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The Road Trackers

Mike Nguyen
Trinity University

Robert Barner
Trinity University

Mike Yockey
Trinity University

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The Road Trackers

First Semester Design Report

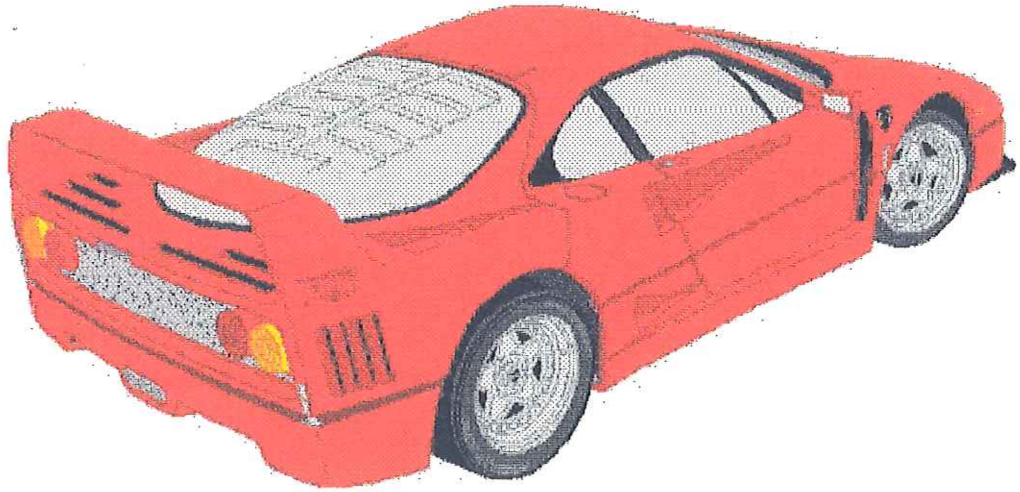
17 December 1993

Group Members:

Mike Nguyen
Robert Barner
Mike Yockey

Faculty Advisor:

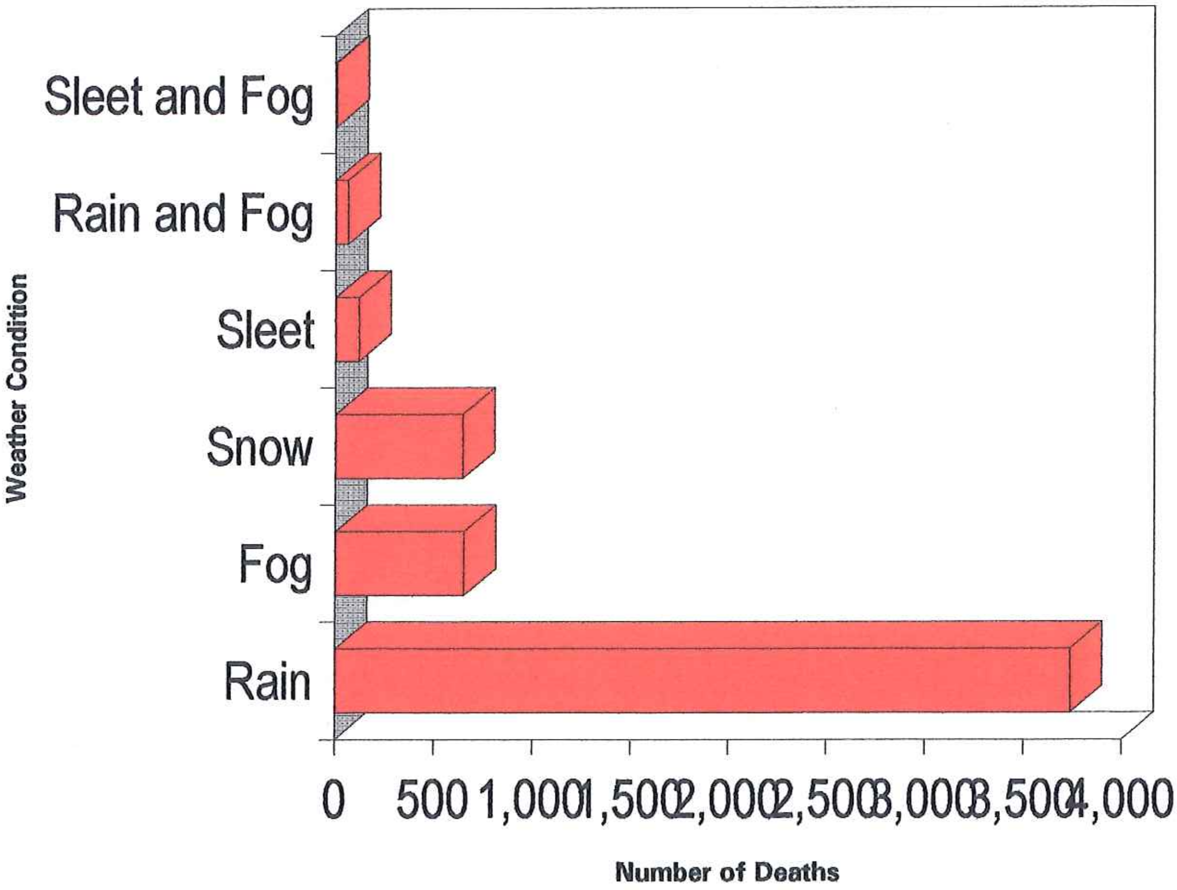
Dr. Peter Vafeades



Warrant

- **"Collision with another motor vehicle in transport was the most harmful event for over one-half of all passenger cars involved in fatal crashes in 1991."**
  - **Fatal Accident Reporting System,**
  - **National Highway Transportation Safety Administration (NHTSA)**

Loss of Life in Poor Weather Conditions, 1991



Abstract

An automotive sensor system is being designed to increase driver awareness in adverse weather conditions. The system can be divided into two sections: detection in the blind spots, and front-rear long range detection. The former will provide the driver with a visual indication whether or not someone is in the blind spot. The latter will tell the driver the distance to an obstacle in front (or behind) up to a distance of 1600 feet. Critical minimum and maximum distances were calculated, and appropriate sensors were selected. Ultrasonic sensors were selected for the blind spot region because of their low cost, acceptable attenuation, and small size. The preliminary selection for long-range detection is millimeter wave sensors because of their low attenuation (even in adverse weather conditions) and small angular resolution. Their cost, while high, should still be within budget.

Introduction

The idea of an automotive radar is nothing new. Poor visibility due to blind spots or poor weather conditions is a hazard which has caused far too many accidents and fatalities. Yet, technology had not progressed to a point at which it may be practically integrated into the automobile until recently. Systems which could overcome the difficulties encountered in these types of hazardous situations have been far too bulky or have required far too much power for practical application in automobiles. Recently, however, advances have been made, largely due to military research, in the realm of sensing technology. Equipment has been developed which is much smaller and effective in detection. Most notably, refinement of microwave technology has resulted in millimeter-wave, which has a much smaller size, fairly narrow angular-resolution, and low-power requirements. All this can be achieved with only slight degradation in signal attenuation. We hope to take advantage of this newly available technology to produce an automotive safety system which has yet to be implemented effectively.

We propose to develop a marketable sensor system to address the visibility problem and thus improve highway safety. The following paper will describe our design approach, calculations, and solutions thus far. We invision our solution being implemented on the dashboard as pictured in Figure 1.

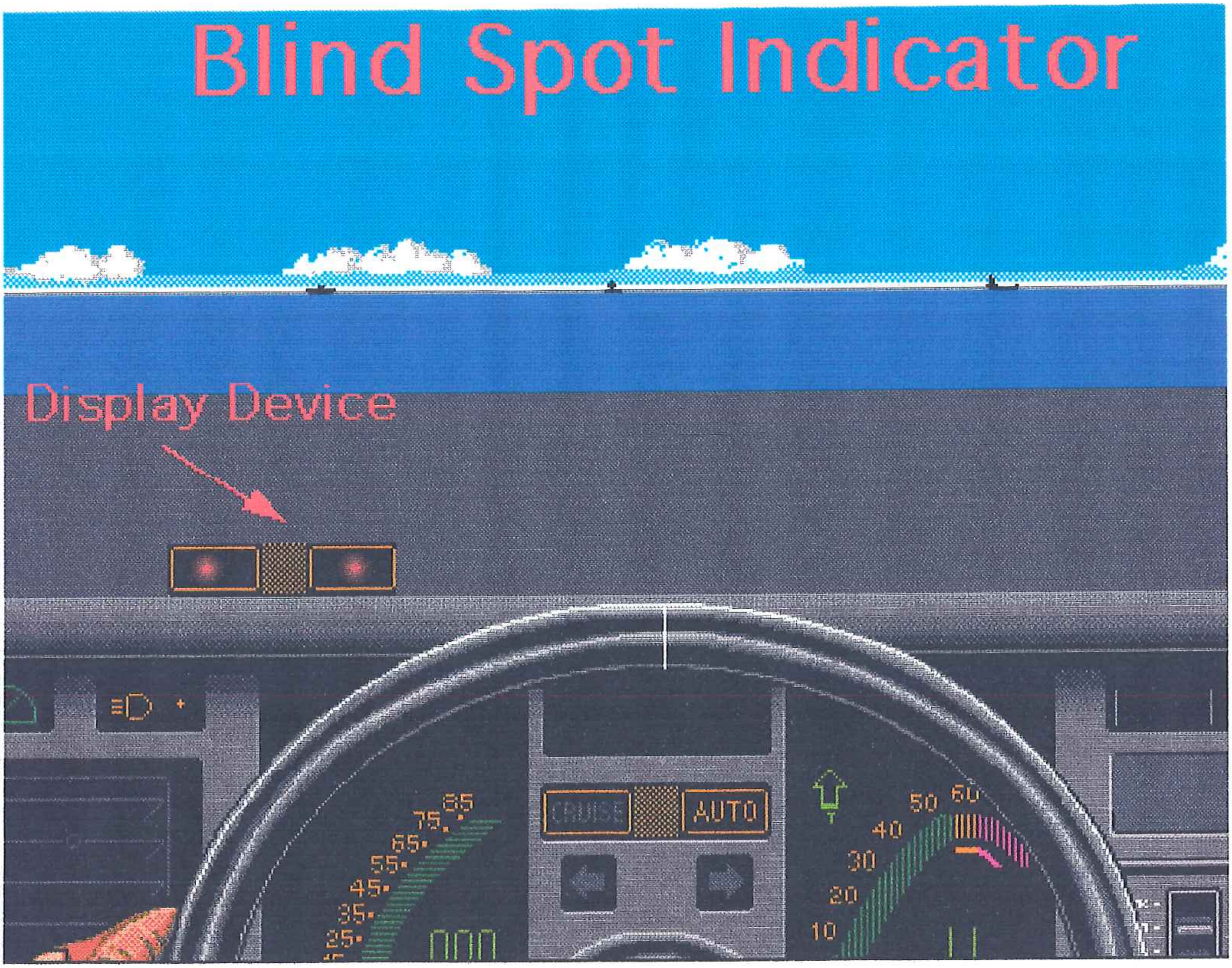

Blind Spot Indicator
Display Device
CRUISE
AUTO
85
75
65
55
45
35
25
60
50
40
30
20
10

Figure 1

Development

Our initial goal in designing our project was to develop a system that could alert a driver to both long and short range driving hazards. This system should be comparable in cost to similar safety features such as anti-lock brakes or air bags and should be mounted in an aesthetic, if not completely inconspicuous, manner. Long range detection would be mainly used to increase awareness of other vehicles or obstacles which might not be visible to a driver in inclement weather conditions. Short range detection would be primarily concerned with alerting the driver to vehicles in the automobile's blind spots. This is illustrated in Figure 2.

One of the primary focuses of the group was in identifying exactly what ranges of detection would be necessary to address long range detection. Some initial calculations gave us a good idea with which to begin. There are two distances which are of particular interest: the minimum distance a system must be able to detect to begin to improve a driver's safety and the maximum range that this system should be able to detect in order to allow safe avoidance times. A calculation based on average reaction time was used to determine the minimum long range detection distance. Given that it takes an average person 0.8 seconds to perceive a hazard, identify it as a hazard, and begin to react, this reaction time may be used in conjunction to relative velocities to determine the distance a car would travel during this reaction time (see Figure 3).

As seen in the sample calculation (Figure 4), if one car is traveling at 50 mph while a second car is traveling at 120 mph the relative velocity between them is 70 mph. If the driver of the faster car perceived the slower vehicle as a hazard, he or she would take 0.8 seconds to react, in

Figure 2

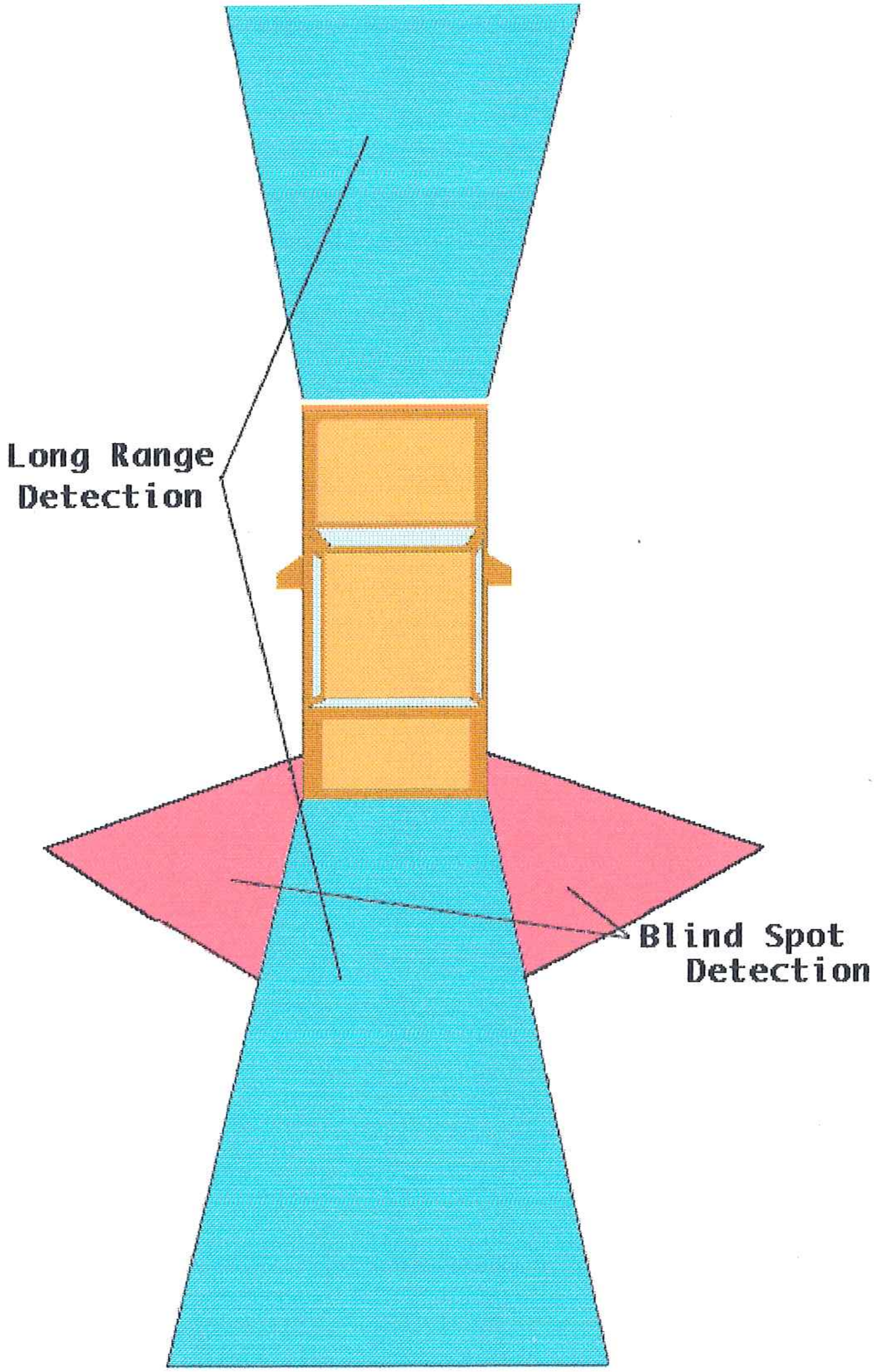


Figure 3

Minimum Detection Distance Estimation

Difference in Speed	Minimum Range
10 mph	11.7 feet
20 mph	23.5 feet
30 mph	35.2 feet
40 mph	46.9 feet
50 mph	58.7 feet
60 mph	70.4 feet
70 mph	82.1 feet
80 mph	93.9 feet

Total reaction time=0.8 sec

0.2 sec = for driver to perceive hazard
0.2 sec = for driver to decide how to react
0.4 sec = implementation of decision
(delay due to motor skills)

Difference in speed is the speed differential of two cars travelling in the same direction.

Figure 4

Minimum Distance Calculation Method

$$x = v_o t + 1/2\ a\ t^2$$

assuming zero acceleration,

$$x = v_o t$$

example : car 1 at 50 mph,
car 2 at 120 mph;

--difference in speed of 70 mph

distance =

$$(70\ \text{mph}) \frac{(5280\ \text{ft})}{(1\ \text{mile})} (0.8\ \text{sec}) \frac{(\ \ 1\ \text{hr}\ \ )}{(3600\ \text{sec})}$$

$$\boxed{= 82.1\ \text{feet}}$$

which time the distance between the cars would reduce by 82.1 feet. Therefore, if the driver in the faster car was made aware of the second car when he or she was only 82 feet from it, the cars would collide just as he or she was able to begin to act to prevent it. If a system were to give the driver any advantage at all, it would have to be able to detect further than this critical distance and convey its information to the driver. This gave us a bare minimum distance that our system must be able to detect for.

In order to determine the maximum distance that our system should be able to detect, we used the recommended highway safety standards as a guideline. The ones we found most helpful were geometric design standards used in highway construction (see Figure 5). These standards state that the minimum passing sight distance required on a flat or rolling highway road is 3200 feet. What this means is that a driver should have 3200 feet of visibility in order to make a determination as to whether or not it is safe to pass a car in front of it. Given that the act of passing a car roughly involves a change of lanes followed by an additional change back into the original lane, we determined that one half of the passing sight distance would be adequate for our case (see Figure 6). Since the situation we will be designing for involves the avoidance of a hazard in ones path, perhaps by moving into an adjacent lane, this assumption should be adequate.

For blind spot detection, an additional maximum distance must be determined. Based upon general measurements and calculations which will be discussed in more depth under the section devoted to ultrasound, it was determined that a maximum detection range of 12 feet would be adequate.

Geometric Design Standards for a Heavily Traveled Two-Lane Highway

GEOMETRIC DESIGN STANDARDS
Class II
Traffic: 2000 V.P.D. and over (2 lanes)

	Desirable				Minimum			
	F	R	H	M	F	R	H	M
Design Speed (mph)	70	70	60	60	70	60	50	40
Max. Curvature (degree)*	3	3	5	5	3	5	7	12
Max. Gradient (percent)	3	3	5	6	3	4	5	6
Min. Stopping Sight Distance	600'	600'	475'	475'	600'	475'	350'	275'
Min. Passing Sight Distance	3200'	3200'	2300'	2300'	2900'	2100'	1800'	1500'
Clear Recovery Area	30'				10'			
Width of Lanes	12'	12'	12'	12'	12'	12'	12'	12'
Width of Usable Shoulder	10'	10'	10'	10'	8'	8'	8'	8'
Width of Graded Shoulder**	12'	12'	12'	12'	10'	10'	10'	10'
Width of Ditch Invert (min.)	2'	2'	2'	2'	2'	2'	2'	2'
Right-of-Way Width (min.)***	130'	130'	130'	130'	100'	100'	100'	100'

Source: Georgia State Highway Department.

*Min. Length Curve = 1000 ft. for desirable.

**Increase width of shoulder 2' where guard rail is required.

***60' acceptable in municipalities on existing right-of-way—or 64' minimum on acquired right-of-way.

Note: The letters F, R, H, and M refer to the classification of terrain:
F—Flat R—Rolling H—Hilly M—Mountainous

Figure 5

Minimum Passing Sight Distance

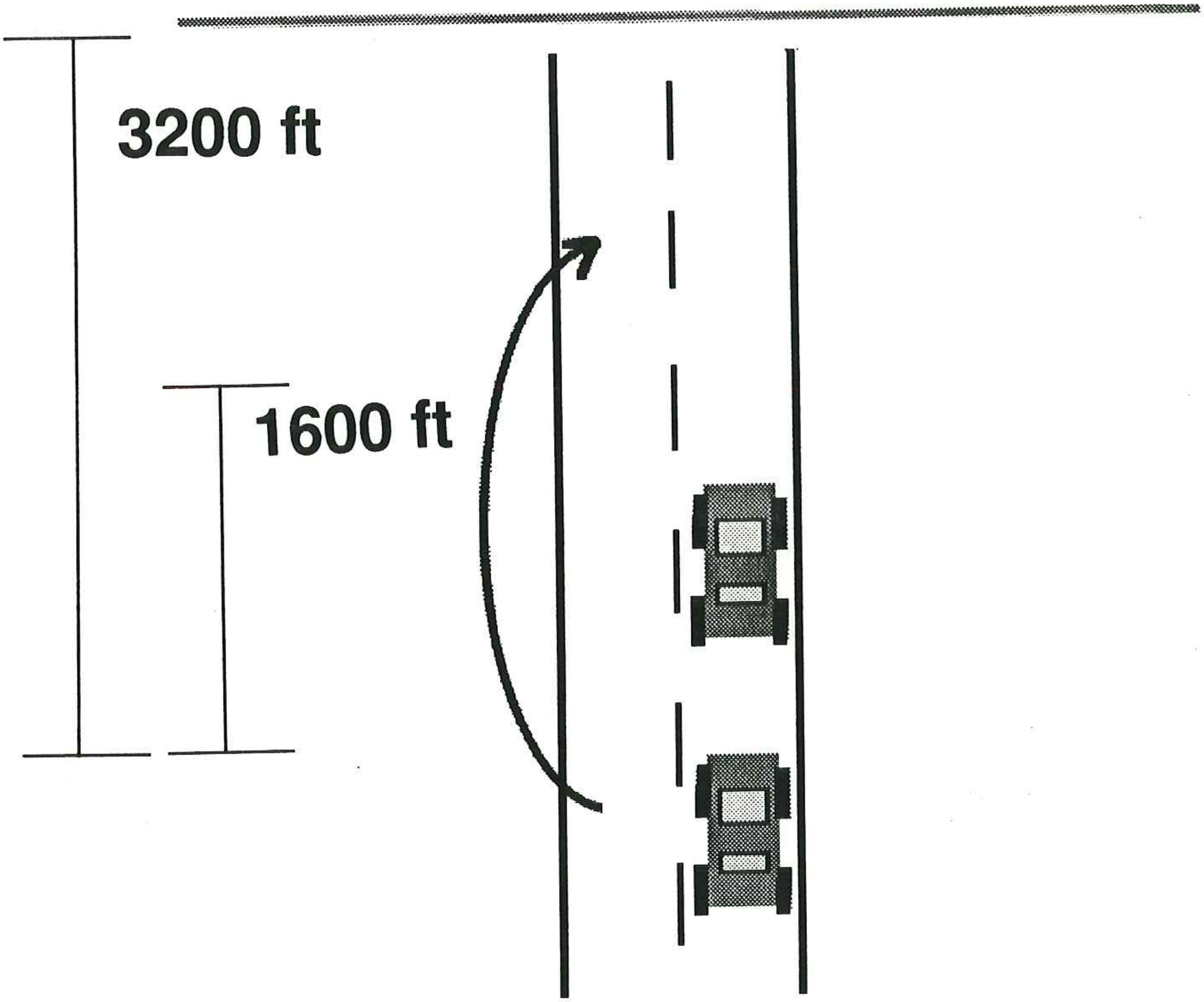


Figure 6

Another factor which was identified to be of importance was that of angular resolution. It is important that a system be able to distinguish between objects of concern to the vehicle and those which should be ignored. In other words, the system should be able to distinguish between hazards on the correct side of the highway versus the opposite and in addition, those off the highway. It would not be appropriate for the system to represent a cow in an adjoining field as a hazard in the vehicle's path. Therefore, the angular resolution, or spread of a sensor's beam pattern, is crucial. In our initial calculations, we designed for application on a 3-lane highway of 36 feet width (given standard lane width of 12 feet). Thus, a system should have less than 36 feet beam spread at a distance of 1600 feet from the vehicle to be beneficial. Angular resolutions of various sensors at 500 m is shown in Figure 7.

An additional important factor was attenuation. Since we wish our project to operate under inclement weather conditions, it is essential that a signal's degradation in these conditions be considered. A sensing method must be able to detect up to the required 1600 feet range for long range and 12 feet for short range, despite these weather conditions. We wish this system to operate under conditions of rain, fog, and snow.

One last factor to be considered is the minimum cross-sectional area which our sensor must be able to detect. The smallest target our system should be able to detect is a human being. This area at 1600 feet is approximately 1 square foot. Radar cross sections of various objects appear in Figure 8.

Given these initial design specifications, we could proceed with our research of sensing methods to determine which types would be applicable for our project.

Angular Resolution at a Range of 500m

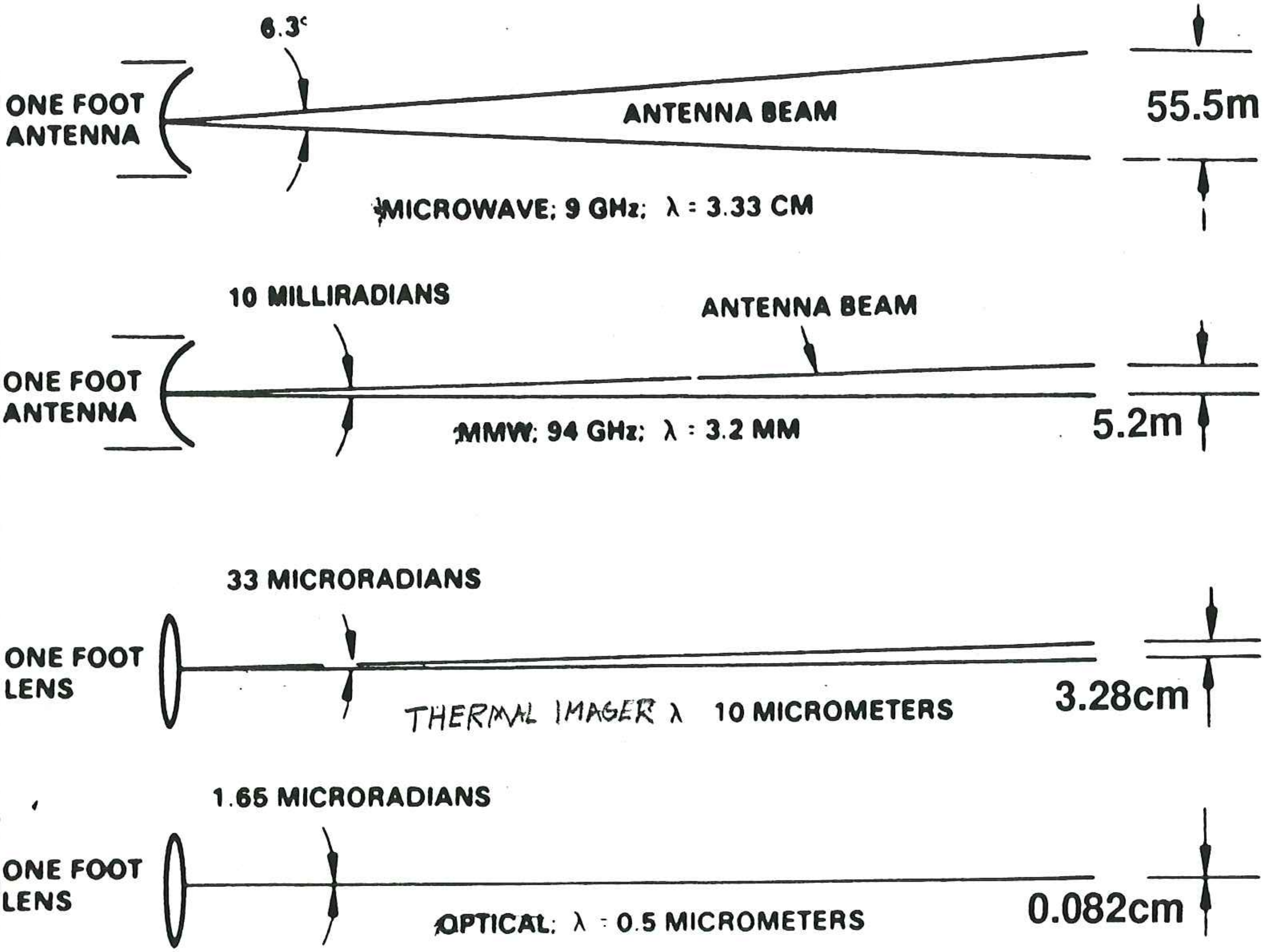


Figure 7

Figure 8

Reliability Requirements

The following is a list of approximate values of the Radar Cross Section which can be expected from various tyical automotive radar targets at a range of about 200-300 m.

Target	RCS
Person	1 m^2
Car	10 m^2
Van	30 m^2
Debris on Road	0.1-10 m^2

✱ The smallest target which the systems must detect reliably is that of a human. The aim of our system will be to obtain a detection probability of 99.99 % with a false alarm due to noise less than once every 1000 hours of operation.

Sensor Options

A spectrum of frequency ranges for various sensors appears in Figure 9. Specifically, the radar frequency bands (a subset of the microwave band) appear in Figure 10. Sensors have advantages and disadvantages, which make some sensor options more attractive than others.

Laser Sensors

Laser sensors would perform well at detecting in this situation except for several drawbacks. Lasers have an excellent detection range (up to 5 km). Modern laser diodes, like those used in police laser radar guns, are small in size. Since the laser beam is a coherent beam, it naturally has a small angular resolution.

One disadvantage of lasers is their cost. Compared to ultrasonics, a laser transducer (not including controlling electronics) would cost about twice that of an ultrasonic system. A laser sensor costs approximately $100, while an ultrasonic transducer and transceiver module costs about $50. The attenuation also is high for the expected application. Police laser radar guns are used for distances similar to our requirements, but they are only effective in good weather conditions.

Infrared Sensors

Infrared imaging systems were also considered, but also were ruled out. These systems actually produce a visual image of the surroundings, and were considered for brainstorming purposes. We found that these

Figure 9

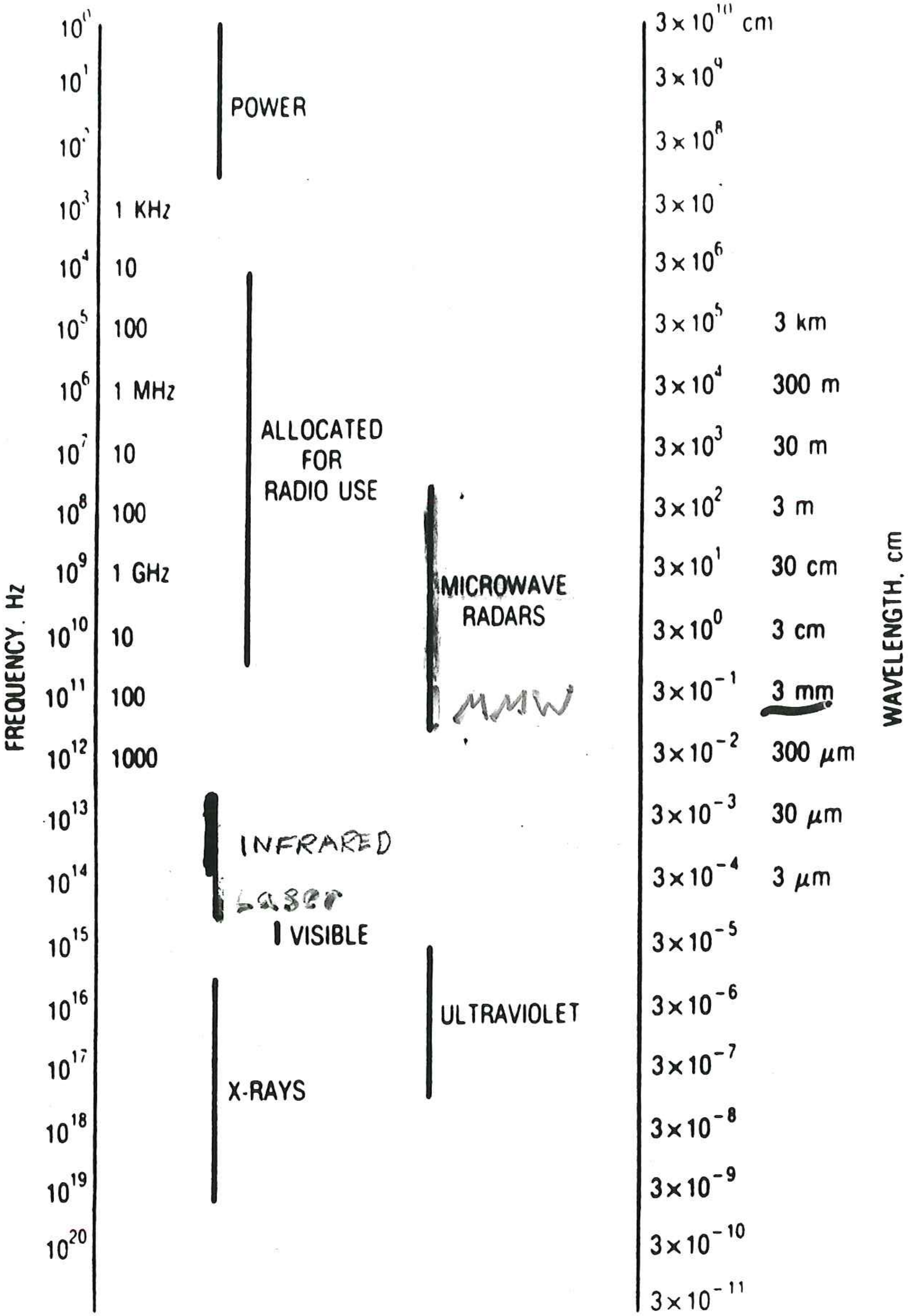

FREQUENCY, Hz
10^0
10^1
10^2
10^3 1 KHz
10^4 10
10^5 100
10^6 1 MHz
10^7 10
10^8 100
10^9 1 GHz
10^10 10
10^11 100
10^12 1000
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
POWER
ALLOCATED FOR RADIO USE
MICROWAVE RADARS
MMW
INFRARED
Laser
VISIBLE
X-RAYS
ULTRAVIOLET
3 × 10^10 cm
3 × 10^9
3 × 10^8
3 × 10^7
3 × 10^6
3 × 10^5 3 km
3 × 10^4 300 m
3 × 10^3 30 m
3 × 10^2 3 m
3 × 10^1 30 cm
3 × 10^0 3 cm
3 × 10^-1 3 mm
3 × 10^-2 300 μm
3 × 10^-3 30 μm
3 × 10^-4 3 μm
3 × 10^-5
3 × 10^-6
3 × 10^-7
3 × 10^-8
3 × 10^-9
3 × 10^-10
3 × 10^-11
WAVELENGTH, cm

Figure 10

Radar Frequency Bands

Band	Frequency Range	Wavelength (cm)
VHF	30-300 MHz	1000-100
UHF	300-1000MHz	100-30
L	1000-2000MHz	30-15
S	2000-4000 MHz	15-7.5
C	4000-8000 MHz	7.5-3.75
X	8000-12,500 MHz	3.75-2.40
Ku	12.5-18 GHz	2.40-1.67
K	18-26.5 GHz	1.67-1.13
Ka	26.5-40 GHz	1.13-0.75
MMW	$f < 30$ GHz	$\lambda < 1.0$

infrared imaging systems can see up to 15 km, are small in size (goggles), and possess a small angular resolution.

Large attenuation is a problem for these goggles, which limit their usefulness in bad weather situations. These sensors are also very expensive (about $1000 for a pair of goggles). Hot sources also interfere with the detection of surrounding objects. The primary reason for ruling out this detection scheme is that it does not provide an output we can use with our user interface. The only usable output would be a massive image recognition system to identify a car, determine its direction of travel, and alert the driver to it. This is not the best solution.

Microwave Sensors

We also researched microwave sensors. It was discovered that microwave sensors possessed an unlimited range of detection with very little attenuation. However, the equipment size of microwave sensors are too large for our application. Another disadvantage with microwave sensors is that they have a large angular resolution at long distances, which make it difficult to distinguish if an object is directly in front of the sensor or if it is off to the side. Also, interference from other microwave sources, such as police radar guns, automatic doors of convenience stores, or security alarms, can effect the sensor's ability to perform reliably. Therefore, microwave sensors were ruled out.

Millimeter Wave Sensors

Millimeter wave sensors were also considered. Millimeter waves are a subset of microwaves. Their frequency ranges from 3 GHz to 300 GHz. They are capable of detecting up to 10 km with little attenuation and with a small angular resolution. The equipment size of millimeter wave sensors are small, which makes it possible to mount them on an automobile. However, they are more expensive than microwaves.

Ultrasonic Sensors

Ultrasonic sensors were also considered. They operate by transmitting an inaudible sound wave and then detects the echo of the sound wave after it bounces off an object. The time it takes to return to the sensor it then used to calculate the distance of the object. From our research, it was discovered that ultrasonic sensors are inexpensive, small in size, and require a low power consumption. All of these features are ideal for our purpose.

A disadvantage with ultrasonic sensors is that they have a large attenuation over a large detection range and in adverse weather conditions. It also possesses a large angular resolution. It maximum detection range is only 50 feet.

Evaluation of Research Information/Sensors

Looking at the attenuation of these sensing methods under inclement weather conditions, it is apparent that some will not be suitable for our project. It is illustrated in the following graph of attenuation versus frequency in fog and rain that any frequency greater than 100 Hz would be unsuitable. This would indicate that infrared and laser must be eliminated due to their high attenuation. However, microwaves and the lower frequencies of millimeter waves would meet the attenuation requirements for our project.

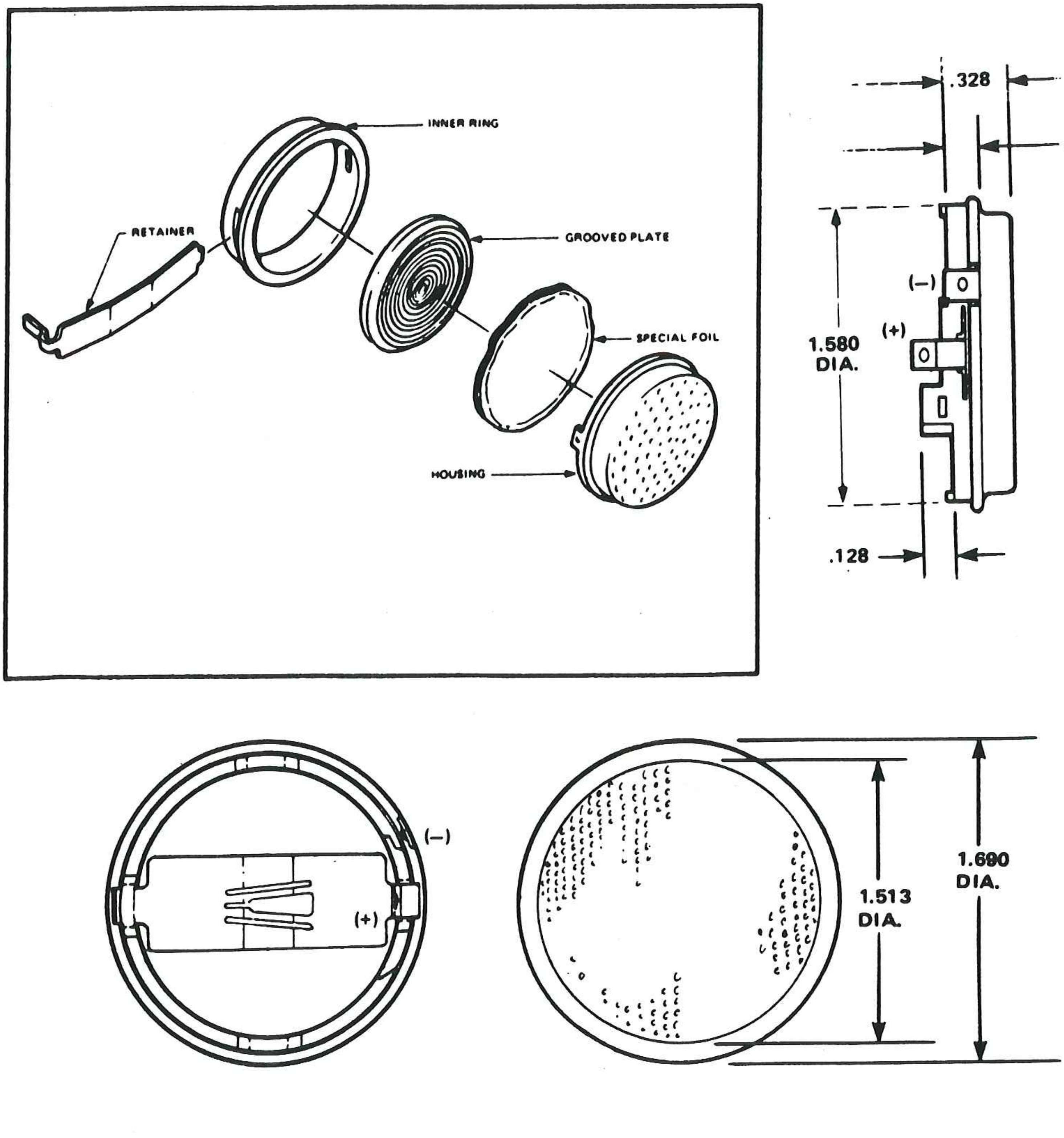
As for meeting the angular resolution requirements, lasers and infrared sensors as thermal imagers would best fit our project criteria. However, because of their high attenuation they would only be suitable for short range detection. Microwave, while having the least attenuation, has the widest angular resolution, spreading 55.5 meters over a distance of 500 meters. This would be unsuitable for our system, which we wish to have a beam spread less than 10 meters at this distance.

While methods such as lasers or ultrasound would be unsuited for long range detection, due to their high attenuation, they might be used for the short range detection of the blind spot. Ultrasonic sensors are especially attractive mainly because of their low cost and their wide sensing area. Therefore, we decided that ultrasonic sensors would be ideal for detecting the blind spot area.

Ultrasonic Data

After determining that ultrasonic sensors would be a good candidate for short range detection, an ultrasonic sensor from Polaroid was obtained. The ultrasonic sensor is comprised of two components, the transducer and the transceiver module. The transducer acts both as a loudspeaker and a microphone built in one. It is capable of transmitting an ultrasound wave and its also capable of detecting ultrasound waves. The ultrasonic transducer seen in Figure 11 is made to operate in air and is packaged for all types of weather conditions. The transceiver module controls the operating modes of the transducer (transmission and reception). A schematic diagram of the transceiver module appears in Figure 12, and a board layout diagram appears in Figure 13.

Figure 11


INNER RING
RETAINER
GROOVED PLATE
SPECIAL FOIL
HOUSING
.328
.159
(–)
(+)
1.580 DIA.
.128
(–)
(+)
1.513 DIA.
1.690 DIA.

Pin 1 = Ground
Pin 4 = INIT
Pin 7 = ECHO
Pin 9 = Power Supply (5 Volts)

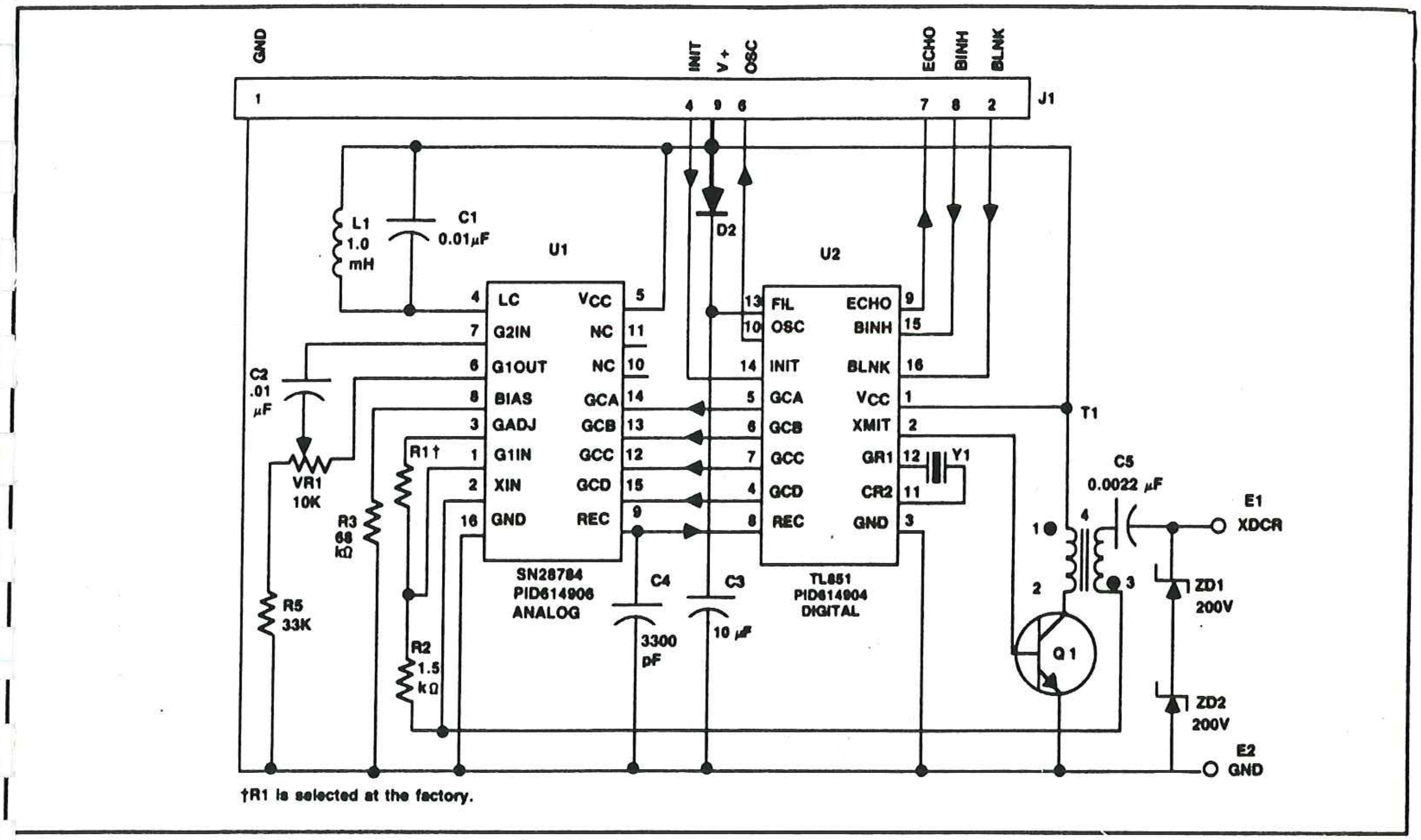


Figure 12

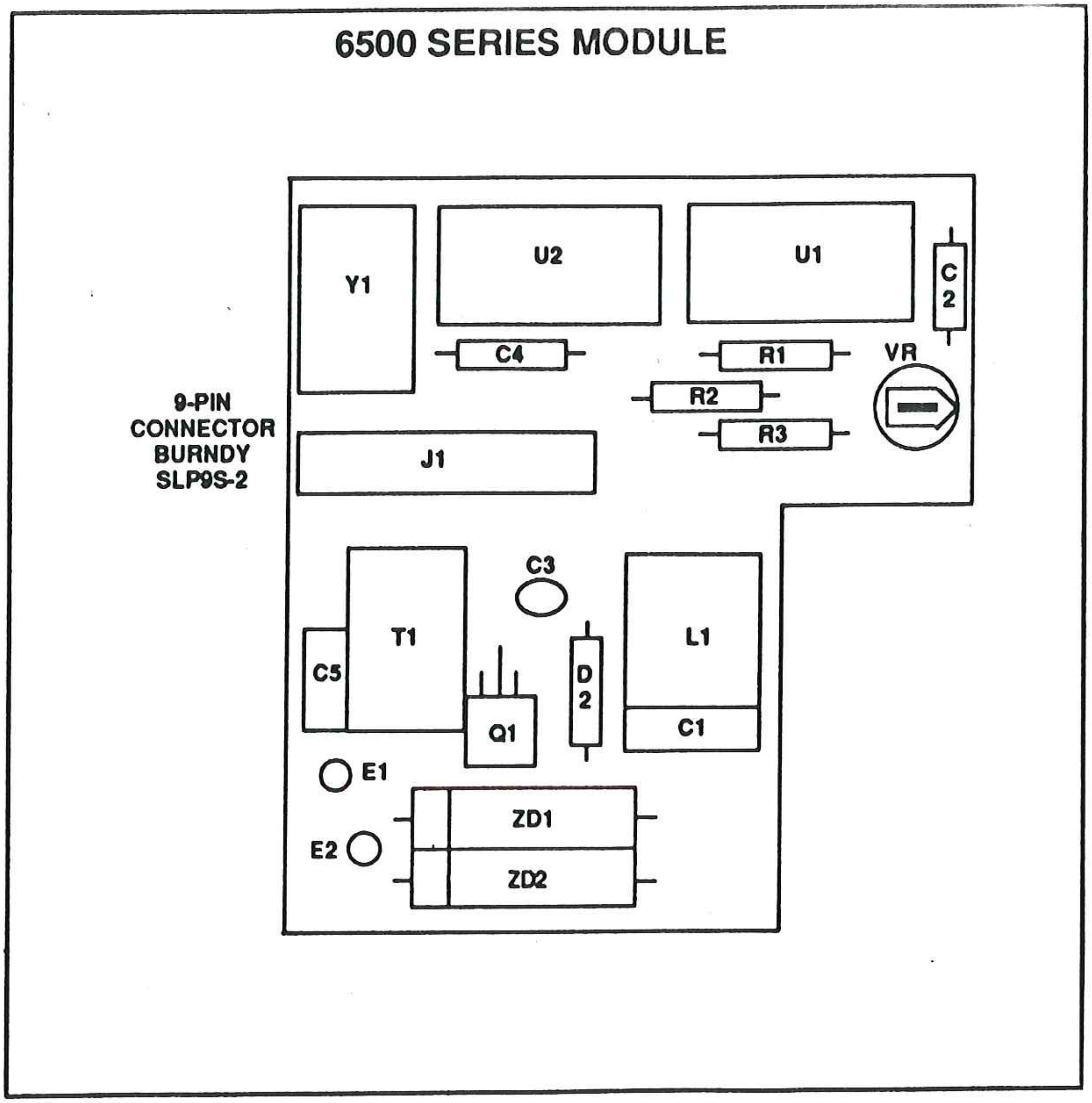


Figure 13

Y1 - Ceramic Resonator 420Khz
U2 - Digital Chip TL851
U1 - Analog Chip SN28784
C4 - Cap 3300pf
R1 - Resistor (selected at factory)
R2 - Resistor 1.5K 1/4W 5%
R3 - Resistor 68K 1/4W 5%
VR1 - Variable Resistor 10K
J1 - Burndy 9 Pin Connector SLP9S-2
C3 - Cap Solid Tant 10μf
L1 - Variable Inductor 1mh
C5 - Cap Polyproplene Film 0.0022μf
T1 - Transformer
Q1 - Transistor, NPN 2SC3279
D2 - Diode Shottky SD103C
C1 - Cap Polyproplene Film 0.01μf
E1 - Transducer Output
E2 - Transducer Output
ZD1 - Diode, Zener DZ870511A
ZD2 - Diode, Zener DZ870511A
C2 - Cap Ceramic 0.01μf

The general operation of the sensors is that it transmits a sound pulse, detects the resulting echo, and the elapsed time between the initial transmission and echo detection can then be converted to distance with respect to the speed of sound. This is accomplished by apply a 5 volts power supply to the transceiver module (pin 9). Then, take the INIT line high by applying 5 volts to pin 4. This initials the board and the board causes the transducer to emit sixteen pulses at frequency of 49.4 KHz. Each pulse is a high-frequency, inaudible "chirp", which lasts for about 1/2 millisecond. Immediately after the sixteen pulses are emitted, the transducer changes, in effect, from a loud speaker to an electrostatic microphone. It waits to receive the echo return from whatever object the sound pulse struck. Upon receiving the echo, the transducer converts the sound energy to electrical energy, which is then amplified and an echo received signal is produced. The elapse time between the INIT line going high and the ECHO line going high allows us to determine the distance of an object. The circuit also contains an internal blanking line. When this line is high, it represents the circuit disregarding any sound waves the transducer picks up. This is needed to avoid detection of acoustic ringing of the transducer after it emits the sixteen pulses. A timing diagram appears in Figure 14. A sample calculation of determining the distance of an object was performed and can be seen on the following page (Figure 15).

These ultrasonic sensors can detect the presence and distance of objects within a range of approximately six inches and 35 feet.

Figure 14

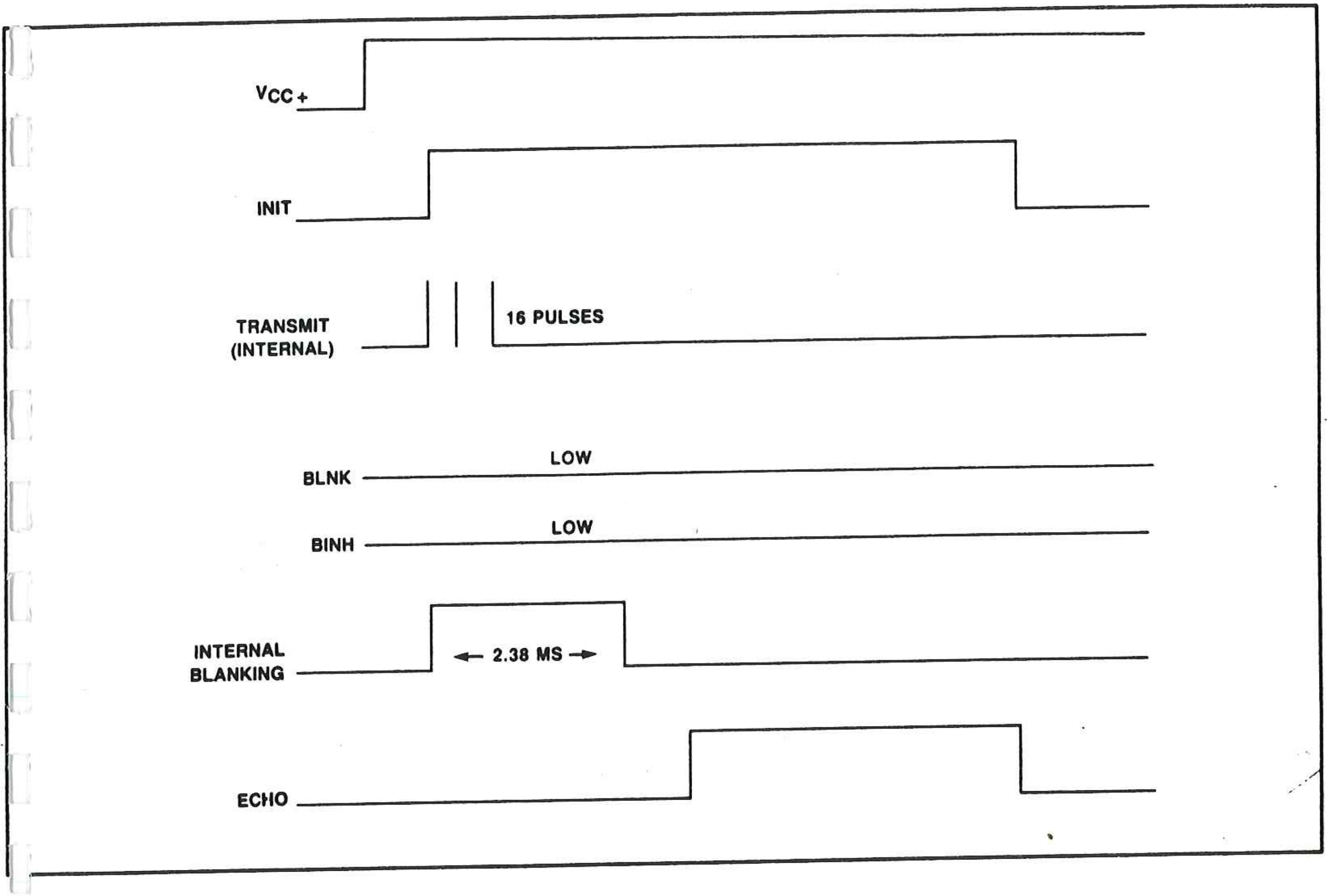

VCC +
INIT
TRANSMIT (INTERNAL)
16 PULSES
BLNK
LOW
BINH
LOW
INTERNAL BLANKING
← 2.38 MS →
ECHO

Figure 15

Elapse Time = 3.55 ms
Speed of Sound = 1150 ft/sec.

$$3.55 * 10^{-3} \text{sec.} * 1150 \frac{ft}{\text{sec}} = 4 ft$$

$$\frac{4 ft}{2} = 2 ft$$

Conclusions

While the project is not yet completed, it is possible to draw several conclusions from the work completed so far. Our initial research allowed us to determine that ultrasonic sensors would be effective for detecting in the blind spot region. Their combination of price, compactness, detection range, attenuation performance and ease of design caused us to choose them. For detection in the long range region in front of and behind the car, we will have preliminarily selected millimeter wave sensors. These have a very good angular resolution, as well as low power consumption. They are, however, rather expensive. The price should be just about within budget, however. The attenuation of these sensors is excellent, with very little attenuation occurring over a distance of several kilometers, even in adverse weather conditions.

We prepared a working demonstration for the second presentation, and showed that the ultrasonic sensor works even when simulated snow and rain is sprayed in front of the sensor. By the next presentation, we hope to have a mounted and tested blind spot detection system to demonstrate. We also intend to perform more extensive experiments on the ultrasonic system, such as interference, wind, and simulated weather condition effects. Work also will continue on the front-rear long range detection system, with a goal of having a working prototype system by mid-spring semester.

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