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VOLTAGE RATIO DETECTOR FOR MILLIVOLT SIGNALS

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U. S. DEPARTMENT OF COMMERCE
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by J. R. Houghton

ABSTRACT

A voltage ratio detector circuit for measuring ratios of a-c and d-c signals 5 millivolts or larger is described. The ratio is determined with a precision voltage divider which is accurate to within 0.001 percent of the indicated ratio when the ratio is near one. The detector has sufficient sensitivity and stability to indicate differences between two signals of 0.01 percent. Experimental results are presented to show the relative improvement in sensitivity of this voltage ratio detector over the previously used transfer admittance method for the calibration of vibration pickups.

Key words: Voltage ratio, vibration, calibration, thermal converter, electronic circuit, test method.

1. INTRODUCTION

In the calibration of vibration standards and vibration transducers at NBS, the ratio of two a-c voltage signals is the required measurement. These voltage signals range from 5 millivolts to 5 volts in amplitude, differ in phase or change phase relative to each other as the frequency varies from 5 to 2500 Hz, and have source impedances between 100 and 1000 ohms.

Available ratio measuring devices were found to be dependent on the phase difference of the two a-c signals and required input signal amplitudes greater than the signals generated by many vibration transducers. To offset these deficiencies a ratio detector was designed and constructed to meet the particular requirements for measurements of voltage ratios in vibration measurements. These requirements are:

1. To handle low signal levels to 5 mV,

2. To be independent of phase differences between the two signals,

3. To permit direct comparison of two signals in one measurement,

4. To compare signals ratios up to 20:1 which is accurate to within 0.1 percent, and

5. To compare signals from piezoelectric or velocity coil type of vibration sensing devices.

Since available d-c instrumentation provides a very sensitive means for determining ratios of d-c signals, the possibility of converting two separate a-c signals to independent d-c signals was investigated. This would permit the signals to be balanced with a high sensitivity galvanometer and would eliminate the problems caused by phase differences between the two a-c signals.

Of the various devices available for converting a-c signals to d-c signals, thermal converters[1] were chosen since the d-c output is the true rms equivalent (heating value) of the a-c input, i.e. the conversion contains the true effects of the harmonics in the input signal's wave form. Development of thermal converters has been in progress at NBS for several years. The converter is used as a transfer device in the calibration of current and voltage instruments[1,2][2].

2. RATIO DETECTOR DESIGN

2.1 Description of Circuit and Components

A block diagram of the circuit designed to determine the ratio of two voltages is shown in figure 1. Several experimental ratio detectors were built following the basic design of figure 1.

The final circuit is shown in figure 2. A description and discussion of the circuit components, starting from the left in figures 1 and 2, is given below.

Switch 1 permits equalization of the transfer characteristics of channels A and B before measuring the ratio. The CHECK position of switch 1 causes signal B to be a common input to both channels. The trim variable resistors are adjusted to indicate a null on the galvanometer. The RATIO position of switch 1 connects signal A to channel A and through the voltage divider. The divider is adjusted until the galvanometer returns to the null position. The ratio of signal B to signal A is then indicated on the divider. Signal A must be equal to or greater than

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[1]Commercially available thermal converters have a heater current range from 2 mA to 1000 mA for a corresponding heater resistance range of 1100 ohms to 0.2 ohms. Amplifiers are required to provide such currents from the output signals of vibration transducers.

[2]Numbers in brackets designate references at the end of the paper.

signal B. The switching impedance of switch 1 should be considered in relation to the output impedance of the transducer being tested. Switch 1 was chosen to have as high a capacitive reactance as possible between channel A and B because the internal impedance of most vibration pickups is capacitive. For signals from piezoelectric transducers, the capacitance from the high side of input terminal A or input terminal B to ground, or from the high side of terminal A to the high side of terminal B can act like a partial short causing a loss of accuracy in the final voltage ratio.

Cathode follower amplifiers are provided to reduce loading errors between the signal and voltage divider or between the signal and the voltage amplifiers. If loading errors can be neglected or if either A or B is a d-c signal, the cathode follower amplifiers should be removed from the circuit. The gain linearity of these amplifiers is important because signal A may be up to twenty times the magnitude of signal B which is used for balancing the two channels.

Voltage dividers are available for a-c and d-c signals with indicated ratios accurate to within 0.001 percent at a ratio of one. The divider may be either an a-c or d-c divider, whichever is compatible with signal A.

The voltage amplifiers are necessary to provide high input impedance and to amplify the signal voltage for operation of the thermal converters.

Gain and trim variable resistors are provided to adjust the output current from both voltage amplifiers[3].

Thermal converters provide a root-mean-square rectification of a-c signals for frequencies of approximately 5 Hz and higher. Below 5 Hz the thermal converter output begins to follow the wave shape of the input current. Briefly, a thermal converter is a thermo-junction welded to a heater wire and mounted in a small highly-evacuated glass bulb. Current passes through the heater, causing a rise in temperature of the heater wire and generating a d-c voltage in the thermo-junction proportional to the temperature rise. Since temperature of the thermo-junction is a critical characteristic of the converter, thermal insulation is provided by enclosing the two thermal converters in a copper box and surrounding them with insulating material. The thermal converters were electrically insulated between the heater wire and the thermo-junction.

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[3] A heater current of 50 mA to the thermal converter was used for the design discussed in this paper. This is well below the rated current of the converters chosen (80 mA with a safety factor of 2) and still high enough to produce ample output from the thermocouple.

The galvanometer was of the conventional electronic null indicator type.

The voltmeter section was provided to obtain an approximate balance between the two signals before they are switched to the thermal converters by switch 2. This was desirable to prevent inadvertent burn out of a thermal converter heater while attempting to balance the galvanometer[4]. Initially, an approximate determination of the ratio should be made from indications of the input signals on the panel voltmeters (VM). This is done through adjustments of the gain settings of the amplifiers and gain variable resistors. Final balance of the currents through the thermal converters and final determination of the ratio are made when switch 2 is set to the thermal converter (TC) position.

2.2 Procedure for Determining Voltage Ratio

A procedure has been developed for using the voltage ratio detector shown in figures 1 and 2. This procedure assumes prior knowledge of the type of voltage signal, a-c or d-c, and some information about the relative magnitudes of the signals. The ratio of the magnitude of signal A to signal B can be determined using the ratio detector shown in figure 2 as follows:

1. Set switch 1 to C (CHECK).

2. Set switch 2 to VM.

3. Turn power switches ON and allow about 15 minutes for thermal equilibrium of the electronic equipment.

4. Connect signal sources to input terminals A and B with the larger signal connected to terminal A.

5. Adjust the gain of the amplifiers and the gain variable resistors to read 0.5 volts on the VM's.

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[4] When a new circuit is put into operation, it is recommended that a check be made to determine that the current through the thermal converters and voltmeters are equal. In this circuit (Fig. 2), the current through the voltmeter was 50 mA when the voltmeter indicated 0.5 volts. The current to each thermal converter was checked with a milliammeter inserted in place of the short. With switch 1 in the CHECK position and switch 2 in the TC position, the input signal level at B was increased until 50 mA was indicated on the milliammeter. Then switch 2 was set to the VM position. The resistance of each voltmeter circuit was adjusted with variable resistors until the voltmeter read 0.5 volts.

6. Set switch 1 to R (RATIO).

7. Adjust the divider until VM A reads 0.5 volts.

8. Set switch 1 to C.

9. Set switch 2 to TC.

10. Tune the trim variable resistors to balance the galvanometer.

11. Set switch 1 to R.

12. Adjust the divider to balance the galvanometer.

13. Return switch 1 to C as a check on the balance of the detector circuit.

14. Retune the trim variable resistors if necessary to balance the galvanometer.

15. Set switch 1 to R.

16. If necessary, adjust the divider to balance the galvanometer.

17. Set switch 2 to VM before changing the signal level or turning off the equipment.

If the agreement between readings of the galvanometer with switch 1 in the C or R position (steps 13 to 16) is within acceptable limits, the voltage ratio is read from the divider.

3. RESULTS AND DISCUSSION

3.1 Voltage Ratio Detector Applications

The applications of an a-c voltage ratio detector are numerous in the electrical measurements field. Three applications are of interest in the calibration of vibration transducers.

The reciprocity calibrations of vibration standards[3] require measurements of voltage ratio and transfer admittance. The need for increased accuracies in these measurements was the primary reason for developing this circuit. In using a vibration standard calibrated by the reciprocity method to calibrate transfer standards (vibration pickups), it has been necessary to make transfer admittance measurements. The ratio detector has been used in a similar way to compare transfer standards with the primary standard.

A second application for this voltage ratio detector in a vibration standards laboratory was to use it with a compressor oscillator to survey the characteristics of a device continuously over a wide range of frequencies--often called a sweep frequency test. A compressor oscillator is one which keeps a signal constant by using feedback. This test is useful to "weed-out" unsuitable transfer standards before expending any significant time making a calibration. This ratio detector adapted for sweep frequency tests is shown in figure 3. It is necessary that signals A and B come from similar sources such as two acceleration sensitive pickups or two velocity sensitive pickups. A velocity signal could be differentiated electrically to be compared with an acceleration signal. In sweep frequency testing the RATIO position of switch 1 of the ratio detector is used, and as the oscillator changes frequencies an autographic record of the ratio of two signals versus frequency is made. Since the CHECK position of switch 1 cannot be used to balance the electrical components during a sweep frequency test, it is necessary to make one run through the frequency range of interest with switch 1 in the CHECK position. The record made with the switch in the RATIO position can be compared with the record for the CHECK position. The differences between these records provides information on the performance characteristics of the vibration pickup.

A third and perhaps less significant application of the ratio detector is for measuring the magnitudes of a-c signals. By using a d-c standard reference cell as one of the input voltages, the true root-mean-square magnitude of an a-c voltage can be determined within 0.1 percent using the circuit shown in figure 2. The cathode followers and the capacitors following the voltage amplifiers are by-passed for such measurements. This technique for measuring the magnitude of an a-c voltage signal can be used for checking the performance of vacuum tube voltmeters used in vibration pickup calibrations.

3.2 Transfer Admittance Versus Voltage Ratio Detector

Data from the calibrations of a limited number of vibration pickups show that the voltage ratio detector has significant advantages over the transfer admittance method. A basic advantage is that two signals can be compared simultaneously without the delays between the four measurements required to obtain the transfer admittance. For the operator, there are advantages in the greater sensitivity and reduced time (approximately one-half) to complete a calibration with the voltage ratio detector. The ratio detector built as shown in figure 2 has consistently given results that are repeatable within 0.02 percent and with a sensitivity of about 1 part per 10,000 when comparing two a-c signals and the ratio is near one.

A piezoelectric accelerometer suitable for use as a transfer standard was calibrated using the transfer admittance method and the voltage ratio detector. The results given in table 1 were obtained on two different exciters at different times.

Table 1 - Calibration Factors for a Piezoelectric Accelerometer

Frequency	Applied acceleration	Calibration factor: Transfer admittance measurement	Calibration factor: Voltage ratio measurement
Hz	g	mV/g	mV/g
2000	10	13.18	13.260
	5	13.15	13.262
	2	13.13	13.266
1000	10	-	13.085
	5	-	13.084
	2	-	13.086
900	10	13.13	-
	5	13.11	-
	2	13.11	-
500	10	13.09	13.048
	5	13.04	13.040
	2	13.00	13.043
100	10	12.96	12.993
	5	12.97	12.996
	2	12.97	13.002
10	2	12.95	13.19
	1	12.89	13.15
	0.5	12.98	13.16

Of particular note is the reduced scatter in the results obtained with the ratio detector as compared with the transfer admittance method. Comparisons of the sets of three factors measured for each frequency (values at 10 Hz excluded) show repeatabilities of 0.02 to 0.07 percent for the results obtained with the voltage ratio detector and of 0.08 to 0.7 percent for the transfer admittance method.

The number of significant figures given in table 1 are more than can be justified by the overall accuracies of the vibration standards. They are shown here for comparisons of the relative sensitivity and repeatability of the transfer admittance and ratio detector methods.

4. CONCLUSION

A voltage ratio detector for comparing a-c signals of 5 mV and larger was designed and put into operation. The principle of operation for this ratio detector is to divide the larger of two signals with a precision divider such that the output of the divider equals the smaller signal. Then the signals are amplified, converted to d-c signals with thermal converters and compared on a galvanometer. The transfer characteristics of the amplifiers and thermal converters are equalized by using the smaller of the two signals as a common input to the two amplifiers.

Based on the experimental measurements, some of which are presented in this paper, and observations of improvements in speed, accuracy and convenience during calibrations of vibrations and vibration transducers, it is believed that the current requirements for measurements of voltage ratio were met.

ACKNOWLEDGMENT

Messrs. James A. Miller and Douglas R. Bryant assisted in the design and construction of the voltage ratio detector described in this report.

REFERENCES

1. AC-DC Transfer Instruments for Current and Voltage Measurements, F. L. Hermach, IRE Transactions Vol. I-8, 1958.

2. A Differential Thermocouple Voltmeter, J. E. Griffin, F. L. Hermach, AIEE Transactions Paper No. 62-819, 1962.

3. Calibration of Shock and Vibration Pickups, ASA Publication S2.2-1959, Nov. 27, 1959.

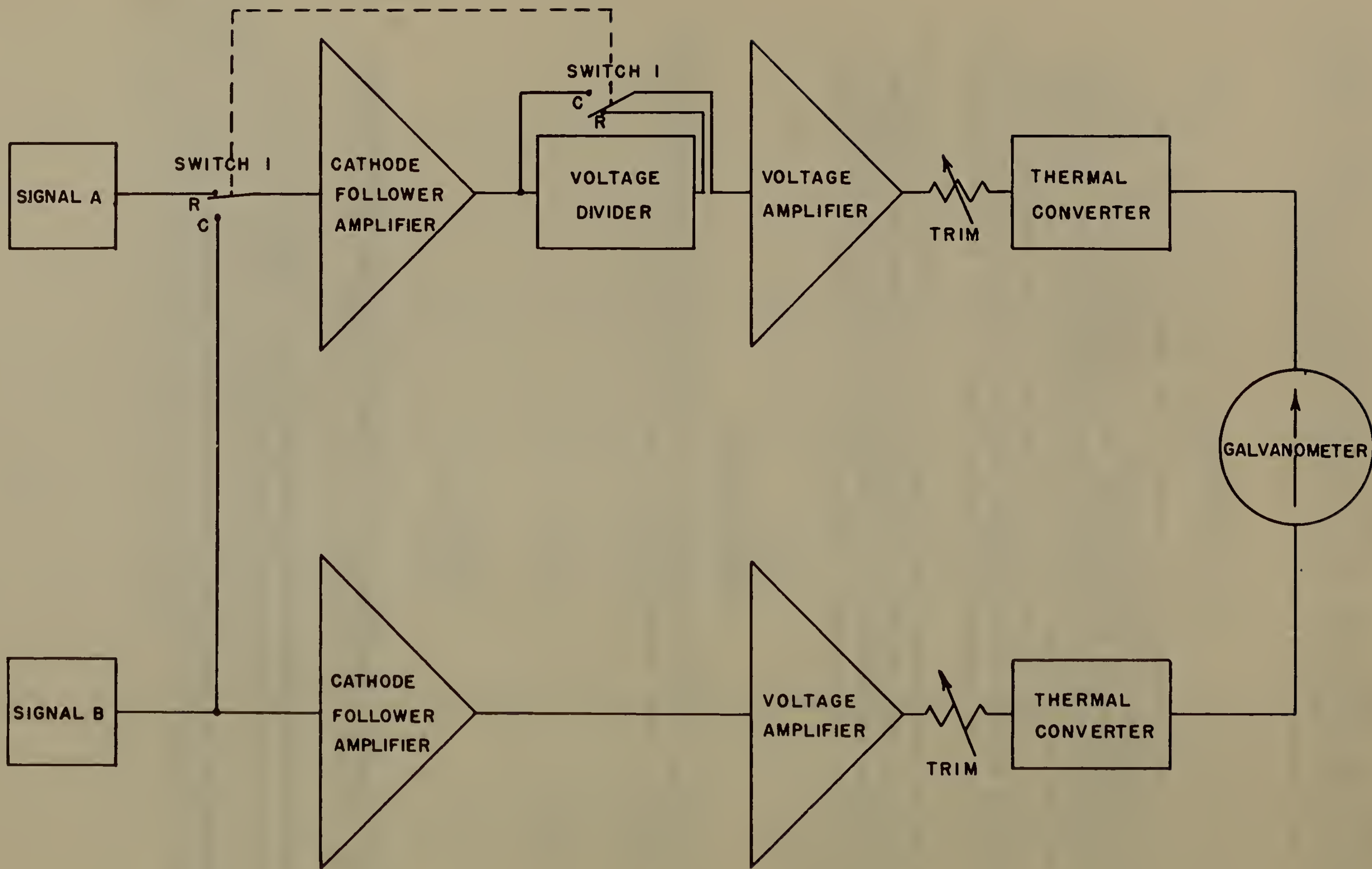

Fig. I Block diagram of ratio detector

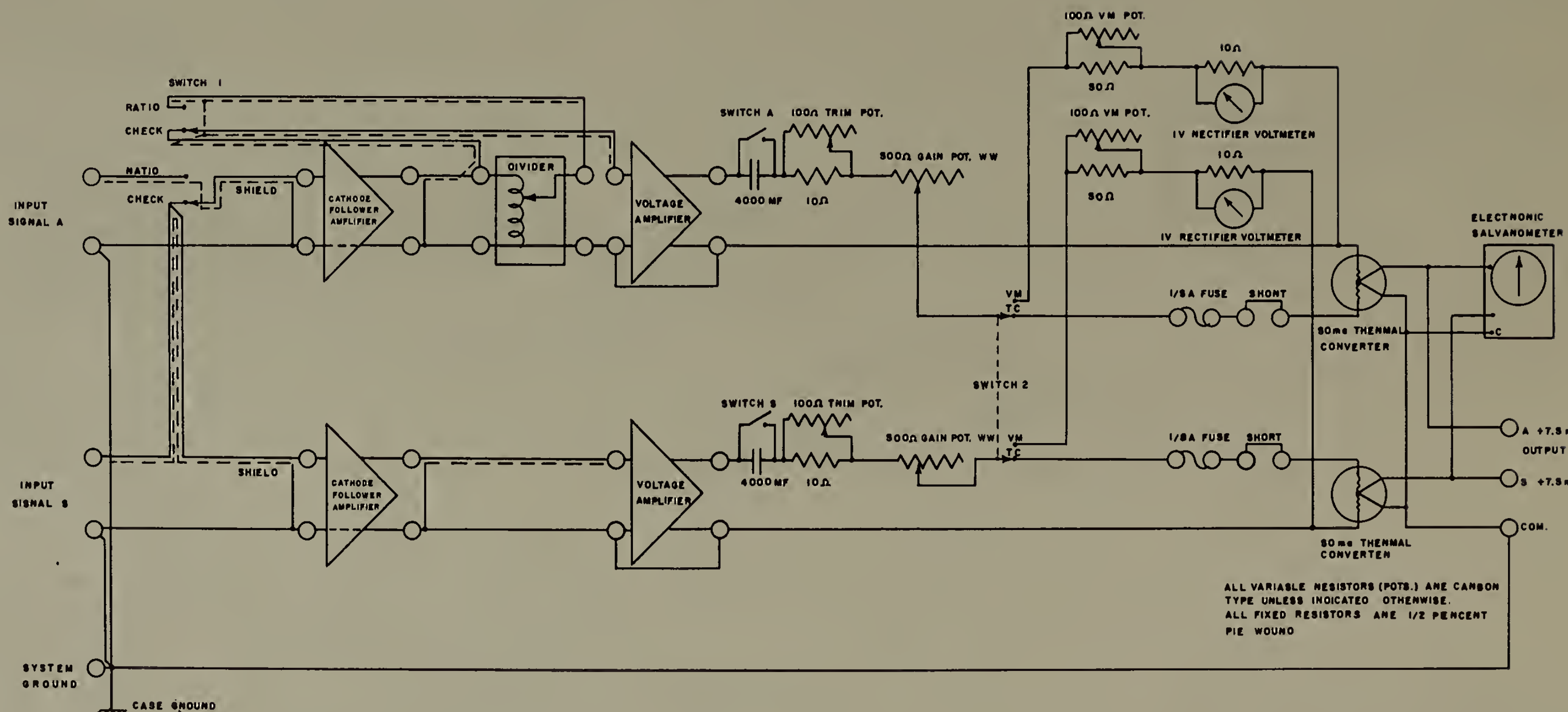

Fig. 2 Ratio detector circuit model III

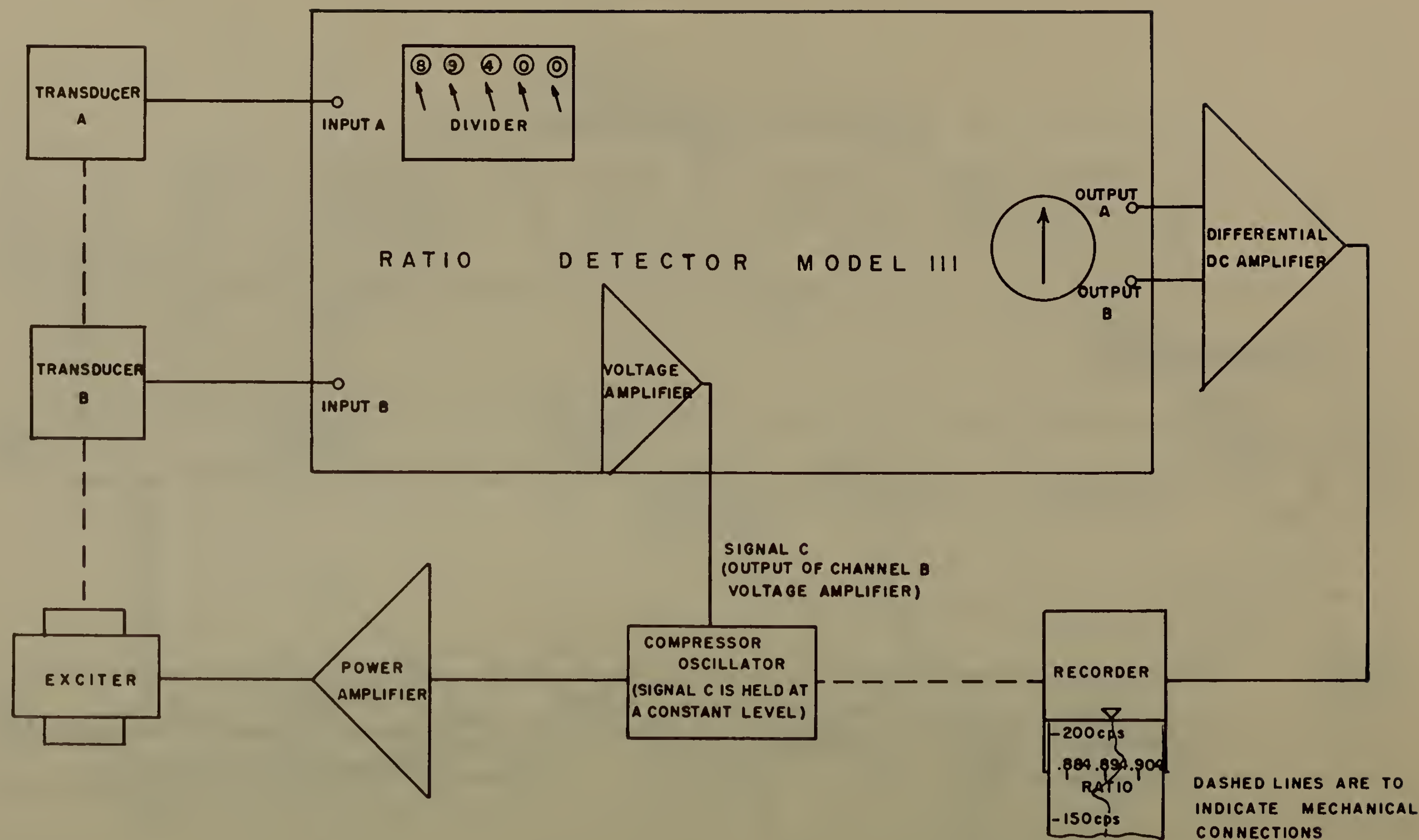

Fig. 3 Block diagram of sweep frequency ratio test

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