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16. Abstract

The current practice of installing traffic sensors on or in the highway has often caused serious traffic delays and congestion due to lane closures along with hazardous working conditions for the Department's employees. In recognition of these problems and with the recent availability of non-contact sensor technology, the Department funded Study 426, "Development of an Overhead Vehicle Sensor System."

This report presents the research and results of this study along with procedures for operating the prototypes which were constructed. After careful evaluation, a prototype was constructed using the infrared sensor technology. However, it was discovered that the infrared was too sensitive for use as a remote vehicle sensor. After further investigation, an ultrasonic ranging device was chosen for implementation as an overhead vehicle sensor. A prototype was then constructed and tested under laboratory and field conditions and was accepted as being well-suited for use as an overhead vehicle sensor system. Several more prototypes were constructed and put into operation during the period June 1986 through the present. They operate continuously and their accuracy is checked periodically with traffic counts collected with inductive loops.

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DEVELOPMENT OF AN OVERHEAD VEHICLE SENSOR SYSTEM

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Research Report 426-1F
Research Study 2-10-84-426
Development of an Overhead Vehicle Sensor System

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Federal Highway Administration

TEXAS TRANSPORTATION INSTITUTE
The Texas A&M University System
College Station, Texas

October 1987

METRIC CONVERSION FACTORS

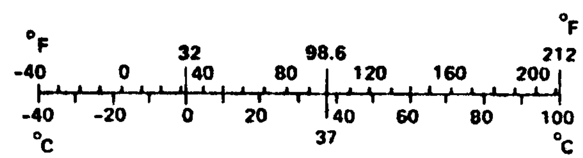
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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This research was sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. Dr. Wiley D. Cunagin was the Study Supervisor and Curtis L. Goss of D-10R and Stan Swinton of D-18T were the SDHPT Study Contact Representative. Dr. Albert B. Grubbs provided valuable technical insights. Mr. Michael R. Leggett and Mr. Said Majdi provided technical investigation and production efforts.

SUMMARY

The need has arisen for a better means for vehicle detection in areas of high traffic volumes and/or high speeds. The current practice of using traffic detectors placed on or in the highway has often caused serious traffic delays and congestion due to lane closures for installation or repair of these devices. It has also caused hazardous working conditions for the Department's employees. In recognition of this situation and the recent availability of non-contact sensor technology, the Department funded Study 426, "Development of an Overhead Vehicle Sensor System."

This study reviewed the available sensor technology for possible overhead vehicle sensor designs including infrared, photoelectric, laser radar, microwave, and ultrasonic sensors. After careful consideration to sensitivity, cost, reliability, and other needs, an infrared sensor system was chosen to be constructed and tested. However, it was discovered through extensive testing that the infrared system was too sensitive for use as a remote vehicle sensor without complex and expensive signal conditioning and processing circuitry. After further investigation, an ultrasonic ranging device was chosen for implementation as an overhead vehicle sensor. A prototype was then constructed and tested under laboratory and field conditions and this product was accepted as being highly suitable for use as an overhead vehicle sensor system. With this acceptance, several prototypes were constructed and put into operation from June through November, 1986. They operated continuously with data collected monthly at each site.

IMPLEMENTATION

Several prototype overhead vehicle sensors were constructed in accordance with the design provided in this report. These prototypes were then tested under both laboratory and field conditions. The field tests were conducted between June and November, 1986, at high speed (55 mph) and low speed (under 40 mph) sites. Data for the high speed site is given within the report. Traffic count data for the overhead vehicle sensor were compared to data collected with conventional devices (inductive loops and tapeswitches) in order to verify the results. Additional data were collected using timelapse photography and video recorders to further assess the accuracy of the overhead vehicle sensor. In addition, an overhead sensor was in operation in Austin during the period December 15, 1986 through April 8, 1987 for the purpose of providing further analyses of the differences.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.

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INTRODUCTION

The placement and maintenance of vehicle detectors on or in the pavement has caused serious problems, particularly in areas of high traffic volumes and/or high speeds. The result has been either significant delays and traffic congestion to the public in conjunction with very hazardous working conditions for the Department's employees or a loss of data due to an unwillingness of the Department to allow these very undesirable conditions to occur.

Recent advances in non-contact sensor technology offered several possible approaches to addressing the problem of providing traffic information without the attendant disadvantages described in the previous paragraph. As a result, the Department funded Study 426, entitled "Development of an Overhead Vehicle Sensor System." The research began in 1984 and has been successfully completed.

As part of the investigation of overhead vehicle sensor technology, two products that had been announced as commercially available were identified. These were an ultrasonic device manufactured by Koito Industries, Ltd., of Yokohama, Japan, and an infrared device produced by Siemens AG of Munich, Germany. Several attempts were made to contact these vendors to learn more about their products and to ascertain whether samples could be obtained for testing. Detailed information was received from Koito, but Siemens stated that their device was still in the research and development stage and not available. Koito quoted a price for the sensing unit of their ultrasonic overhead vehicle sensor of $450, F.O.B. Tokyo, Japan. In addition, they required payment in advance. This stipulation was contrary to State of Texas purchasing procedures, so negotiations were undertaken to persuade the vendor to relax the advance payment requirement. These were not successful. Consequently, neither the Koito device nor the Siemens device were tested in this study. A review of available sensor technology was conducted to determine which concepts might be applicable to the problem. Interviews were held with SDHPT staff to identify problems with current sensors and needs which should be addressed by a new device. The following sections describe the work and analyses performed and products developed during the research.

The objective of this research was to produce an overhead vehicle sensor which could be installed and operated without closing or otherwise disrupting the flow of traffic on the main lanes. Several technologies were considered for this purpose. These included infrared, photoelectric, laser radar, microwave, and ultrasonic sensors. In addition, both active and passive concepts were evaluated. Active sensors generate energy which is either interrupted or reflected by vehicles in traffic to produce actuations. Passive sensors generally are actuated by energy received from the vehicles themselves.

Active infrared devices operate by producing a narrow beam of energy in the infrared frequency band. This beam is projected onto an infrared-sensitive cell. Vehicles are detected by the interruption of the beam. Alternatively, the beam can be focused on a reflective surface from which it returns to be detected at the emitter location. Vehicles are then detected by the change in the level of infrared energy received by the infrared-sensitive cell. Because the installation of the active infrared device requires the placement of either a receiver or a reflector on the pavement surface, which is contrary to the objectives of this research, the active infrared sensor was not considered further.

Passive infrared devices detect a change in the level of ambient infrared energy being received from the road surface. If the level of infrared emissions radiated from a vehicle is significantly different from that radiated by the pavement surface, that vehicle can be detected. The accuracy of infrared detectors is dependent upon several factors. For the passive detector, the width of the field of influence from which energy is received is a critical attribute. It may also be necessary to use a parabolic reflector or a lens to focus the infrared energy on the sensing element. Hardware and/or software provisions may also be incorporated to: compensate for changing ambient infrared energy conditions; filter out noise due to sonic or mechanical vibration of electromagnetic interference; and provide for interpreting variations in infrared emissions from a single vehicle, as with a tractor/semitrailer combination.

Photoelectric sensors operate in a manner analogous to the active infrared devices briefly described in the previous paragraphs. They cannot be operated as passive sensors for traffic data collection. That is, they require a light source which must be interrupted or reflected to produce an actuation. Therefore, this technology was not considered further in this research.

Laser radar is now used in a wide range of applications. The term "laser" is an acronym for "light amplification by stimulated emission of radiation." "Radar" means "radio detection and ranging." The laser is produced by a device which contains a crystal, gas, or other material in which atoms are stimulated by focused light waves. These light waves are amplified and concentrated into a very narrow, intense beam. Although this is an active device, it does not require the placement of a receiver or reflector in the traffic lane. The receiver is built into the transmitter and actuations are detected by changes in the characteristics of the laser beam. Microwave sensors operate in a manner similar to the laser device, except that the transmitted energy is in the microwave band of frequencies. Ultrasonic sensors are also analogous to the laser device, again with a different range of frequencies.

These sensor concepts were reviewed for applicability to the problem of producing an overhead vehicle sensor. Sensitivity, cost, reliability, and other advantages and disadvantages were considered. In addition, the needs of the Department for such a device were evaluated. The most critical areas were identified as:

1. Detection of vehicles on high speed and/or high traffic volume urban freeways where it is hazardous and very disruptive to close lanes.

2. Detection of vehicles in sections of reinforced concrete pavement where the use of inductive loops is not appropriate.

3. Detection of vehicles in sections of highway where the movement of the pavement causes frequent breaks in the conductors of inductive loops.

4. Detection of vehicles which do not have continuous ferrous components of sufficient mass to produce accurate actuations in inductive loop detectors.

It was concluded that the use of infrared sensor technology, which had been widely used for out-of-door detection of intruders and other applications of movement sensing, would be undertaken. A detailed laboratory and field testing program was under-taken to determine the feasibility of using this technology for the overhead vehicle sensor. A prototype device was constructed and tested under laboratory and field conditions.

The use of polyvinyldene fluoride film (PVDF) as the basic element of a new class of transducers for the detection of vehicles was investigated. The initial phases of the investigations required the familiarization with previous work and applications of the material. A design set of calculations was made based on information supplied by the manufacturer of the material for a passive vehicle detector to be constructed. Problems encountered in the production of such a device were overcome by the utilization of existing subsystems available from Statitrol Corporation.

The components available from Statitrol allowed a more reliable detector to be built and tested in less time. Investigations regarding detection sensitivity, temperature, and environmental effects, and electronic circuitry required for reliable, consistent vehicle detection were conducted.

As a result of investigations performed as described above, it became apparent that a cost effective transducer suitable for vehicle detection in the environments required during normal use would be prohibitive. An alternative technology (ultrasonic) that provided cost benefits and the required transducer capability was adopted.

In the sections that follow is a description of the research conducted regarding the PVDF film. The first section describes the basic characteristics and design parameters in using the film as an infrared detector. The second section provides a summary of the design notes regarding the construction of a detector using the film. Lastly, the Statitrol PVDF film transducer is described along with the results of evaluating a detector constructed with it as the detection element. A reference list is included identifying sources of information on the film.

PVDF FILM CHARACTERISTICS

Organic polymeric materials have been used extensively as electrical insulators and dielectrics. In the past few years a number of other important and useful electrical properties of polymeric materials have been investigated. Of all the polymeric materials investigated, PVDF exhibits the largest piezoelectric and pyroelectric coefficients when appropriately polarized.

Piezoelectricity and pyroelectricity were discovered in the nineteenth century. Piezoelectric materials transform force into an electrical response. Conversely, when an electrical charge is applied to the material, a dimensional charge occurs. Pyroelectric materials develop an electrical charge from a thermal change.

A clear definition of the piezoelectric phenomenon according to W.G. Cady is as follows: Piezoelectricity is "electric polarizations produced by mechanical strain in crystals belonging to certain classes, the polarization being proportional to the strain and changing sign with it." It should also be noted that an electrical polarization will induce a mechanical strain in piezoelectrical crystal.

PROPERTIES OF PVDF

Piezoelectric Properties: The PVDF film possesses piezoelectric properties which are the ability to transform force to an electrical response. This film is made up of long polymer molecular chains of hydrogen, carbon, and fluoride. Further processing with heat, pressure, and electric fields causes the molecular chains to become parallel, similar to a crystalline form.

PVDF is a semi-crystalline high molecular weight polymer of repeat unit (CH_2-CF_2) whose structure is essentially head-to-tail, i.e. -CH_2-CF_2-(CH_2-CF_2)n -CH_2 CF_2. PVDF is approximately 50% crystalline and 50% amorphous. The main crystalline forms of PVDF are the highly polar beta form and the non-polar alpha form.

Pyroelectric Properties: Piezo film also exhibits pyroelectric properties which are the ability to develop electronic charge from a thermal change. Pyroelectric materials absorb thermal energy, raising the material's temperature, therefore inducing an electrical signal. The current response of piezo film depends on the rate of change of temperature rather than just direct temperature. This makes the output signal proportional to temperature change.

The most efficient pyroelectric material should have the following properties:

a) large pyroelectric coefficient,
b) high volume resistivity,
c) low dielectric constant,
d) low dielectric loss,
e) low specific heat,
f) low density, and
g) broad usable temperature range.

Even though piezo film is less sensitive than some other pyroelectric materials, it still has significant advantages. These include a relatively high operating temperature, insensitivity to moisture, small thermal conductivity, chemical inertness, and low cost.

DESIGN OF A VEHICLE SENSOR USING PVDF PYROELECTRIC SENSOR

Measurements

1. Vehicle temperature readings

Cars on Wellborn Road	Cars in Parking Lot
Max. = 48°C	Max. = 69°C (deep red color)
Min. = 29°C	Min. = 35°C (white)
Avg. = 37.8°C	Avg. = 52.2°C
# of samples = 35	# of samples = 12

Atmospheric temperature = 33°C

For an average temperature of 37.8°C

$$\text{max} = \frac{2898}{T} = \frac{2898}{319.8^{o}K} = 9.3234 \text{ mm.}$$

Since 25% of the radiated energy is at wavelengths below λmax and 75% of the radiated energy is at wavelengths above λmax we arbitrarily fix λ_{low} = 6µm and λ_{high} = 20µm. From tables, it was found that this covers 65% of the total radiated energy from a body at 37.8°C.

To avoid interference from visible radiation sources and to avoid high frequency noise, the device can be operated anywhere in the range of 3 µm to 30 µm. This covers almost 80% of the total energy radiated from the body. The possible sources of interference include reflected light, headlights, etc.

1. Since the average temperature of the vehicle is very close to that of the ambient, it is necessary to discriminate between two very similar temperatures. Possible solutions to this problem can be:

   (i) To use the changing signal coming from a vehicle assuming a certain minimum speed that it will have. It was assumed that the maximum rate of change of the ambient temperature is less than the minimum rate of change of temperature created by a moving vehicle. This could be done by having two different sensors, one sensing the ambient temperature and the other sensing the vehicle temperature. Each signal can then be differentiated to get a rate of change signal and the difference between the two signals can then serve as the actuating signal. If the difference signal is negative (if the ambient temperature changes faster than the vehicle induced temperature change) an error condition would result. All this signal conditioning can be done by either hardware or software.

2. Rough calculations of steady state response from the sensor:

   Assumptions:

   (i) The sensor surface will be parallel to the vehicle. The vehicle has area A_1, emissivity E_1, and temperature T_1. The sensor has area A_2, emissivity E_2, and temperature T_2.

(ii) $A_1 = 2.5m \times 1.5m = 3.75m^2$ (length = 2.5m and breadth = 1.5m)

T_1 avg = $40^oC = 313^oK$

$E_1 \cong 0.9$

for two parallel bodies

$$f_1 = \frac{\cos\theta_1 \cos\theta_2 \, dA_1}{r^2} = \frac{A_1}{r^2}$$

$$f_2 = \frac{\cos\theta_1 \cos\theta_2 \, dA_2}{r^2} = \frac{A_2}{r^2}$$

where r = distance between vehicle and sensor = 15 ft ($\cong$ 5m).

The total heat transfer between surfaces A_1

and A_2 is $q = \sigma A_1 (E_1 T^4_1 \; f_2 - E_2 T^4_2 \; f_1 \frac{A_2}{A_1} + r_1$

$E_2 T^4_2 \frac{A_2}{A_1} f_1 f_2 - r_2 E_1 T^4_1 f_1 f_2)$

Ignoring the reflection terms we have

$$q = \sigma A_1 (E_1 T^4_1 f_2 - E_2 T^4_2 f_1 \frac{A_2}{A_1}) = \sigma A_1 (E_1 T^4_1 \frac{A_2}{r^2}$$

$$- E_2 T^4_2 \frac{A_2}{A_1} \frac{A_1}{r^2}) = \frac{\sigma A_1 A_2}{r^2} (E_1 T^4_1 - E_2 T^4_2)$$

$$= \frac{5.670 \times 10^{-8} (W/m^2 - {}^ok)}{\times 5 \times 5 \, (m^2)} \times 3.75 \, (m^2) \, A^2 \, (0.9 \times$$

$$(313)^4 - 1.0 \, (T_2)^4)$$

$$= 2.707225 \times 10^{-9} A_2 \, (8638132465 - (T_2)^4).$$

Table 1 shows calculated values of q (electrical charge) for given values of T_2 and A_2.

Table 1. Calculated Values of q (Electrical Charge) Given T_2 and A_2

q	T_2	Radius of Detector	A_2 (m^2)
0.02694891	$20^{o}C$ ($293^{o}k$)	5cm	.00785
0.01598090	$25^{o}C$ ($298^{o}k$)	5cm	.00785
0.00444670	$30^{o}C$ ($303^{o}k$)	5cm	.00785
0.0076728	$35^{o}C$ ($308^{o}k$)	5cm	.00785
0.24236855	$20^{o}C$ ($293^{o}k$)	15cm	.0706
0.14372639	$25^{o}C$ ($298^{o}k$)	15cm	.0706
0.03999205	$30^{o}C$ ($303^{o}k$)	15cm	.0706
0.0690067	$35^{o}C$ ($308^{o}k$)	15cm	.0706
0.673894441	$20^{o}C$ ($293^{o}k$)	25cm	.1963
0.399624517	$25^{o}C$ ($298^{o}k$)	25cm	.1963
0.11119604	$30^{o}C$ ($303^{o}k$)	25cm	.1963
0.19187006	$25^{o}C$ ($308^{o}k$)	25cm	.1963

Using the relation for temperature change at the sensor

$$\Delta T = R_t P_t \quad (P_t = q)$$

the output voltage from the detector is

$$V_m = pt \frac{\Delta T}{\varepsilon} = \frac{(25 \text{ X } 10PT\text{-}6PT) \text{ X } 28 \text{ X } 10PT\text{-}6PT \text{ X } \Delta T}{11 \text{ X } 8.854 \text{ X } 10^{-12}}$$

where P is the pyroelectric coefficient, t is the detector thickness, ΔT is the temperature rise of the material, and ε is the dielectric constant.

This model reduces to a series thermal impedance of the PVDF film and the heat sink if the following assumptions are made:

1. The thermal impedance of conducting adhesive is negligible,
2. The thermal impedance of the metal deposits on the film is negligible,
3. Selective coating is approximately 20 µm thick making it negligible.

Sensor Construction:

1) Two identical sensors will be constructed and used together for temperature compensation.

2) The sensors should be mounted in a vibration-free mounting. This is because any vibration will cause relatively high voltage spikes to be introduced because of the piezoelectric effect of the sensor, thus causing false signals.

3) The enclosure of the sensor should be:

   i) directional, pointing in the direction of the vehicle

   ii) should be of metal to prevent RF interference

   iii) should be insulated on the inside so that the metal does not absorb the sun rays and increase the ambient temperature of the sensor. This will result in false trigger.

   iv) It should be sealed so that air currents cannot come in and generate false triggers.

4) A wavelength selective coating will be used. It has been found that white paint has a very low absorbitivity for radiation below 2 μm and has an absorbitivity of 0.8 in the range 2-30 μm. This will enable us to reflect all visible radiation and absorb almost all other types. This white paint has to be of conducting material so that it does not violate the assumption that it has no affect on the thermal impedance of our sensor. Furthermore, to achieve this, the thickness of the coating should be around 20 μm.

STATITROL INFRARED DETECTOR

A Statitrol Infrared Detector assembly consisting of a parabolic reflector, PVDF film detector, and electronic circuitry on a printed circuit board was procured for testing the proposed infrared vehicle detector concept. The part number of the assembly is 2550-0007-001. The recommended schematic (Statitrol drawing number 2550-0008) for the circuitry to process the signal from the film is shown in Figure 1. U.S. Patent #4379971 is also attached providing the necessary technical details regarding the assembly.

Application notes accompanying the Statitrol Test Circuit suggest the following;

1. A stable and regulated voltage in the range of 6 to 12 VDC should be provided with the positive connection to the red wire of the assembly.

2. The unit should be placed in a box with a look through polyethylene window to restrict air movement near the sensor that might cause false signals.

3. The logical output signals are capable of driving 50K ohm loads.

4. The analog signal output is proportional to the increasing or decreasing infrared energy detected by the sensor and has a 50k ohm ouput impedance.

5. The spherical mirror provides optical gain with a maximum signal being obtained when mounted approximately 1 inch from the sensor material.

6. The sensor is coated with a material to maximize its sensitivity to infrared energy in the 7-8 micrometer wavelength.

The attached schematic displays the circuitry provided by Statitrol which was used for testing the device. The red pigtail wire was connected to +12VDC and the black to the -12VDC. Capacitors C1 and C2 are used to block the DC voltages from the sensor material and to couple the voltage transitions due to the infrared signal being focused on the film by the spherical reflector. IC2A is a high impedance differential amplifier used to amplify differences between the signals that appear on its inputs (pins 5 and 6). The film is mounted in such a manner to provide complementary signals to the differential amplifier when an object radiating heat in the infrared spectrum moves across a plane parallel to the spherical reflector. The ouput of IC2A is coupled to IC2B and IC2C where digital outputs are produced. TTL compatible signals of opposite logical levels are generated for external use. The analog output representing the increasing or decreasing infrared energy detected by the sensor is available at pin 7 of IC2A. Other components are used for biasing or current limiting as appropriate in the circuit. A change in the infrared being received by the film causes an impulse response giving an output as shown in Figure 2.

The Statitrol test circuit and sensor were mounted into metallic boxes and tested to determine sensitivity. From a location approximately 12 feet perpendicular and at a height of 10 feet above the roadbed, the device was successful in detecting vehicles as they traveled in a plane parallel to the transducer. It was possible to align the detector to isolate the detection of vehicles to one lane of traffic. The speed of the vehicles was approximately 30 mph as they were approaching a stop sign and slowing to a stop.

Due to the high gain required to amplify the signal output it was necessary to use a low pass filter in order to remove extraneous noise that triggered the counter. The amp-out trace is the output from the Statitrol amplifier producing a voltage change that represented a change in the temperature of the film as a result of the infrared signal that was received. The low pass filter output caused a signal pulse that was used to trigger a counter circuit. The film produces a signal of approximately 15mv when detecting a human body passing across the detector aperture at a distance of 10 feet in 1 second. In Figure 3 is a copy of the strip chart recording of the output of the Statitrol detector as nine (9) vehicles are detected. The variable pulse widths and amplitudes are a result of the speed of the vehicles as they crossed the detection field of view. Figure 4 is a strip chart recording illustrating the digital output signals with bias voltage levels of 12.5VDC.

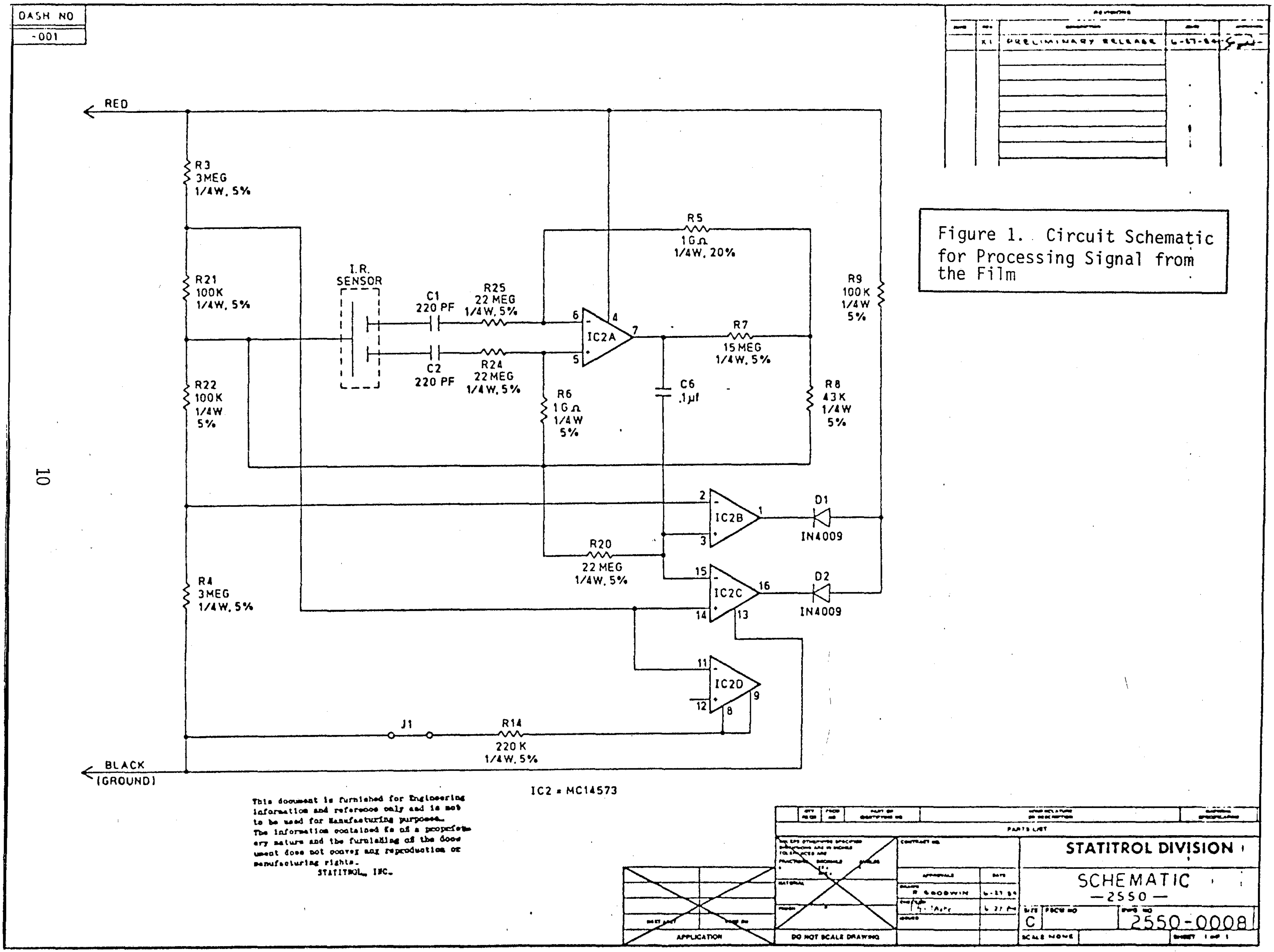


Figure 1. Circuit Schematic for Processing Signal from the Film

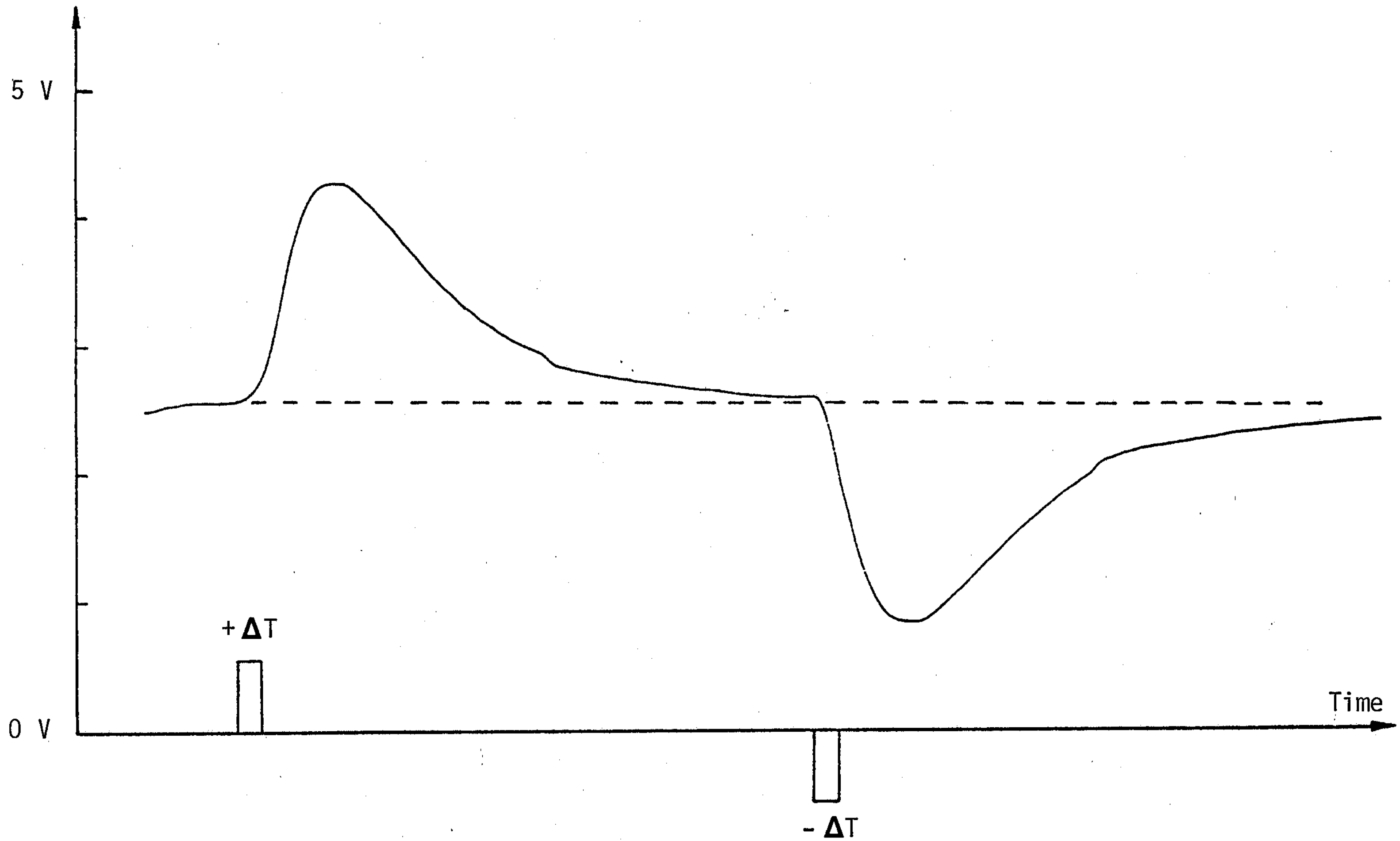


Figure 2. PVDF Impulse-Response

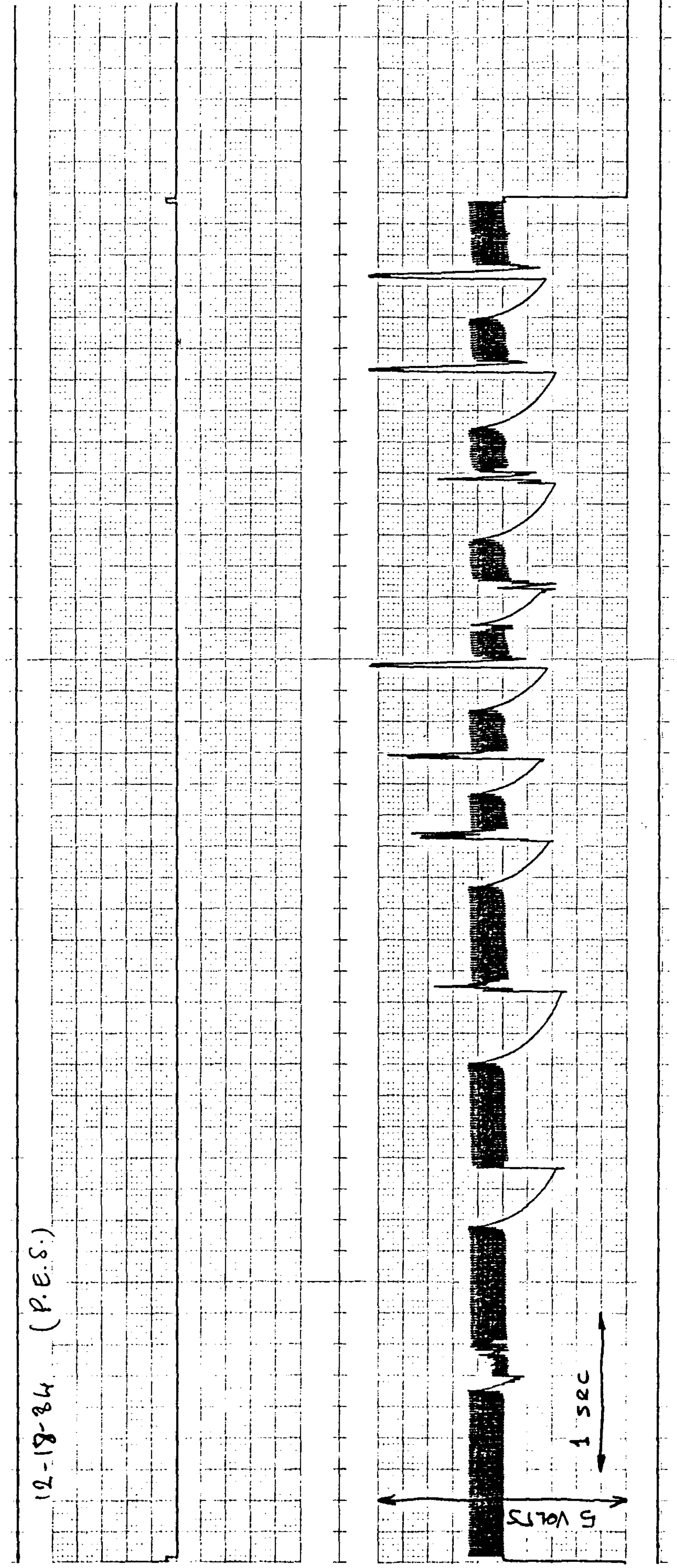


Figure 3. Strip Chart Recording of Statitrol Detector

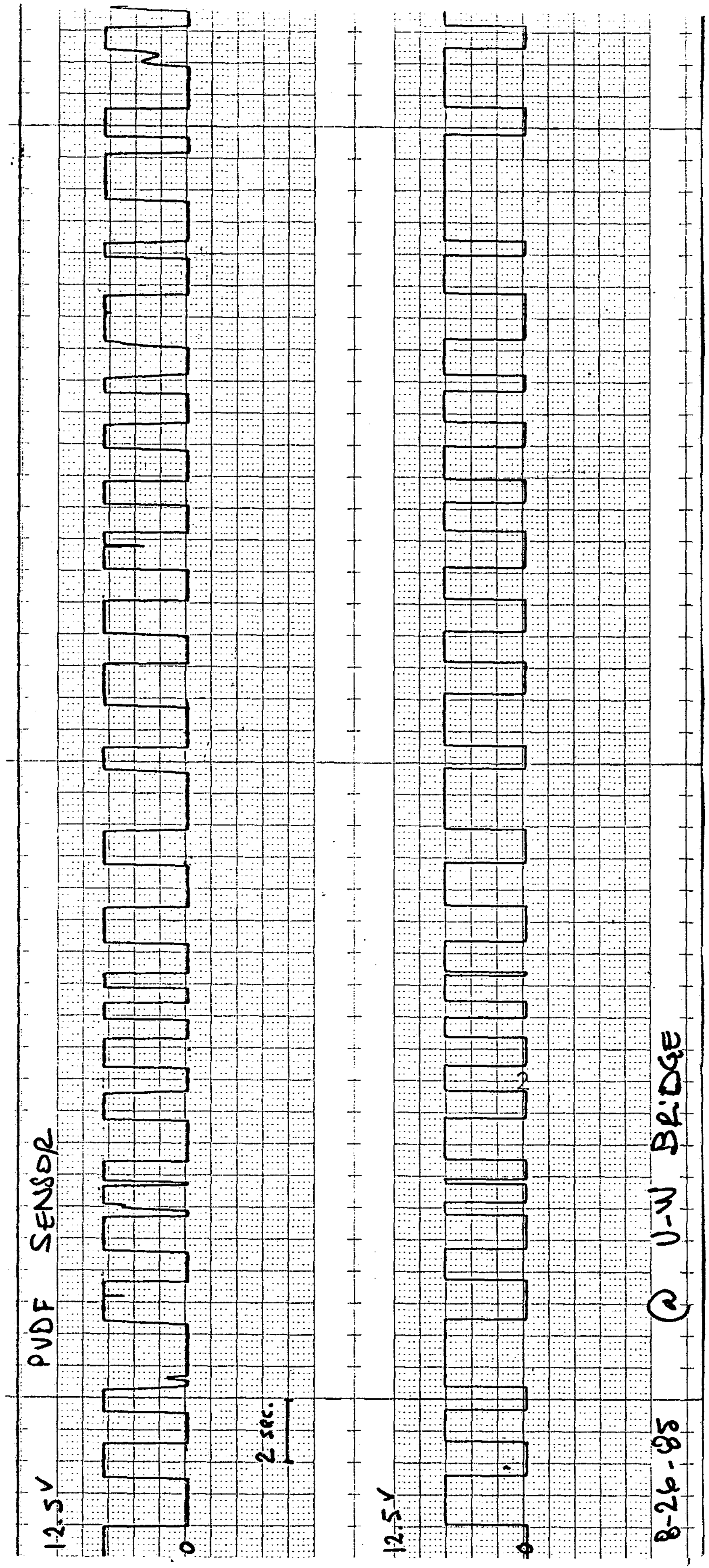


Figure 4. Strip Chart Recording of Digital Output Signals

Subsequent testing of the Statitrol detector led to the conclusion that the cost and circuitry to provide reliable vehicle counts were greater than desired. Digital signal processing using Fast Fourier Transform (FFT) techniques calculated by a microcomputer would be required to remove unwanted noise elements. These extraneous signals were due to stray infrared signals received from solar reflections and other heat radiating sources, vibrations that caused piezoelectric action, and the sensing of pressure changes by the film as a result of wind modulating the instrument case. In addition, an automatic gain adjustment circuit would be required to compensate for decreased amplitude signals as the ambient temperature increases caused the overall film temperature to increase. Additional problems due to differences in sections of the PVDF film as a result of nonuniformity created during the manufacturing process were not dealt with in these investigations.

OVERHEAD VEHICLE SENSOR SYSTEM

Based upon the findings of the previous section, it was decided to investigate available ultrasonic sensor technologies. It was learned that the Polaroid Corporation had developed and was offering to researchers and original equipment manufacturers (OEMs) an ultrasonic ranging device which had been originally produced for automatic focusing in cameras. A typical device of this type was obtained and tested under controlled laboratory conditions. The initial results were promising, so further investigations were carried out. A prototype was constructed using off-the-shelf components as much as possible to enhance the availability, reliability, and durability of this device. The following paragraphs describe the subsystems, construction, operation, and field tests of the ultrasonic overhead vehicle sensor system.

The overhead vehicle sensor system as designed and constructed consists of two major subsystems, the Polaroid Ultrasonic Ranging Subsystem and the interface electronics. Figure 5 shows a block diagram of the system. This device produces a digital vehicle presence signal which can be used by a data collection device or other equipment that requires this input.

The major components of the system are shown in Figure 6, System Assembly, and consist of the subsystems mentioned above as well as an ac power cable and interconnecting cable.

SUBSYSTEMS

As indicated in Figure 5, the overhead vehicle sensor system includes: a Polaroid ultrasonic ranging subsystem, interface electronics for providing a suitable actuating signal to a traffic data collector or other device, and mounting hardware. Each of these subsystems is described in the following paragraphs.

Polaroid Ultrasonic Ranging System

This subsystem is shown in Figure 7. The major components of this unit are the Polaroid Ultrasonic Transducer, the ranging board, the transducer interface board, and the mechanical components such as connector, transducer cone, and case. The unit is designed to be waterproof and capable of operation in harsh environmental applications.

The Polaroid ultrasonic ranging subsystem uses an electrostatic transducer to generate a short burst of high frequency sound as indicated in Figure 8. The sound travels out from the transducer, through the "horn" in a narrow cone and reflects back to the transducer from objects in its path. This same transducer then acts as a "microphone" and receives this reflected sound energy and converts it to an electrical signal. This signal is then processed and used to show a detection.

Figure 9, Wire Connections of Transducer Electronics, is a wiring diagram showing the interconnections between the Polaroid ranging board, the transducer interface board, and the connector (P1) for the Interface Unit cable. The transducer is connected to the Polaroid ranging board with shielded coaxial cable to minimize radiation of the signal to surrounding electronics.

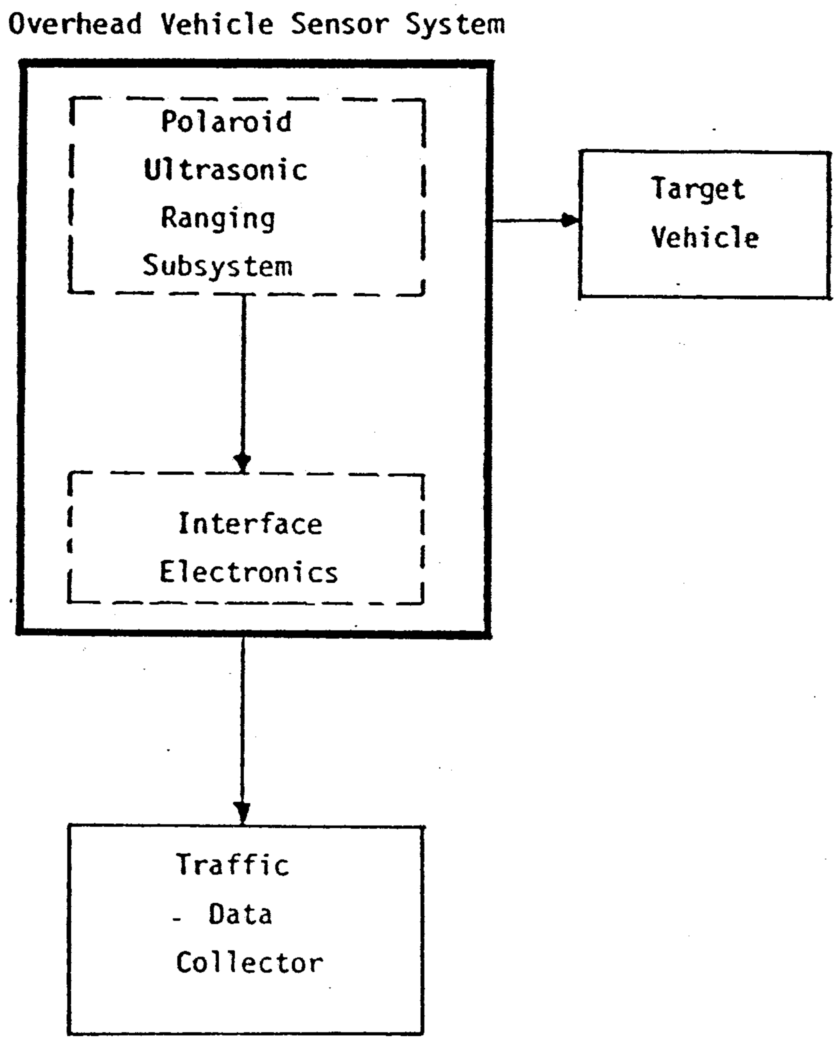
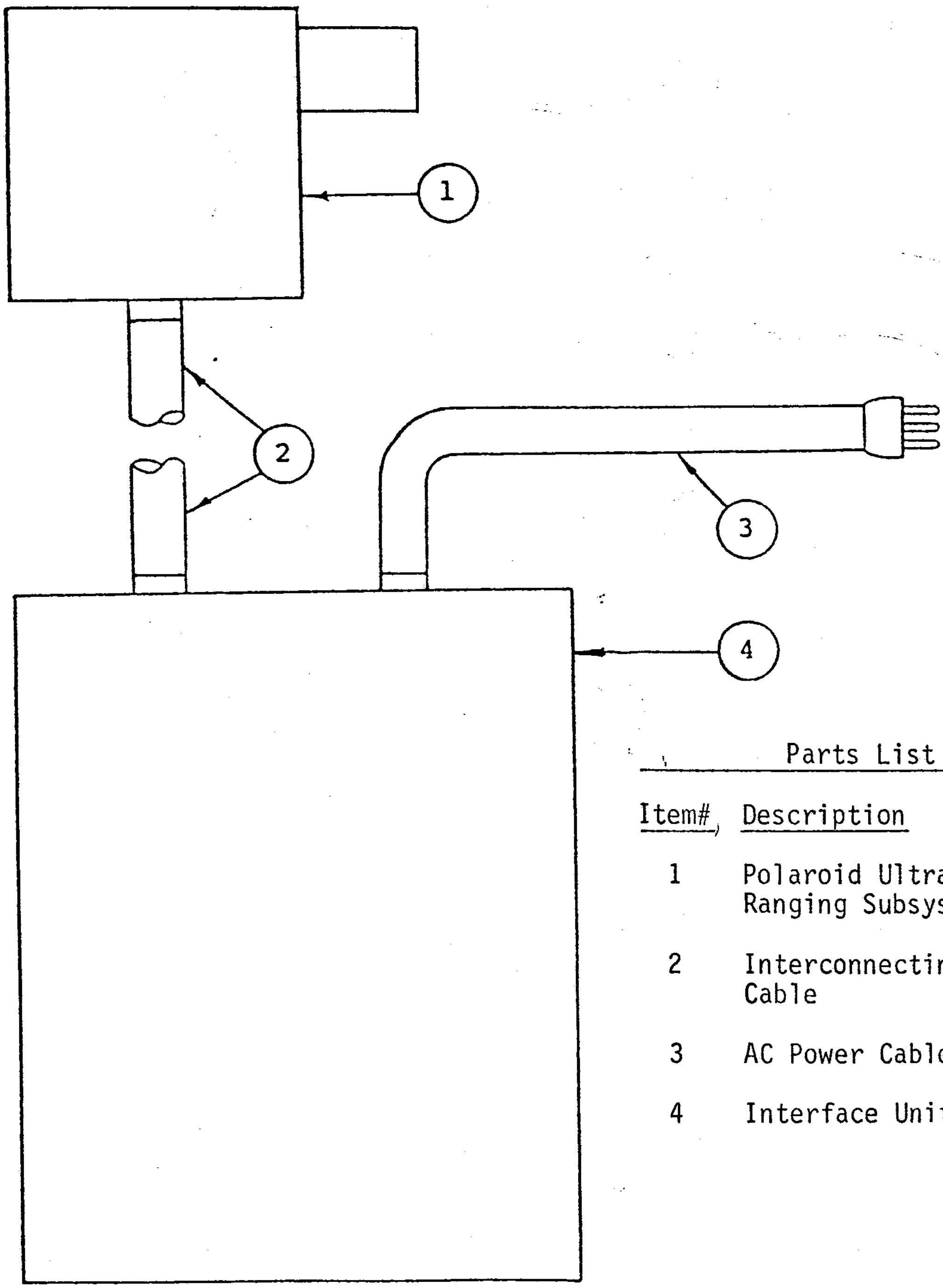
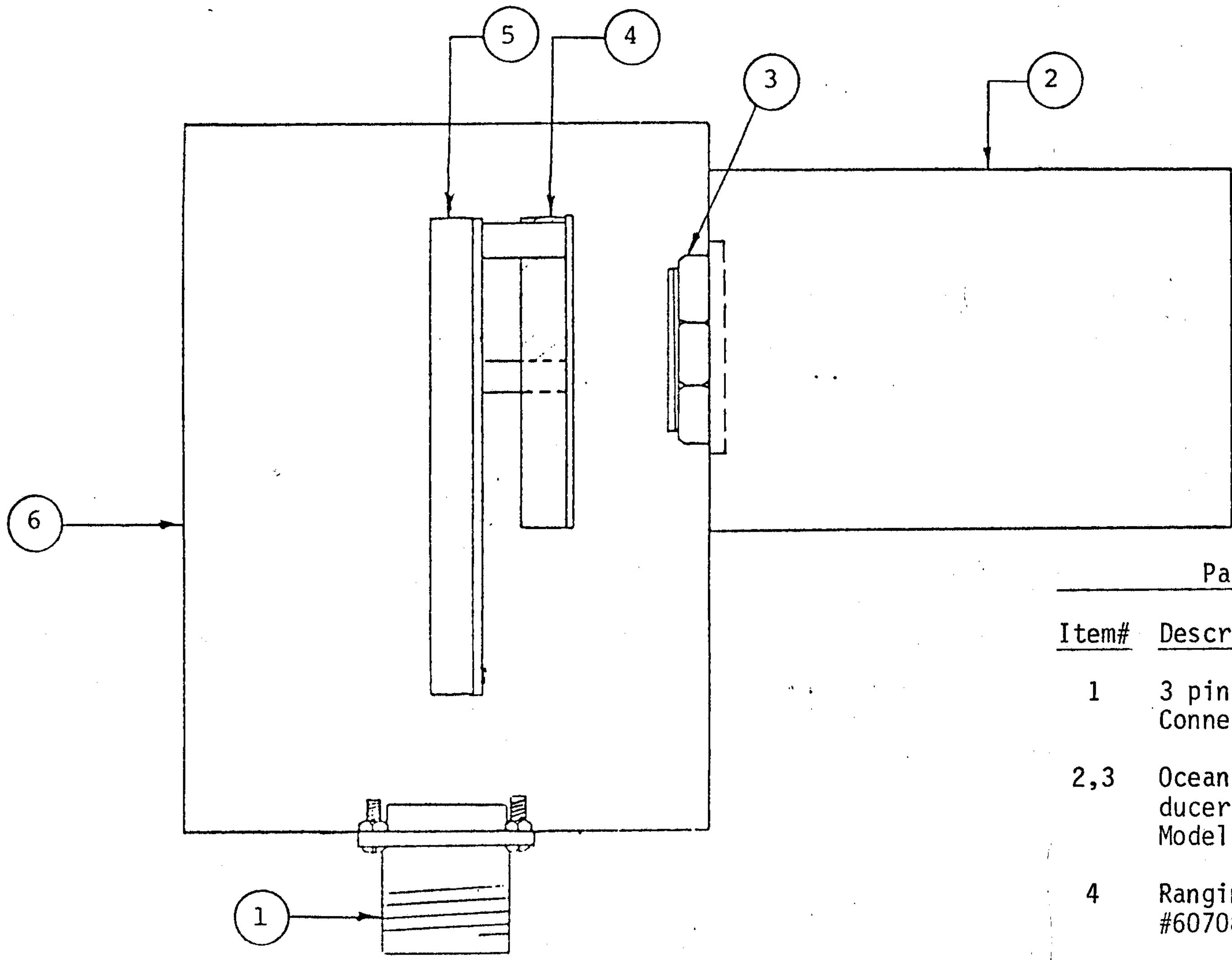


Figure 5. Block Diagram of Overhead Sensor System



	Parts List	
Item#	Description	Qty
1	Polaroid Ultrasonic Ranging Subsystem	1
2	Interconnecting Cable	1
3	AC Power Cable	1
4	Interface Unit	1

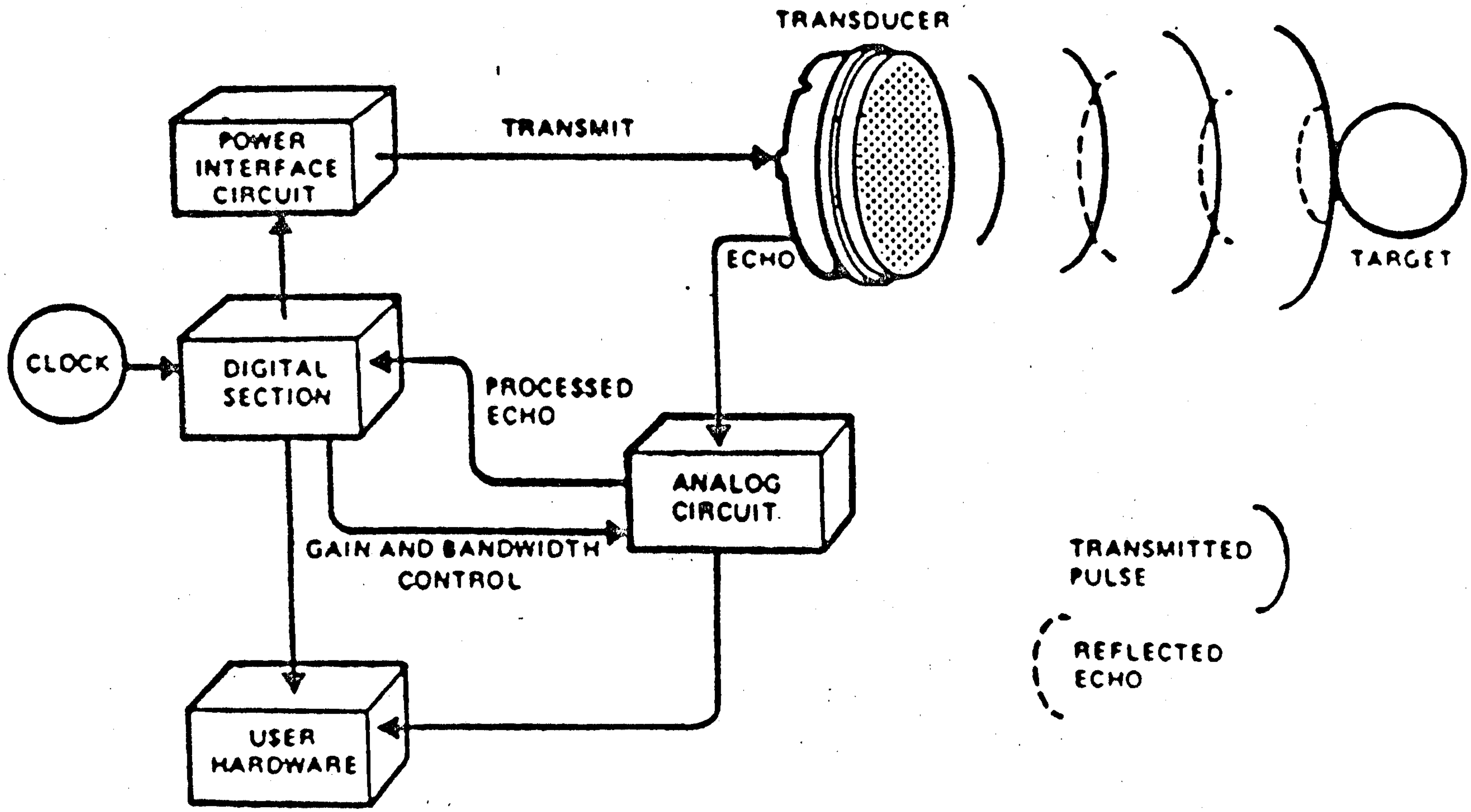
Figure 6. System Assembly



Parts List

Item#	Description	Qty
1	3 pin Amphenol Connector 14S-7	1
2,3	Ocean Motion Transducer with Hood Model #1020102	1
4	Ranging Board #607089	1
5	Signal Conditioning Circuitry	1
6	Transducer Box #A433FNM	1

Figure 7. Polaroid Ultrasonic Ranging Subsystem



TRANSMITTING/RECEIVING

Figure 8. Operation of Polaroid Ultrasonic Ranging Subsystems

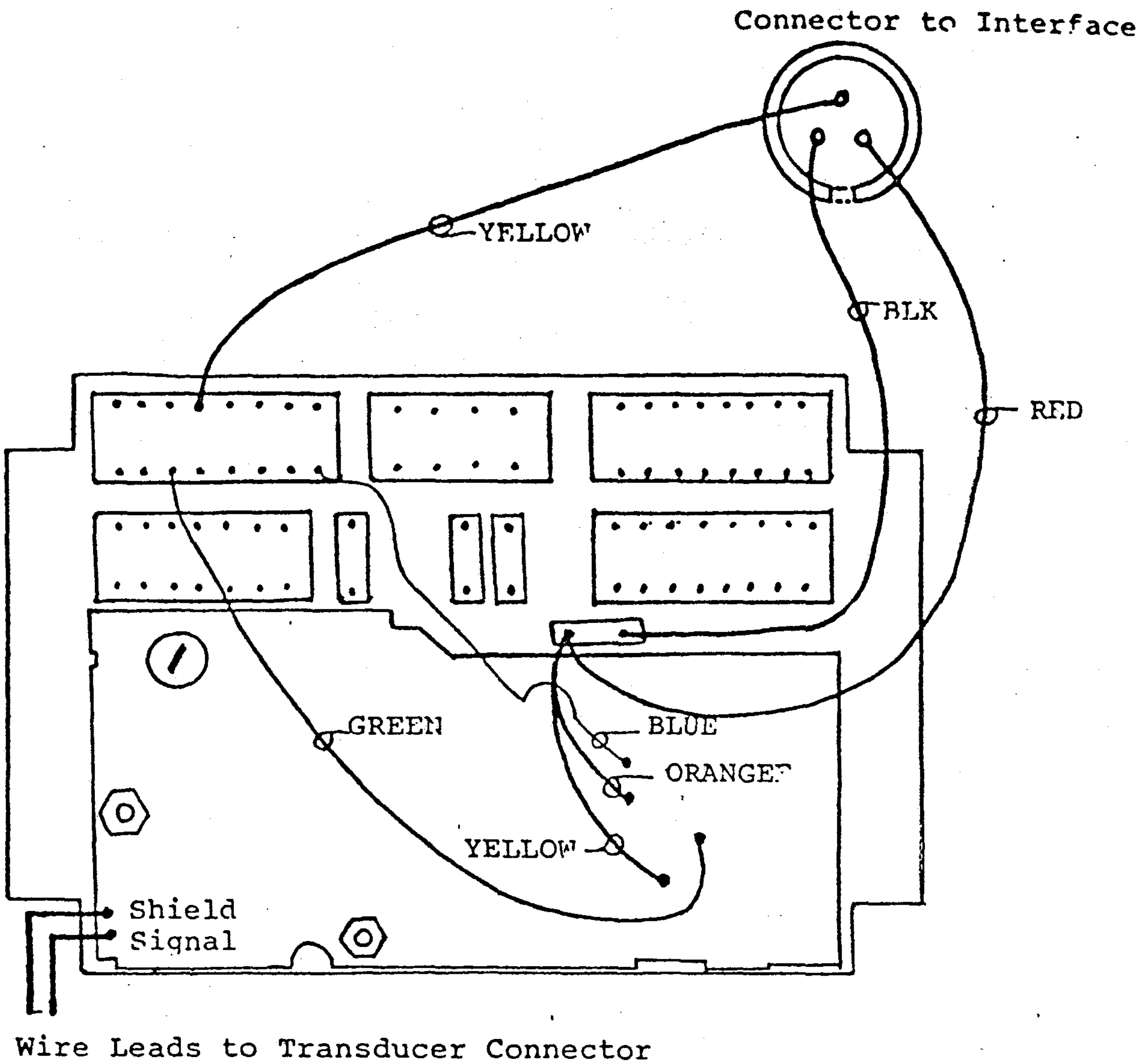


Figure 9. Wire Connections of Transducer Electronics

Transducer Interface Board. Figure 10 is the Transducer Circuit Schematic with the detailed parts list provided in Table 2. This schematic shows the interconnections that are required to the ranging board and the interface unit. The interface unit provides power for the system either by a 6VDC battery or AC power supply. The power and common are provided through connector P1. In addition the signal required by the interface unit is connected through P1.

The electrostatic transducer acts both as transmitter and receiver of sound waves. It has been designed to transmit the outgoing signal at a frequency of 50 kHz and also to function as a microphone in order to receive the echo. As indicated in Figure 11, this has been done by stretching a specially manufactured foil over a grooved plate, which is in contact with the insulating side of the foil, thus forming a capacitor which, when charged, exerts an electrostatic force on the foil. This forms the moving element which transforms electrical energy into sound waves and the returning echo back into electrical energy. The transducer is sealed within a horn, making it weather proof, and acting as a focus for the outgoing signal. Figure 12 shows a typical beam pattern for the transducer output with a focusing horn. All of this is controlled from the ranging circuit board's electronics.

The interconnections to the ranging board are also shown in Figure 12. These signals are labeled MFLOG, XLOG, and VSW. Note that the power for this board and the ultrasonic transducer are provided by interconnection with P1. The signal MFLOG is fed to transistor package U5 pin 6 where it switches an NPN transistor to provide a conditioned pulse to the inverter U1F to drive the S0 input of the RS flip-flop U4. Similarly XLOG is also conditioned to provide the R0 input to U4. These two signals are used to set or reset the RS flip-flop providing an output pulse from U4-13 to a switching transistor that drives the interface unit board.

The signals MFLOG represents the detected echo from the transducer. XLOG is the digital logic drive for the transmitted signal and represents when the transducer is transmitting. Note that XLOG and the MFLOG are driving the R0 (reset) and S0 (set) inputs respectively of the SR flip-flop. Thus, when XLOG is a 1 and MFLOG is a 0, the unit is transmitting and the flip-flop U4 is reset. When both XLOG and MFLOG are 0 the unit is passive awaiting an echo. An echo results in a signal combination of XLOG of 0 and MFLOG of 1 thus setting the flip-flop turning on the transistor U5 to provide a low active signal to the connector feeding the interface unit. The signal is reset upon receipt of the signal combination XLOG of 1 and MFLOG of 0 which occurs on the next transmitting cycle. The result is a pulse with a pulse duration or width that is proportional to the distance between the detected object and the transducer.

The signal VSW is the switched voltage that is fed to the transducer. It is derived on the transducer interface board and provided to the ranging board. The components that surround and include U1d make up the oscillator circuit that drives the switching transistor of U5 (pin 7). When the transistor U5 is turned on by positive voltage on pin 7 it provides a path to signal common allowing Q2 to switch on applying a positive voltage (VSW). This signal is interconnected to the ranging board supplying the power to the transducer that is switched on/off by the signal XLG. This is the same signal that is fed back to U4 to reset the flip-flop.

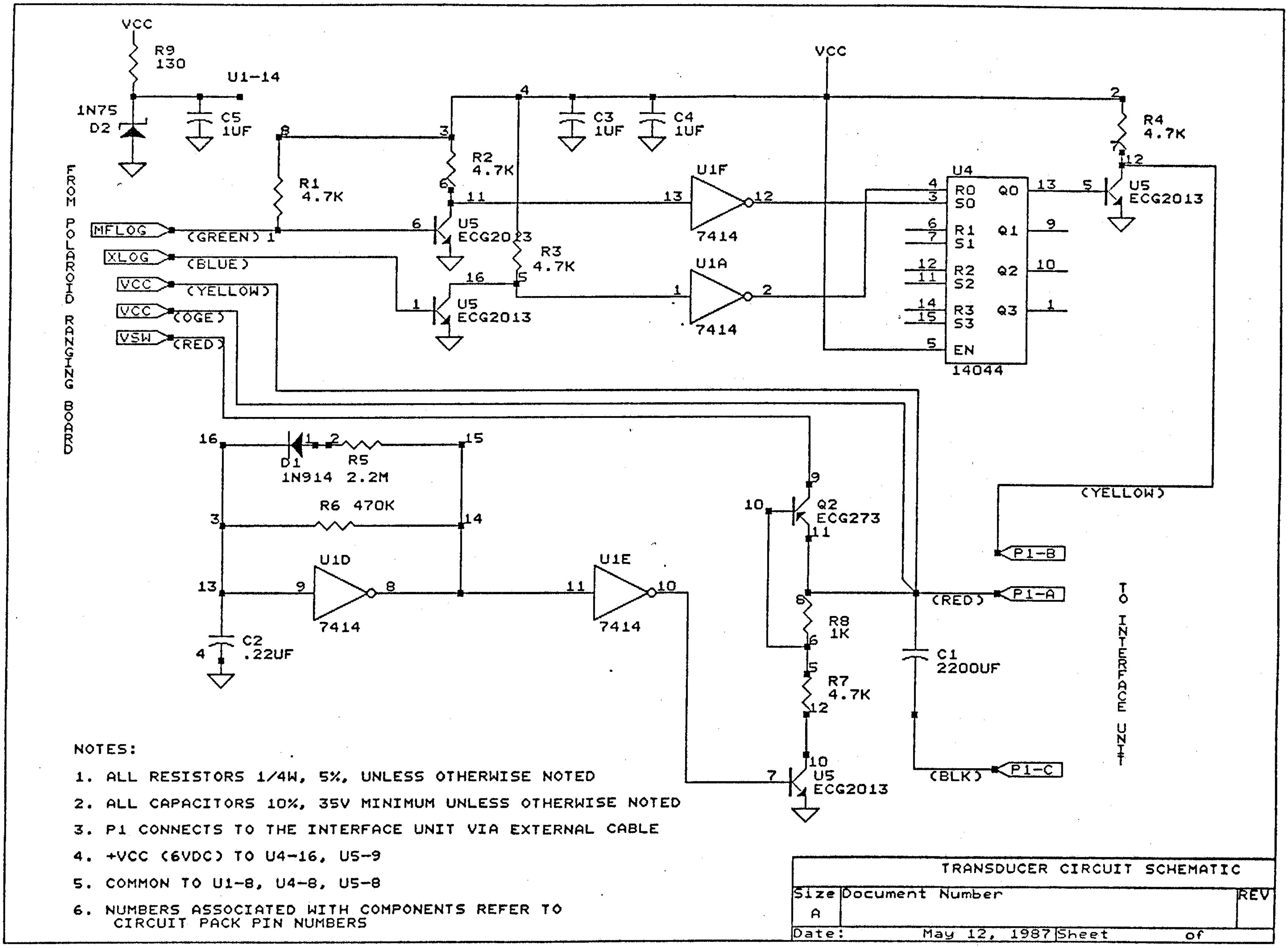
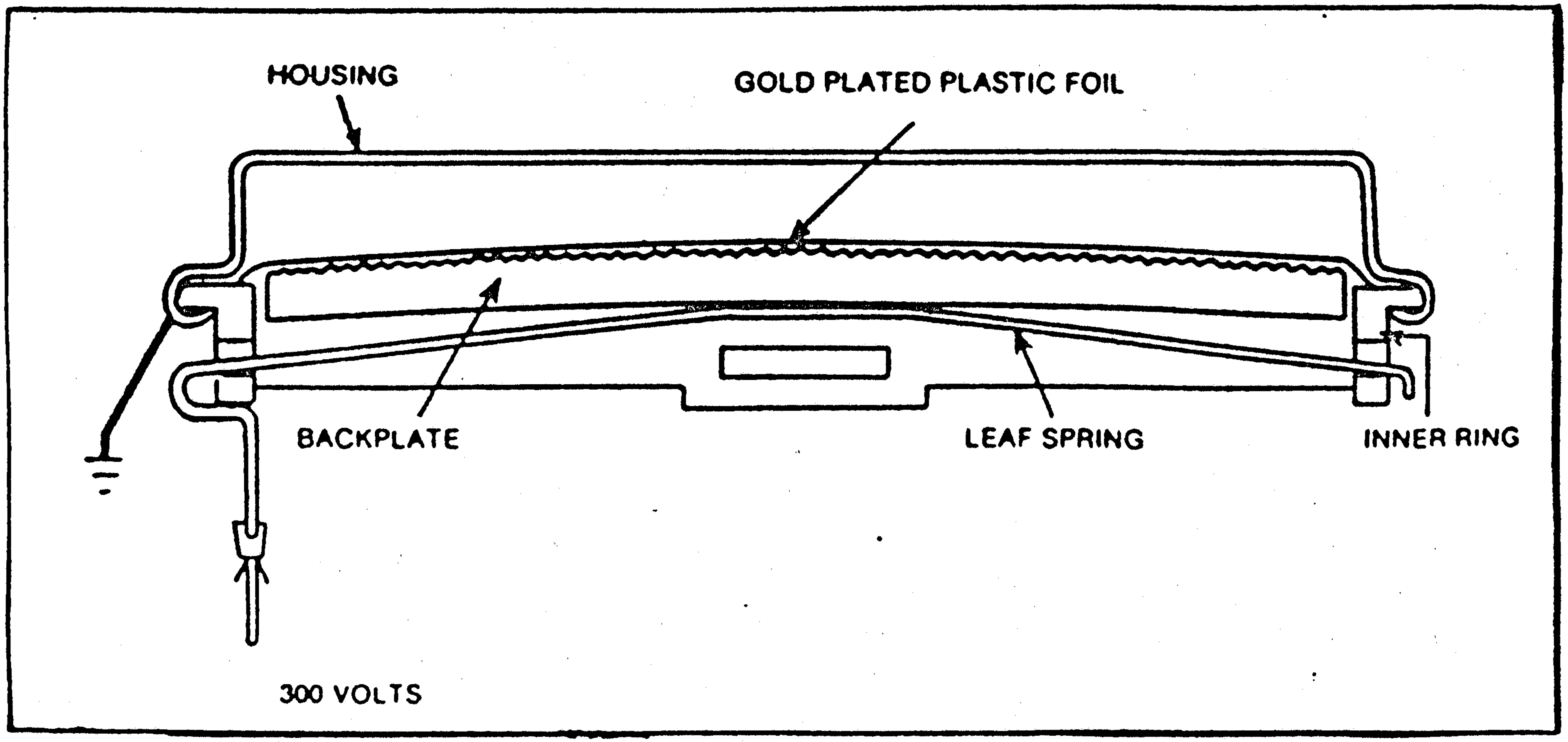


Figure 10. Transducer Circuit Schematic Diagram

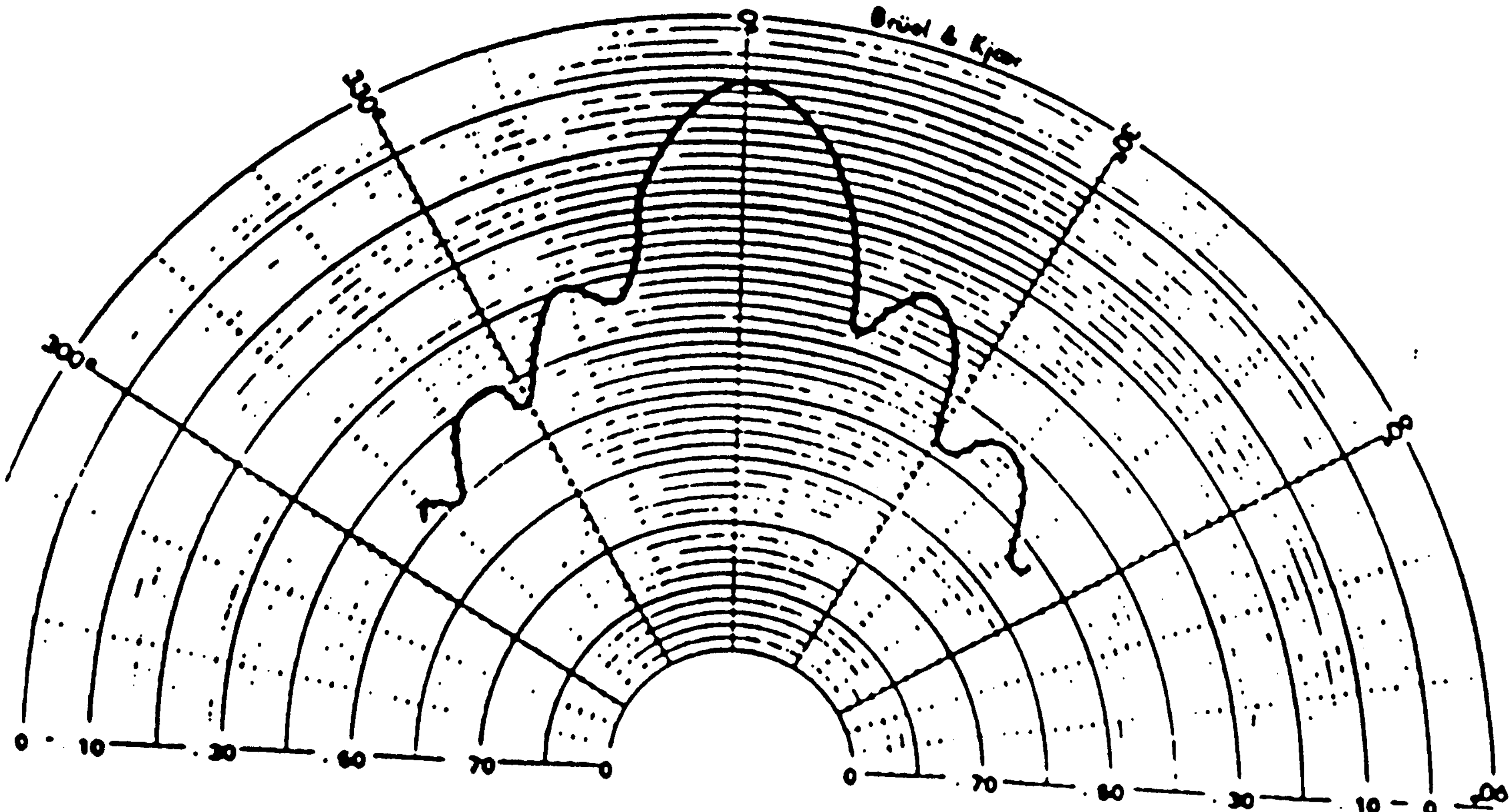
Table 2. Transducer Circuit Parts List

Item	Quantity	Reference	Part
1	1	U4	14044
2	1	U1	7414
3	5	R1,R2,R3,R4,R7	4.7K
4	1	R6	470K
5	1	R5	2.2M
6	1	C1	2200uF
7	1	U5	ECG2013
8	1	D1	1N914
9	1	R8	1K
10	3	C3,C4,C5	1uF
11	1	Q2	ECG273
12	1	C2	0.22uF
13	1	R9	130
14	1	D2	1N75



TRANSDUCER ASSEMBLY (SIDE VIEW)

Figure 11. Transducer Assembly



TYPICAL BEAM PATTERN
AT 50 kHz

(Note: dB normalized to an on-axis response)

Figure 12. Typical Beam Pattern

Additional circuitry is provided on this board to derive a 4.7VDC signal required by U1. This is accomplished by using zener diode D2 and resistor R9 to regulate the 6VDC provided by the battery or AC power supply.

Interface Electronics

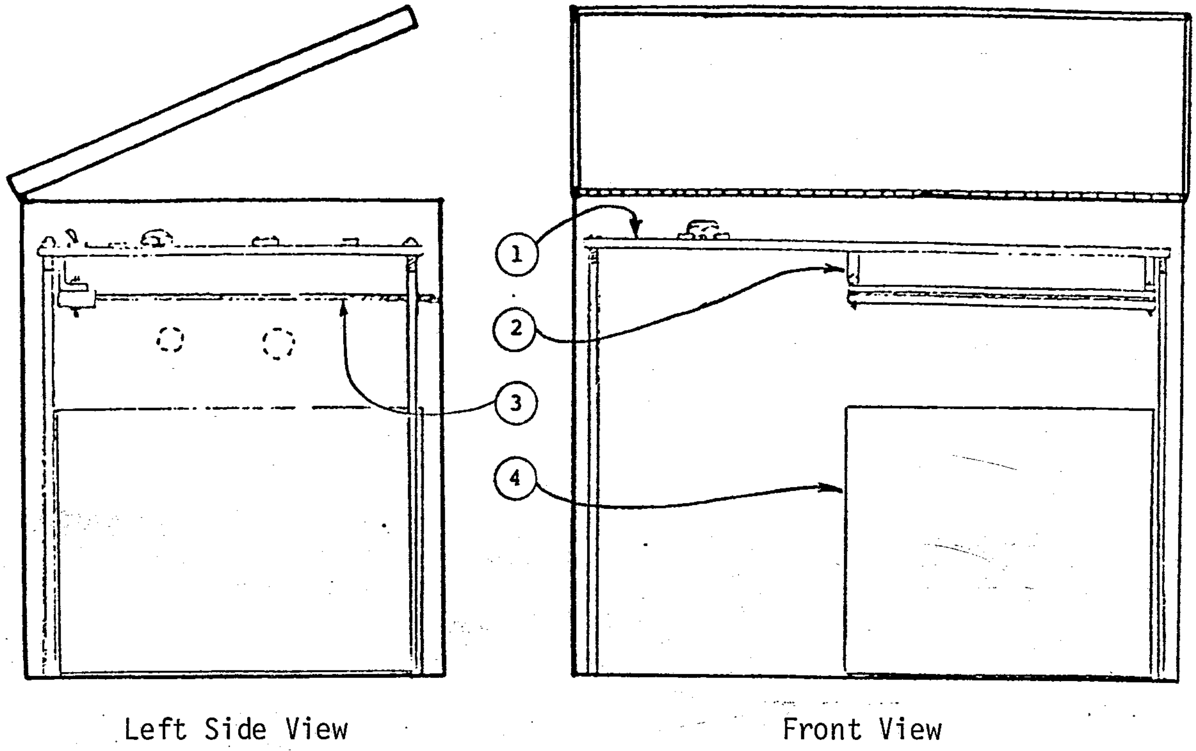
Figure 13 illustrates the assembly of the interface unit. This subsystem consists of the watertight box; connectors for AC power, output signal to counter, and the transducer interface; front panel; interface board; battery; and AC power supply. The parts list accompanying the figure details the components and boards required for the interface unit.

Figure 14 is the detailed drawing showing the required dimensions for producing the front panel. On this panel is an LED used to visually confirm operation of the transducer during setup. A switch is provided to disable the LED to conserve power after the unit has been placed in service. A power switch is also located on the front power to disable power to the detector when not needed. Figure 15, is a wiring diagram of the interface unit showing the electrical relationship of the components on the front panel and their wiring to the pc connector for the interface electronics. Potentiometer R10 is also located on the front panel to be used in setup of the detector as explained in the setup procedures.

Figure 16 provides an assembly drawing of the Interface Board showing the placement of the components for its construction or maintenance. Further detail is provided as to the electronics function by the Interface Unit Schematic of Figure 17 with a detailed parts list in Table 3.

In the schematic it should be noted that signals are provided to/from the front panel indicators and controls. These are routed and interconnected through the printed circuit board connector that the interface electronics board is mounted. The board and connector are mounted to the rear or blind side of the front panel. A signal from the transducer interface is conditioned by U1a and U1B and used to charge a capacitor in an RC circuit consisting of the front panel potentiometer R10 and the capacitor C1. The capacitor forms the noninverting input of an opamp and is used to compare to a fixed voltage fed to inverting input of U2A. Since the transducer is fixed and has a constant echo duration in relation to the road surface when no vehicles are detected, potentiometer R10 is adjusted to provide a voltage on the comparator U2A to keep the D flipflop U3B set. Any object intercepting the ultrasonic signal will cause an echo to provide a pulse to capacitor C1 shorter than that of the road surface thus resulting in a lower voltage charge. Hence the comparator U2A will provide low voltage to the D flipflop causing the flipflop to reset. This in turn turns transistor Q1 on putting a low active signal out to the data collector.

Figure 18 is the AC power supply schematic used to provide power to the unit when it is available. The AC input line voltage is rectified and regulated to provide a stable 6.3VDC that is used in place of the battery. This same voltage is used to recharge the battery allowing the battery to serve as backup power in situations of power outages.



Parts List

Item#	Description	Qty
1	Display Panel of Interface Unit	1
2	Mounting Bracket for Interface Board	2
3	Interface Electronics board	1
4	Battery	1

Figure 13. Interface Unit Assembley Drawing and Parts List

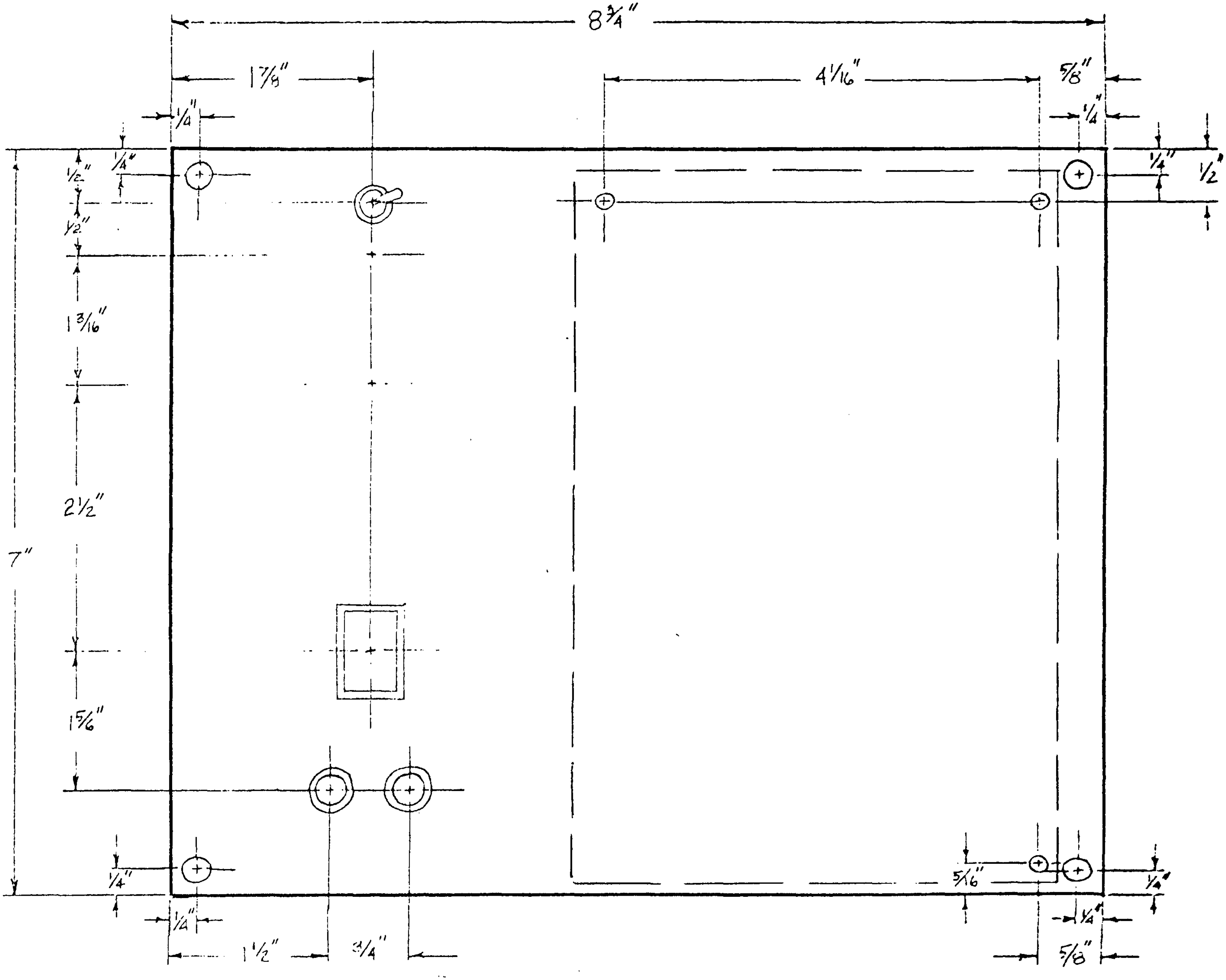


Figure 14. Display Panel of Interface Unit

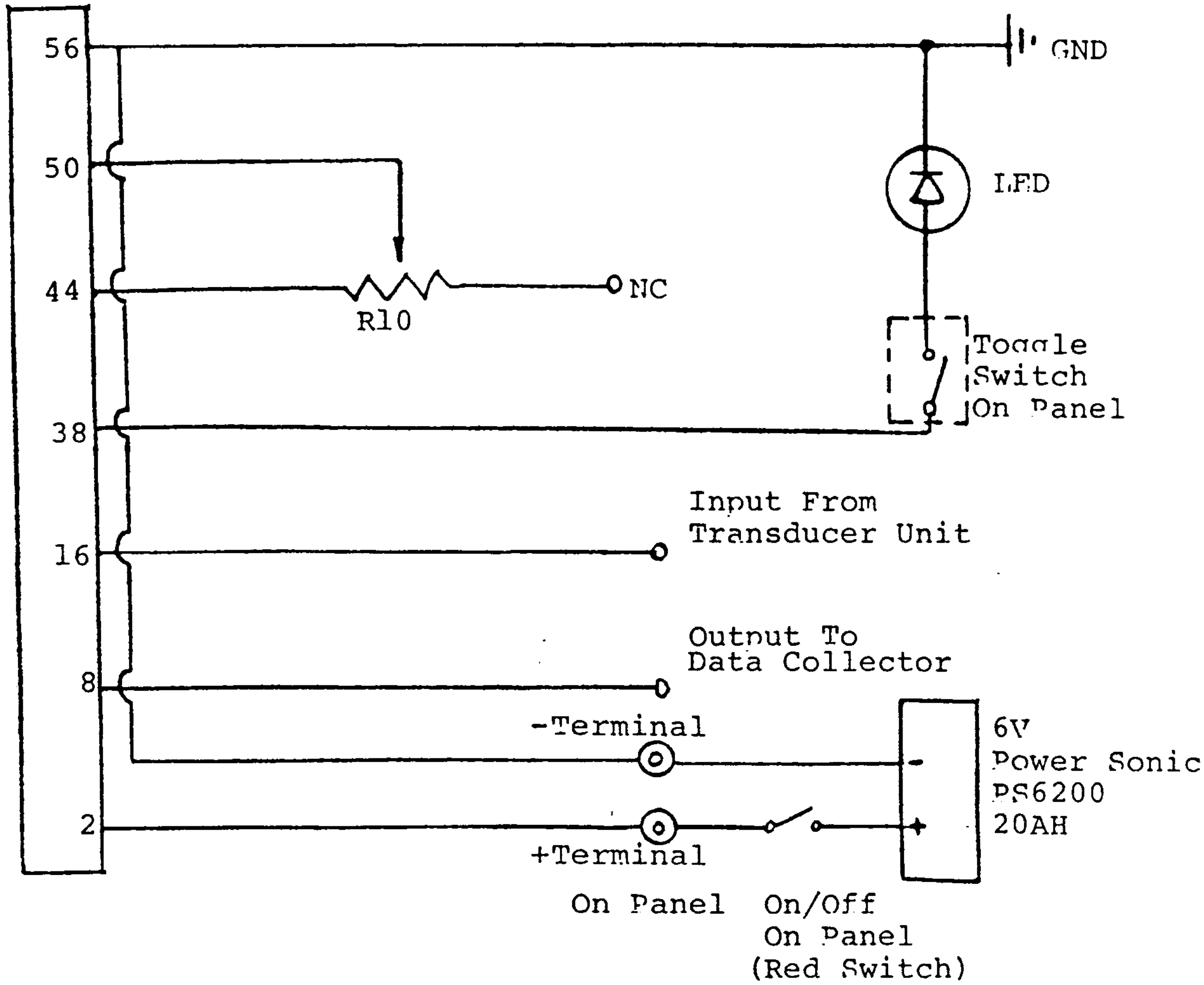


Figure 15. Wiring Diagram of Interface Unit

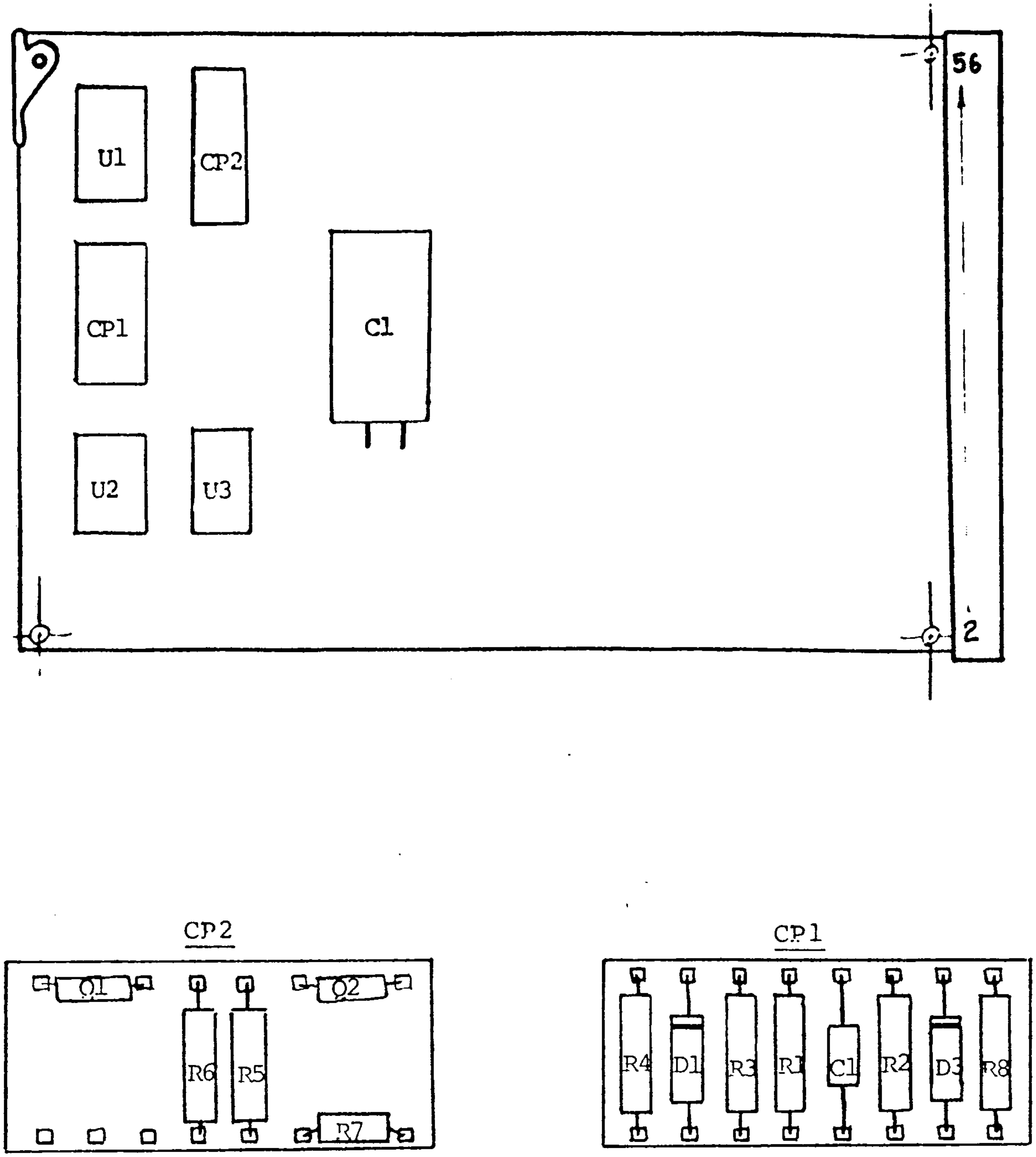


Figure 16. Interface Unit Schematic Assembly Drawing

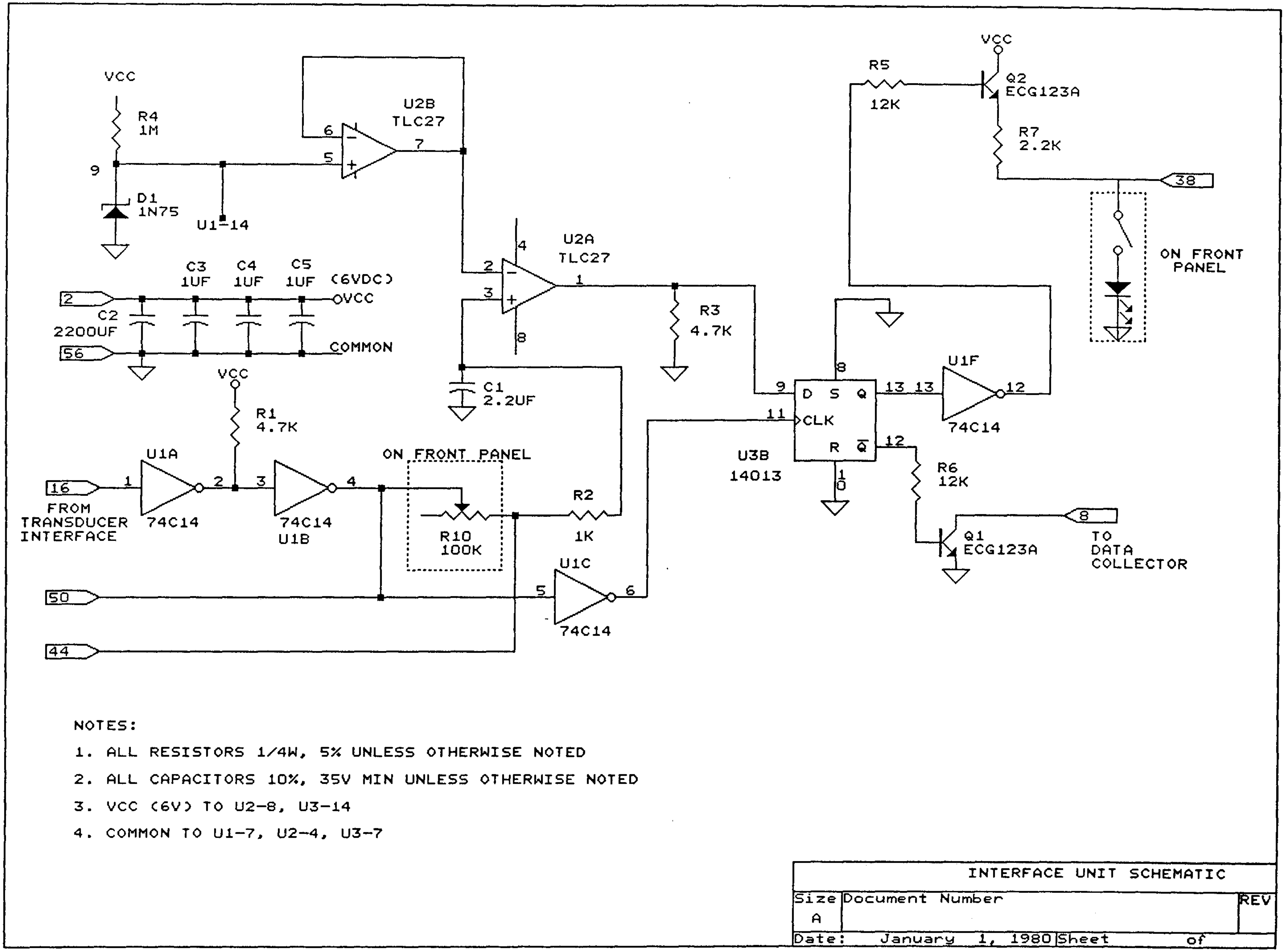


Figure 17. Detailed Interface Unit Schematic Drawing

Table 3. Interface Unit Parts List

Item	Quantity	Reference	Part
1	1	U3	14013
2	1	R4	1M
3	1	D1	1N75
4	1	C1	2.2uF
5	2	R3,R1	4.7K
6	2	R5,R6	12K
7	2	Q2,Q1	ECG123A
8	1	R7	2.2K
9	1	U1	74C14
10	1	R2	1K
11	1	R10	100K
12	1	U2	TLC27
13	1	C2	2200uF
14	3	C3,C4,C5	1uF

Parts List

(1) 60Hz 120V to 12V AC Transformer
(1) 7500uF Capacitor
(1) 2200uF Capacitor
(1) LM150
(4) 1N914 Diodes
(1) 240Ω Resistor
(1) 1 K Pot.

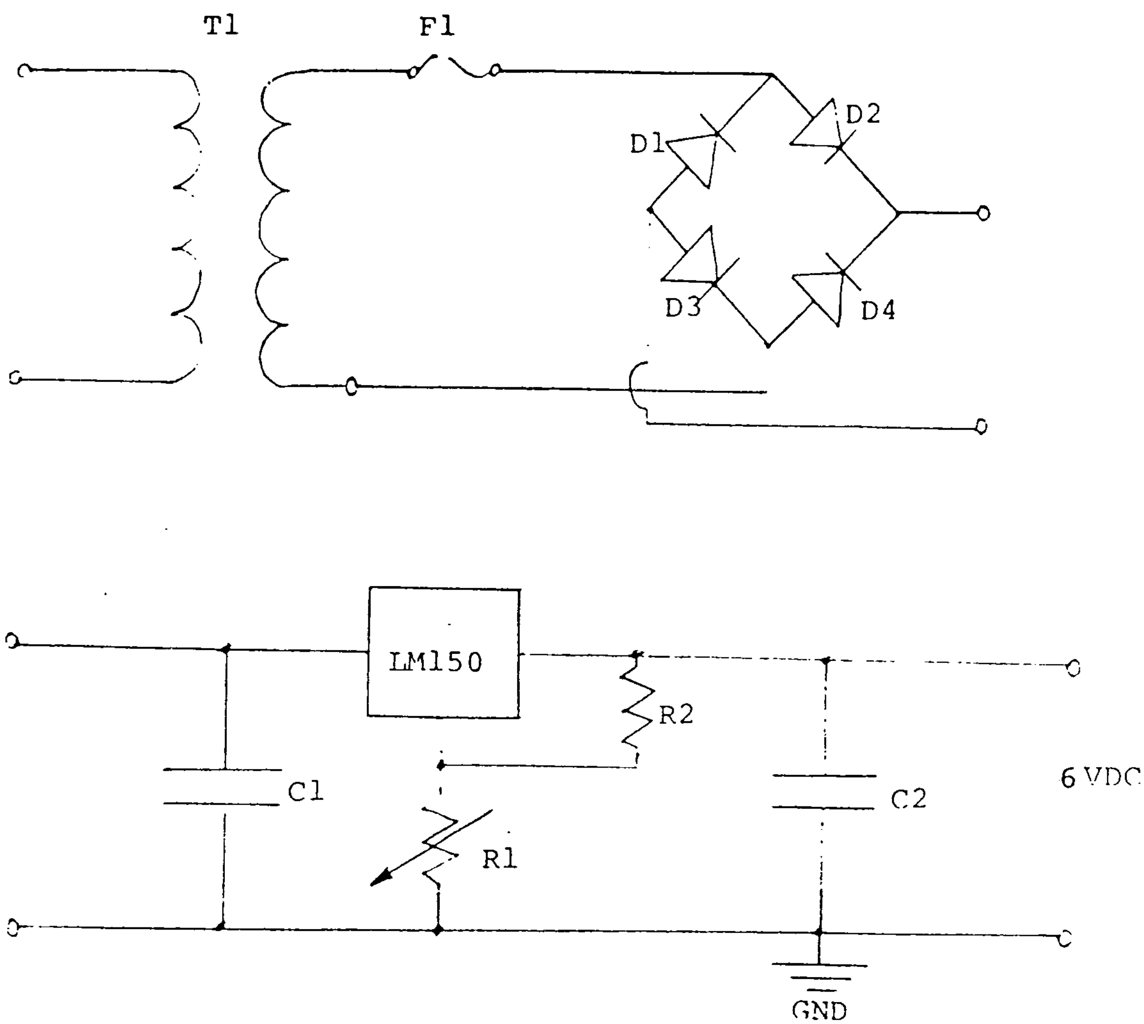


Figure 18. AC Power Supply Schematic and Parts List

Mounting Hardware - Installation

The overhead vehicle sensor is mounted to a bridge by means of a coupler which physically connects the transducer unit to one of the guardrail bolts. Two "T" joints and several feet of conduit, cut to dimensions appropriate for the specific bridge, make up the remainder of the mounting assembly. Therefore, the only requirement for installation is a crescent wrench.

Once installed, the transducer unit is connected to the interface unit by a three-wire cable, the connection made at each end with an amphenol connector. This system is illustrated in Figure 19. The three wires within this cable are: power (6 volts), ground (0 volts), and signal (6 volt pulse translating the distance between the transducer and the target). The interface unit is connected to the Data Collector by a two-wire cable - ground (0 volt) and signal (6 volt pulse translating the detection of a vehicle).

OPERATING INFORMATION

After installing and interconnecting the different subsystems the overhead vehicle sensor system can be activated for operation by opening the interface unit to gain access to the control panel, pictured in Figure 20.

Power-up procedure

To turn on the power,push the red push-button on the panel. This should give power to both the transducer and interface units. The source of power is a 6 volt-20 AH battery. Table 4 provides some observations for normal operating conditions which were made after a three-month testing period.

Table 4. Observations Under Normal Operating Conditions

(1) The overhead vehicle sensor system pulls an average current of 100 mA.

(2) The average voltage drop is 76 mV/day.

(3) The minimum acceptable battery level is 5.1 Vm.

(4) The maximum charge on battery is 6.3 V.

The battery level can be checked from the panel and should not fall below 5.1 V. In the case that it does drop below 5.1 V, the battery would need to be recharged to insure proper operation of the system.

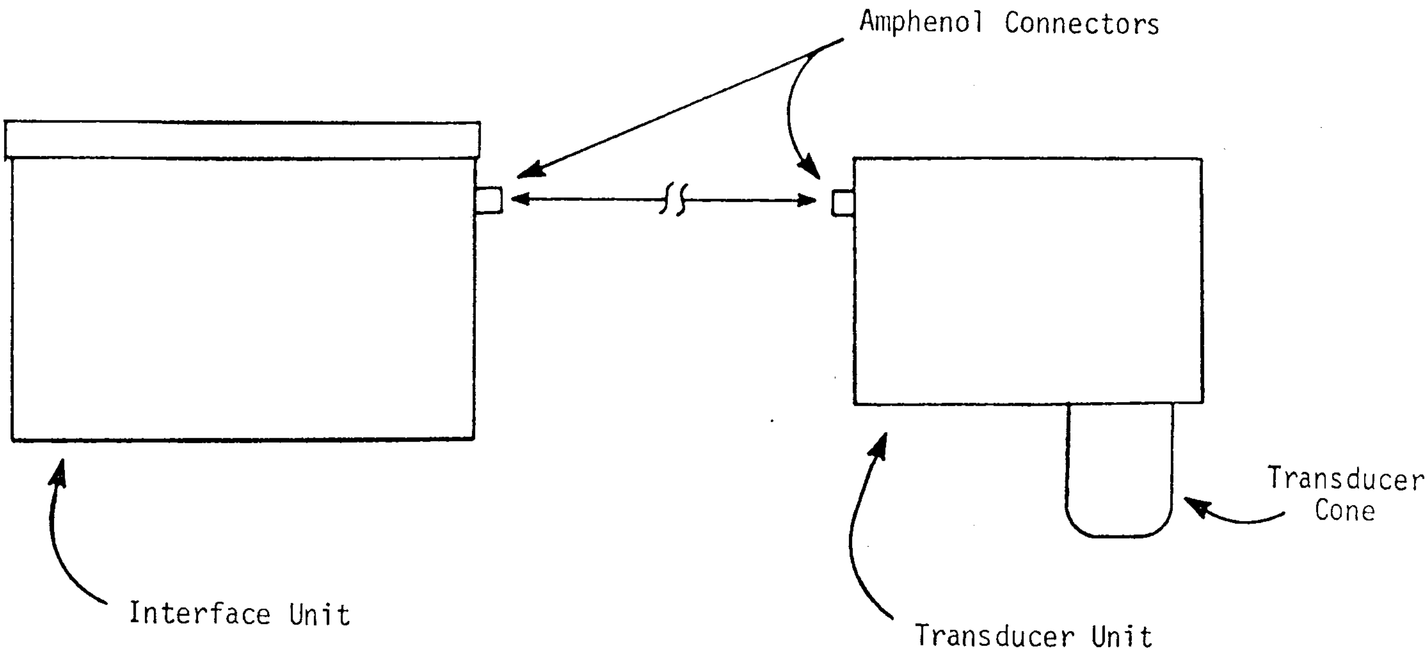


Figure 19. Connection of Transducer Unit and Interface Unit Subsystem

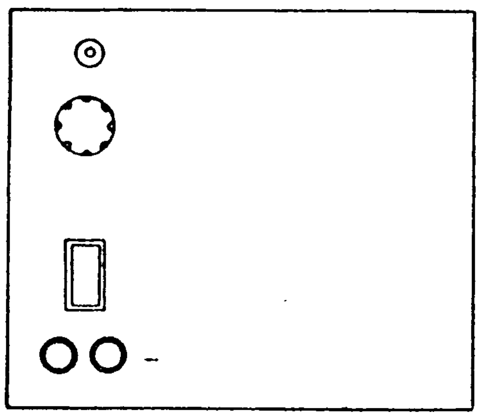


Figure 20. Control Panel on the Interface Unit

Calibration procedure

After the Power-up procedure, the overhead vehicle sensor system needs to be calibrated for the bridge height. This latter purpose is served by the LED and the potentiometer (black knob) on the panel of the interface unit. Because of power considerations, an SPDT switch allows the use of the LED only during calibration and when it is required. The LED is normally deactivated during a regular session of data gathering. If the LED is continuously ON, the sensor is then "over-detecting"; if it is continuously OFF, the sensor is "under-detecting."

In the case of "over-detection", turn the potentiometer until the LED goes OFF. In the other situation ("under-detection"), turn the potentiometer until the LED goes ON then turn it in the opposite direction to turn the LED OFF. The calibration point is right on the border between "over- and under-detection". The LED is now OFF. If a vehicle enters the detection field of the sensor, the LED will go ON then OFF to show a detection. At the same time, a pulse is sent by the interface unit to the Data Collector to register the presence of a vehicle.

After the above procedures have been accomplished, the overhead vehicle sensor system is calibrated and ready to sense the presence of vehicles for conducting a traffic count.

FIELD TESTING

Two sites in the College Station area were selected for testing the overhead sensor system. One of these is high speed (55 mph) location on the east bypass of State Highway 6 at University Drive. The second location is on University Drive at Wellborn Road (FM 2154). Traffic at this location travels at less than 40 mph.

At each site, two additional vehicle sensors (an inductive loop and a tapeswitch) are used to verify the counting results from the overhead vehicle sensor. Timelapse photography and video recorders were used to provide additional data for assessing the accuracy of the overhead vehicle sensor results. In addition, two different traffic data collection units were used. The first is a conventional traffic data collection device which accumulates traffic counts for a preset time interval. The inductive loop was connected to this device. The second data acquisition unit was a programmable microcomputer which can record individual sensor actuations. The overhead vehicle sensor and tapeswitch were connected to this equipment. Table 5 shows a comparison of typical results obtained from each sensor when the individual actuations are accumulated for the same time intervals. Table 6 presents a comparison of the results obtained when both the inductive loop and overhead vehicle sensor were connected to the same conventional traffic data collection unit.

The test setup is shown in Figure 21. As indicated in Table 5, the total count of the tapeswitch was 788 vehicles during the morning test period. This can be considered to be a more accurate count than the inductive loop for the reason that the inductive loop overcounts traffic due principally to the fact that trucks often "gap out" on the loops, resulting in two actuations for the same truck. This circumstance was confirmed by comparing the pattern of tapeswitch actuations with the inductive loop counts. Both the inductive loop and the overhead sensor overestimated the traffic volume. The overestimate in the overhead vehicle sensor was probably due to noise in the signal lines.

Both the inductive loop and the overhead vehicle sensor could benefit from the addition of a "smart sensor" capability which could look at the actuation times and combine and/or eliminate spurious signals when the actuations occur too close together (for example, less than 0.5 seconds). This feature has been incorporated into the traffic data collection software.

The overhead vehicle sensors were in operation from June through November, 1986 at the two sites described above. Both of the devices have operated continuously. Data were collected monthly at the sites. The data shown in Table 6 are <u>typical</u> of that observed throughout the testing period.

Table 5. Traffic Count Data from Inductive Loop, Tapeswitch, and Overhead Sensor in the Same High Speed Lane

TIME	LOOP	TAPESWITCH	OVERHEAD
10:30	19	19	19
10:35	26	26	25
10:40	25	24	25
10:45	33	33	33
10:50	29	28	27
10:55	36	34	36
11:00	31	31	31
11:05	29	27	29
11:10	27	26	27
11:15	31	31	31
11:20	32	35	33
11:25	28	28	28
11:30	28	27	33
11:35	31	31	31
11:40	42	42	42
11:45	37	37	37
11:50	39	37	36
11:55	24	24	23
12:00	36	36	35
12:05	53	51	53
12:10	47	45	45
12:15	45	45	44
12:20	35	34	33
12:25	36	37	35
TOTAL	799	788	795

Table 6. Traffic Count Data from Inductive Loop and Overhead Sensor in the Same High Speed Lane

TIME	LOOP	OVERHEAD
14:00	12	13
14:05	24	24
14:10	32	32
14:15	30	31
14:20	32	32
14:25	32	33
14:30	30	30
14:35	32	32
14:40	39	38
14:45	33	34
14:50	27	26
14:55	29	29
15:00	36	37
15:05	28	27
15:10	24	24
15:15	25	25
15:20	33	33
15:25	31	33
15:30	26	25
15:35	41	41
15:40	29	28
15:45	31	31
15:50	33	33
15:55	38	37
16:00	34	34
TOTAL	761	762

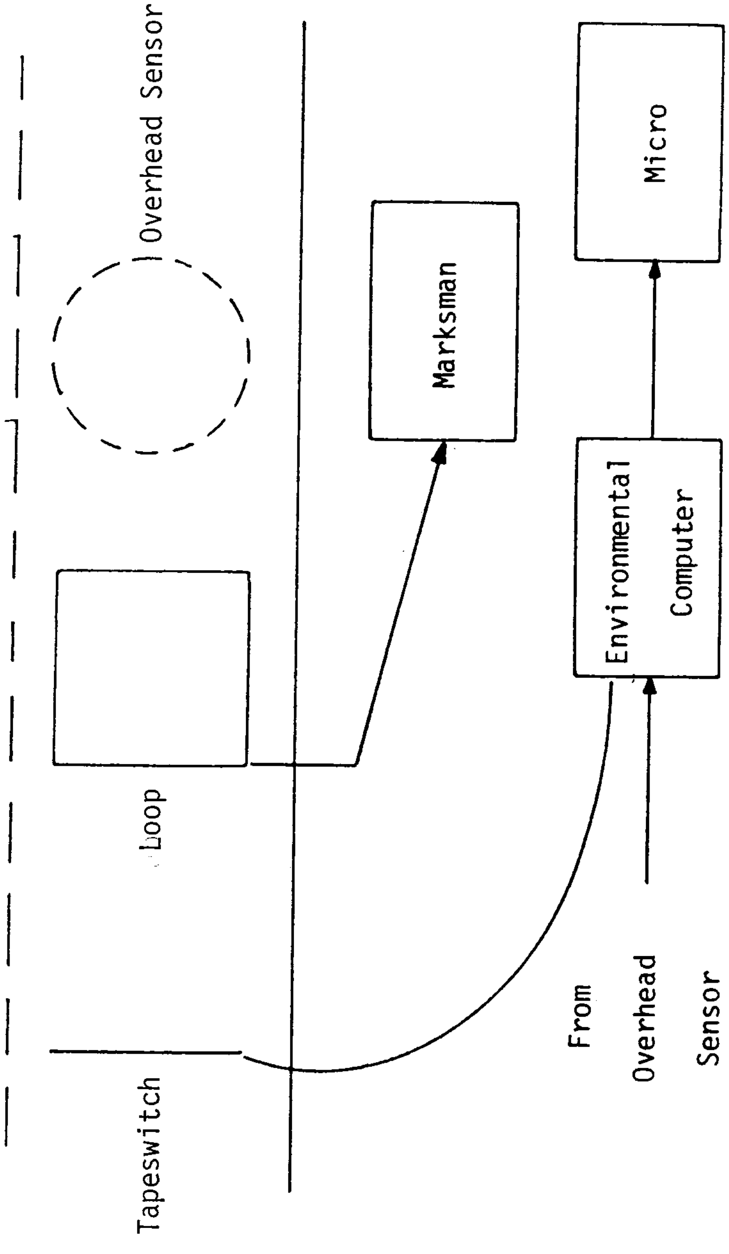


Figure 21. Initial Field Test Set-up

Additional Field Testing

Additional field testing has been ongoing since November 1986 at a site in Austin, Texas. The counts in this test for the overhead vehicle sensor are compared to counts taken using loops. Table 7 lists the daily counts for both the loop and the overhead sensor during the period December 15, 1986 thru April 8, 1987. This table also gives the absolute differences (AD) and percent differences (PD) for each day's counts. Table 8 provides further statistical analyses of the daily comparison after calculation of the mean and standard deviation for the loop alone, the overhead sensor alone, and the absolute and percent differences between the loop and the overhead sensor. The mean of the percent difference was found to be -0.15%, which implies that the overhead sensor is a highly accurate vehicle counter as compared to a loop.

Table 7. Comparison of Count Data from the Period 12-15-86 to 4-8-87

DATE	LOOP	OVERHEAD	AD	PD
12-15-86	10281	10187	-94	-0.9143
12-16-86	14299	14094	-205	-1.4337
12-17-86	14994	14779	-215	-1.4339
12-18-86	14970	14221	-749	-5.0033
12-19-86	15955	15845	-110	-0.6894
12-20-86	11732	11605	-127	-1.0825
12-21-86	8731	8746	15	0.1718
12-22-86	13188	14171	983	7.4537
12-23-86	13725	13656	-69	-0.5027
12-24-86	11140	11058	-82	-0.7361
12-25-86	5279	5237	-42	-0.7956
12-26-86	8453	8402	-51	-0.6033
12-27-86	8137	8104	-33	-0.4056
12-28-86	6952	6895	-57	-0.8199
12-29-86	12384	12305	-79	-0.6379
12-30-86	12905	12987	82	0.6354
12-31-86	13350	13302	-48	-0.3596
01-01-87	7371	7350	-21	-0.2849
01-02-87	11934	11848	-86	-0.7206
01-03-87	9290	9304	14	0.1507
01-04-87	7898	7873	-25	-0.3165
01-05-87	13504	13361	-143	-1.0589
01-06-87	13839	13674	-165	-1.1923
01-07-87	13996	14016	20	0.1429
01-08-87	13786	13660	-126	-0.9140
01-09-87	14483	14255	-228	-1.5743
01-10-87	11091	11147	56	0.5049
01-11-87	8694	8676	-18	-0.2070
01-12-87	14247	14422	175	1.2283
01-13-87	14098	13932	-166	-1.1775
01-14-87	14787	14541	-246	-1.6636
01-15-87	14906	14848	-58	-0.3891
01-16-87	14899	14808	-91	-0.6108
01-17-87	10674	11685	1011	9.4716
01-18-87	8684	8501	-183	-2.1073
01-19-87	13416	13418	2	0.0149
01-20-87	14341	14311	-30	-0.2092
01-21-87	13581	13549	-32	-0.2356
01-22-87	14459	14487	28	0.1937
01-23-87	15072	15035	-37	-0.2455
01-24-87	12248	12308	60	0.4899
01-25-87	9348	9299	-49	-0.5242
01-26-87	14240	14368	128	0.8989
01-27-87	14665	14558	-107	-0.7296
01-28-87	14760	14462	-298	-2.0190
01-29-87	14744	14538	-206	-1.3972
01-30-87	15358	15292	-66	-0.4297
01-31-87	11663	11530	-133	-1.1404
02-01-87	9414	9328	-86	-0.9135
02-02-87	14607	14501	-106	-0.7257
02-03-87	14844	14707	-137	-0.9229

Table 7. Comparison of Count Data from the Period 12-15-86 to 4-8-87 (Continued)

DATE	LOOP	OVERHEAD	AD	PD
02-04-87	14876	14675	-201	-1.3512
02-05-87	14430	14361	-69	-0.4782
02-06-87	15035	14981	-54	-0.3592
02-07-87	12317	12402	85	0.6901
02-08-87	10078	10172	94	0.9327
02-09-87	14563	14531	-32	-0.2197
02-10-87	14754	14579	-175	-1.1861
02-11-87	15257	15006	-251	-1.6451
02-12-87	14936	14595	-341	-2.2831
02-13-87	15751	15379	-372	-2.3618
02-14-87	12193	12184	-9	-0.0738
02-15-87	8523	9937	1414	16.5904
02-16-87	13167	13100	-67	-0.5088
02-17-87	14874	14926	52	0.3496
02-18-87	14979	14958	-21	-0.1402
02-19-87	14459	14517	58	0.4011
02-20-87	14306	14618	312	2.1809
02-21-87	11745	11692	-53	-0.4513
02-22-87	9652	9646	-6	-0.0622
02-23-87	14152	14233	81	0.5724
02-24-87	14015	13815	-200	-1.4270
02-25-87	14224	14235	11	0.0773
02-26-87	14241	14541	300	2.1066
02-27-87	14967	15161	194	1.2962
02-28-87	11827	12537	710	6.0032
03-01-87	9809	9525	-284	-2.8953
03-02-87	14672	14612	-60	-0.4089
03-03-87	15003	14933	-70	-0.4666
03-04-87	15061	15028	-33	-0.2191
03-05-87	15309	15266	-43	-0.2809
03-06-87	15523	15459	-64	-0.4123
03-07-87	12395	12388	-7	-0.0565
03-08-87	10467	10434	-33	-0.3153
03-09-87	14844	14685	-159	-1.0711
03-10-87	14839	14880	41	0.2763
03-11-87	14701	14764	63	0.4285
03-12-87	14975	14912	-63	-0.4207
03-13-87	15646	15540	-106	-0.6775
03-14-87	11432	11196	-236	-2.0644
03-15-87	8778	8583	-195	-2.2215
03-16-87	13250	13026	-224	-1.6906
03-17-87	13577	14188	611	4.5003
03-18-87	13834	13801	-33	-0.2385
03-19-87	13481	13318	-163	-1.2091
03-20-87	14044	13699	-345	-2.4566
03-21-87	10395	10176	-219	-2.1068
03-22-87	9115	9051	-64	-0.7021
03-23-87	14485	14588	103	0.7111
03-24-87	14669	14601	-68	-0.4636
03-25-87	14371	14418	47	0.3270

Table 7. Comparison of Count Data from the Period 12-15-86 to 4-8-87 (Continued)

DATE	LOOP	OVERHEAD	AD	PD
03-26-87	14880	14752	-128	-0.8602
03-27-87	15918	15811	-107	-0.6722
03-28-87	12205	12386	181	1.4830
03-29-87	9321	9497	176	1.8882
03-30-87	13983	14029	46	0.3290
03-31-87	14668	14650	-18	-0.1227
04-01-87	15071	15027	-44	-0.2920
04-02-87	15170	15137	-33	-0.2175
04-03-87	15482	15471	-11	-0.0711
04-04-87	11902	11858	-44	-0.3697
04-05-87	8896	8790	-106	-1.1915
04-06-87	14246	14183	-63	-0.4422
04-07-87	14793	14711	-82	-0.5543
04-08-87	14927	14278	-649	-4.3478

Table 8. Summary of Results of Comparison of Counts for Three Month Period

N Obs	Variable	Minimum	Maximum	Mean	Std Dev
115	LOOP	5279.00	15955.00	13016.30	2417.11
	OVERHEAD	5237.00	15845.00	12987.98	2378.81
	AD	-749.00	1414.00	-28.31	260.91
	PD	-5.00	16.59	-0.15	2.36

CONCLUSION

The overhead vehicle sensor developed in this research has been shown to be an effective vehicle sensor which meets the objective of this research of not requiring lane closure for either installation or maintenance. However, the evaluation to date has consisted of testing under controlled laboratory and field conditions. There remains a need for further evaluation of the device under a wider range of traffic, geometric, and environmental conditions before it can be concluded whether it is suitable for routine long term deployment.

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Cunagin, W.D., et al, "Portable Sensors and Equipment for Traffic Data Collection," Transportation Research Board, Transportation Research Record #1060, Washington, D.C., January, 1986.

Biber, C., et al, "The Polaroid Ultrasonic Ranging System," Presented at the 67th Convention of the Audio Engineering Society, October 31-November 3, 1980, New York City, NY.

Statitrol, Inc. "Pyroelectric Sensor," U.S. Patent No. 4,379,971. Denver, Colorado. Filed November 10, 1980.

OVERHEAD VEHICLE SENSOR SYSTEM
USERS GUIDE

INTRODUCTION

The systems is designed and built comprising of two major subsystems. Figure M1 is the block diagram of the overhead sensor system showing the major subsystems. These are the Polaroid Ultrasonic Ranging Subsystem and the Interface Electronics. The systems produces a signal that is used by a data collector to maintain a total count of detected vehicles.

The major components of the system are shown in Figure M2, System Assembly, and consist of the subsystems mentioned above as well as an ac power cable and interconnecting cable.

Polaroid Ultrasonic Ranging Subsystem. This subsystem is shown in Figure M3. The major components of this unit are the Polaroid Ultrasonic Transducer, the ranging board, the transducer interface board, and the mechanical components such as connector, transducer cone, and case. The unit is designed to be waterproof and capable of operation in harsh environmental applications.

Figure M4, Wire Connections of Transducer Electronics, is a wiring diagram showing the interconnections between the Polaroid ranging board, the transducer interface board, and the connector (P1) for the Interface Unit cable. The transducer is connected to the Polaroid ranging board with shielded coaxial cable to minimize radiation of the signal to surrounding electronics.

Transducer Interface Board. Figure M5 is the Transducer Circuit Schematic with the detailed parts list provided in Table M1. This schematic shows the interconnections that are required to the ranging board and the interface unit. The interface unit provides power for the system either by a 6VDC battery or AC power supply. The power and common are provided through connector P1. In addition the signal required by the interface unit is connected through P1.

The interconnections to the ranging board are also shown in Figure M5. These signals are labeled MFLOG, XLOG, and VSW. Note that the power for this board and the ultrasonic transducer are provided by interconnection with P1. The signal MFLOG is fed to transistor package U5 pin 6 where it switches an NPN transistor to provide a conditioned pulse to the inverter U1F to drive the S0 input of the RS flip-flop U4. Similarly XLOG is also conditioned to provide the R0 input to U4. These two signals are used to set or reset the RS flip-flop providing an output pulse from U4-13 to a switching transistor that drives the interface unit board.

The signals MFLOG represents the detected echo from the transducer. XLOG is the digital logic drive for the transmitted signal and represents when the transducer is transmitting. Note that XLOG and the MFLOG are driving the R0 (reset) and S0 (set) inputs respectively of the SR flip-flop. Thus, when XLOG is a 1 and MFLOG is a 0, the unit is transmitting and the flip-flop U4 is reset. When both XLOG and MFLOG are 0 the unit is passive awaiting an echo. An echo results in a signal combination of XLOG of 0 and MFLOG of 1 thus setting the flip-flop turning on the transistor U5 to provide a low active signal to the connector feeding the interface unit. The signal is reset upon receipt of the signal combination XLOG of 1 and MFLOG of 0 which occurs on the

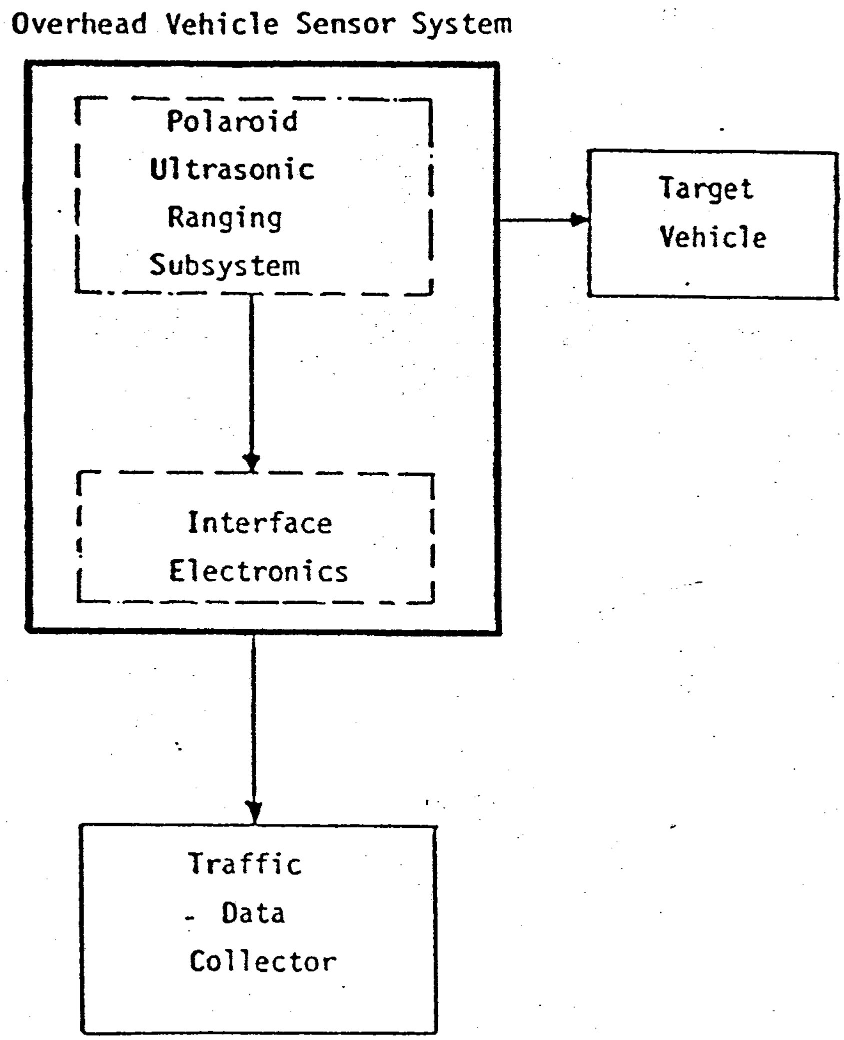
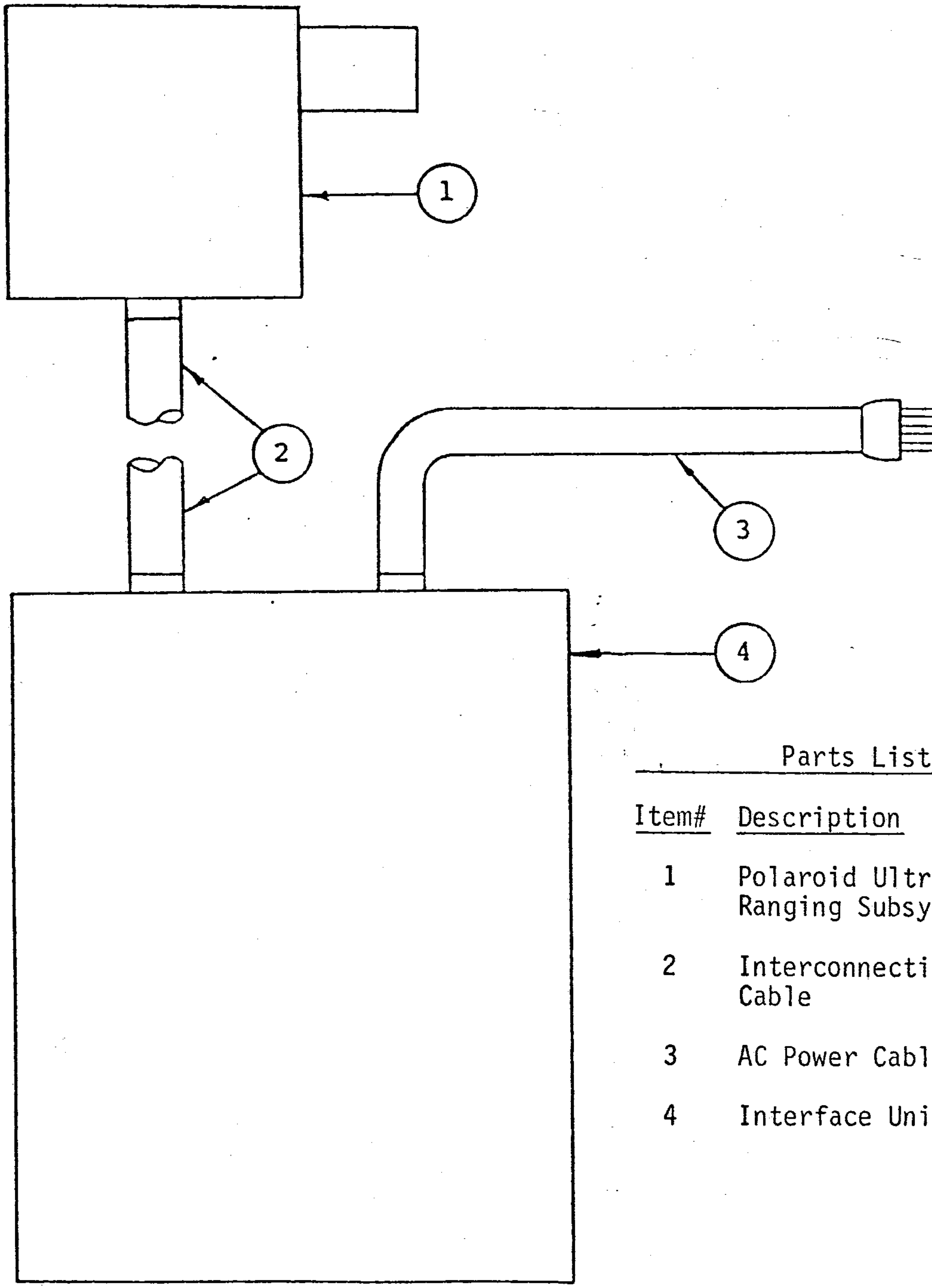


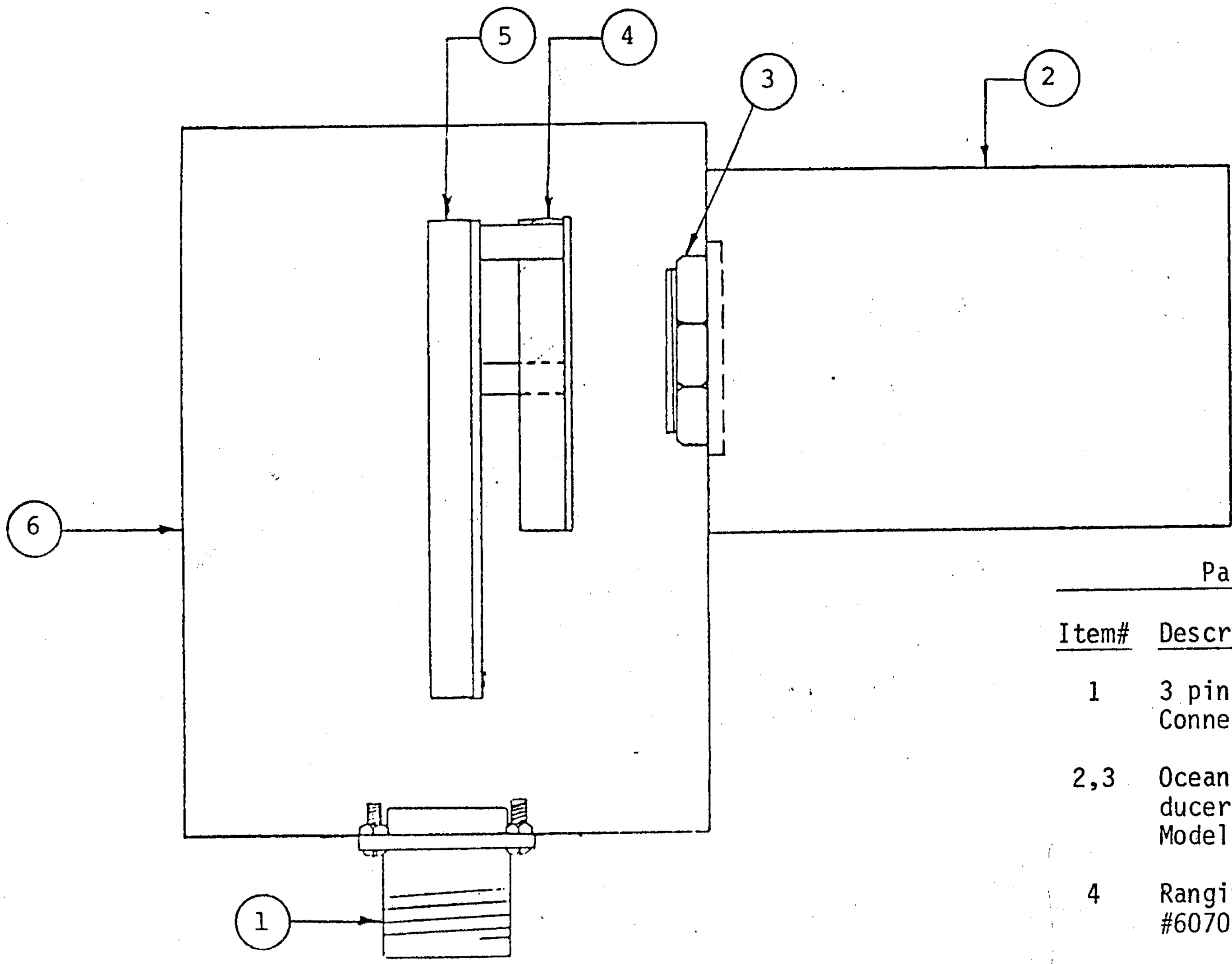
Figure M1. Block Diagram of Overhead Sensor Diagram



Parts List

Item#	Description	Qty
1	Polaroid Ultrasonic Ranging Subsystem	1
2	Interconnecting Cable	1
3	AC Power Cable	1
4	Interface Unit	1

Figure M2. System Assembly



Parts List

Item#	Description	Qty
1	3 pin Amphenol Connector 14S-7	1
2,3	Ocean Motion Transducer with Hood Model #1020102	1
4	Ranging Board #607089	1
5	Signal Conditioning Circuitry	1
6	Transducer Box #A433FNM	1

Figure M3. Polaroid Ultrasonic Ranging Subsystem

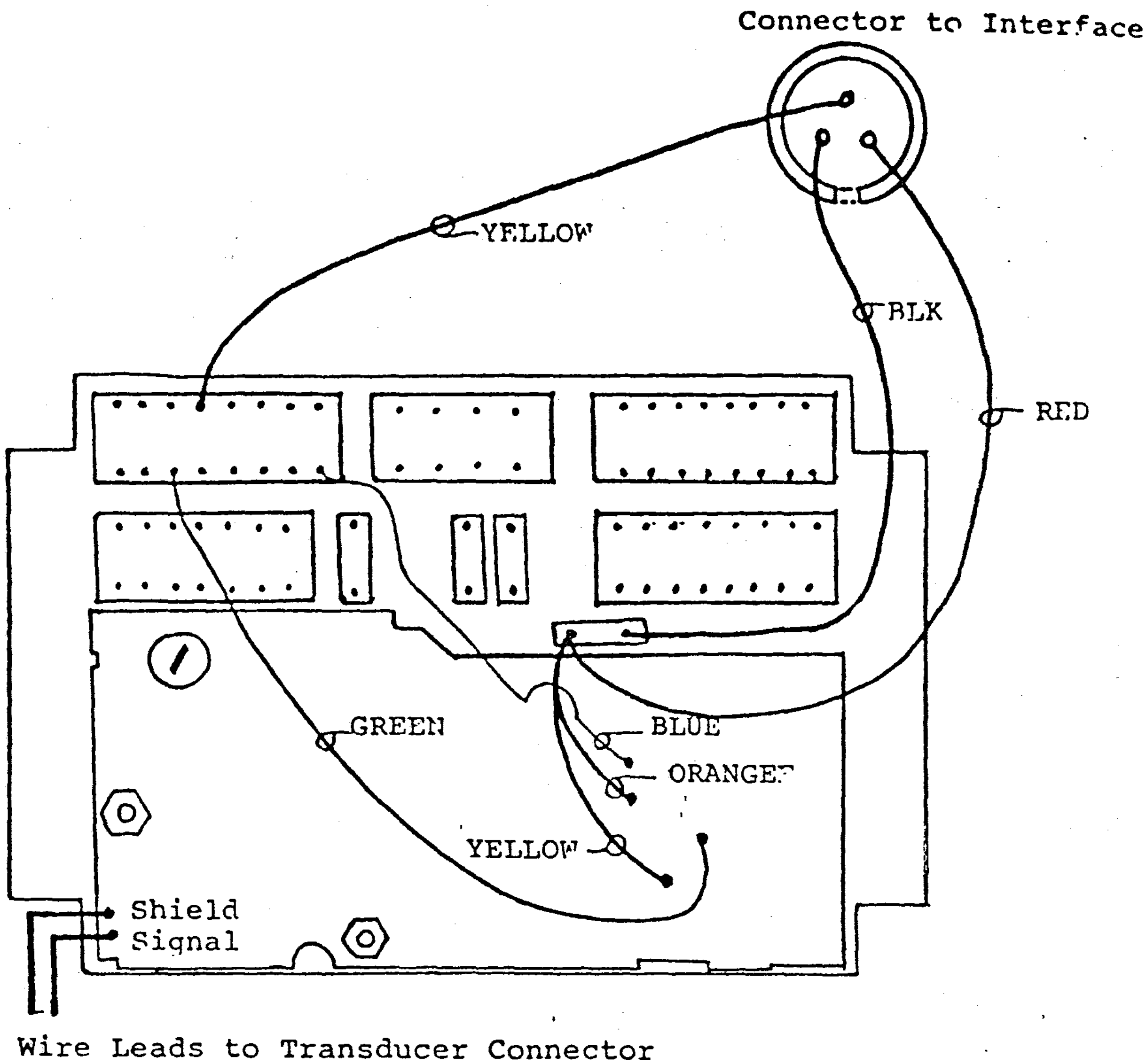


Figure M4. Wire Connections of Transducer Electronics

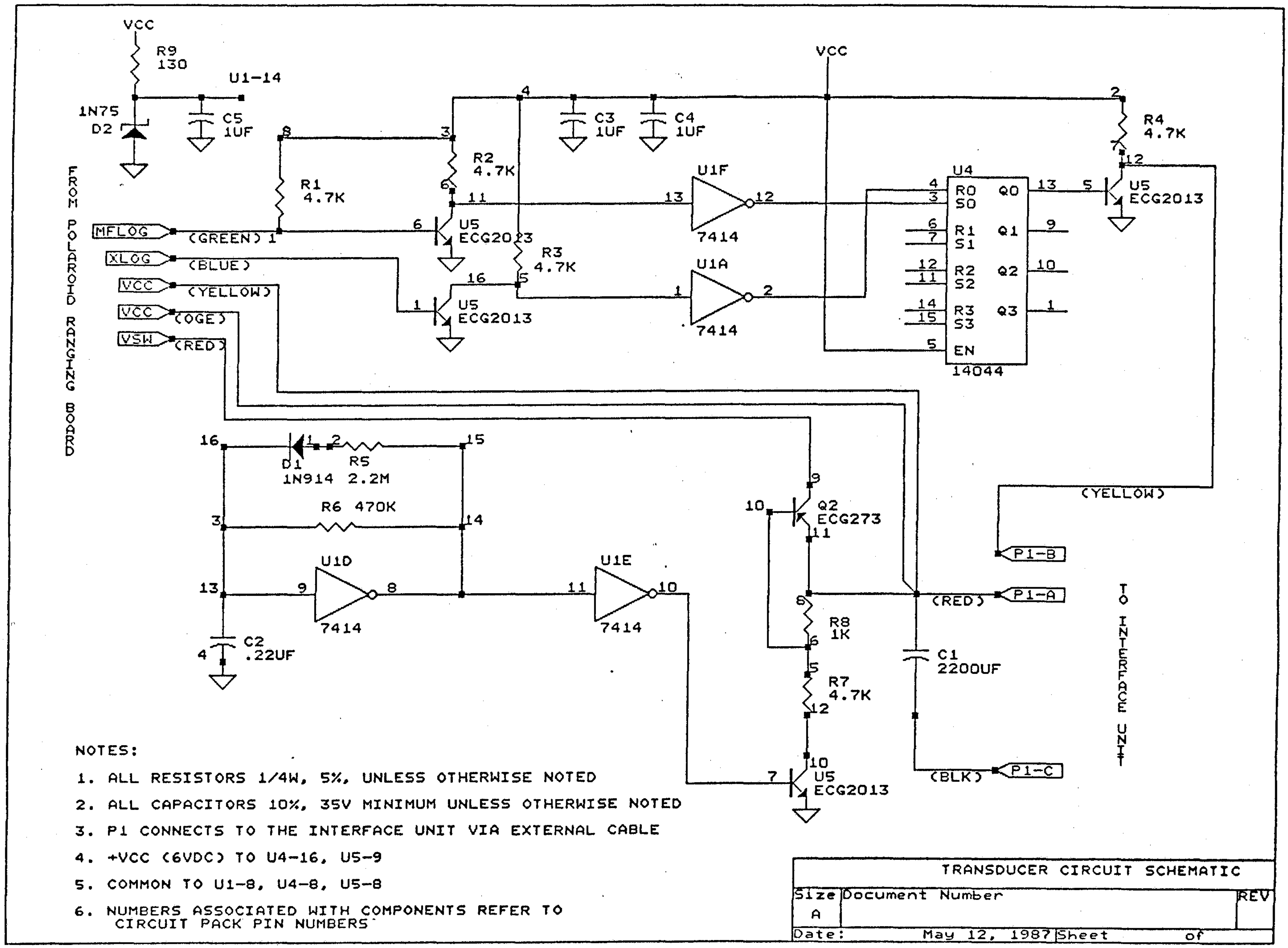


Figure M5. Transducer Circuit Schematic Diagram

Table M1. Transducer Circuit Parts List

Item	Quantity	Reference	Part
1	1	U4	14044
2	1	U1	7414
3	5	R1,R2,R3,R4,R7	4.7K
4	1	R6	470K
5	1	R5	2.2M
6	1	C1	2200uF
7	1	U5	ECG2013
8	1	D1	1N914
9	1	R8	1K
10	3	C3,C4,C5	1uF
11	1	Q2	ECG273
12	1	C2	0.22uF
13	1	R9	130
14	1	D2	1N75

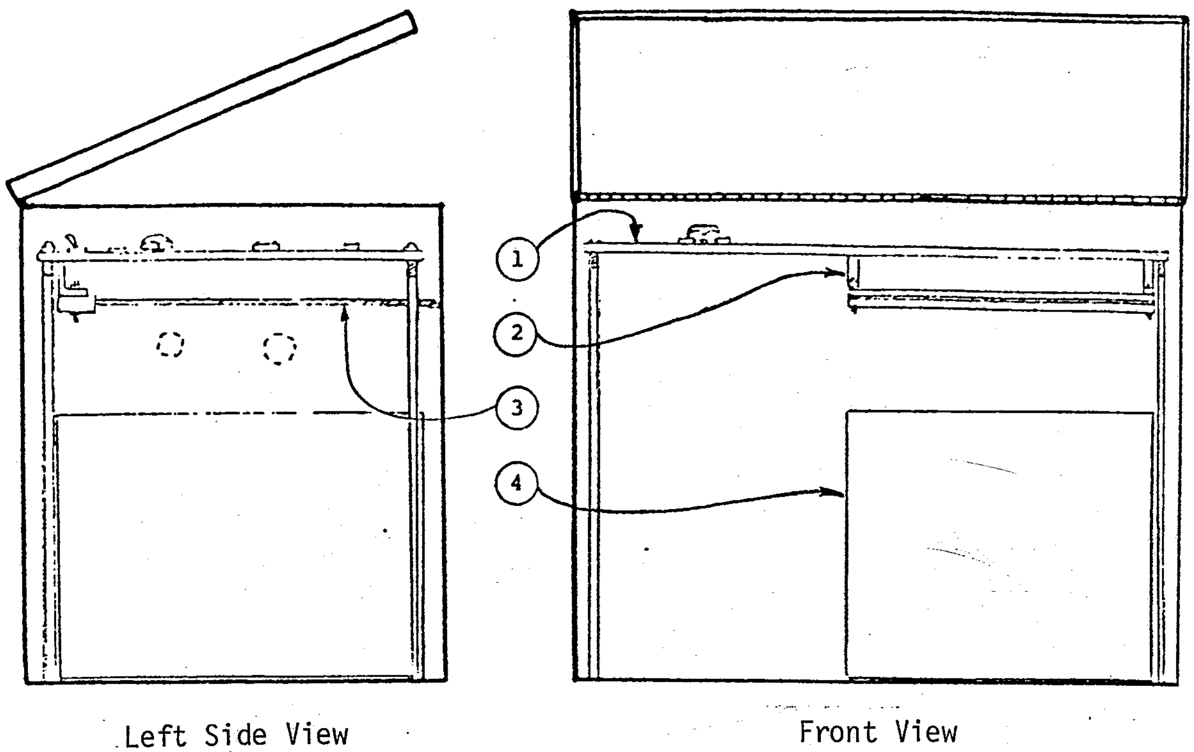
next transmitting cycle. The result is a pulse with a pulse duration or width that is proportional to the distance between the detected object and the transducer.

The signal VSW is the switched voltage that is fed to the transducer. It is derived on the transducer interface board and provided to the ranging board. The components that surround and include U1d make up the oscillator circuit that drives the switching transistor of U5 (pin 7). When the transistor U5 is turned on by positive voltage on pin 7 it provides a path to signal common allowing Q2 to switch on applying a positive voltage (VSW). This signal is interconnected to the ranging board supplying the power to the transducer that is switched on/off by the signal XLG. This is the same signal that is fed back to U4 to reset the flip-flop.

Additional circuitry is provided on this board to derive a 4.7VDC signal required by U1. This is accomplished by using zener diode D2 and resistor R9 to regulate the 6VDC provided by the battery or ac power supply.

Interface Unit. Figure M6 illustrates the assembly of the interface unit. This subsystem consists of the watertight box; connectors for ac power, output signal to counter, and the transducer interface; front panel; interface board; battery; and ac power supply. The parts list accompanying the figure details the components and boards required for the interface unit.

Figure M7 is the detailed drawing showing the required dimensions for producing the front panel. On this panel is an LED used to visually confirm operation of the transducer during setup. A switch is provided to disable the LED to conserve power after the unit has been placed in service. A power switch is also located on the front power to disable power to the detector when not needed. Figure M8, is a wiring diagram of the interface unit showing the electrical relationship of the components on the front panel and their wiring to the pc connector for the interface electronics. Potentiometer R10 is also located on the front panel to be used in setup of the detector as explained in the setup procedures.



Parts List		
Item#	Description	Qty
1	Display Panel of Interface Unit	1
2	Mounting Bracket for Interface Board	2
3	Interface Electronics Board	1
4	Battery	1

Figure M6. Interface Unit Assembly Drawing and Parts List

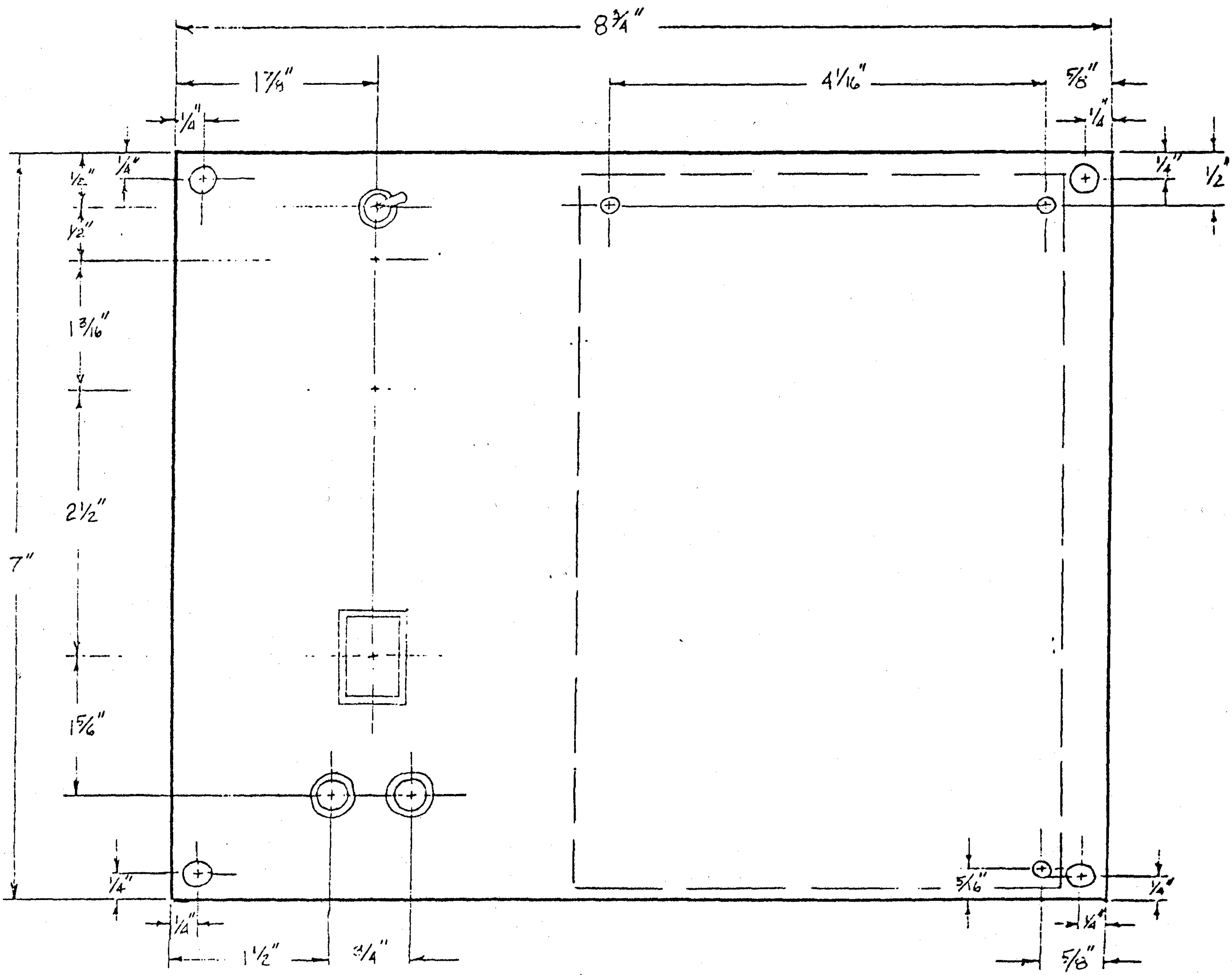


Figure M7. Display Panel of Interface Unit

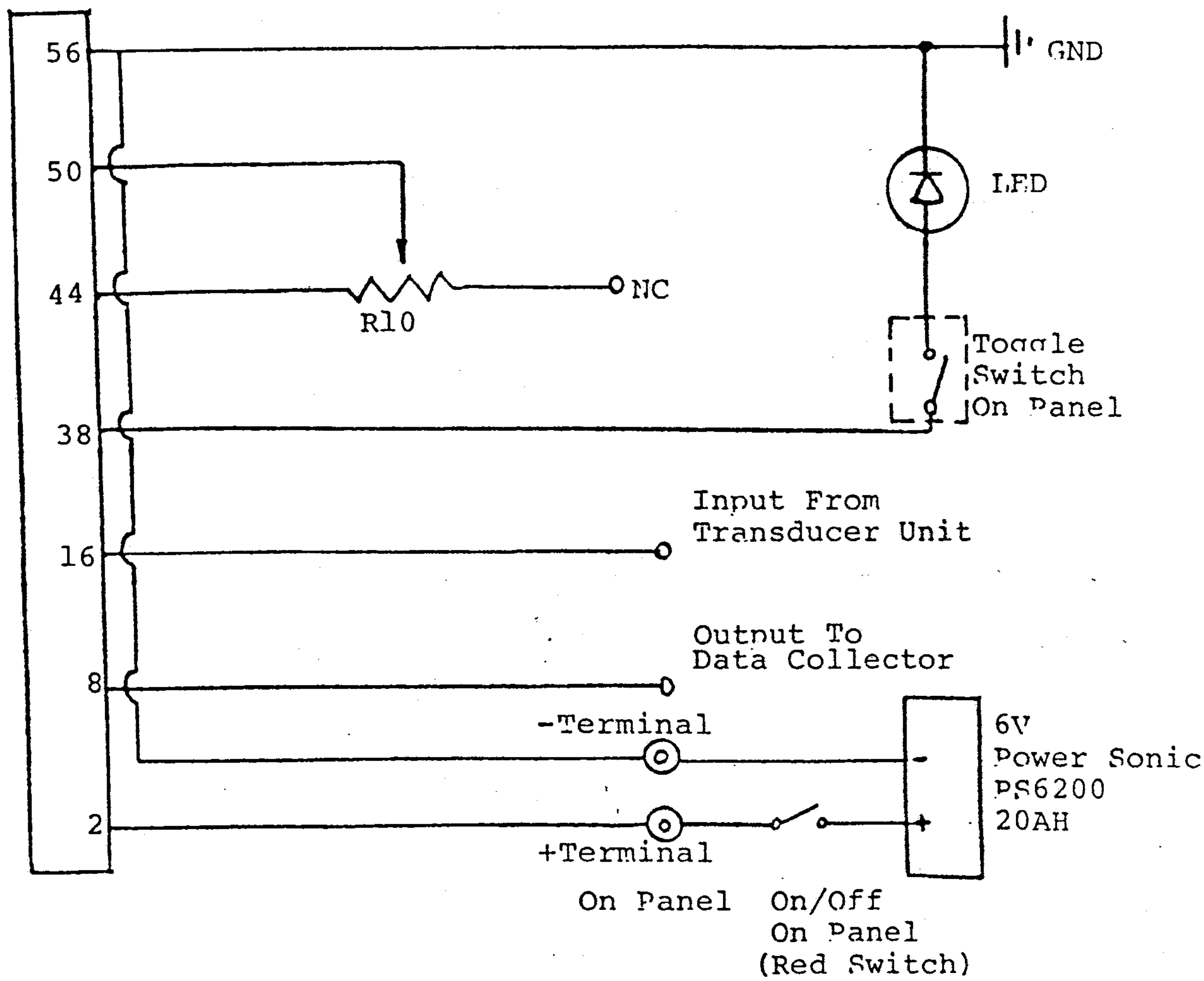


Figure M8. Wiring Diagram of Interface Unit

Figure M9 provides an assembly drawing of the Interface Board showing the placement of the components for its construction or maintenance. Further detail is provided as to the electronics function by the Interface Unit Schematic of Figure M10 with a detailed parts list in Table M2.

In the schematic it should be noted that signals are provided to/from the front panel indicators and controls. These are routed and interconnected through the printed circuit board connector that the interface electronics board is mounted. The board and connector are mounted to the rear or blind side of the front panel. A signal from the transducer interface is conditioned by U1a and U1B and used to charge a capacitor in an RC circuit consisting of the front panel potentiometer R10 and the capacitor C1. The capacitor forms the noninverting input of an opamp and is used to compare to a fixed voltage fed to inverting input of U2A. Since the transducer is fixed and has a constant echo duration in relation to the road surface when no vehicles are detected, potentiometer R10 is adjusted to provide a voltage on the comparator U2A to keep the D flipflop U3B set. Any object intercepting the ultrasonic signal will cause an echo to provide a pulse to capacitor C1 shorter than that of the road surface thus resulting in a lower voltage charge. Hence the comparator U2A will provide low voltage to the D flipflop causing the flipflop to reset. This in turn turns transistor Q1 on putting a low active signal out to the data collector.

Figure M11 is the AC power supply schematic used to provide power to the unit when it is available. The AC input line voltage is rectified and regulated to provide a stable 6.3VDC that is used in place of the battery. This same voltage is used to recharge the battery allowing the battery to serve as backup power in situations of power outages.

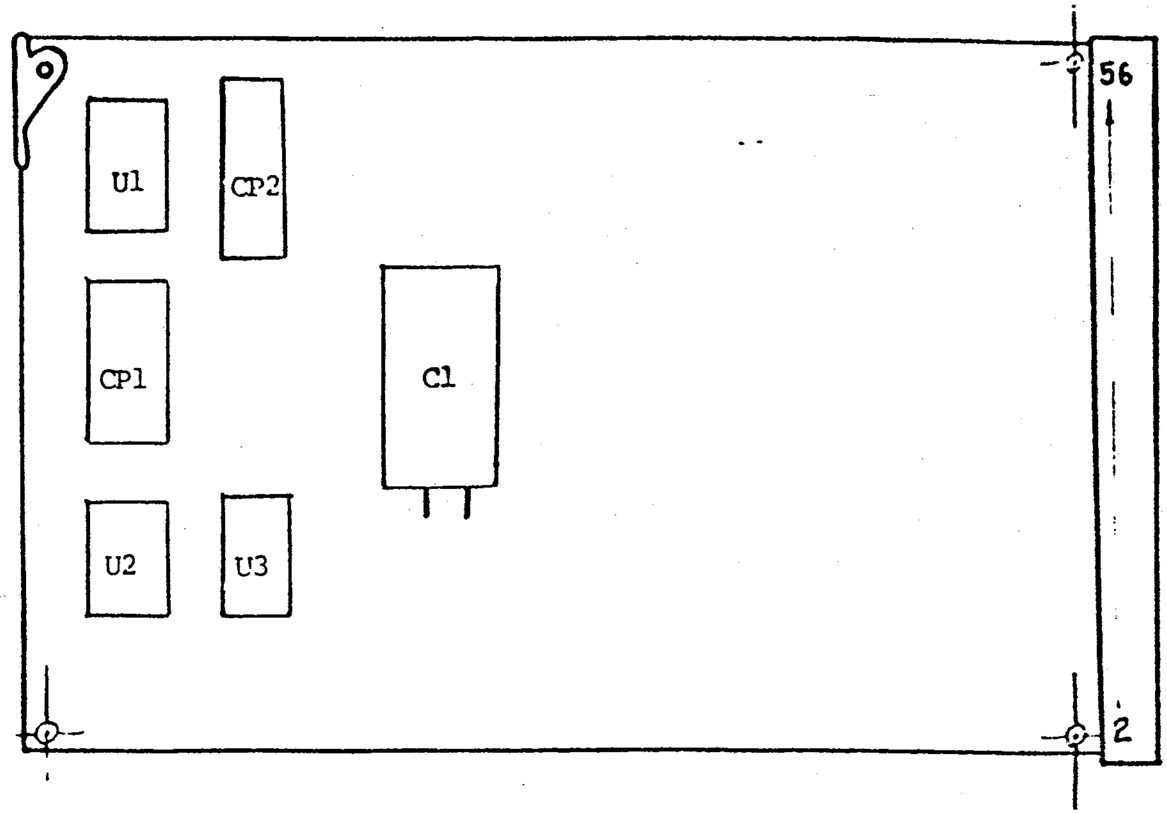
INSTALLATION

The overhead vehicle sensor is mounted to a bridge by means of a coupler which physically connects the transducer unit to one of the guardrail bolts. Two "T" joints and several feet of conduit, cut to dimensions appropriate for the specific bridge, make up the remainder of the mounting assembly. Therefore, the only requirement for installation is a crescent wrench.

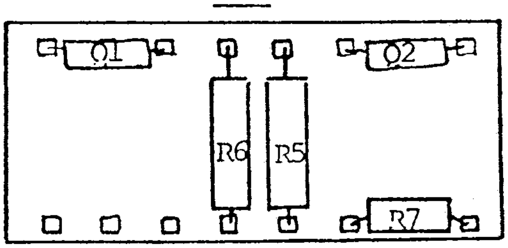
Once installed, the transducer unit is connected to the interface unit by a three-wire cable, the connection made at each end with an amphenol connector. This system is illustrated in Figure M12. The three wires within this cable are: power (6 volts), ground (0 volts), and signal (6 volt pulse translating the distance between the transducer and the target). The interface unit is connected to the Data Collector by a two-wire cable - ground (0 volt) and signal (6 volt pulse translating the detection of a vehicle).

OPERATING INFORMATION

After installing and interconnecting the different subsystems the overhead vehicle sensor system can be activated for operation by opening the interface unit to gain access to the control panel, pictured in Figure M13.



CP2



CP1

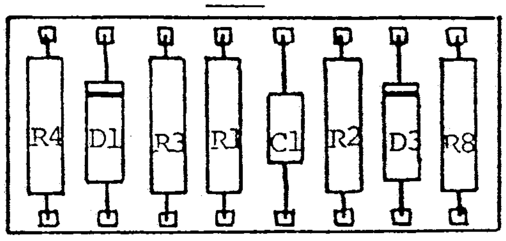
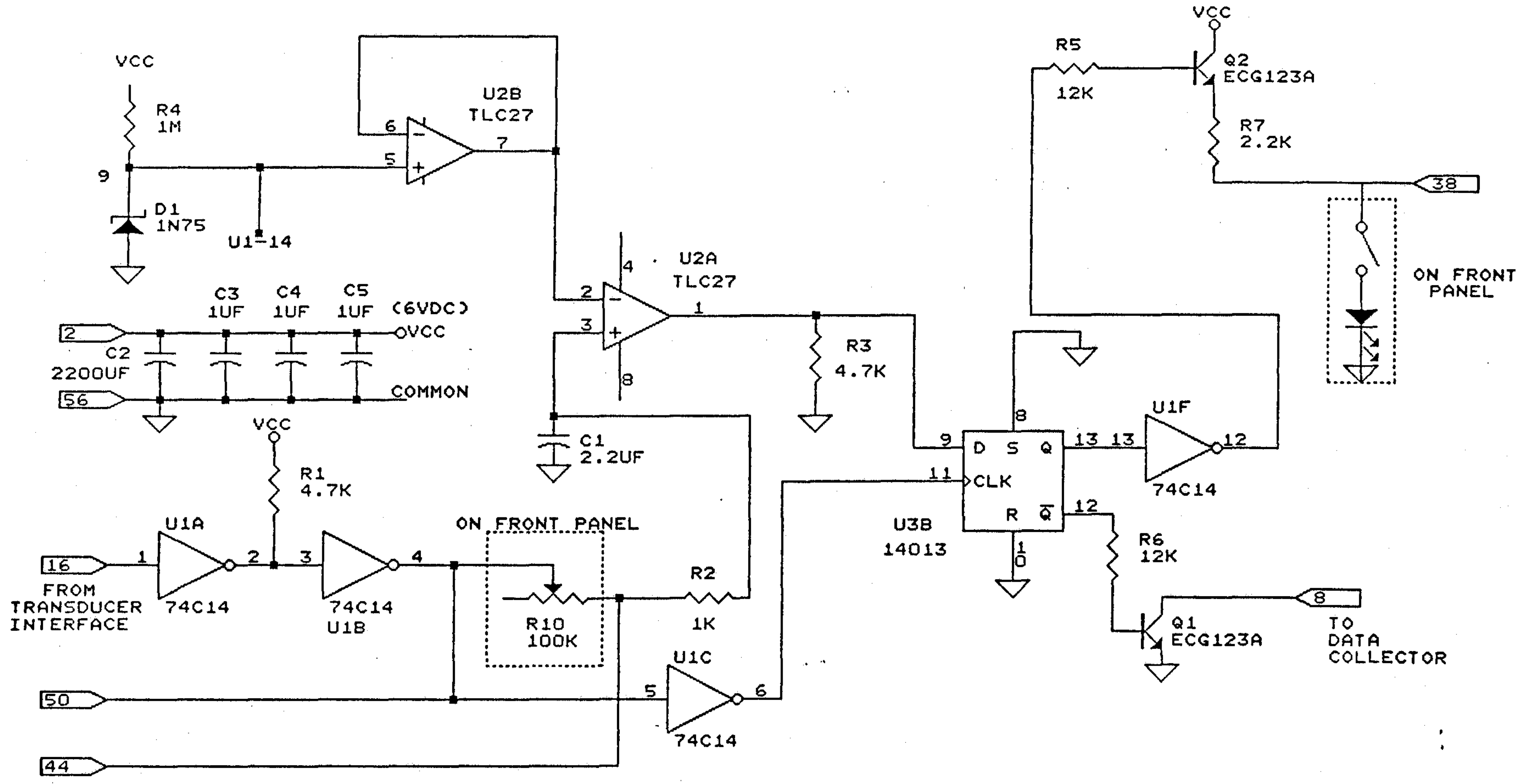


Figure M9. Interface Unit Schematic Assembly Drawing



NOTES:

1. ALL RESISTORS 1/4W, 5% UNLESS OTHERWISE NOTED
2. ALL CAPACITORS 10%, 35V MIN UNLESS OTHERWISE NOTED
3. VCC (6V) TO U2-8, U3-14
4. COMMON TO U1-7, U2-4, U3-7

INTERFACE UNIT SCHEMATIC		
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Figure M10. Detailed Interface Unit Schematic Drawing

Table M2. Interface Unit Parts List

Item	Quantity	Reference	Part
1	1	U3	14013
2	1	R4	1M
3	1	D1	1N75
4	1	C1	2.2uF
5	2	R3,R1	4.7K
6	2	R5,R6	12K
7	2	Q2,Q1	ECG123A
8	1	R7	2.2K
9	1	U1	74C14
10	1	R2	1K
11	1	R10	100K
12	1	U2	TLC27
13	1	C2	2200uF
14	3	C3,C4,C5	1uF

Power-up procedure

To turn on the power, push the red push-button on the panel. This should give power to both the transducer and interface units. The source of power is a 6 volt-20 AH battery. Table M3 provides some observations for normal operating conditions which were made after a three-month testing period.

Table M3. Observations Under Normal Operating Conditions

(1) The overhead vehicle sensor system pulls an average current of 100 mA.

(2) The average voltage drop is 76 mV/day.

(3) The minimum acceptable battery level is 5.1 Vm.

(4) The maximum charge on battery is 6.3 V.

The battery level can be checked from the panel and should not fall below 5.1 V. In the case that it does drop below 5.1 V, the battery would need to be recharged to insure proper operation of the system.

Calibration procedure

After the Power-up procedure, the overhead vehicle sensor system needs to be calibrated for the bridge height. This latter purpose is served by the LED and the potentiometer (black knob) on the panel of the interface unit. Because of power considerations, an SPDT switch allows the use of the LED only during calibration and when it is required. The LED is normally deactivated during a regular session of data gathering. If the LED is continuously ON, the sensor is then "over-detecting"; if it is continuously OFF, the sensor is "under-detecting."

In the case of "over-detection", turn the potentiometer until the LED goes OFF. In the other situation ("under-detection"), turn the potentiometer until the LED goes ON then turn it in the opposite direction to turn the LED OFF. The calibration point is right on the border between "over- and under-detection". The LED is now OFF. If a vehicle enters the detection field of the sensor, the LED will go ON then OFF to show a detection. At the same time, a pulse is sent by the interface unit to the Data Collector to register the presence of a vehicle.

After the above procedures have been accomplished, the overhead vehicle sensor system is calibrated and ready to sense the presence of vehicles for conducting a traffic count.

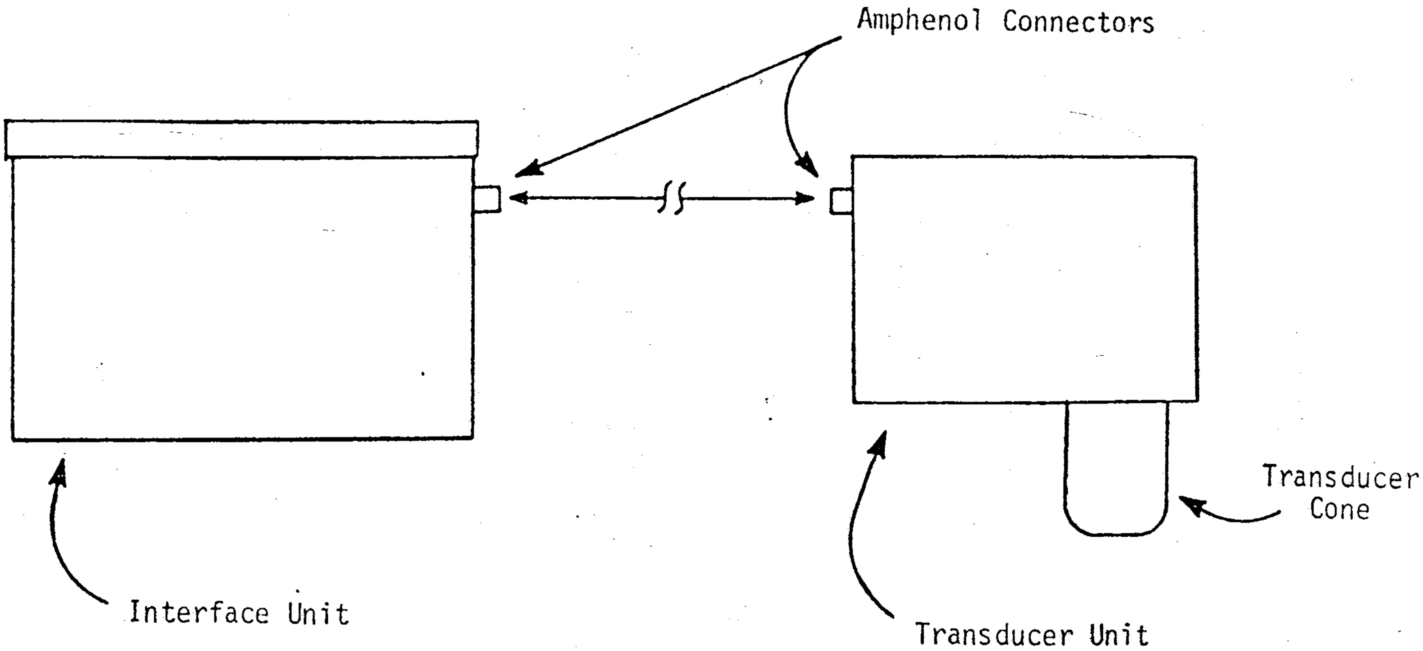

Figure M11. Connection of Transducer Unit and Interface Unit Subsystem

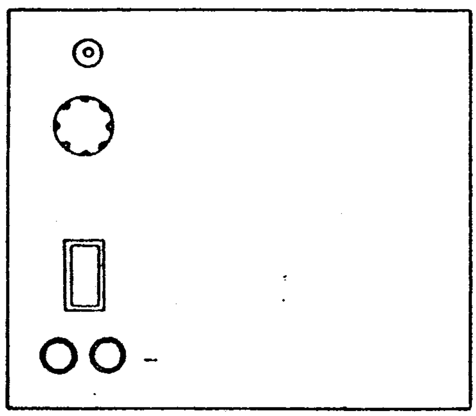

Figure M12. Control Panel on the Interface Unit