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PERFORMANCE OF THE PROTOTYPE ANALOG FIBER OPTIC LINK FOR THE BOOSTER PUE SYSTEM IN THE AGS BOOSTER

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Introduction

The Meret Inc. MDL288TV analog fiber optic link using Ensign-Bickford HCR series fiber has been identified for use as a wideband analog data transmission system. The optical link will transmit the Booster Pick-up Electrode (PUE) analog data to systems such as the Tune Meter, Kicker, and Damper. An optical fiber transmission system has been selected because it provides the required electrical isolation between the PUE electronics and external equipment. The transmitters will be located in the PUE electronics sub-racks in the Booster tunnel. There is the possibility that the electronics racks will be radiation shielded. The optical links will transmit the PUE data over a step index 200 micron core fiber at a wavelength of 820 nm. The fiber has a 15 MHz-Km length-bandwidth product. Therefore, the receivers can be placed up to 500 m (cable length) from the transmitters and still maintain the required signal bandwidth. It is planned to locate the receivers outside the tunnel with the processing electronics for the systems using the PUE data. However, constraints may warrant the receivers to be located in the Booster tunnel and it may not be possible or feasible to radiation shield the receiver modules. Therefore the link characteristics such as linearity, distortion, transfer function and attenuation were tested before, during and after a radiation exposure to quantify any changes in the level of performance. The radiation exposure selected is equivalent to a cumulative dose of at least 5 years of unshielded operation at a typical point on the floor of the Booster[1]. The remainder of this report summarizes the test procedure and results for the links.

Test Results

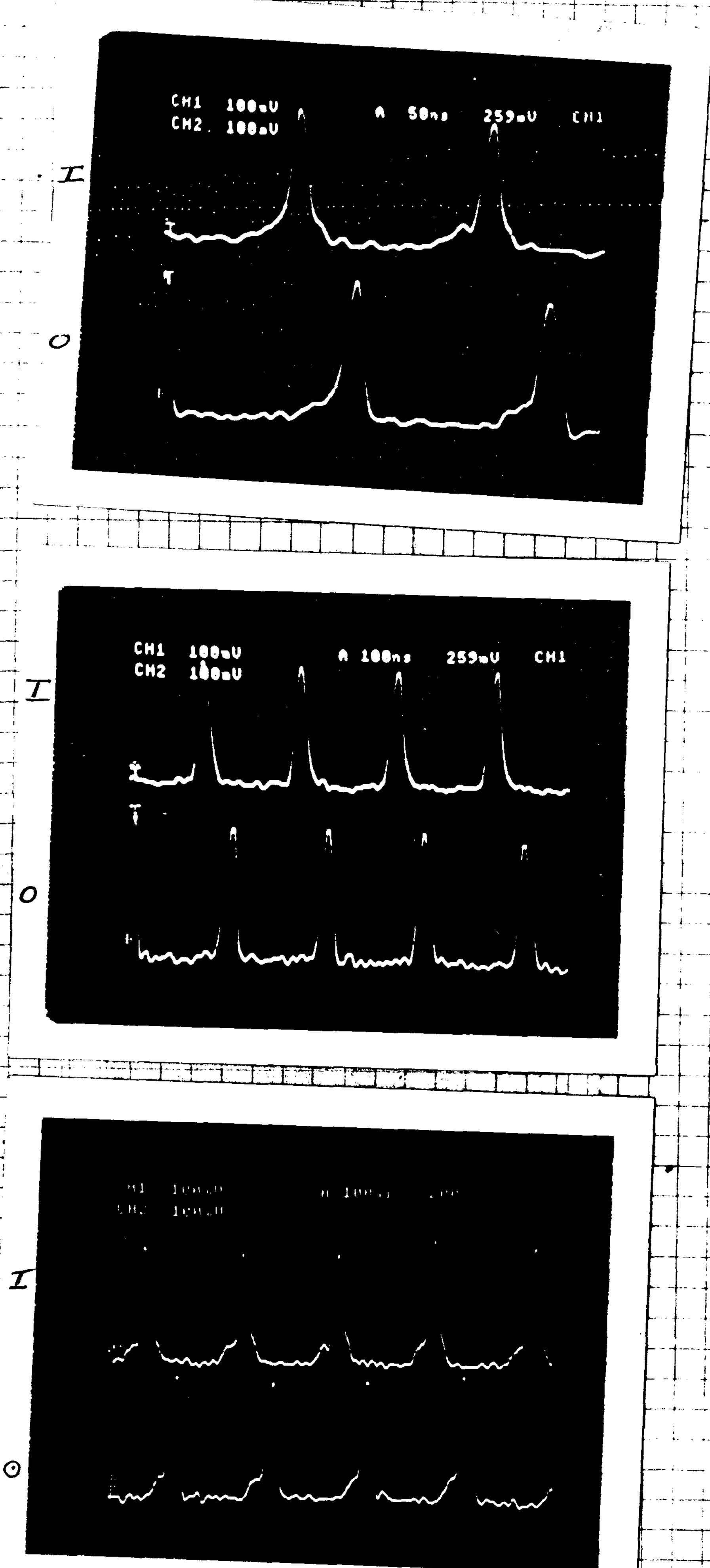
PUE Specific Test

This test was performed to qualitatively decide whether or not the links should be considered for further testing. This test was set up in the AGS terminal room. The fiber optic link was used to transmit the AGS PUE signals over a short length of fiber. The links were setup for a gain of 1 from input to output. The photos in figure 1 show the PUE signal (I) and the link response (O). These pulses are similar to the pulses expected during the operation of the Booster. The links demonstrated adequate performance and as a result it was decided to proceed with the other tests.

Linearity and Distortion Products

A major concern in analog data transmission is the linearity of the channel. Linearity is the parameter that describes the input-output transfer curve's deviation from a straight line. To quantify the deviation from linearity the total harmonic distortion (THD) is often used. To perform the THD test the test setup in figure 2 was used. With the source connected to the transmitter and loading the receiver with 50 ohms, link voltage gain was set at unity using a 100 mv (pk) sine wave. An oscilloscope was used to monitor the input and output waveforms. A fifth order chebychev low pass filter was used at the signal source

FIGURE 1:
AGS PUE Signals



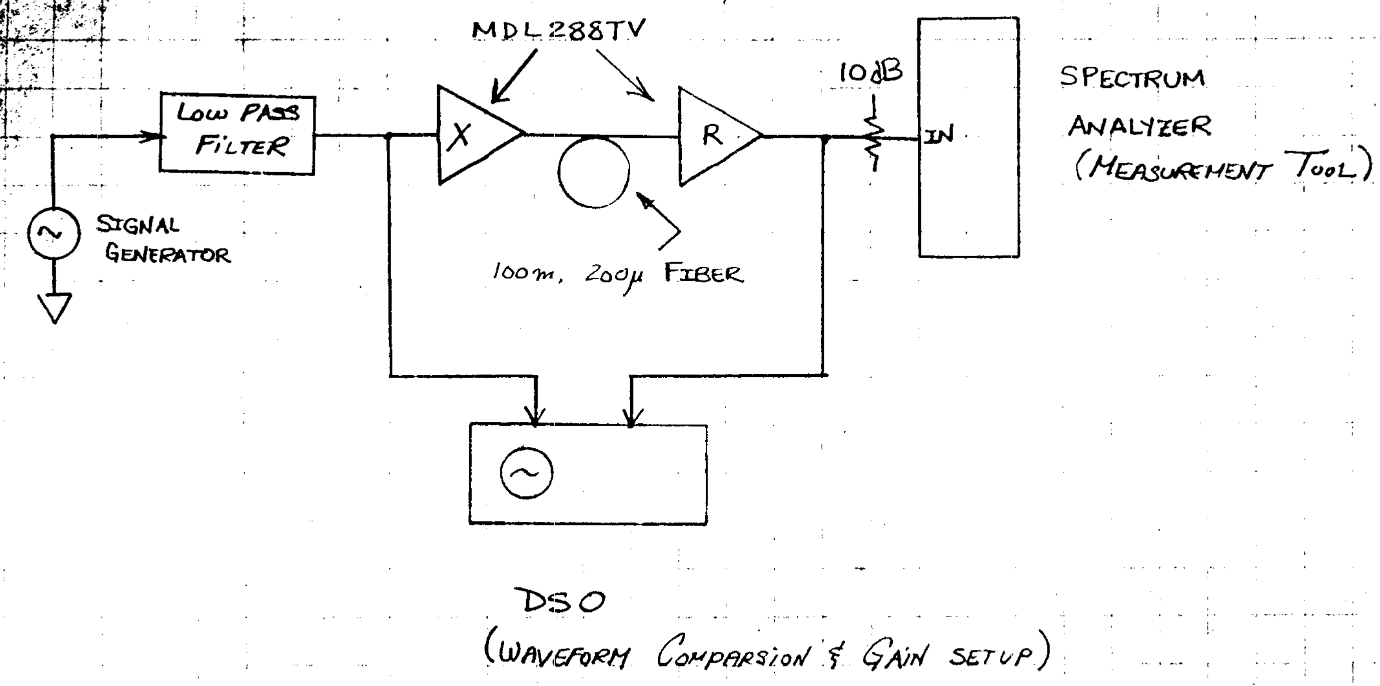


FIGURE 2: THD TEST SET-UP

output to attenuate harmonics from the source. The filter reduced the highest harmonic to -60 dbc. The 10 db pad at the spectrum analyzer input is used to avoid overdriving the input and generating harmonics in the analyzer. The spectrum analyzer was used to display the power spectrum of the receiver output and also to measure the source power spectrum at each input power level. Because the analyzer measurements are referenced to a 50 ohm system, the 75 ohm input impedance of the link introduces a measurement error at the link output when using the analyzer(50 ohm load). The impedance mismatch at the source causes the link input voltage to be 1.2 times greater than that measured by the analyzer. Then since the link output voltage is directly proportional to the transmitter input voltage, the output power appears 1.58 db higher than expected. Because the system is nearly linear, even for large inputs this error does not affect relative measurements such as THD. However, to calculate the absolute input and output voltages the 1.58 db factor must be added to the measured input. The results of the THD test are shown in figure 3. The input is shown in voltage because specifying the voltage removes the ambiguity of reference impedance. The result of this test is that at the peak input signal recommended by the manufacturer, .5 V (pk), less than 3.2 % THD is present in the output of both links. For inputs up to .5 V (rms) the main source of harmonic distortion is the second harmonic. Inputs above .5 V (rms) cause significant signal components of up to 10 harmonics. At these inputs the irradaited link shows lower THD because its frequency response rolls off in comparison the non-irradiated link.

Using the fundamental input and output the maximum deviation from linearity can be determined. The input and output voltages were used to compute the least mean square (LMS) curve for both links. In both cases the best fit is a straight line with unity slope. The LMS fit shows that at signal levels up to .5 V (pk) the typical worst case deviation from linearity is approximately 4 %. The manufacturer claims better than 2 % linearity. This value could not be verified because the accuracy of the test setup is only about 3 %. This is due to a combination of the limited readout precision of the spectrum analyzer and fluctuations signal source output.

Another measure of linearity is the Intermodulation Distortion Products (IMD). The setup for this test is given in figure 4. This test uses two tones to evaluate the linearity of the system. A linear system would output only the two tones scaled by the link gain. However, the non-constant transfer curve slope indicates each input will generate harmonics and mixing products, otherwise called m by n terms. The level of these outputs is a measure of linearity and directly influences dynamic range. Again the spectrum analyzer was used as an input power meter and output spectrum analyzer. The pad and filters were used to preent the test setup from generating unwanted harmonics. The applied input signal consisted of 5 MHZ and 6 MHz tones summed together. The individual signal amplitudes were varied together over the range of 200 uv (pk) to 1 V (pk). The photo in figure 5 shows a sample of the test results at approximately .5 V (pk envelope). The photo shows that at high level inputs, the second order IMD products are a limiting factor, not the third order as is usually the case. At this time it is not possible to explore this effect further. A graph of the IMD data is given in the next section.

Dynamic Range and SNR

There are many definitions of dynamic range for a system. Therefore, no attempt to quantify the link performance by one number is attempted here. A graph of link parame-

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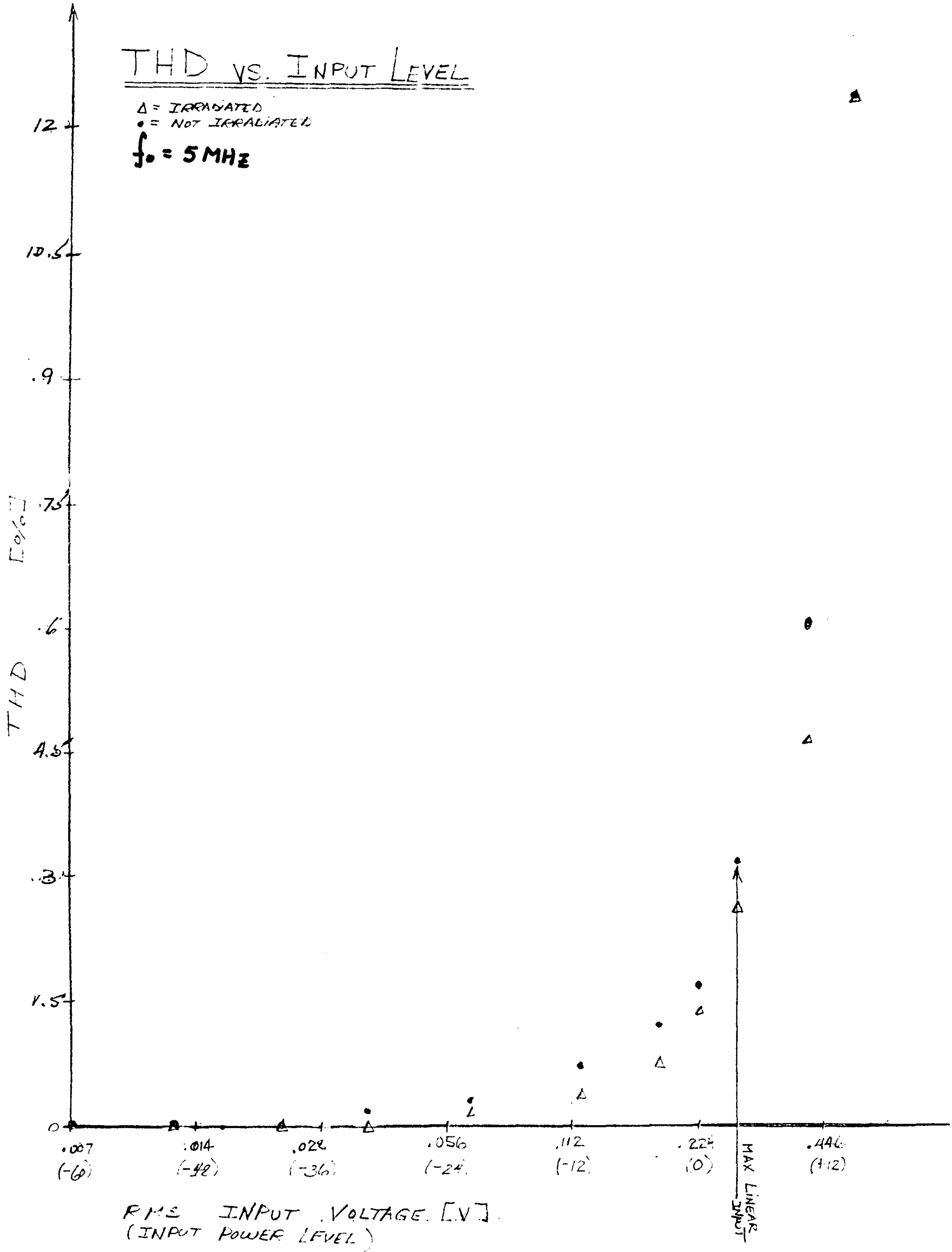
DEPT. OR PROJECT________ FIGURE 3



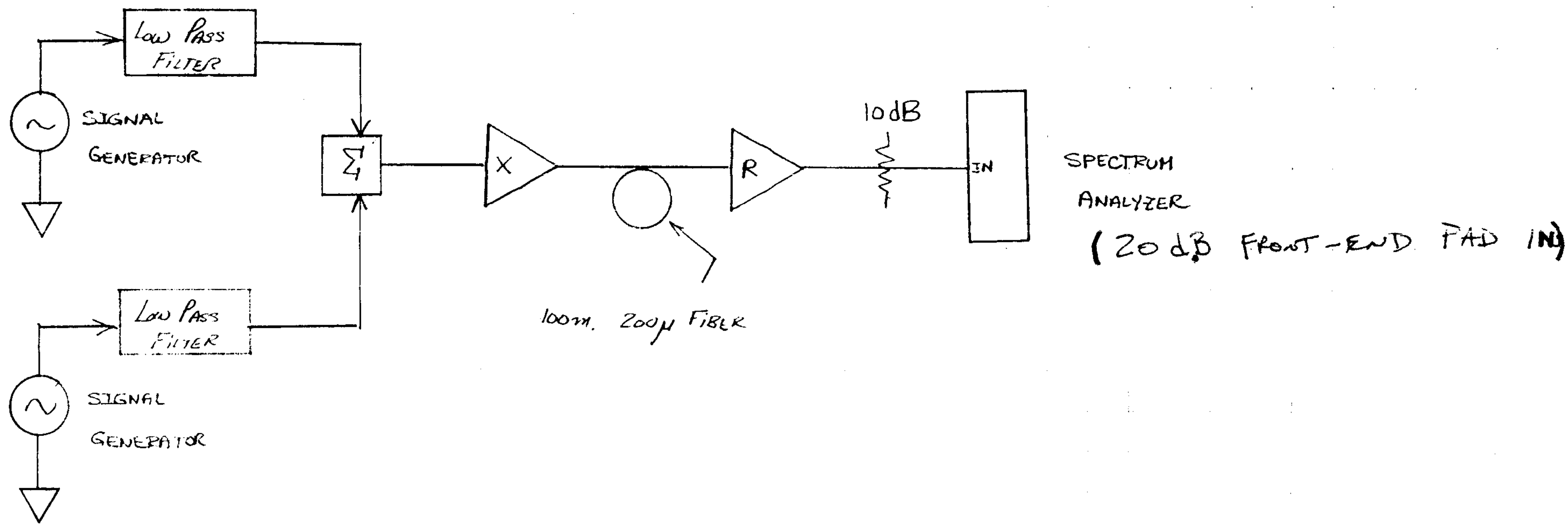


Figure 4: IMD Test Set-up

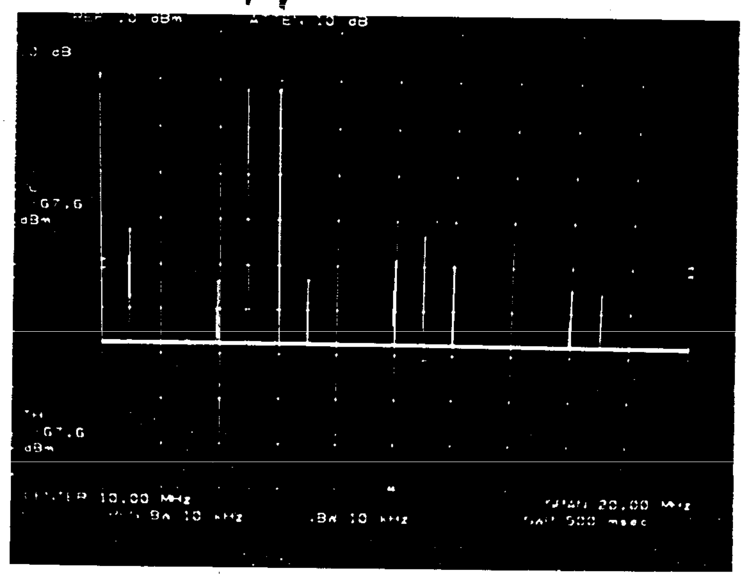


FIGURE 5: SAMPLE OF IMD RESULTS

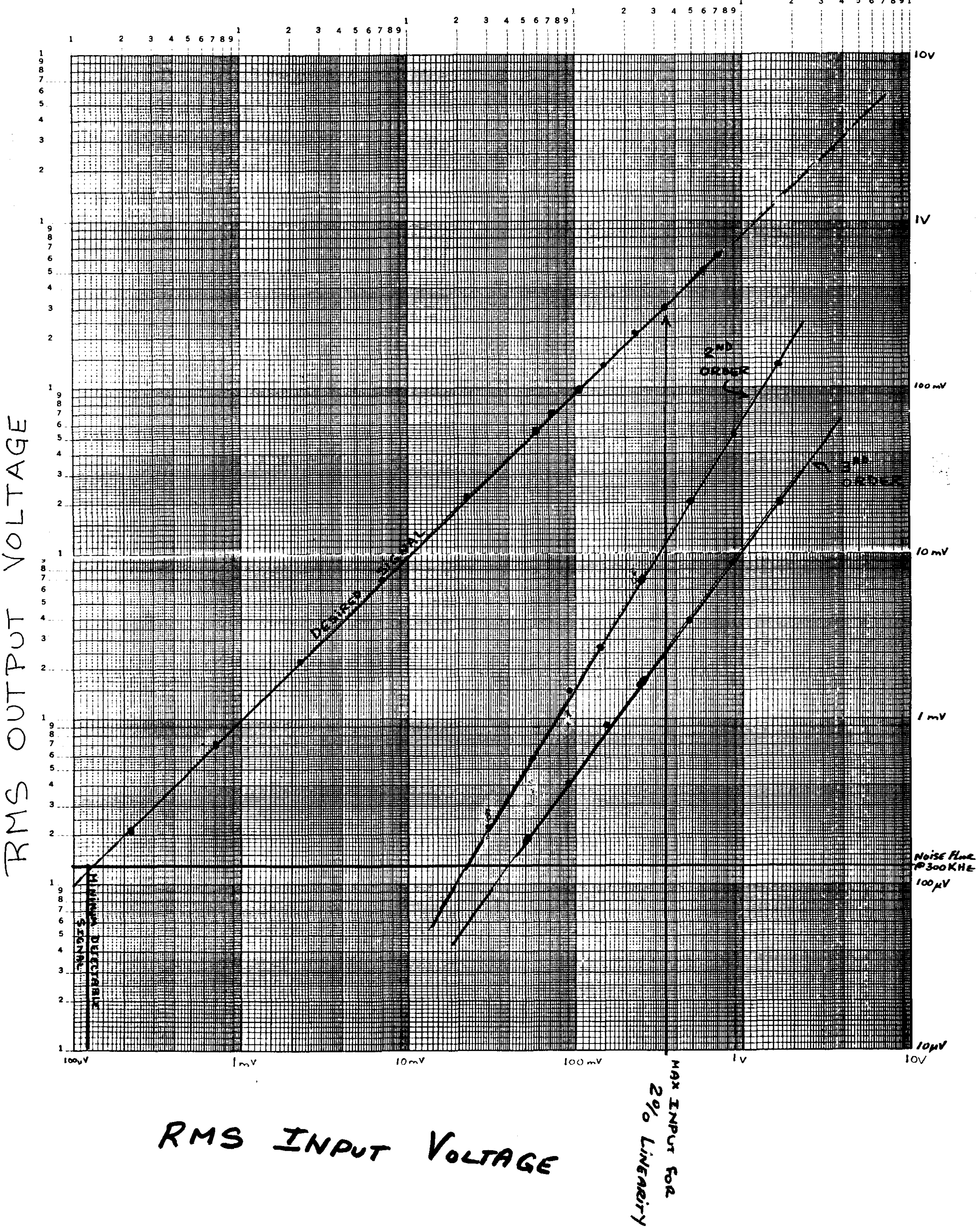
ters is given so that each user can extract their own information (figure 6).

To maximize the SNR several steps can be taken when setting up the link The SNR is bounded by the maximum signal swing and link noise floor. Therefore, if the link is driven with a less than maximum (linear) swing signal the maximum SNR at that link gain will not be achieved. As a result it is desirable to input a 1 V (p-p) signal. In the receiver, the noise floor is proportional to the receiver gain, therefore the transmitter trim pot should be adjusted for maximum optical power output. This minimizes the receiver gain required at any input level. For any transmitter drive signal the receiver setting that provides a 1 - 2 v (p-p) output optimizes the link SNR. If the receiver is set so the link gain is < 1, then the received signal is attenuated without a compensating decrease in the link noise floor. The result is wasted SNR. As the gain is increased the output grows faster than the noise floor and the SNR can be maximized. At higher gains, output swings > 2 V (p-p), the noise floor rises faster than the output and the output will clip causing excessive distortion.

Connector and Fiber

It was found that the SMA connectors do not perfectly align the fiber at the connectors to the transmitter and receiver. The result is varying power transmission due to the connector misalignment. Therefore, care must be exercised when connecting the fiber to the end units, or the resulting transmitted power variation can be as high as 6 db. The best method to connect the fibers is to hold the connector collar and slowly twist the connector without bending the fiber. It has been experimentally verified that this method provides connections repeatable to within 5 %. The connector misalignment does not have any effect on the electrical frequency response of the system except for the resulting attenuation of the signal, which is constant across the band.

During this experiment the effects of radiation and photobleaching on the fibers were tested. The non-irradiated fiber has a transmission efficiency of .977. The irradaited but not photobleached fiber has a transmission efficiency of .936 and the irradiated and photobleached fiber has an efficiency of .916. The results show that the expected benefits of photobleaching did not occur. This can be attributed to a combination of two things. First there is only a small amount of UV power available from the LEDs. Second, because the radiation induced attenuation was small, no photobleaching effects are noticeable. Also, the attenuation in the irradiated fibers as compared to the control fiber increased less than .33 dB. This implies that the HCR fiber selected will work well in the radiation environment.



$f_1 = 5$ MHz, $f_2 = 6$ MHz

FIGURE 6

Radiation Results

A complete link was irradiated in the AGS near the F20 magnet from April 21, 1989 to July 5, 1989. The radiation dose was measured using high range TLDs. The TLDs were periodically changed to avoid saturation of the detectors. After receiving approximately 45 - 50 Krads(Si) the link was removed. During the irradiation the link performance was monitored by injecting a 1 MHz tone into the link. The 1 MHz tone was used because the coax cables available for use in the test could not pass higher frequencies. The link gain at various input amplitudes was periodically checked. It was found that the link gain degraded approximately 1 db over the test. Approximately .3 db of the degradation can be attributed to fiber loss. The remaining .7 db is most likely due to the receiver output buffer gain degradation. This was determined during post-irradation tests in the lab.

After irradiation the link was examined to determine which components caused the link to degrade. The overall frequency response of the control and irradiated links was tested. It was found that the irradiated link had a decrease in high frequency response (figure 7). The two transmitters were tested and it was found that the shape of the frequency responses is identical. However the power outputs differ by approximately 5 db across the dc - 35 MHz band. The drive electronics from both transmitters were tested and results indicate that the output power difference must be due to diode lot variations. It is not expected that radiation has induced any diode degradation because during the irradiation, degradations would have been recorded. Also, it has been reported that GaAs diodes should perform into the megarad doses[2]. The irradiated receiver did show a marked change in frequency response with the high frequency end of the response becoming attenuated. This change in shape (figure 8) correlates very highly with the change in the overall frequency response. The receiver modules were completely tested and it was found that the receiver diode-amplifier plug-in has degraded. It is believed that the GaAs PIN receiver diodes are not affected because of the rad-hardness of GaAs. Therefore, it is suspected that the proprietary transimpedance amplifier in the plug-in has degraded. The exact mechanism for degradation is unknown at this time.

Conclusion

The Meret Inc. MDL288TV and Ensign-Bickford HCR fiber have demonstrated radiation resistance to a cumulative dose equivalent to almost 10 years of unshielded operation in the Booster. The irradiated link has displayed only a degradation in high frequency response. The other link parameters such as transmitter power output, fiber attenuation, and linearity do not appear to be affected. However, if the receivers can be located outside the tunnel or radiation shielded the high frequency response can be preserved. Therefore, the Meret MDL288TV links using the Ensign-Bickford HCR fiber are an excellent candidate for use as the PUE analog data transmission system.

Acknowledgement

The author wishes to thank Dominic Ciardullo and John Cupolo for their aid in measurement and determination of the Link RF parameters.

[1] Memorandum, A. Stevens
[2] Booster Tech. Note 124

IRRAD VS. NON-IRRAD. FREQ RESPONSE

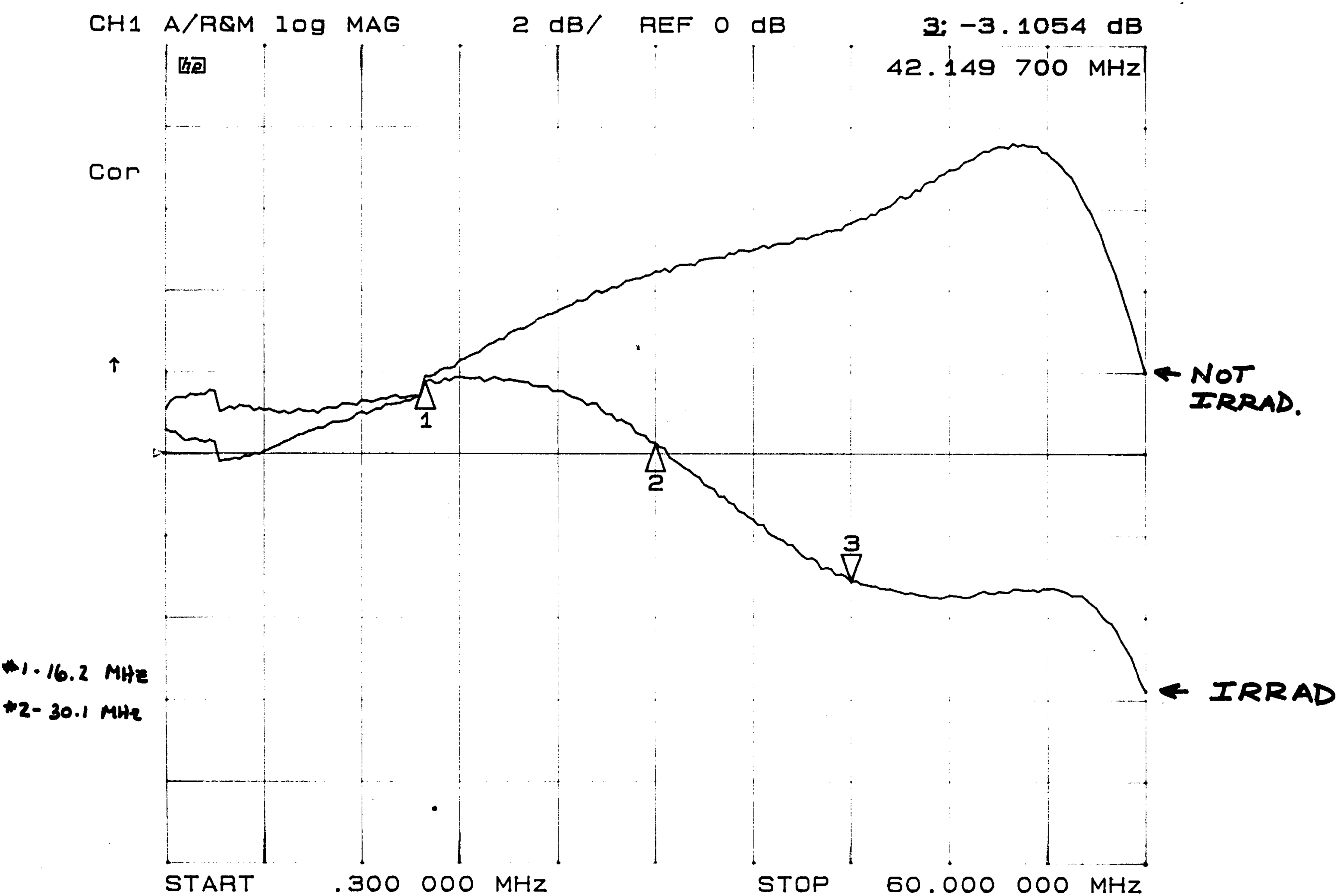


FIGURE 7: LINK FREQUENCY RESPONSE

IRRAD R VS. NOT IRRAD. R (W/ NOT IRRAD XMITR/CABLE)

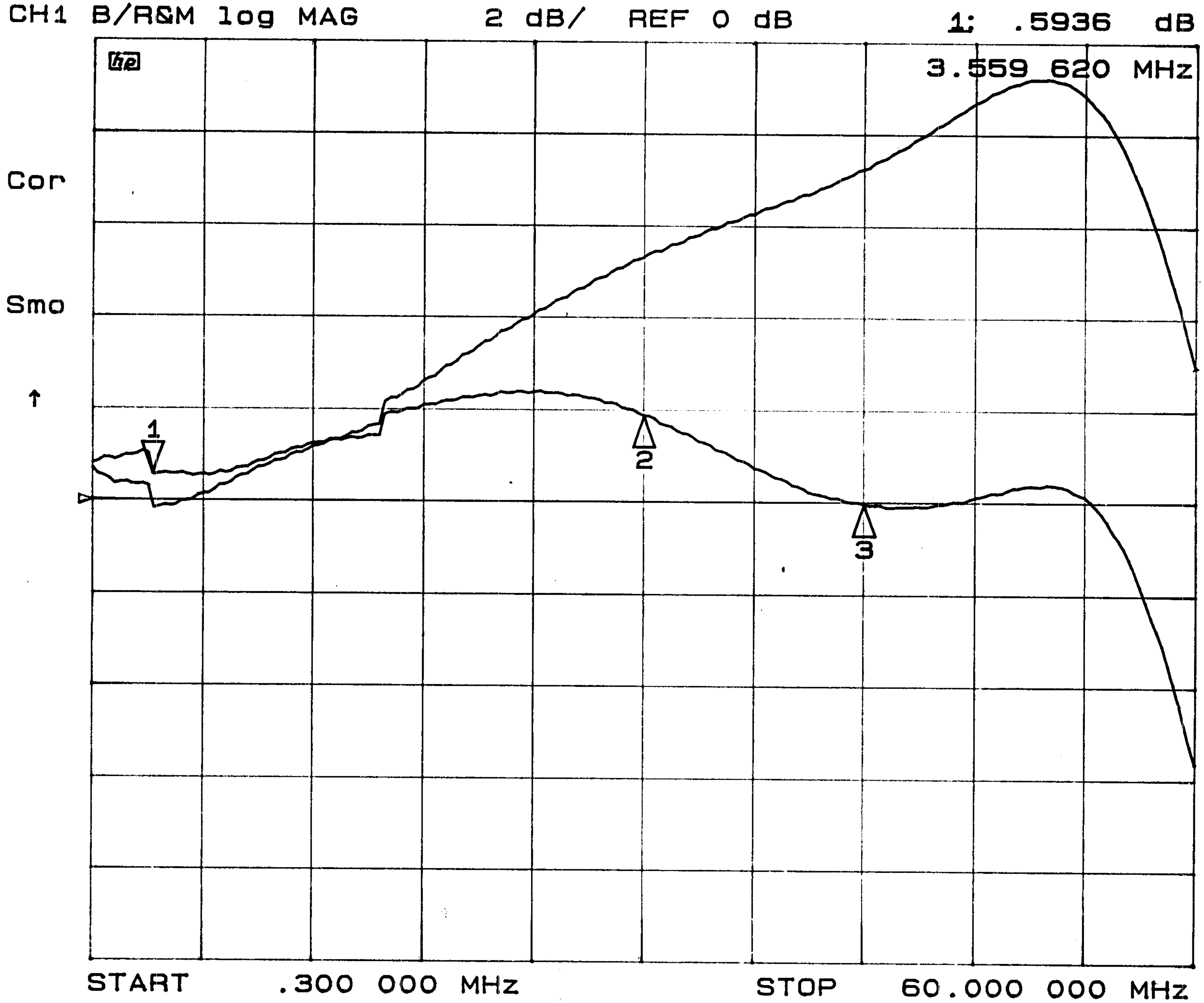


FIGURE 8: COMPARISON OF RCVRS.