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16. Abstract

The existing horn antennas used in commercial pavement ground penetrating radar (GPR) systems are based on 20-year-old technology and design concepts. In recent years rapid advances have been made in designing planner miniature antennas. In this study a prototype antenna has been designed and tested in the laboratory. The preliminary results indicate that the antenna could transmit and receive GPR energy.

In future studies, researchers hope to build a field unit capable of stand-alone operation or a unit that will be mounted on a falling weight deflectometer (FWD) to provide layer thickness information at each test location.

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# DESIGN CONCEPTS FOR A MINIATURE PAVEMENT GPR ANTENNA

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## IMPLEMENTATION STATEMENT

This study presents the findings of an antenna design concept evaluation. Existing commercial GPR antennas are bulky. The antenna proposed in this study is capable of becoming part of a man-portable GPR system or of being incorporated into existing strength testing devices such as a falling weight deflectometer (FWD).

Although initial laboratory test results are promising, more development work is needed to assemble a field unit.

# DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation. It is not intended for construction, bidding, or permit purposes. The engineer in charge of the project is Tom Scullion, P.E. #62683.

# ACKNOWLEDGMENT

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# SUMMARY

The existing horn antennas used in commercial pavement ground penetrating radar (GPR) systems are based on 20-year-old technology and design concepts. In recent years rapid advances have been made in designing planner miniature antennas. In this study, a prototype antenna has been designed and tested in the laboratory. The preliminary results indicate that the antenna could transmit and receive GPR energy.

In future studies researchers hope to build a field unit capable of stand-alone operation or a unit that will be mounted on a falling weight deflectometer (FWD) to provide layer thickness information at each test location.

# CHAPTER 1
# INTRODUCTION

## REVIEW OF GPR USED IN HIGHWAYS AND BRIDGE DECKS

Applying ground penetrating radar (GPR) techniques for nondestructive tests on highways and bridge decks has become popular in recent years. For different applications on highway pavements, different types of radar may be used. Distinguished by the way they operate, radar falls into two categories: air-launched and ground-coupled.

As the name implies, air-launched GPR operates with the antenna mounted at a specific height perpendicular above the pavement surface. Since there is no contact between the antenna and the pavement, this type of GPR is ideal for highway speed data collection. Major applications include rapid thickness assessment on asphalt pavements and abnormal moisture and void detection in both rigid and flexible pavements.

Ground-coupled GPR, on the other hand, operates with planner antennas in close contact with the pavement. Consequently, this type of GPR is not intended for high speed pavement data collection. However, close contact with the pavement surface allows better horizontal resolution (i.e., along the pavement, in the direction of survey motion). The advantage of this antenna type can be seen during investigations of defects in concrete pavements and bridge decks in that the locations of reinforcing steel can be identified and distinguished from signatures in the GPR waveforms. The defects mentioned above refer to subsurface cracks, delaminations, voids, etc. In addition, relatively deep (~1 m below surface) sinkholes invisible to available air-launched radar can sometimes be detected with low-frequency ground-coupled radar.

Today, almost all air launched radar systems available in the market work at a center frequency of approximately 1 GHz, while most ground-coupled radar systems work at lower frequencies, typically 50 to 500 MHz. Higher frequency implies better resolution in thickness\depth. Moreover, as the size of the antenna increases, the frequency of operation becomes lower. All of the known existing air-launched GPR systems use TransElectroMagnetic (TEM) horn antennas. Figure 1 shows a typical TEM horn antenna with the package material removed.

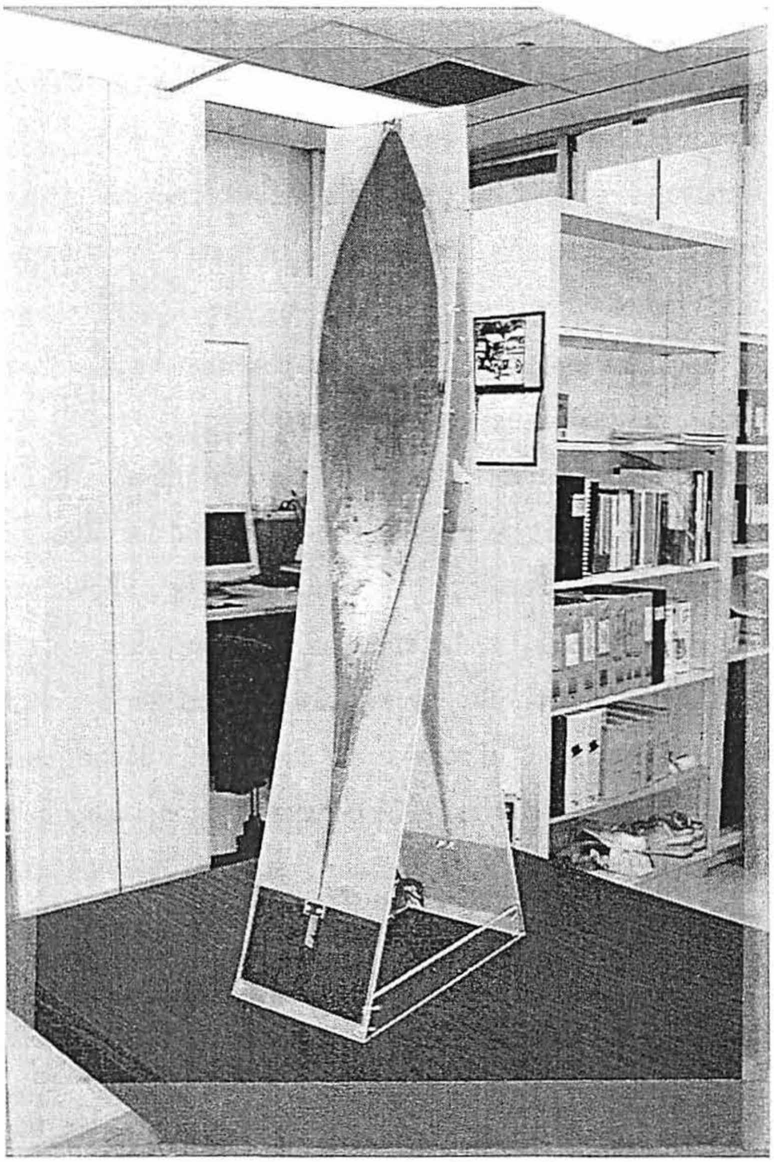


Figure 1. A Typical TEM Horn Antenna Structure.

A monostotic GPR system uses one such horn antenna. An example of such a monostotic system is Penetradar Model PS-24. Figure 2 shows the antenna of this system. It measures 1.2 m in length with biggest aspect about 0.4 m x 0.4 m, and weighs about 6.25 kg. For a bistatic GPR system, like Pulse Radar Inc.'s Rodar IV, two TEM horn antennas are needed, one for transmitting and the other for receiving signals. Figure 3 shows the Rodar IV antenna. It measures 1.05 m in length, and its biggest aspect measures 0.45 m x 0.34 m. This antenna weighs about 19 kg. There are two TEM horns inside the Pulse Radar unit, and the transmitter and receiver electronics are packed together at the top portion of the antenna package. (This arrangement shortens the cable route from the antennas to the receiver and transmitter, and hence, reduces signal degradation and minimizes connection problems.). Note that the size of the antenna (not the weight) is relatively large compared to the transmitter and receiver electronics.

In current practice, the antenna is mounted on a vehicle to collect pavement data. However, there are numerous situations that require a detailed survey of pavement structure meter by meter in various directions around the pavement surface. These situations include locating and sizing voids, detecting utility pipelines underneath pavements, evaluating backfill behind reinforcing walls, finding fine and developing cracks, etc. A relatively bulky GPR mounted on a vehicle is inconvenient to move around potential problem locations. This puts a high premium on GPR portability, which translates into small size and weight.

Another application for antennas which is critical for pavement engineers is in determining layer thicknesses during structural strength testing of highways. In Texas the falling weight deflectometer (FWD) is used for this purpose. The information collected with the FWD can only be adequately processed if the pavement layer thicknesses are known. It is difficult to consider using the bulky commercial horns with the FWD. If a miniature antenna could be developed, it would greatly enhance deflection testing data analysis.

A GPR contains a high frequency microwave circuit section and a digital/analog electronics section that controls the GPR operation. The microwave section consists of an antenna, a transmitter, and a receiver, which together dictate the GPR's performance as well as the size.

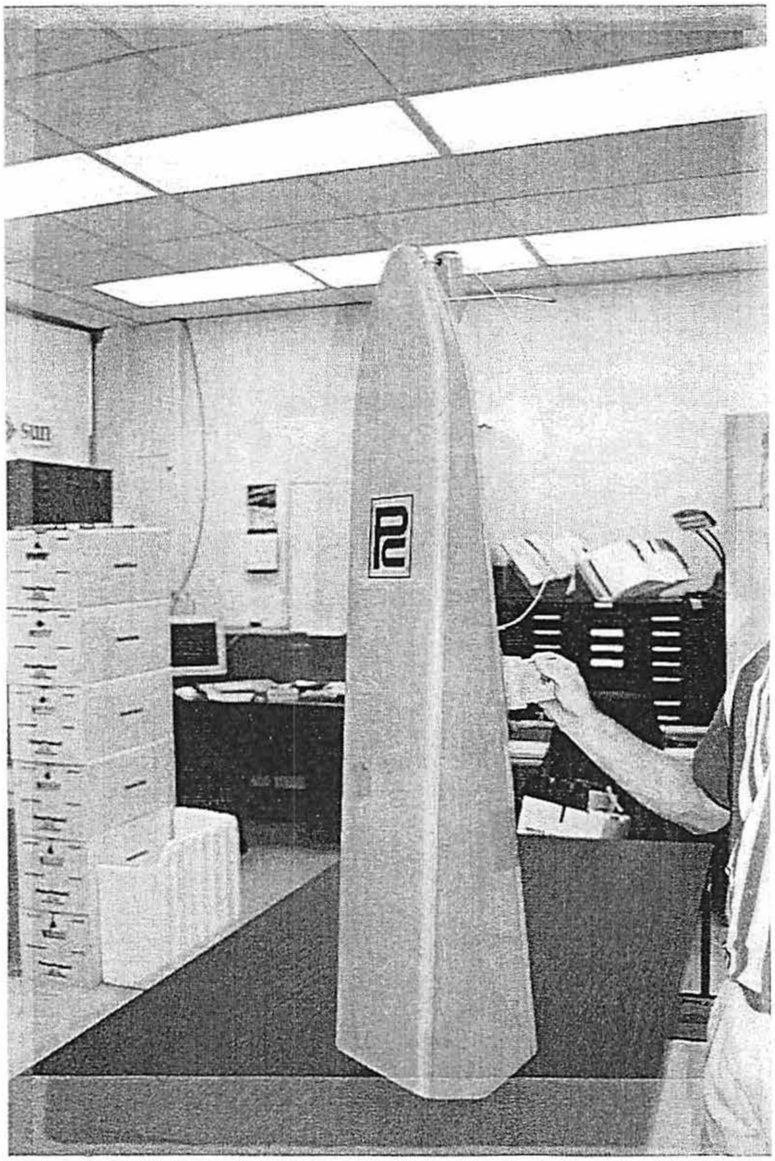


Figure 2. Penetradar Model PS-24 Antenna.

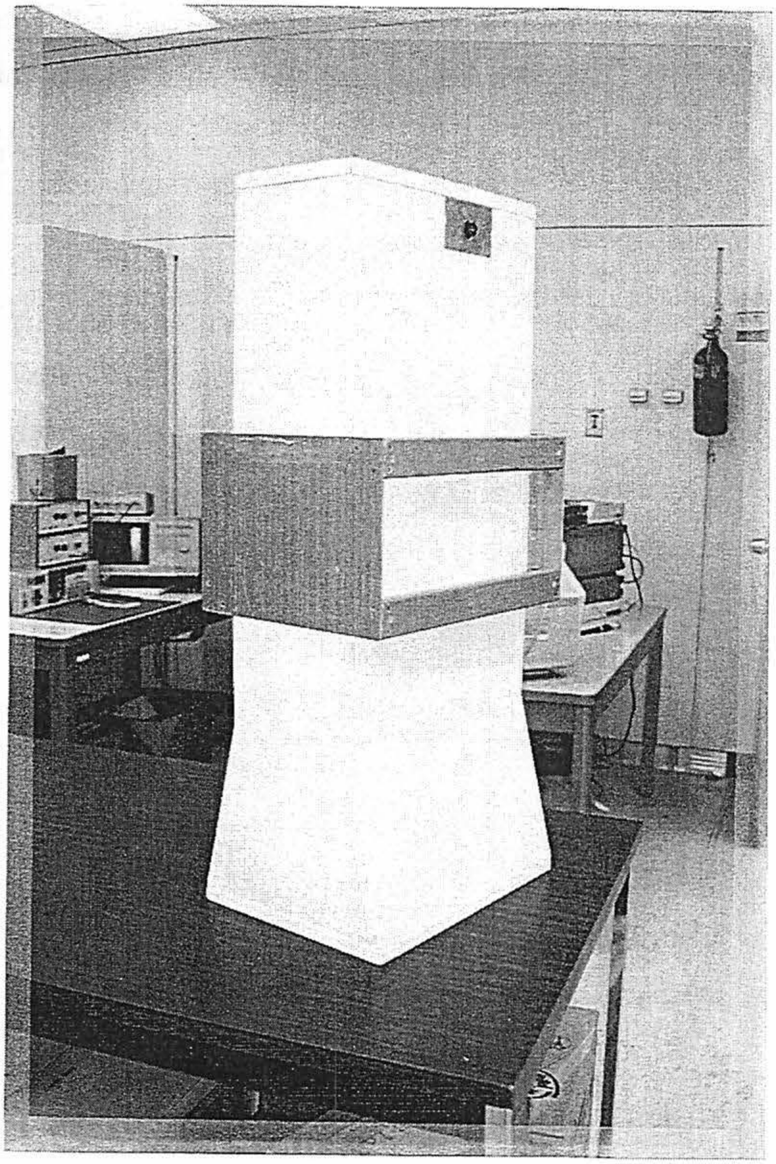


Figure 3. Pulse Radar Rodar IV Antenna.

(Note that there are two TEM horns in the package. Also, there are the transmitter and receiver are located at the top portion of the antenna package.)

In this report, researchers propose the concept of a compact planner antenna. The antenna pattern is etched on a printed circuit board (PCB) made of regular or low-loss microwave substrate. It is planner and lightweight. By employing advanced planner microwave integrated circuit technology, it is also possible to build the antenna, transmitter, and receiver on a single-piece dielectric substrate. This is highly desirable as it eliminates the need for distortion-causing cable routes to interconnect different components. The resulting GPR will be lower in cost, easier to manufacture, and compact as well as portable. The portable GPR will represent a significant breakthrough and have a far-reaching impact in highway engineering and practice.

# CHAPTER 2
# CONSTRUCTION AND TESTING OF PROTOTYPE ANTENNA

It is well known that the short duration impulse signal, which a GPR transmits and receives, has frequency components spreading across a very wide bandwidth. Existing GPR antennas (TEM horns) have very wide bandwidth with the drawback that they are relatively bulky. The challenge facing a GPR designer is in designing an antenna possessing required capabilities such as wide bandwidth, compactness and low voltage standing wave ratio (VSWR) (or high return loss). Recognizing the importance of reducing the antenna's size while still maintaining the high performance needed for a portable GPR, we have concentrated our efforts on designing an antenna possessing the characteristics of wide bandwidth, low VSWR, and small size.

Toward this objective, researchers have successfully conceptualized and designed a wide-band printed-circuited antenna. Figure 4 shows the physical pattern of this antenna on a PCB substrate. This antenna type is referred to as a slot-line antenna. The size of this antenna is only 30.5 cm x 30.5 cm x 0.16 cm, which is substantially less than the TEM-horn antenna currently used in existing GPR systems. This small antenna could eventually lead to the development of a portable GPR system. Figure 5 shows the antenna's measured return loss as compared to commercially available horn antennas. As can seen, a return loss of more than 10 dB was obtained over a very wide bandwidth from 0.5 to 6 GHz. However, the loss was not as good as that obtained with the Penetradar system which was over 20 db between 1 and 3 GHz. There is still room to improve the return loss of the new antenna, perhaps to match the horns. By using two identical slot-line antennas, one connected to a pulse generator and the other to a digitizing oscilloscope, researchers demonstrated the transmission and reception of pulsed signals as occurring in a typical GPR. The setup for this test is shown in Figure 6. Figures 7 and 8 show the pulses received by one slot-line antenna when the other slot-line antenna transmitted the 0.1 and 0.25 ns pulses respectively. These measured pulses resemble the pulses generated by the pulse generator and transmitted by the transmitting slot-line antennas, and thus clearly demonstrate that these antennas can transmit and receive pulses of GPR energy, and therefore, could potentially be built into a field unit.

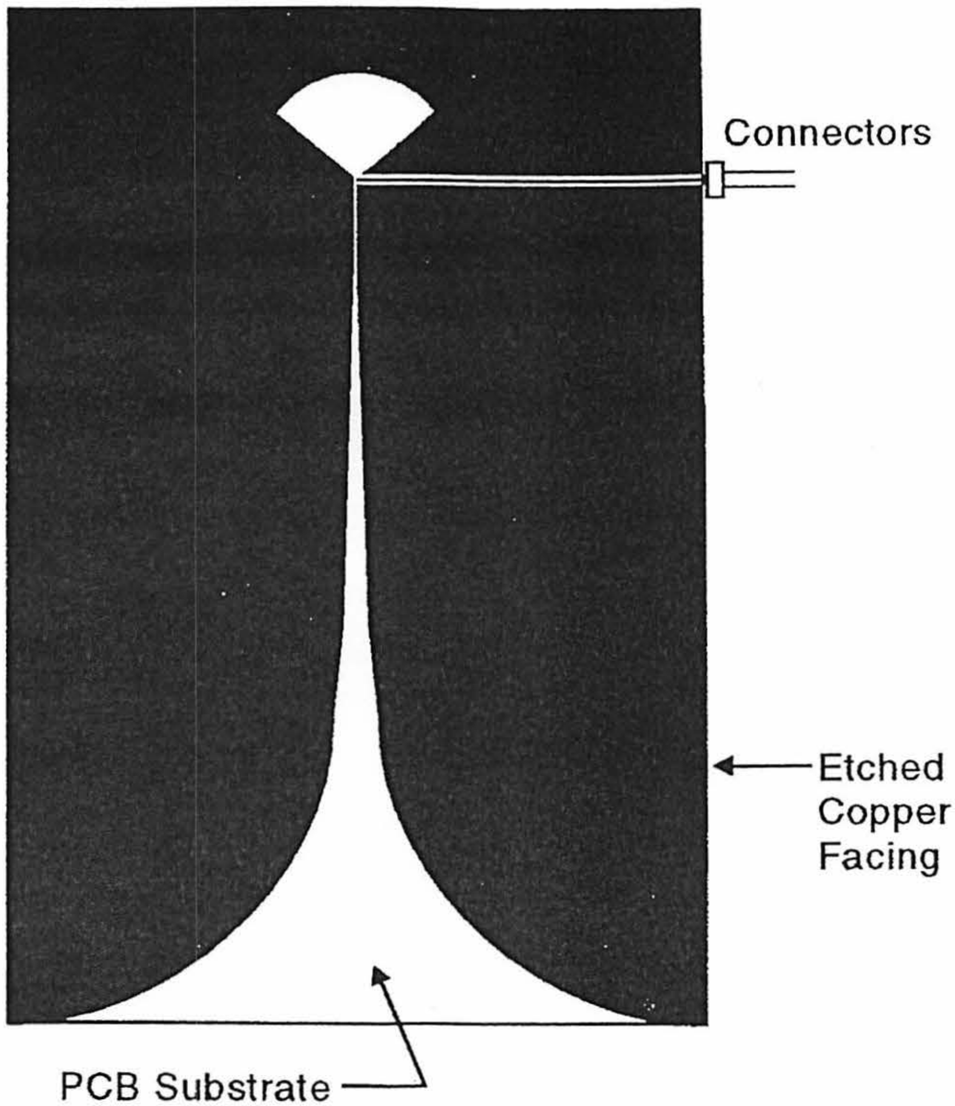
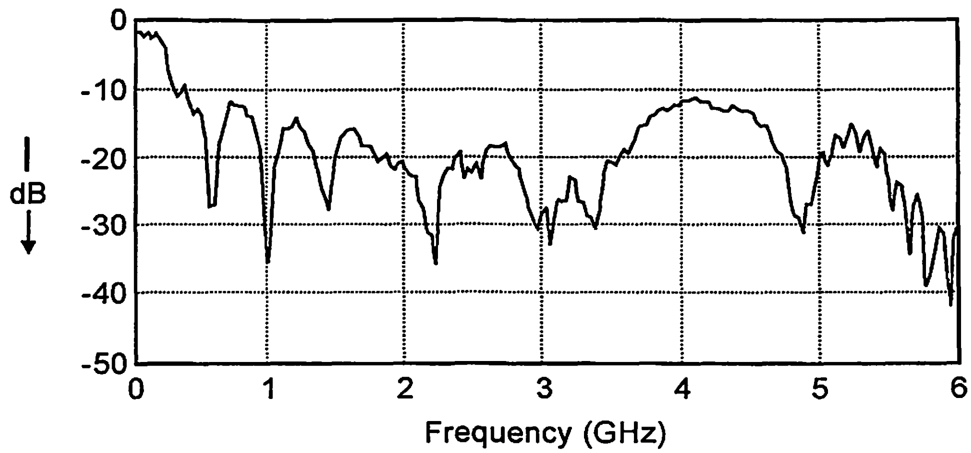
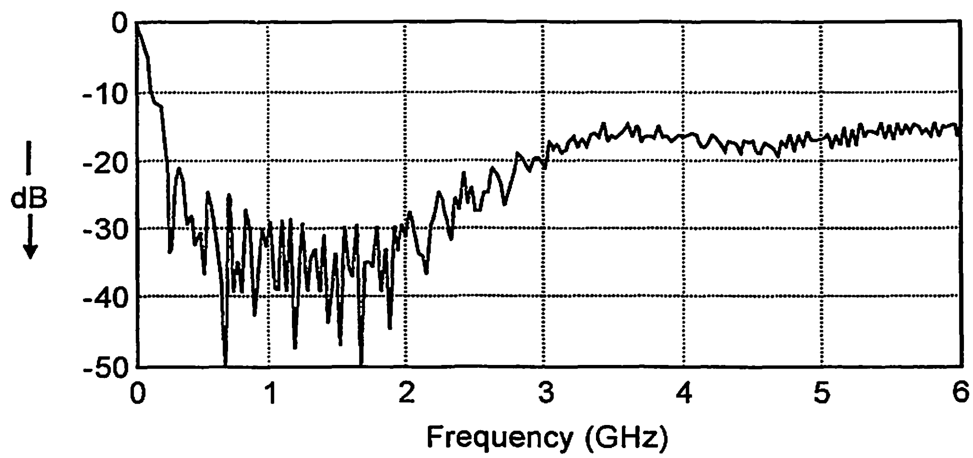


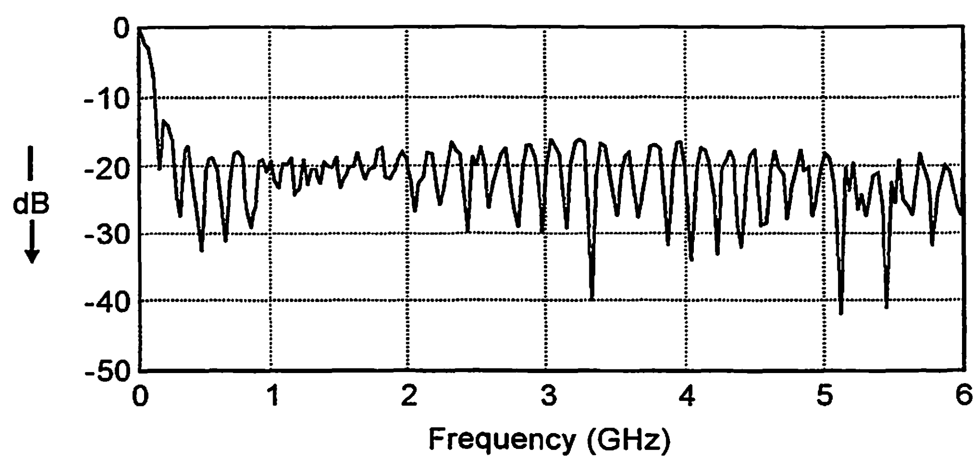

Figure 4. Antenna Circuit Pattern.




a) New Slot Line




b) Penetradar




c) Pulse Radar

Figure 5. Measured Return Loss from Various Antenna.

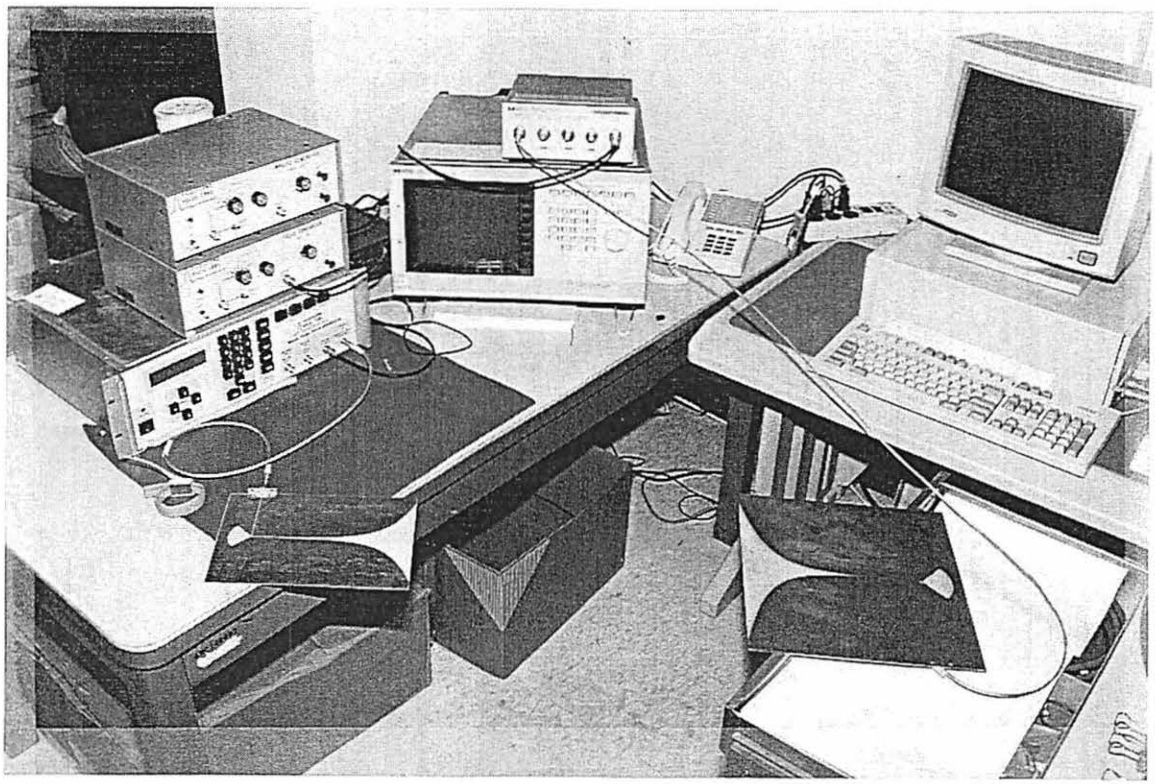


Figure 6. Test Setup for Testing the Transmission and Reception of Short Pulses. Although the Antennas are of Different Sizes, They Are Very Similar Electrically.

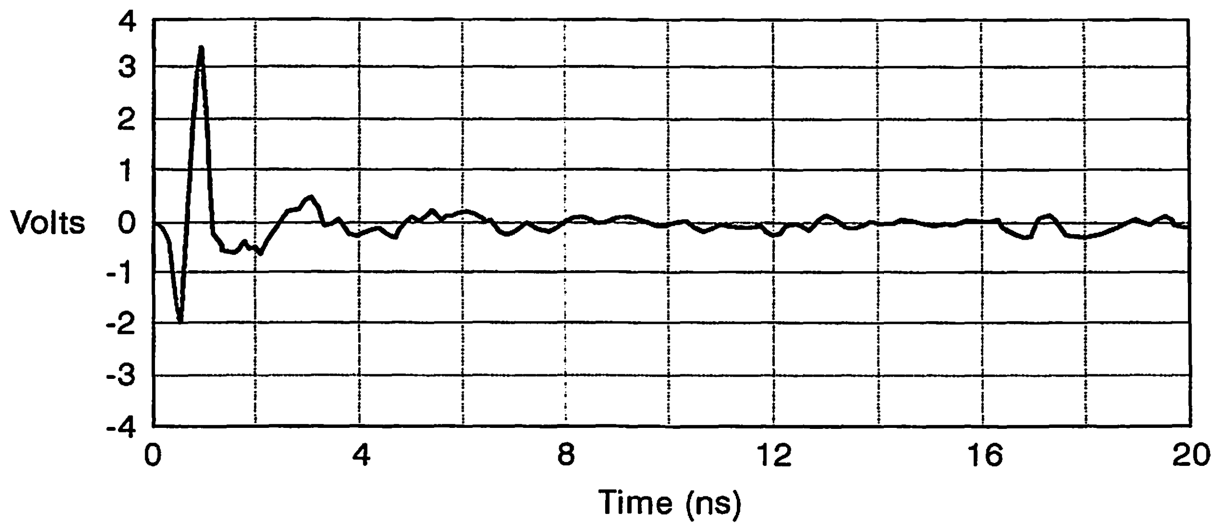



Figure 7. Pulse Received by One Developed Slot-Line Antenna Functioning as a Receiving Antenna. Another Identical Antenna is Used as a Transmitting Antenna Radiating 0.1-ns Pulse.

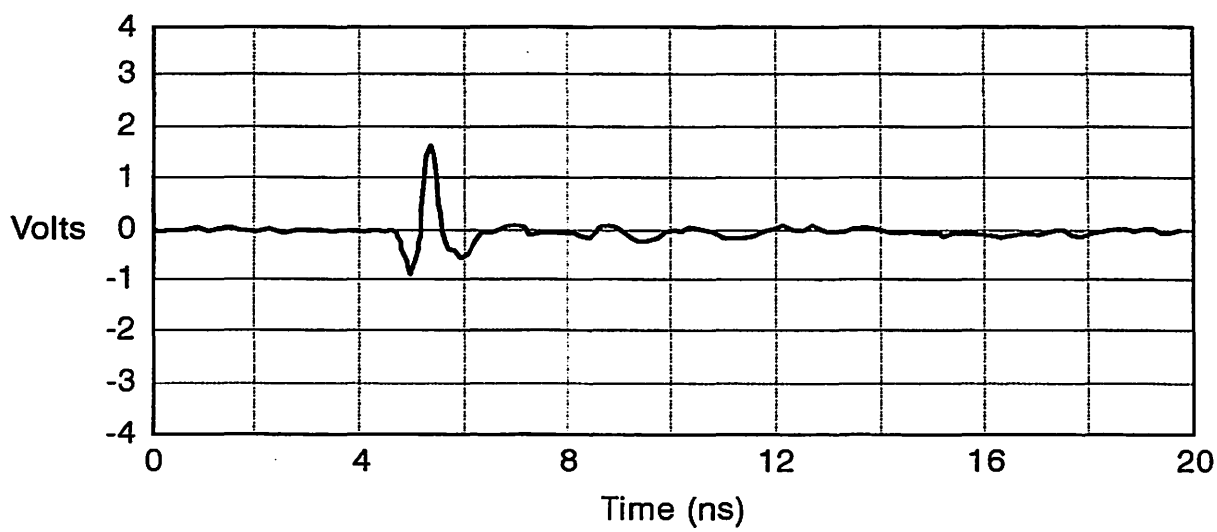



Figure 8. Pulse Received by One Developed Slot-Line Antenna Functioning as a Receiving Antenna. Another Identical Antenna Is Used as a Transmitting Antenna Radiating 0.25-ns Pulse.

In general, the prototype test was successful. However, as mentioned earlier, the return loss needs further refinement. A small return loss means that more signal energy is being reflected towards the transmitter. The impedance from the coplanar waveguide to the feed of the antenna can be improved. The next phase of the research will focus on minimizing the return loss. Also, in addition to the major radiation, there are some unwanted radiations from the board side. These will become the clutter (noise) in the received waveform and will need to be minimized. Since the prototype slot-line antenna is designed to work with narrower pulses (less than 1 nanosecond), it had to be hooked up with bulky pulse generators and digitizing scope in order to function. The system is not a stand-alone radar yet, so no field test have been performed.

The successful development of this antenna has demonstrated the feasibility of a future portable GPR. Researchers have also studied a packaging concept for such a portable unit based on the antenna developed. Figure 9 illustrates the concept, in which the antenna, transmitter, and receiver are fabricated on the same dielectric substrate (PCB). One side of the substrate is used for the slot-line antenna, whereas the other side contains the transmitter and receiver circuitries. Both the transmitter and receiver will be developed using printed-circuit microstrip lines with the ground plane formed by the fins of the underside slot-line antenna. This novel design and packaging concept allows a very compact, hence, portable GPR system to be realized. The overall size of the complete system will remain at the size of the antenna alone (30 x 30 x 0.2 cm).

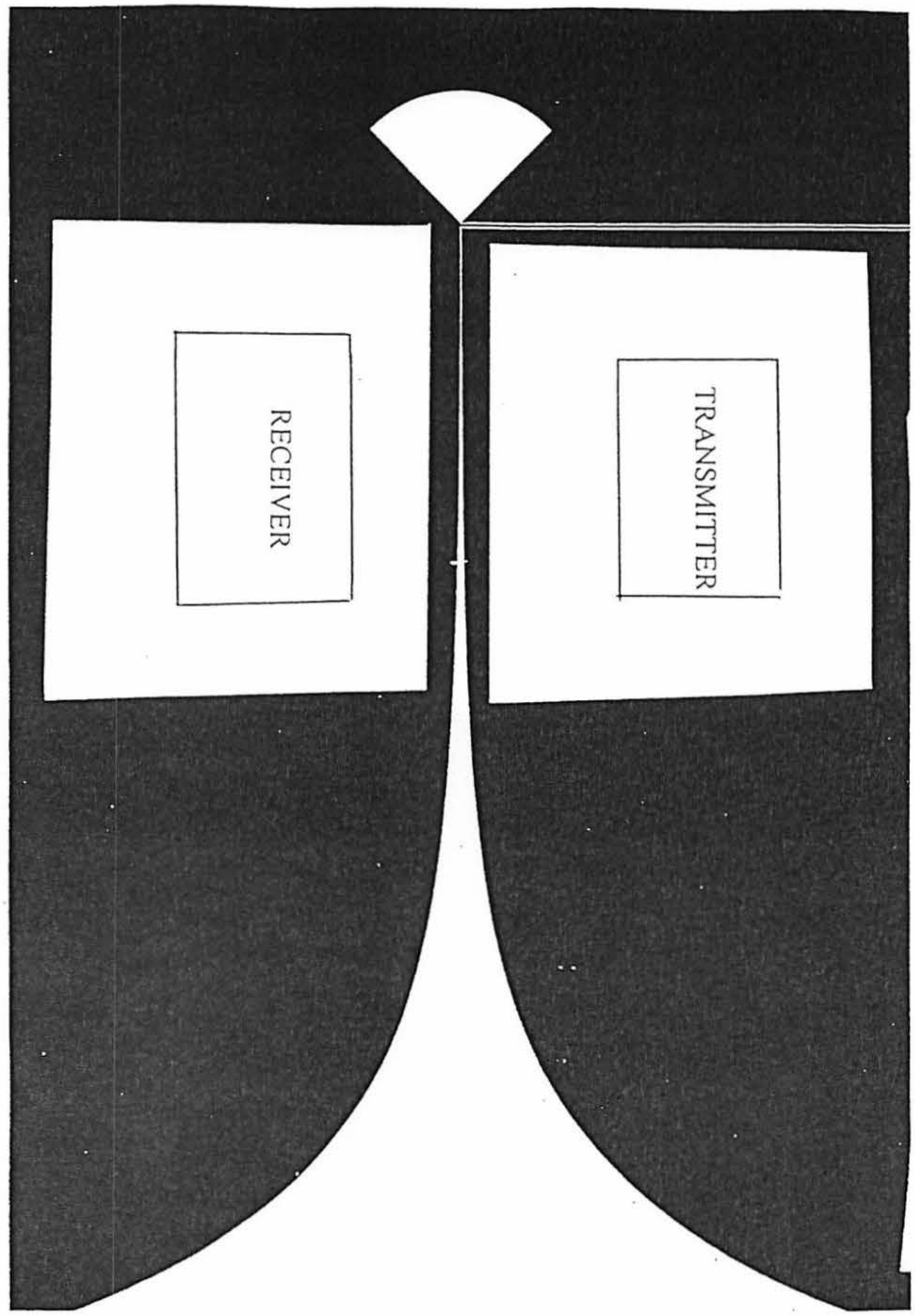



Figure 9. A Portable GPR Concept Using the Developed Slot-Line Antenna. The Receiver and Transmitter Will Be Fabricated Using Printed Circuits on the Opposite Side of the Antenna. The GPR's Size Is Estimated to be 38 x 46 x 7.6 cm.

# CHAPTER 3
# FUTURE DEVELOPMENT

To complete the development of the slot-line antenna for use in a practical system, researchers will conduct further evaluations using the existing transmitters and receivers of Pulse Radar's Rodar IV and Penetradar's PS-24. The antenna's performance will then be optimized for achieving best performance in gain, beam width, return loss, and bandwidth. Causes of unwanted board side radiation will be identified and eliminated possibly by using wave-absorbing materials along the left and right edges of the antenna (see Figure 10).

In using GPR for buried object detection, note that the strength of the reflected wave from an object depends on the azimuthal position of the antenna relative to the object. This is the case for linearly polarized antennas which are employed by all known commercial systems. In addition, if the transmitting and receiving antennas are oriented orthogonally in order to reduce coupling between the antennas, the receiving antenna will hardly detect the reflected wave from the object. To avoid this problem, it is proposed to develop a new prototype antenna consisting of a circular polarized antenna. The antenna will be a semi-circle spiral antenna nonconductively epoxied directly to the back of a hyperhemispherical dielectric lens. This kind of antenna features very broad bandwidth and a circular polarization, allowing the detection of buried targets at arbitrary orientation relative to the antenna. The use of the hyperhemispherical lens together with the antenna will enhance the radiation in the lens side and provide a highly focused radiation over wide bandwidth. This translates into precise target detection. Figure 11 illustrates the antenna and its integration in a GPR system.

To summarize, the plan for future development of the new GPR antenna is to

1. Improve the signal feed to antenna slot structure so that the signal being conveyed from the transmitter to the antenna structure is smooth with minimum reflection,
2. Fine-tune the slot structure pattern to improve the return loss over the designed operating frequency bandwidth of the antenna, and

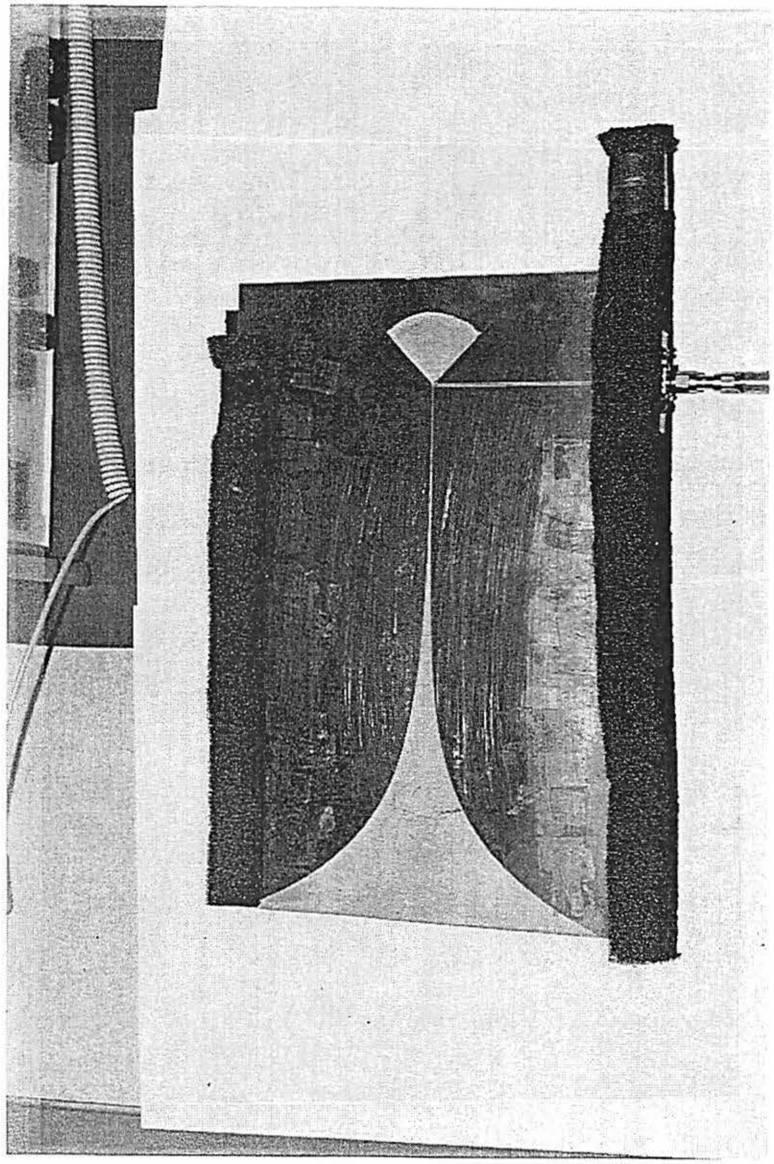


Figure 10. Foam Type Wave-Absorbing Material Is Used to Reduce Unwanted Edge Radiation. In the Final Design, These Foams Will Be Replaced by Epoxy Type Which Can Be Painted Along the Edges.

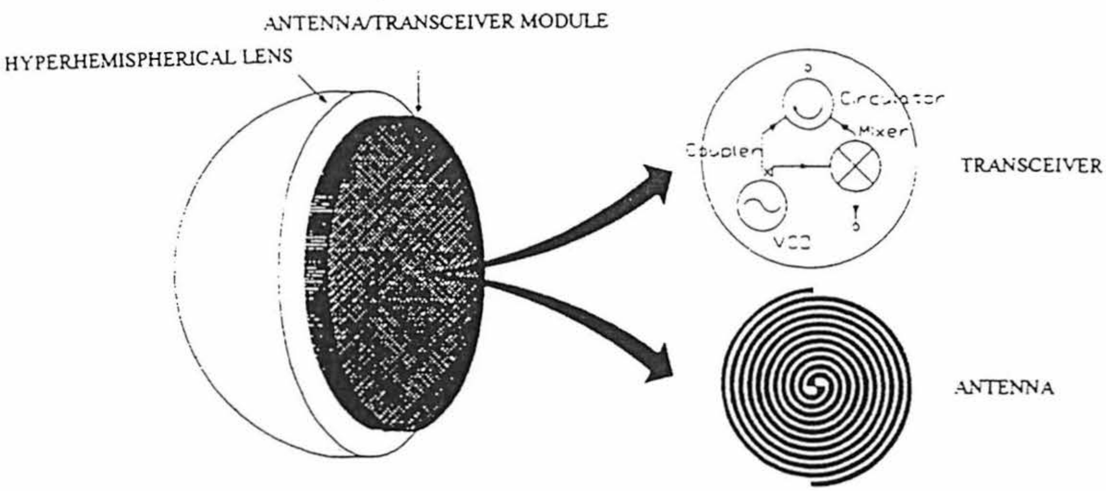



Figure 11. A Novel Portable GPR Having the Characteristics of High Gain, High Resolution, and The Ability to Detect Buried Objects at Any Location. The GPR Can Be Packaged in a Cylinder with a Diameter of 12 Inches and a Length of 14 Inches.

3. Locate and identify the positions and causes of unwanted radiation and test various wave absorbing materials to reduce or eliminate such radiation.

As an alternative, researchers will also investigate a circularly polarized antenna together with the development of the slot-line antenna. The circularly polarized antenna will be a semi-circular spiral antenna. After an initial test for its validity for pulse radiation and reception, it will be placed on a hyperhemispherical dielectric lens. It is expected that the lens will help focus the energy radiating towards the ground.

# CHAPTER 4
# CONCLUSION

It is proposed to develop a planner "slot-line" antenna as the "mini" antenna for GPR. The design of the mini antenna has been completed and two prototypes fabricated. The antennas were tested for impulse transmission and reception. One of the prototype antennas was hooked up to an impulse generator and acted as the GPR transmitter. The other antenna was connected to a Hewlett Packard sampling scope and acted as the GPR receiver. The received impulse was well defined in pulse shape and closely resembled those of the commercial systems. Thus basic functionalities were successfully demonstrated although further improvement in return loss and elimination of unwanted radiation is needed.