Appendix C
Electromagnetic Detection of Metal and Weapons

Introduction

This appendix describes and assesses the potential of radiofrequency electromagnetic methods of detecting metal and weapons. The two major categories of methods are inductive methods, such as those used by metal detectors in airports, and reflectometry, including dielectrometry and short-range imaging radar.

Inductive Metal Detectors

Most metal detectors used at airports function either by detecting changes in mutual inductance caused by additional presence of metal in the portal or by detecting eddy currents produced in metal within the portal by a radiofrequency pulse. Those using the former technique are called mutual-inductance metal detectors (MIMD). Those using the latter, more modern technique are called eddy-current metal detectors; they can, in principle, acquire more information about metal objects and use it to improve specificity-i. e., discrimination of weapons from innocuous objects. Older systems used other techniques. All use the principle of electromagnetic induction and can be called inductive metal detectors.

Inductive metal detectors are likely to be useful for some time; however, they cannot detect nonmetallic weapons and, in order to reduce false alarms to an acceptable level, they require subjects being inspected to empty their pockets of metal objects. This slows inspection and precludes covert inspection. Designers polled by OTA believe there is some room for improvement in performance.

If a system is well sited to avoid electromagnetic interference (EMI), the signals of innocuous metal objects on searched persons may limit the performance of the system. However, if a system is poorly shielded or located near a strong source of EMI, the performance of the system may be reduced. In such a case, performance might be improved by better shielding or by relocating the system. If neither of these is practical, it is possible to improve performance by using a stronger magnetic signal to produce a stronger signal from metal objects-strong enough to be distinguished from the EMI.

However, the magnetic field to which the public may be exposed is limited to 1 gauss (1 G) by a standard (NILECJ-Std.-0601 .00) issued by the National Institute of Law Enforcement and Criminal Justice (now the National Institute of Justice) in June 1974 and by exposure guidelines set by the Bureau of Radiological Health (BRH) of the Food and Drug Administration (FDA). The limit was set at 1 G because of concern that stronger fields might upset the operation of cardiac pacemakers. Some designers speculate that modern pacemakers are less susceptible to such EMI from metal detectors and that the maximum field could be increased without harmful effect. A committee of the American Society for Testing and Materials (ASTM) debated for several years a proposal to increase the limit to 3 gauss but has now abandoned pursuit of this aim, convinced that they cannot induce a disinterested third party, such as the National Institutes of Health, to do the human experimentation that would be required to prove safety at this level. They doubt that an ASTM standard, which would be characterized as an "industry standard," would be credible to all stakeholders.

Some passengers wearing hearing aids have complained of the loud noise that an eddy-current metal detector can cause in some hearing aids, and some hearing aids have apparently been damaged by existing metal detectors. Allowing 3-G fields might exacerbate this problem.

Radio reflectometry is the measurement of radiofrequency electromagnetic (RFEM) waves reflected by an object. It is widely known that metal objects such as airplanes reflect radio waves that can be detected by radar receivers.[1] Smaller metal objects, including firearms, knives, and other weapons, can be detected at short range (a few meters) by low-power radar systems that maybe used to "frisk" suspects electronically. Because of concerns about health, x-ray or nuclear methods of inspection would be controversial or prohibited for this important application.

Simple, inexpensive systems can detect weapons but cannot generally distinguish them from innocuous objects. More expensive millimeter-wave (MMW) radar systems (so called because they use radio waves having wavelengths of a few millimeters) can display TV-like radar imagery of weapons concealed under clothing, permitting an operator to distinguish weapons from innocuous objects, reducing false alarms. Nonmetallic objects also reflect radio waves and can be detected and imaged by radio reflectometry. This is called dielectrometry; it maybe used to ''frisk' suspects electronically for nonmetallic weapons or explosives.

[1] Originally RADAR: an acronym for RAdio Detection And Ranging.

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Dielectrometry

If an RFEM wave propagating through the air inside a suitcase encounters a material with a different refractive index, it will be partially reflected.[2] The refractive index of a medium is proportional to the square root of its dielectric constant (also called its relative permittivity) and to the square root of the magnetic permeability. Common nonmetals and nonferrous metals have nearly the same magnetic permeability as air, but in most cases, a different dielectric constant, so they will partially reflect an incident wave propagating through air. Estimating the dielectric constant of a reflecting material by irradiating it with radio waves and measuring the amplitude of the reflected wave is called dielectrometry. Some portable and relatively inexpensive dielectrometers designed to detect concealed explosives, weapons, and other contraband are already on the market. More sophisticated versions are in development.

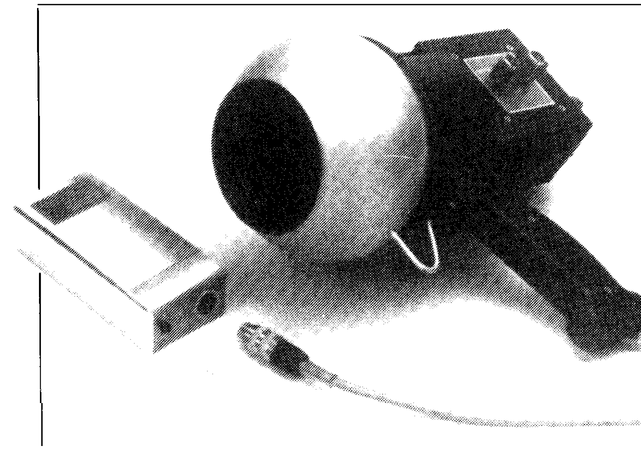


Photo credit: Spatial Dynamics Applications, Inc.

M600P portable drug and contraband detector

SDA Model M600P, M600L, and M1800L Dielectrometers

Spatial Dynamics Applications, Inc. (SDA) of Acton, MA markets dielectrometers for use in detecting concealed items with a different dielectric constant than that of the material or space within which they are placed. One such device is the model M600P Portable Drug and Contraband Detector (see photo), which has been tested for operational effectiveness in detecting weapons (knives, firearms) concealed in various objects, and has been used to detect a concentrated solution of cocaine hydrochloride concealed in beer bottles. It is also capable of discriminating beverages from liquid explosives within bottles, and could thus play a role in many security applications, including airline security.

In response to a Broad Agency Announcement solicitation by the FAA (see app. A), SDA has proposed modifying the M1800L Laboratory Dielectric Tester to screen people for explosives or weapons. The modification would involve equipping the M1800L with an extended lens "suitable for screening people. " SDA also proposed designing an automatic scanning unit for the system. Extensive testing would be required to determine the device's capability and false alarm rate.

GDE Vehicular Detection System

The Electronics Division of General Dynamics Corp. (GDE) has developed and is marketing a Vehicular Detection System capable of detecting buried metallic objects, such as firearms (see figure C-1), as well as nonmetallic objects such as explosives, and displaying low-resolution images of them. This technology uses long-wavelength radar that is able to penetrate the ground to various depths (depending on the wavelength and power of the device and on the water content of the ground) and provide return images.

GDE Improved Hand-Held Detector

Under contract to the Defense Advanced Research Projects Agency, GDE is developing an improved, imaging version of a hand-held mine detector it expects to complete in 1991 (see figure C-2). The Improved Hand-Held Detector will be technologically similar to the GDE Vehicular Detection System.

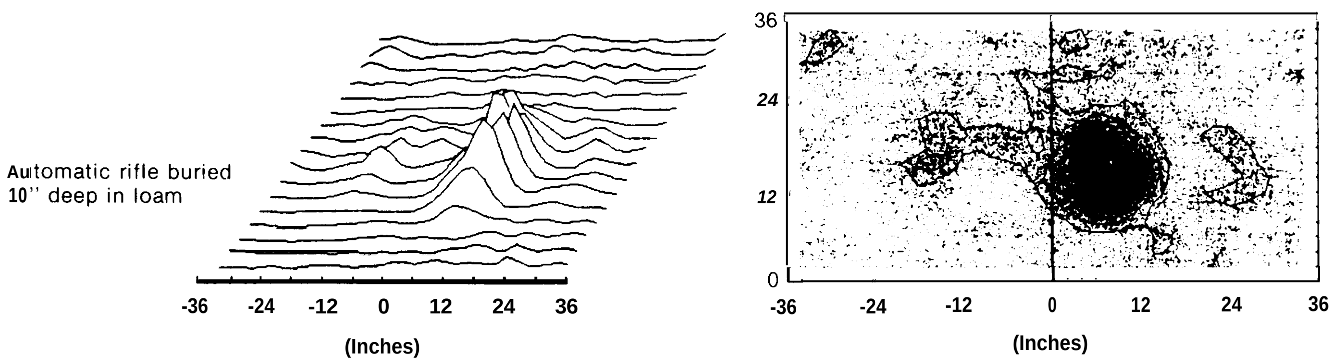
Millimeter-Wave Radar

Several short-range, high-resolution, imaging radar systems for detecting weapons concealed in clothing are now being developed. In weapons-detection applications, these compete with the commonplace mutual-inductance and eddy-curent metal detectors and with the existing and proposed reflectometers described above. Potential advantages of radar over such devices are: 1) radar images would allow weapons to be distinguished from coins, prostheses, etc., so the false-alarm rate would be low, and 2) suspects would not have to empty their pockets of innocuous metallic items; hence 3) suspects could be "electronically frisked' covertly.

Distinguishing a pistol, for example, from a prosthesis requires imagery showing details as small as about 1 cm. Obtaining such resolution requires using waves with wavelengths shorter than about 1 cm—i.e., millimeter-wave radar.

[2] If the incident wave strikes the material broadside, the reflected electric field strength will equal the incident electric field strength multiplied by (n'- n)/(n' + n), where n is the refractive index of the medium in which the incident and reflected waves propagate, and n' is the refractive index of the dissimilar medium encountered by the incident wave.

Figure C-l—Vehicular Detection System and Imagery of Buried Automatic Rifle



Signal strength plotted as height.

Dot-density plot with contours.

SOURCE: General Dynamics Corp., Electronics Division, 1990.

Figure C-2—Hand-Held Detector

This hand-held detector, under development by GDE, can detect buried, or similarly concealed, explosives. An improved version, to be completed in 1992, is being developed to produce imagery similar to that of GDE's technologically similar Vehicular Detection System.

SOURCE: General Dynamics Corp., Electronics Division, 1990.

The FAA has funded competitive development of weapons-detecting MMW radars at two companies: Battelle Pacific Northwest Laboratories (PNL) and Science Applications International Corp. (SAIC). At present, the FAA is funding only the Battelle PNL work. Other companies developing millimeter-wave radar technology applicable to weapons and explosives detection include Westinghouse (Advanced Technology Division, Baltimore), EVI, Inc. (Baltimore), and General Dynamics Corp.

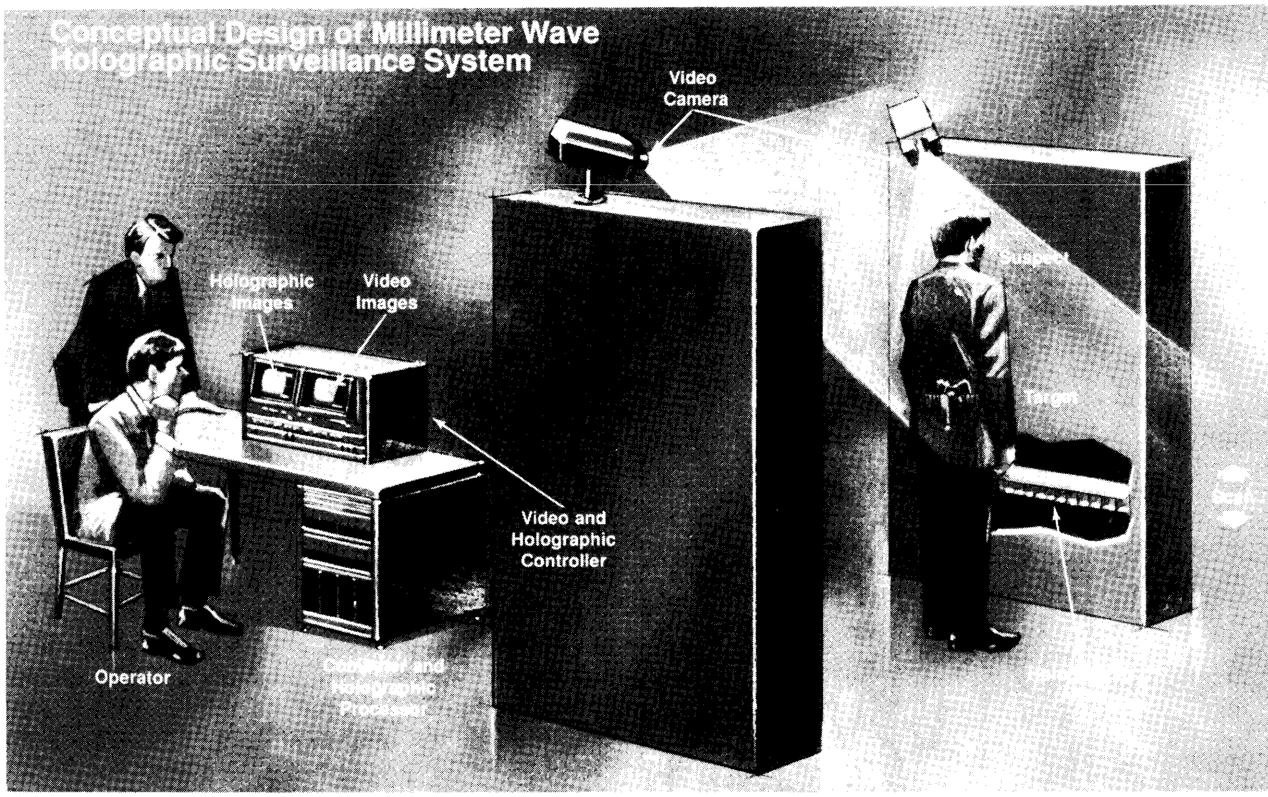
This section describes technology development by Battelle and Westinghouse. EVI, a leading designer of eddy-curent metal detectors, is still exploring conceptual designs for MMW weapon detectors. The General Dynamics system was developed for a different application. It is described in greater detail in chapter 7, incident Response (SECRET); only aspects relevant to weapons detection are mentioned here.

Battelle MMW

Battelle PNL is developing a "Millimeter-Wave High-Resolution Holographic Surveillance System" to permit security personnel to "frisk" suspects electronically and covertly for concealed metal or plastic weapons. Figure C-3 shows an artist's concept of an operational system. The device would obtain and store in computer memory a digitized millimeter-wave hologram (a three-dimensional image obtained using coherent radiation) of a "suspect" (possibly an ordinary airline passenger) recorded by mechanically scanning the subject with a linear array of millimeter-wave antennas. Presumably the suspect must be momentarily still while being scanned-i. e., move no more than a small fraction of a wavelength, which, at 35 GHz, is about 9 mm. Holographic images may be reconstructed from the stored hologram computationally and displayed on a computer graphics terminal. An operator may select and change the depth at which the reconstructed image is focused. If desired, a closed-circuit TV image of the suspect maybe displayed on a separate video monitor.

In 1989 Battelle demonstrated a developmental version of the system, obtaining the images shown in figures C-4 and C-5 by scanning the test objects in two directions with

Figure C-3—Artist's Concept of Millimeter-Wave Radar for Detecting Concealed Weapons



SOURCE: Battelle Pacific Northwest Laboratories, 1991.

a single antenna. Battelle is currently developing a linear array of antennas to permit recording of a hologram faster, in a single scan, and is investigating the possibility of a two-dimensional array real-time scanning system.

Westinghouse MMW Radar Technology

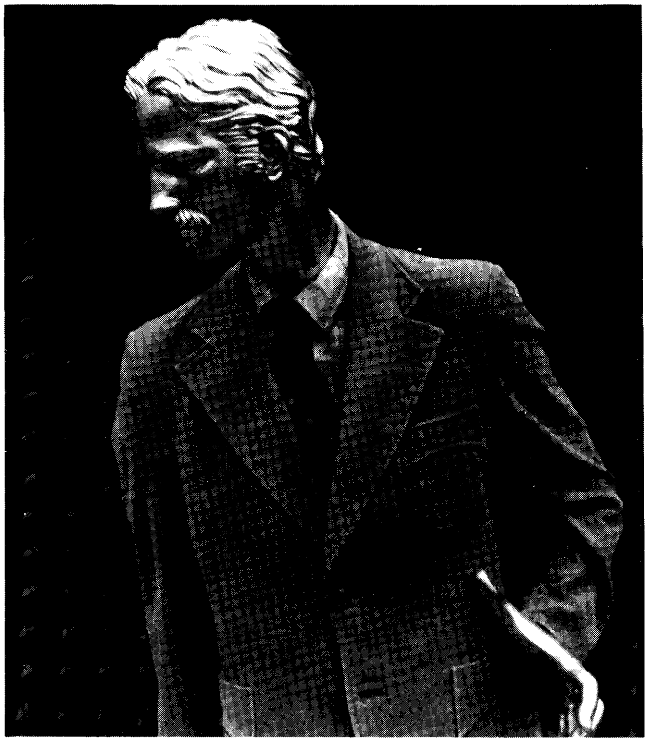
Westinghouse Advanced Technology Division in Baltimore is developing millimeter-wave radar technology applicable to weapons and explosives detection systems. The Westinghouse Electronic Systems Group responded to the FAA's Broad Agency Announcement of interest in weapons-detection systems by proposing to develop enabling components for a millimeter-wave weapon-detection system and to assess the potential of such a system. The system would use large (wafer-scale) gallium arsenide monolithic microwave integrated circuits (GaAs MMICs) similar to some that Westinghouse developed for DARPA and the Naval Research Laboratory (NRL). It would be used for short-range detection of weapons concealed on persons or in baggage.

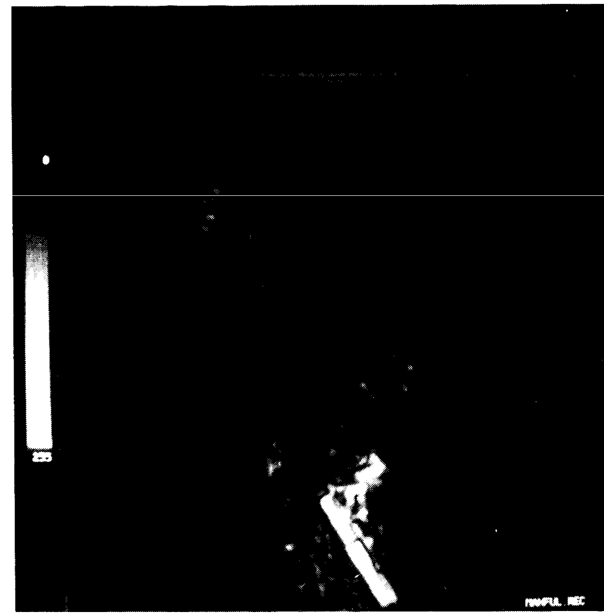
For the NRL, Westinghouse developed GaAs tiles (large chips), each containing an array of 16 antennas and integral detectors of 93- to 95-GHz millimeter waves. An array of such tiles was covered with a metal plate drilled with conical holes-one over each antenna-to concentrate received millimeter waves, increasing power at each antenna tenfold. The entire assembly would be used at the focus of a parabolic ("dish") reflector to provide a low-resolution image of millimeter-wave radiation sources.

For weapons detection, a similar system could provide imagery of millimeter-wave radiation reflected by weapon parts--e. g., a firing pin. Westinghouse estimates that a 10-milliwatt source would suffice for some applications and that the power-flux density of the millimeter-wave radiation at the target (e.g., skin) would be less than 10 milliwatts per square centimeter. Such an exposure, if shorter than 3 minutes, would comply with the current ANSI standard and NCRP guidelines. A weapons-detection system would include an appropriate millimeter-wave source.

Researchers at Westinghouse are interested in developing critical components-schottky-barrier diodes—for a weapons-detection system operating at 183 GHz. At this frequency, radiation from the source would be absorbed by the atmosphere in a much shorter distance than at 94 GHz, thereby reducing the potential of one weapons-detection system to interfere with a nearby one.

Figure C-4—Millimeter-Wave Radar Image of Metal Gun Concealed Under Clothing



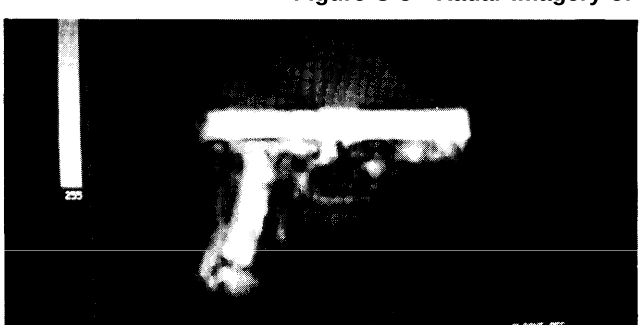


Left: Photograph of plastic mannequin wearing cotton/acetate suit concealing metal pistol.

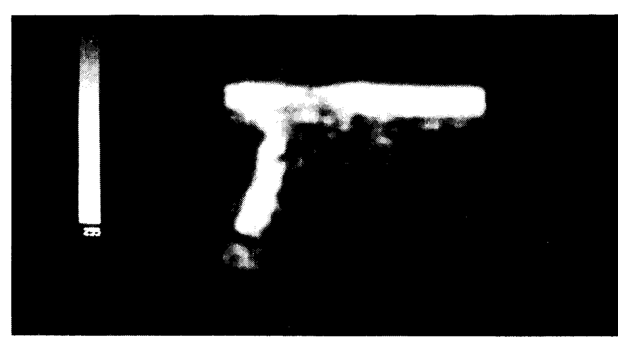
Right: 35-GHz radar image of mannequin and concealed pistol.

SOURCE: Battelle Pacific Northwest Laboratories, 1991.

Figure C-5—Radar Imagery of Glock-17 Plastic-Handled Pistol

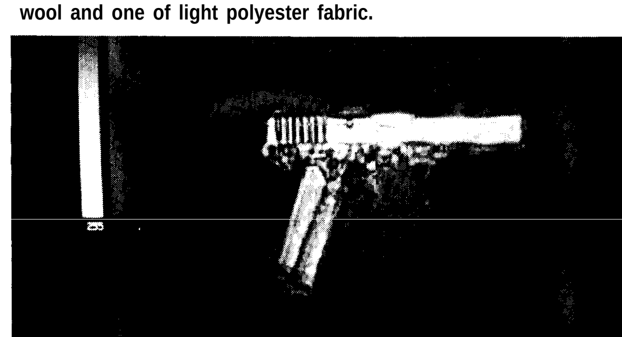


35-GHz radar image of Glock-17 pistol in air.



35-GHz radar imageofGlock-17 pistol behind one layer of heavy wool and one of light polyester fabric.

90-GHz radar image of Glock-17 pistol in air.



90-GHz radar imageofGlock-17 pistol behind one layer of heavy wool and one of light polyester fabric.

SOURCE: Battelle Pacific Northwest Laboratories, 1991.