DESIGN CONSIDERATIONS IN PRE-D RECEIVING AND RECORDING EQUIPMENT

E. E. SWANSON
Technical Advisor to the President
Defense Electronics, Inc.

Summary Design factors to be considered in wide band Pre-D recording and playback equipment for usage in a versatile Pre-D system are presented. These design factors are introduced in a discussion of both the down-translator and up-translator. The mechanisms which produce spurious outputs from the up-translator and the effects caused by these spurious outputs are treated in detail. The extension of Pre-D techniques to FM Electronics equipment is covered.

Introduction Predetection recording (Pre-D) provides a convenient and universal means to store telemetered data with a minimum number of operational adjustments needed to assure a proper recording. Since the receiving system up to the point of recording is completely linear, no system threshold is established at the point of data recording. Successive playbacks using different IF bandwidths and demodulator types provide a means to optimize marginal data.

Modern telemetry data receivers are double superheterodyne with a second IF center frequency of 10 mc. Plug-in modules provide a wide range of IF bandwidths. The Pre-D Record Module down-translates the second IF signal and its associated sidebands to a Video Carrier frequency (with the same sidebands) suitable for direct recording on magnetic tape. The Pre-D Playback Module up-translates the played-back tape recording to restore the original IF signal and sidebands. The Pre-D Playback Module output is fed through the second IF channel of the receiver thus utilizing the second IF amplifier, FM demodulator, and video amplifier circuitry of the playback receiver.

Versatility is provided by a choice of Video Carrier frequencies and associated Data Bandwidths compatible with tape recorder speeds and direct record frequency response. Since IF filtering is always provided before recording and after playback, the Pre-D modules need not contain bandwidth restricting circuitry. Consequently the Pre-D equipment can provide a flat amplitude response for all ranges without the need for switching any bandwidth determining circuitry.

Choice of Video Carrier Frequencies Four Video Carrier frequencies are provided to accommodate the four standard tape speeds. These frequencies are directly related to tape speed to provide for time-base expansion by a factor of 8 to 1. A fifth Video Carrier frequency is provided to realize maximum possible Data Bandwidth with the fastest (120 ips) tape speed. Table I presents the Video Carrier frequency, Data Bandwidth, and frequency range to be recorded for each tape speed when using the DEI Model PD-101 Predetection Record/Playback Unit, shown in figure 1.

Data Bandwidth The maximum possible Data Bandwidth is realized by the use of a Video Carrier frequency which is the arithmetic mean of the direct record frequency response of the tape recorder for the speed being considered. The PD-101 utilizes 86% of this maximum on the four Video Carrier frequencies normally used with the four tape speeds. More than 1 1/2 octaves are dropped from the low frequency end of the range of frequencies associated with each Video Carrier by this slight reduction in Data Bandwidth which considerably eases the requirements for the phasing networks associated with the up-translation process.

Tape Speed	Data Bandwidth	Video Carrier Frequency	Frequency Range To Be Recorded
120 ips	1.4 mc	800 kc	100 kc - 1.5 mc
120 ips	1.2 mc	900 kc	300 kc - 1.5 mc
60 ips	600 kc	450 kc	150 kc - 750 kc
30 ips	300 kc	225 kc	75 kc - 375 kc
15 ips	150 kc	112.5 kc	37.5 kc - 187.5 kc

Table 1. Video Carrier frequency, Data Bandwidth, and frequency components to be recorded for each tape speed.

A tape-speed servo-control signal can be recorded along with the Pre-D data if necessary by choosing a frequency near the low limit of tape recorder direct frequency response since this now falls outside the range of frequencies associated with the Pre-D data. Both signals can be extracted (before up-translation) by suitable filtering.

Overall amplitude response of the Model P-101-R Record Module is held constant within 1 db (total variation) over the full Data Bandwidth for all Video Carrier frequencies. This is verified by measuring the Record Module output while varying the IF frequency over the range associated with each selection of Video Carrier frequency. Overall amplitude response of the P-101-P Playback Module is held constant within 2 db (total variation) over the full Data Bandwidth for all Video Carrier frequencies. This is verified by measuring the Playback Module output while varying the Video Carrier input frequency over the range associated with each selection of Video Carrier frequency.

Record Level The signal-to-noise ratio of a wideband tape recorder is typically about 25 db. Tape recorders have an abrupt overload point (with accompanying high distortion) at tape saturation. Since the S/N ratio of the tape recorder becomes the maximum carrier-to-noise ratio of the played back signal it is desirable to record just below tape saturation. Distortion is also an important consideration since it represents a component of signal present on playback that was not present in the IF signal to be recorded. Distortion effects will be considered presently.

The nominal level of a 10 mc IF input available to the Record Module and the variations in this level will depend upon receiver design. Typical variation with RF input level over the dynamic range of a telemetry receiver is about 3 db for receivers using amplified AGC and about 12 db for those which do not. A variation in the nominal level of IF output from one receiver design to another can be expected and a few db variation may occur when IF bandwidth or RF Tuning Units are changed. This indicates the need for a “local” AGC loop within the Record Module. AGC loop gain in the DEI P-101-R Record Module is such that a 20 db variation of input level (30-300 mv) is reduced to less than a 3 db variation in Video Carrier output level. The mixer design in the Record Module is such that there is a negligible change in output level when the Video Carrier frequency is switched. The need for operational adjustment of the Pre-D Record Module except for selection of the desired Video Carrier frequency is thereby eliminated. Furthermore, the tape recorder can be operated within a db or so of tape saturation utilizing the full SIN ratio capability of the recorder without danger of overload and possible loss of data.

Sufficient isolation must be provided in the 10 mc circuitry of the Record Module to prevent a signal from the translating oscillator from being introduced via the input lead to the IF channel of the receiver. Such a signal will produce a spurious video output from the receivers demodulator with possible disasterous effect on the real time post-detection data from the receiver. Figure 2 is a block diagram of the Record Module.

Equipment Interfacing IF signal patching is normally done at a 50 ohm impedance level and therefore the Record Module input and Playback Module output should be at 50 ohms. Since the source impedance of the IF output from all receivers may not be 50 ohms the Record Module input should provide a good 50 ohm termination. Likewise the Pre-D playback output impedance should be a good 50 ohm source. The Pre-D playback input of the receiver should be (and normally is) arranged such that AGC action is obtained for the playback IF. The playback signal level in the IF channel is not particularly critical but should be high enough to reduce the IF gain to the point where there is no carrier-to-noise ratio degradation by IF noise but well below any overload point. IF output level from the Playback Module of approximately 80 mv has been found to be a more than adequate available signal level.

The most modern telemetry equipment is designed for video signal distribution and patching at a 75 ohm impedance and a level of about 4 volts p-to-p. Therefore, the Video Carrier output from the Record Module should provide this level. The input sensitivity of the Tape Recorder is generally less than this which allows the use of inexpensive power splitters for parallel connections. Likewise the Playback Module should have an input sensitivity of about 1 volt p-to-p but be able to accommodate input levels up to at least 4 volts p-to-p.

Pre-D signals must be treated as linear signals in the record and playback processing and as such it is important to maintain proper video carrier level at all points. Distortion must be kept low to achieve peak performance. The elimination of operational adjustments on the Record Module means that the possibility of operator error (during the one chance to record) is greatly reduced. The set-up procedure for Pre-D recording can be accomplished very easily by feeding a CW signal into the receiver at the highest RF input level and simply adjusting the Tape Recorder input level control for optimum record level.

Up-Translation Figure 3 is a block diagram of the DEI P-101-P Playback Module. The input Video Carrier signal is amplified and applied to a phase shift network. The phasing network provides two outputs equal in amplitude and 90° apart in phase over the range of frequencies associated with the selected video carrier and associated sidebands. Each of these signals are then fed to individual balanced modulators through wideband video transformers which apply push-pull signals to the deflection electrodes of RCA type 7360 Beam Deflection tubes. The heterodyning crystal oscillator is fed to an RF phase shift network to provide two outputs which are equal in amplitude and 90° apart in phase. These outputs are fed to grid number one of the beam deflection tubes.

Present at the output plates of each balanced modulator and applied to the combining transformer is a push-pull signal at the difference frequency and at the sum frequency of the oscillator signal and the video carrier signal. Also present at each plate is the oscillator signal.

The combining transformer has a balanced primary and an unbalanced secondary and operates as a transitionally-coupled double-tuned circuit with a flat-top response approximately 1.4 mc wide centered at 10 mc. The phase relationships existing between the video carrier signals and the oscillator signals coupled with the characteristics of the combining transformer provides addition of the desired “difference frequency” voltages and subtraction of the undesired “sum frequency” voltages. The oscillator output voltages from each balanced modulator are in phase and are adjusted, by the associated oscillator balance control, to be of equal amplitude. Consequently there is no current through the primary of the combining transformer due to oscillator signal and therefore no voltage at the oscillator frequency present across the transformer secondary. The 10 mc (difference frequency) output is amplified by a bandpass amplifier with the output circuit arranged to provide a 50 ohm source impedance.

Self-contained metering circuits permit translating-oscillator balance and input-levei adjustment to be performed without the need for additional test equipment.

Spurious Outputs There are spurious signal outputs associated with all wideband-heterodyning type up-converters. These spurious outputs warrant extra design care due to their proximity to the desired signal bandwidth. Their effects can be reduced to a tolerable amount by the rejection obtainable within the up-translator and the rejection obtained from the skirt selectivity of the IF amplifier used for playback.

Figure 4 presents in graphical form the IF output frequency range (desired output) and the important spurious signals over the range of video carrier components covered by the data bandwidth associated with the 450 kc Video Carrier. Superimposed on this graph is the selectivity curve of a typical 750 kc: bandwidth IF amplifier.

The spurious outputs from the up-translation process are symmetrical about the translating oscillator frequency. The desired output and the image output represent the (fundamental) difference and sum of the instantaneous video carrier frequency and that of the translating oscillator. The second harmonic difference and sum are caused by second harmonic distortion of the instantaneous video carrier frequency and the third harmonic difference and sum are caused by third harmonic distortion. As can be seen on figure 4 there is additional attenuation provided by the playback IF amplifier to all undesired components except second and third harmonic difference which fall within the IF passband over part of the range of instantaneous video carrier frequencies.

Harmonic distortion occurring in the mixer or video amplifier of the Record Module, the tape recorder, or the video amplifiers in the Playback Module should be held to less than 1% or 2% for frequencies below the nominal video carrier center frequency.

The mixer in the down-translator is a source of video distortion since the second harmonic of the IF signal at the mixer and the second harmonic of the translating oscillator produce the second harmonic of the desired video difference.

Spurious signal rejection at the output of the Playback Module is generally specified as 40 db minimum for the translating oscillator, 25 db minimum for the (primary) image, and 30 db minimum for all other components. In a carefully designed up-translator the oscillator rejection, the image rejection, and rejection of the other spurious output signals are to a first approximation independent. The oscillator rejection is primarily controlled by the degree of perfection obtained in the combining transformer and symmetry in the balanced modulators. The image band rejection is primarily controlled by the constancy of the 90° phase difference and the amplitude equality in the video carrier circuitry. The other spurious output signals are primarily related to distortion.

Image rejection varies considerably over the image band due to slight variations in amplitude or phase of the video carrier input signals applied to the balanced modulators. It is not uncommon to have nearly 40 db image rejection over most of the image band.

Second and third harmonic difference and sum components are generated in the mixing process and are primarily controlled by design parameters such as signal levels and operating points in the balanced modulators. Distortion in the video carrier amplifier circuitry produces only difference components (the sum components being eliminated as an image) and these are normally small compared to the distortion products generated in the mixing process.

Measurement of Spurious Outputs Measurement of spurious outputs from a Playback Module is best accomplished on a quasi-steady state basis using a visual indication.

A Display Unit (such as the DEI Model SA-101 Spectrum Analyzer) or a spectrum analyzer having a 10 mc center frequency and a 3 mc to 4 mc sweep width is connected to the Playback Module Output. A Test Oscillator is used as a source of video carrier input. The Playback Module is set up for operation in the normal manner with an input frequency equal to one of the nominal Video Carrier frequencies and the gain of the Signal Analyzer is adjusted to produce a reference output level for the desired 10 mc output signal. The gain of the Signal Analyzer is then increased (by a known amount) and the rejection of each spurious component is evaluated by observing its output level as the frequency of the Test Oscillator is varied over the range of input frequencies associated with the Video Carrier frequency under evaluation.

The Effect of Spurious Outputs The effect of spurious output signals generated in the up-translation process is to produce extraneous components in the video output of the playback receiver. It is well known that an interfering signal present at the input to the limiters will produce an output from the demodulator. When the ratio of the weaker (interfering) signal to the stronger (desired) signal is quite small, as is the case here, the resulting output from the demodulator is sinusoidal in appearance and follows the relation $\Delta f = ar$ where “all is the amplitude ratio of the interfering to the desired signal, “r” is the frequency separation, and “Δf” is the equivalent (peak) deviation.

Figure 5 presents in graphical form the extraneous output frequencies that will appear at the demodulator output of the playback receiver for all values of video carrier frequency when using a Pre-D Video Carrier of 450 kc. Fortunately, most of these video output components lie at frequencies much higher than the baseband video range[*] of interest and are relatively unimportant. It is interesting to note that the frequency of each extraneous video output is exactly equal to a multiple of the instantaneous video carrier frequency at the input to the Playback Module. Furthermore, there are two mechanisms by which the same video disturbance is produced.

To evaluate the magnitude of each video disturbance at the output of the demodulator it is necessary to know the relative amplitude of the undesired signals and the desired signal at the input to the limiter.

The desired signal is the 10 mc ±300 kc signal representing the original IF signal that was recorded. The undesired signal is one of the spurious outputs from the Playback Module. The relative effect of each spurious output can be examined on a quasi-steady state basis for both frequency and amplitude (equivalent deviation) of the resulting video disturbance by taking into account the level of each spurious at the Playback Module output and any additional attenuation that may be provided in the playback IF amplifier. Figure 6 is a graph comparing the relative effect of oscillator rejection with the second harmonic difference output and image rejection with third harmonic difference output. The effects of distortion are worse than those due to oscillator and image rejection which demonstrate that adequate oscillator and image rejection have been achieved.

The effect of the output video disturbances are to produce noise[**] on the positive peak of the video output from the playback receiver. The positive peak of the output signal corresponds to the minimum video carrier frequency and this corresponds to the lowest frequency video disturbances. The relative amplitude of the noise depends upon the deviation and modulating frequency which is used. A determination of the video output disturbances under dynamic conditions with complex modulation would be extremely difficult and is beyond the scope of this paper.

Extension to Other Video Carrier Frequencies The foregoing analysis can be extended to the other Video Carrier frequencies by taking into account the fact that the data bandwidths are related and the base band frequency responses are related. For example, the 900 kc video carrier would use a 1.5 mc playback IF bandwidth and the frequency and amplitude scale factors for the video disturbances would double. Of

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[*] The video frequency range encompassed by the demodulated intelligence on the received signal.

[**] Extraneous undesired signals as opposed to thermal noise or tape noise.

course baseband video frequency response and probable deviation of the signal to be processed would also double.

Consideration of AGC Time Constant Receiver AGC time constant is of importance when the RF input level to the receiver is varying at rates greater than a few cycles per second particularly if there are large fluctuations. A sudden decrease in received signal level causes corresponding decreases in the IF output level from the receiver and the Video Carrier output level from the Record Module. Normal output levels are reestablished as the AGC time constant of the receiver allows the receiver gain to build up. The time constant of the local AGC in the Record Module may also be involved but this' depends upon the relationship between receiver and Record Module AGC time constants and the tightness of the AGC loop in the receiver. Reduced record level will reduce carrier-to-noise ratio on playback since tape noise level is fixed. The video output from the playback receiver will be noisy for a period of time even though the received signal may still be quite strong.

The effect of a sudden increase in received signal level is to increase record level for a period of time. During this time saturation of the tape with attendant distortion will cause greater than normal spurious signal output levels from the Playback Module which in turn will increase the severity of the video disturbances at the video output of the playback receiver.

Fast AGC in the receiver used for recording and relatively long AGC time constants in the Record Module and playback receiver will minimize the time duration of data degradation.

Use of Limited IF Output for Pre-D Recording Some telemetry receivers provide an IF output before limiting (linear) and an IF output after limiting (non-linear) for use in Pre-D recording. At first glance it would appear that the use of the limited output is the ideal thing, however, there are other factors to consider besides quasi-steady state constancy of output. As stated earlier, the Pre-D record and playback process is basically a linear process and the use of limited output inserts a non-linear process in the data stream <u>prior</u> to the actual demodulation. If interfering signals are present there are components at the output of a limiter that were not present at the input. The presence of such signal components can well disrupt the Pre-D process since these components can occur at frequencies outside the desired bandwidth as set by the IF amplifier in the receiver used for Pre-D recording. Once such components have been produced they cannot, in all likelihood, be removed.

Telemetry data receivers generally use two limiter stages where the stage driving the discriminator is the second limiter. Overall limiting characteristics usually provide a 30 db or so limiter overdrive to protect the real-time demodulator from data dropout due to signal fading and to achieve good AM rejection. A substantial part of the limiter overdrive is usually the first limiter overdriving the second limiter. Pre-D limited output taken from only one limiter may be rather inadequate for optimum operation.

The possibility of providing optimum limiting characteristics for Pre-D recording has been considered . [(1)] The use of an auxiliary module to pre-process the non-limited IF output of a telemetry receiver could be used when the presence of interfering signals (such as multipath) was anticipated.

Selection of Record and Playback IF Bandwidths The 2nd IF bandwidth used in a telemetry receiver is generally chosen to accommodate the "real time" data to be received. However, there is an advantage to be gained in Pre-D by recording with the widest IF bandwidth (compatible with the data bandwidth of the Pre-D for a chosen tape speed) and playing back using an IF bandwidth that will just accommodate the recorded data. [(2)] Some receiver designs provide two second IF channels in which optimum bandwidth for "real time" and maximum bandwidth for Pre-D recording can be used simultaneously.

Typical receiver IF bandwidths are 100 kc, 500 kc, 750 kc, 1 mc, and 1.5 mc which represent the users choice for "real time" receiver bandwidth. Usually the selection of bandwidth for Pre-D record and playback is made on the basis of the best fit from what is readily available. While t his may provide satisfactory Pre-D operation the bandwidths are not necessarily optimum.

Typical receiver IF amplifiers have a I db bandwidth equal to about 70 or 80% of the 3 db bandwidth. Typical skirt selectivity provides a 60 db to 6 db bandwidth ratio of approximately 2.5.

As shown in figure 4, a 750 kc bandwidth fits nicely as a maximum playback IF bandwidth for the 450 kc video carrier (60 ips tape speed). Maximum playback bandwidths for the related Video Carrier frequencies can be scaled and are shown in table 2. Use of the minimum playback IF bandwidth that will accommodate the data is recommended.

Selection of maximum record IF bandwidth must consider image foldover. The desired Video Carrier output frequency from the Record Module is the instantaneous difference between the translating oscillator frequency and the signal in the IF channel with the translating oscillator being high beat. IF signal components at frequencies above that of the translating oscillator will also produce a video carrier output (difference) with the translating oscillator being low beat. Video carrier components so generated will be up-translated, but to a different IF frequency. For example: A component at 10.3 mc (against

Video Carrier Frequency	Pre-D Data Bandwidth	Maximum IF BW for Recording	Maximum IF BW for Playback
112.5 kc	150 kc	150 kc	187 kc
225 kc	300 kc	300 kc	375 kc
450 kc	600 kc	600 kc	750 kc
900 kc	1.2 mc	1.2 mc	1.5 mc
800 kc	1.4 mc	1.2 mc	1.5 mc

Table 2. Recommended maximum second IF amplifier bandwidths for Pre-D recording and playback using typical data receiver IF modules.

10.45 mc) will be down-translated to 150 kc and up-translated to 10.3 mc. A component at 10.75 mc will also be down-translated to 150 kc but will be up-translated to 10.3 mc.

Bandwidth and skirt selectivity of the second IF amplifier used for Pre-D recording must be such that substantial attenuation is provided in the record image band. A maximum IF bandwidth equal to the Pre-D data bandwidth will provide adequate protection against image foldover for most Pre-D applications. See figure 7.

Application of Pre-D Techniques to FM Electronics The DEI Model FM-501 FM Record/Playback Equipment shown in figure 8 provides a means for recording post detection video signals or other video data. Frequency response from DC to 62.5 kc, 125 kc, 250 kc, or 500 kc is provided with tape speeds of 15 ips, 30 ips, 60 ips, or 120 ips.

The FM Record Electronics consists of a 10 mc VCO driving a downtranslator and the FM Playback Electronics consists of an up-translator driving a limiter discriminator and video amplifier. Video Carrier frequencies of 112.5 kc, 225 kc, 450 kc, and 900 kc are used. The carrier deviation used with each range is such that a modulation index of 0.4 occurs at the highest modulating (video) frequency. This requires a data bandwidth equal to twice the (baseband) video bandwidth. Phase compensated sharp cut-off post detection video filters are used to remove the effects of spurious outputs from the up-translator.

Since the same video carrier frequencies are used for FM Electronics and for Pre-D, an FM Electronics tape can be played back through Pre-D equipment and a receiver. A 10 mc (up-translator) output is also provided from the FM Playback Electronics to allow playback through a receiver if desired.

DEI Pre-D and FM Electronics tapes are essentially identical. The Pre-D intelligence to be processed is the signal present in the second IF channel of a data receiver with baseband video, and deviation being variables. The FM Electronics intelligence to be processed is a locally generated signal from the VCO in the record module. Baseband video is a variable but deviation is fixed.

The FM Electronics Record module is provided with self-contained metering circuits to set the VCO frequency exactly to 10 mc with zero dc input and to set the desired carrier deviation for different amplitudes of baseband video input. The FM Electronics Playback module is provided with self-contained metering circuits to permit translating oscillator balance, input (video carrier) level adjustment, and to set zero volts dc output with an up-translated signal of exactly 10 mc. These provisions eliminate the need for additional test equipment or special calibration units.

The main chassis contains the necessary power supplies and interconnecting wiring. Design is such that two record modules, two playback modules, or one of each module can be accommodated.

(1) "High Ratio Capture Discriminators, Design Considerations and Experimental Results", E. E. Swanson, DEI Development Engineering Report (unpublished).

(2) "IF Magnetic Recording Technique Simplifies Telemetry Ground Stations", V. A. Ratner, Microwave Journal, January 1965.

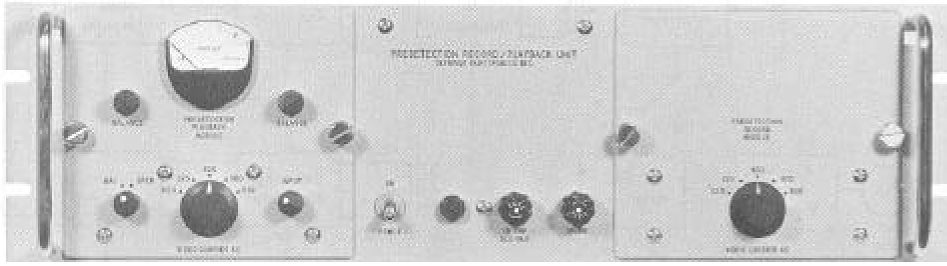

Figure 1. DEI PD-101 Predetection Record/Playback Equipment Accommodates Two Plug-in Record Modules, Two Plug-in Playback Modules or a Pair of Modules

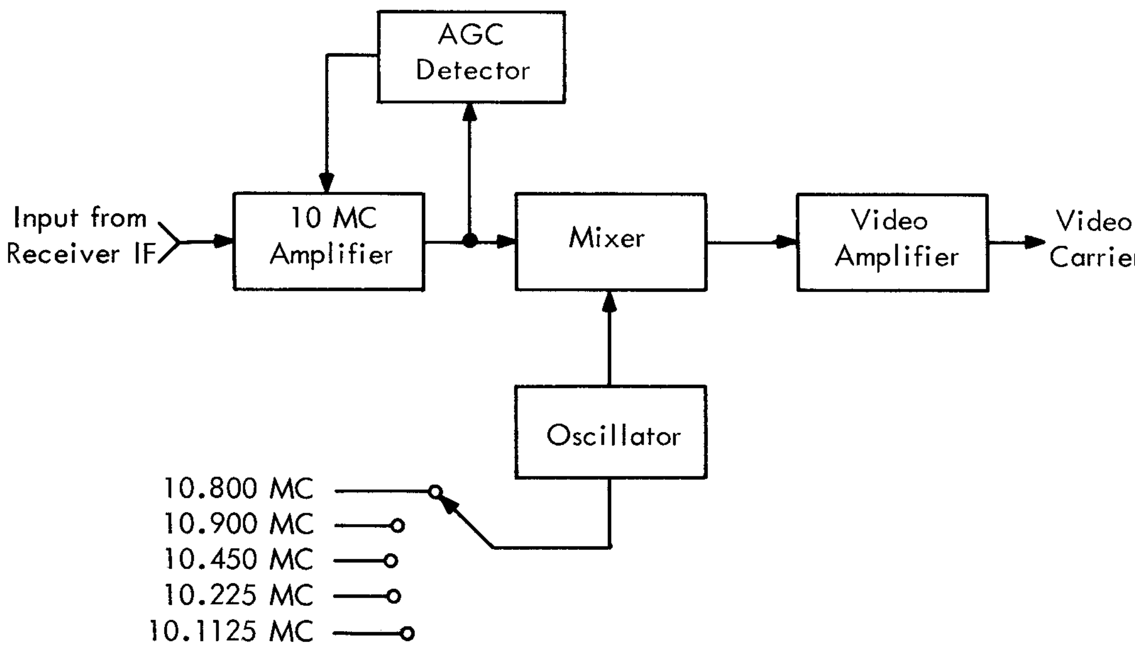

Figure 2. Pre-D Record Module, Block Diagram

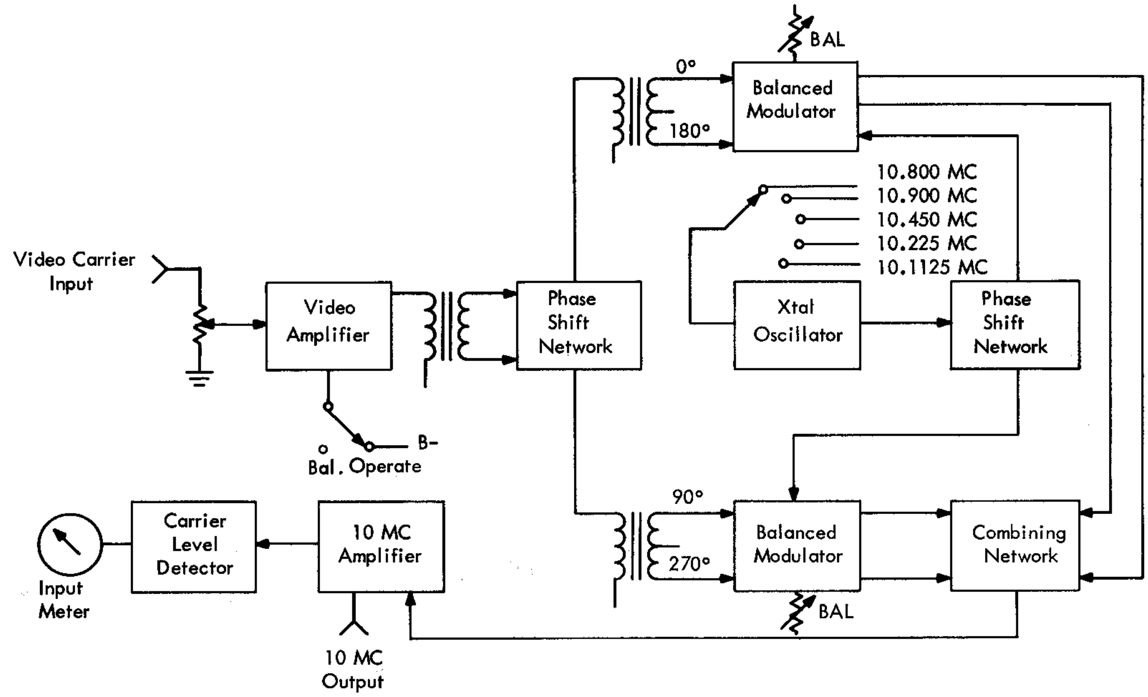

Figure 3. Pre-D Playback Module, Block Diagram

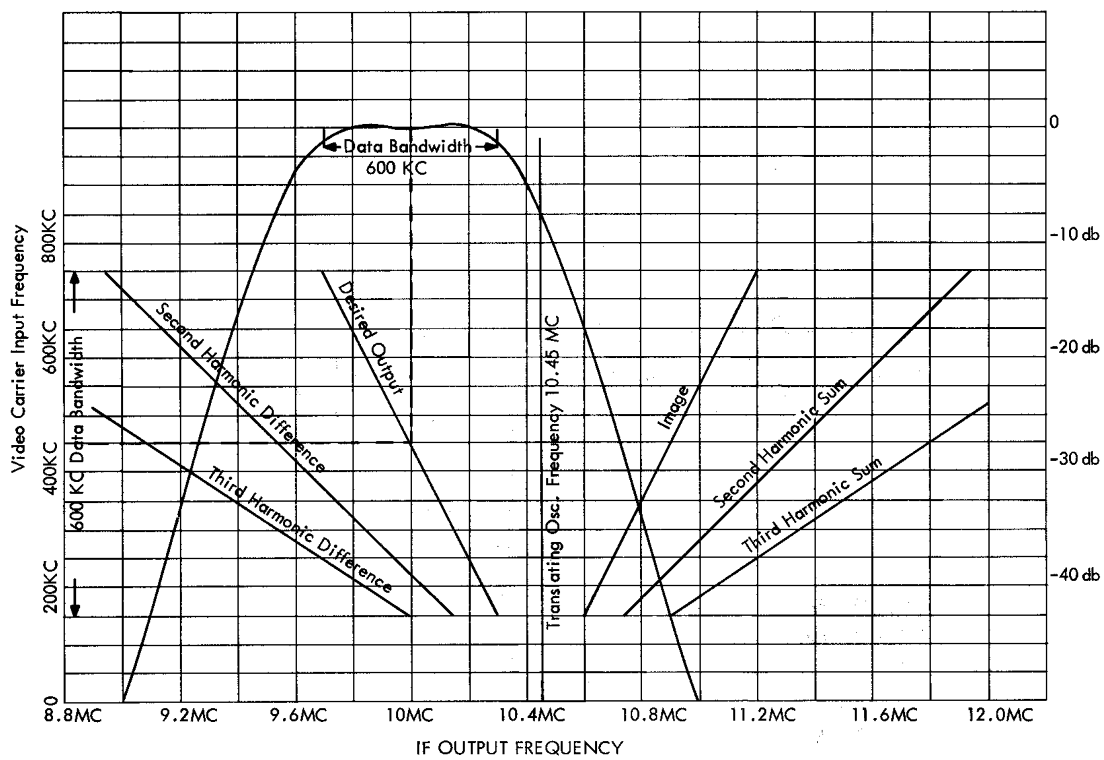

Figure 4. Graphical Representation of Output Signal Components of Up-Translator Using 450 kc Video Carrier with Response 1 of 750 kc BW IF Amplifier Superimposed

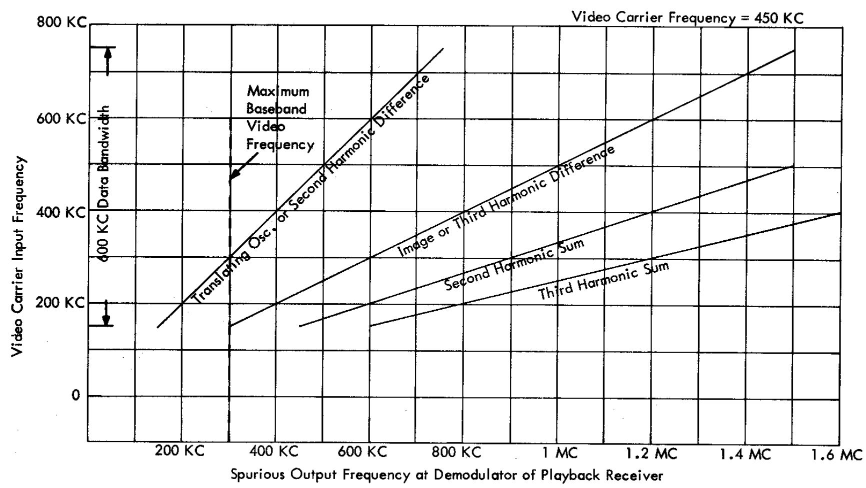

Figure 5. Spurious Output Frequencies at the Demodulator of the Playback Receiver vs Instantaneous Video Carrier Frequency

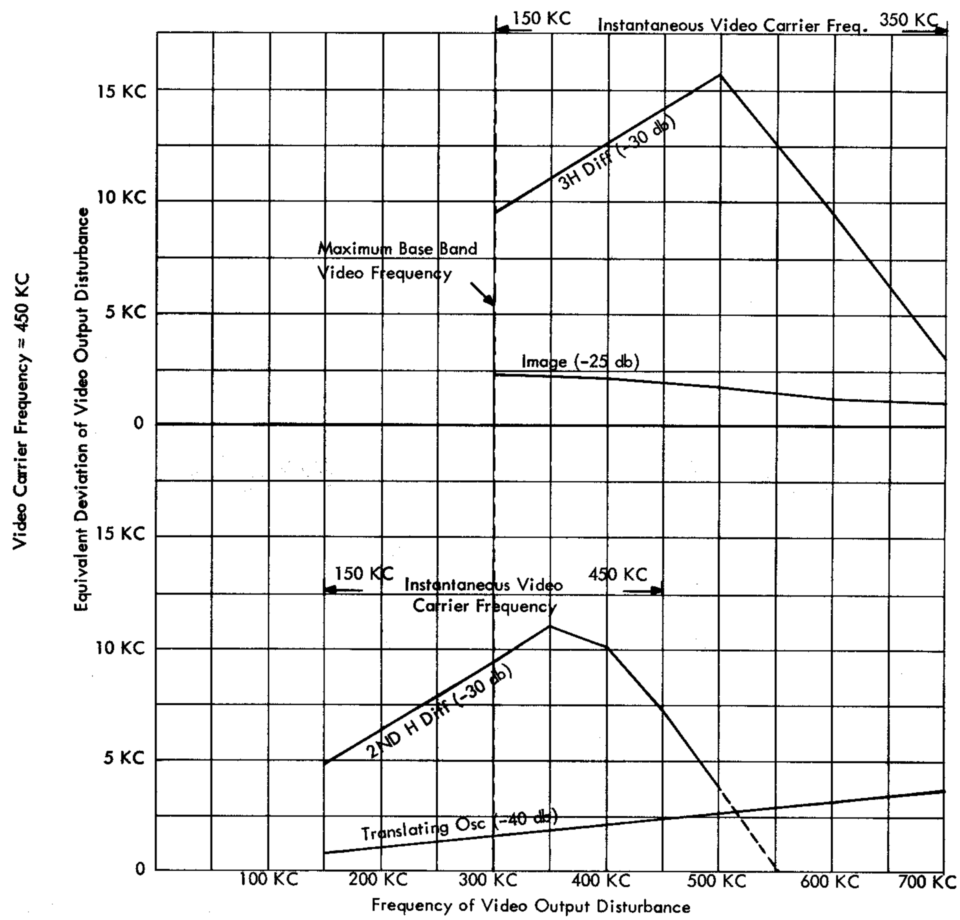

Figure 6. Effect of Spurious Up-Translator Outputs at the Demodulator of the Playback Receiver

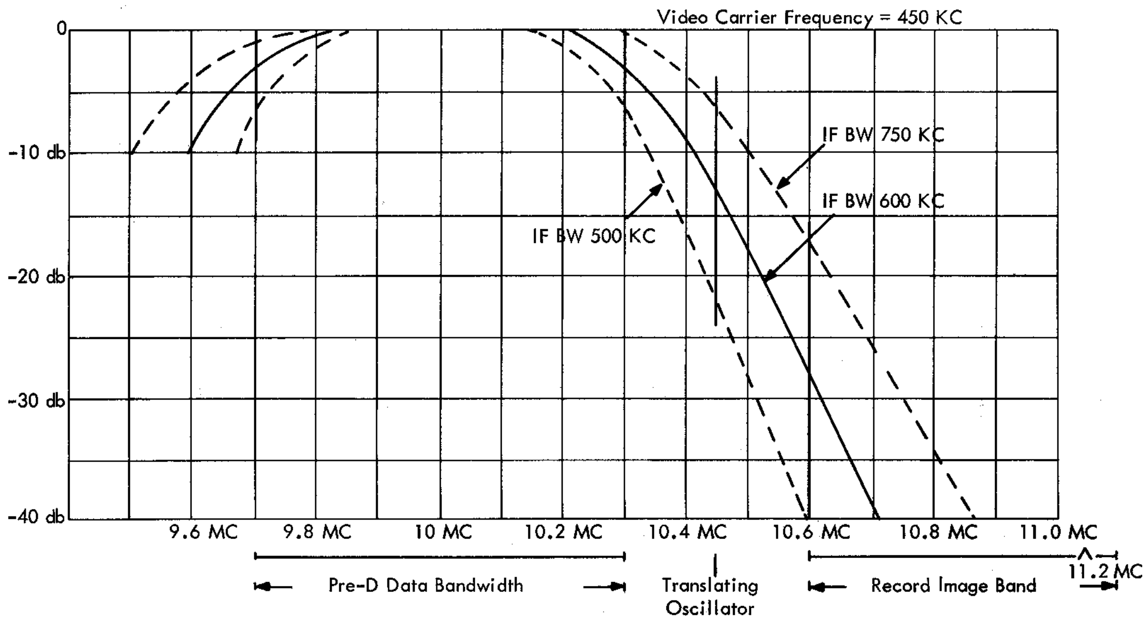

Figure 7. Pre-D Record Image Band Rejection for Typical Receiver IF Bandwidths

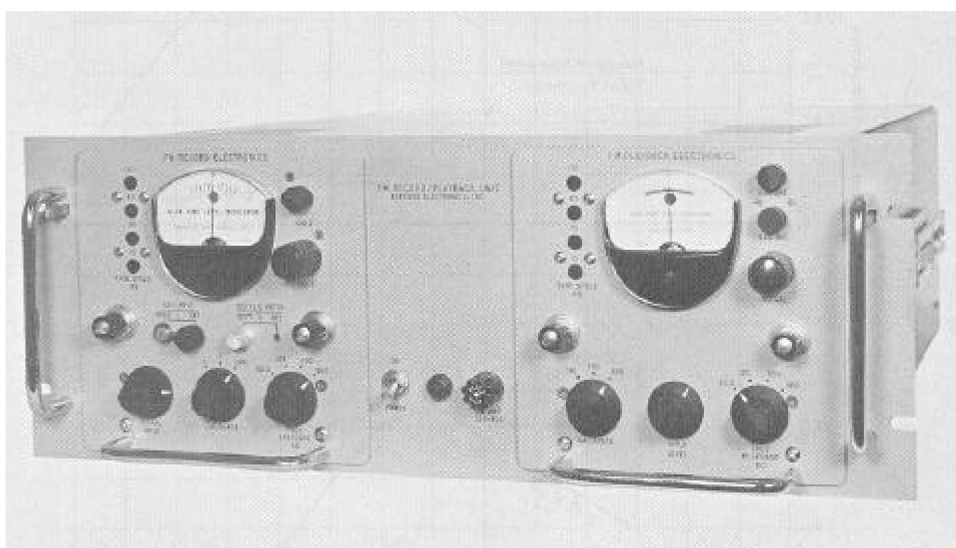

Figure 8. DEI FM-501 FM Record/Playback Unit Based on Pre-D Techniques Does Not Require Additional Equipment for Set-up or Calibration