COMPATIBILITY REQUIREMENTS AND CONSIDERATIONS OF RANGE TELEMETRY TAPE

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Summary Range Telemetry Tape crossplay operations may be arranged into four major classes each with unique compatibility considerations:

a. Between like recorders at the same Range.
b. Between unlike recorders at the same Range.
c. Between unlike recorders at different Ranges.
d. Between unlike recorders at Range User facilities and the Ranges.

Like model recorders at the same Range are more likely compatible and capable of optimum tape crossplay than any other combination. Sometimes this very fact produces an atmosphere of complacency which can invite problems. The assumption that the recorder manufacturer has properly controlled his production for optimum crossplay or for complete conformance to IRIG[1] is naive and should not be a substitute for compatibility testing at the using Range facility. With field use and equipment aging, compatibility can be gradually lost without becoming detected. Adjustment procedures at one' site may not be identical to procedures at other sites and perfectly compatible equipments can unknowingly become incompatible. The absence of adequate compatibility testing is the major cause of difficulty with this class of crossplay.

Crossplay between unlike model recorders at the same Range poses unique problems but these can be controlled providing the unlike recorders have individually been strictly specified and tested to conform to IRIG Standards. Compatibility testing by the using Range is a definite requirement as manufactures may differ in their interpretation of the IRIG Document or may differ in the extent to which they conform. No manufacturer appears to be knowledgeable regarding crossplay between competitive recorders, and some appear to be just as uncertain about compatibility between complimenting recorders from their own product line.

Crossplay between unlike recorders at different Ranges is being accomplished but many factors stand in the way of automatic success for this type of venture. When different

equipments, different tape types, different operational procedures, and different procurement specifications all combine, the compatibility of the whole system is strained. The possibility of different tape types specified by competing equipment manufacturers should produce cautious awareness by the user and compatibility testing with both tapes should be conducted. The question “Which Range is responsible for the incompatibility?” can be difficult to answer. Currently, no central agency exercises control over Range-to-Range crossplay compatibility, and each Range conforms to IRIG Standards on an individual basis.

Crossplay between unlike reproducers at Range User facilities and Range copy recorders is probably the most severe test of compatibility that exists. In this type of crossplay IRIG Standards may not have been invoked by the Range User, different bandwidth classes of systems may be involved and the fact that the User, and the Range may be virtually strangers all promote an environment unconducive to compatibility. Anything that can possibly go awry usually does. The major responsibility must lie with the Range who supplies the original or copy tapes to the Users. Ideally, the copy tapes should all be generated identically regardless of individual recipient requirements, and the IRIG Standards should be religiously followed:

Compatibility Requirements Crossplay compatibility of recorded Range telemetry tapes is required for successful two-way exchange of “live” telemetry signals between the Ranges responsible for reducing the data. Although the bulk of the exchange is from Range to User, the exchange in the opposite direction should not be ignored. Simulation tapes of new and future planned telemetry formats, supplied by the Range Users to the Ranges is an excellent insurance technique for determining the support capability of the Ranges.

As used above, our definition of a successful two-way exchange of tapes is an exchange in which no degradation -of data quality occurs because of the crossplay with each of the participating tape systems configured to IRIG Standards with its own mechanical and electrical alignments and adjustments. Recorded tapes and reproducers which cannot provide non-degraded crossplay performance, unless the reproducer is aligned especially for that tape, are not compatible by this definition. This seemingly arbitrary definition is based on the daily press of workload which does not permit the luxury of customized alignment. More likely all alien tapes will be played with the same alignment as the locally generated tapes and the degradation in data quality is the price paid when compatibility is absent.

The various types of crossplay which are possible, listed in ascending order of difficulty, are:

a. Crossplay between like recorders and reproducers at the same Range.

b. Crossplay between unlike recorders and reproducers at the same Range.
c. Crossplay between unlike recorders and reproducers at different Ranges.
d. Crossplay between unlike recorders and reproducers at Range User facilities and the Ranges.

As used above, the definition of like recorders and reproducers are recorders and reproducers of identical model number designation with identical bandwidth/speed characteristics. The definition of unlike is a recorder and reproducer of different model number but with common bandwidth/speed characteristics.

All four types of crossplay listed above occur with penalizing frequency and all are necessary requirements imposed by the Range, Range User exchange interface. A fifth and far more difficult type of crossplay was purposely omitted from the above list because of its controversial nature and supposedly infrequent usage:

e. Crossplay between unlike recorders and reproducers of different bandwidth/speed characteristics.

This type of crossplay is briefly addressed in the following discussion.

As the operation of the Test Ranges has become more sophisticated, the requirement for specifying the specific commitment level for a given mission as accurately as possible has appeared. In arriving at the level to which a Range will commit itself, the question of what crossplay loss might be present in the delivered tape should be asked. Although the crossplay loss is normally not a pacing factor, the only sure guarantee to this end is an adequate program of compatibility assurance including adequate testing.

Throughout the remainder of this paper individual problems will be presented with direct connection made to the crossplay types most likely affected.

Type a. -Crossplay Problems Although crossplay problems between like recorders and reproducers operated by one crew at one Range are easily remedied, they deserve important consideration because of their subtleness. All too often this arrangement leads to complacency on the part of the individuals responsible who may incorrectly assume the original manufacturer has obviously provided crossplay interchangeability because his advertising claimed full compliance with IRIG Standards.

The manufacturer's QC efforts are more important in ensuring IRIG conformance and, hence, crossplay between his own recorders than his printed claims. As recently as April this year, a leading manufacturer delivered a 14 track one inch IRIG system for evaluation testing in which two tracks contained a reversal of head winding connections resulting in inversion of the output signal polarity. His embarrassment was no substitute

for failing to provide a complete IRIG-based QC on this sytem and gave rise to the question- -What other IRIG requirements were absent from his QC inspections? Although FM carrier recording is immune from this type of polarity reversal, Direct Mode recording of NRZ-L wavetrain data is an example of an operation that cannot tolerate polarity inversion.

Signal loss from individual head track gap azimuth misalignment is a compatibility characteristic which results in degraded amplitude response crossplay performance when the head assembly construction does not meet certain uniformity tolerances. A single adjustable head azimuth control for each multi-track head stack is not a sufficient answer to a head assembly which contains nonuniform individual track azimuths. Even though the range of azimuth adjustment is sufficient to permit optimizing each track one at a time, the multi-track simultaneous operation during tape copying requires that all tracks be as near optimum as possible with one common azimuth adjustment. Head manufacturers are reluctant to specify head gap azimuth misalignment signal loss under these tape copying conditions, i.e., one azimuth adjustment. This loss is related to the angle of mis-alignment by the following expression:

$$\text{dB Azimuth Alignment Loss} = 20 \log \frac{\pi w \theta / \lambda}{\sin(\pi w \theta / \lambda)}$$

where w = width of track in mils

θ = mis-alignment angle between record and reproduce gaps in radians.

λ = recorded wavelength in mils

At 1.5 MHz and 120 ips a mis-alignment between record an reproduce head of 1.3 minutes of arc will result in a 0.8 dB loss. A mis-alignment of 2.6 minutes of arc will result in a 3.5 dB loss. Most head manufacturers are able to produce pairs of multi-track heads with alignment loss somewhere between these values, but users should be alert to the absence of this constraint in the IRIG Document, which only addresses mean gap azimuth alignment tolerance.

A third problem in this type of crossplay deals with the track-to-track uniformity of record amplifier transfer function and record level of multi-track IRIG systems. Although the IRIG Document recognizes recording standards and standard tests for these two parameters, track-to-track nonuniformity of the heads and non-uniformity of the associated record amplifiers prevents all tracks from being uniformly recorded. Track-to-track recorded uniformity is not just a desirable goal that will provide for easier operation through modular interchangeability but it is a fundamental requirement for successful crossplay. The greater the recorded non-uniformity between the tracks of a multi-track recording the greater will be the crossplay degradation upon an alien reproducer whose alignment has been performed without consideration of the recorded non-uniformity. Accordingly, the crossplay success can be no better than the recorded

tapes track-to-track uniformity. An adequate test for proper record amplifier transfer function (or amplitude vs. frequency response) is contained in the IRIG Document but requires a multi-speed system capability of 8 to I for implementation. Single speed recorders require additional attention and testing for this possible crossplay problem. The closely related uniformity of phase vs. frequency characteristics of multi-track recording has never been addressed in any standard and remains essentially an unknown compatibility commodity.

An example of non-uniformity of record level is indicated by the following results obtained by crossplaying a tape between two supposedly identical model 14 track recorders. Both recorders were adjusted identically with the same test equipment for record bias and signal current levels, per IRIG 106-66. The output levels of the first record/reproducer were locked at 0 dBm output for the reference set frequency recorded at the normal level of 1% third harmonic distortion. The same tape, identically recorded by the second recorder, was crossplayed on the first recorder/ reproducer and the following output levels and distortions observed without chan in out ut levels:

Output	Dist. (3rd Harm.)	Output	Dist. (3rd Harm.)
0 dB	-40 1/2 dB	0 dB	-41.5 dB
-2 1/2	-41	+4	-37
-4 1/4	-44 3/4	+4 1/4	-37 3/4
-6 1/2	-46	+ 1/4	-45 1/4
-3 3/4	-43 1/4	+ 3/4	-43 3/4
-3 1/2	-43 1/2	- 1/4	-41 1/4

Obviously, the associated tracks from two recordings were far from recorded at the same level. The suspected causes of this difference are the unequal head/amplifier amplitude response between the fundamental and the third harmonic signals between tracks and the unequal contribution of third harmonic distortion from the heads and amplifiers.

Type a. -Problem Solutions The four above mentioned problems of non-uniform polarity, azimuth alignment, record level and transfer function should all be controlled in order to provide optimum crossplay. Very often, even between like recorder/reproducers of the same model, these parameters escape factory QC and adequate acceptance testing. Even if only one recorder/reproducer is involved there need not be an excuse for abandoning acceptance testing for crossplay compatibility. All four of these parameters can be reasonably tested for recorded uniformity (and hence, crossplay compatibility with like recorders) by reproducing a recorded test tape in the reverse direction so that the recorded tracks are reproduced by a different reproduce head and amplifier, i.e., 1 by 7, 2 by 6, etc. Within reasonable limits, this reverse test is equivalent to crossplay on a different reproducer and previously neutralizing characteristics between record and reproduce head and amplifiers will be exposed in their non-uniformity.

One example of the revealing results obtainable by the simple reverse play technique has been recently published.[2] The particular parameter under investigation was the phase vs. frequency characteristic of a recorder/reproducer system, as depicted by the change of shape of a Direct recorded square wave. In the forward direction of tape motion the reproduce equalization was set for optimum and essentially no phase difference appeared between the fundamental and the third harmonic of the square wave. By reversing the playback direction of the recorded tape without changing the playback equalization a significant phase difference between the fundamental and the third harmonic resulted, i.e., approximately 180 degrees. This discrepancy can be attributed to one or both of two causes:

a. Phase shift in the tape itself.
b. Phase shift in the record amplifier prior to the tape.

In either event the recorded signals phase integrity was not the same as the original input signal and therefore represents a potential crossplay problem. The fact that the reproduce equalizer can provide satisfactory performance in the forward direction is desirable but all indications are that a tape produced on another recorder would demand a different equalization. A better situation would be the incorporation of a selective phase shifting network in the record amplifier of sufficient amount that would permit recording square waves without phase shift such that playback in either direction would produce identical output results with the same playback equalization.

Type b. -Crossplay Problems One of the most pursued, but rarely achieved, compatibility goals is the maintaining of a flat amplitude vs. frequency response between unlike recorders without destroying the individual recorder's response compatibility with itself. To successfully accomplish this obviously desirable goal with brute force strategy requires strict conformance to a standard record transfer function, achievable by (1) a record amplifier pre-emphasis curve of the correct values, (2) a standard overbias loss, and (3) a correct record head azimuth. If all of these items are dutifully controlled the possibility of success in achieving a crossplay bandflatness to ±3 dB exists.

The definition of a few terms must be established before a discussion can be totally beneficial.

Record Transfer Function: The net variation in magnitude of the signal flux recorded on the tape, as a function of the frequency and wavelength being recorded while maintaining a constant input level considering all sources of variation.

Record Pre-emphasis: The designed increase in record amplifier amplitude response beginning at midband or below and reaching a maximum at the upper bandedge

frequency required to just offset the frequency dependent record head eddy current, hysteresis and other core losses.

Standard Overbias Loss: The loss of equality in recorded signal flux level across the recorded band of wavelengths caused by the overbiasing technique of the high bandedge frequencies.

It is important to appreciate that certain of the above effects are wavelength dependent while others are frequency dependent, because of the difference of their impact on multi-speed recording transfer functions.

For more than five years, the IRIG Document has recognized a preemphasized record amplifier requirement in order to prevent record heads with different degrees of loss from reflecting those unique losses in the recorded tapes they generate. The verification that these unique frequency dependent losses have been adequately neutralized by pre-emphasis circuits is easily demonstrated using the previously cited IRIG 8 to 1 test procedure. When this desirable condition is achieved, and assuming no other losses for the moment, it is correct to describe the result as a constant flux record transfer function. This contracts to, and is not compatible with the earlier constant current record transfer functions coupled with a lossy record head.

However, the introduction of the IRIG overbiasing technique several years later introduced once again a loss of recorded flux levels at short wavelengths compared to the recorded levels at the long wavelengths, exactly the same type of error in record transfer function found undesirable in constant current recording.

At first this realization gives rise to a rather skeptical feeling about the wisdom of the IRIG overbiasing recommendation, but a close look at the end results are reassuring. These man-made overbias losses are at least 3 dB with the low and intermediate band systems and 1 dB with the wideband system, i.e., the values of the overbias settings specified in IRIG. Actually, a swept frequency signal generator will clearly show that the net effect of a 3 dB overbias between the high and low bandedge frequencies is about 6 dB because the low frequencies have not yet reached their biasing peak. Hence, these man-made losses are a pproximately 6 dB on low/intermediate band systems and 3 dB on Wideband systems respectively, sizable losses which should not be discounted. Fortunately, the overbias loss is better behaved than the previously discussed record head losses because it is identical in dB loss in all record systems regardless of manufacturer providing the tape is the same, the amount of overbias value is the same, and saturation is not occurring in the record heads or record electronics. The end result is a standard amount of man-made wavelength dependent loss which is duplicated at all speeds on all IRIG adjusted equipments, even though a <u>true</u> constant flux record transfer

function has been destroyed in the process. Crossplay between equipments and speeds has in no way been impaired. These general relationships are shown in Figure 1.

At this point it may occur to the reader to ask “Since pre-emphasis is successfully used in combating record head core losses could it not be equally successful in recovering the man-made overbias losses thus reestablishing a true constant flux record transfer function?” The answer is theoretically yes, but the practical implications are costly and would require a different pre-emphasis curve for each speed because the overbias loss, unlike the record head core losses, are wavelength dependent. Such a system would have one advantage which is not immediately obvious, i.e., it would help to remove the current IRIG recognized limitation of crossplaying low, intermediate and wideband tapes because true constant flux recording would be produced. In other words, the current limitation on crossplaying tapes from different bandwidth systems is the man-made differences arising out of different overbiasing losses.

Figure 2 graphically displays the general lack of compatibility between different bandwidth systems arising out of the IRIG overbiasing losses. Figures 3, 4 and 5 present actual measured crossplay results between several recorders at the Eastern Test Range.

It is unfortunate that these compatibility aspects were not clearly realized during the introduction of overbiasing. Although certain segments in the industry were uncertain at that time about the wisdom of overbiasing they were not able to specifically cite this disadvantage. The end resulting man-made mismatch between low, intermediate and wideband systems is not to be discounted. Expressed in common terms or rather a common frequency, the dB overbias record transfer function difference of the three different systems equated to low band terms, i.e., 100 kHz at 60 ips is -6 dB, -2 dB and 0 dB for low, intermediate and wideband respectively.

If one or both of the unlike recorders incorporates an adjustable record head azimuth an additional problem area exists which is not immediately obvious. Just because the record head’s azimuth error is within the range of the reproduce head’s azimuth adjustment, caution should not be abandoned. One specific problem has occurred when crossplaying tapes recorded with rounded profile heads with an azimuth error of about Z minutes of arc. Playback was attempted on a reproducer with a sharp pointed profile head with the reproduce heads optimized, i.e., maximum output at short wavelength. A persistent 5 dB loss of high frequency response always resulted but crossplay in the reverse direction was excellent. Success in both directions was finally achieved after the adjustable record heads of the first recorder were made to agree with the fixed record heads on the second recorder. The apparent explanation was that the rounded reproduce head excelled the sharp reproduce head in the ability to reproduce recordings with a sizable aximuth error, even with optimum alignment.

Type b.-Problem Solutions Successful crossplay between unlike model recorders of equal bandwidths at the same Range has been accomplished after considerable effort to produce the same record transfer function. If the following steps are followed success should be attained.

a. Use the same IRIG bias and record level adjust technique on both record systems.
b. Verify that the record amplifier pre-emphasis value is correct using the IRIG 8:1 test.
c. Verify that the record heads do not have incorrect azimuth alignments. (Reverse direction testing provides an adequate technique for this determination.)
d. Use the same type of tape to align both participating systems.

If successful crossplay between systems of different bandwidths is required, one of two techniques may be used.

a. Signal condition the input signal prior to the record amplifier to approximate the required change in record transfer function. (This usually consists of attenuating the upper bandedge signal spectrum being recorded on wideband systems for playback on low band systems.)
b. Remove the overbias loss difference between systems by using peak bias at the upper bandedge frequencies. (It should be recognized that this adjustment change produces a non-IRIG configuration.)

Type c. -Crossplay Problems Assume that two separate Ranges are equipped with unlike model 1.5 MHz recorder/reproducers. Also assume each responsible crew has achieved successful crossplay between all like recorders at their respective sites by giving proper attention to the items discussed in the previous sections. Can we then expect successful crossplay between these two Ranges? The answer is yes, but we should not expect success automatically without regard to a few possible problem areas.

One likely cause of unsuccessful crossplay between such sites is the possible difference in the response uniformity of the magnetic tape being used. Currently there are no industry-wide standards controlling short wavelength response uniformity of magnetic tapes below the ranges of 1/2 mil. Only the internal QC standards of individual tape manufacturers control this important performance parameter. One tape manufacturer has a production tolerance window of 6 dB (±3 dB about his process average reference tape) at 1/12th mil wavelength coupled with a tolerance window of 4 dB (±2 dB) at 1/2 mil wavelength and longer. Assuming for the moment that the two Ranges are operating from different delivery lots of the same type tape from this manufacturer, the worst case possibility could produce a 4 dB difference in output at low bandedge frequencies and a 6 dB difference in output at upper bandedge frequencies, even though both recorders are completely compatible with each other using identical tape. Even worse, the low

frequency difference could be opposite in direction to the high frequency difference so that the net effect could be a 10 dB between the high end output of these tapes after output levels are normalized near the low frequency bandedge (an IRIG recommendation). Notice that the tolerances selected by this tape manufacturer and his failure to normalize the response measurements tend to indicate his choice of tolerance bands was based on something other than customer crossplay considerations.

As if this were not enough, consider the ramifications of the two separated Ranges using different types of tapes from different suppliers. Recent tests indicate that a small, random sampling of wideband 1.5 MHz tapes from three different manufactures covered a 5 dB spread in output level difference at 1/12th mil wavelength, and a 3 dB spread at 1/2 mil wavelength. An inspection of a number of production lots from each manufacturer would more than probably have exceeded the 4 and 6 dB tolerance standards of the one manufacturer.

The complete lack of industry-wide standards in short wavelength response characteristics is one of the major limiting items preventing completely successful crossplay in wideband applications. Although it is not fully realized, the IRIG Document in no way addresses the compatibility problem arising from the non-uniformity of short wavelength response of magnetic tapes.

Non-uniform biasing requirements between tapes are also suspected of introducing lack of compatibility. The wavelength response of a given tape when measured by the tape manufacturer may not be biased per IRIG because of the enalizin affect of the short wavelength losses. Most manufacturers state their test condition as “optimum bias” without further elaboration. With the significant amount of overbias required by IRIG at the two lower bands of operation, the change of wavelength response of a given tape resulting from overbiasing may be completely different from the change of another tape. Manufacturers specification sheets depicting non-IRIG response performances may mean very little to a compatibility study.

Type c. -Problem Solutions Until a suitable industry standard is forthcoming the only alternative to improving the current situation is for the Ranges to adopt a standard response tape, to which each maintains uniformity when procuring tape. This could be easily satisfied through joint procurement from one supplier and then dividing the tape into two appropriate shipments for each site. Fortunately, experience shows that tape produced from the same lot of raw materials, in the same time period, and offered for delivery at one time, agrees in reel-to-reel uniformity much closer than the previously mentioned 4 and 6 dB windows. These broad tolerance limits are probably chosen for a year or longer production period. Both the wavelength response non-uniformities and biasing non-uniformities should be controlled as closely as possible by the tape manufacturer for all tape in one delivered lot. In the event the subsequent delivery of

tape 3, 6 or 12 months later has appreciably changed in uniformity, the crossplay compatibility can be retained by each Range recognizing this change and re-equalizing the involved recorder/reproducer systems.

Type d. -Crossplay Problems Crossplay between Range Users and Ranges is the most difficult class of crossplay to optimize because of the wide variation possible in equipments, tapes and procedures. Anything that can go wrong usually does.

An example of a recent problem illustrates the level to which care must be exercised. An illusive 1/2 millisecond timing error was repeatedly appearing during the reduction of telemetry tapes containing an IRIG B 100 pps/1000 Hz time code signal. After considerable effort it was discovered that the FM record amplifier used a deviation directionality opposite to that of the FM reproduce amplifier. This phase reversal resulted in a delay of 1/2 cycle of the 1000 Hz carrier in the playback time decoder, i.e., 1/2 millisecond. Although the solution was simple the detection task was diff icult.

In addition to FM carrier deviation directionality, the record level of wide-band FM carriers has been a problem area. In the absence of a specific recommendation by IRIG, one leading manufacturer records wideband FM carriers to approximately 9 dB above the 1% third harmonic level. Playback of these tapes on an unlike reproducer has revealed a previously unknown inability of the playback system. At approximately 4 to 5 dB above normal IRIG level the reproduce pre-amplifiers begin to oscillate, completely obscuring the data. Fortunately, reducing the gain of the pre-amp provided a simple solution, but the problem was not immediately detected and time was lost in data reduction which had to be repeated.

The subject of time base error, jitter and speed accuracy can become a compatibility problem. If a high performance reproduce tape speed servo system is available at the end point of production these problems can be quite easily solved. However, arriving at a mutually agreeable speed control reference frequency with the recording format for that frequency is not necessarily simple. Although IRIG specifies and limits the number of reference frequencies, it does not completely address the subject of recording format. If the crossplay must be performed without the benefit of a servo, the time base error performance between the acquisition recorder, the master/copy recorders and the final Range User reproducer will be hard to predict and a controlled test should be performed.

Type d. -Problem Solutions The only reliable technique for optimizing crossplay compatibility between Range and Range Users is to implement an adequate test program aimed at uncovering problem areas before they occur. Recorder/Reproducer system characteristics which are candidates for compatibility testing, listed in order of importance are:

a. Record transfer function.
b. Wavelength response of tape.
c. Head azimuth alignment.
d. Time base error.
e. Head polarity.
f. FM Record carrier deviation directionality.
g. FM Record carrier level.
h. Tape speed reference frequencies.
i. Track spacing, position and numbering.
j. Reel and hub dimensions.

The current IRIG Document 106-66, revised March, 1966, contains specific recommendations for all but two of the above parameters and if properly enforced, will prevent severe compatibility problems. However, no substitute exists for specific and detailed compatibility testing after equipment has been procured. In summary, a recommended plan for assuring compatibility of Range telemetry tapes should consist of at least the following four phases:

a. Invoke full IRIG Document conformance at the time of equipment specification.
b. Perform-adequate acceptance testing to insure complete IRIG conformance.
c. Perform adequate compatibility testing between equipments engaged in tape crossplay.
d. Standardize the wavelength response of the magnetic tape.

REFERENCES

1. Inter Range Instrumentation Group, Document 106-66, Amended July 1966.

2. Distortion in Wideband FM Magnetic Tape Recording Systems, Finn Jorgensen, Telemetry Journal, Apr/May 1968, Vol. 3, No. 3.

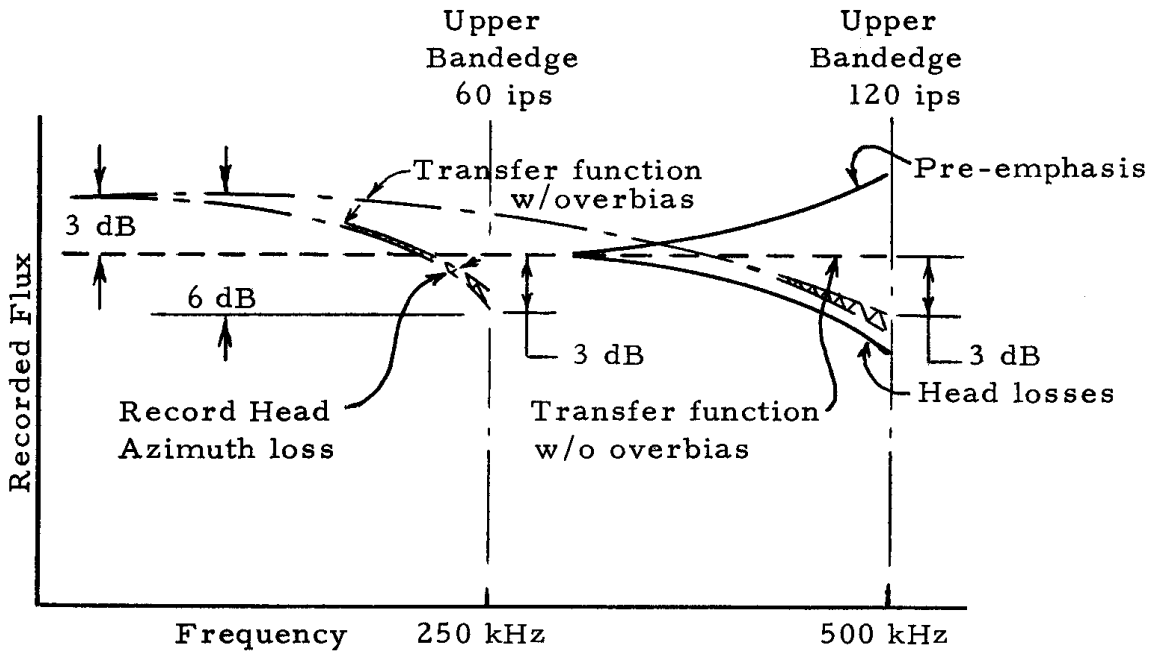

Figure 1. Record Transfer Function Parameters, Intermediate Band

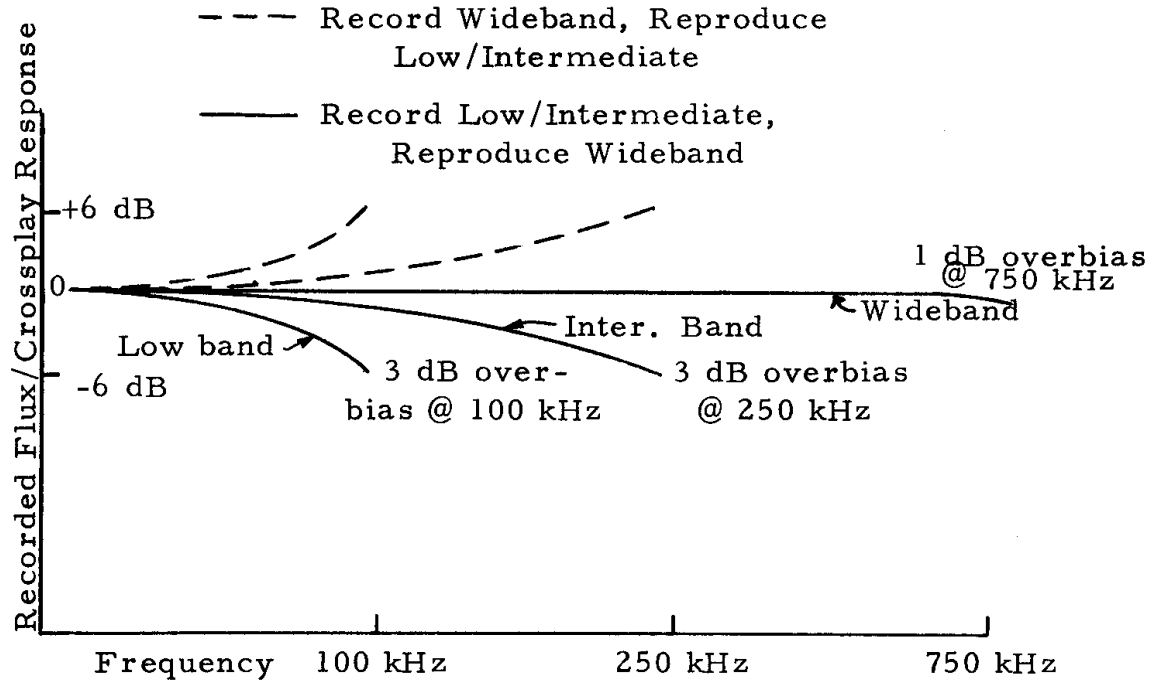

Figure 2. IRIG Record Transfer Functions and Crossplay Response at 60 IPS

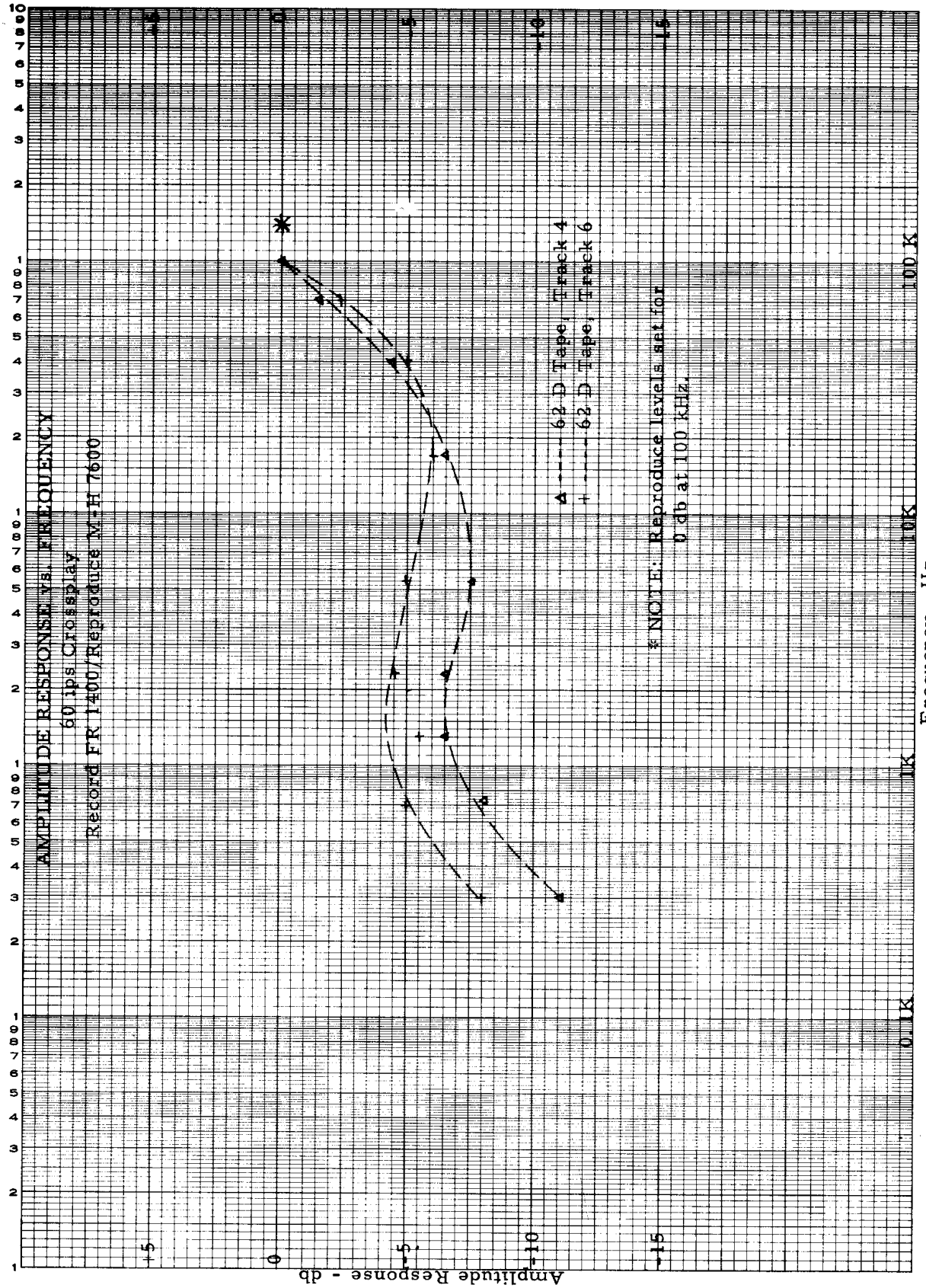
AMPLITUDE RESPONSE vs. FREQUENCY
60 ips Crossplay
Record FR 1400/Reproduce M-H 7600
62 D Tape, Track 4
62 D Tape, Track 6
* NOTE: Reproduce levels set for
0 db at 100 kHz.
Amplitude Response - db
Frequency - Hz
0.1K
1K
10K
100K

Figure 3

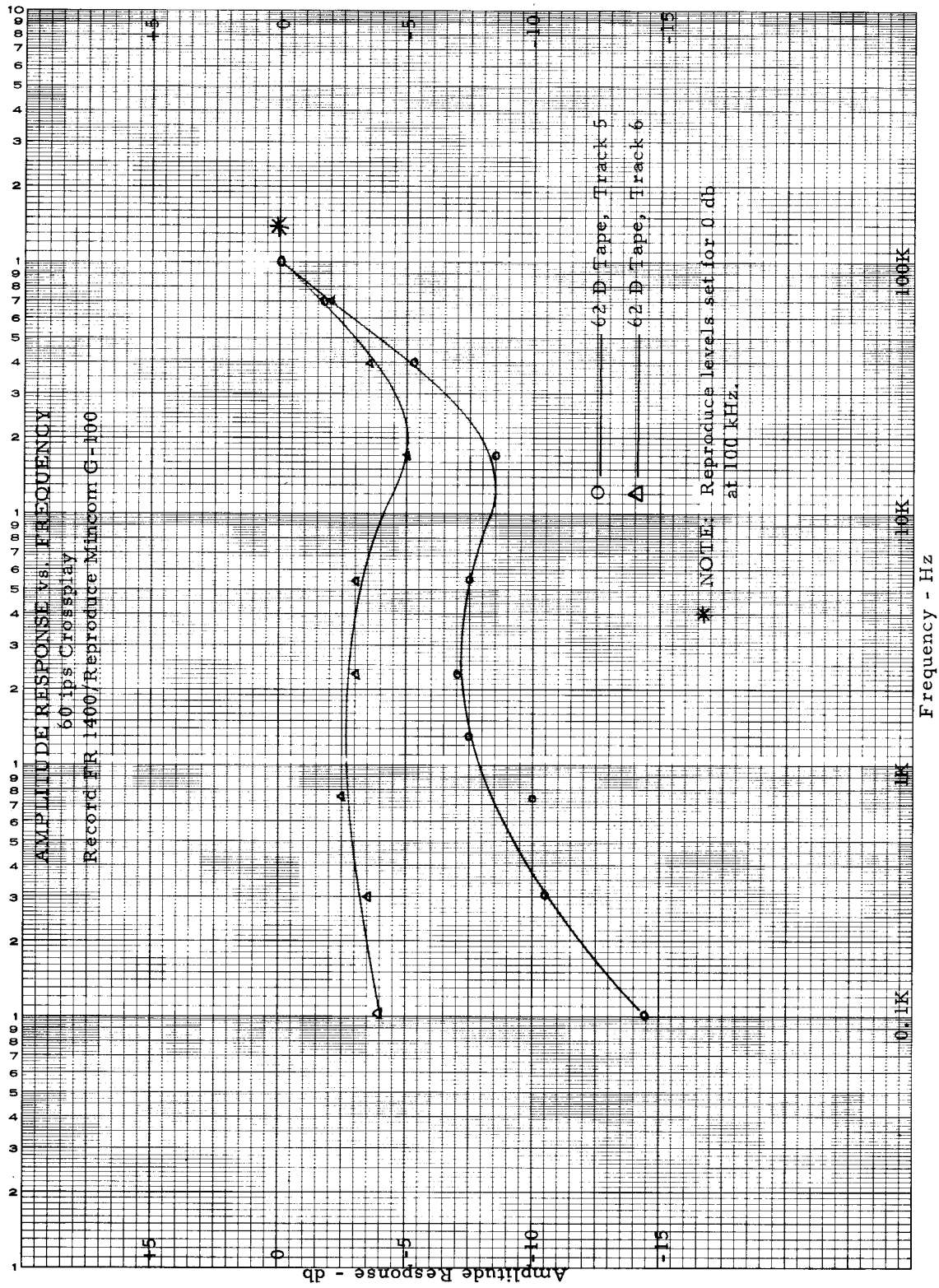
AMPLITUDE RESPONSE vs. FREQUENCY
60 ips Crossplay
Record FR 1400/Reproduce Mincom G-100
O ——— 62 D Tape, Track 5
Δ ——— 62 D Tape, Track 6
* NOTE: Reproduce levels set for 0 db at 100 KHz.
Amplitude Response - db
Frequency - Hz
+5
0
-5
-10
-15
0.1K
1K
10K
100K

Figure 4

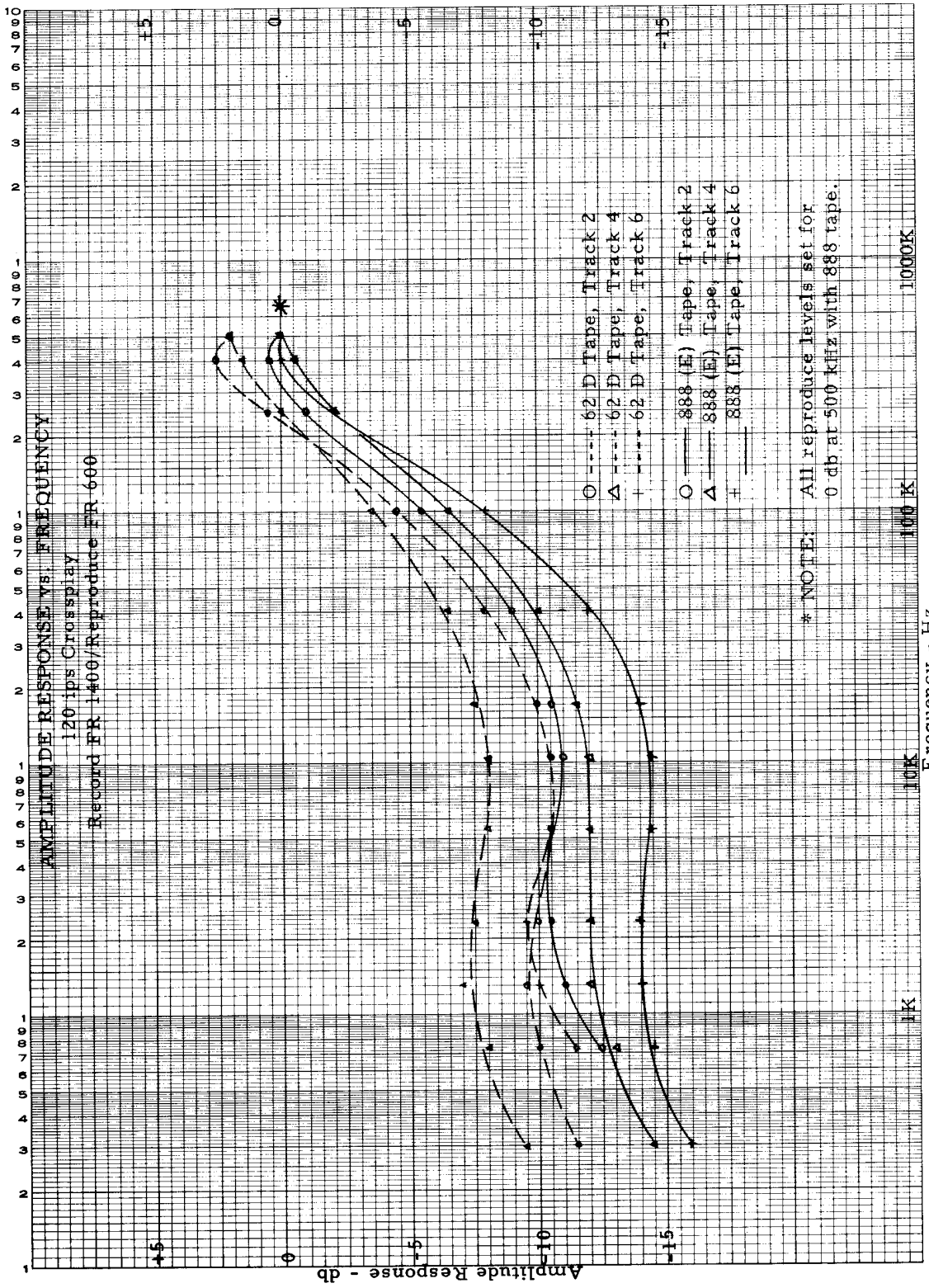
AMPLITUDE RESPONSE vs. FREQUENCY
120 ips Crossplay
Record FR 1400/Reproduce FR 600
O ---- 62 D Tape, Track 2
Δ ---- 62 D Tape, Track 4
+ ---- 62 D Tape, Track 6
O —— 888 (E) Tape, Track 2
Δ —— 888 (E) Tape, Track 4
+ —— 888 (E) Tape, Track 6
* NOTE: All reproduce levels set for 0 db at 500 kHz with 888 tape.
Amplitude Response - db
Frequency - Hz
+5
0
-5
-10
-15
1K
10K
100K
1000K

Figure 5