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MICROWAVE BASED CIVIL STRUCTURE INSPECTION DEVICE

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1994 Spring Meeting of the Materials Research Society
San Francisco, CA
April 5, 1994

*Managed by Martin Marietta Energy Systems, Inc., for the U. S. Department of Energy under contract DE-AC05-84OR21400.

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ABSTRACT

A microwave based "wall probe" has been developed which is capable of nondestructive evaluation of architectural structures. By using microwaves in the 8 to 12 GHz range this probing instrument can detect subsurface characteristics through concrete, brick, wood or other building materials to depths in excess of 12 inches.

The instrument interrogates a structure from a single side by transmitting a microwave signal into the surface at some angle of incidence and receiving the reflected signal some distance away on the same side of the structure. The transmitted signal is partially reflected at each internal boundary of different dielectric constant, giving a composite reflection which contains information from each internal layer. The reflected composite signal is compared in phase and amplitude to the transmitted signal and that reading is considered the "signature" of the structure under test. Computer algorithms analyze the signature for recognizable features and nonstandard construction.

INTRODUCTION

A complex of buildings in Oak Ridge, TN., built from terra cotta hollow clay tile blocks, was under study to determine its tolerance to seismic events. See Fig. 1. The normal engineering approach to the study included modeling typical walls and verifying the models with test samples. Test samples of the walls were removed from actual buildings and set up in the seismic lab to be tested. During the removal of wall sections it was discovered that the alternating courses of 8" and 4" blocks with courses of 4" and 8" blocks was occasionally interrupted. Some courses had 4" and 4" blocks while others had the flutes turned vertically. This probably resulted from material shortages during construction and exacerbated by a demanding completion schedule. This discovery generated doubt as to the as built status of the walls and therefore the validity of the seismic tolerance models.

To determine the as built status of the walls, a nondestructive technique was needed that could rapidly interrogate each block location and indicate the type of surface block, hidden block, and identify nonstandard combinations. Commercially available instruments were tried with less than acceptable results. Ultrasonic instruments lacked the necessary penetration to determine the type of hidden block and infrared thermography required heating the wall from the opposite side. Radiography was considered but locating a radioactive source on opposite side of the wall was inconvenient and posed personnel safety concerns. The need for a new instrument was apparent so the development of the microwave based wall probe was initiated.

*Work supported by the U.S. Department of Energy under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

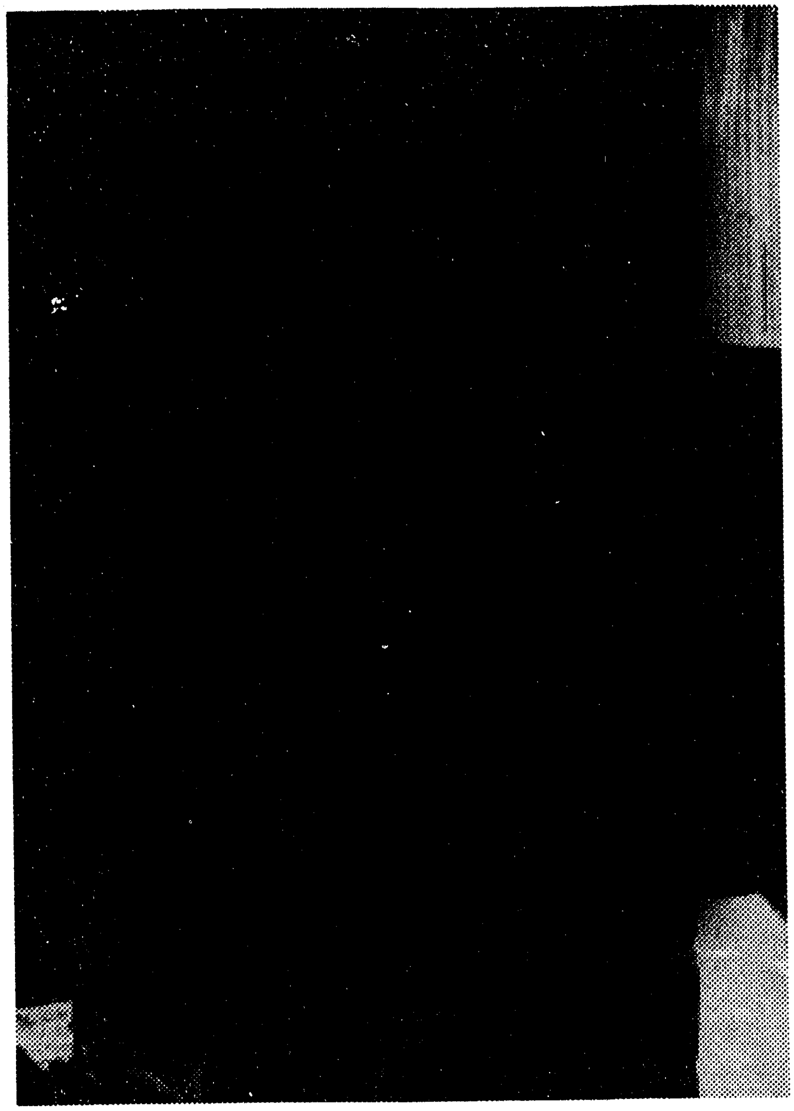

Fig. 1 Terra Cotta Tile Block Wall System

INSTRUMENT DESIGN

After studying the response of terra cotta to microwaves over a wide range of frequencies, the configuration shown in Fig. 2 was determined to be a reasonable approach to a prototype instrument. A description of the separate instrument systems follows.

<u>Microwave System</u>

The microwave source used for this instrument is a HP Model 8350A with an 86290C plug-in, under control from the system computer discussed in a later section. The microwave signal is split with a Sage Laboratories, Model 4234 microwave splitter to develop a probing signal and a reference signal. The probing signal is launched into the terra cotta block system by a transmitting horn of moderate gain [1]. As the microwave signal penetrates the blocks, a portion of the signal is reflected at each dielectric boundary while the remaining signal

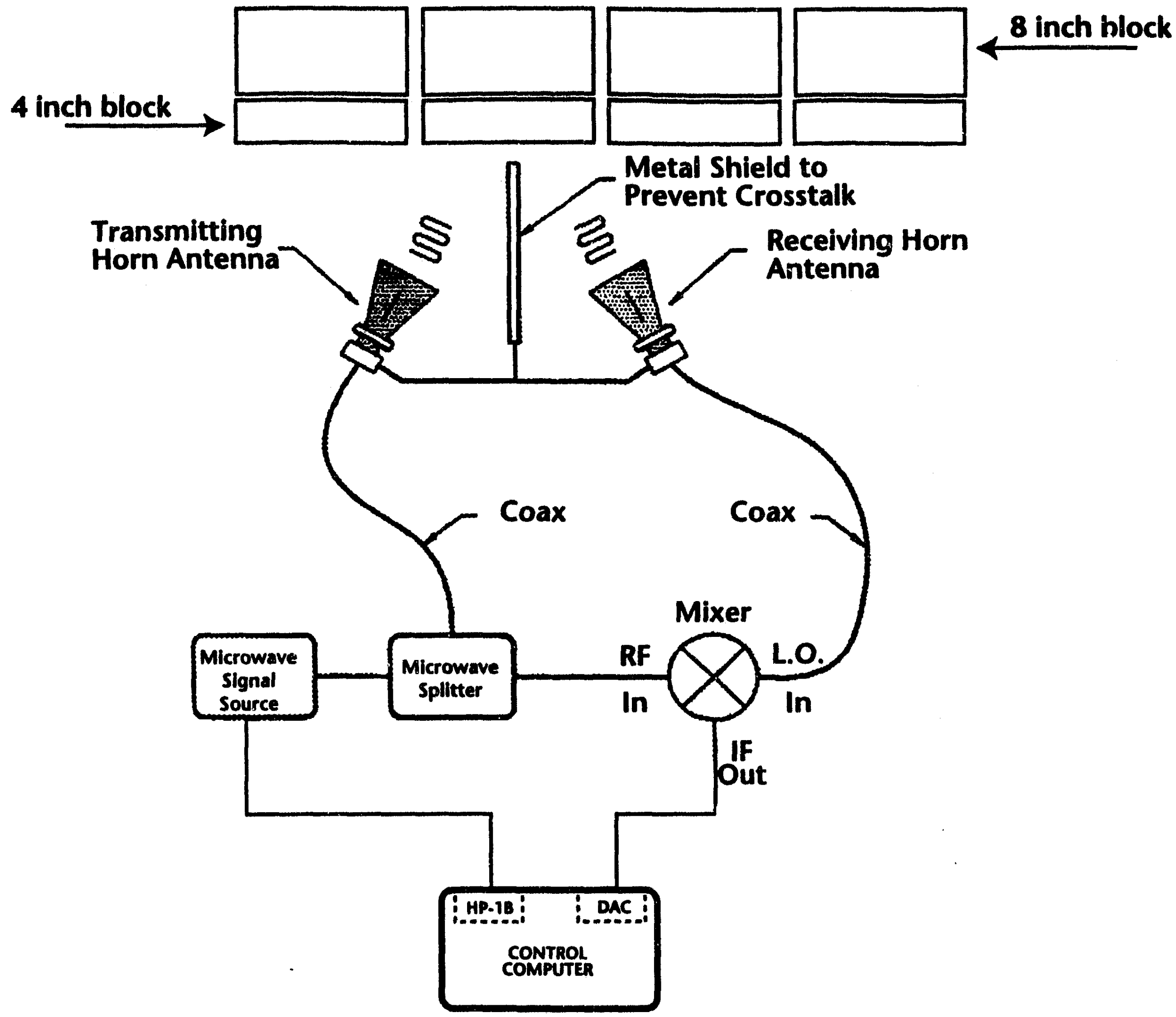

Fig. 2 Microwave Based Wall Probe System

penetrates deeper into the block system. The reflected signal has an angle of reflection equal to the angle of incidence, thus emerging from the block system on the same side it entered. The remaining probing signal continues to be partially reflected at each dielectric boundary and the reflected signals combine to form a composite reflection. As each reflected signal component propagates back out of the block system, it has a phase angle dependant on the total distance traveled. The amplitude of each reflection is also affected by the distance traveled and the attenuation of the material penetrated.

The resulting composite signal is picked up at the receiving horn and contains multiple constituent reflections, each having a phase angle and amplitude dependant on its path through the block system. As the microwave generator frequency is swept from 6.5GHz to 9.5GHz, the composite signal varies in phase and amplitude relative to the reference signal. When the reflected composite is compared to the reference signal by a balanced mixer, Model M77C sold by Watkins Johnson, a sum and difference of the composite reflected signal and the reference signal tends to be generated. The sum frequency is twice the operating frequency of the generator and is beyond the bandwidth of the mixer. The difference signal is a direct current (DC) voltage, containing both phase and amplitude information. The DC voltage from the balanced mixer is applied to an analog input on the computer where it is measured and recorded.

Computer System

The computer system is a Compac 486C Portable with DOS, Windows, and Lab Windows. It controls the microwave generator, reads the analog voltage from the balanced mixer, and analyzes the data or signatures resulting from scanning the unknown blocks.

Control of the HP microwave source is via an HP-IB bus that initializes the generator and increments the output frequency when a test is performed. RF output levels are set to 15dBm which is low enough for personnel safety and high enough to penetrate into and out of the terra cotta block wall. After scanning an unknown, the output of the generator is effectively turned off to minimize unnecessary personnel exposure to RF. An analog to digital converter (ADC) is used to read the voltage from the balanced mixer. After a reading is made, the generator is incremented 1.0MHz and another reading is taken from the balanced mixer. This process continues over the 6.5GHZ to 9.5GHz range which was experimentally determined to be the most unique range for the type blocks tested.

Data Analysis

A typical response of the microwave system to scanning a block set is shown in the upper right corner of Fig. 3. There, the output of the balanced mixer is plotted against the output frequency of the microwave generator and a typical signature results. The positive and negative responses are a result of repetitive phase reversals between the generator reference signal and the reflected composite signal. The peak amplitude variations are dependant on the relative amplitude of the reflected composite. The degree of signature variation is dependant upon the degree of variation in blocks tested.

During the seismic study program, a test wall was constructed of terra cotta blocks in normal and abnormal patterns and used to assess various NDE instruments for potential use in the field. The test wall was well documented so it could be used to develop a data base of signatures for all likely block combinations expected in the field. Each block set was "scanned" with the microwave wall probe and the response or signature was stored for each of the tests. Data was recorded for 180 known samples representing 12 different combinations of construction.

Each time a scan was made of an unknown, the resulting signature was translated into an "signature envelope" as shown in the lower right side of Fig. 3. The envelop is defined as the area between a line connecting the positive peaks and a line connecting the negative peaks. When all the available known blocks were scanned and recorded, those of like construction were grouped together and averaged. The average envelop for a particular block type was stored in memory as a reference.

The possible combinations available from the test wall are listed on the left side of Fig.3. As a new unknown is scanned, a signature envelop is generated and compared to the data base containing the known wall combinations listed to the left of Fig. 3. The difference between the new signature envelop and the known envelops is calculated and the closest match results from minimum difference between envelops. The computer display shows the magnitude of error between the new unknown and each known and illuminates an indicator by it "selection". The selection made by the computer

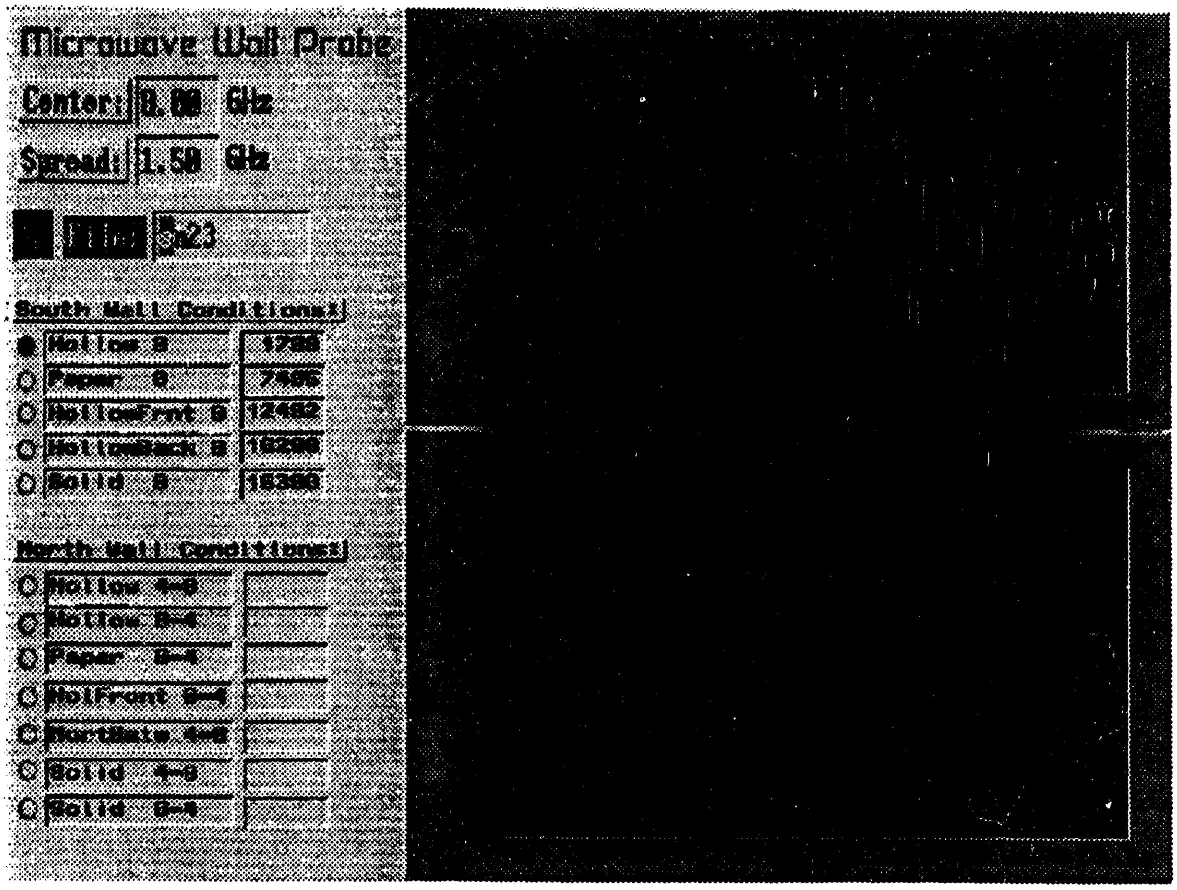

Fig. 3 Computer System Display

CONCLUSIONS

Microwaves can be used to probe a nonmetallic structures and objects [2]-[3] resulting in unique signatures dependant on the internal characteristics of the target. Comparing new signatures to known signatures provides a powerful diagnostic tool.

The technique described here could be applied to other inspection applications, such as:

- Bridge inspection
- Monitoring composites for voids
- Concrete encased rebar inspection
- Locating buried PVC pipes
- Inspecting surfaces for absorbed moisture

Motion detection in adjacent rooms

This relatively simple signature development and recognition technique could replace more expensive imaging techniques in some applications. Microwave diagnostics could therefore be used in a wider range of applications.

ACKNOWLEDGMENTS

R. I. Crutcher and S. R. Maddox were involved in the development of the original microwave based wall probe. Funding for the project was supplied by the Center For Natural Phenomenon Engineering at the Y-12 Plant in Oak Ridge, TN. The plant is operated by Martin Marietta Energy Systems for the Department of Energy under contract DE-AC05-84OR21400.

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MICROWAVE BASED CIVIL STRUCTURE INSPECTION DEVICE

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Department of Energy questions seismic tolerance of terra cotta block buildings at Y-12 Plant in Oak Ridge

Hundreds of buildings are involved, some four and five stories tall

Study undertaken by the Center for Natural Phenomenon Engineering, a division of Martin Marietta, the operating contractor

Study reveals non-standard assembly in random wall samples

As - build condition in question, compromising validity of seismic models

Spin - off study initiated to determine as - built status of vast facility

NDE TECHNOLOGIES TRIED

- **Ultrasonics lacked penetration**
- **Infrared lacked resolution and simplicity**
- **Radiography required "Source"**

Need for new technology was apparent

DISCOVERED MICROWAVES ARE PARTIALLY REFLECTED BY DIELECTRIC BOUNDARIES IN TERRA COTTA BLOCKS

Microwave Attributes:

- **Low power interrogation from same side**
- **Signal penetrates to hidden blocks**
- **Composite reflection depends on all layers**

OTHER APPLICATIONS

- Bridge inspection
- Monitoring composites
- Locating hidden PVC pipes
- Inspecting surfaces for absorbed moisture
- Motion detection in adjacent rooms

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