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DESIGN AND ANALYSIS OF AN AUTOMATIC METHOD OF MEASURING SILICON-CONTROLLED-RECTIFIER HOLDING CURRENT

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16. Abstract

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DESIGN AND ANALYSIS OF AN AUTOMATIC METHOD OF MEASURING SILICON-CONTROLLED-RECTIFIER HOLDING CURRENT

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SUMMARY

The design of an automated silicon-controlled rectifier holding current measurement system is described. The circuits used in the measurement system were designed to meet the major requirements of automatic data acquisition capability, reliability, and repeatability. Performance data are presented and compared with calibration data. The data verified the accuracy of the measurement system. Data taken over a 48-hour period showed that the measurement system operated satisfactorily and met all of the design requirements.

INTRODUCTION

The silicon controlled rectifier (SCR) requires a certain minimum anode current to maintain it in its conducting state. This minimum current is designated as the holding current. Nearly all the methods of turning off or commutating an SCR involve the reduction of the anode current to some value less than the holding current.

The measurement of holding current proved to be one of the more difficult measurements to obtain in a program to determine the effects of reactor radiation (neutron flux) on SCR's. An SCR holding current measuring system was needed to meet the following requirements:

(1) Reliability

(2) Repeatability

(3) Radiation effects response

(4) Automatic data acquisition

These requirements could not be met by any commercial units available at the time. An automated system to measure the holding current was, therefore, designed and fabricated to meet these requirements. The design and operation of the circuits in this measurement system are discussed. Data are presented to verify the reliability of the measurement system.

SYSTEM DESCRIPTION

The essential components of the SCR holding-current measurement system are shown in figure 1. The triangular wave generator provides the input voltage to the sys-

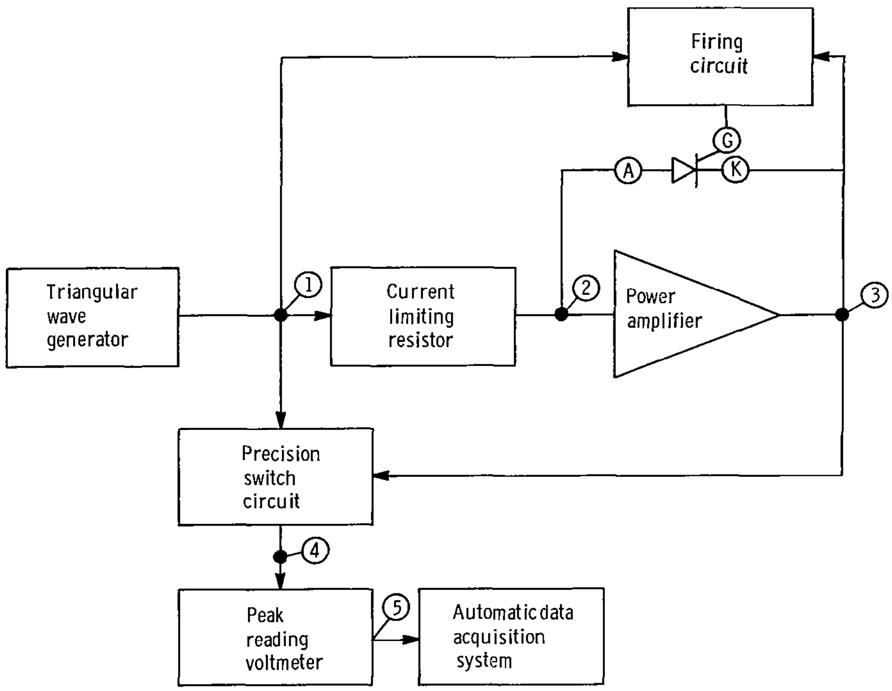


Figure 1. - SCR holding current measuring system. (Note: The circled numbers used in this diagram correspond to the circled numbers used in the circuit drawings of this report. The numbers indicate electrically common points, and they are used as subscripts to indicate voltage at those points.)

tem. This voltage is applied to the current limiting resistors in series with the test SCR. The test SCR is connected in the feedback path of a power amplifier, so that the forward voltage drop of the SCR has no effect on the anode current of the SCR. The precision switch circuit detects the point at which the anode current equals the holding current and then connects the corresponding input voltage to a peak reading voltmeter. The output of the voltmeter is proportional to the holding current and is recorded by the automated data acquisition system.

Triangular Wave Current Generator

The function of the triangular wave current generator (fig. 2) is to provide anode current for the test SCR. A triangular waveform is obtained from a signal generator. Operational amplifier A1 acts as dc restorer to transform the bipolar output of the signal generator to a unipolar triangular wave. This is followed by an inverting, unity-gain, power amplifier, which consists of operational amplifier A2 and a current amplifier consisting of transistors Q1 to Q4. Negative feedback is provided to achieve unity voltage gain. The output of this circuit is capable of supplying 1 ampere to the test SCR.

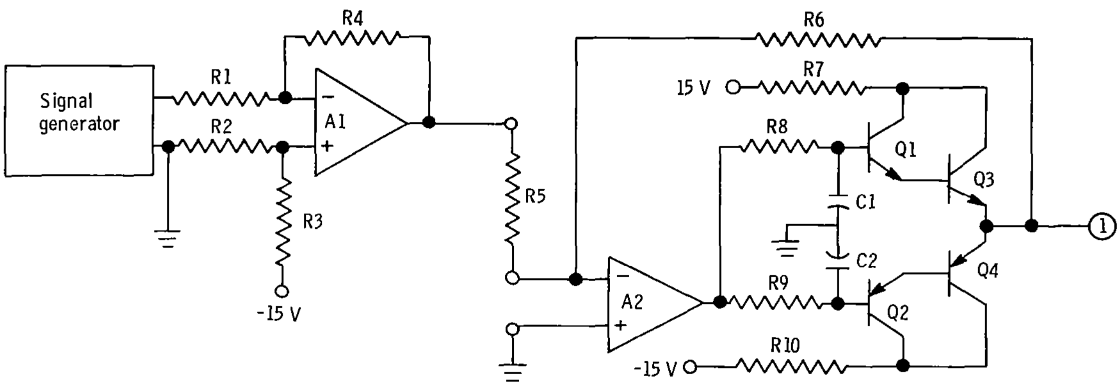


Figure 2. - Triangular wave generator.

SCR Test Circuit

The SCR test circuit (fig. 3) eliminates the effect of the forward voltage drop of the SCR on the measurement of the anode current. This is accomplished by connecting the test SCR in the feedback path of a power amplifier. The instantaneous anode current flowing in the SCR is given by

$$i_F = \frac{v_1 - v_2}{R}$$

where

v_1 triangular wave generator output

v_2. error voltage at input terminals of operational amplifier A3

R value of current limiting resistor

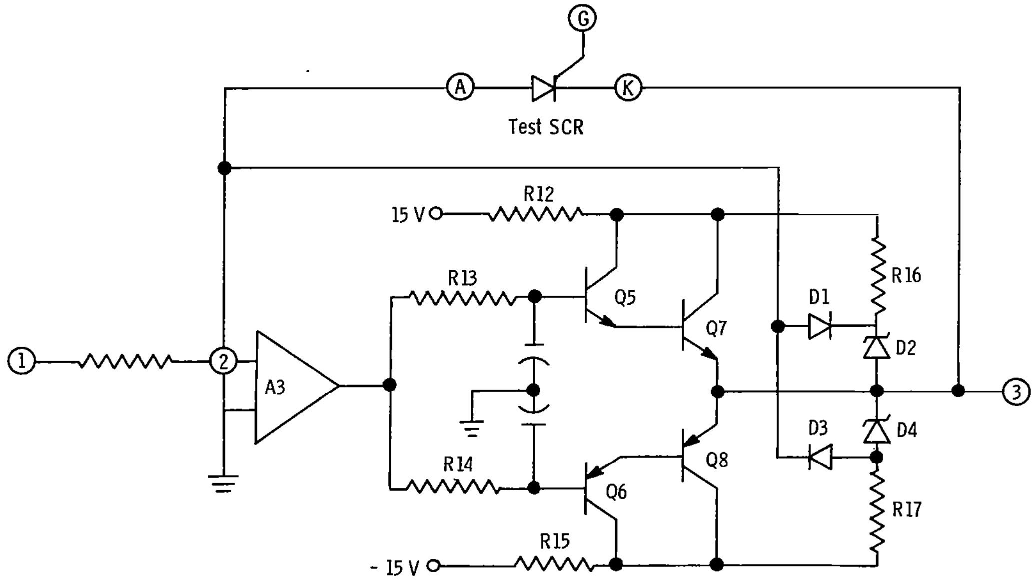


Figure 3. - Test SCR circuit.

This operational amplifier has an open-circuit voltage gain of 20 000, or greater, and is coupled to a unity-voltage-gain current amplifier. Because of this high gain, the input error voltage is negligible compared with v_1, and the current flowing in the SCR can be expressed by

$$i_F = \frac{v_1}{R}$$

The input current to the amplifier is also negligible because of the high-input impedance of the amplifier. Thus, it is apparent that the entire input current must flow through the test SCR. The voltage output of the amplifier will be the negative of the forward voltage drop v_F of the SCR. This output is used for control purposes to determine whether the SCR is conducting or blocking. A bound circuit limits the output to ±7 volts (ref. 1, p. 23). The transition from the bound limit of -7 volts to the negative value of the forward voltage drop v_F of the SCR indicates the point at which the SCR turns on. A transition from $-v_F$ to -7 volts indicates the turnoff point of the SCR. The other possible transition that can occur is from -7 volts to 7 volts. This transition will occur whenever the triangular wave voltage goes negative as may happen as a result of drift. The circuitry is designed to discriminate against this type of transition.

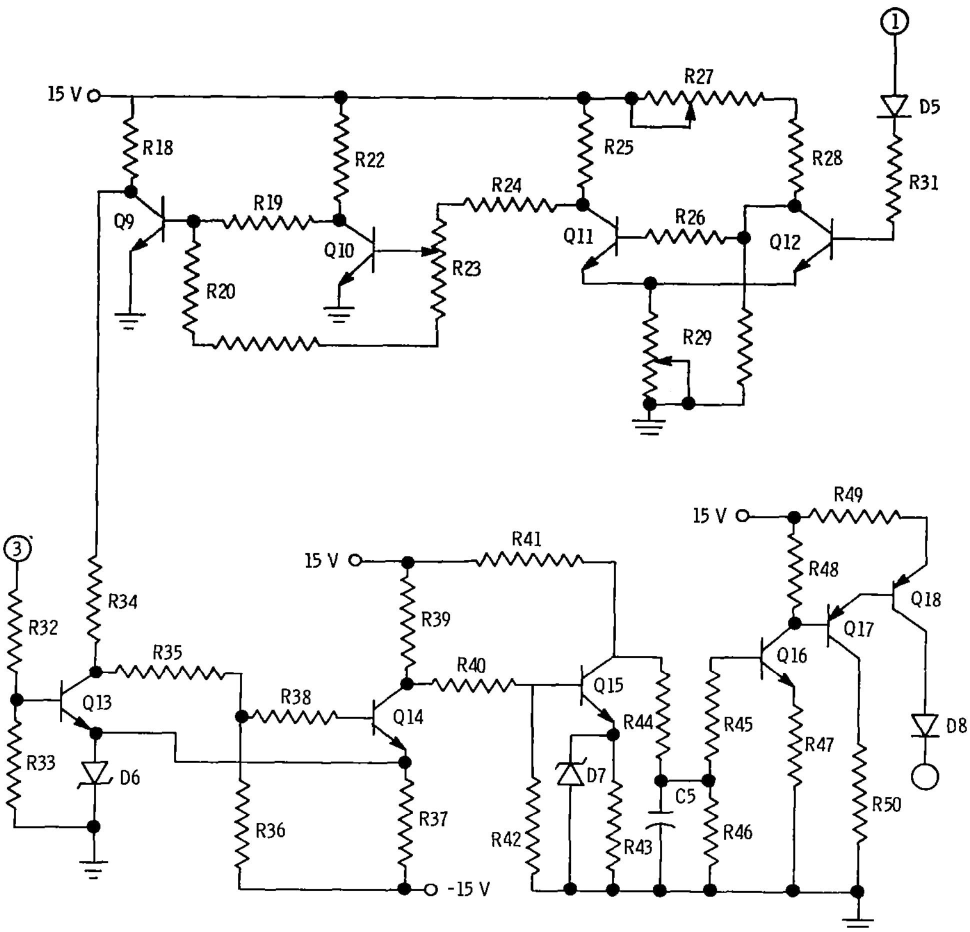


Figure 4. - SCR firing circuit.

SCR Firing Circuit

The firing circuit (fig. 4) provides a continuously increasing current to the gate of the test SCR. This current goes to zero when the SCR turns on. A positive going current ramp is produced by the circuit consisting of transistors Q16, Q17, and Q18 and associated components. The slope of the ramp is determined by R43 and C5 and the voltage divider, R44 and R45. This circuit is initiated by an output of Q15, which is controlled by an output of the modified Schmitt trigger Q13 and Q14 (refs. 2 and 3). To obtain this controlling signal at the collector of Q15, two things must occur simultaneously:

(1) The voltage at point 3 must be less than -5 volts.

(2) The voltage at point 1 must be greater than +9.5 volts.

These two conditions insure that turn-on occurs near the peak current level and that current is applied to the SCR only while it is off.

Precision Switch Circuit

The precision switch circuit (fig. 5) is a critical unit in the holding-current measurement system. This circuit senses the precise time when the SCR turns off, that is, when the anode current of the SCR drops below the holding current. When the precision switch circuit senses this point, it connects the triangular-wave voltage to the peak reading voltmeter. The result is a train of negative pulses, the peak of which corresponds to the holding current.

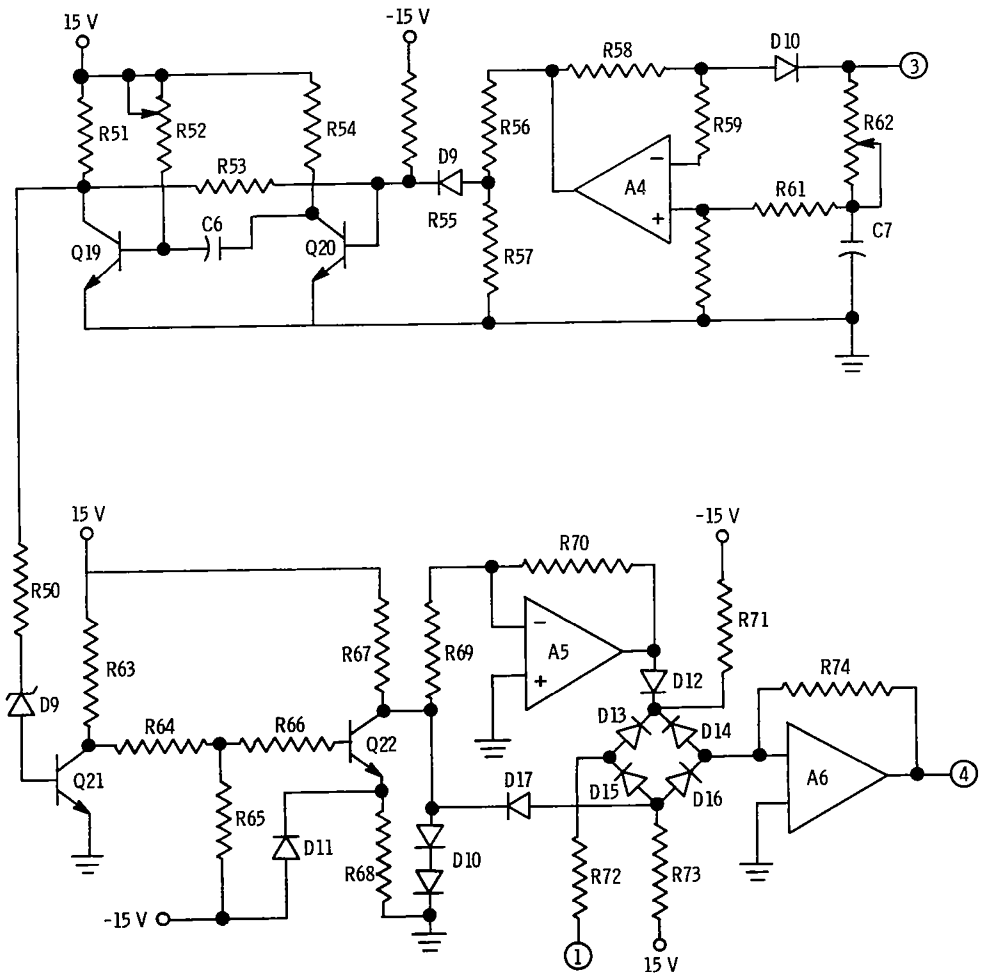


Figure 5. - Precision switch circuit.

This circuit uses an electronic switch consisting of amplifiers A5 and A6 and diode bridge D12 to D17. A description of this type of circuit can be found in reference 1 (p. 58). Point 1 is gated to the noninverting terminal of amplifier only if the control voltage is ≥1 volt. Negative values of this control voltage will render the bridge nonconducting. This control signal is obtained at the output of the trigger circuit (ref. 4) consisting of transistors Q21 and Q22. The collector of Q22 has one of two possible outputs, ±1 volt. A positive input at R50 will result in +1 volt output; with no input, the output will be -1 volt. The controlling input to R50 is obtained from the output of the monostable multivibrator consisting of transistors Q19 and Q20 and associated components. The multivibrator is activated by an output from amplifier A4 and has a positive pulse width of about 100 microseconds (adjustable by R52).

The amplifier A4 will have a sufficient output to trigger the multivibrator when the input at point 3 senses a transition from a voltage $-v_f$ to the bound voltage of -7 volts. (The voltage $-v_f$ is considered to be always between 0 and -5 V.)

Peak Reading Voltmeter

The pulse train produced at the output of the precision switch circuit must be conditioned to display and record on punch tape the holding current as required. The peak reading voltmeter shown in figure 6 will produce an output equal to the most negative peak appearing at the input. Amplifier A7 acts as a switch and will charge the integrating capacitor C9 until the output of the amplifier following the integrator has an output equal and opposite in sign to the maximum input to the peak reading voltmeter. This output is directly proportional to the SCR holding current. A relay contact across the integrating capacitor is used to reset the circuit for the next reading.

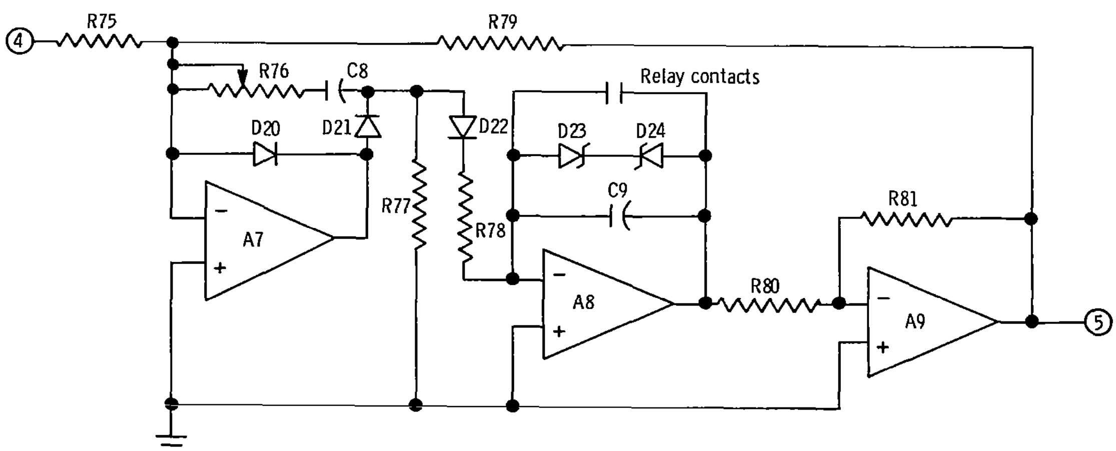


Figure 6. - Peak reading voltmeter.

Automatic Data Acquisition System

The automatic data acquisition system consisted of the following components:

(1) Crossbar scanner

(2) Digital voltmeter

(3) Digital clock

(4) Digital recorder

(5) Output control

(6) Paper tape punch.

The crossbar scanner was used to operate relays in a special relay unit. This was done to increase the power handling capabilities of the scanner. The relay unit, controlled by the scanner, selected the SCR to be tested. The scanner operation was initiated by the digital clock. Results were recorded, via the voltmeter, by a digital recorder and a paper tape punch. Once the system was set, all subsequent data were taken automatically at predetermined intervals (from 2 to 16 hr).

SYSTEM PERFORMANCE

Calibration

Fourteen SCR's have had their holding-current measured for calibration reference purposes by using three different methods:

(1) The voltage and resistance in the anode circuit of the SCR was varied; current was measured by means of a digital voltmeter and a precision series resistor.

(2) A high-speed current power supply was used in place of the voltage supply and resistor; the preceding procedure was followed.

(3) A commercial SCR measurement instrument was used with its output modified for a more accurate reading on a digital voltmeter.

The reference calibration measurements described were used to calibrate the automatic measurement system as follows: A systematic error had been identified as occurring as a result of the time delay between the time the SCR turns off and the time the triangular voltage is applied to the peak reading voltmeter. Taking this error into consideration, the holding current can be expressed by the following:

$$i_H = \frac{1}{R}(v_5 + V_c)$$

where

v_5 direct-current voltage output of peak reading voltmeter

V_c calibrated correction factor for delay error

R value of current limiting resistor

The value of V_c was determined by plotting the measurement system voltage V_5 against the calibrated value of holding current I_H, as shown in figure 7, for two resistor values. The value of the correction factor V_c is 0.28 volt as determined by the calibration curves. The time delay determined from oscilloscope traces was about

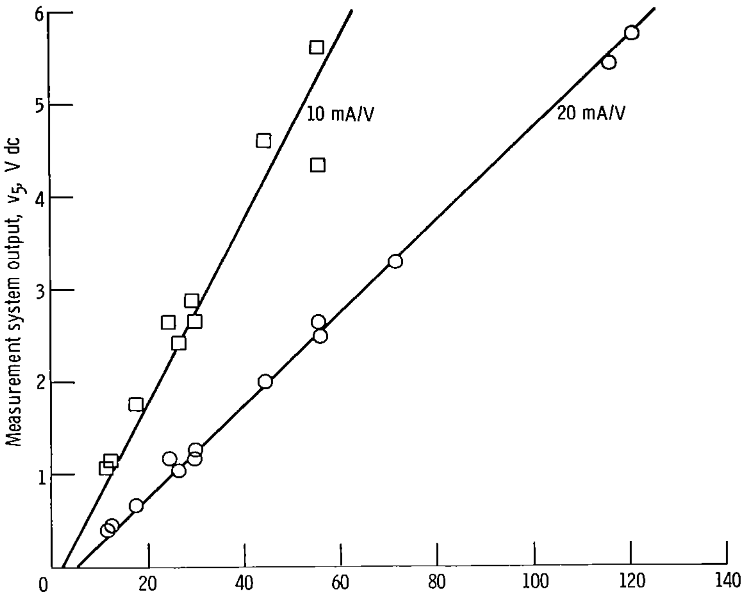
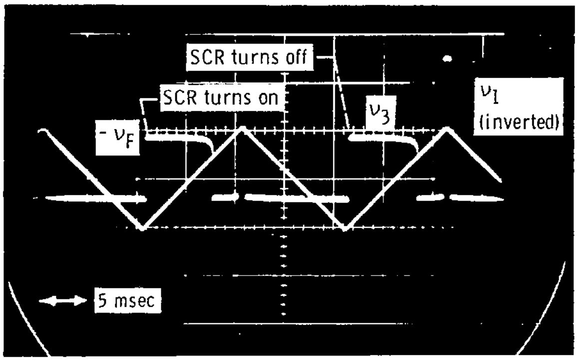


Figure 7. - Determination of correction factor.

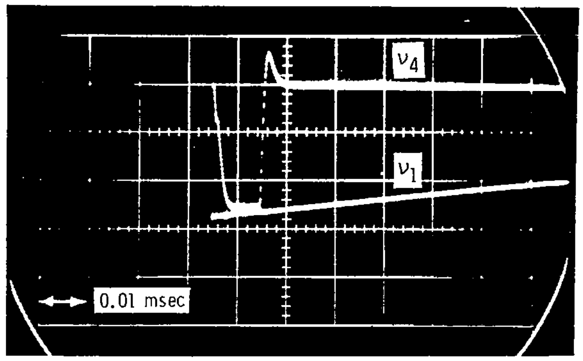
0.3 millisecond. Since the slewing rate of the voltage ramp of the triangular wave is 1 volt per second, the predicted error would be about 0.3 volt. This compares well with the calibrated 0.28 volt.

System Operation

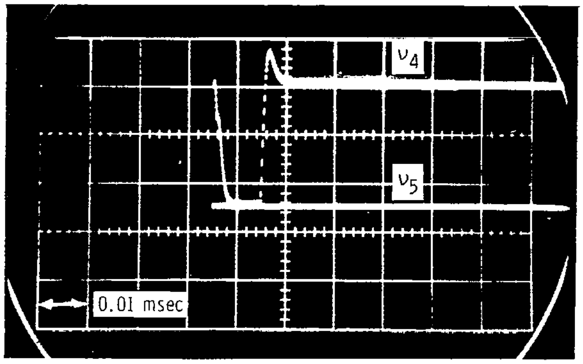
Some typical oscilloscope traces of the important waveshapes occurring in the circuitry are shown in figure 8. In figure 8(a), the triangular wave voltage is shown compared with the output of the power amplifier. Figure 8(b) shows that portion of the triangular wave voltage switched to the peak reading voltmeter. The input and output of



(a) Output of triangular wave generator (ν_1) and output of power amplifier (ν_3).

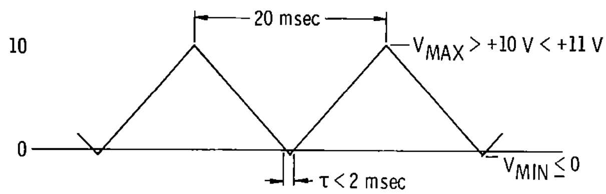


(b) Input voltage to peak reading voltmeter (ν_3) compared with triangular wave voltage (ν_1).

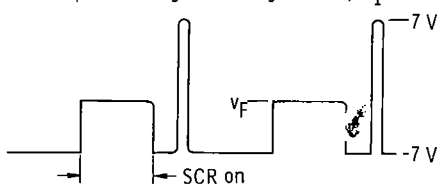


(c) Input and output voltages for peak reading voltmeter.

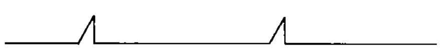
Figure 8. - Typical waveforms.



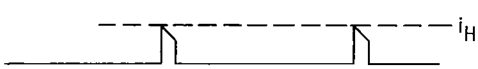
(a) Output of triangular wave generator, v_1.



(b) Output of power amplifier, v_3.



(c) SCR gate firing current, i_{GK}.



(d) Input to peak reading voltmeter, v_4.

Figure 9. - Significant circuit waveshapes.

TABLE I. - COMPARISON OF AUTOMATED MEASUREMENTS WITH REFERENCE CALIBRATIONS

SCR	Holding current, mA		Change in holding current, Δ_{IH}, mA
	Reference calibration	Automated system average	
1	11.3±0.2	13.3	2.0
2	24.7±0.4	29.0	4.3
3	12.4±0.2	14.3	1.9
4	26.4±0.2	25.6	.8
5	17.7±0.1	18.9	1.2
6	29.9±0.1	29.4	.5
7	120.7±1.9	120.3	.4
8	9.5±0.3	14.1	4.6
9	44.7±0.5	45.6	1.1
10	55.5±0.4	55.9	.4
11	71.7±0.7	71.9	.2
12	29.2±0.8	-----	---
13	116.1±0.5	114.3	1.8
14	56.2±0.5	55.2	1.0

the peak reading voltmeter is shown in figure 8(c). In order to show the time relation, these waveshapes are sketched to the same time base in figure 9.

Data taken with the measuring system are shown in table I. Comparison with the calibration data shows a difference of 2.3 percent of full scale in the worse case with an average change of 0.8 percent of full scale. The repeatability of the measurements is shown by the following summary table based on 20 measurements made over a 48-hour period:

SCR	Holding current, mA			
	Maximum	Minimum	Mean	Standard deviation,[a] S
A	115.4	112.4	113.9	0.769
B	55.0	52.8	54.4	.675

$$^{a}S = \left(\frac{\sum_{i=1}^{n} (I_{Hi} - \bar{I}_H)^2}{n - 1} \right)^{1/2}$$ where n is the number of measurements, I_{Hi} is the holding current measurement, and $\bar{I}_H$ is the mean value of n holding current measurements.

CONCLUDING REMARKS

The requirements of reliability and repeatability were achieved by the design of the automated circuitry. Switching circuitry was designed to make allowances for changes in silicon-controlled-rectifier (SCR) characteristics due to radiation effects. The following are the significant features of the holding current measurement system design:

1. A triangular wave generator provided a current source to make a large number of dynamic measurements on each SCR.
2. The uncertainty of the forward voltage drop of the SCR was eliminated by the use of a power amplifier.
3. An SCR firing circuit was used that was capable of responding to increased gate current requirements.
4. A precision switch circuit gated the input voltage corresponding to the turnoff of the SCR to a peak reading voltmeter.
5. A peak reading voltmeter converted the pulses to a direct-current signal compatible with an automatic data acquisition.
6. An automatic data acquisition system permanently recorded this direct-current signal.

The direct-current signal obtained by the data acquisition system was readily converted to a holding-current measurement by applying the correct range multiplier and the calibrated time-delay correction factor.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, October 15, 1971,
112-27.

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