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Prototype wide-band analog fiber optic link

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BROOKHAVEN NATIONAL LABORATORY

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Experimental Planning and Support Division Technical Note

AGS/EP&S Technical Note No. 144.

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I. Introduction.

In developing the analog isolation fanout/buffers for the AGS experimental floor instrumentation systems, a preliminary design for a low-cost analog fiber optic link was conceived and tested. The testing was performed to determine if this design is a viable alternative to currently available commercial units for isolated wideband analog data transmission over long distances. The design was based on several technical articles[1,2,3] and the experience gained in the development of the Booster Beam Position Monitoring System (BPM) optical link.[4] The test results indicate that this design provides comparable performance at a much lower cost than currently available units. However, it is recommended that for specific applications this design be further characterized to determine the potential usefulness on a case-by-case basis.

In the table below, the performance of the proposed link and the optical link used in the BPMs, Meret MDL288TV, are compared. The proposed link provides a wider bandwidth and lower noise floor. The reduction in the noise floor accounts for the increase in dynamic range. In addition the low-end cutoff frequency has been decreased, thus reducing the droop encountered on long pulses.

	MDL288TV	Proposed Link
Bandwidth	6 Hz - 30 MHz	.005 Hz - 50 MHz
Noise Floor (20 MHz)	3 mV(rms)	.7 mV(rms)
THD (1 Vp-p @ 5 KHz)	1.22%	1.28%
SNR @ 2% THD (20 MHz BW)	43 db	54 db
Cost (Xmitr/Rcvr)	$800	$100

II. Preliminary Design.

Introduction.

The design of the proposed transmitter and receiver are shown in Figures 1 and 2. This link design uses the Hewlett-Packard X400 series of low cost plastic fiber optic components ($50/pr.). Although these components are most often shown in digital links, they can be successfully used in linear designs. They are attractive for this design due to the small size and low cost.

The design philosophy of this link is to modulate the LED optical output power by directly controlling the LED forward current and to demodulate the optical signal with a PIN photodiode. This technique is called direct intensity modulation (D-IM). D-IM is the simplest and lowest cost approach in optical signal transmission. It is generally limited by the "speed" of the transmit diode. In switching applications, the speed is limited by diode capacitances and carrier lifetimes.[5] However, when using the diode in a linear mode, the limitations imposed by these parameters are not as severe. For example, the present design has an overall bandwidth of > 50 MHz. It is expected that improving the hand-wired prototype layout, and using wider bandwidth components that the system bandwidth can be increased. It is also possible that the transmitter bandwidth can be extended without selecting new components, by simply locating the LED in the collector of the drive transistor rather than the emitter as shown. This alternative reduces the capacitance in the feedback loop, and may increase the bandwidth of the system.

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BY______ DATE 9/29/92 SUBJECT 50 MHz OPTICAL LINK XMITR SHEET No. 1 OF 1

CHKD. BY______ DATE______ JOB No.______

DEPT. OR PROJECT______

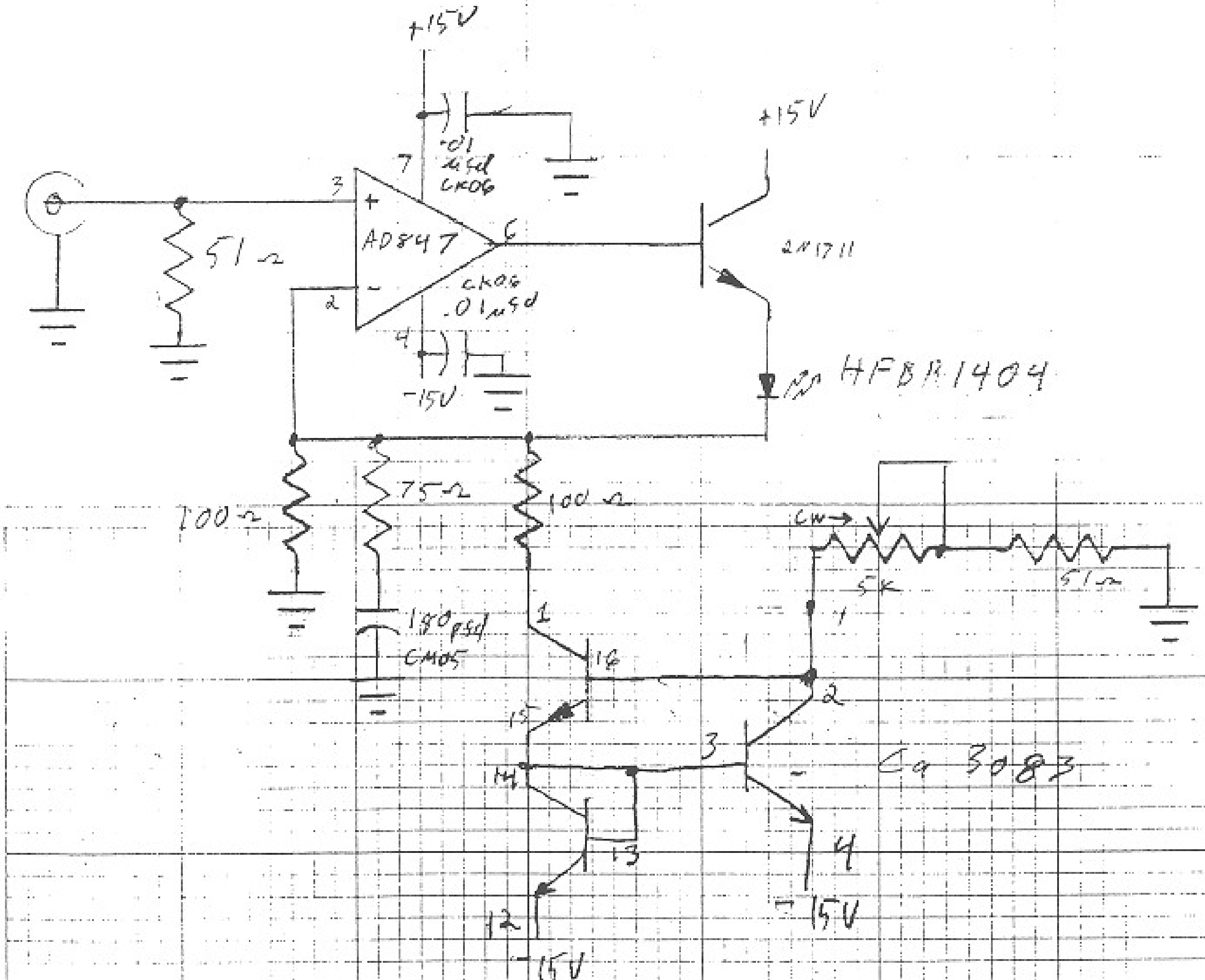


FIGURE 1: TRANSMITTER

BY________ DATE 9/29/92 SUBJECT 50 MHz OPTICAL LINK RCVR SHEET No. 1 OF 1

CHKD. BY________ DATE________ JOB No.________

DEPT. or PROJECT________

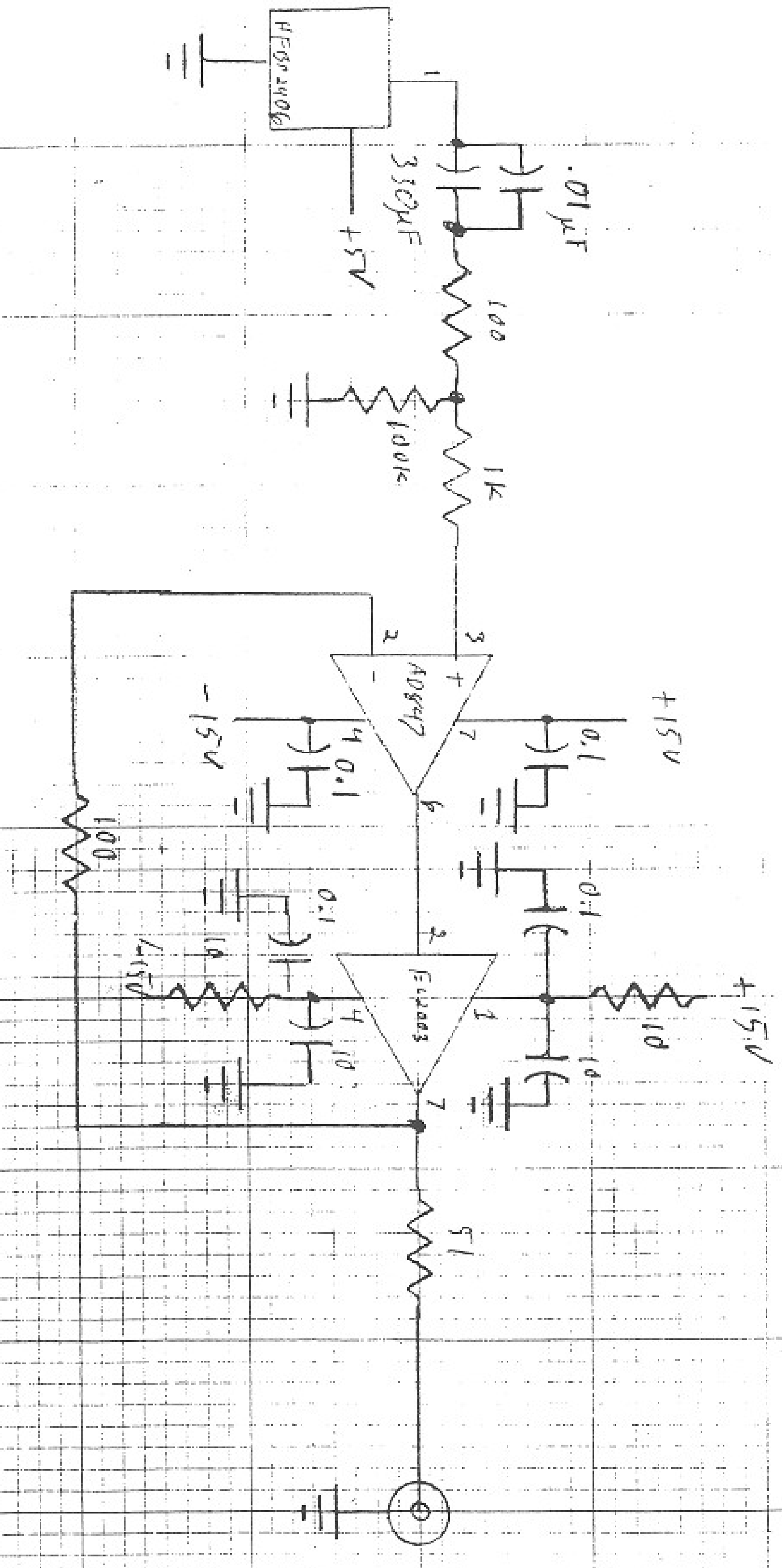


FIGURE 2: RECEIVER

Transmitter Design: (Figure 2).

The circuit is designed as a transconductance amplifier with a constant current bias for the LED. The current source and negative feedback of the amplifier cause the LED bias to remain constant, independent of the LED v-i characteristic. This helps stabilize the DC operating point of the link against parameter variations in the diode.[6] The opamp is used in the voltage follower configuration, thus the full unity-gain bandwidth (50 MHz nominal) is available. The input voltage is directly impressed across the 100 ohm resistor, and due to the virtual ground of the amplifier, a current proportional to the input signal will flow. This current is the LED's modulation. Thus the amplifier acts as a voltage-to-current converter with negative feedback used to linearize the relation between V_{in} and P_{out}. In addition, the distortion can be further reduced by selecting LEDs optimized for analog data transmission.[7,8] These diodes will provide a more linear transfer curve of output power versus drive level than the diodes intended for digital links, such as the HFBR-1404, where harmonic distortion is not a concern. Finally, feedback in the transconductance configuration provides a method by which the LED's modulation depth, which is the peak-to-peak excursion of the diode current around the bias point, is unaffected by the variations in the LED forward voltage or v-i characteristics of the one used. It is reported in [6] that by using feedback, as is done here, the LED optical power swing will be unaffected by choice of LED.

The 100 ohm resistor can be either increased or decreased, so that for a given peak-to-peak input, the circuit achieves the largest modulation depth consistent with"linear operation." Therefore, the signal-to-noise ratio and linearity are optimized together. The definition of linearity will depend on the allowable total harmonic distortion tolerable in an application.

Three transistors are used to form the constant current source for the LED bias. The bias is set at 16 mA by using the pot and monitoring the voltage drop across the 100 ohm resistor in series with the source. The bias point was selected by trial and error in order to simultaneously maximize the bandwidth, linearity, and dynamic range. It was found that the standard two transistor current source cannot be used in this application because the typical output impedance for NPN type transistor is very low when supplying current over 1 mA. The low output impedance is problematic when the 100 ohm resistor is increased to control the modulation depth of the LED. Therefore, the Wilson source shown in the figure was used. This source provides an output impedance of roughly $\beta/2$ times that of the two transistor sources.[9]

Receiver Design: (Figure 2).

The receiver design is very simple and consists of a PIN photodiode and a pre-amp packaged together. The part selected is the Hewlett-Packard HFBR-2406. This part is rated for a frequency response of 125 MHz. The receiver circuit is DC blocked to remove the effects of the PIN diode bias. The blocking capacitor is 330 uF, and the .01 uF capacitor is used as a high frequency bypass of the inductive nature of the larger capacitor. The 100 kOhm resistor to ground provides the AD847 with a bias path, as well as setting the lower corner of the link response. The R-C time constant set by the receiver is nominally 33 seconds. Using a single pole model, this equates to a lower cut-off frequency of .005 Hz. The output amplifier (AD847 and EL2003) is a unity-gain follower with a current boosted output.

III. Test Results.

Transfer Curves.

Both the Meret and proposed optical links were injected with a 5 KHz tone varied over a range of 0-3 Vp-p in 100 mV increments. The outputs were recorded on the HP3561 Dynamic Signal Analyzer and Tektronix 2430A Oscilloscope. The resulting input/output transfer curves are shown in Figures 3 and 4. These curves were the best-fit curves determined by the Tablecurve 3.0 curve-fitting program.

Total Harmonic Distortion.

The THD for both links was also measured as a function of signal level over the 0-3 Vp-p range using a 5 KHz tone. The low frequency tone was selected so that the instruments available would be able to capture up to the 20th harmonic.

The test results show that for outputs of less than 1 Vp-p the proposed link has a lower THD than the Meret link. At 1 Vp-p the two links are both similar with approximately 1% THD. Above 1 Vp-p the Meret link performs better, with its THD increasing at a slower rate. Sample THD plots are shown in Figures 5 and 6.

In addition, the test results show that below approximately 1 Vp-p at the output, the proposed link's THD is caused by the nearly equal amplitude of the second and third harmonics,

TRANSFER CURVE FOR HP1404/2406 LINK

r^2=0.999995123 FitStdErr=0.0399617023 Fstat=410116.282

Rank 1 Eqn 6006 $y=a+bx+cx^2+dx^3+ex^4+fx^5+gx^6+hx^7+ix^8+jx^9$

a=-3.6179054E-06 b=556.36509 c=-155.08981 d=341.7395 e=-141.62031

f=-215.28921 g=272.91704 h=-127.91505 i=27.92104 j=-2.366157

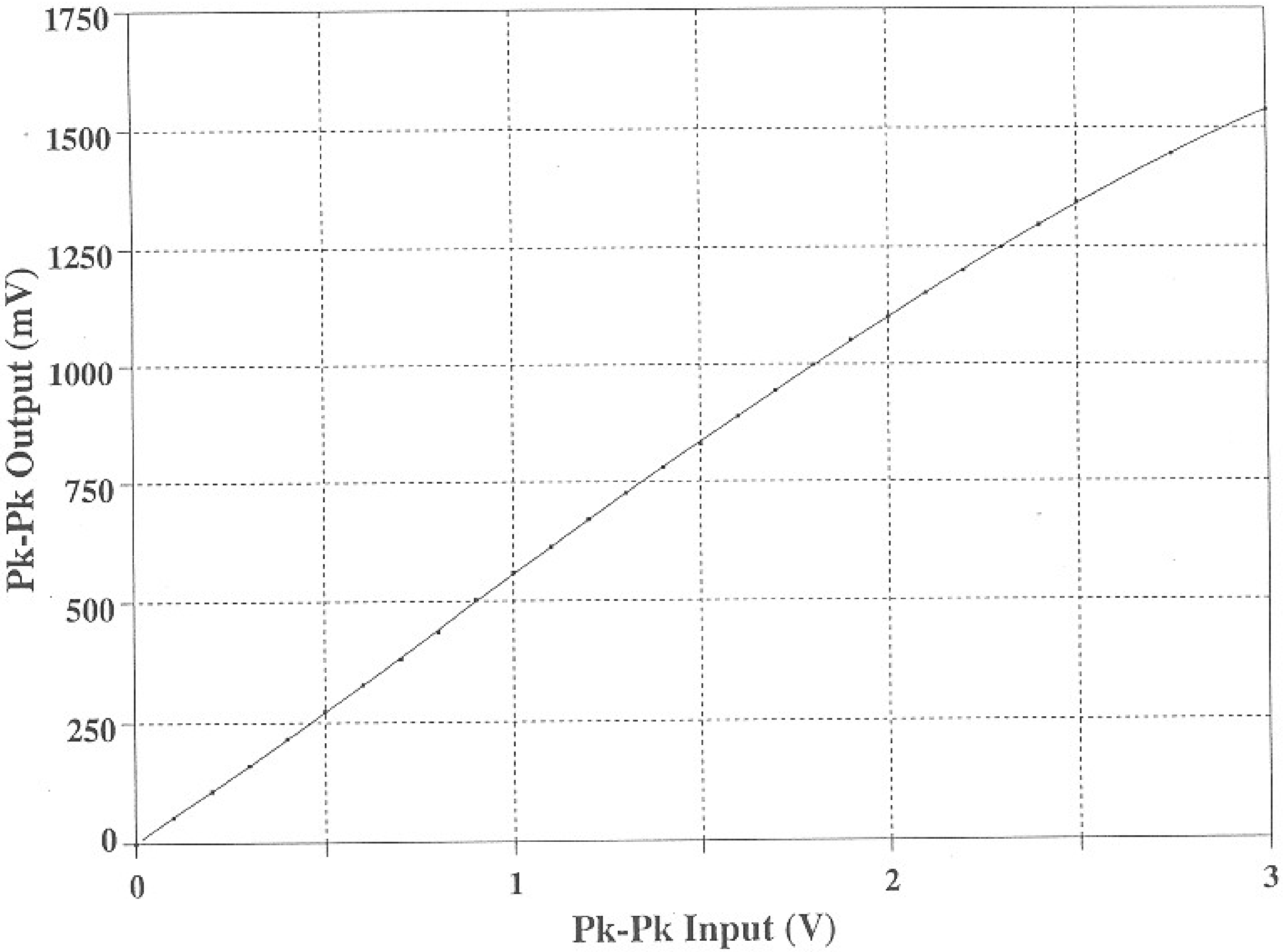


FIGURE 3

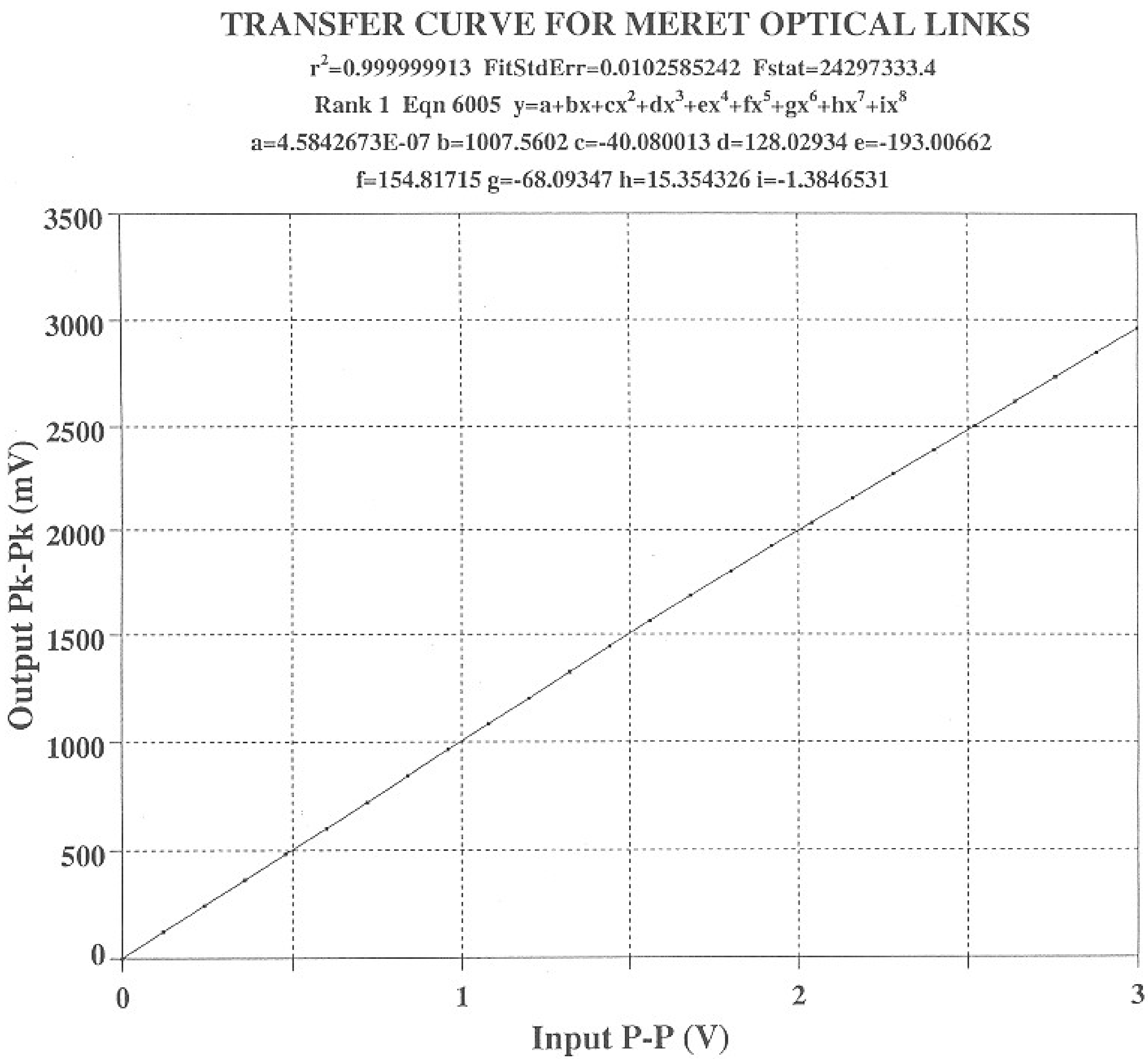

TRANSFER CURVE FOR MERET OPTICAL LINKS
r²=0.999999913 FitStdErr=0.0102585242 Fstat=24297333.4
Rank 1 Eqn 6005 y=a+bx+cx²+dx³+ex⁴+fx⁵+gx⁶+hx⁷+ix⁸
a=4.5842673E-07 b=1007.5602 c=-40.080013 d=128.02934 e=-193.00662
f=154.81715 g=-68.09347 h=15.354326 i=-1.3846531
Output Pk-Pk (mV)
Input P-P (V)
3500
3000
2500
2000
1500
1000
500
0
0
1
2
3

FIGURE 4

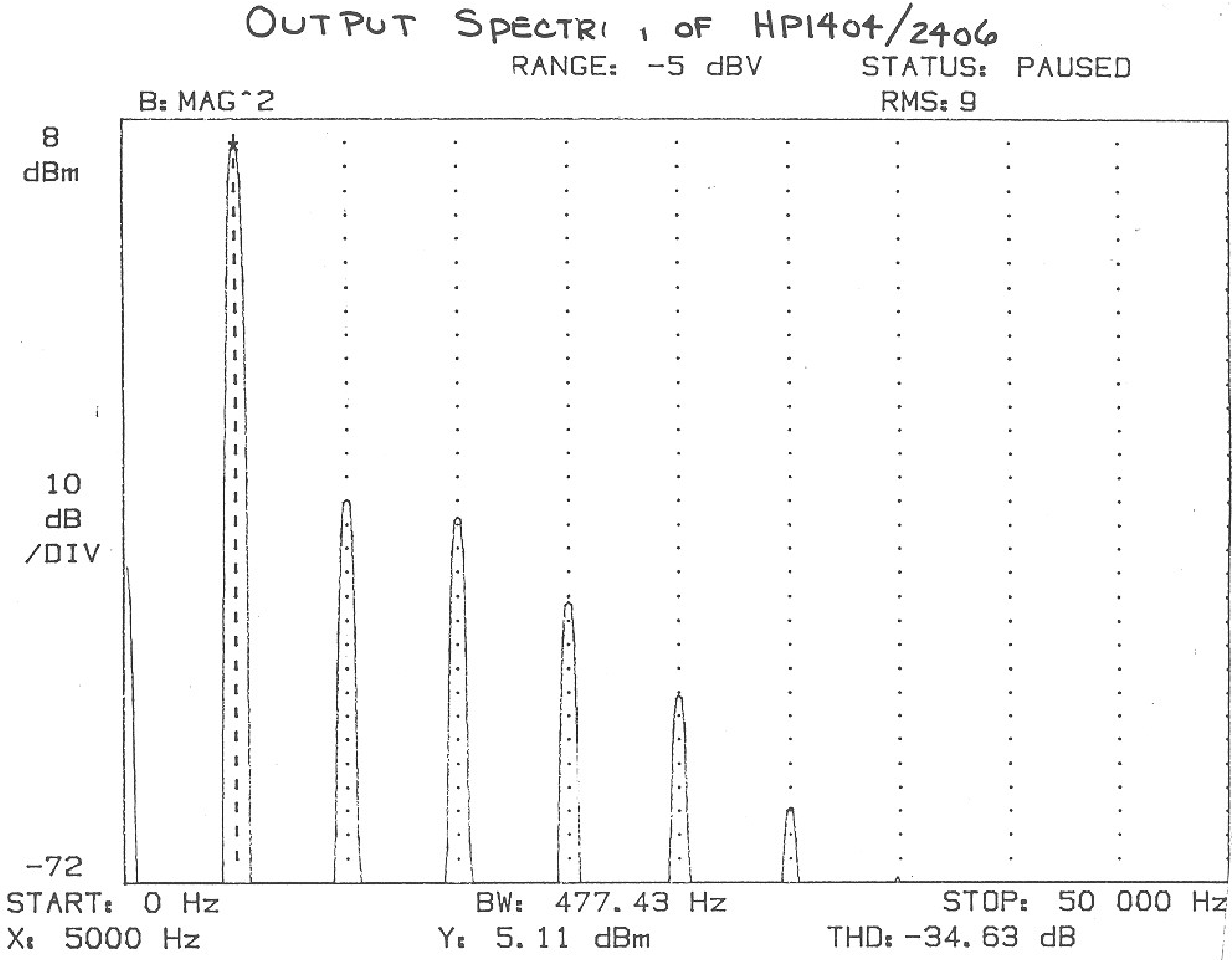
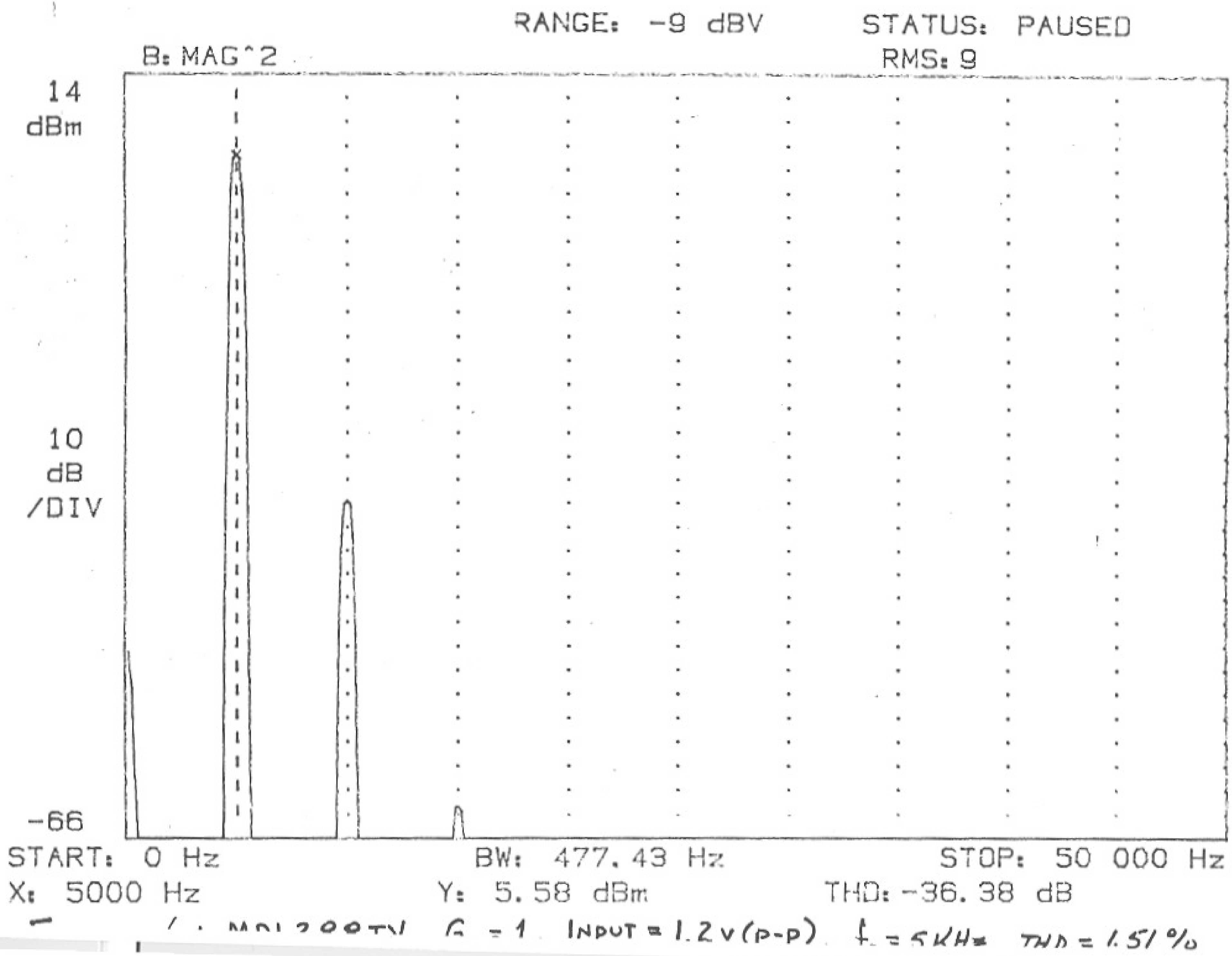


FIGURE 5: HP1404/2406 G = 5 INPUT = 2.0 V(P-P). f_o = 5KHz. THD = 1.86%

OUTPUT SPECTRUM OF MDL288TV



where in the Meret link the second harmonic is predominate. Also, in this range the proposed link has lower THD. Above 1 Vp-p the proposed link shows increases in the fourth and fifth harmonic, while the second and third increase at nearly the same rate. The Meret link showed a more characteristic pattern where as the input level is increased in the linear region, the higher order harmonics grow at faster rates.

Frequency Response.

The overall frequency response is shown in Fig. 7. The response was tested at several DC forward currents. An input signal level of + 4 dbm (1 Vp-p) was selected for this test. The test resulted in showing that a bandwidth of 51.3 MHz was achievable with a bias of 15 mA.

Another bandwidth test was performed to determine the effects of the AC coupling in the receiver. A very low frequency pulsed signal, similar to the type encountered by instrumentation was used and the link response is shown in Fig. 8. The DC offset shown in the output waveform is from the bias current of the AD847. This error can be removed by including some simple DC offset adjustment circuitry.

Using Fig. 8 and assuming a single pole roll-off model for the link, the circuit shows a 35 second time constant which is equivalent to a pole at .0048 mHz. Thus, the droop over 1 second, the nominal AGS spill duration, is approximately 2.8%. Of course the time constant can be increased further if necessary.

Noise Floor.

The noise floor for the proposed link and the Meret link are shown in Fig. 9. This test was performed into a digital storage scope using the 20 MHz bandwidth limit. Thus, aliasing caused by the scope is minimized, and also 20 MHz is within the passband of both links. In both links the link noise is dominated by the receiver noise, and as shown in the figures, the Meret link has a higher noise floor than the proposed link. It was verified though, that the noise level difference was not due to the difference in link gain. It was also verified that at link gains above 2, the Meret link noise floor increases dramatically.

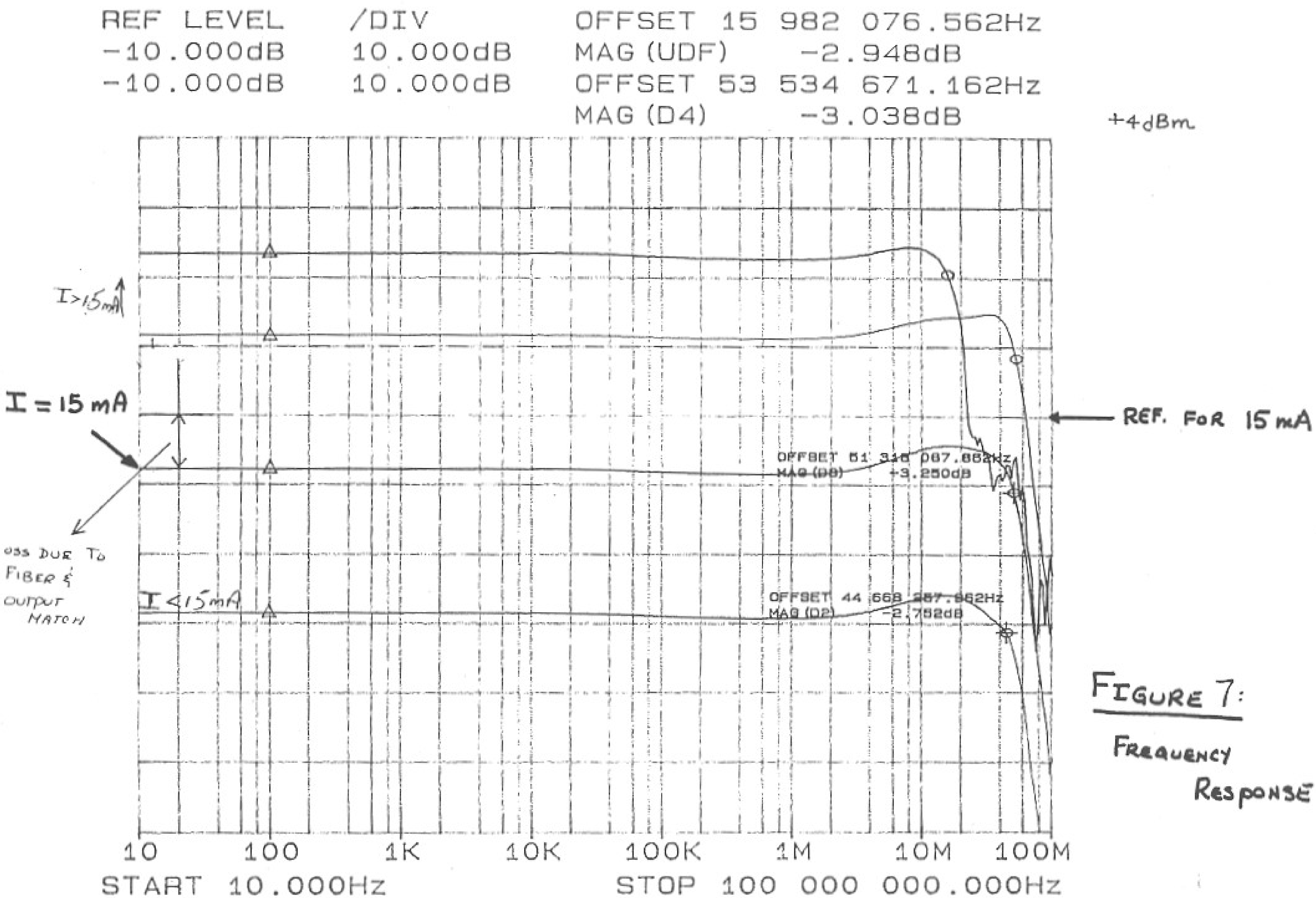


FIGURE 7: Frequency Response

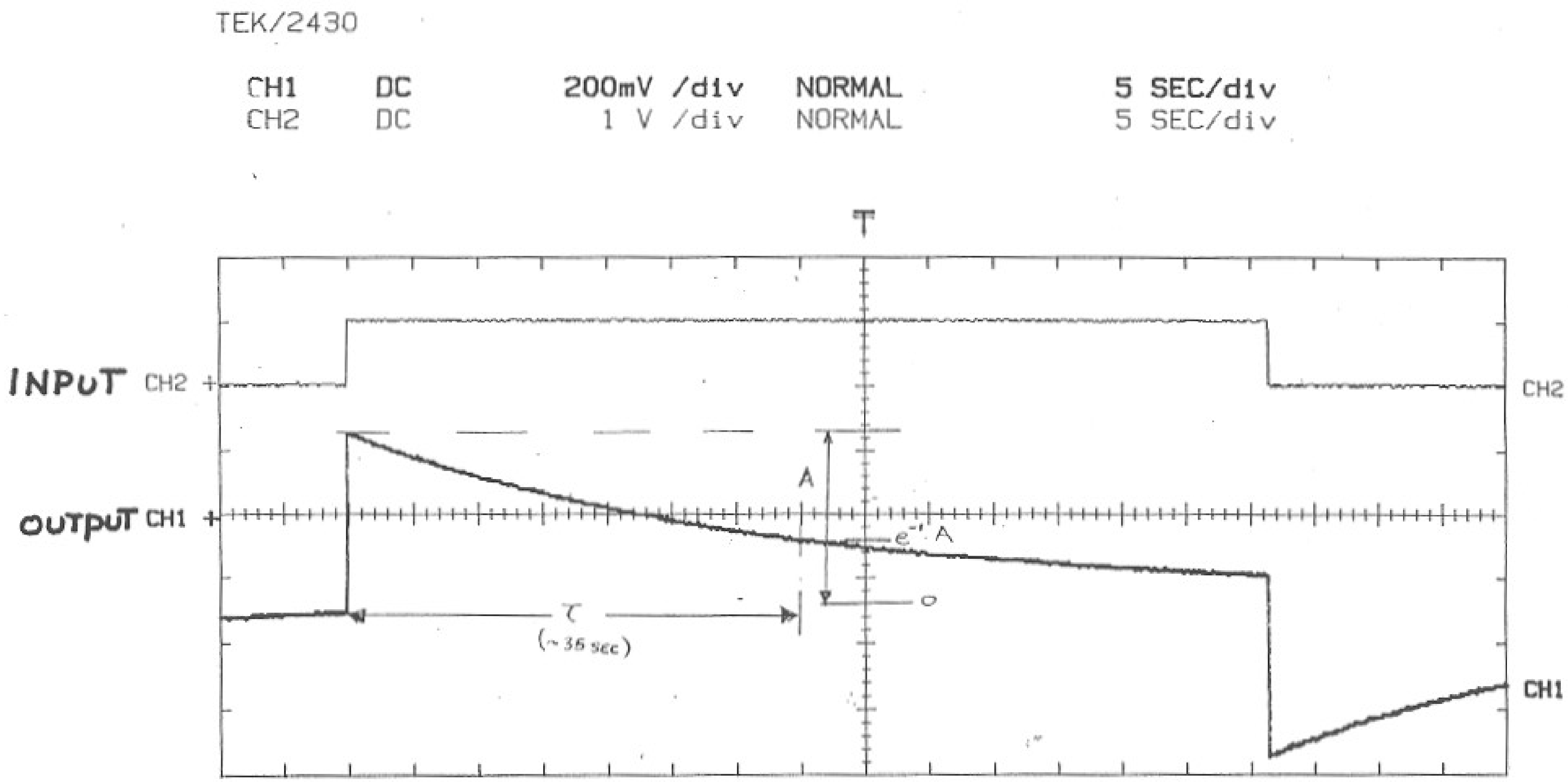
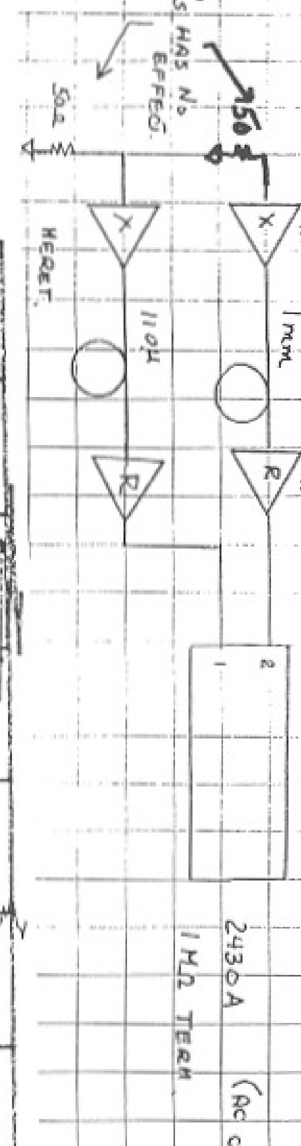


Figure 8: HP1404/2406 Response To Low Frequency Pulse

FIGURE 9: NOISE TESTS

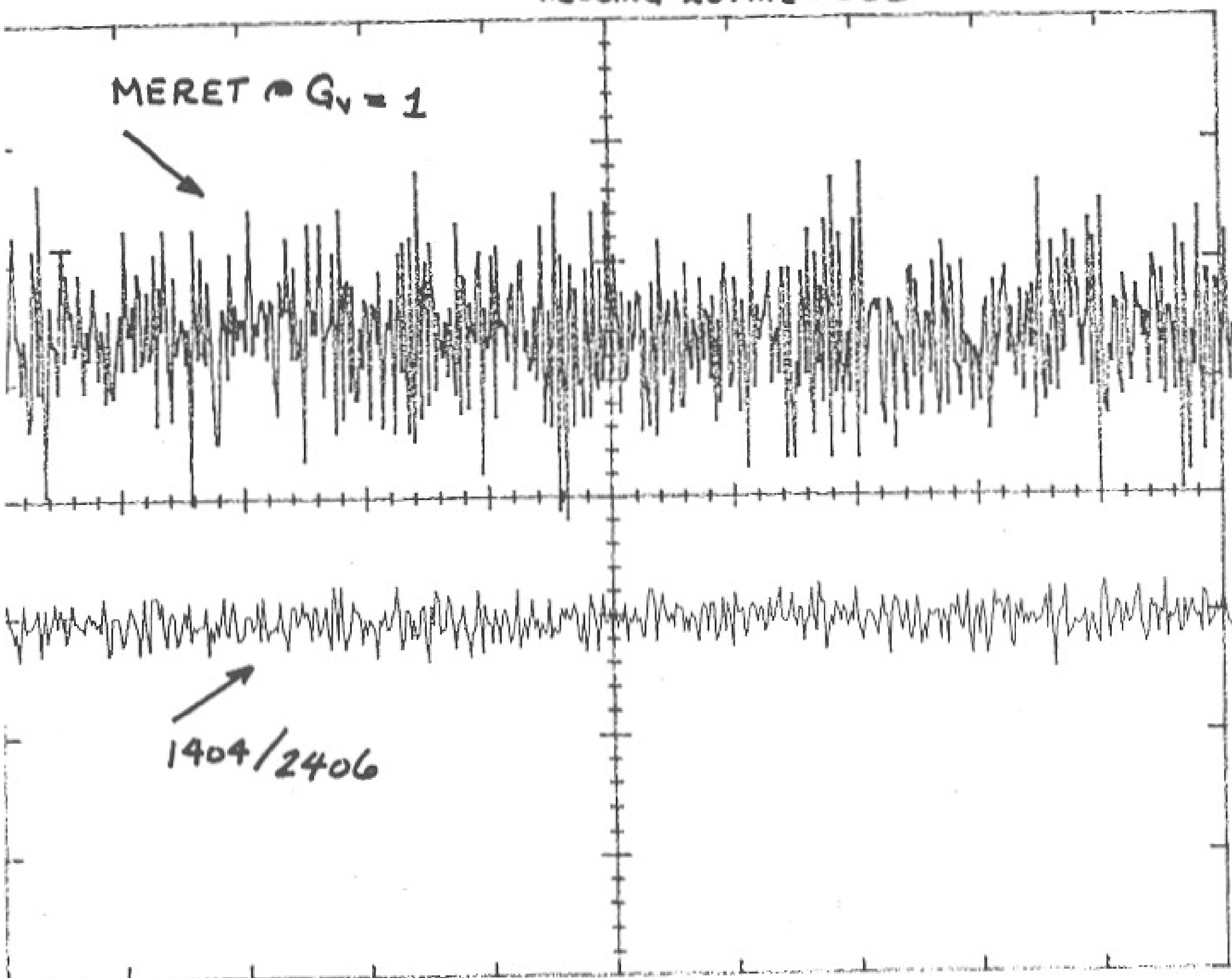
3/12 NOISE TEST:

① COMPARE MERET LINK TO HP LINK, MERET SET @ $G_V = 1$ (AS MONITORED BY SCOPE)
HP @ NOMINAL G_V (SEE TRANSFER CURVE)
SCOPE IS ON 20MHz BW LIMIT, & TB SET FOR MAX VALUE FOR USB = 20MHz.



CH1	5mV	BW	A	1μs	0.0 V	LINE
CH2	5mV~	20MHz				

SLOWEST SWEEP YIELDING 20MHz = USB



CH1	P-P	=	16.0mV
CH1	RMS	=	3.0617mV
CH2	P-P	=	3.80mV
CH2	RMS	=	700.49μV

MERET $G_V = 1$

IV. Conclusions.

The proposed design has performed well in the initial testing; however, for future applications further testing is warranted. These tests should include long-term stability, aging, drift and repeatability of the design. Also a search for a LED/PIN diode combination more suitable for analog transmission should be conducted. However, the much lower cost and increased packing density offered by this prototype solution make even this design a viable alternative to higher cost commercially units.

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