Proceedings of the International
Conference of Wildlife Biotelemetry.
Halifax, Nova Scotia. 1983. 4: 94-103

DIRECTIONAL AIRCRAFT ANTENNA SYSTEM

V. B. Kuechle, R. A. Reichle, James L. D. Smith and R. J. Schuster

University of Minnesota

Cedar Creek Lab, Bethel, Minnesota

ABSTRACT

This paper describes a directional antenna system for use on small aircraft to locate animal borne transmitters. It uses a phased array of vertical monopole antenna which are electronically switched to yield a directional pattern. Performance details, circuit diagrams and limitations are provided.

I. Introduction

As the state-of-the-art of radio tracking animals advances, the interest and need for faster and more automatic location methods becomes apparent. Most tracking is done using a receiver, Yagi antenna and human operator turning the antenna and recording the direction of the signal. In the case of aircraft it means switching the Yagi antennas and maneuvering the aircraft, usually in a circular fashion to locate the transmitter[1]. In all of these cases an electronically steerable or rotated antenna would be an asset. At least one system is commercially available for animal tracking[2], however, it has not gained wide acceptance. It's major limitations are low sensitivity and relative high cost. A number of systems also exist for locating emergency locator beacons (ELT) carried by aircraft.[3,4] These systems are designed for permanent installation in aircraft, and are designed to operate with higher duty cycle transmitters. Additionally they are not directly applicable to radio tracking animals because they are designed to operate at 121.5 and 243 MHz. These systems use phased vertical arrays. Phased arrays have been used for a long time in broadcast antennas to orient the maximum field in a given direction. Although the fundamentals of array design have been known for at least 25 years [5], they have not seen much use in the VHF bands.

Most systems use two antennas at a given spacing and feed the signals in such a manner as to cancel the signal coming from one direction and to add the signals from the opposite direction. The resulting pattern for isotropic sources is shown in Figure 1. (An isotropic source is an antenna that radiates equally in all directions). This pattern will remain approximately the same for spacings up to one-quarter wavelength. For spacings less than one-quarter wavelength the shape remains the same, however the maximum gain is reduced. Most system then switch this pattern 180 degrees as shown in figure 1 and compare signal amplitudes to give a homing direction.

Our goal in this system design was to build an array that could be easily attached to aircraft to give a direction to a transmitter without turning the aircraft. We felt that most users operate with rented aircraft which do not allow the installation of permanent antennas such as used in ELT locating systems[3,4]. Such arrays would also have use in unattended ground stations.

II. Antenna Design

The antenna we used is shown schematically in Figure 2. It switches the pattern of Figure 1 back and forth by alternating which antenna has the delay in its feed line. The signals are then fed to the signal combiner which adds the two signals and feeds the result to a receiver. Referring to figure 1, when the switch is in position I, the signal at the receiver will have amplitude A and when in position II will have amplitude B. A control signal is generated which switches the delay line and also sychronously samples the output of the receiver. The audio output of the receiver is rectified and sent to a buffer and low-pass filter. The output of the low-pass filter is input to the sample and hold amplifiers which are synchronously sampled by the antenna control signal. The sample and hold amplifiers are followed by a difference amplifier which outputs the magnitude of the difference between A and B and also the polarity. If B is greater than A, the relative magnitude will be displayed by LED's on the right display. Since the display integrated circuits only displayed positive voltages, an inverter is used for the other display.

A Wilkerson hybrid[6] was used to combine the signals from two antennas and also to isolate the antennas from each other. Antenna switching was accomplished using PIN diodes[7]. Sampling was commenced on the detection of a signal. In our case this was the output of a phase-lock-loop tone decoder. Each antenna was sampled for five milleseconds. This period was chosen to allow four samples during a typical 20 millisecond pulse. Four samples are needed to give right/left and front/back information. Longer sample periods would allow longer time constants in the low-pass filter, giving somewhat better noise performance.

The antenna assembly was designed to be mounted on a Super Cub forward of the wheel struts with bolts holding the rear of the antenna assembly to the wheel struts and a nylon strap placed around the fuselage holding the front in place. It could also be placed on other aircraft although the details have not been worked out. The antenna assembly also contained the delay lines, switching circuits and combiner. It measured 46 cm x 46 cm x 3 cm.

III. Antenna Performance

The system was tested to determine overall performance and to determine the effects of antenna length, antenna spacing, and size of ground plane. Most tests were conducted on the ground using an antenna test range.

No problems were encountered with the design of the antenna switching and display systems. The switching system has a loss of 1.5 db $\pm$ 0.5 db. Phase errors in switching back and forth were within $\pm$ 1^{o}. Isolation of the system when an out of phase signal equivalent to the antenna spacing was fed to the system was 30 db.

The performance of the system was affected by antenna length and as would be expected by ground plane size. The most significant problem was the effect of mutual coupling or the influence of one antenna on the other. The antenna pattern shown in figure 1 assumes that each antenna has a circular pattern. When the second antenna is included, the pattern of one antenna changes to that shown in Figure 3-A. This indicates the influence of the second antenna on the first. When these two antennas are combined the resulting pattern is shown in figure 3-B. Figure 3-C shows the pattern of a one-eight wavelength antenna. This indicates that the forward direction is not greatly affected by the mutual coupling, while the null side is greatly distorted with the appearance of a back lobe. We would expect this behavior from pattern multiplication theory which states that the pattern of the array is multiplied by the pattern of the antenna.

Antenna length had only a minor effect on the antenna pattern. It did have a marked effect on the gain. For an antenna 1/8 wavelength long, (unmatched) the gain was approximately 20 db less than a resonant antenna. Gain of the system for one-quarter wavelength resonant antennas was 2 db greater than a dipole.

Ground plane size also had a marked effect and had a greater effect on pattern than gain. The general tendency was for the back lobe to increase in size and gain to decrease as ground plane size was reduced. We found that the ground plane should extend at least 1/4 wavelength beyond the antenna base. This could consist of single radials, however, in this case the length and angle became critical. Ground plane material was not critical, aluminum window screen performed as well as continuous metal sheeting.

In all cases the symmetry ± 90 degrees from the peak or null was sufficient to give good data on when the position shifted from front to back or right to left. Current diagrams are shown in figures 4 and 5.

IV. Conclusions

The antenna system was able to accurately indicate whether the transmitter direction was on course or right or left. It also accurately indicated when it was front or back. The design at present does not give the desired accuracy for angular bearing indication.

V. References

1. Gilmer, David S. and Lewis W. Cowardin, Renee L. Duval, Larry M. Mechlin, Charles W. Shaiffer and V.B. Kuechle. "Procedures for the use of aircraft in wildlife biotelemetry studies U.S. Dept. of Interior Resource Publ. No. 140. 1981.
2. Ocean Applied Research Corp. Model ADFS-320-1. San Diego, CA.
3. Dorne & Margolin, Bohemia, N.Y.
4. Cubic Communications, Inc. Oceanside, CA.
5. Brown, G.H. "Directional Antennas". Proc. IRE Vol. 25, #1, p. 78-145.
6. Wilkinson, E.J. "A N-Way Hybrid Power Divider", IRE Trans. Microwave theory and techniques. Vol. MTT-8. Jan, 1960 pp. 116-118.
7. Hartke, Jerome L. "PIN - diode Switches Excel in wide-bandwith use. EDN September 15, 1982, pp. 161-166.

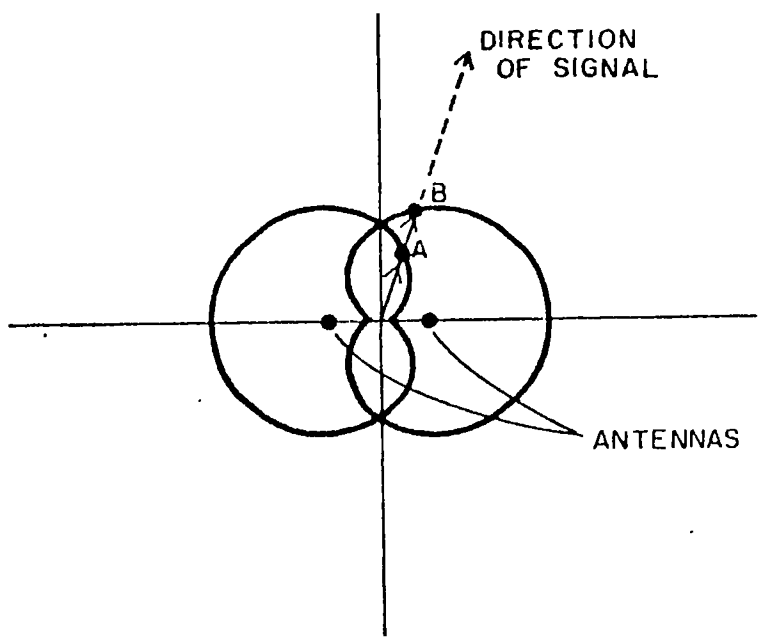

Figure 1. Pattern of system with isotropic source.

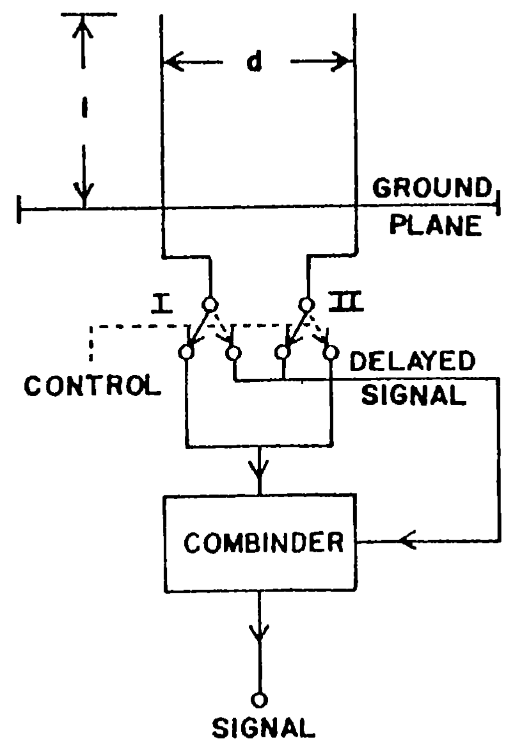

Figure 2. Antenna schematic diagram.

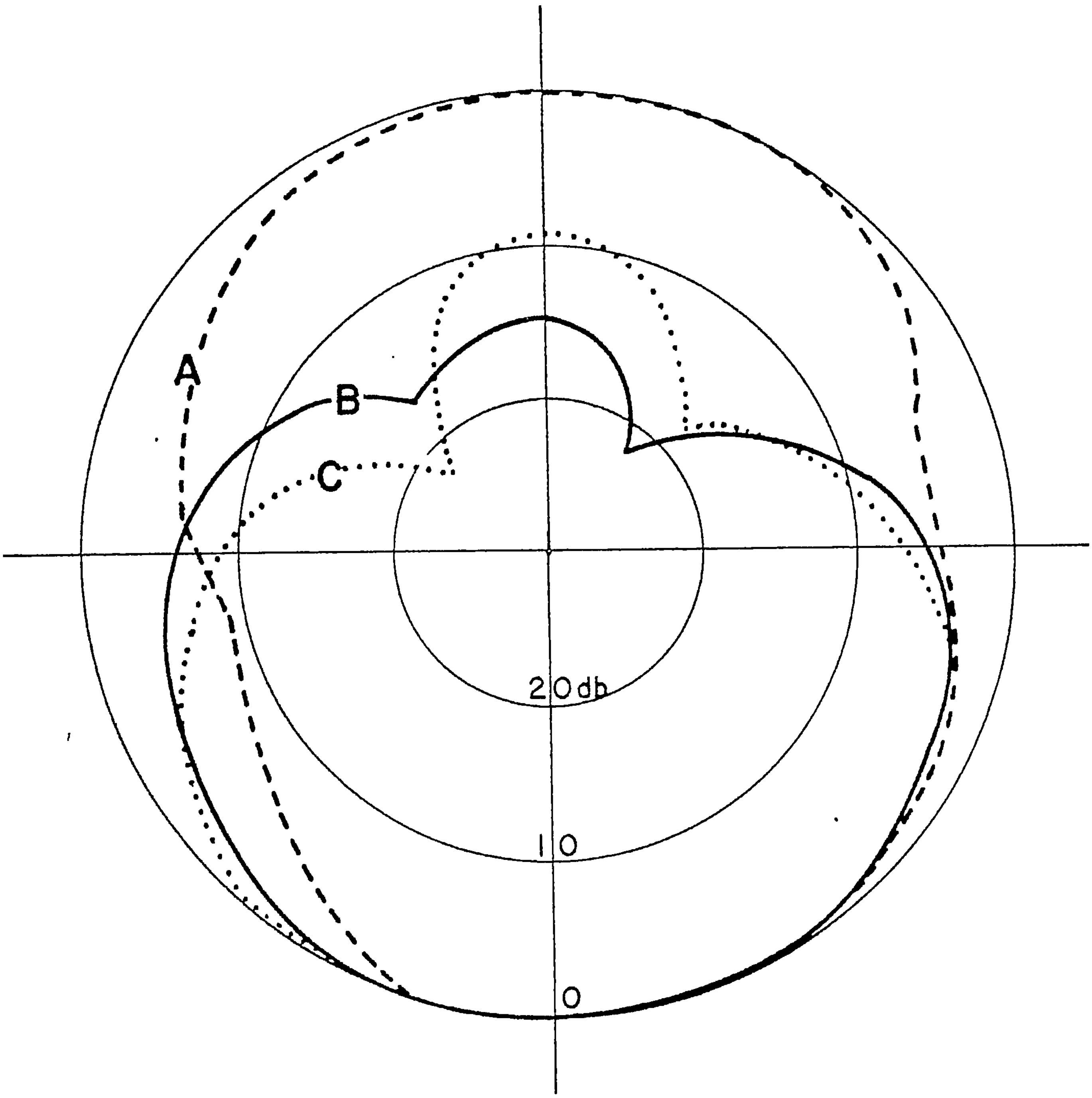

Figure 3. A. Pattern of resonant monopole with second antenna terminated with 50 ohms. B. Normalized pattern of system with resonant monopoles. C. Normalized pattern of system with untuned one-eight wavelength antennas.

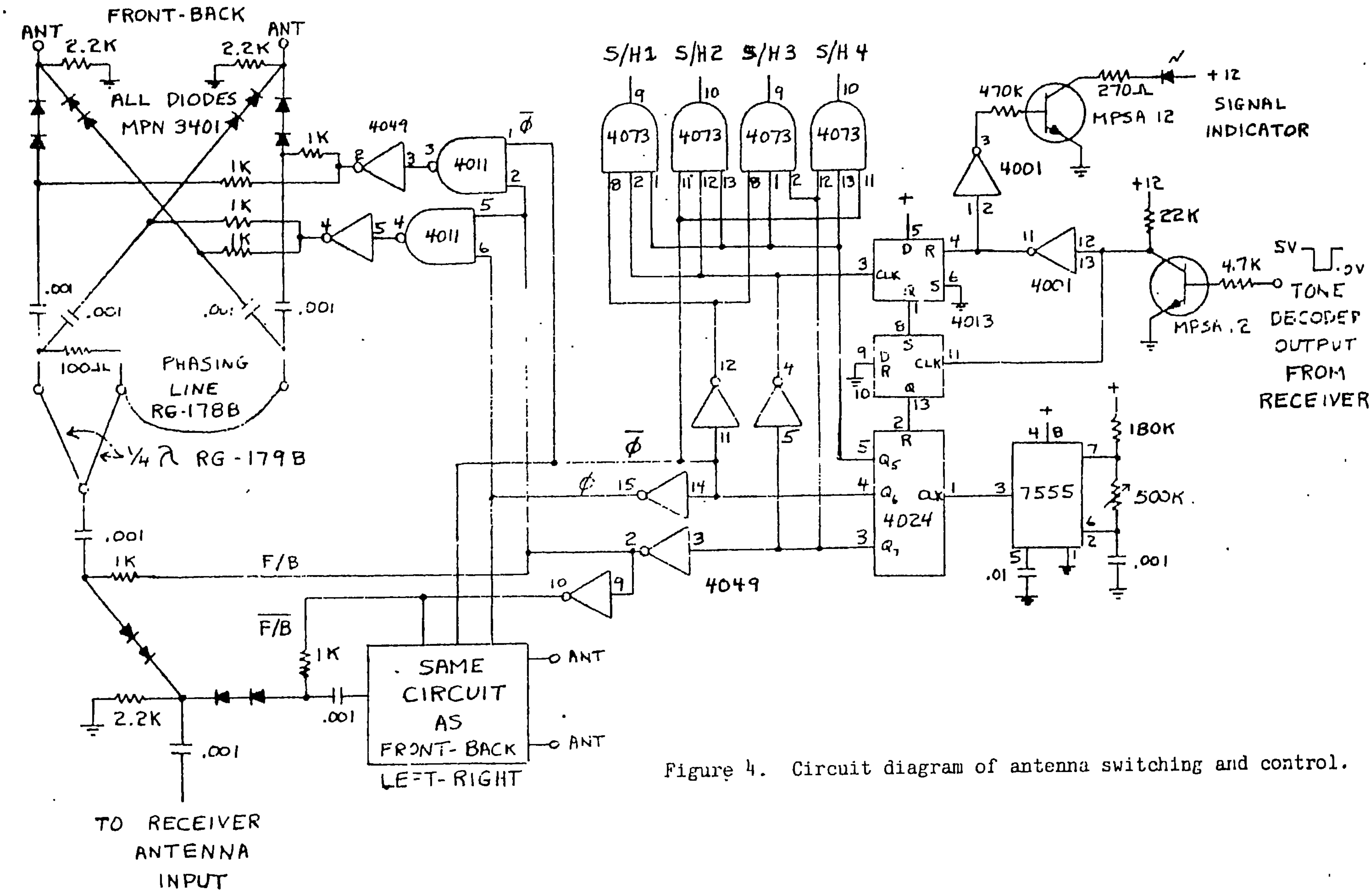

Figure 4. Circuit diagram of antenna switching and control.

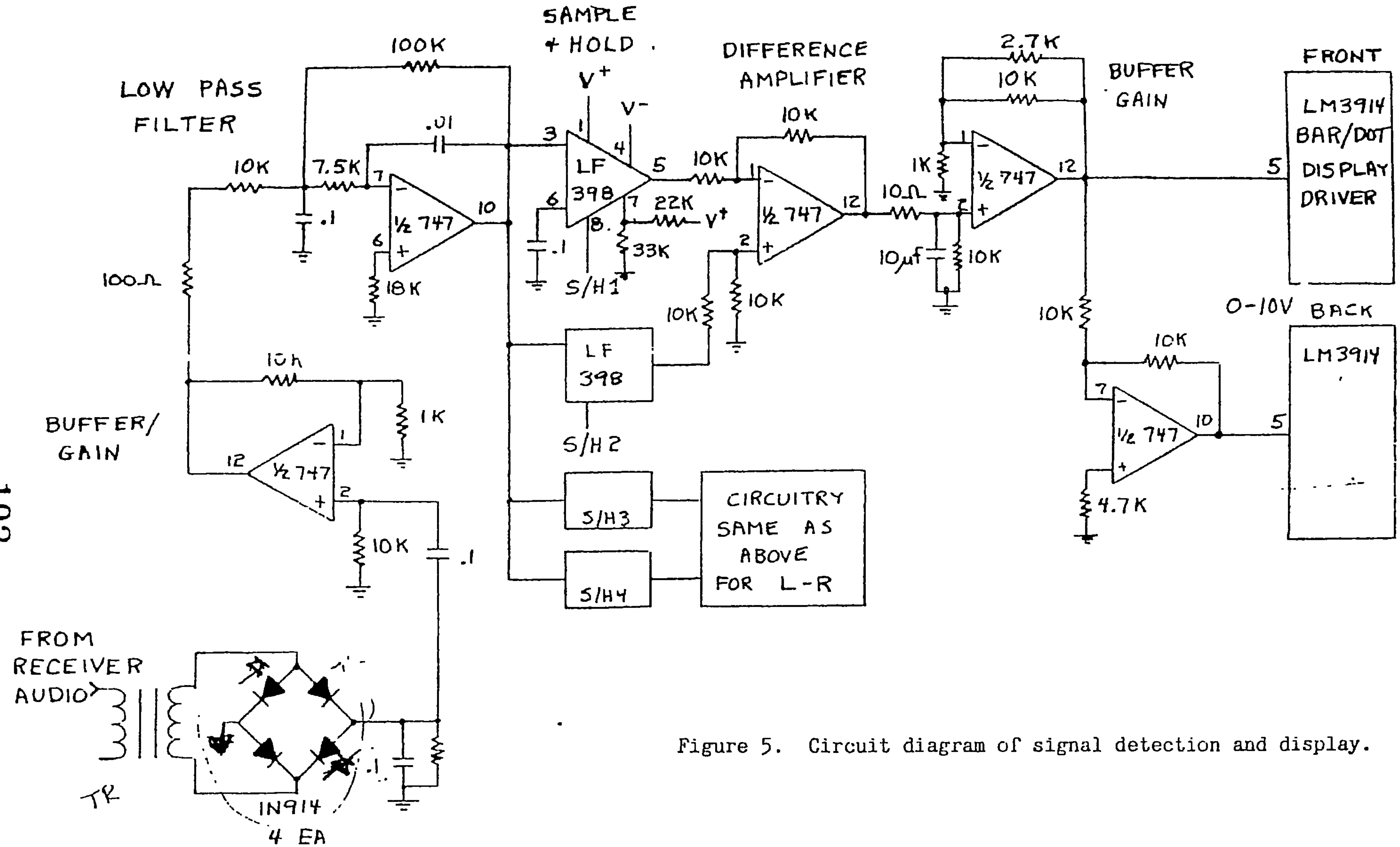

Figure 5. Circuit diagram of signal detection and display.