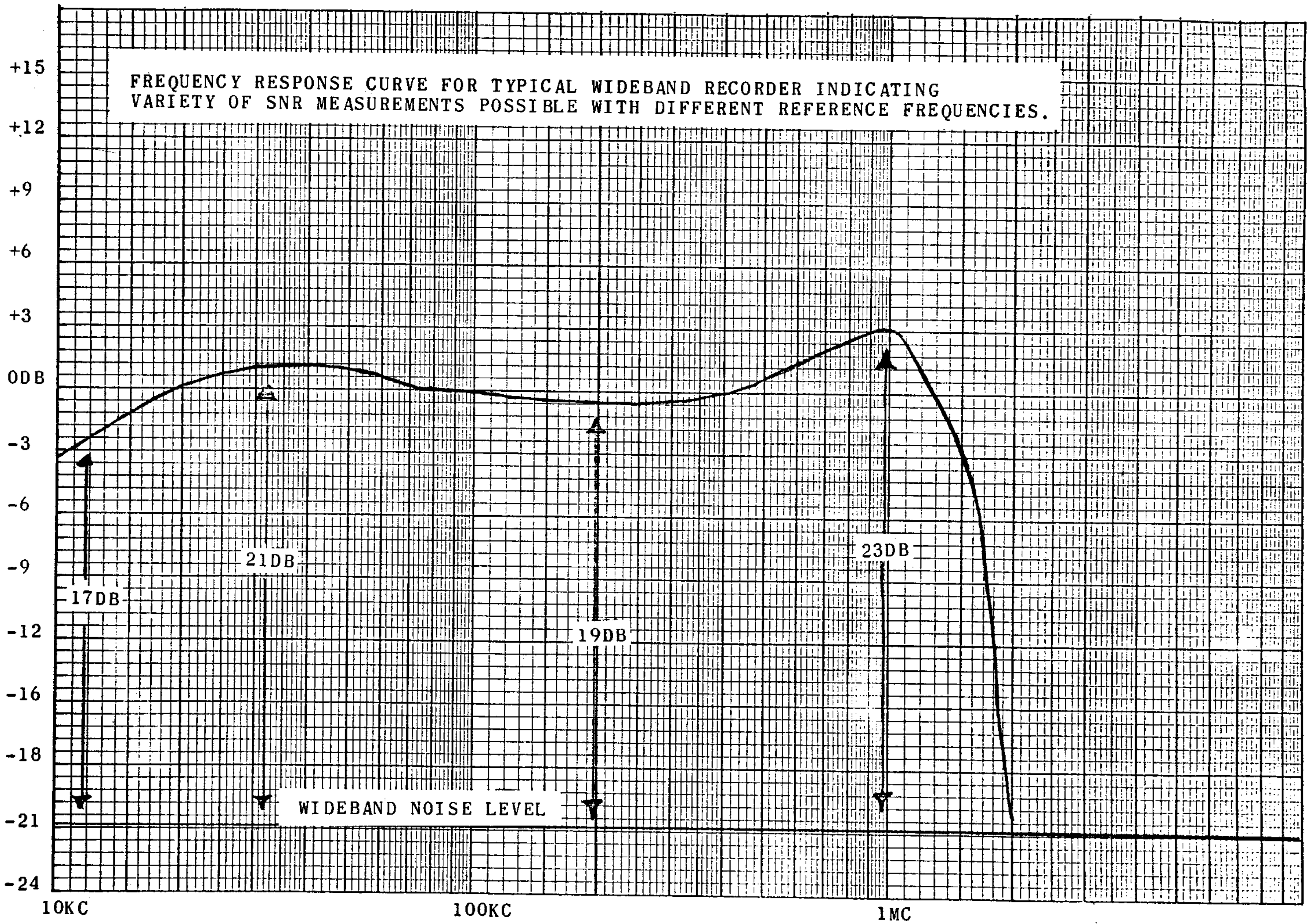
FREQUENCY RESPONSE CURVE FOR TYPICAL WIDEBAND RECORDER INDICATING
VARIETY OF SNR MEASUREMENTS POSSIBLE WITH DIFFERENT REFERENCE FREQUENCIES.
+15
+12
+9
+6
+3
0DB
-3
-6
-9
-12
-16
-18
-21
-24
17DB
21DB
19DB
23DB
WIDEBAND NOISE LEVEL
10KC
100KC
1MC

**FIGURE 3**