Development of Scanning Free-Space Measurement setup and its application to structural imaging.

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ABSTRACT

This paper proposes a scanning free-space measurement (SFSM) setup for the evaluation of microwave absorption properties of a structure. The system works by illuminating the specimen with microwave signals of varying frequencies and measuring the power of reflected microwaves. The reflected power is then divided by the emitted power in order to convert the measurements to the standard parameter known as S_{11}. The system comprises of a vector network analyzer (VNA) to measure S_{11} parameter, focused horn antenna attached to the VNA for transmitting/receiving microwave signals, a dual-axis automated translation stage for raster scanning of the specimen and a standard personal computer. A graphical user interface (GUI) running on the computer manages the configuration and synchronization of the VNA and the stage system, S_{11} reception from VNA and compilation of results for display to the user. The GUI is created in C++ using Qt framework and Qt Widgets for Technical applications (QWT). It is designed with a minimalistic approach to promote usability and adaptability masking the intricacies of actual system operation.

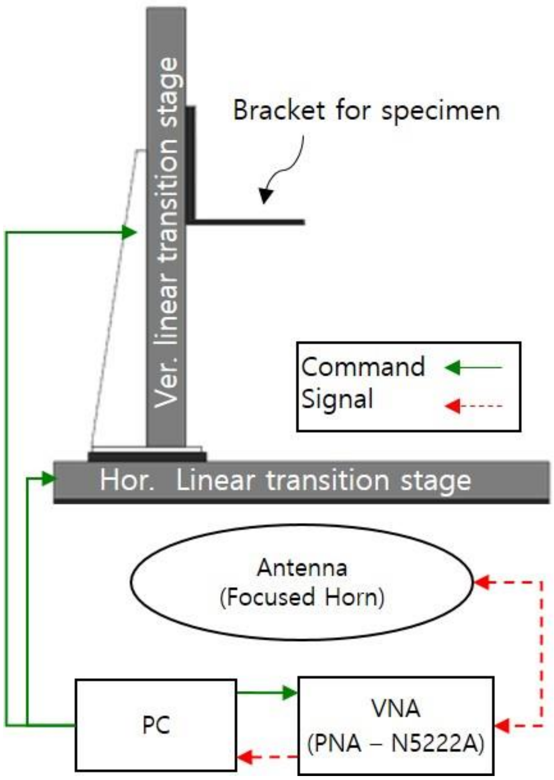
1. INTRODUCTION

Microwave absorbing stealth material design and its applications have been the subject of serious research due to its applications in defense as well as civilian use (K. J. Vinoy, & R. M. Jha, (1996)). This has created a host of new cross-discipline research challenges in design, production and evaluation of structures made up of such materials. Free-space measurement methods, employed for the evaluation of such structures provide inherent advantages of being contactless and nondestructive (Deepak K.Ghodgaonkar, Vasun V.Vardan, & Vijay K.Vardan (1989)). Thus, these methods are suitable for in-situ evaluation of stealth structures. Free space measurement comprises of measuring and calculating a number of parameters including reflection coefficient (S11), transmission coefficient (S_{21}), electric permittivity, and magnetic permeability (Kurokawa.K (1965)), (D.K.Ghodgaonkar, V.V.Vardan, & V.K.Vardan (1990)).

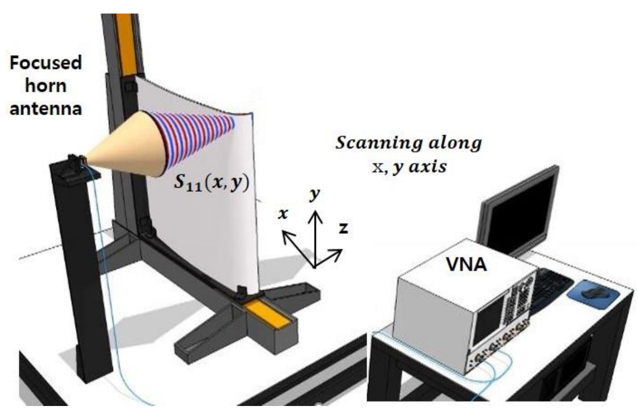
This paper proposes a scanning free-space measurement (SFSM) setup for measuring S_{11} parameter by illuminating the specimen with microwave signals of varying frequencies and measuring the power of reflected microwaves. The reflected power is then divided by the emitted power in order to convert the measurements to S_{11}.

2. SFSM SETUP

The SFSM setup comprises of a vector network analyzer (VNA) to measure the S11 parameter, focused horn antenna attached to the VNA for transmitting/receiving microwave signals, a dual-axis automated translation stage for raster scanning of the specimen and a personal computer for hosting the graphical user interface (GUI) software. Fig.1 (a) shows the connections among these system components. It is evident that GUI software running on the PC is controlling the linear stages and the VNA and receiving the measured S11 values. This GUI is created in C++ using Qt framework and Qt Widgets for Technical applications (QWT). It allows the user to move the specimen mounted on the translational stage to the desired location in front of the antenna before the start of a scan. GUI also performs initial VNA configuration such as frequency sweep range, sweep points, power and inter frequency bandwidth. During the scan, both the vertical and horizontal stages are controlled in tandem to make a raster scan pattern. VNA is triggered at each scan point to perform a measurement and report the data back to PC. In order to ensure the correctness of measured values, the scan stage is brought to a complete rest at each scan point before triggering a measurement. Multiple threads, each with a separate task, are programmed in order to maximize the efficiency of GUI running on a multi-core processor. Figure.1(b) shows the rendition of the same setup in actual setting.



a)



b)

Figure 1. SFSM setup a) block diagram showing signal and command connection in the system b) rendition of actual system in operation

Data received during the scan is stored in a 3-dimensional array with one dimension each for height and width of the scan area and one dimension to represent the number of frequency measurements at each scan point. Fig.2 shows this 3-dimensional arrangement of data in memory buffer. This data can then be viewed in a 2- dimensional frame in which each point corresponds to a scan point in the scan area. Such a data representation can clearly show the difference in reflectivity for a heterogeneous structure comprising of different materials. Additionally, owing to the scattering or diffraction of electro-magnetic waves, any curves or edges in the structure will also be visible. Point wise view of the measurements from a single scan point may also be viewed by clicking on the respective point.

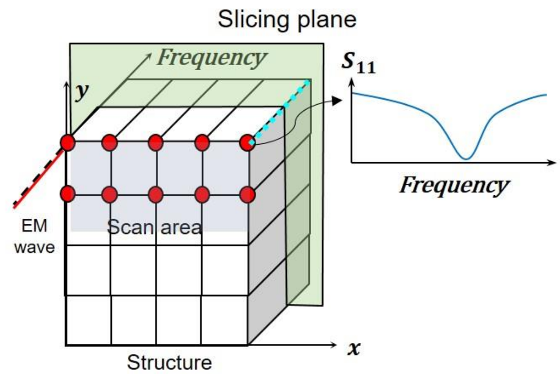


Figure 2. Data representation of measured S_{11} parameter.

3. RESULTS

In order to validate the setup an aluminum specimen (width: 290mm, Height: 220mm thickness: 1.7 mm) was scanned. S_{11} parameter was calculated for a frequency range of 8.2GHz~12.4GHz with 801 sweep points. A scan area of Width: 475mm, Height: 375mm and interval :25mm was selected in order to fully cover the whole specimen. Focused horn antenna with a spot size of 25mm was used. Since aluminum is an excellent reflector of microwaves the scanning clearly shows the specimen and its edges in front of the background which has poor reflectivity. Figure.3(a) shows the specimen mounted on the bracket and fig3(b) shows a freeze frame at 10.50 GHz frequency. The result shows the shape of the specimen as well as the correct width and height. It is also evident from the scan that the reflectivity at the edges is not as good compared to the plane surface.

Figure 4 shows the result from a specimen provided by Agency for Defense Development (ADD). A scan area of width: 375mm, height: 375mm, interval: 25mm was used for the inspection. All other settings are same to those of the scan result in fig.3. Since the specimen comprises of homogenous material, the frame wise view does not show any special difference among the scan points. However, the point wise view clearly shows reflection loss in all the tested frequencies with maximum loss of -33dB at 9.917GHz. The x=0,y=0 describe the point chosen for the plot, which in this case is the start point of the scan located in the top left corner of the

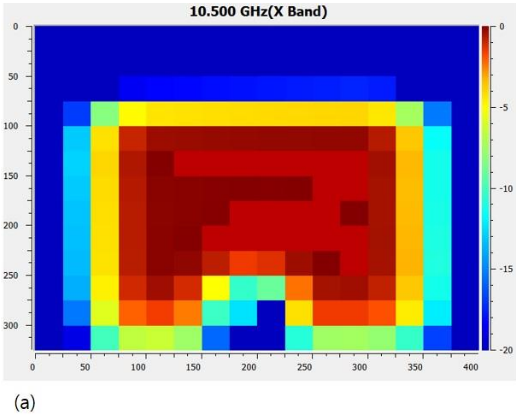


Figure 3. Aluminum specimen scan results a) Scan frame at 10.50 GHz b) Specimen and its mounting bracket

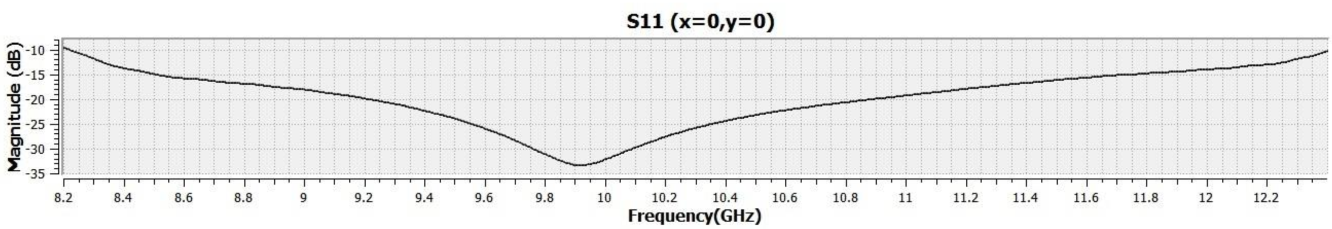


Figure 4 ADD specimen showing frequency selective absorption at 9.917GHz.

mounted specimen. Again, due to the homogenous nature of the specimen all the points in the scan show similar frequency responses.

4. CONCLUSION

This paper proposes a scanning free-space measurement system to evaluate the microwave absorption capability of structure. It comprises of a VNA, focused horn antenna, dual-axis stage and a PC for control. Currently the system relies on reflectivity (S_{11}) measurements and the scan results can detect reflectivity of each scan point and any curves or bends in the specimen. GUI is prepared to control the setup and organize the measurement data from the scan. The measurements are stored in a 3-dimensional array with a dimension each for the height of the scan, width of the scan and frequency measurements at a scan point. This data organization allows for access to data in a frame wise or frequency wise fashion. Currently, the setup supports single horn antenna for measuring the reflectivity parameter but we plan to upgrade the setup to include another antenna for measuring free space parameters such as transmission coefficient (S21), electric permittivity, and magnetic permeability.

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BIOGRAPHIES

Hasan Ahmed is pursuing PhD since Mar 2016 at the department of Aerospace Engineering in Korea Advanced Institute of Science and Technology, South Korea under the supervision of Prof. J R Lee. Before starting his PhD, he was a Senior Engineer at Samsung Electronics Co., Ltd working on modem-chipset for hand-held devices. He served in Samsung from Mar 2009~Mar 2016. The chipsets developed by the team have been used in flagship phones such as S3, S4, S6 etc. He did his MS from department of Electrical Engineering in Korea Advanced Institute of Science and Technology, during Mar 2007~Mar 2009, under the supervision of Prof. In-Cheol Park in the area of Very Large Scale chipset development. Prior to his MS, he worked on digital signal processing algorithms for ground surveillance RADAR during May 2005~Mar 2007. He did his BE in computer Engineering from College of Electrical and Mechanical Engineering, Rawalpindi, Pakistan during Dec 2000~May 2005. He has published 3 papers in international conferences. His research interests include structural health monitoring, ultrasonic imaging and free space measurement systems.

Jong-Min Hyun was born in Daegu, South Korea. He is currently working towards an MS degree about free space measurement of stealth & radome structures at the department of Aerospace Engineering at Korea Advanced Institute of Science and Technology. He has authored or coauthored 3 papers in international conferences. His research interest includes microwave absorbers, frequency-selective surface and free space measurement system.

J R Lee (Full name in Korean: Jung-Ryul Lee) is associate professor of the Department of Aerospace Engineering in Korea Advanced Institute of Science and Technology, South Korea. He served as a co-director of the Engineering Institute-Korea between Los Alamos National Lab and Chonbuk National University from July 2011 to Dec 2014. He was a visiting scholar of Los Alamos National Laboratory in US from Aug 2013 to July 2014. He received his MS from KAIST in Korea, and Ph.D from Ecole Nationale Superieure Des Mines de Saint-Etienne in France with the 1st class honor in 2004. Before joining the university, he has been a scientific staff member at the National Institute of Advanced Industrial Science and Technology in Japan and a research associate at Ecole Nationale Superieure Des Mines De Saint-Etienne. His research interest includes Smart Hangar (Inventor), integrated systems health monitoring, fiber optic, remote and wireless sensing, advanced nondestructive evaluation and measurement, pyroshock, laser ultrasonics, optics in engineering, microwave imaging, and diagnostic artificial intelligence. His application field encompasses space launchers, unmanned air vehicles, engines, wind turbines, power plants, railway structures, automobiles, public safety and radome/stealth structures. He has published over 300 articles and patents in this area, and received several awards, including Emerging Researcher Award in 2007 by the Japanese Society for Nondestructive Inspection, one of 16 Excellent Emerging Researchers Award in 2011 by Ministry of Education, Science & Technology in Korea, Excellent R&D Achievement Award in 2013 by Jeonbuk Province, and Young Scientist Awards in 2015 and 2016 by Korean Composite Material Society and International Sustainable Aviation Research Society (SARES), 2016 KAIST R&D 10, respectively. His research team was appointed as Global Research & Development Center in 2011 and Boeing-KAIST Technical Contact Lab. A proof-of-concept paper of Smart Hangar authored by him and his student won the grand prize of the best papers in 2013 from Ministry of Land, Infrastructure and Transport in Korea. He serves a co-chair of International Conference on ASHMCS2012 and 2014, and an editorial board member of SHM-IJ, ACM, MST. He produced 2 professors in India and Malaysia and 6 Ph.Ds by Feb 2016.