OVLBI-ES MEMO NO. 40

Tests of Digital Attenuators

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1 General

A couple of different models of digital attenuator have been tested for use in the OVLBI X- and Ku-band downconverters. The IF portion of the downconverter has been designed to have a programmable attenuation function so that the signal level can be set before the tracking pass, according to the *expected* received signal level. To account for the possibility of not knowing the correct setting with enough precision before the pass, the level may have to be changed during the pass. Another reason why switching might be needed during a pass is if either the two-way-timing or Costas demodulator modules did not the approximately 20 dB dynamic range expected on any given tracking pass.

Two specifications which are not always listed in manufacturer's data sheets for digital attenuators are the switching characteristics and the phase characteristics. These are both important in our application, the former because of the high data rate (72 Mb/sec) of the spacecraft (one symbol every 14 nsec). The latter is important because the two-way-timing module is keeping track of the round-trip phase, and should a switch in the attenuation level cause a phase 'glitch', the calculated round-trip phase would be incorrect.

The digital attenuators tested were:

- Mini-Circuits ZSAT-31R5 6-Bit (0.5,1,2,4,8,16 dB) attenuator DC-1 GHz
- Alpha AK002D2-24 2-Bit (16,32 dB) attenuator DC-2 GHz
- Alpha AK002D4-24 4-Bit (1,2,4,8 dB) attenuator DC-2 GHz

The two ALPHA attenuators were cascaded in a hybrid circuit to effect one 6-bit attenuator. A number of tests were performed on both attenuators, the results of which follow.

2 Phase measurements

These measurements were done on an HP8720 Network Analyzer with a full 2-port calibration.

- Mini-Circuits attenuator attenuation response vs frequency. This is shown in Figure 1, S_{12} vs. frequency from 200 MHz to 2 GHz, for attenuation levels of 0, 0.5, 1.0, 1.5, 4.0, 8.0, 16.0, 24.0, and 32.0 dB. The insertion loss in the 0 dB state is 5.12 dB at 500 MHz, ramping linearly up to 5.45 dB at 1000 MHz. The change in attenuation with frequency looks nearly the same for all attenuation levels, thus $\frac{\Delta_{dB}}{Delta_f} = .00066\frac{dB}{MHz}$.
- Mini-Circuits phase shift vs. frequency (parameter-attenuation). Figure 2 shows this characteristic, $\frac{S_{12}}{M}$, with M being the transmission phase of the insertion loss (0 dB) state. The Mini-Circuits attenuator has 4-bits (0.5,1.0,2.0, and 4.0 dB) with negative phase shift, and 2-bits (8 and 16 dB) with positive phase shift. The total phase shift can be found by adding the phase shift from each of the bits. For example, at 500 MHz, the 1-dB phase shift is -5 degrees, and the 16-dB phase shift is +3 degrees, so the total phase shift for 17 dB would be -2 degrees. What is important to us is not the phase shift relative to the insertion loss state, but the phase jump between any two attenuation states. With a little thought it can be shown that at 600 MHz, the greatest possible phase jump for this device is 25 degrees, when the attenuation is changed from 24 dB to 7.5 dB. Using a switching algorithm of some sort would probably reduce the greatest phase shift to much less than this value.

- Alpha attenuator response vs. frequency. This is shown in Figure 3. The insertion loss at 500 MHz is 3.5 dB, and 4.8 dB at 1000 MHz. Although it does not slope in a perfectly linear way across the band, if one calculates the average dispersion of attenuation, it is $.0026\frac{dB}{MHz}$. It should be noted that the SMA feedthroughs on the attenuator package were not well-matched, and this may have degraded the performance somewhat at the higher end of the band.

- Alpha attenuator phase shift versus frequency with attenuation level as parameter. This is shown in Figure 4. Again the phase shift is shown for each bit with the 0 dB state as a reference. The lower graph shows the unreferenced phase shift. The Alpha attenuator has good phase shift response, the 1,2,4, and 8 bits have phase shift less than 2 degrees from 500-1000 MHz. The 16 dB bit is +5 degrees from 500-1000 MHz. The 32 dB bit goes from 12 to 40 degrees from 500 to 1000 MHz, however, this bit will generally not be used, as our original specification was for a 0-31 dB attenuator in 1 dB steps. Note that all of the phase shifts are in the same direction. Thus in switching from 0 to 31 dB, the phase shift would be about 19 degrees at 1000 MHz. This is really worse than worst case because we do not expect to switch in such a large attenuation value. In practice the phase shift would be easily kept to 5 degrees, which is 1/72 of a cycle, or 21 psec at 660 MHz.

3 Switching

The test setup for the switching is shown in Fig. 5. An RF signal of either 250 or 500 MHz is input to the attenuator, and the desired bits are switched with a 100 kHz pulse generator at TTL levels. The output is monitored on a Tektronix analog oscilloscope. Only the Alpha attenuator switching characteristic was measured, because it is a GaAs device with very fast switching times, and the switching transients were of interest to us. The following table shows the results of the switching tests.

Switch Test Results					
Photo	f_{rf}(Mhz)	f_{mod}(kHz)	V/div	t(nsec)	Bits(dB)
1	250	10	?	10	16
2	250	10	?	10	16
3	250	10	?	20μsec?	32
4	250	10	?	20	16,2
5	250	10	?	10	16,2
6	500	100	$\frac{2V}{5mv}$	$\frac{2000}{100}$	8
7	500	100	$\frac{2V}{5mv}$	$\frac{2000}{100}$	8
8	500	100	$\frac{2V}{5mv}$	$\frac{2000}{100}$	16
9	500	100	$\frac{2V}{5mv}$	$\frac{2000}{100}$	16
10	500	100	$\frac{20mV}{5V}$	$\frac{1000}{20}$	8,32
11	500	100	$\frac{20mV}{5V}$	$\frac{1000}{20}$	8,32
12	500	100	$\frac{20mV}{2V}$	$\frac{500}{20}$	8,16
13	500	100	$\frac{20mV}{2V}$	$\frac{500}{20}$	8,16

Table 1: Switching waveforms for cascaded 6-bit Alpha attenuator. f_{rf} is the RF frequency, f_{mod} is the switching pulse frequency. Several photos show both the RF and switching waveforms for both long and short time scales, so two voltage and time scales are listed.

<u>Discussion:</u>

- Photos 1 and 2 show the rising and falling edge of the envelope for a 16-dB switching waveform. The rising edge gets pinched off by 6 to 10 dB (estimate) for about 5 nsec. Phot 3 shows the switching pulse and the RF envelope for 32 dB switching. Note that the switching waveform has a risetime and falltime on the order of some microseconds, while for the switch the rate is impereptible at this scale.

- Photos 4 and 5 show switching waveforms for 2 dB and 16 dB. Note the 10 nsec pinch-off on the rising edge.

It was thought at the time that there might be something wrong with one of the chips when this photo was taken, so it was replaced. Photos 10-13 show results with new chip in place. Results follow, which show the *16-dB bit anomaly.*

- Photo 6: The switching waveform is superimposed on the RF waveform. The waveform on top is 2 usec/div, while the one below is 100 nsec/div. This shows the typical characteristic for 1,2,4,8, and 32 dB switching (8 dB in the picture).
- Photo 7: This is the same as Photo 6, only for 16 dB switching. Note the difference: because the input impedance to the 16 dB pin is very low (around 20 ohms), the pulse generator only goes 0-3V instead of 0-5V. However, the switching is still good.
- Photo 8: Rising edge waveform characteristic for 1,2,4,8,32 dB (8 dB shown).
- Photo 9: Falling edge waveform for 16 dB. This is the trouble-spot. The switching waveform voltage is reduced due to the low input impedance of the pin, but now 3V is barely enough to cause the 16-dB attenuator to turn on, and when it does 200 nsec have elapsed.

The switching delay caused by the 16-dB bit is not necessarily bad in itself, but if two bits are being switched, one will likely switch well before the other. Thus the next series, photos 10-13, show switching of two bits.

- Photos 10-11 show switching waveforms for 40 dB(8, 32 bits) switching. The distinct action of the two bits can be seen in each case, with switching times of 30 and 50 nsec for the rising and falling edges of the envelope.
- Photos 12-13 show the switching waveforms for the 24 dB(8,16 bits). Again there is a distinct level between the off and on states due to one bit switching before the other. In this case, the 16 dB bit lags the 8 dB bit. For the rising edge the total switching time is 60 nsec and for the falling edge it is 200 nsec due to the large delay of the 16 dB bit.

4 Improve Switching Speed

A further effort was made to see if the 16 dB switching result was inherent in the devices. First, the feedthrough capacitors were removed from the TTL-bias lines of the package to improve the risetime of the driver. Also, the 2-bit attenuator was replaced with a new chip. Figure 14-16 show results of these measurements.

- Figure 14 shows 16 dB switching. The control voltage is now 0-5V, and the risetime of the control pulse is less than 10 nsec. The switching delay, the amount of time after the start of the control pulse until the time that the new RF level is present, is about 15 nsec. Figure 15 shows the same switching results for the rising control edge, with slightly better switching times.
- Figure 16 shows 4- and 8-dB switching, where the switching is done alternately, so that when the 4-dB bit is on, the 8-dB is off, and vice-versa. This looks good.
- The problem area in the new configuration is now the 32-dB bit, which does not switch at all. The control pulse to the 32-dB bit swings from 0-2V so that the switching level is never reached. A lower impedance driver might drive the bit, but it begs the question, what causes the sporadic performance of these attenuators?

5 Conclusions

The development of a reliable, fast, and phase-free digital attenuator continues. The reliability is the biggest question, and towards improved reliability we will be ordering some new devices from Alpha which are protected against damage to the devices in case the TTL signals are applied before the power. That may have been the reason for the sporadic switch performance. The attenuators already appear to switch fast enough and have adequately-low phase shift from one state to the next.

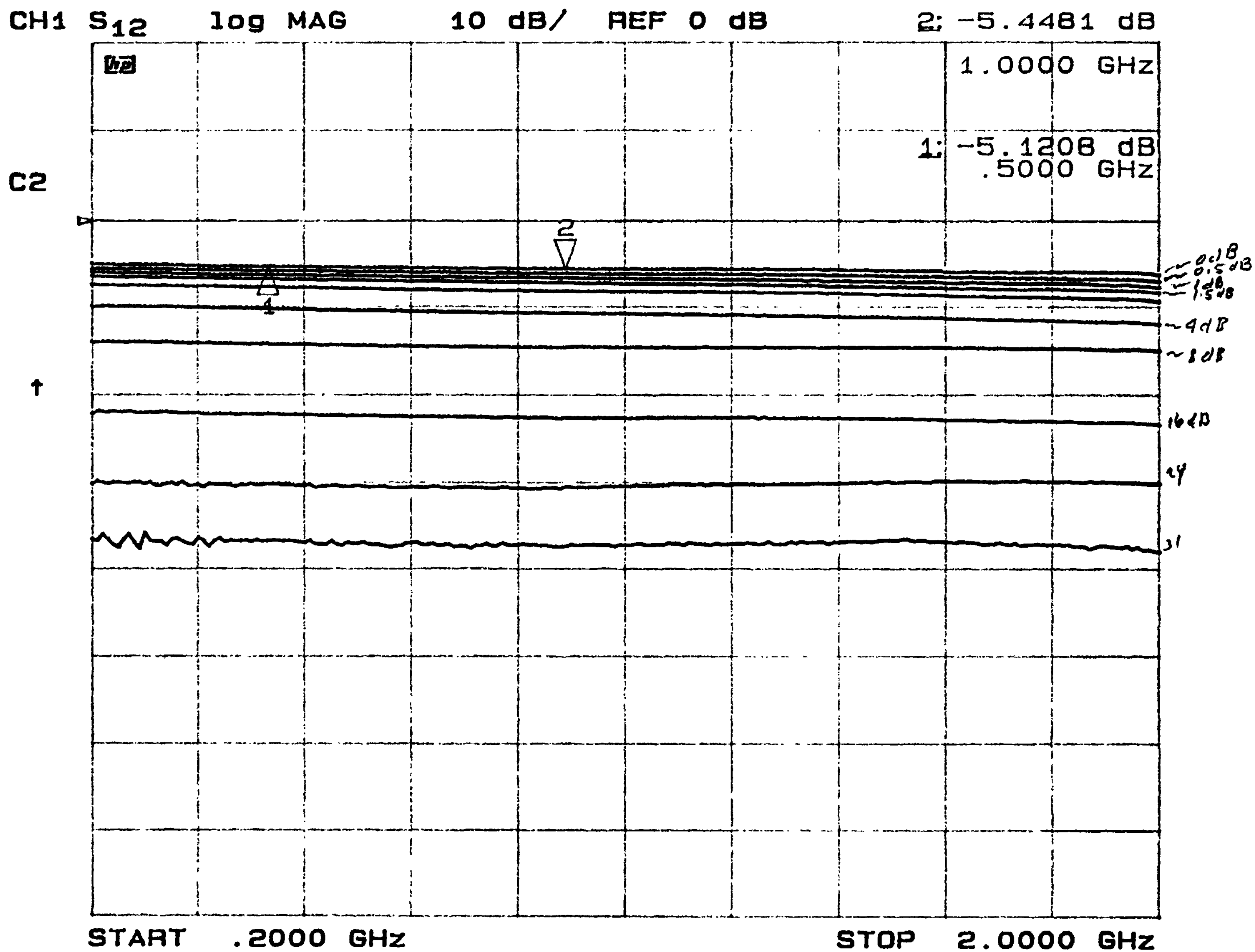


FIGURE 1 - S_{12} vs. freq for MINI-CIRCUITS DIGITAL ATTENUATOR ZSAT-31R5

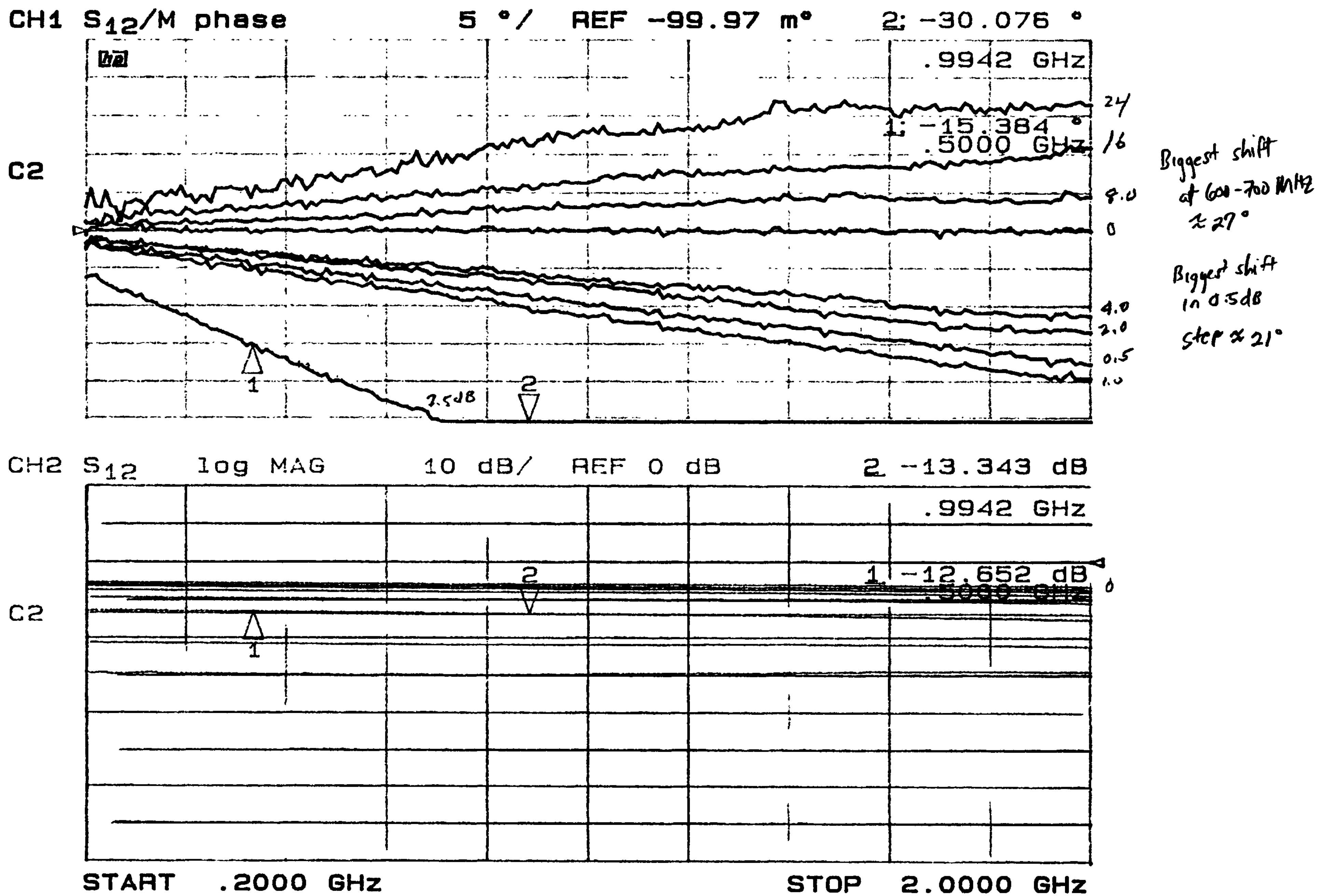


FIG.2 - upper frame - phase shift vs. frequency MINI-CIRCUITS ZSAT-31R5

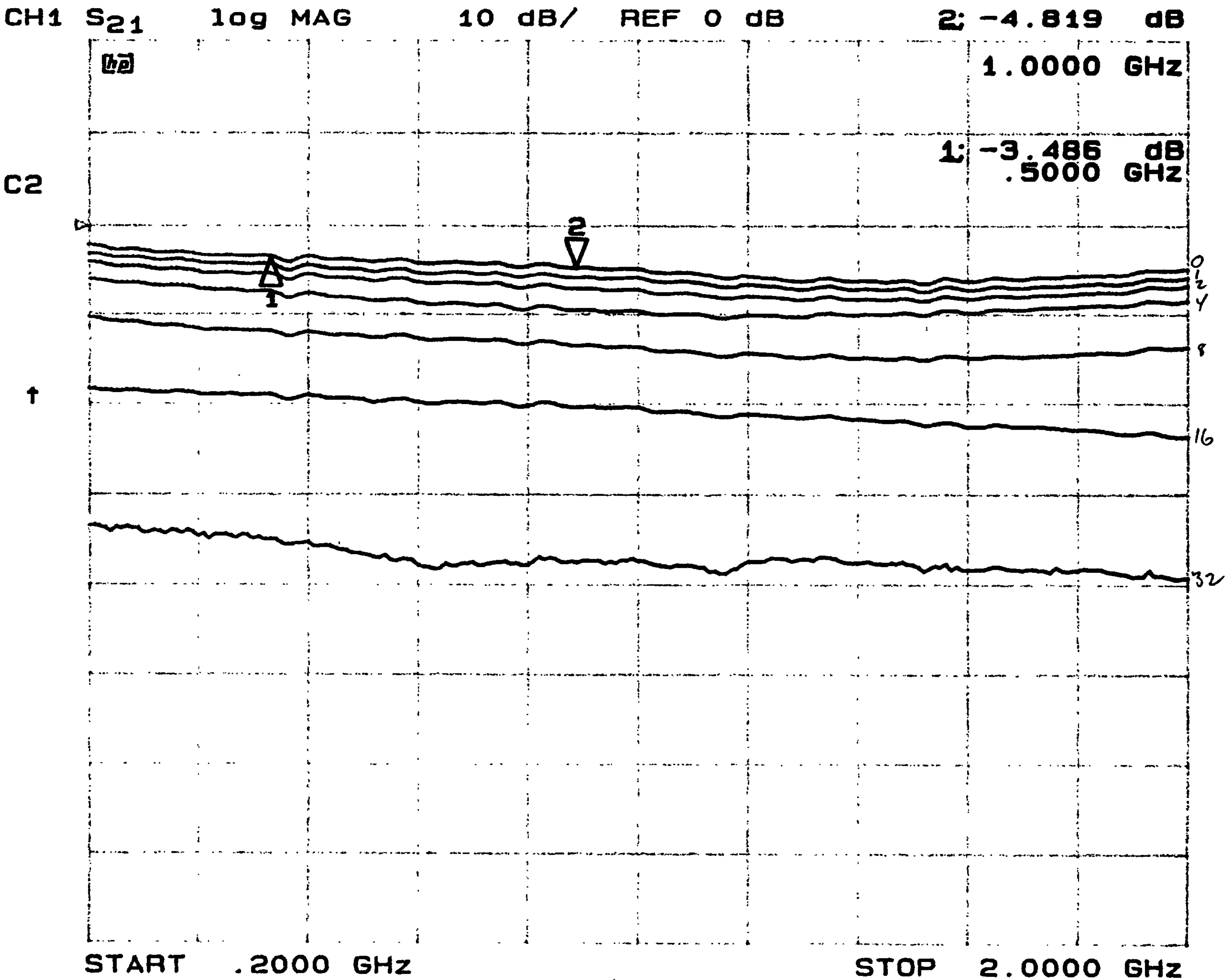


FIG. 3 - Alpha attenuator - Attenuation level vs. frequency for each control bit

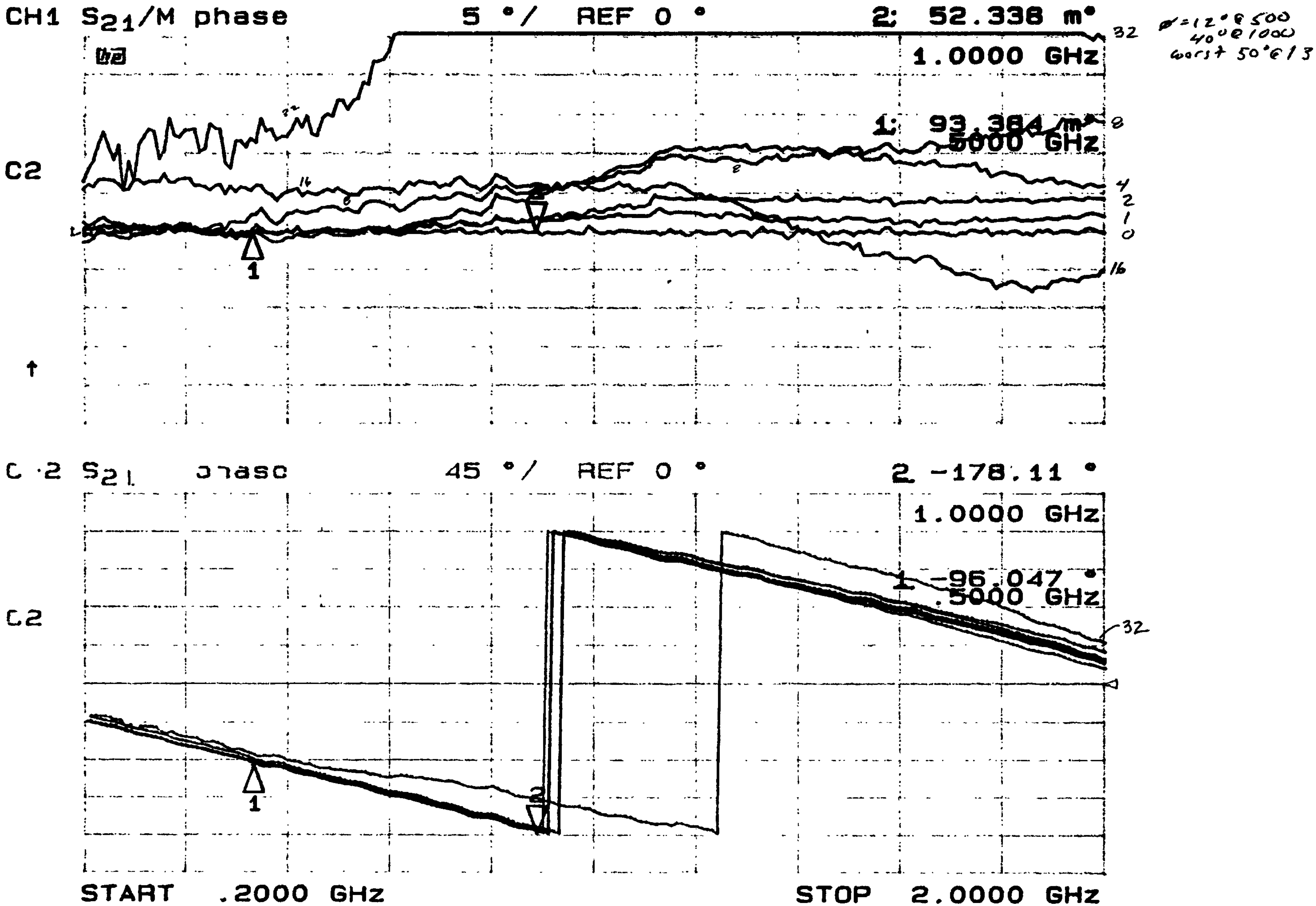
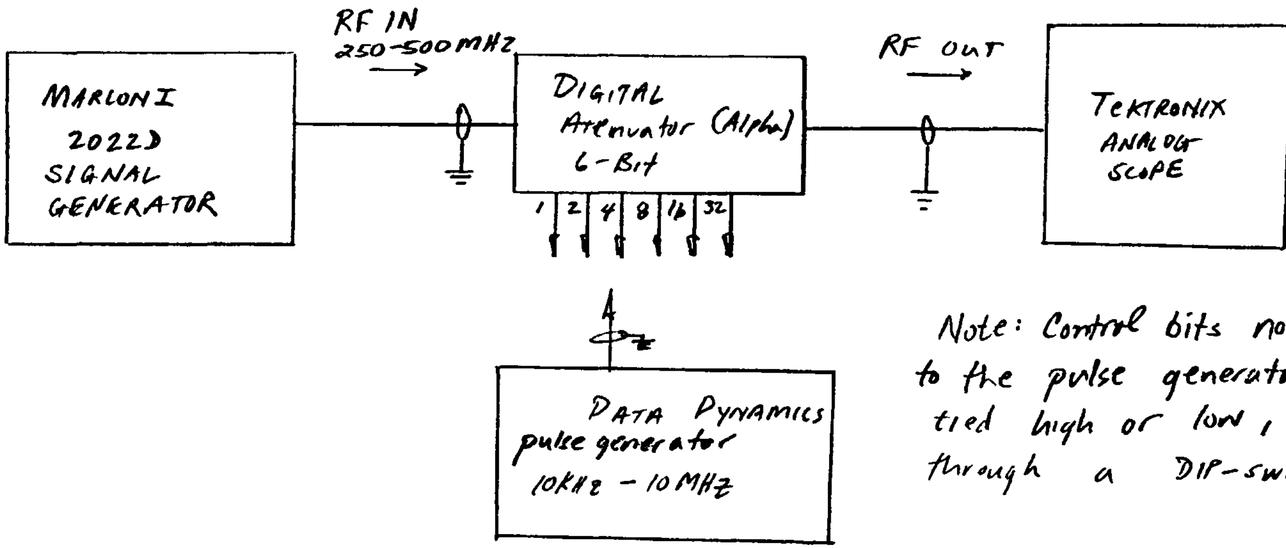
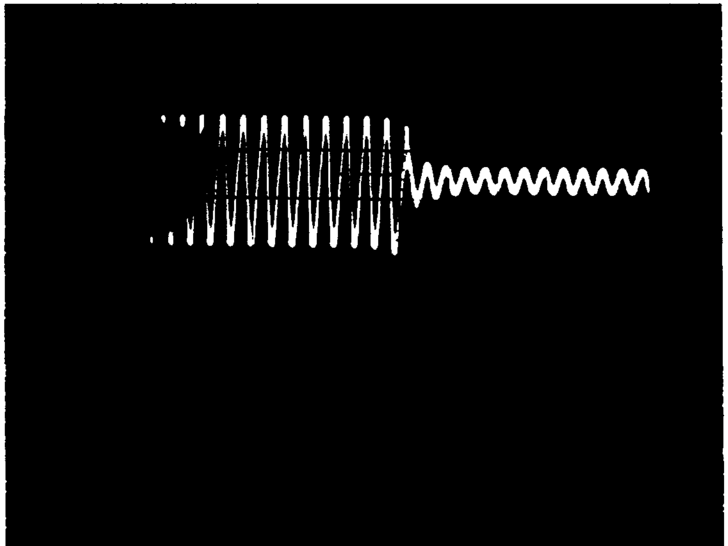


FIG. 4 - Alpha attenuator phase response vs. frequency
upper frame - normalized to insertion loss response

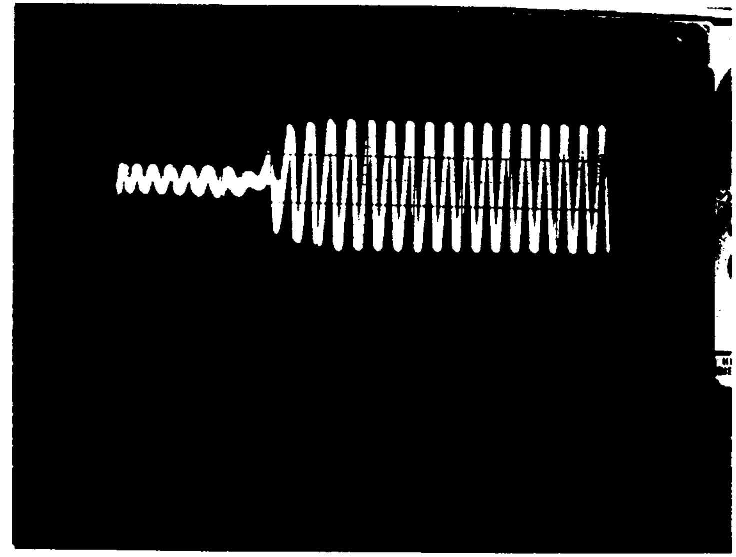


Note: Control bits not connected to the pulse generator were tied high or low, as appropriate, through a DIP-switch.

FIG. 5 - Test setup for switch measurements



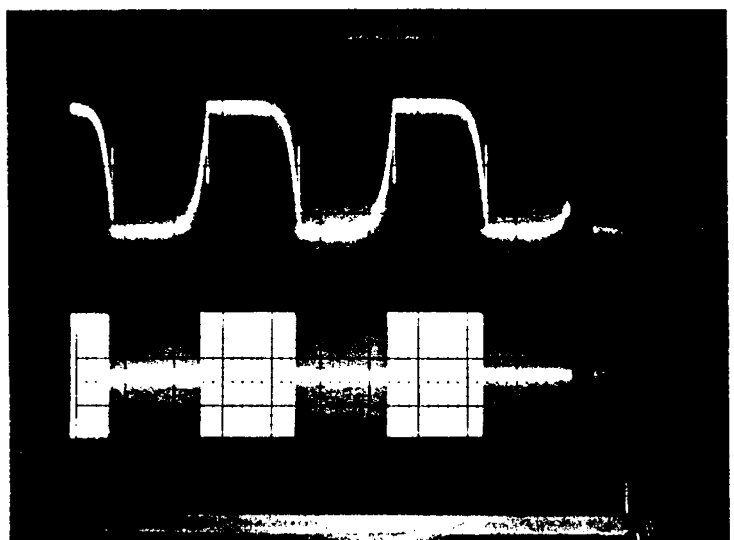
16dB .01 μsec/div falling edge



.01 μsec/div rising edge 16dB

#1 ↑

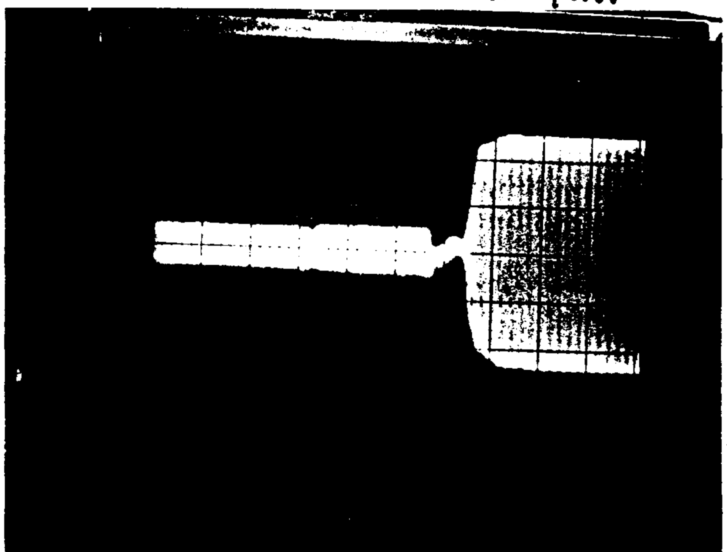
#2 ↑



32dB switching 10KHz

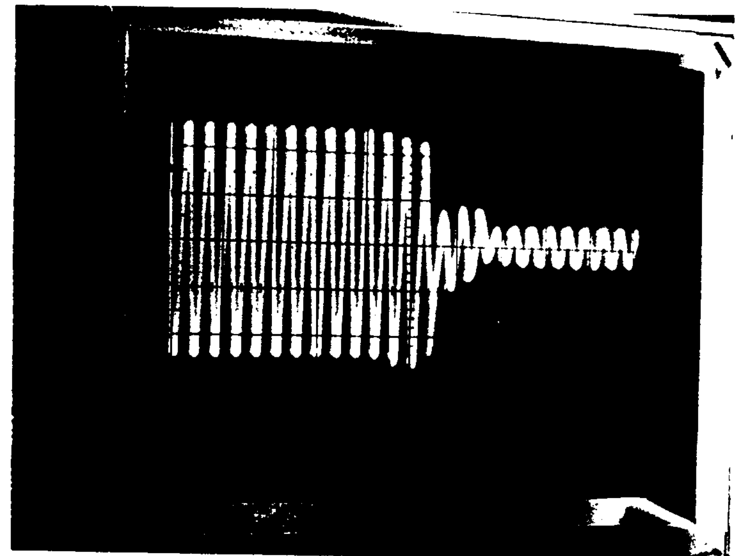
#3 ←

.02 usec/div



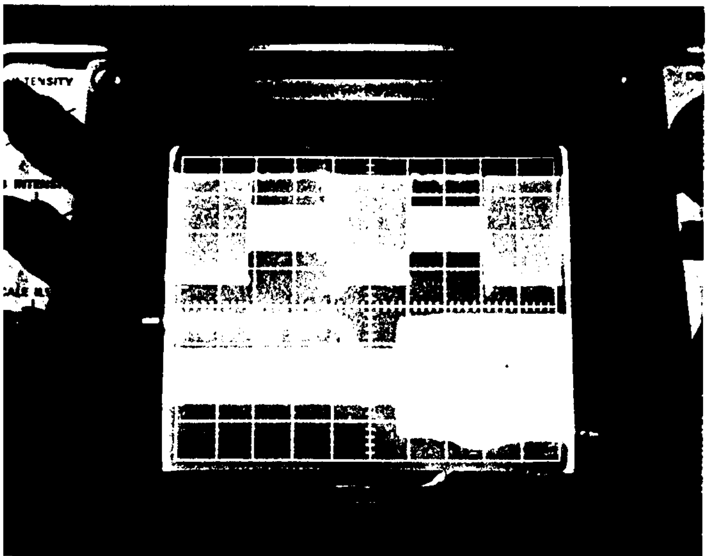
.02 usec RISING EDGE 2dB and 16dB

#4

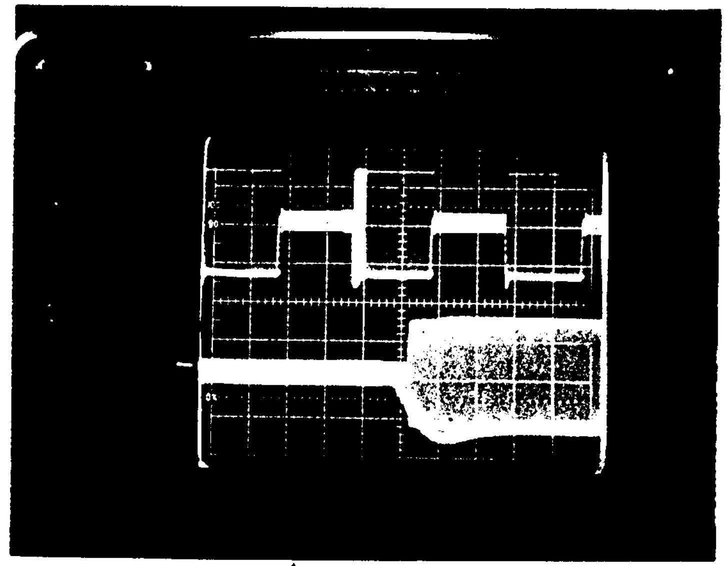


16+2 dB FALLING EDGE .01 usec/div

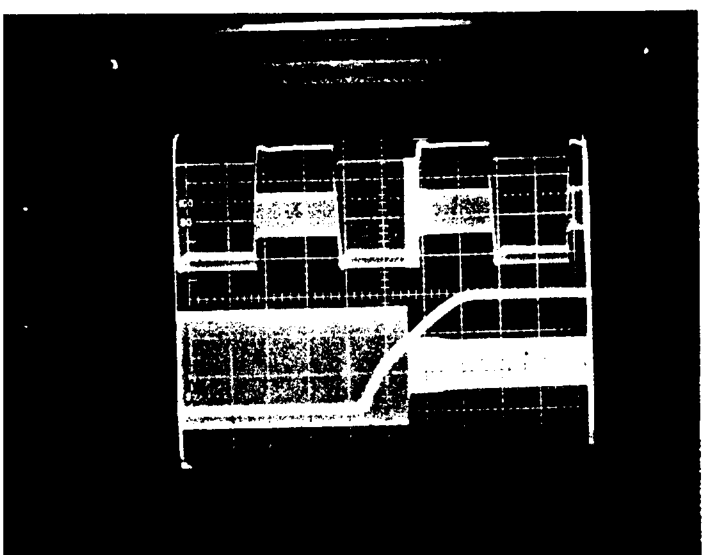
#5



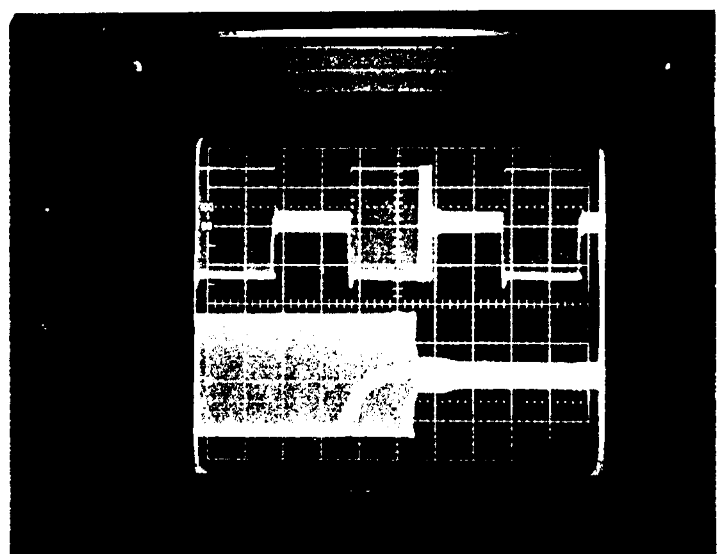
1[illegible]0 KHZ, 500 MHZ 8dBSW 2V, 5MV 2ms 100 NSEC



16 dB



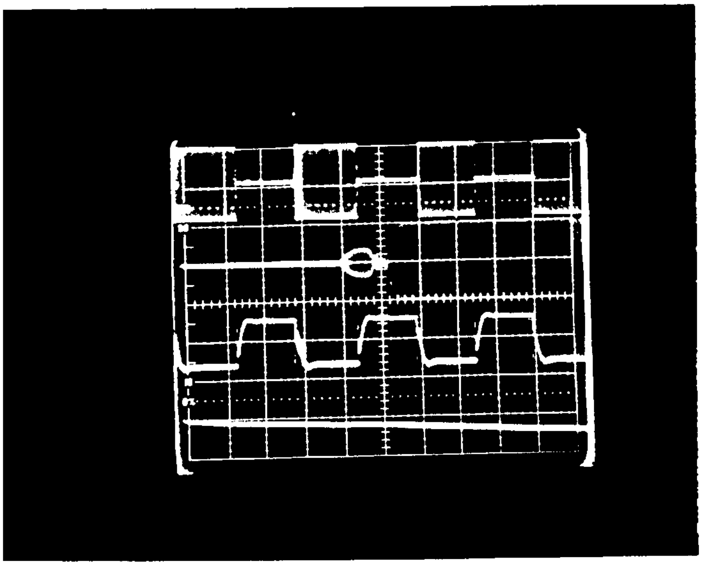
8 dB



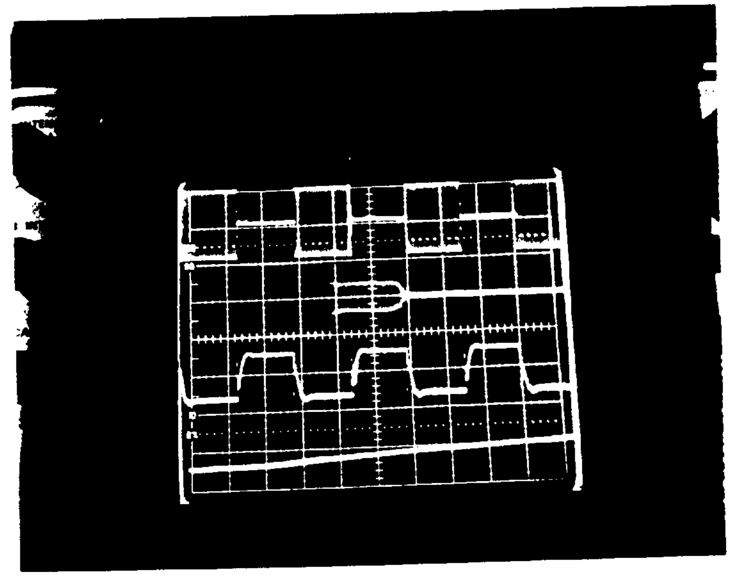
16 dB

Photos #

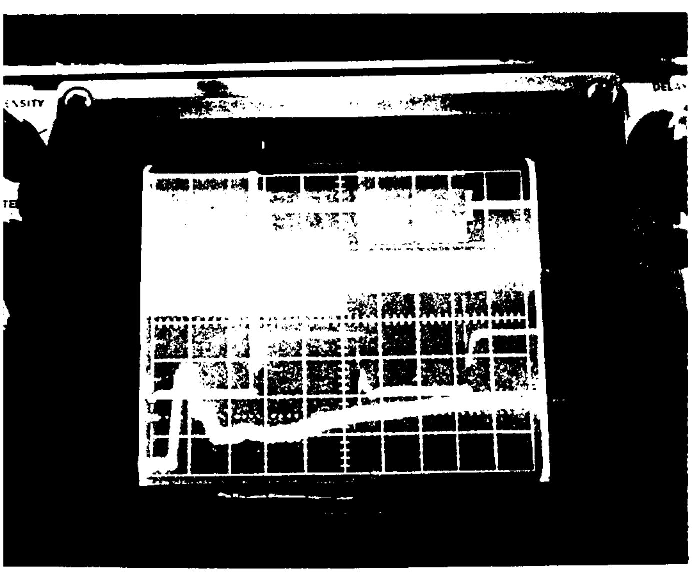
6	7
8	9



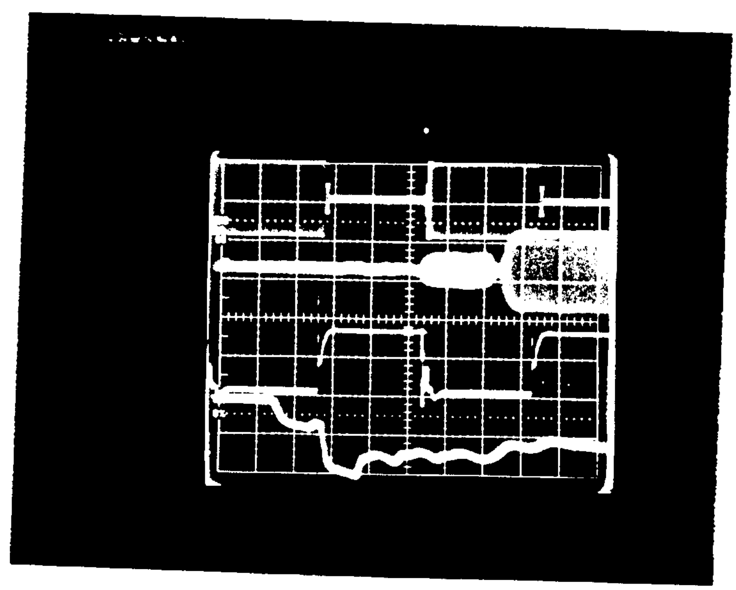
#10



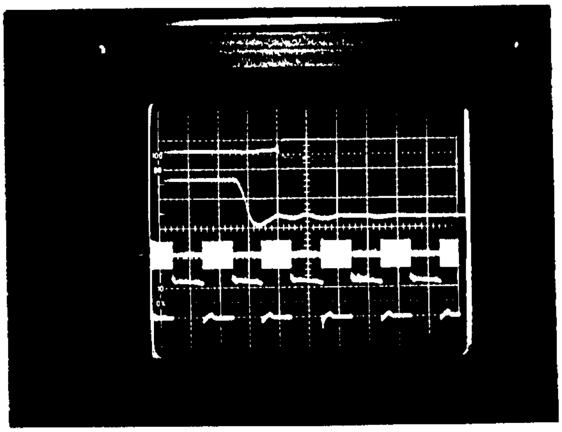
#11



#12



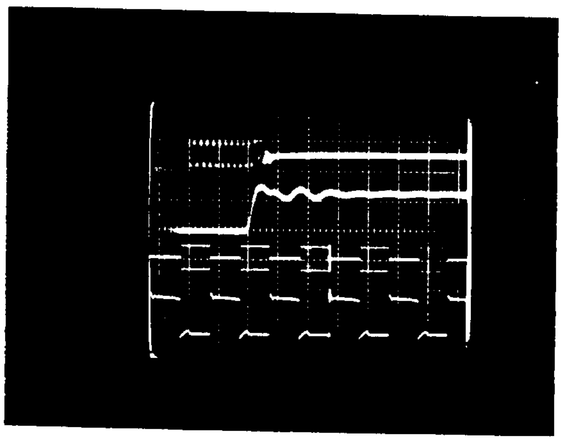
#13



11

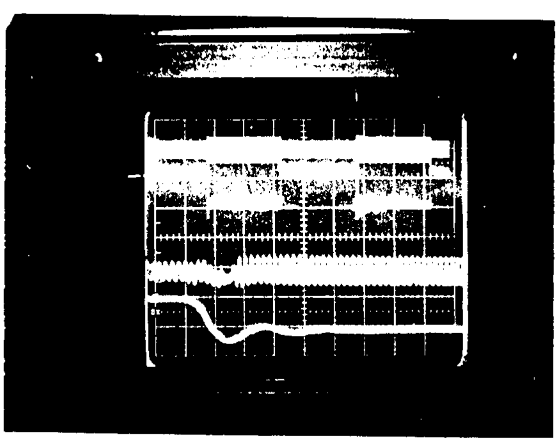
50mV/div
5 V/div
100mV/div
5V/div

16dB switching, 500Mhz, 100Khz switching
t_1 = 5μsec/div
t_2 = 10nsec/div



15

Same as above - rising edge



16

4,8 dB switching simultaneously
one off, one on at all times
50mV, 5V, 2μsec, 10nsec