SLAC-PUB-2309
April 1979
(A)

A NORMALIZED DETECTOR OF BEAM TRANSVERSE OSCILLATIONS*

Jean-Louis Pellegrin
Positron Electron Project
Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

This beam detector accepts the narrow pulses typically encountered in electron storage rings. It is composed of a peak detector with a threshold held constant by means of an automatic gain control (AGC) loop, and of a sampler. The output is proportional to the instantaneous position of the beam center of charge and is independent of the beam current. In addition, the very small phase shift of the AGC attenuator allows the use of the undetected, constant amplitude pulse as a trigger for time of flight measurements, with a remarkably small time slewing over a 30 to 1 beam current range.

Submitted to Nuclear Instruments and Methods

---

* Work supported by the Department of Energy under contract number EY-76-C-03-0515.

1. Introduction

The circuit we present is used for detecting the transverse oscillations of the barycentre of bunched beams, and is also meant to be sensitive to higher order bunch oscillations. The induced pulses from these beams have very large amplitudes, typically several hundreds of volts; as observed in the control room the pulse width is less than one nanosecond for the case of small pick-up electrodes, or can be made a little longer if a strip line is used as beam pick-up element.

The transverse bunch motion produces a variation of the pulse amplitude; the smaller the vacuum chamber, the larger the variation, and for a chamber such as PEP's* where the distance between the pick-up electrodes and the beam is of the order of 20 mm, a bunch oscillation of 1 mm produces a modulation of the induced pulses of the order of 1/20, or 5%.

The design philosophy lays stress upon the following two points:

(i) The detection in the time domain of such a modulation is more easily achieved with some kind of a peak detector, operating on a single electrode pulse, as suggested in ref. 1, than attempting to measure the difference between two opposite electrode pulses with a hybrid junction as in ref. 2. Indeed, wideband subtraction always yields some common mode signal due to mismatches, phase errors, or the finite isolation of the hybrid junction, and in a feedback system this common mode signal can saturate the final amplifier and result in a DC orbit shift. Moreover, we would like

---

* PEP: Positron Electron Project, Stanford Linear Accelerator Center, California.

this detector to be sensitive to the largest number of bunch modes; detecting the signal of a single electrode enhances the bunch higher order modes.

(ii) This detector is intended to be used to apply wideband feedback to the beams of a storage ring. If the detector is not normalized, the dynamic range required from the circuitry is very large, since it is multiplied by the operating current range of the machine, typically 30. It is agreed that most beam instabilities exhibit a rate of growth proportional to the beam current and that an unnormalized detector yields, as required, a loop gain which automatically increases with the beam current. Yet the task of detecting small beam oscillations is best performed over a reduced dynamic range, and if the system gain must be changed in proportion with the beam current, it is easier to program this gain separately. Besides, the normalization makes the operation of any kind of peak detector more linear, since the circuit remains biased at a fixed point. Normalizing circuits of different kinds have been devised; one that deserves attention is one found in refs. 3 and 4, where individual, closely spaced beam bunches are separately normalized. The circuit described here operates on gated bunches and the normalizing speed is of no concern.

2. Threshold Circuit, Integrator and Peak Detector

The spectrum of the pick-up electrode signal is made of lines spaced by the beam revolution frequency, each line being accompanied by a family of sidebands, whenever the bunch oscillates. However, since the beam-electrode coupling is an induction process, the spectrum amplitude is zero at DC; the spectrum lines increase linearly with frequency and with the bunch σ, and they reach their maximum at $\omega = 1/\sigma$, where σ is in seconds. Detecting the modulation at a frequency near the spectrum maximum is a logical choice and has been done often, with or without heterodyning.[5,6]

The circuit presented here can be used in cases where the time difference between bunches is small, since gating is done by turning on and off the input circuit threshold. As for the demodulation, as in ref. 4, it is performed around the spectrum DC line, created by the non-linear process of active integration and sampling at the revolution frequency.

The circuitry of fig. 1 operates with positive pulse of 1.5 to 2 ns FWHM, the negative excursion being ignored. To obtain such a pulse width, the pick-up stripline signals have been somewhat integrated by the dispersion of a transmission line; for the case of PEP, we use 800 feet of half-inch coaxial cable having an attenuation of 2.4 dB/100 feet at 1,000 MHz.

In the presence of a -500 mV gate, Q1 and Q2 amplify the crest of the pulse and stretch it by means of the collector capacities. The time constant C2-R2 is made long for the signal and short for the gate. The biasing of U1 is such as to provide approximately zero volts across CR1. As the input signal level increases above the threshold, the output of U1 decreases in proportion to the train DC component; this is the feedback voltage of the AGC loop. The input termination R1 can be replaced by a cable and brought out of the circuit as a constant amplitude trigger.

3. Beam Pulse Normalization Loop

The control element for this loop is a double-balanced mixer attenuator which exhibits 4 dB minimum insertion loss for 2 ns pulses, and has an attenuation range of approximately 40 dB. Since the option is available to invert or not to invert the signal by forward biasing one pair of diodes or the other pair, a switch is provided to this effect which allows to dedicate the circuit to positron or electron beam pulses. Two low noise amplifiers (fig. 2) have been inserted between the variable attenuator and the threshold circuit to take advantage of the full dynamic range of the attenuator without exceeding its input 1 dB compression level. The output pulse amplitude can be adjusted with the reference potentiometer of the loop amplifier. Since the AGC loop ignores the modulation and operates with the pulse train DC component only, the output modulation amplitude is independent of the carrier amplitude, and is simply amplified by a factor of about 50 (gain of Q1 and Q2, fig. 1). Thus besides their width, the main output and the alternate output also differ by the amount of modulation they carry.

As an attenuator, a double-balanced mixer exhibits very little phase shift. This property has been put to advantage here in the generation of a phase stable trigger. Time of flight measurements require a trigger which is usually derived from a discriminator to which a beam induced pulse is applied. As the beam current decreases, the trigger occurs later (fig. 3) by the play of the discriminator time slewing. Triggering the discriminator with the AGC alternate output reduces substantially the time slewing. The data of fig. 3 was taken with a Tektronix 661 oscilloscope, measuring the time difference between the beam pulse zero crossing and the half level point of the TR204 discriminator output. The dual channel sampling oscilloscope time base was set at 200 pSec/div and the SPEAR storage ring beam was scraped down from 30 mA. This circuit is presently in operation on the SPEAR Mark II Detector. Larger ranges of beam current have not been investigated but laboratory measurements indicate that the phase stability of the AGC attenuator is maintained over at least 30 dB.

4. Synchronous Detector

Final detection of the beam modulation is done by the sampler of fig. 4. Two paths can be traced: a forward path consisting of a diode bridge, the charging capacitor, a high impedance buffer and an amplifier, and a feedback path carrying the sampling pulse along with the output voltage. This positive feedback restores the sampling efficiency to 100%; when the amplifier gain is properly adjusted, the output can be made an exact reproduction of the input modulation. However, the sampling efficiency varies with the modulation frequency, so the above adjustment requires a compromise over the frequency band of the modulation. This circuit has been optimized for the case of the PEP ring where sampling will be done at 136 KHz and the modulation is expected to vary between 1 and 50 KHz over the range of synchrotron and betatron tunes.

5. Overall Detector Operation and Experimental Results

A modulation of 5% of the beam pulses corresponds approximately to a peak to peak beam oscillation of 1 mm on PEP, and for a beam current dynamic range in excess of 37 dB, the detector delivers ±316 mV or 0 dBm per mm. The photograph of fig. 5 represents a typical input-output for the circuit of fig. 1; the notch observed at the top of the output waveform indicates the location of the sampling point. Figure 6 shows the detector response to a 10 mA SPEAR beam, and fig. 7 is the spectrum of the same output. On SPEAR, a 1 mm peak-to-peak bunch oscillation corresponds to 1% modulation, or -14 dBm at the detector output. On fig. 7, the reference level is at -20 dBm and the first pair of sidebands which corresponds to the bunch dipole motion are at -34 dBm; this is approximately a peak-to-peak oscillation of 0.1 mm, at least five times larger than the noise, which is evaluated to be -50 dBm. Since the detector output saturates when it reaches approximately ±1 Volt, or +10 dBm, the usable oscillation dynamic range is 60 dB.

The author would like to thank M. Breidenbach for his interest in the time of flight trigger and A. Millich for discussing with him various schemes of beam oscillation detection.

REFERENCES

1) M. Bergher, Laboratoire de L'Accélérateur Linéaire, Orsay. "Amplificateur pour Feedback bétatron," (1973) unpublished.

2) J.-L. Pellegrin, Nucl. Instrum. Methods 108 (1973) pp. 365-373.

3) E. F. Higgins, IEEE Trans. on Nucl. Sci., Vol. 22, No. 3 (June 1975) pp. 1581-1585.

4) E. F. Higgins, IEEE Trans. on Nucl. Sci., Vol. 24, No. 3 (June 1977) pp. 1830-1832.

5) K. Wille, Deutches Elecktronen - Synchrotron, Hamburg, "Damping of Coherent Transverse Oscillations in PETRA," presented by S. Pätzold at the 1979 Particle Accelerator Conference in San Francisco.

6) M. A. Allen, M. Cornacchia and A. Millich, Stanford Linear Accelerator Center, "A Longitudinal Feedback System for PEP," presented at the 1979 Particle Accelerator Conference in San Francisco.

FIGURE CAPTIONS

Fig. 1. Threshold Circuit, Integrator and Peak Detector.

Fig. 2. Schematic Diagram of Beam Pulse Normalization Loop.

Fig. 3. Time Slewing Improvement of TR 204 Discriminator when Preceded by Beam Pulse AGC Circuit.

Fig. 4. Circuit Daigram of the Synchronous Detector.

Fig. 5. Input-Output Waveforms for the Circuit of Fig. 1. Input 100 mV/div, Output 500 mV/div, Time Base 5 nSec/div.

Fig. 6. Detector Output in Response to a SPEAR Colliding Electron Beam. Top Picture 10 μSec/div, Bottom Picture 2 mSec/div. Both 100 mV/div.

Fig. 7. Detector Output Spectrum in Response to a SPEAR Colliding Electron Beam. Reference Level is -20 dBm. Vertical Scale is 10 dB/div, Horizontal Scale is 50 KHz/div. Resolution 3 KHz.

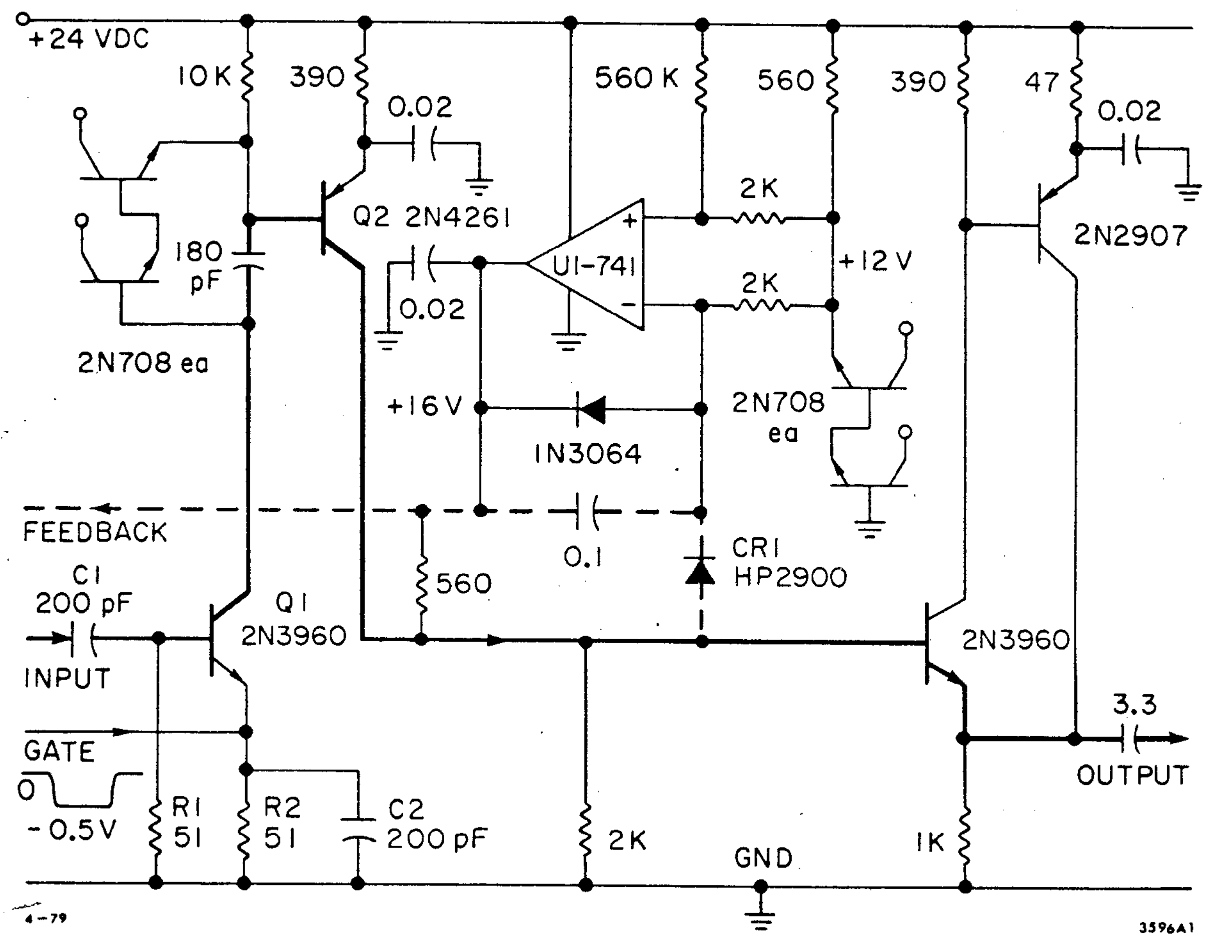
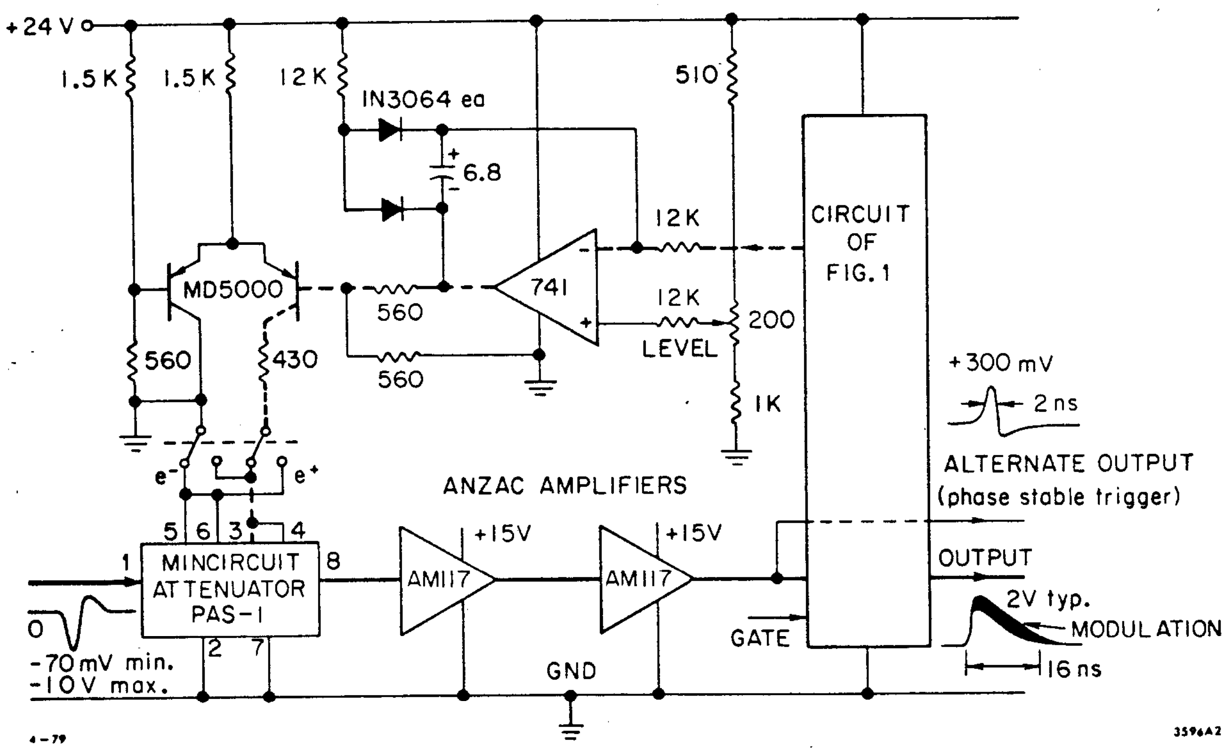
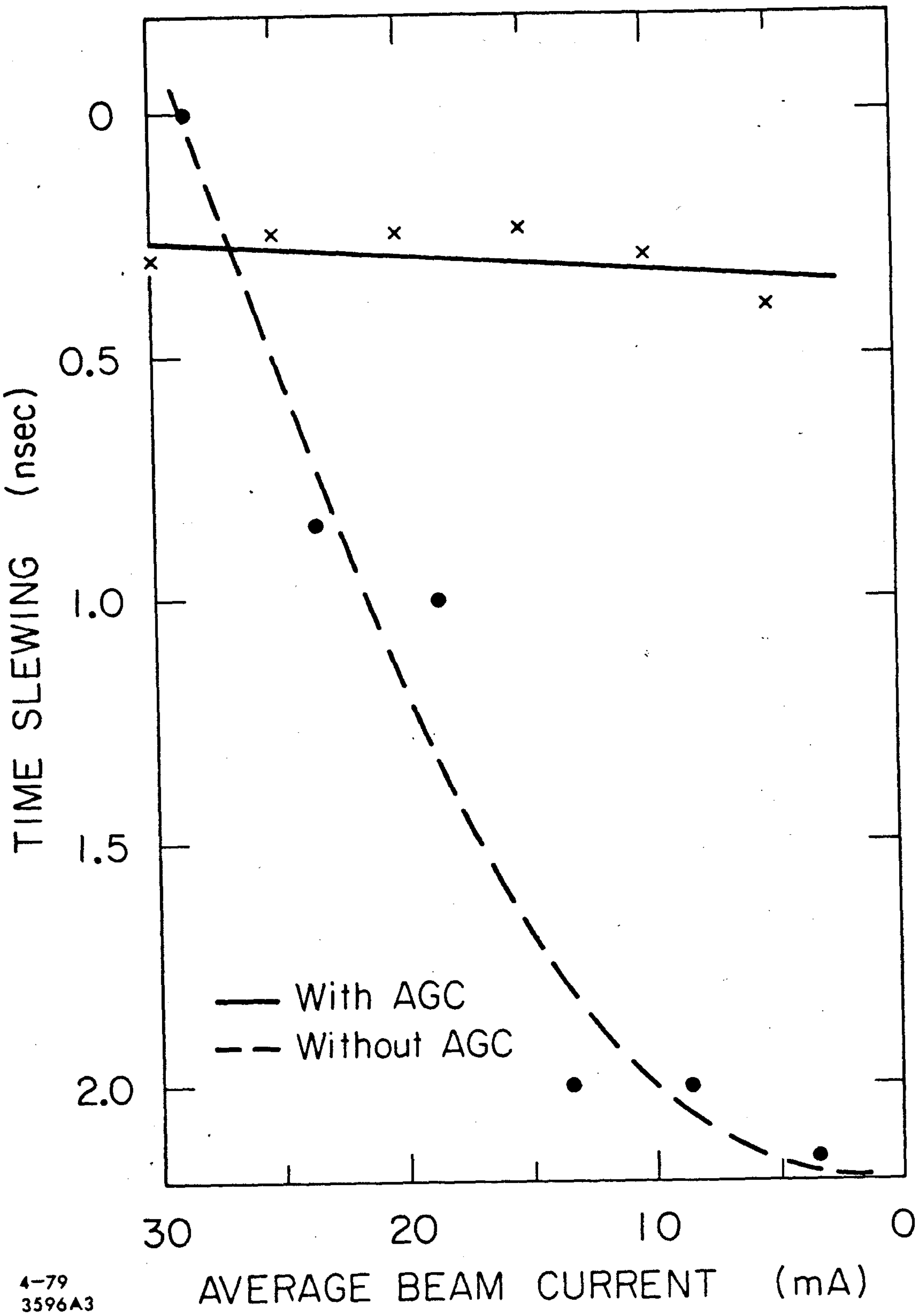

+24 VDC
10K
390
0.02
560K
560
390
47
0.02
Q2 2N4261
2K
2N2907
180 pF
0.02
U1-741
+12V
2K
2N708 ea
+16V
IN3064
2N708 ea
FEEDBACK
0.1
CR1 HP2900
C1 200 pF
560
Q1 2N3960
2N3960
INPUT
3.3
GATE
OUTPUT
0
-0.5V
R1 51
R2 51
C2 200 pF
2K
GND
1K
4-79
3596A1

Fig. 1



+24 V
1.5 K
1.5 K
12 K
IN3064 ea
6.8
510
CIRCUIT
OF
FIG. 1
12 K
MD5000
560
741
12 K
200
560
430
560
LEVEL
+300 mV
1K
2 ns
e⁻
e⁺
ANZAC AMPLIFIERS
ALTERNATE OUTPUT
(phase stable trigger)
5 6 3 4
+15V
+15V
1
MINCIRCUIT
ATTENUATOR
PAS-1
8
AM117
AM117
OUTPUT
2V typ.
MODULATION
0
2 7
GATE
16 ns
-70 mV min.
-10 V max.
GND
4-79
3596A2

Fig. 2



0
0.5
1.0
1.5
2.0
TIME SLEWING (nsec)
With AGC
Without AGC
30
20
10
0
AVERAGE BEAM CURRENT (mA)
4-79
3596A3

Fig. 3

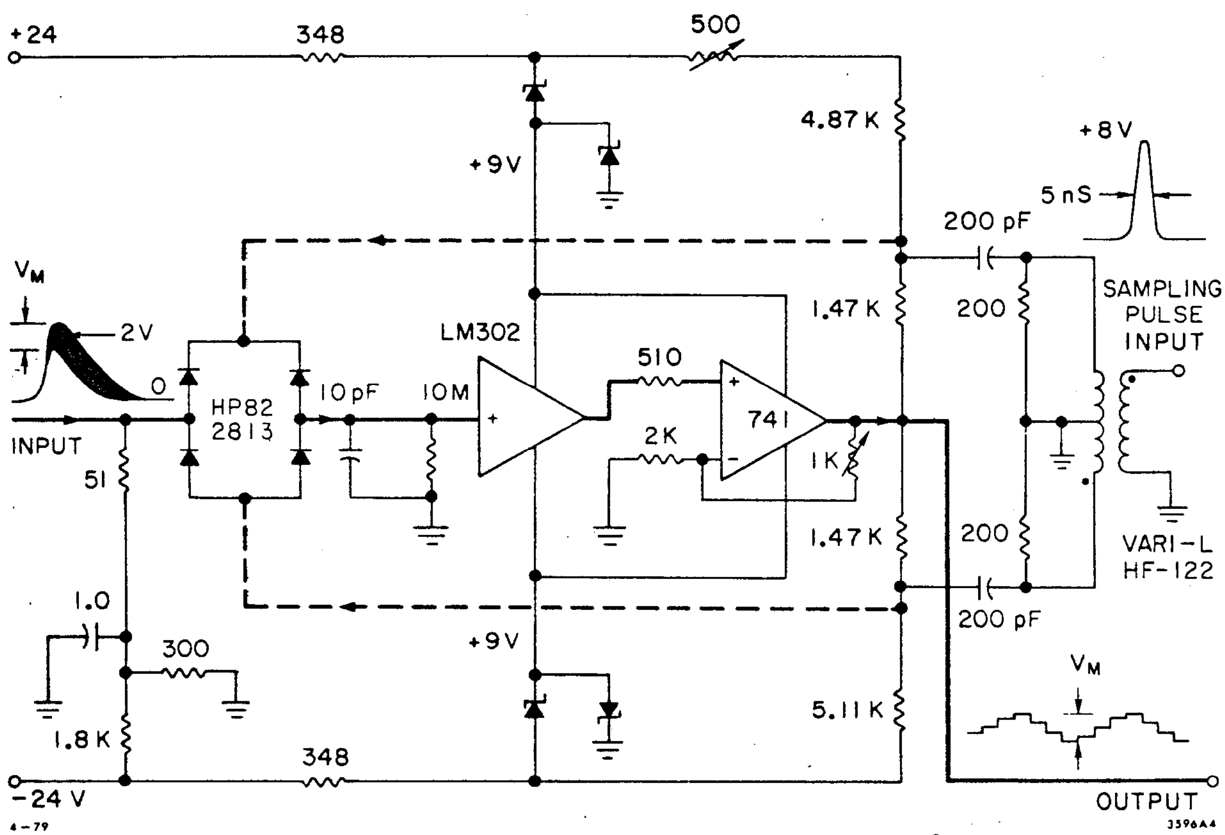
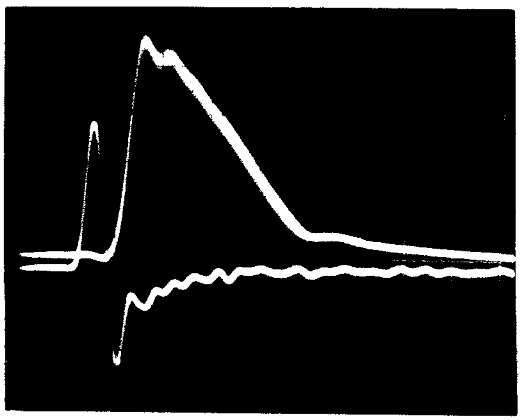

+24
348
500
4.87 K
+9 V
+8 V
5 nS
200 pF
SAMPLING
PULSE
INPUT
V_M
2V
0
INPUT
HP82
2813
10 pF
10M
LM302
510
741
2K
1K
1.47 K
200
51
1.47 K
200
VARI-L
HF-122
200 pF
1.0
300
+9 V
V_M
1.8 K
5.11 K
348
-24 V
OUTPUT
4-79
3596A4

Fig. 4

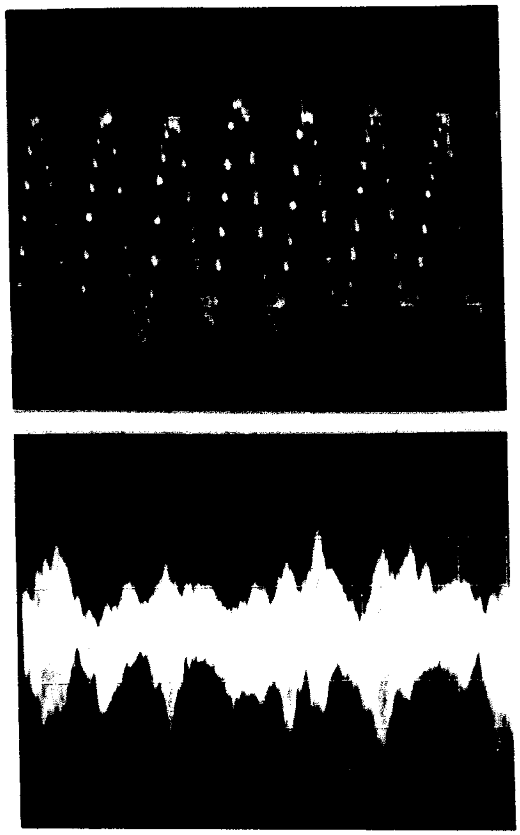


4—79 3596A5

Fig. 5

147
8

5/5



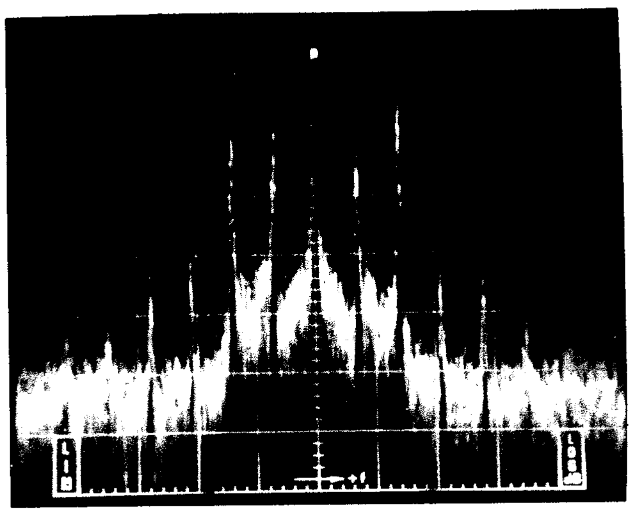
4 – 79 3596A6

Fig. 6

144

9

5/5



4-79 3596A7

Fig. 7

148
7

5/5