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MICROWAVE APPLICATIONS TO TRANSPORTATION

Introduction

In view of the fact that microwaves first impacted our technology during or slightly before World War II, it is natural that the greatest number of microwave applications have been directed to the solution of military problems. Very advanced techniques have been developed and form the basis of many of our modern weapon systems. Development costs have been astronomical but were made possible by a very large military budget. Now with a shrinking military budget, thoughts must be directed toward applying microwave technology to other areas. At least one of these areas is transportation, both public and private. Although it does not begin to have the kind of federal budget that the Department of Defense enjoyed for many years, it can sustain a modest amount of development effort.

Microwaves are currently in wide use in transportation systems. Examples are the many thousands of miles of microwave links used by American railroads, radar speedometers used by law enforcement officers, radar controlled signal lights used in some urban environments and, of course, airborne and shipboard radars and the familiar ground controlled approach radar.

At the Transportation Systems Center (TSC) in Cambridge, Massachusetts, work is proceeding on a number of conventional applications as well as on more advanced and complicated developmental programs. As examples of the former kind, one may consider the development of an instrument landing system for civil aviation and the development of a harbor advisory radar for the Coast Guard to be used in monitoring our sea ports. To be sure,both of these tasks involve the solution of specialized and difficult problems. The harbor advisory radar for example must overcome sea clutter and rain clutter in choppy waters (a type 3 sea) to identify targets of two square meters ($2M^2$) cross sectional area for several miles. This requires shaped beam techniques to provide a narrow azimuth beam having circular polarization and the use of digital signal processing. The instrument landing system on the other hand will require high scanning rates for the antennas. Current thinking calls for the development of circular arrays. Requirements of 0 to 30^o elevation capability and $\pm 60^o$ azimuth scans at 30 scans per second involved formidable engineering problems.

It is the purpose of this paper, however, to focus attention on some of the more unconventional microwave applications under study at our Center and elsewhere in the United States and abroad.

Civil Aviation Security

(a) Passenger Surveillance

An imaging microwave scanner for screening aircraft passengers has been proposed by the Radio Corporation of America. In such a system, a passenger would be illuminated by monochromatic millimeter radiation. The reflected microwave signal would be imaged by a large lens on a light sensitive semiconductor plate. A light beam scanning the plate has the effect of changing the conductivity under the scanned area thus changing the reflectivity for microwaves. In this way, the image on the plate can be sequentially transcribed into a video presentation with a second short focus microwave lens projecting the image plate onto a horn and detector. This work is being sponsored by the Army Electronics Command at Fort Monmouth.

Preliminary work on both active and passive approaches to the problem of passenger screening is currently in progress at TSC. Special emphasis is being given to passive radiometric approaches to avoid political and legal entanglements certain to accompany active microwave transmission configurations. Present efforts are directed toward establishing emissivity values for persons, clothing and weapons.

(b) Bomb Detection

While hijacking has become a serious problem and has received a considerable amount of public attention in recent years, a problem of longer standing but equally dangerous has had official attention for an even longer period. This is the problem of preventing explosives from being placed on an aircraft by a saboteur or suicidal maniac.

A number of methods involving the detection of effluents from common explosives have been developed for this purpose and include microwave spectroscopy. In the past, this work was for the most part performed at X-band frequencies. Since microwave absorption lines are, however, generally stronger in the millimeter region and since the concentration of the effluent vapors in the ambient air are quite small, the microwave spectra of explosive effluent vapors are of potential interest and should be tabulated. TSC is currently looking into this problem and may institute some in-house research. It may be noted in passing that microwave methods once fully implemented and understood lead to positive identification of compounds while competing methods such as mass spectroscopy and gas chromatography frequently encounter difficulty in making unique identifications.

Crash Sensors

The National Highway Safety Bureau, now an Administration under the Department of Transportation, has issued regulations that all new cars sold in the U.S. and manufactured after July 1, 1973, (i.e., the 1974 model) must be equipped with "passive" restraints...that is, a passenger restraint system which operates with no action required of the driver (such as fastening seat belts). The most extensively investigated method is commonly referred to as the "air bag system." Impact of the vehicle with a significant obstacle, and resultant deceleration, triggers inflation of large balloon-like structures stored under the dash or in the steering column in approximately 30 milliseconds. This is a sufficiently long time interval to provide passenger protection before severe deformation of the vehicle has reached the passenger compartment. For small cars (some foreign) or higher impact speeds (above 30 to 40 mph), the front portion of the car will crush in a time too short for full deployment of the air bags (or other restraint system) to occur before the passenger compartment deformation begins. Hence, to increase the value of such passive restraints, it is necessary to detect impending collisions several feet prior to impact. For reasons of both safety and economics, it is important that deployment occur only for serious collisions... that is, there must be no false alarms. A promising concept is being investigated at TSC and is schematically illustrated in Figure 1. The system is a 10 Ghz. microwave CW Doppler radar. In operation, positive discrimination is achieved through use of separate transmitting and receiving antennas. An object is not detected unless it is within the region of overlap of the two antenna patterns so that transmitted energy is scattered or reflected into the receiving antenna only by the target as shown in Figure 2. This method of spatial discrimination makes possible acquisition of the required range formation and velocity information with very simple circuitry. An unmodulated CW microwave source is used. A one percent sample of the transmitted signal is applied to a crystal mixer, where it is mixed with the received signal. The rectified crystal output voltage is a function of the relative phases (at the crystal) of the transmitted and received signals, and the received signal amplitude. Velocity discrimination is obtained by insertion of a high pass filter in the receiver circuit eliminating response for low speed objects. A threshold circuit permits adjustment of the minimum reflected signal to which the system will respond so that targets of low reflectivity are ignored. A breadboard model of this system is now in use as a test bed for optimization of circuits, thresholds, and antenna patterns. Field tests and studies of radar reflectivity of typical targets are planned with a few specially equipped vehicles.

Automated Braking

Several companies such as Sanders Associates and Bentley Associates have developed devices to provide for constant or at least minimum headspace for vehicles on our highways. Such devices can be designed to provide for automated braking and/or alarm in case of an impending collision. In general, such devices are pulsed Doppler radars and must include suitable logic circuitry since both range and speed information must be obtained and processed without false alarm indication to prevent resulting crashes. This calls for FM or dual frequency operation and digital logic. Field tests of such instrumentation are now in process with moderate false alarm indications. Effort is needed in the development of instrumentation which is effectively "false-alarm free" before extensive use of the system is adopted. Further, the environment on our highways is unusually harsh and frequently consists of vibration and shock extremes, salt spray, sand, oil and gasoline fumes plus extreme swings in temperature which may vary from -50 to 120°F.

Railroad Grade Crossing Protection

Each year approximately 1200 people are killed and 3000 are injured in railroad grade crossing accidents. Eighty percent of the 225,000 rail-highway intersections in this country are protected only by passive signs, and these crossings are the scene of many collisions. A goal of the personnel of TSC with Federal Railroad sponsorships is development and implementation of new concepts for grade crossing protection, with the aim of achieving significantly lower cost, thereby permitting more widespread installation.

A major part of the cost of conventional grade crossing protective systems is associated with the use of track circuits. Not only does this make necessary a substantial installation effort, but also requires considerable engineering design in order to achieve a system which covers all rail traffic situations and is completely compatible with the various block signalling systems which may be in use. Further, the track circuit system, which has been used for many decades, has been developed to the extent that significant further improvement is unlikely. On the other hand, modern technology includes many diverse means of transmitting information between two points. It is appropriate, therefore, that these means be examined in detail for possible application to the grade crossing problem. One promising alternative approach now being implemented at TSC is based upon the use of a low-power, solid-state microwave communication link between the train sensing point and the crossing which is typically a distance of $\frac{1}{4}$ to $\frac{1}{2}$ mile. Fail-safe operation will be obtained by operating the sensing point transmitter continually and interrupting transmission only when a train is detected by a state-of-the-art sensor. Low duty cycle pulse modulation will permit operation with very low power consumption. The technique avoids much of the complexity and expense of conventional track circuit installations. This simple system is shown schematically in Figures 3 and 4. More complicated devices are also under investigation. These capitalize on the availability of an explicit communication channel in order to implement more sophisticated protective systems in circumstances where safety and public convenience warrant the additional cost. Such advanced systems include use of a single microwave transmitter to signal for several tracks in a multi-track case, or to provide activation of several closely spaced crossings; relaying of train velocity information for uniform advance warning time and measurement of total train length. Suitable signals can then indicate the advisability of motorists' choosing an alternative route when long, slow trains are imminent or provide for satisfactory accommodation of switching moves and station stops in the vicinity of the crossing.

Communications for High Speed Ground Transportation

Communication systems for high speed rail or tracked air cushion vehicles requires bandwidths of several hundred megahertz in order to encompass all of the requirements for control, voice and video transmission which will maintain constant and complete contact with a stationary environment. This bandwidth requirement automatically means a microwave command-control system since there are no channel allocations of sufficient bandwidth available from the FCC. For the transmission portion of the system, various configurations have been suggested in the past including several kinds of open waveguides such as the leaky coaxial waveguides (moderate bandwidth capability), leaky circular waveguides and a number of dielectric waveguides. The Japanese have performed a considerable amount of research and development on surface waveguides with comb structures and beam waveguides with reflectors.

The major thrust of the Japanese National Railways was made about ten years ago in planning and development of the telephone communication system for the new Tokaido line. A parallel conductor pair was adopted mainly from an economical point of view. More recently, a decision to use the leaky coaxial waveguide for the new Sanyo line was made. Installation during 1970 and beyond will cover a distance of 60 kilometers or 34 miles. The main features of the system include:

(1) Uniform coupling due to a regular radiation field by the zigzag arrangement of the slots.

(2) Controlled radiation depending on the slot design, which permits longer repeater spacings with a "graded design."

(3) Greater immunity to environmental conditions because of the protection offered by the outer conductor and the sheath.

(4) An IF-RF conversion system in which the IF band signals are used for repeating and the RF signals are used for coupling.

(5) A cable structure of the waveguide which greatly simplifies manufacture and installation

The Japanese plan to employ a PCM-FM modulation system which is less affected by the carrier channel signal to noise ratio and phase distortion than an FM system. Figures 5 and 6 show salient features of a leaky coaxial waveguide system.

Dielectric waveguides received a considerable amount of attention during the early stages of development of microwave technology. Simplicity of construction and the lack of critical requirements in the shape and dimensions of the dielectric element are the most appealing features of this type of waveguide. In addition, a lower attenuation can be achieved in a dielectric waveguide compared to conventional metallic waveguides without the difficulties arising from mode instabilities and generation of unwanted modes.

An experimental program has been conducted by the General Applied Science Laboratories in Westbury, New York to assess the feasibility of a new concept of a repeater station suitable for a dielectric waveguide communication system. The new concept does not require the physical interruption of the dielectric waveguide. A short element of auxiliary waveguide is used to extract a fraction of the signal which propagates in the main waveguide. The signal in the auxiliary waveguide is amplified and is coupled back into the main waveguide. This new concept eliminates some of the undesirable effects encountered in the feasibility study of a conventional repeater station configuration, which requires the physical interruption of the main waveguide. For convenience, the experimental program has been developed in the 10 gigahertz frequency region using the GASL test facility. The recommended operating frequency of the dielectric waveguide communication system is in the 4 gigahertz region. Thus, the repeater station components, and in particular the transition units, have been designed in such a way as to be applicable to the 4 gigahertz region. Figures 7 and 8 show certain features of the work conducted at GASL.

Many problems must still be overcome before practical systems operating over large distances becomes a reality. Mechanical structures are critical and curvature effects must be compensated for in design. Finally, the control function must be maintained, even when repeaters fail or other catastrophes occur. One solution for maintenance of the control function might be the immediate and automatic operation of emergency walkie-talkie communication. This must, however, be viewed as a crutch pending more suitable applications of microwave technology.

Aircraft Satellite Communication System

A major activity in which the United States and Europe is dedicated involves experimentation and development of elements of a satellite system which will provide telecommunication services to aircraft and maritime users over the Atlantic and Pacific Oceans in the 1975 time period and beyond. Much of this work has been motivated by a need to improve communication and radio location services to accommodate increased densities of air traffic across the oceans. The high incidence of collisions and groundings of maritime vessels, particularly in confluence areas, provides added impetus for work of this nature. Identification of parameters by FAA and NASA that require definition has led to the development of selected avionics equipment and the specification of field tests which will be required in order to firmly define such a system. TSC is currently involved in the execution of an experimental program which has as its goal the resolution of remaining unknown propagation parameters and the evaluation of the hardware developed. These experiments will use a series of high altitude balloon launches to simulate a satellite. Originally, it was hoped to use NASA's ATS-5 satellite as a transmitting station to acquire certain needed data. Unfortunately, malfunctions of certain equipment at time of launch on August 12, 1969, caused the satellite to tumble. Receiving equipment will be located in a CV-880 aircraft which has been made available to the program by the FAA facility at Atlantic City known as NAFEC. The frequency of operation occurs at L-band or 1540 to 1660 megahertz. As soon as necessary system parameters are defined, it is expected that an RFP will be issued for implementation of the satellite system.

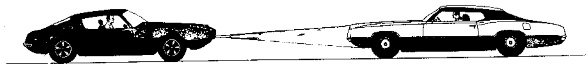
Conclusion

An attempt has been made to identify some of the potential applications of microwave technology to problems of transportation. The examples given are by no means all-inclusive nor are they necessarily the most important applications. If anything, they are a little less obvious than for example a microwave beacon transponder system now being contempated by the FAA. Many more general types of microwave links necessary for the military and private sectors also have applications to transportation. The field is large and challenging and requires only the exercise of American ingenuity and manufacturing expertise to enjoy greater use and application.

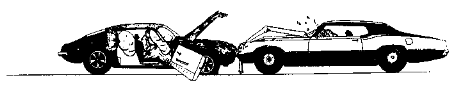
One very important feature, however, which makes consumer systems different from military systems is the aspect of cost. Systems must be cheap and must perform a needed function which cannot conveniently be performed by any other approach.

IMPACT SENSING

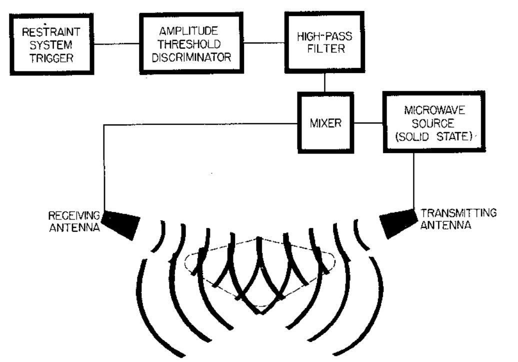
MICROWAVE TECHNIQUES

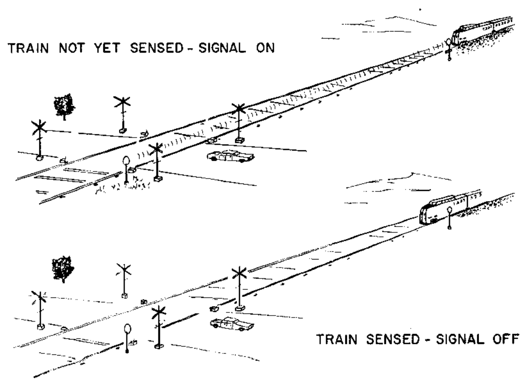


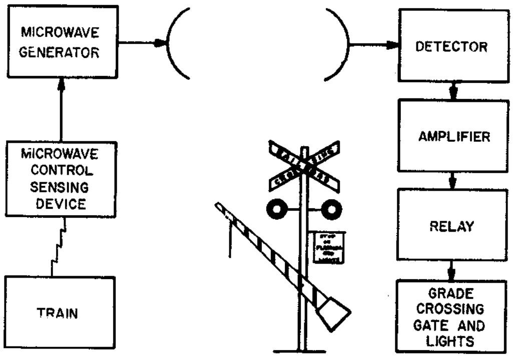
AIR BAG INFLATION

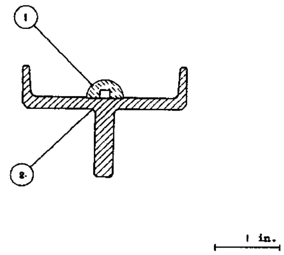


AUTOMOBILE CRASH SENSOR

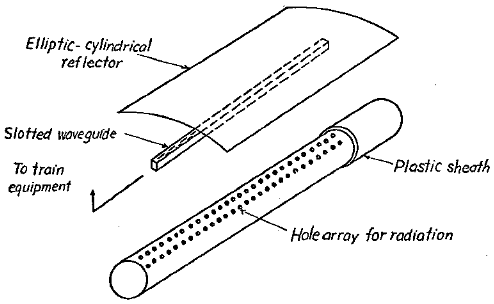




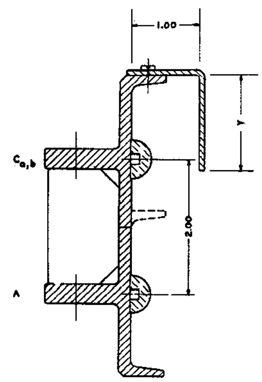




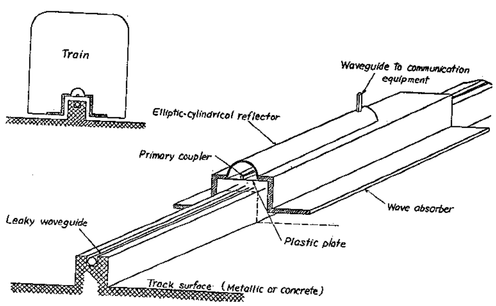
Cross Section of the Dielectric Waveguide:
(1) is the dielectric rod;
(2) is the metallic shield



Leaky circular waveguide and train coupler



Arrangement of Main Waveguide and Auxiliary Waveguide of the Repeater



Artist's view of arrangement of leaky waveguide and train coupler
(Half section of coupler is shown)

Notes