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BEARING READOUT TECHNIQUES FOR GONIOMETRIC DIRECTION FINDERS

[UNCLASSIFIED TITLE]

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ABSTRACT

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A bearing readout system reflecting earlier developments at the Naval Research Laboratory has been installed for use in connection with the wide-aperture direction finder developed by the Laboratory. An 1800-tooth tone wheel is mounted on the goniometer shaft and pulses derived from its signal are fed to a counter which contains the instantaneous azimuth to the nearest 0.1 degree. This azimuth data is sent to a number of remote units, each of which contains an analog-digital converter for presetting an azimuth. At the moment of equality of the preset and instantaneous azimuth, a pulse is generated to form an electronic alidade. Bearing readout is achieved by reading the preset azimuth on a digital printer. Continuous visual digital display of the preset azimuth is also available.

PROBLEM STATUS

This is an interim report; work on these problems is continuing.

AUTHORIZATION

NRL Problems R06-06 and R06-25
Projects NE 070-154-8 and NE 070-154-17
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BEARING READOUT TECHNIQUES FOR GONIOMETRIC DIRECTION FINDERS
[Unclassified Title]

INTRODUCTION

Naval Research Laboratory Memorandum Report 830 (1) discusses the philosophy underlying the hf-df bearing readout systems being developed within the Countermeasures Branch. Figure 10 of this previous report also outlined a system proposed for use in connection with the NRL wide-aperture direction finder (2,3). This system has now been installed and will be described in the present report. Appendix A of this report describes an experimental indicator for the wide-aperture df, and Appendix B presents the circuit diagram of the narrow-aperture bearing readout system.

BEARING READOUT SYSTEM

General Description

Figure 1 is a diagram of the bearing readout system. The upper half represents the "central" equipment required; the lower half represents the "remote" equipment required for each indicator. Although the central equipment is capable of driving several remote units, at the present time only one remote unit has been installed.

The 1800-tooth tone wheel described in NRL Memorandum Report 830 is mounted on the goniometer shaft and produces sine waves in a magnetic pickup at 1800 times the goniometer revolution frequency. These sine waves are fed to a pulse-forming circuit which detects their zero crossings and produces 3600 pulses per goniometer revolution or one pulse for every 0.1-degree change in goniometer azimuth. Also mounted on the goniometer shaft is a "north pipper," which consists of a sector of a ring slotted so as to produce one pulse in its associated magnetic pickup each time the beam of the direction-finder swings past north. This "north pip" is used to reset four cascaded decade counters to zero, while the pulses derived from the tone wheel are fed to the input of the counter string. Thus the counters always indicate the instantaneous azimuth of the goniometer, and therefore the instantaneous azimuth of the direction-finder beam, to the nearest 0.1 degree. Because the last counter in the string, which records hundreds of degrees, can read only 0, 1, 2, or 3 instead of 0 through 9, only two of the four Eccles-Jordan-circuit plates in this counter need be examined, while all four of the plates in the other three counters must be examined in order to determine the instantaneous azimuth. These fourteen outputs are inverted by the output driver and sent at low impedance to the remote units.

Each remote unit contains an analog-digital converter which is used to select the azimuth at which the comparison pulse of the electronic alidade appears. The converter has outputs from 0.0 to 359.9 degrees in binary-coded decimal weighted 1-2-4-8. It is a double brush converter, and its outputs must be fed into an antiambiguity circuit.

The output of the antiambiguity circuit, which is still weighted 1-2-4-8, is fed into the converter. This unit converts the selected azimuth to binary-coded decimal weighted 1-2-2-4 to match the outputs of the counters. The 1-2-2-4 output is also fed to a digital printer which is used to make a tape record of the selected azimuth. Printing can be

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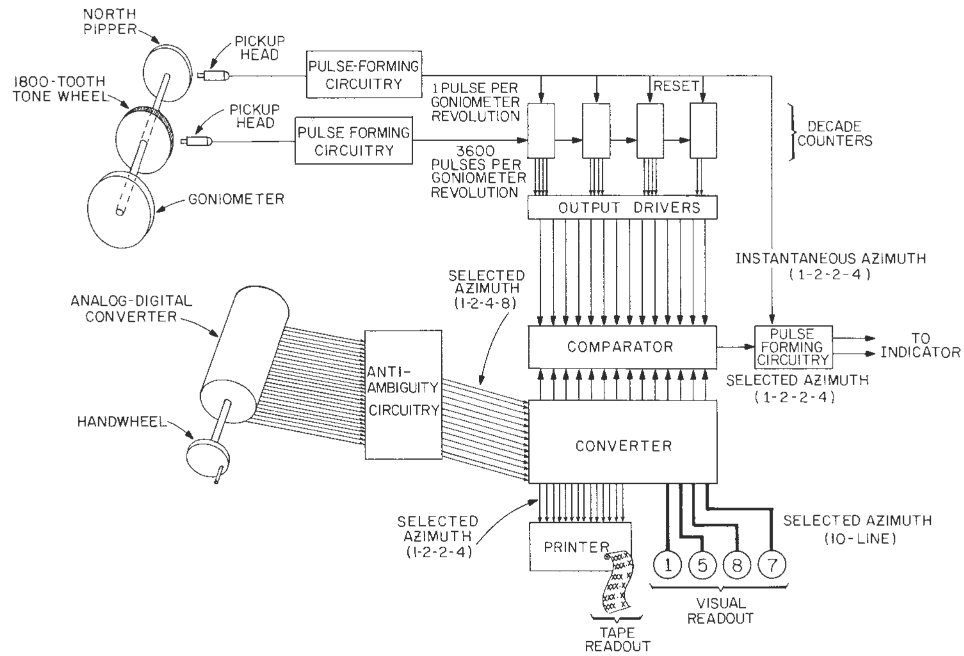

Fig. 1 - Bearing readout system

initiated either by an operator-controlled pushbutton or by a clock-motor-driven switch. The converter also has four 10-line outputs to operate a visual readout of the selected azimuth. This visual readout consists of four Nixie indicator tubes.

The comparator circuitry produces an output when the selected azimuth from the converter matches the instantaneous azimuth from the counter output driver. This output is used to form the comparison pulse of the electronic alidade.

Circuit Details

Counters and Output Drivers - The counter string consists of four LFE Model 1704 decade counters. Since the maximum anticipated goniometer speed is 20 rps, the maximum possible counting rate is 3600 x 20 or 72 kc, which is within the 100-kc rating of these counters. Each counter consists of four Eccles-Jordan circuits connected in cascade with the usual feedback between stages so that the scale of 16 is permuted into a scale of ten with 1-2-2-4 weighting.

The plate of each Eccles-Jordan circuit which is nonconducting (i.e., more positive) after commutation is available as an output through a 1.5-megohm isolating resistor. Each of the 14 significant counter outputs is connected to an output driver, the circuit of which is given in Fig. 2. This driver provides a low-impedance output and inverts the signal so that the absence of a bit is indicated by a voltage above +3 and presence by a voltage below -6.

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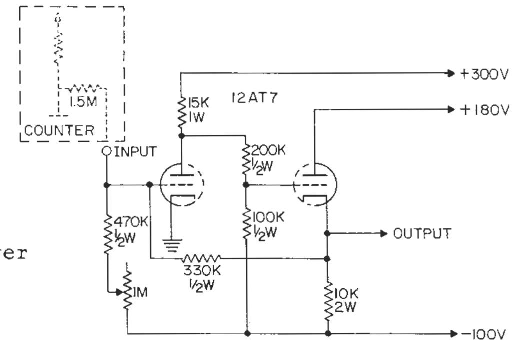
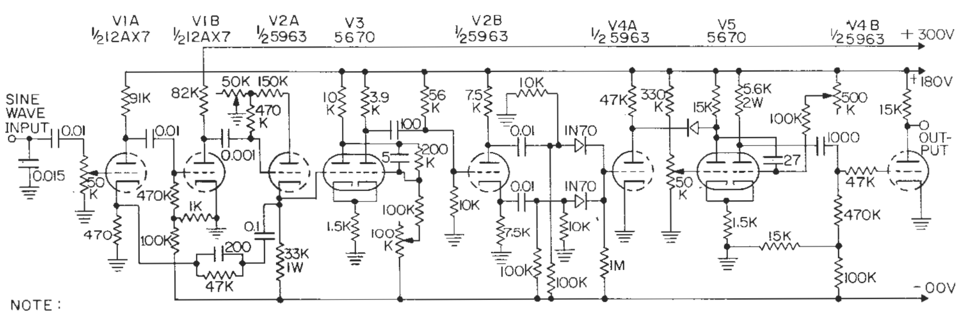


Fig. 2 - Counter output driver

Azimuth Pulse Forming Circuit - Figure 3 is the circuit diagram of the unit that forms the pulses counted by the azimuth counter. The sine waves from the tone wheel are amplified by V1 and V2a, and then squared by the Schmitt circuit, V3. The resulting square waves are differentiated and the pulses are sent to the split-load phase inverter, V2b. The positive pulse associated with each zero crossing of the original sine wave is selected by the diode pair and amplified by V4a, which, in turn, triggers the monostable multivibrator, V5, through a keying diode. V5 produces a positive pulse of suitable width to drive the leading counter, and this pulse is inverted and raised to a suitable amplitude by V4b.



NOTE:
ALL RESISTORS ARE ½ WATT UNLESS OTHERWISE NOTED
CAPACITORS >1 ARE IN μμf CAPACITORS ≤1 ARE IN μf

Fig. 3 - Azimuth pulse forming circuit

North Pulse Forming Circuit - Figure 4 is the circuit diagram of the unit that forms the north pip. This pip is used to reset the counters to zero and is also sent to the remote units. The pip from the magnetic pickup is amplified by V6 and V7a. The amplified pip is converted to a square positive pulse by the Schmitt circuit, V8. This pulse is fed to amplifier V7b, and is used to trigger the monostable multivibrator, V9, through a keying diode. V9 produces a positive pulse of suitable amplitude and width to reset the counters. This pulse is fed to the output cathode follower, V10. It should be noticed that V10 is biased so that its cathode would normally rest below ground if it were not for the diode. This arrangement assures a low-impedance ground on the reset bus.

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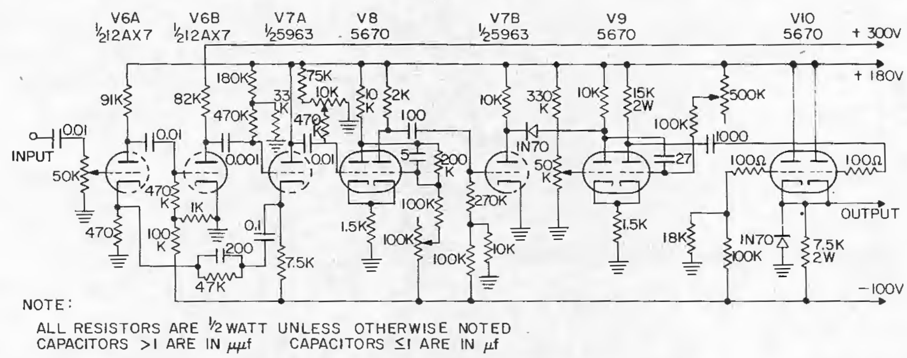

Fig. 4 - North pulse forming circuit

ADC and Antiambiguity Circuitry - The analog-digital converter (ADC) is a Librascope Model 733. This device has a total of 14 rings on two code wheels. The precise relationship between shaft position and electrical output is disregarded in the bearing readout system which utilizes the ADC only as a one-knob presetting device, but the ADC can be geared to another goniometer which can be utilized for intercept.

Except for the least significant bit, each ring is provided with a pair of brushes displaced on either side of the "proper" position. This characteristic can be used to eliminate the ambiguity caused by brush transition. Figure 5 illustrates a number of typical cases. In this diagram shading indicates conductive material connected to the common lead of the ADC. Inspection of Fig. 5 reveals that application of the following rule will always remove brush ambiguities: If a decision has been made that a given bit is "on" (i.e., connected to common), read the upper brush of the next higher order bit, otherwise read the lower brush.

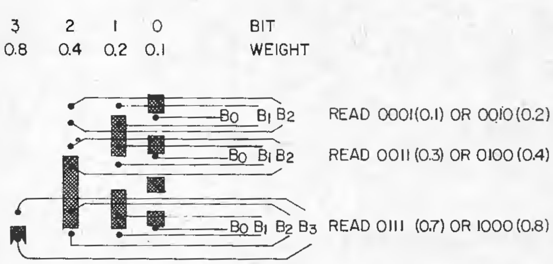

Fig. 5 - Reading of double brush system (basic case)

This rule is effected by the antiambiguity circuitry, which is illustrated in Fig. 6. The common is connected to -6 volts so that "on" is represented by -6 volts and "off" by an open circuit. If the (n - 1)th bit is "on," the transistor associated with the lower brush of the nth bit is saturated so that the signal on that brush cannot affect the output, while the transistor associated with the upper nth brush is cut off so that it has no effect on the signal. Conversely, if the (n - 1)th bit is "off," the roles of the transistors are reversed so that the signal on the lower brush associated with the nth bit appears on the output. Thirteen of these circuits are required, as the lowest order bit has only a single brush. These circuits are mounted on printed circuit cards in pairs, and seven cards are required.

Some complications are created by the fact that the ADC is coded in binary-coded decimal rather than true binary. Referring to Fig. 7, it is seen that when the count lies between 9 and 10, sampling of bit 3 should be controlled by bit 0 rather than by bit 2.

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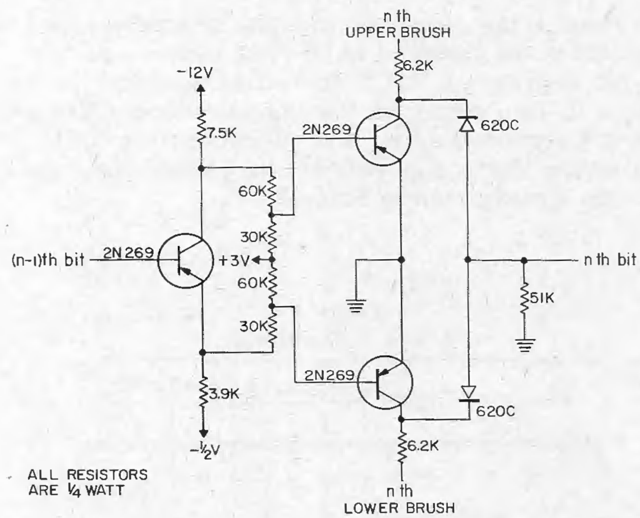

Fig. 6 - Antiambiguity circuit

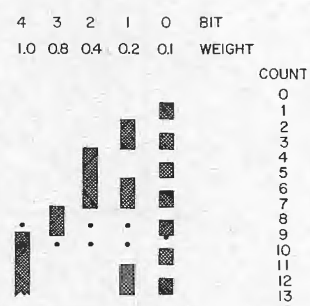

Fig. 7 - Reading of double brush system (cycling complications)

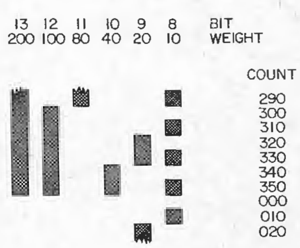

Fig. 8 - Reading of double brush system (cycling complications)

Similarly, sampling of bit 7 should be controlled by bit 4 and sampling of bit 11 should be controlled by bit 8. Referring to Fig. 8, it is seen that bits 10 and 12 should also be controlled by bit 8.

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Converter - The input to the converter consists of binary-coded decimal weighted 1-2-4-8 in which a signal in the range -4 to -6 volts represents "on" and a signal in the range +1/2 to -1/2 volt represents "off." One role the converter must perform is to convert this coding to a 10-line signal for the visual readout. Table 1 displays the 1-2-4-8 coding. In this table, a 1 represents "on" and a 0 represents "off." Now, letting a prime indicate negation and letting a plus sign indicate the logical "or," the usual Boolean manipulations yield the results summarized in Table 2.

Table 1
1-2-4-8 Weighting

Decimal Digit	Order of Binary Bit			
	1	2	3	4
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	0	1	0
5	1	0	1	0
6	0	1	1	0
7	1	1	1	0
8	0	0	0	1
9	1	0	0	1

Table 2
Conversion of 1-2-4-8 to 10-Line

Decimal Digit*	Order of Binary Bit*†
0′	1 + 2 + 3 + 4
1′	1′ + 2 + 3 + 4
2′	1 + 2′ + 3
3′	1′ + 2′ + 3
4′	1 + 2 + 3′
5′	1′ + 2 + 3′
6′	1 + 2′ + 3′
7′	1′ + 2′ + 3′
8′	1 + 4′
9′	1′ + 4′

*The prime indicates negation.
†The plus sign indicates "or."

[redacted]

The converter generates the affirmations and negations of the four input bits and combines them in accordance with the rules of Table 2 to produce the negation of each of the ten decimal digits. Each of these negations is connected to a circuit of the form shown in Fig. 9. If no negation is present, the transistor is cut off and the corresponding indicator cathode lights. If a negation is present, the transistor saturates, holding the indicator cathode near ground and preventing ionization. Actually the indicator tube anode is connected to +180 volts through a current-regulating resistor instead of directly to +100 volts, but the fact that nine of the ten cathodes will always be negated assures that the indicator tube anode will be in the vicinity of +100 volts.

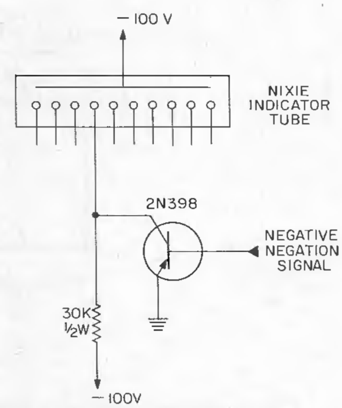

Fig. 9 - Negating circuit

The converter must also produce a binary-coded decimal output with 1-2-2-4 weighting to correspond with the counter outputs. This weighting is shown in Table 3. It may be noticed that the bit-1 elements of Tables 1 and 3 are identical and the output for this bit may therefore be obtained from the input. The other bits differ and the outputs may most easily be obtained by the operations on the 10-line outputs summarized in Table 4.

The affirmation of a 10-line output consists of a negative voltage on the collector of the corresponding cathode control transistor and the negation consists of a near ground at this point. Thus the relation of Table 4 can be effected by combining these points with diodes and inverting, producing a 1-2-2-4 output in which affirmation is near ground and negation is a negative voltage.

Table 3
1-2-2-4 Weighting

Decimal Digit	Order of Binary Bit			
	1	2	3	4
0	0	0	0	0
1	1	0	0	0
2	0	1	0	0
3	1	1	0	0
4	0	1	1	0
5	1	1	1	0
6	0	0	1	1
7	1	0	1	1
8	0	1	1	1
9	1	1	1	1

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Table 4
Conversion of 10-Line to 1-2-2-4

Order of Binary Bit	Decimal Digit*
2	2 + 3 + 4 + 5 + 8 + 9
3	4 + 5 + 6 + 7 + 8 + 9
4	6 + 7 + 8 + 9

*The plus sign indicates "or."

The complete circuit diagram of a converter is shown in Fig. 10. Figure 11 is a photograph of a card containing the circuitry of Fig. 10, and a card containing two of the antiambiguity circuits of Fig. 6. Four cards are used to convert the four decimal digits, although a simpler converter could have been used for the hundreds of degrees.

Printer - The printer employed is a Berkeley Model 1452. The voltage levels and polarity of the 1-2-2-4 converter outputs are suitable for direct operation of the printer. Printing is initiated either by an operator-controlled push button or else by a switch operated by a cam on a clock motor. In the latter mode of operation, a foot switch is provided to allow the operator to indicate whether the reading was valid.

Comparator - Figure 12 is the circuit diagram of the comparator. Ideally the comparator would produce an output only if the converter output equalled the number in the counter. This characteristic would take considerable circuitry, however, so a scheme is employed in which comparator outputs appear at several different counts but in which the first output after the counter resets occurs at the time of equality.

If the output of the converter is negative for some particular bit, the implication is that that bit should not be required from the counter in order to produce a comparator output. Conversely, if the output of the converter is near ground, the implication is that the counter output must be "on," i.e., negative, in order to produce a comparator output. Stated another way, the only combination of circumstances on a given bit that should inhibit comparator output is a ground input from the converter and a positive input from the counter. Inspection of Fig. 12 reveals that this is the only situation where the emitters of the input buffers are not negative. As soon as this situation is removed in all 14 buffers, the output transistor can conduct and the comparator output voltage rises from near -12 volts to near ground.

Output Pulse Forming Circuit - The output circuit contains five EECO transistor plug-ins arranged as in Fig. 13. The squaring circuit converts the output of the comparator into a series of rectangular pulses, with the first one which follows a north pulse occurring at the selected azimuth. The north pulse is connected to one input of the first flip-flop, while the output of the squarer is connected to the other input, thus producing a positive commutation of the flip-flop at the selected azimuth. The second flip-flop is employed as a scale-of-two so as to activate the electronic alidade on alternate rotations of the goniometer and hence prevent breakage of the indicator pattern baseline. This flip-flop triggers two one-shots, one of which produces the intensity pulse for the electronic alidade, while the other produces the deflection pulse.

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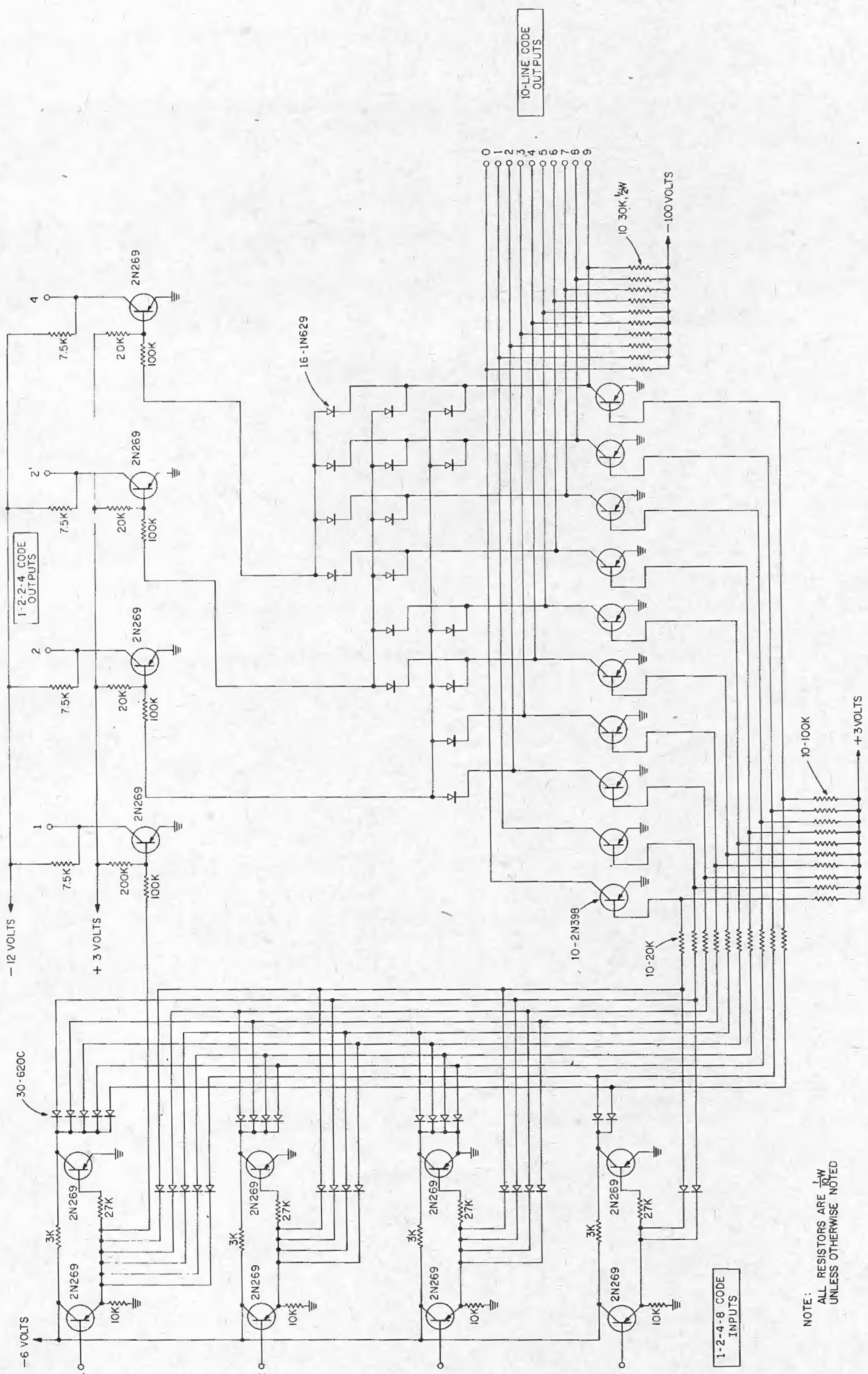

Fig. 10 - Converter

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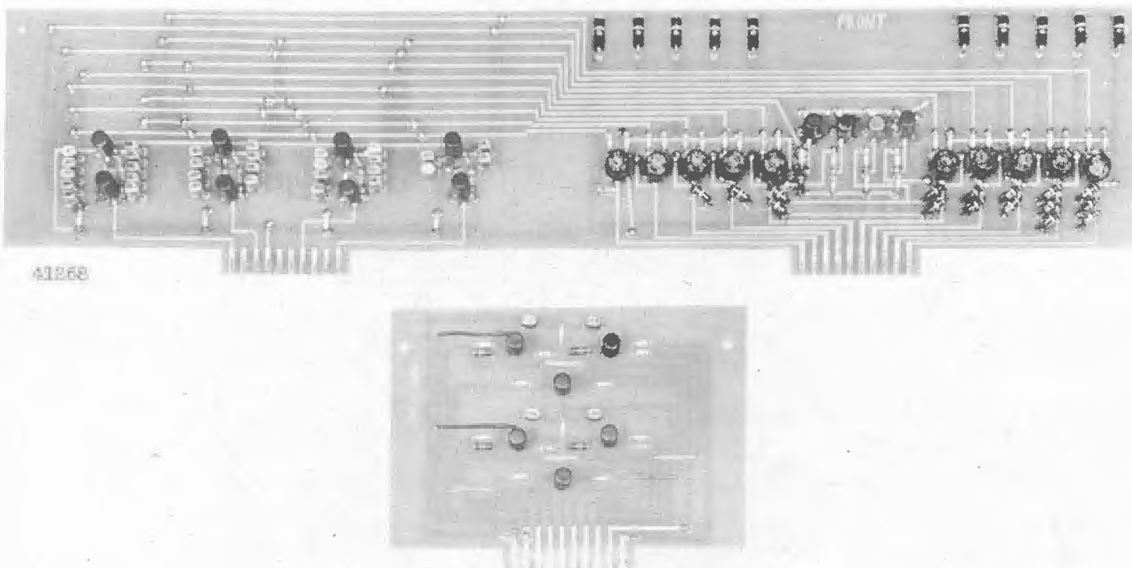

Fig. 11 - Converter and antiambiguity cards

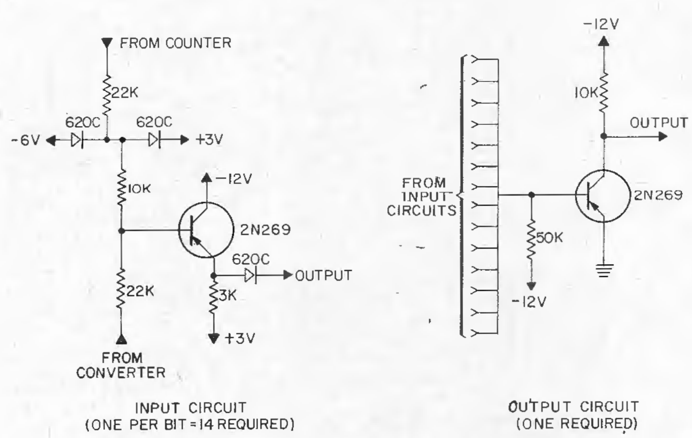

Fig. 12 - Comparator

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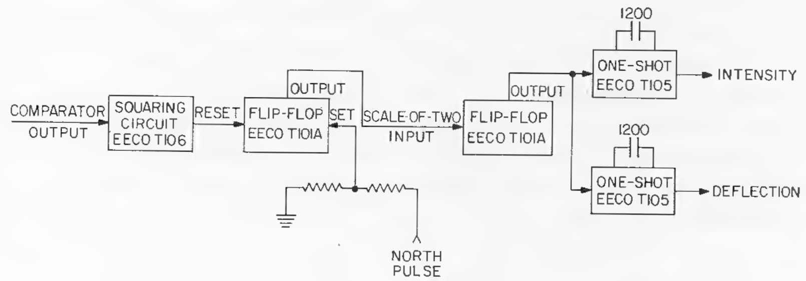

Fig. 13 - Output circuit

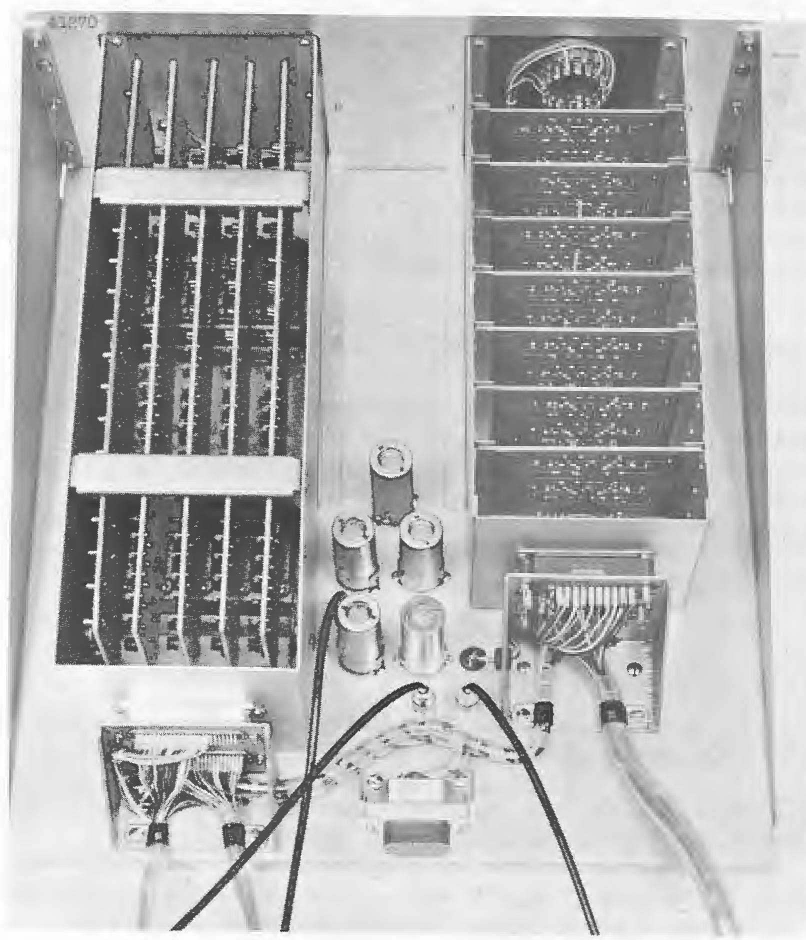

Fig. 14 - Remote unit

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Assembly - Figure 14 is a photograph of the electronics of the remote unit. Each of the seven cards mounted on the subchassis on the right contains two antiambiguity circuits. The cable leading to this subchassis connects to the ADC. The subchassis on the left contains four converter cards and the comparator cards. Two cables may be seen leading to this subchassis; the one on the left connects to the central unit and supplies power and instantaneous azimuth, the one on the right connects to the Nixie indicator tubes and contains the selected azimuth in 10-line code. The printer is plugged into the connector in the center. The five plug-ins of the output circuit are mounted on the main chassis. The three coaxial cables supply the north pulse input to the output circuit and carry the two outputs to the indicator.

CONCLUSIONS

The philosophy of bearing readout presented in NRL Memorandum Report 830 has been applied to the NRL wide-aperture direction finder. A bearing readout system has been recently installed and is being tested at the field site of the wide-aperture direction finder.

This device appears to fulfill the requirements of its task, although it is not claimed that the approach adopted is the only satisfactory one. The circuitry is reliable, although considerable circuit simplification could be achieved if the ADC, counter, printer, and visual readout devices utilized the same codes. In summary, it may be stated that while the equipment described does not necessarily represent an optimal system, it does constitute a convenient bearing readout device having precision considerably greater than the inherent accuracy of the direction finder.

ACKNOWLEDGMENTS

Many persons contributed to the work reported herein. The Engineering Services Division developed special techniques to hob the 1800-tooth gear. Within the Countermeasures Branch, the advice and support of Messrs. Robert D. Misner and Mack J. Sheets were most valuable. The mechanical design and layout of the component boards and chassis, as well as the construction and assembly of the equipment, were performed by Mr. William M. McDavit of the Countermeasures Branch, whose skill and enthusiasm assured satisfactory prosecution of the project.

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2. Gleason, R.F., and Greene, R.M., "A Wide-Aperture HF Direction-Finder," NRL Memorandum Report 746 [redacted]), Oct. 1957

3. Gleason, R.F., and Greene, R.M., "A Wide-Aperture HF Direction-Finder With Sleeve Antennas," NRL Memorandum Report 843[redacted]), Aug. 1958

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APPENDIX A

A NOVEL METHOD OF ELECTRONICALLY GENERATING A CIRCULAR SWEEP
[Unclassified]

Goniometric direction finders usually employ a circular sweep on a cathode-ray-tube indicator. Often this sweep is achieved by rotating deflection coils in synchronism with the goniometer. In connection with the work described previously, however, it was desired to employ a commercial oscilloscope with a 17-inch tube as the indicator and this necessitated developing an electronic system for producing a circular sweep in synchronism with the goniometer and capable of radial deflection.

The conventional approach to this problem is illustrated in Fig. A1 and depends on the use of a resolver mounted on the goniometer shaft. This type of approach has given satisfactory service over the years, although some care is needed in its realization, especially in the maintenance of consistent phase shifts at the high carrier frequency and in the balance of the demodulators.

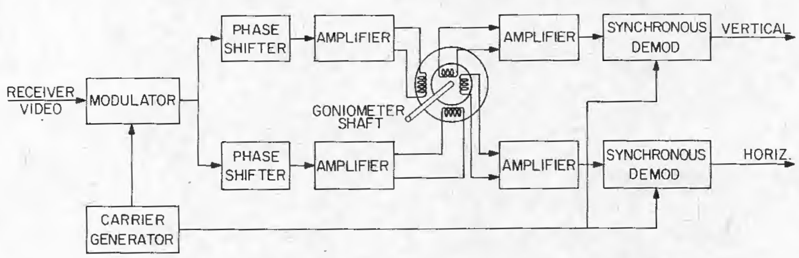

Fig. A1 - Resolver display

A tight time schedule did not permit the development and refinement of such a system, so the approach of Fig. A2 was conceived. A two-phase generator was mounted on the goniometer shaft, and the amplified sine and cosine of the instantaneous azimuth was multiplied by the video. The two products are then directly connected to the vertical and horizontal channels of the oscilloscope.

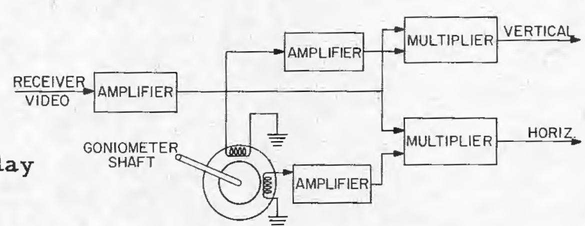

Fig. A2 - Generator-multiplier display

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It is still necessary to match phase shifts in the two channels, but this is a much simpler task at 15 cycles in the multiplier system than at tens or hundreds of kilocycles in the carrier-resolver system. The generator must produce low-distortion waveforms 90 degrees apart. Standard two-phase tachometers proved less satisfactory in this respect than a small two-phase instrument servo motor magnetized by connecting a battery across its windings. The multipliers must be true multipliers of reasonably good linearity, but the requirements on them are less stringent than those imposed in analog computing.

A Philbrick MU/DV provided the multiplier pair, and Philbrick K2-W's and K2-P's were plugged into an HK manifold to provide the necessary amplifiers. The system has a bandwidth from dc to about 6 kc. It was constructed experimentally in about two hours using the available blocks of commercial circuitry. Performance appeared comparable with that expected from a carrier-resolver system.

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APPENDIX B

BEARING READOUT SYSTEM FOR AN/GRD-6
[[redacted]]

Figure 4 of NRL Memorandum Report 830 presented the block diagram of the bearing readout system then being installed for use with the AN/GRD-6 direction finder, but did not include the circuit diagrams. These are presented as Figs. B1 through B3. The contributions of Mr. Jack D. Hortman in the installation and calibration of this equipment are gratefully acknowledged.

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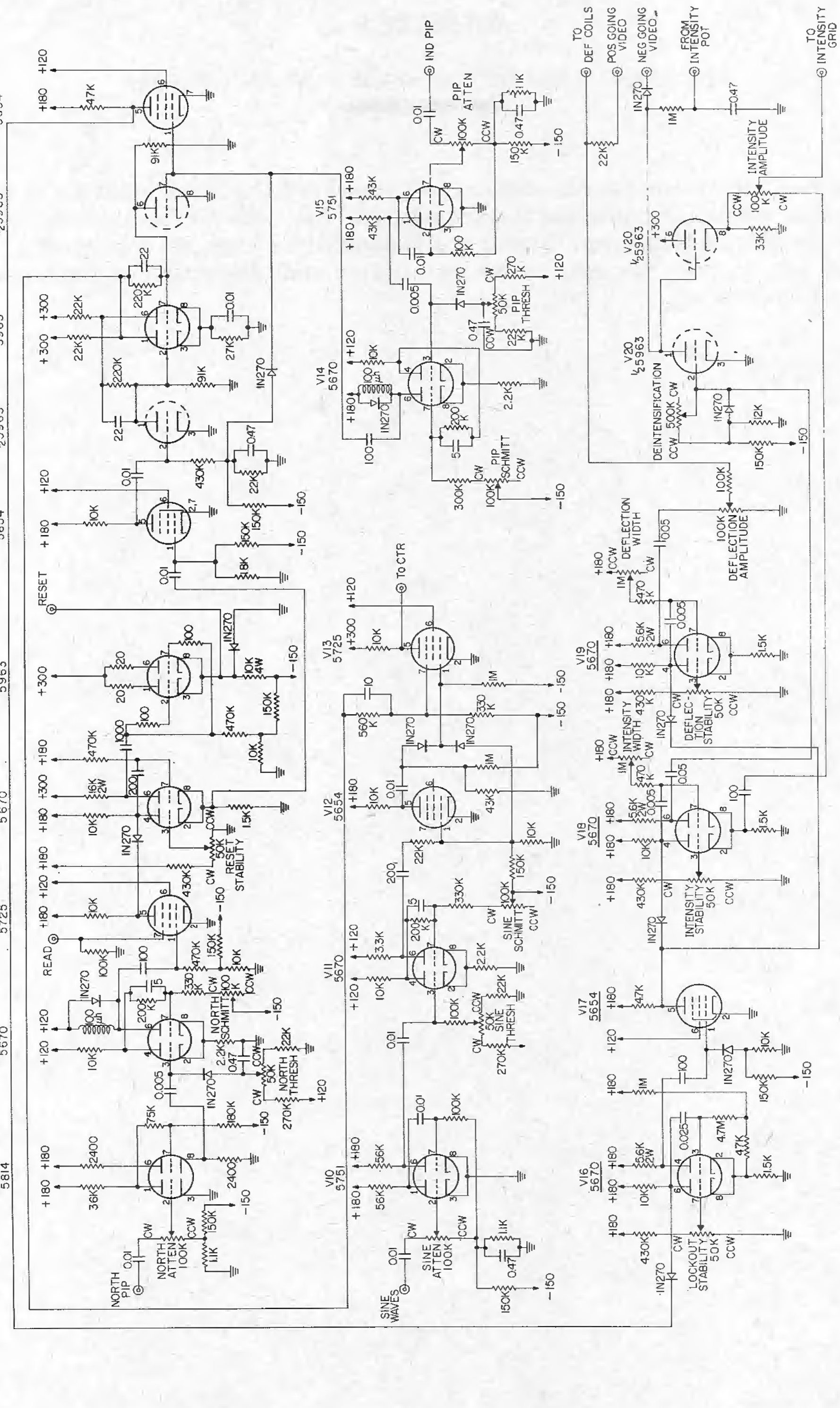

Fig. B1 - Indicator electronics of bearing readout system

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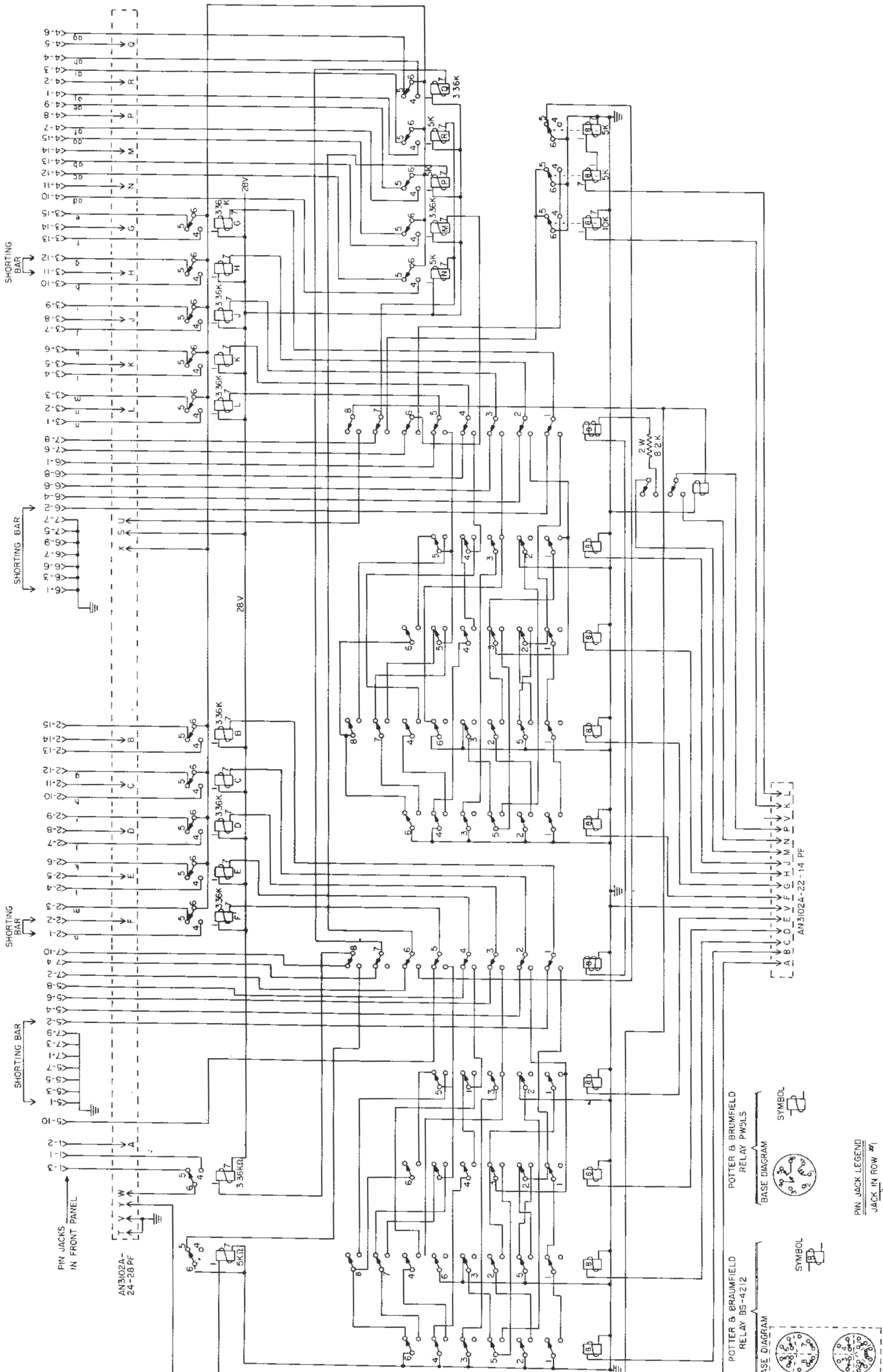

Fig. B2 - Teletype translation of bearing readout system

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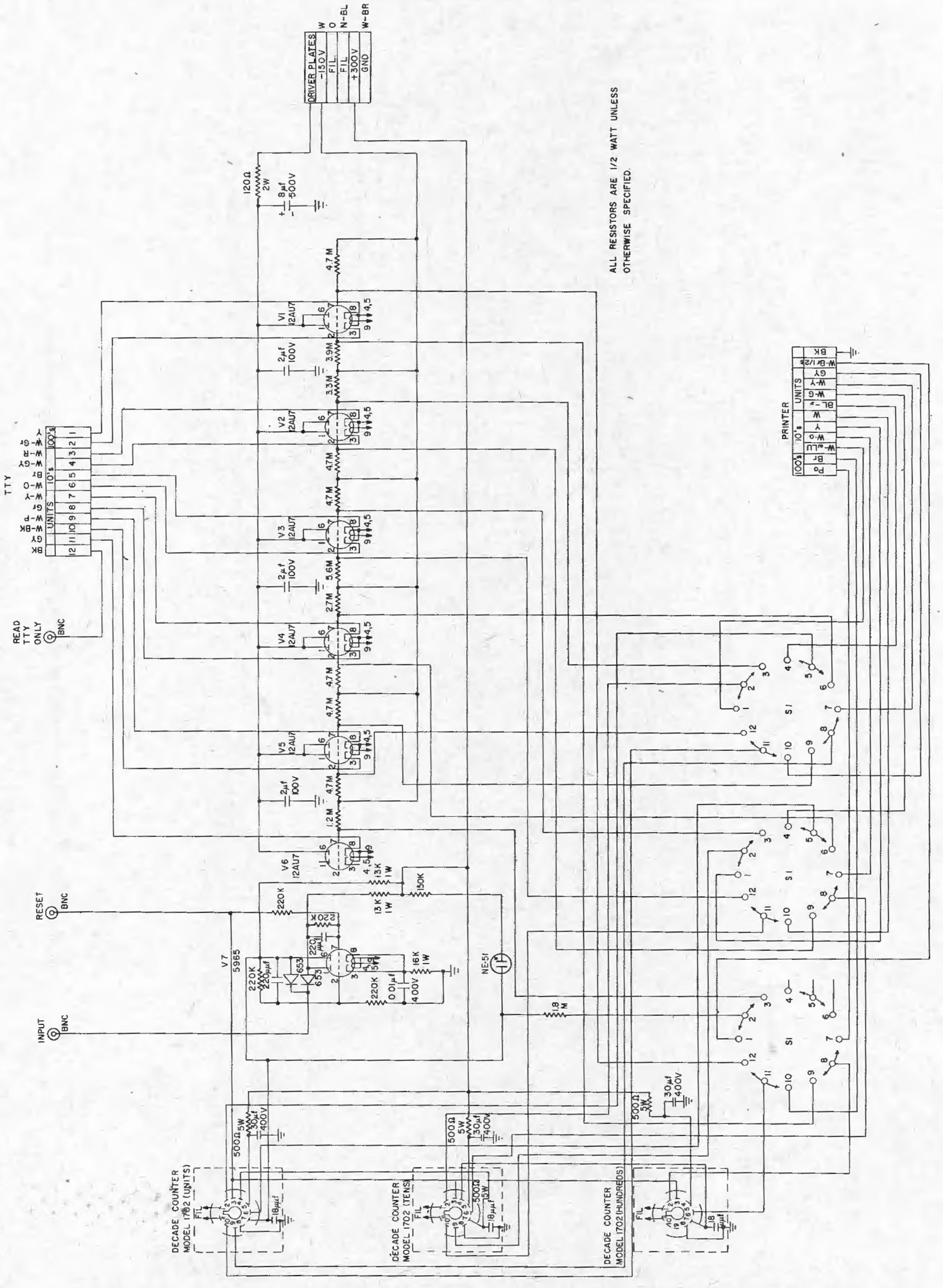

Fig. B3 - Counter and assembly of bearing readout system

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