Document Title: Development of Inexpensive RADAR Flashlight for Law Enforcement and Corrections Applications

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Summary of Findings

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RADAR Flashlight for Through the Wall Detection of Humans

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EXECUTIVE SUMMARY

The RADAR Flashlight was developed to be a law enforcement tool. It can detect the respiration signature of a motionless individual standing up to 5 meters behind a 20 centimeter hollow core concrete block wall. Wooden doors typical of those found on most homes are almost transparent to the system. Dry plywood, particle board and wall board do not attenuate the signal significantly.

Most system applications for the RADAR Flashlight involve inspection of enclosed spaces beyond a door or wall. For example, the system could be used to determine if a subject is standing behind a door without a requirement that the door be opened. This technique could be used to detect a subject behind a front door who fails to answer a knock. It can also be used to inspect a closed space such as an interior closet. Normally, the closet would have to be opened to determine if someone was hiding inside. If the subject in the closet were armed, a police officer without the warning provided by the RADAR Flashlight would be at a distinct disadvantage.

The RADAR Flashlight was first developed as a laboratory model. The prototype has transitioned from a laboratory model that underwent extensive testing to a ruggedized model that has been field tested by police agencies. This report discusses the summary findings relating to both the laboratory and field test models developed by Georgia Tech Research Institute (GTRI).

UTILITY OF THE RADAR FLASHLIGHT

The RADAR Flashlight will detect the body movement of a subject at longer ranges than the range at which the respiration signature can be detected when the subject is stationary. Total body motion presents a much larger Doppler modulated radar cross section than the small respiration induced movement of the chest wall. Unfortunately, when the RADAR Flashlight is used for law enforcement applications, the subject can not be depended upon to voluntarily move during the search process. Thus, the detection of the involuntary respiration signature is necessary to ensure that the motionless subject can be detected.

Several system utilization scenarios have been developed for the RADAR Flashlight. When a fugitive warrant is being executed, interior closets are often the hiding places of choice for sometimes armed and dangerous individuals. It is the duty of those serving the warrant to open each closet door and inspect the interior space. This requirement puts the law enforcement personnel at a disadvantage. The RADAR Flashlight can detect fugitives or others hiding in a closet without requiring that the closet door be opened to complete the inspection. The same principle applies to a subject hiding in an attic area. The RADAR Flashlight can be used to inspect attic areas through the ceiling of the room below the attic area.

During a hostage situation, it may be possible to determine a hostage's location within a room and it may also be possible to determine where the hostage takers are located at any given time, assuming that the usual hostage scenarios are followed. Hostages are usually closely controlled and may be physically restrained or under duress to prevent their escape. Thus, a hostage is generally not moving but will be breathing. The hostage taker may be highly mobile and may move from room to room to inspect his or her defenses, communicate with police, and continually assess the environment. There are exceptions, however, but if this scenario is the case even 50 percent of the time, the RADAR Flashlight may be able to help determine the location of the hostage taker(s) and determine the location of the hostages. It is envisioned that a member of the Special Weapons and Tactics Team (SWATT) would take a position against the outside wall of the room of interest. The SWATT RADAR Flashlight operator would attempt to first detect motion and later detect respiration in a more careful search. The RADAR antenna beam would be scanned slowly across the room.

Warrant servers are required to go to a home or business to serve warrants on persons who, in many cases, do not want to accept the warrant or even let the server know that they are present. This is especially true when the individual will go to jail if they are discovered. The RADAR Flashlight could help determine if there is an individual behind the door but not responding to a knock on the door. Discovery of the non-responsive individual with the RADAR Flashlight would alert the police officer to a potentially dangerous situation that could require back-up officers before proceeding with the warrant serving procedure.

LABORATORY PROTOTYPE

Figure 1 is a photograph of the early laboratory prototype RADAR Flashlight that was first developed by GTRI to prove the concept of respiration detection using a man portable system. Referring to Figure 1, the laboratory prototype is housed in a flashlight shaped enclosure. The radar is mounted in the front of the housing, and the system's microwave lens, used to "shape" the antenna beam, is installed in the position of the optical lens normally found on a standard flashlight. The battery compartment is longer than those found on a normal flashlight.

The early version of the external signal processor used with the laboratory prototype is shown as the printed circuit board to the left of the prototype RADAR Flashlight. No attempt was made to miniaturize this signal processor which is used to filter the respiration signature from other signals caused by radar self motion, fluorescent lights and other clutter effects. The laboratory prototype unit operates on a frequency near 10.525 GHz, although an earlier version of the system was operated at 24.1 GHz and demonstrated less more attenuation through a 20 centimeter hollow brick block wall. The laboratory prototype is a homodyne radar configuration, although a frequency modulated continuous wave (FM-CW) system has been used for applications where information is required to determine the range to the target. The laboratory prototype operates in the near field region of the antenna for most through the wall detection scenarios.

The laboratory system signal processor (shown in Figure 1) processed the respiration signal and the associated signal in the time domain so that the time domain record was preserved for detailed analysis. The processor essentially served as a low pass filter with the cut off frequency shoulder just above the highest respiration frequencies that are expected. This first filter rejected most of the ambient clutter sources such as fluorescent lights. The analog time domain signal was fed into an analog to digital converter hosted by a laboratory computer where the input signal was converted into a 12 bit analog word and displayed on a computer generated strip chart recording. Once in digital format, the signal was subjected to more rigorous processing to retrieve the respiration signal under heavy clutter conditions including those due to body motion and other artifacts.

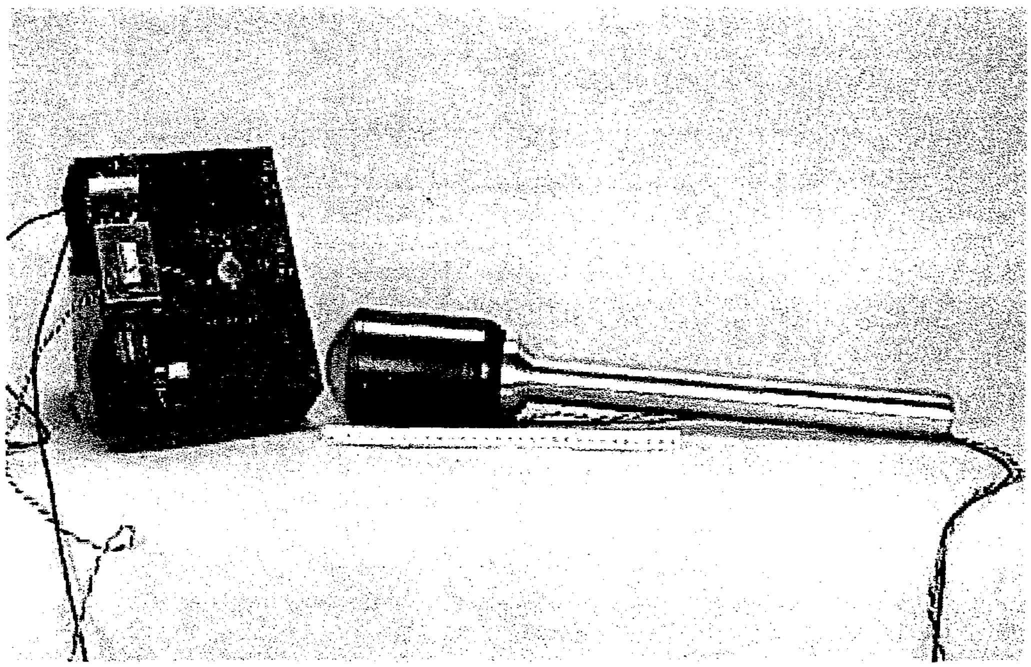

Figure 1. Laboratory model of RADAR Flashlight with signal processor board

Figure 2 is a recording of a respiration signature that was taken by the laboratory version of the RADAR Flashlight located 24 centimeters from a hollow core 20 centimeter thick concrete building block wall. The test subject was instructed to stand 1.8 meters beyond the brick wall and not to move once in position but to breathe normally. The RADAR Flashlight's beam projected through the wall and was approximately centered on the thorax region of the subject's chest.

Referring to Figure 2, time increases from left to right. The ambient signal level without a subject in the beam is shown as point A. The point at which the subject enters the beam is shown as point B. Upon the subject's entry into the beam, there is a large downward shift in signal level. This shift occurs because the detector was D.C. coupled to the first stage of the signal preamplifier. As a result, there is a shift in the level of the signal due to a change in phase along the signal path caused by the placement of the subject's body into the beam. Points C, D, E, F and G are negative excursions caused by the movement of the chest wall toward the radar during respiration. The subject was told to breathe once approximately every five seconds and the record shows that this instruction was followed. The subject steps out of the beam at approximately 52 seconds. The signal level returns to the ambient level at point H. There was a D.C. level drift of approximately 230 millivolts over the 60 second period during which the test was conducted. The circuit element that caused the D.C. drift has since been identified and replaced.

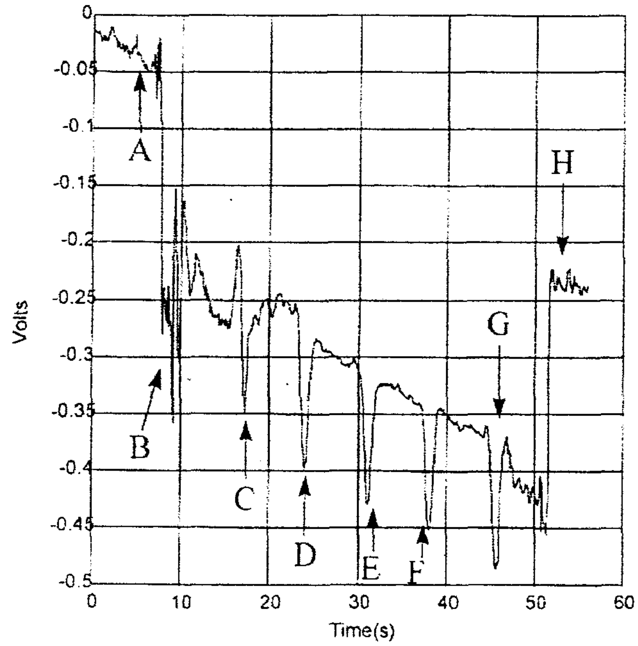

Figure 2. Respiration signature taken by RADAR Flashlight through a 8 inch hollow core concrete wall

Antenna Beam Measurements

The GTRI "near-field" antenna range was used to perform microwave measurements on the antenna pattern of the laboratory prototype in order to verify antenna beamwidth and pattern in the near-field and areas close to the radar. Using the near-field range, the antenna horn was excited by a 10.525 GHz signal, and a calibrated probe was automatically scanned across a plane in front of the antenna. The measurements were performed in a single plane in front of the antenna, and data reduction software provided calculated field strength results for other distances from the antenna. The measurement probe measured two orthogonal components of field strength and these components are combined in the data-processing software. The measurements on this antenna indicated that the antenna is designed to transmit a left-hand circularly-polarized (LHCP) signal, since this processing gave the most reasonable antenna pattern.

An antenna near field region is characterized by a field strength that varies in a complicated way with radial distance. The theoretically calculated near-field distance ($2D^2/\lambda$) for this antenna is 66 cm (26 in.). In the far field region, the field strength is inversely proportional to radial distance, and the antenna "pattern" is well established, i.e., the lobes and nulls appear at the same polar angles independently of the radial distance from the antenna. Since this antenna has a circular aperture, the pattern should have near circular symmetry around the axis of the circular horn, i.e., it is a function of only one polar angle.

Figure 3 shows the radar-flashlight antenna pattern as measured by the nearfield range, assuming LHCP. The measured antenna 3 dB beamwidth is about 16 degrees, and the sidelobes are more than 20 dB down relative to the main lobe and are reasonably symmetrical. Figure 4 shows the two-dimensional amplitude and phase plots in front of the antenna, and demonstrates that the antenna has good circular symmetry. Figure 5 is a plot of field strength versus distance from the antenna, and shows that the field strength has decreased by about 31 dB at 16 ft. on axis in front of the antenna. Finally, Figure 6 shows the entire radiated beam pattern.

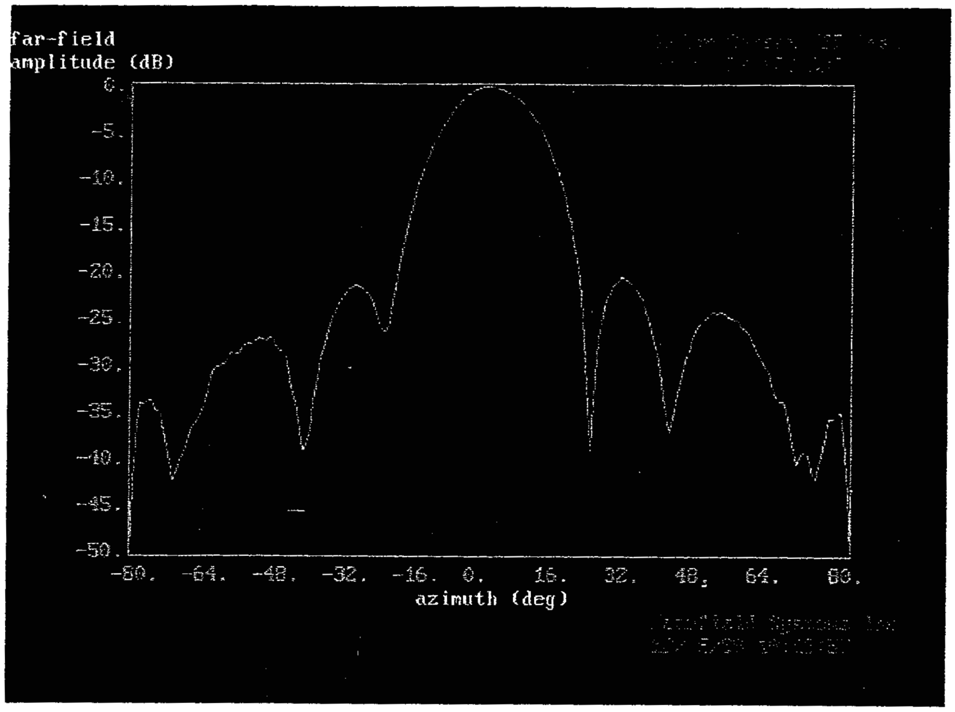

Figure 3. Antenna pattern magnitude response

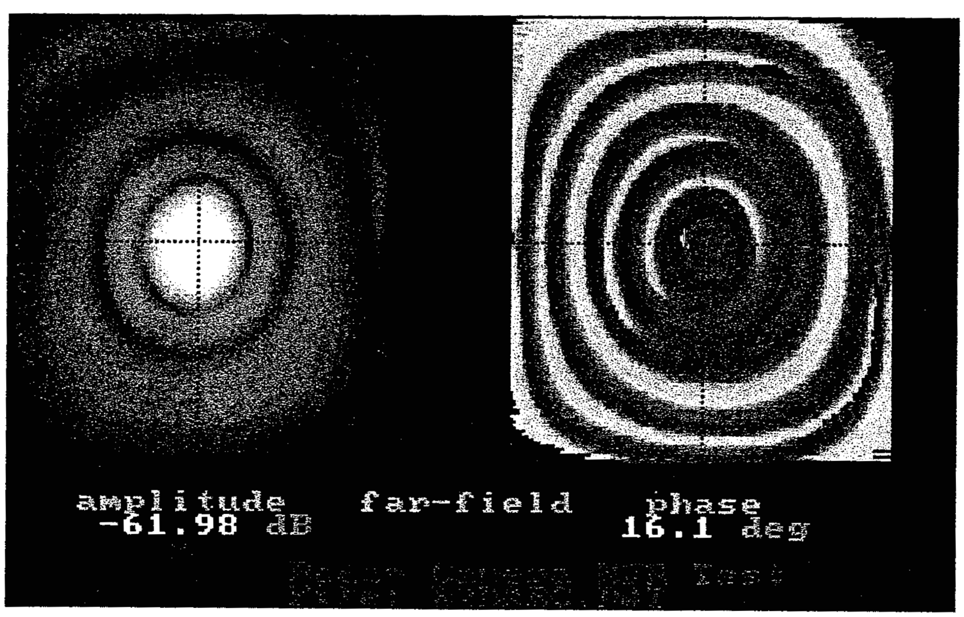

Figure 4. A 2-D magnitude and phase of antenna pattern showing circular polarization

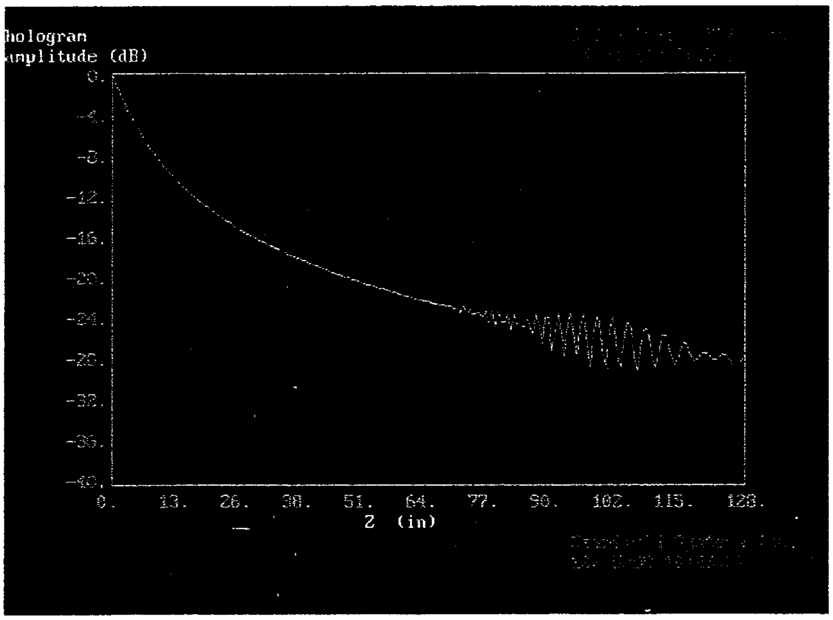

Figure 5. Power vs. distance for the antenna on boresight

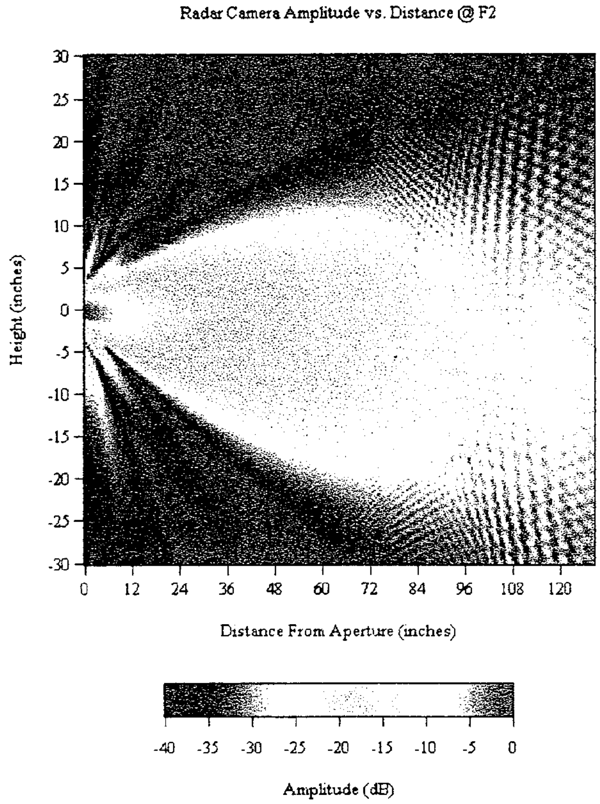

Figure 6. A 3-dimensional beam pattern

Thus, the flashlight will work best when energy is reflected from the target with a single bounce (so that the transmitted LHCP signal is received as RHCP). Two bounces (or any even number of bounces) at the target will tend to cause a null in the received signal. In normal operation of the RADAR Flashlight, subjects to be detected will be in the far-field region (beyond 26 in.).

There was concern that the antenna beam could be distorted due to phase shifts as the beam penetrated the brick wall. The power density of the antenna beam pattern was measured 6 feet beyond a hollow core cinderblock wall, after penetrating the brick wall. The results were plotted. On the basis of these measurements, it was determined that the beam was uniform and agreed with the near field range measurements to an accuracy of approximately 3 dB.

Final Test Prototype System

A final test prototype system design was developed and a breadboard version of the final system was built and tested. All sub-systems were verified to be operational after several problems were located and corrected in the design.

Figure 7 shows the three primary component assemblies that comprise the RADAR Flashlight field prototype test system. The housing, shown on the left, is a black anodized aluminum cylindrical housing with a slot cut in the top for the display. The microwave, display and processor assembly is to the right of the housing. The pistol grip handle, shown upper center, serves as the user support piece, housing for the trigger mechanism and host for the system's 14 volt rechargeable battery.

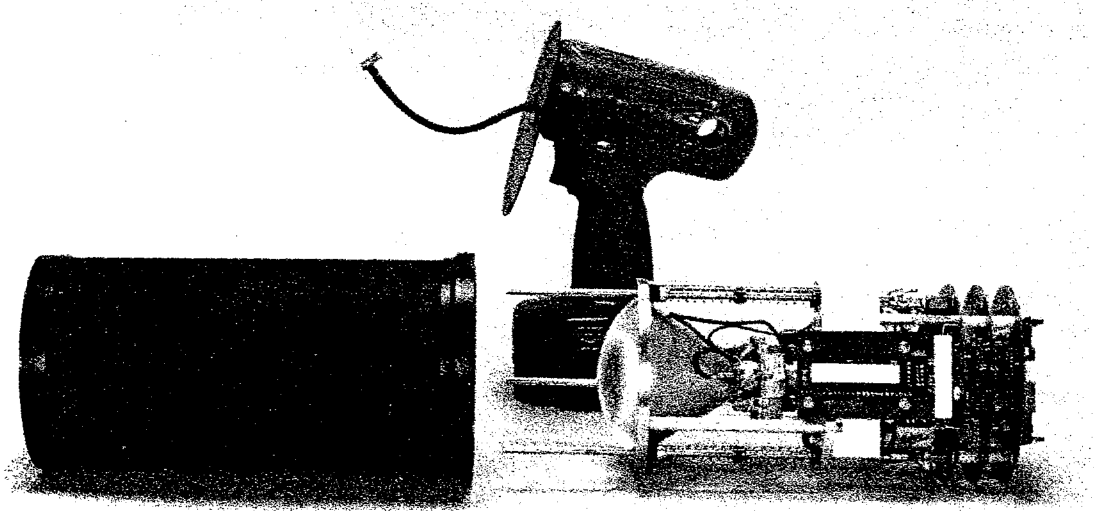

Figure 7. Primary component assemblies that comprise the RADAR Flashlight

Figure 8 shows the self-contained final design RADAR Flashlight in use and being tested before shipment for testing. The operation is very simple. The operator pulls the trigger. The system is energized. The rod lock releases allowing the stabilization rods to extend fully. The system conducts a self test and if all systems are operational, there is an indication on the 20 segment bargraph operator display. Each bargraph segment illuminates, starting from the bar nearest the handle moving forward toward the lens. When the self test is finished, the operator presses the RADAR Flashlight against the wall or other intervening object. The pressure moves the stabilization rods into the RADAR Flashlight housing. When the microprocessor senses that proper bias is being generated by the detector diode, the command is issued to lock the stabilization rods in place. The bargraph becomes active and the operator begins observing the bargraph display to determine if there is movement behind the wall or other intervening object.

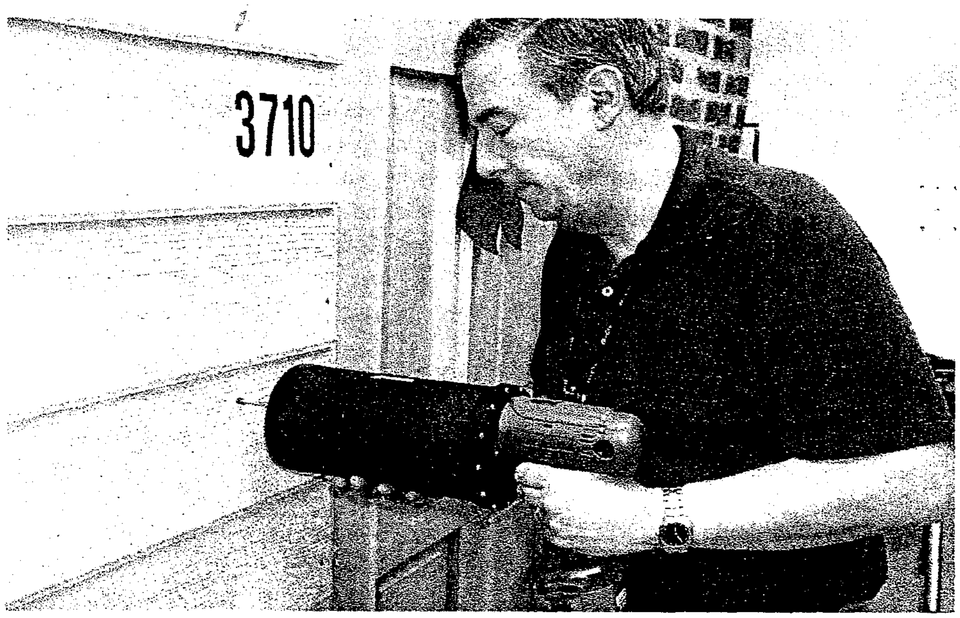

Figure 8. Testing of assembled RADAR Flashlight at GTRI's laboratory test facility

USER SURVEY AND TESTING OF THE RADAR FLASHLIGHT

The RADAR Flashlight was introduced to the Smyrna Police Department during 1998. A marketing survey was conducted using selected Smyrna Police sworn officers as potential candidate users of the system. The Smyrna Police survey provided feedback from the sworn officers. They commented on potential operational features, performance requirements and also provided insight into other applications that might be incorporated into the system, once the basic RADAR Flashlight has been perfected for the through wall and door application. In addition, this first marketing survey provided experience for discussion during the first design review held during October at Georgia Tech Research Institute (GTRI).

Mr. Bill Deck of the Charleston, South Carolina National Law Enforcement Correctional Technology Center – South East (NLECTC - SE) was contacted and asked to help conduct the marketing survey and assist in testing of the RADAR Flashlight when it was ready to be fully tested. Mr. Deck took the RADAR Flashlight to the Cobb County Police Department for testing on 1 December 1999. Later testing was conducted by other law enforcement organizations.

The RADAR Flashlight was also tested by the Charleston, South Carolina Police Department and it was demonstrated to a corrections representative. Further tests could have been conducted at other law enforcement and corrections agencies but the results and comments achieved became repetitive in nature. There is a great deal of practitioner interest. Mr. Deck reported that he was, "inundated with numerous calls from law enforcement agencies, corrections institutions, and university police." Generally, the agencies expressed a need for a portable, easy-to-carry, easy-to-use device that will indicate the presence of a person in a room prior to entering. The following are scenarios of how practitioners see the RADAR Flashlight being used:

Officers purse a suspect who runs into a vacant multistory building. The area is quickly cordoned off and a team is set up to enter and check each room. With the RADAR Flashlight, they would like to be able to detect the presence of a person prior to entering. Upon responding to a security alarm, the officers would use the device to check for the presence of a person prior to entering and possibly precluding a search of the building. If such an item is reasonably priced and reliable, these agencies indicated they would place one with each shift supervisor/leader. Mr. Deck speculated when talking with these representatives, the item is to cost about $750.00 (retail) once into production. They seemed to indicate the price was reasonable for the item. (Keep in mind that there are in excess of 1,700 law enforcement agencies). Several of the agencies wanted to know if it would detect the presence of a person who is not moving. Mr. Deck told them that to his knowledge, the answer was no, but that thermal imagery could be used to detect the presence of a warm body and should be considered for hours of darkness. (The RADAR Flashlight will detect respiration induced motion in many of the search scenarios). The corrections representative could foresee two in each facility to be used by the Correctional Emergency Response Teams (CERT) during escapes, and riots type scenarios.

Comments on the item as tested are:

1. The configuration is acceptable and easy to use.
2. The power source is easy to replace and maintain.
3. Longevity of the battery during use is good.
4. Ease of operation is good.
5. Very little training is required.
6. Only moderate movement is required to detect presence. Tests indicated that positive detection with just arm movement by the test subject.
7. Stability of the item is a problem. Any discernible motion gives a false reading.
8. The locking system for the wall offset is noisy and gives away the officer's position. There are two loud distinctive clicks when activating the device.
9. Depth of penetration appears to be as far as 20 feet in light material type walls (wallboard) and 10-12 feet in heavy materials (brick and mortar).
10. The LED display is hard to see in bright sunlight and gives the operator's position away in the dark. Perhaps an audio or vibration device could be used as an accessory, which would bypass the LED display.
11. There is a variance in the degree of movement identification depending on the density of the material. In some materials, the device goes to the maximum reading, where other materials it only lights up half of the display. This caused the operator to disregard the reading as false.

It should also be noted that the item was not tested in inclement weather, on wet materials, or in extreme cold.

Comments by GTRI Regarding Police Testing

Three RADAR Flashlight improvement areas were suggested in Mr. Deck's report and each is shown in italics. The GTRI response follows each of the suggested improvements.

1. *The locking system for the wall offset is noisy and gives away the officer's position. There are two loud distinctive clicks when activating the device.*

The solenoid action that locks the stabilization system does cause a click that is transmitted through the wall or door against which the system is pressed. One improvement that GTRI is investigating is the development of a stabilization technique that does not require that the RADAR Flashlight have contact with the wall or door. Availability and amount of future research funding by government or industry will determine if this line of research is pursued.

2. *The LED display is hard to see in bright sunlight and gives the operator's position away in the dark. Perhaps an audio or vibration device could be used as an accessory, which would bypass the LED display.*

The bargraph display was adopted as an inexpensive operator interface device. A brighter LED display could be used for daylight operation. A photo-diode detector used to sense ambient illumination levels could be used as an automatic dimmer circuit to reduce the illumination level of the display at night. In addition, a directive light shield could be developed to prevent the display from being visible except to the operator when the system is operated in the daytime.

3. *There is a variance in the degree of movement identification depending on the density of the material. In some materials the device goes to the maximum reading, where other materials it only lights up half of the display. This caused the operator to disregard the reading as false.*

GTRI plans on solving this technical challenge. The microprocessor controller currently used in the RADAR Flashlight has unused processing capability. When additional research and development funding is identified, the development of signal processing routines that can be implemented in the RADAR Flashlight microprocessor controller will be developed to sense the attenuation of the specific wall that is being penetrated by the RADAR Flashlight. System gain would be automatically adjusted to compensate for the amount of signal loss produced as the signal passed through the intervening wall or door. Sensing and compensation for intervening structure attenuation would ensure that the operator would be presented a consistent bar-graph display that is independent of attenuation effects of intervening wall material.

Real World Requirements

The system must be inexpensive to produce in large quantities and in the same price range as a top end weapon carried by a law enforcement officer. Thus, a target price for the RADAR Flashlight product was set at between $300 and $500. It is thought that the most expensive part of the system would be the RF section, followed by the cost of the digital signal processor. If future marketing studies should determine that high sales volumes can be achieved, the parts count in the system can be reduced significantly by implementing the system in a chip set. The cost of converting the system to a chip set would be amortized over the high number of systems sold.

There is a requirement that the system should be capable of being operated by a relatively unskilled operator. This requirement suggested that the packaging of the system was important and that the associated signal processor should be "smart" and make many of the decisions regarding target identification for the operator. Given this requirement, a flashlight configuration was adopted as housing. The final form of the target display has not yet been determined, although a simple display would appear to be an acceptable option.

REFERENCES

1. E. F. Greneker, "Radar Sensing of Heartbeat and Respiration at a Distance with Security Applications," *Proceedings of SPIE, Radar Sensor Technology II*, Volume 3066, Orlando, Florida, pp. 22-27, April 1997.

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