Mar 7th, 8:00 AM

Instrumentation Recorder Specifications and Tests

Glen H. Schulze

Pan American World Airways, Inc.

Follow this and additional works at: https://commons.erau.edu/space-congress-proceedings

Scholarly Commons Citation
https://commons.erau.edu/space-congress-proceedings/proceedings-1966-3rd/session-7/4
Introduction

Analog instrumentation recorders may be classified according to bandwidth, operational environment and application. Classification extremes are great and given specifications are subject to differences in importance as well as in numerical value. Performance testing, evaluation techniques and system specifying are vastly different and must be designed for the subject application if results are to be productive. The information presented in the following sections has been derived primarily from tests conducted with broadband recording systems. This effort has been directed toward discussion of new measurement techniques advanced by predetection recording requirements at the Eastern Test Range. The goal of this work is to widen the scope of testing, evaluation and specifying thereby promoting fuller and better understanding of predetection recording systems, their limitations and their capabilities.

Recorder Classification

A classification of instrumentation recorders according to maximum bandwidth in the DIRECT mode falls logically into four classes:

1. Ultra low bandwidth - 100 cps
2. Low bandwidth - 100 kcps
3. Intermediate bandwidth - 600 kcps
4. Wide bandwidth - 1.5 mcps

Each of the four classes is sufficiently different to warrant separate listing. Classes 1 and 4 are the newest additions having received active usage within the last four years. The oldest classification, Class 2, is no longer in active expansion having been curtailed by the advantages of the newer bandwidth classifications.

According to environmental usage, the following classifications are prominent:

a. Laboratory
b. Portable, ground based
c. Portable, vehicular based
d. Airborne
e. Satellite

In addition to the obvious weight and size differences, the designs are tailored to achieve maximum performance in the intended operational environment. Laboratory and portable systems operated while in a fixed location are relatively easier to test and evaluate because the environment is not a variable. Systems operated while in motion or in environmental extremes of temperature and pressure are subject to performance degradation compared with laboratory performances. Tape speed accuracy and flutter are prime examples of vehicular performance degradations.

A classification according to major field of application closely parallels the bandwidth classification:

- **100 cps**: Geological studies and long term monitoring
- **100 kcps**: Post detection telemetry and environmental testing
- **600 kcps**: Predetection telemetry and environmental testing
- **1.5 mcps**: Predetection telemetry and environmental testing

Testing and evaluation techniques for the lower bandwidth applications are similar in nature particularly for the 100 kcps and 600 kcps applications. Predetection 1.5 mcps system testing requires somewhat different emphasis than sub-megacycle testing. This is due partly to the predetection application and partly to the unique nature of the megacycle systems.

Special Requirements of Megacycle Recorder Testing

Head life and tape wear are two parameters which require added attention in megacycle systems. Tape tensions are as high as 20 ounces and head contours are sharper. As a result, temperatures and wear rates are appreciably increased. Head life and tape wear tests are best performed at 120 ips, a worse case situation, while measuring high frequency response or dropouts. The number of times a given recorded portion of the tape may be replayed without head cleaning is a relative measure of tape wear or oxide shedding. The better megacycle tapes used with slightly worn heads appear to be capable of at least 50 to 100 plays without head cleaning. Tape life might be somewhat less with new heads possessing sharper contours.

Normal head life at 120 ips appears to be between 300 and 600 hours depending on the tape used, the end-of-life criterion, and other parameters. A reliable agency reports a definite relationship between head life and the head cleaner solution. A satisfactory measure of head...
life during acceptance testing does not exist. The only known positive measure of head life is to actually wear a head to the point where it will no longer meet specified performances. This is not practical for small scale operations because of head cost.

An innovation of some type is definitely needed which would enable simple measuring of remaining head life and head wear rate. Possibly a special reproduce edge track could be designed for the single purpose of indicating wear depth through a proportional change in its output characteristics. As an example, a head with a funnel-shaped gap cross section arranged such that its short wavelength response would increase proportionately with head wear up to the point of 80 to 90% of the useable life. At this point the response would remain constant with wear thereby giving a warning that head life is near an end.

Other problems affiliated with megacycle heads and tapes are non-uniformity of frequency response and non-uniformity of bias requirements. Most of the non-uniformity appears to be attributed to the magnetic heads rather than tapes. In most megacycle systems modular interchangeability is possible but realignment is required if specifications are to be met. Because non-uniformity between tracks is a real and existing liability and can vary from one system to the next, limits should be placed on the acceptable degree of non-uniformity. Without such limits, an important gap exists in the quality control of recording systems. The lack of interchangeability of a typical megacycle system is displayed in Figure 1. Three swept frequency response tests from 10 kcps to 2.0 mcps are shown for three adjacent tape channels. Equalization has been adjusted for approximately 42 db bandflatness. Arbitrarily interchanging the reproduce modules without resetting equalizers and replaying the same portion of tape resulted in the second set of responses. The 42 db bandflatness widened to approximately 46 db, an unacceptable degradation requiring a somewhat laborious re-equalization.

Unique Recorder Tests

Time Base Error Measurements

With the increased availability of high performance low time base error recording systems in all bandwidths, many new applications are being investigated. Closer scrutiny of the TBE measurement techniques promoted by manufacturers should be part of any application analysis. Conventional procedures of visually inspecting an oscilloscope trace and extracting peak-to-peak jitter readings are sufficient for gross observations only.

One of the most demanding applications involving low TBE is facsimile tape recording. For example, a 30-minute weather map facsimile is transmitted asynchronously after the original phasing tone has started the fax printer. For the entire duration of the 30-minute transmission, the scanner and printer must remain in step on a line by line basis operating asynchronously except for the single originating phasing tone. Should either the scanner or printer tuning fork references change more than a few parts per million the result will be a skewed, distorted map. Recording 30-minute weather maps on magnetic tape and reproducing the maps at a later time without fidelity loss is demanding for even high performance instrumentation recorders. Besides the long term TBE requirements imposed by map skew limits, the reproduce servo TBE jitter should not reduce picture sharpness and the servo must not be fooled into skipping sync when a dropout occurs in the reference track.

Similar demands are placed on TBE performance when coherent tape combining of predetection recordings is attempted. Because at least two recorders are involved, a master and slave, the problems are at least compounded by a factor of two. Either the two tapes must both be slaved to the same clock or the slave must be matched to the master. In either method neither tape system can contain excessive jitter, speed drift or servo dropout susceptibility.

Satellite communication activities have generated recognition of the handover problem between satellites in the same system. Instrumentation recorders with high performance drives are being considered as temporary storage devices capable of compensation speed programming to accommodate Doppler shifts and transmission delay differences. The goal is handover without discontinuities in minimum lag time. This application imposes severe demands on TBE performance.

An excellent TBE test has been previously publicized and deserves repeated mention.1 This test does not rely on the visual interpretations of an operator but instead provides a graphical record of the instantaneous TBE as a function of elapsed time. As such, the test documents complete quasi-static and dynamic components of the time base error for a complete tape reel.

In a sense, the subject TBE test is similar to simulating a facsimile test pattern consisting of a single vertical line at right angles to the direction of scan. The signal is recorded, reproduced and the pattern is graphically printed. The recorded TBE is documented by any skew, jitter or other contamination of the straight line. The TBE test block diagram is shown in Figure 2. A frequency synthesizer serves the function of providing a low jitter 20 kcps signal simulating a straight line fax signal. During reproduction, the synthesizer is adjusted to a frequency precisely 5 times greater and used as the reference grid generator. An oscilloscope with a strip film camera oriented to drive film at right angles to the oscilloscope trace and extracting peak-to-peak jitter readings are sufficient for gross observations only.
AM noise sources include tape bounce, scrape and FM noise. A recorder with inferior quiescent system noise spectrum will reproduce with less discriminator output noise on the channels in the more favorable center portion of the recorder noise spectrum. An efficient flutter compensation system must be employed if this relationship is not to be masked by flutter induced noise. Subcarrier output noise predictions based on FM to AM improvement ratios applied to the recorder's quiescent noise spectrum are not achieved in actual usage. The discrepancy usually amounts to between 6 and 10 dB with higher output noise than anticipated. The difference is explained by modulation noise components introduced by adjacent subcarrier channels and by intermodulation distortion components, both of which do not appear in the quiescent noise spectrum.

Measuring techniques are beginning to develop which include modulation noise as well as zero signal noise. In general, these techniques share two characteristics:

1. The system noise is measured in the presence of a known controlled signal
2. The system noise is presented in spectrum form

One method uses a broadband random noise generator followed by a 3000 cps notch rejection filter with high attenuation positioned in the band of interest. The resulting signal is recorded at various record levels. On reproduction the output spectrum is displayed and the noise contamination of the rejected 3000 cps band is monitored as the system narrow band noise level. This method includes zero signal noise, modulation noise and intermodulation distortion components in the noise measurement. The latter two components increase in proportion to the record signal level whereas the zero signal noise does not. Optimum record level, where the signal to narrow band noise is maximum, can be easily adjusted by observing the relative contamination of the 3000 cps slot as a function of record level. An excessive record level will cause increased slot noise because of modulation and intermodulation noise. An insufficient record level will be performance limited by zero signal noise.

A second modulation noise test uses a tunable voltmeter or wave analyzer to examine the noise spectrum with and without a signal present. The signal may be a single discreet frequency anywhere in the band. Record level should be at normal full scale level to present the modulation noise components at full level. On reproduction the tunable voltmeter is used to examine the slot accepted noise levels to determine the presence of intermodulation noise. A sufficient record level will be performance limited by zero signal noise.

The oscilloscope sweep speed is adjusted to a rate consistent with the repetition rates of the reference grid lines and the TBE test line. Sweep rates less than the rate of the TBE test line (20 kcfs) will cause multiple TBE traces while sweep rates greater than the rate of the grid lines will result in loss of grid line display. Proper selection of grid reference repetition rate and oscilloscope sweep speed will optimize the time scale sensitivity for the particular magnitude of TBE measured. The display information, the reproduced TBE test signal and the reference grid signal, is linearly mixed and supplied to the oscilloscope Y axis for intensity modulation. The result is a printed record similar to a facsimile printing with black/white capability.

A typical TBE result is shown in Figure 2. Since the test yields a plot of the instantaneous time base error versus elapsed reproduced time, interval errors may be extrapolated from the printed results. The illustrated TBE sample shows a cyclic component of 3 cps at 10 microseconds peak-to-peak amplitude in combination with a slow drift through a 30 microsecond band.

**Modulation Noise**

Conventional noise levels in the DIRECT mode are usually measured with zero signal recorded using a wideband meter. When ratioed against the normal signal level, the result is termed signal-to-noise ratio. This value is usually accepted as the major indicator of noise performance. Actually, this measurement defines the wideband dynamic range limits between which the signal may vary without excessive distortion or becoming buried below the noise. This ratio should receive less attention than the more meaningful system noise level when signals are present.

The quiescent system noise level of a tape recorder always increases when a signal is applied because of the introduction of a new noise source, modulation noise. Generally described, this noise is the byproduct AM and FM sidebands of the recorded signal introduced by the system sources of undesirable amplitude and frequency instability. AM noise sources include tape bounce, scrape and oxide non-uniformity. Flutter is the source of FM noise. A recorder with inferior quiescent system noise might actually outperform a system with lower quiescent noise in an application extremely sensitive to modulation noise. All applications involving frequency multiplexing of several narrow band channels on one tape track are susceptible to modulation noise.

Recording narrow bandwidth and constant bandwidth FM subcarrier multiplexes are examples of DIRECT mode applications which can only be analyzed by a spectrum study of recorder modulation noise. Test results show constant bandwidth FM systems, recorded without pre-emphasis of the subcarriers, will reproduce with less discriminator output noise on the channels in the more favorable center portion of the recorder noise spectrum. An efficient flutter compensation system must be employed if this relationship is not to be masked by flutter induced noise. Subcarrier output noise predictions based on FM to AM improvement ratios applied to the recorder's quiescent noise spectrum are not achieved in actual usage. The discrepancy usually amounts to between 6 and 10 dB with higher output noise than anticipated. The difference is explained by modulation noise components introduced by adjacent subcarrier channels and by intermodulation distortion components, both of which do not appear in the quiescent noise spectrum.

Measuring techniques are beginning to develop which include modulation noise as well as zero signal noise. In general, these techniques share two characteristics:

1. The system noise is measured in the presence of a known controlled signal
2. The system noise is presented in spectrum form

One method uses a broadband random noise generator followed by a 3000 cps notch rejection filter with high attenuation positioned in the band of interest. The resulting signal is recorded at various record levels. On reproduction the output spectrum is displayed and the noise contamination of the rejected 3000 cps band is monitored as the system narrow band noise level. This method includes zero signal noise, modulation noise and intermodulation distortion components in the noise measurement. The latter two components increase in proportion to the record signal level whereas the zero signal noise does not. Optimum record level, where the signal to narrow band noise is maximum, can be easily adjusted by observing the relative contamination of the 3000 cps slot as a function of record level. An excessive record level will cause increased slot noise because of modulation and intermodulation noise. An insufficient record level will be performance limited by zero signal noise.

A second modulation noise test uses a tunable voltmeter or wave analyzer to examine the noise spectrum with and without a signal present. The signal may be a single discreet frequency anywhere in the band. Record level should be at normal full scale level to present the modulation noise components at full level. On reproduction the tunable voltmeter is used to examine the slot noise increase in the area adjacent to the discreet frequency compared with the same slot noise with zero signal present. The noise increase,
Amplitude limiting on playback removed the pre-waveform applied to the shaker coils, the magnitude and duration of the shaker frequencies, etc.

Vibration and Flutter

A sharp 940 cps flutter frequency appears at 940 cps as a result of flutter modulating the FM 54 kcps recorder carrier. The same flutter component appears as a low and high sideband of the 6200 cps discrete test frequency, i.e., 7140 and 5260 cps. A broad peak representing a flutter concentration between 600 and 700 cps is also apparent as symmetrical modulation noise. Had the 6200 cps test frequency been recorded via the DIRECT MODE rather than FM the flutter induced FM modulation noise alone. From the above analysis, it should be apparent that flutter components will cause an increase in system modulation noise of any type of recorded signal regardless of how it is encoded. Two modulation noise spectrums are given in the instruction manual for one commonly used tunable voltmeter.

Vibration and Flutter

In the preceding section flutter was shown to be a contributing factor to recorder modulation noise regardless of the signal and the encoding technique utilized. Airborne and vehicular recorder operations are conducted in environments which are likely to increase the flutter level above the values shown on the manufacturer's specification sheets. For complete assurance of acceptable flutter magnitude during operational use, a vibration flutter test should be conducted.

Recorder vibration or shake tests can follow several formats depending on the position of the shaker or shakers to the recorder frame, the waveform applied to the shaker coils, the magnitude and duration of the shaker frequencies, etc. The most susceptible vibration plane of a tape recorder is usually the plane of tape motion over the heads, and the most revealing test in this plane is usually rotation about an axis perpendicular to the plane. High mass drive systems in particular will be adversely affected by rotational shaking in the plane of tape motion. The effective coupling between the rotating capstan mass and the recorder frame is quite small and the applied angular rotation is directly converted into tape speed error or flutter. High mass vehicular recorders at one automotive proving ground have actually produced negative tape speeds when operated at 1 3/4 ips. Low mass high performance recorders with capstan tachometer speed control servo systems can conceivably buffer tape speed from rotational effects occurring at rates below the cut-off frequency of the control loop. Unlike off-tape servo speed control, these capstan tachometer driven systems perform during the record operation and if successful result in a low flutter recording.

More conventional shake tests take the form of sinusoidal sweep frequency testing in each of the three major axes. The applied shaker force is translational and angular rotation is not introduced. Although not as severe in some respects as rotation, the translational testing can provide a means for detecting resonances in the tape path components and the drive system. Continued shaking at the resonating frequency usually provides revealing results.

During the shake test, a signal must be recorded which will document the change in flutter performance. The signal may be unique such as a 500 kbps PCM wavetrain near a noise threshold or it may be a relatively simple unmodulated carrier frequency which will become flutter contaminated. Reproduction and analysis is best performed on a separate low flutter tape system in order to prevent masking the flutter resulting from the record run. If an instantaneous readout of flutter is required during the vibration test the above signal processing may be reversed by reproducing a pre-recorded low flutter test signal.

The analysis of the vibration affect on flutter can take several forms depending on the nature of the test signal. If an unmodulated carrier has been selected as the test signal reproduction through an FM discriminator is indicated. The discriminator bandwidth should be at least as broad as the highest shaker frequency and ideally it should be equal to the bandwidth of the intended application. In addition to a single broadband cumulative flutter measurement, narrow band filters should be employed in order to detect narrow band resonances.

An example of narrow band resonance resulting
in increased flutter is shown in Figure 4. These direct-write oscillograms resulted from vibration tests on an airborne recorder subjected to translational sweep frequency shaking. During vibration, an unmodulated carrier was recorded at a frequency of 100 kcps. A separate laboratory recorder was employed for reproduction followed by a conventional FM discriminator. The discriminator output was filtered and displayed on a direct-write recorder. Shaker frequency was slowly swept from 20 to 500 cps at a constant G level. The narrow band oscillogram shows a clear resonance occurring between 40 and 50 cps while the broad band oscillogram, plotted simultaneously from the same discriminator without a narrow band filter, almost completely disguises the severe resonance. Hence, even a partial spectral analysis can reveal the details of a flutter resonance. Notice that the peak flutter magnitude occurs a few cycles before the resonance zero beat.

**Group Delay Distortion**

Group delay distortion or envelope delay variation are synonymous terms describing phase response versus frequency. Both terms have made recent appearances in manufacturer reports as well as the new IRIG Document 106-65. Most references to delay characteristics have been limited to 1.5 mcps systems designed for predetection recording. An occasional delay specification will appear for instrumentation recorders used for PCM data recording from high quality phone lines.

Before predetection telemetry recording "phase equalized" reproduce electronics were common but quantitative performance data was difficult to obtain. The common test procedure, still in wide use, is to record a high quality square wave at approximately 1/10th bandwidth or a lone rectangular pulse and measure the overshoot and ringing on playback. These techniques are used because conventional phase response measurements requiring simultaneous input/output phase comparisons are difficult when a storage medium with time delay is involved.

Predetection recording of extremely wideband carrier spectrums precipitated the need for specific information regarding delay variation. The typical predetection recording signal consists of a translated 900 kcps carrier with AM, FM or PM sidebands sometimes extending out as far as ±500 kcps. Ideally, the recorded and reproduced sideband spectrum is an exact duplicate of the originally received RF signal, having been down converted to the frequency range of a 1.5 mcps recorder. If sidebands in the recorded spectrum are subjected to unequal time delays, the baseband or video information will be distorted. Because the degree of precision in phase equalization depends largely upon the reproduce equalizer design, it is likely that competitive systems will not display equivalent delay performances. In order to evaluate which equipment will cause minimum delay introduced distortion of predetection signals, a direct measurement of group delay is indicated.

A Group Delay and Loss Distortion Test Set of foreign manufacture is available through local representatives. Approximately ten of these equipments are in use in this country by recorder users and manufacturers. The problem of input/output circuit separation was considered in the test set design which was oriented toward long distance transmission circuits. The device consists of a complex signal generator and companion receiver. The generated signal is a time division multiplex of two carrier signals. For one half cycle a reference frequency serves as carrier while a test frequency becomes the carrier during the last half cycle. Both carrier frequencies are amplitude modulated by the same "split frequency" of 20 kcps whose instantaneous phase angle is not altered during transitions between carriers. The device under test will pass the time division multiplex signal and introduce a sudden phase discontinuity of the 20 kcps split frequency equal to the delay difference between the reference and test carriers. The test frequency may be swept through a band while the reference frequency remains constant. The split frequency is small enough to prevent gross inequality of delay between the upper and lower 20 kcps sidebands of the carriers.

The receiving device has the capability of converting the sharp phase discontinuity of the split frequency into an error voltage. The test set is automated and can be programmed to sweep through a test frequency band from 100 kcps to 14 mcps at rates between 0.7 and 14 mcps per second. In the sweep mode, the meter indication is replaced by a companion oscilloscope which displays the delay versus frequency curve. The same test set yields the attenuation versus frequency curve on a subsequent sweep without need for repositioning controls or repeating the recording operation.

Figures 5 and 6 display the delay and loss curves resulting from two different 1.5 mcps tape channels. Figure 5 shows a channel which displays excellent attenuation characteristics but unfortunately also displays a severe 500 nanosecond peak in the delay curve near 1.5 mcps. In Figure 6 the attenuation curve has been compromised at approximately -2 db at 1.5 mcps and the delay curve is essentially free of the severe peak. Through the joint delay/attenuation measurements, it is clearly seen that interaction exists between the equalizer adjustment effect on delay and attenuation response for the subject recorder.

Summarizing specific test set findings and recommendations:

1. Inflection points in the attenuation curve occur near the same frequency as inflection points in the delay curve. The number of inflection
points in the two curves appear in equal number.

2. The smoother the attenuation curve roll-off near the upper band edge, the less the accompanying delay variation.

3. Instantaneous delay and loss jitter on the oscilloscope presentations are attributed to head-to-oxide coupling variations and noise. Therefore, they are not considered as valid components of the group measurements.

4. The disadvantages of the test set are cost and low end frequency limitation to 100 kcps.

5. Where the volume of 1.5 mcps measurements warrant the expenditure of approximately $20,000, the subject test set fulfills the requirements. The cost might be reduced to the value of the receiving equipment alone if a suitable tape recording is available containing the complex test signals.

Oxide Ratings and Biasing Techniques

Ten and fifteen years ago the shortest wavelengths being recorded at telemetry sites were greater than 0.6 mils and the type of magnetic tape and the biasing technique used were not major considerations. Head life and tape wear were not generally considered as operational or reliability problems. Compatibility problems between cross-playing of tapes was limited to minor difficulty as bandwidths were jointly fixed at 100 kcps and below by the 0.6 mil wavelength and 60 ips maximum tape speed.

With the steady increase in recording density up to and beyond 0.08 mils, the role of the tape oxide formulation has increased in importance and Federal Specification W-T-0070 (Navy-Ships) currently recognizes 4 distinct oxide ratings. These ratings have been recently indirectly reflected in the new IRIG Document 106-65 (July 1965 Revision) which lists three distinct recorder classifications based on wavelength/bandwidth capability. Tabulating recorders and matching oxides provide an indication of the most common applications:

<table>
<thead>
<tr>
<th>Application Wavelength/Bandwidth</th>
<th>IRIG Recorder Designation</th>
<th>Federal Oxide Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6 mils/100kcps</td>
<td>Low Band</td>
<td>A, B</td>
</tr>
<tr>
<td>0.24 mils/500kcps</td>
<td>Intermediate Band</td>
<td>B, D</td>
</tr>
<tr>
<td>0.08 mils/1.5 mcps</td>
<td>Wide Band</td>
<td>D, E</td>
</tr>
</tbody>
</table>

The choice of tape oxide for a given application is sometimes arbitrary and reflects the possibility of using more than one oxide for each entry listed. Tape cost, future crossplay requirements and other considerations should be evaluated in the oxide selection. The current cost ratio between oxide grades is approximately 1.3 to 1 for both B to A and E to B. Hence, A oxide tape is recommended for 100 kcps/60 ips applications unless it is known the same tape will be used with an intermediate band recorder.

The 1.5 mcps wideband recorders require the D and E oxide tapes if they are to meet bandwidth, noise and distortion specifications. The following wavelength sensitivity comparison between oxides, taken directly from one supplier's catalog, shows the major performance distinction:

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Wavelength Sensitivity, DB, Relative to 10 mils</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 mil</td>
<td>Std. A B D E</td>
</tr>
<tr>
<td>1</td>
<td>0 0 0 0 +1.5 +1</td>
</tr>
<tr>
<td>1/2</td>
<td>0 0 +2 +3 +2.5</td>
</tr>
<tr>
<td>1/4</td>
<td>0 0 +3 +4 +5</td>
</tr>
<tr>
<td>1/8</td>
<td>- - +6 +9</td>
</tr>
<tr>
<td>1/12</td>
<td>- - - +12</td>
</tr>
</tbody>
</table>

NOTES:

1. The above wavelength sensitivities are all normalized to the 10 mil sensitivity of the given oxide in order to present only variation of sensitivity versus wavelength.

2. The above sensitivities are catalog listed relative to the response of a "standard" tape in order to provide data independent of the recorder/reproducer used for measurement.

A cursory examination of oxide classification would be incomplete without brief discussion of relative output differences between oxides. The differences in maximum output measured at long wavelength are greatly dependent upon the recorder/reproducer bias frequency, head characteristics, etc. For this reason, it is advisable to become familiar with oxide output characteristics when measured on both a low band and wide band recorder:

<table>
<thead>
<tr>
<th>Recorder Classification</th>
<th>DB Output, at 1% Distortion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Band, at 7.5 mils</td>
<td>Std. A B D E</td>
</tr>
<tr>
<td>Wide Band, at 10 mils</td>
<td>0 0 +1 +3 +4.5</td>
</tr>
</tbody>
</table>

NOTES:

1. All outputs are referenced to the standard tape output.

2. The source of the Low Band output relationships is Federal Specification 0070/4 and 5.

3. The source of the Wide Band output relationships is a supplier's catalog. This is the explanation of the two different long wavelength output characteristics of the E oxide tape rests on two points:

1. E oxide tapes are thin coated tapes, usually less than 200 microinches.
2. Wide band recording heads and high bias frequencies do not penetrate the oxide as deeply as low band heads.

Because relative output measurements are normalized to 1% distortion, it follows that the thicker coated tapes (A, B, and D) will be higher output tapes only when tested on a low band recorder which can penetrate their full depth. This advantage is lost when testing is performed on a 1.5 mcpps system which does not penetrate to the full depth of the thick coated tapes. In this type of test, the oxide formulation of the high density E oxide tape results in greater output because more magnetic particles are contained in a given area.

Bias level adjust techniques have also been changed over the last several years and current practices are reflected in IRIG Document 106-65. The past technique of maximizing a 1/5th upper band edge frequency has been replaced by using a bias set frequency at the upper band edge coupled with a bias level greater than that which yields maximum output. After reaching maximum output, the bias current is further increased until the output drops 3 db for low and intermediate band systems and 1 db for wide band systems. Experimental results justify the "overbias" technique on the basis of greater dynamic range for 1% distortion.

Examination of Figures 7, 8 and 9 show results of tests performed on a B oxide tape with an intermediate band recorder which support the 3 db overbias technique. First, from Figure 7 observe the slope of the 250 kcps output curve versus bias level. The output falls off rapidly after maximum output at 9 milliamps of bias while the lower frequency curves have slopes which change little beyond 9 milliamps. Hence the upper band edge frequency is better suited for bias level adjusting as it is a more sensitive indicator. Secondly, from Figures 8 and 9 note the difference in input level at which the crossover occurs between the output fundamental and output third harmonic (the crossover point corresponds to 1% third order distortion). Translating the distortion improvement seen with 13.5 milliamps versus the 9 milliamps into a higher record level results in a rise of 3 db, from -1 to +2 db. Hence the record level for all frequencies is 3 db higher. Thirdly, the absolute off tape output at 1000 cps and +2 db input has risen 2 1/2 db, from +38 to +35.5 db. Finally, because the noise level has essentially remained constant (rising 1/2 db from 9 to 13.5 milliamps of bias) the net change of 3 1/2 db overbias of a 250 kcps frequency is a 5 1/2 db improvement at 1000 cps and a loss of only 1/2 db at the high band edge. The apparent loss from 3 1/2 db overbias is more than offset by the improvement in linearity resulting in increased broadband dynamic range without exceeding the 1% distortion limit.

Cross Correlation of Multitrack Flutter

Virtually no information exists concerning the coherence of the flutter spectrum between tracks of a multitrack recorder. Several existing and planned applications would benefit by data derived from cross correllograms of multitrack flutter characteristics. Correlation measuring devices are beginning to become common and may be advantageously used to promote a better understanding of flutter.

Cross correlation techniques may offer a method of separating dynamic skew and "differential flutter". Differential flutter is a term usually seen mentioned simultaneously with dynamic skew and jointly expressed in units of time. The implication is that opposite edges of the tape are experiencing different vertical flutter. If differential flutter as such does exist and if the tape does not stretch the net result is a dynamic skew and time error between tracks. Time errors from differential flutter would appear as an inseparable component along with dynamic skew, usually considered as arising from the dynamic weaving occurring in the plane of ideal tape motion. It seems reasonable to expect dynamic skew to exist instantaneously as a "lead" on one edge and a "lag" on the opposite edge of the tape. Also, because dynamic skew magnitude increases linearly across the width of the tape, we expect a high degree of correlation. Therefore dynamic skew should have a high degree of negative correlation between outside tracks.

Extensive use of single carrier FM recording occurs in ground based environmental testing facilities. The use of electronic flutter compensation is found particularly where low tape speeds are employed. The standard technique consists of using one track solely for accommodating an unmodulated reference signal which provides the flutter compensation signal on playback. Since a single error signal is used in common by all FM data tracks the resulting improvement depends directly upon how well the error signal matches the flutter spectrum of the individual tracks. If an outside data track has little flutter resemblance or time/amplitude coherence to the center reference track improvement on the outside track will be slight. This requirement for coherence does not usually exist in FM telemetry subcarrier systems or in constant bandwidth FM systems because each tape track multiplex contains a separate reference signal added before recording.

A multitrack recorder application under current study at the Eastern Test Range concerns wideband tape combining to very small timing tolerances. A slave recorder is synchronized to a master recorder to within less than a microsecond by a device which actually compensates for the flutter of the slave recorder. The coherence of flutter between tracks could play an important part in the detailed design of a multitrack tape combiner system. On a limited single track basis two separate tapes containing the same pre-detection signals have been successfully brought into phase agreement and coherently combined for the duration of a 12 minute period. Since final combining takes place at a carrier frequency of 10 mcpps, the time correlation must be considerably
better than the carrier period of 100 nanoseconds. If the flutter and associated dynamic time base errors are coherent between tracks, the simultaneous combining of a 7 track system might incorporate common coarse error sensing and control circuitry. If coherence does not exist, a separate flutter control system is indicated for each track.

Summary

The broad family of instrumentation recorder/reproducers has been classified according to bandwidth, operational environment and major field of application. Several fundamental differences between recorder classes have been outlined and analyzed from procurement specification and performance testing considerations.

The high tape speed, short wavelength megacycle recorders are shown to be uniquely demanding when specifying and testing head life, tape life, envelope delay distortion and other characteristics. The difficulty of testing multichannel, multispeed systems is recognized as time consuming and expensive when utilizing manual antiquated techniques. Automated testing is suggested as the inevitable solution to the problem of obtaining more repeatable test results in greater volume at less total cost.

Several unique specifications, relatively new to the recorder/reproducer industry, have been acknowledged and have been traced to the applications responsible for their introduction. Specifically:

1. Reproduce Servo Time Base Error requirements have become important in facsimile, tape combining and other data handover applications.

2. Flutter specifications and measurements during vibration are being forced by more vehicular acquisition applications.

3. Narrow bandwidth and frequency multiplex recording applications are requiring specification of noise spectrum distribution characteristics and modulation noise measurements.

4. Envelope delay distortion measurement has been made necessary by extremely broad banded pre-detection applications.

5. Head and tape life specifications have been necessitated by higher tape speeds, sharper heads, greater tape tension and more expensive heads and tapes.

6. Tape oxide ratings have been designated by Federal Specification in recognition of the interrelationship between oxide short wavelength response and recorder application.

Modular amplifier interchangeability in megacycle recorders has been shown to be a cause of performance degradation when indiscriminately intermixing modules without resetting of bias and equalization adjustments. Improvement is necessary in specifying acceptable interchangeability criteria until the uniformity of megacycle heads is perfected. Better means for establishing the original and remaining head life hours are suggested coupled with a more scientific determination for realignment requirement as a function of head wear.

Several new tests and testing techniques have been presented. Four tests, all eliminating the conventional logging of data by human hand, are presented as indicative of future testing trends:

Reproduce TBE. Reproduce tape speed Time Base Error and calibration grids are automatically plotted on a film strip camera for an entire tape reel.

Modulation Noise. Unwanted AM and FM noise sideband amplitudes are plotted as a function of the separation frequency from a discreet recorded frequency.

Amplitude vs. Frequency Response. Swept frequency generators used in conjunction with a direct-write recorder yield frequency response curves directly and economically.

Delay Distortion. Envelope delay distortion data has been presented, obtained from a special test set capable of performing the measurement in spite of the delay time between record and reproduce functions. Additional techniques are discussed which can be performed more economically.

Magnetic tape has been discussed with particular emphasis on megacycle recorders at 120 ips. The previous practice of using any available tape of the correct width, successful with 100 kcps applications at tape speeds of 60 ips, is not recommended. Crossplaying of tapes from recorder to recorder and alternate use of different types of tape must be approached with caution if degradation is to be minimized. The over biasing of high resolution tapes, although seemingly destroying the high frequency response, actually permits better broadband signal-to-noise without bandwidth loss. Ideally, the bias technique should be designed for the given recording application.

The present day instrumentation tape recorder/reproducer is a complex multichannel, multimode system. The megacycle bandwidth capability has pointedly publicized the interrelationship between the magnetic recording medium and the recorder/reproducer system. Specifying the desired performance and testing for compliance is not a simple task. Those who believe procurement specifications for recorders can be obtained directly from printed brochures, and who believe all magnetic tapes are equivalent, and who do not plan carefully for astute performance testing, cannot be assured of a successful system.
References


10. Minnesota Mining and Manufacturing Company, Bulletins:

   M-IPMP-11(13.5)R Type 850,"A" Oxide  
   Type 860,"B" Oxide  
   M-IPMP-7a(721)K Type 999,"D" Oxide  
   M-IPMP-12A(34.2)R Type 951,"E" Oxide
Fig. 1 FREQUENCY RESPONSE VS. REPRODUCE MODULE INTERCHANGEABILITY
FIG. 2   TIME BASE ERROR
Tape Speed: 30 ips
FM Recording Mode
54 kcps carrier frequency
Deviation: ± 40%
6200-cps Signal
Spectral Resolution: 10 cps

Fig. 3 FM MODULATION NOISE SPECTRUM
Flutter Amplitude Vs. Vibration Frequency
Tape Speed: 120 ips
Vibration Amplitude: 1 G P-P
Vibration Frequency: 40 to 50 cps, linear sweep

Fig. 4 VIBRATION INDUCED FLUTTER
Tape Speed: 120 ips
Loss Scale: 0.2 db/small division
Delay Scale: 100 ns/small division
Frequency Scale: 150 kc/division beginning at 100 kc

Fig. 5 TRACK A

Fig. 6 TRACK B

Figs. 5 and 6 GROUP DELAY AND LOSS VS FREQUENCY
Tape Speed: 60 ips
Test Frequencies: 1, 5, 20, 80 and 250 kc
Bias Current: 1.5 to 15 ma 10 equal steps
Tape Type: B oxide

Fig. 7 UNEQUALIZED PLAYBACK LEVEL VS. BIAS LEVEL
Bias Level: 9.0 ma, adjusted for maximum 250-kc output
Frequency: 1000 cps
Tape Speed: 60 ips
Tape Type: B Oxide
Record Level: -6 to +12 db of normal record level, in ten 2-db steps

Fig. 8 FIRST AND THIRD HARMONIC OUTPUT VS. RECORD LEVEL
Bias Level: 13.5 ma, 3.5 db overbias at 250 kc
Frequency: 1000 cps
Tape Speed: 60 ips
Tape Type: B Oxide
Record Level: -6 to +12 db of normal record level, in ten 2-db steps

Fig. 9 FIRST AND THIRD HARMONIC OUTPUT VS. RECORD LEVEL