DEVELOPMENT AND TESTING OF THE TIME-DOMAIN MICROWAVE NON-DESTRUCTIVE EVALUATION SYSTEM

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INTRODUCTION

There has been a continuing pursuit in developing an ultra-wideband (UWB) time-domain microwave impulse radar nondestructive evaluation (NDE) system at the University of Illinois at Urbana-Champaign [1]. The UWB time-domain microwave NDE system employs a low power and UWB monocycle pulse source [1]. The advantages of the UWB time-domain system are its better spatial resolution, more information of the test targets, and shorter measurement time. However, the time-domain system suffers a worse signal-to-noise ratio (SNR) compared to the frequency-domain system. In order to improve the SNR of the time-domain system, the averaging (stacking), time-gating, and wavelets techniques [8,9] can be applied to the measurement data.

The collected time-domain measurement data can be processed with nonlinear iterative inverse scattering imaging algorithms such as the distorted Born iterative method (DBIM) [3,4] and the local shape function (LSF) method [5,6] or the linear algorithm such as diffraction tomography [10]. The DBIM and LSF methods account for multiple scattering effects of the test targets and have a high resolution image reconstruction capability. However, when the multiple scattering phenomenon is not significant, the first order Born approximation method such as diffraction tomography can be used in order to save the intensive computational time of DBIM and LSF methods. In the past, the DBIM and LSF methods have been demonstrated to generate high quality reconstruction images for small metallic and dielectric objects [1]. In this paper we show the image result from a larger test target by applying the diffraction tomography to save the intensive computational time.

UWB TIME-DOMAIN MICROWAVE NDE SYSTEM

The DARPA panel defined the ultra-wideband radar as "Ultra-wideband radar is any radar whose fractional bandwidth is greater than 0.25, regardless of the cen-
fractional bandwidth is defined as \( \frac{2(f_h - f_l)}{(f_h + f_l)} \), where \( f_h \) is the upper limit of the frequency bandwidth and \( f_l \) is the lower limit of the frequency bandwidth. The transmitting monocycle pulse source signal [1] employed in the UWB microwave NDE system does not satisfy the UWB definition.

The system block diagram of the UWB microwave NDE system is shown in Figure 1. The NDE system consists of a Hewlett-Packard (HP) 54120B digitizing oscilloscope mainframe, an HP 54121A 20 GHz four-channel test set, a Picosecond Pulse Lab (PSPL) 4050B voltage step generator, a PSPL 4050RPH remote pulse head, two PSPL 5210 impulse forming networks, two UWB amplifiers, a dual stepping motor positioning system, and an UWB antenna system. There are two different types of UWB antenna systems, Vivaldi antenna [7] array and ridge horns synthetic aperture radar (SAR) system, employed in the UWB microwave NDE system. The whole NDE system is controlled and automated by a personal computer via the IEEE-488 bus. The PSPL 4050B step generator with the PSPL 4050RPH remote pulse head generates a 10 volt, 45 ps rise-time pulse. A 1.5 volt, 10 GHz monocycle pulse is generated by attaching two PSPL 5210 impulse forming networks [1]. The reason of using the monocycle pulse as the transmitting source is to match the operational frequency bandwidth of the antennas. Figure 2 shows the Vivaldi antenna and Vivaldi antenna array. The Vivaldi antenna array consists of five transmitting antennas and six receiving antennas. Those antennas are separated by 8 cm each. Figure 3 shows the ridge horns antenna SAR system. The SAR systems consists of a pair of a ridge horn antennas, a dual stepping motors system, and a two-dimensional positioning table. The UWB amplifier at the transmitting port is a 30 db gain, 23 dbm output power amplifier and the low noise amplifier at the receiving port is a 20 db gain, 10 dbm output power amplifier.
MEASUREMENT DATA PROCESSING

The measurement system data acquisition and calibration procedures has been explained in [1]. The time-domain system suffers a worst signal-to-noise ratio (SNR) compared to the frequency-domain system. In order to improve the SNR of the time-domain system, the time-gating function, the averaging (stacking), and wavelets techniques [8,9] can be applied to the time-domain measurement data. The time-gating function can be applied to the measurement data in order to remove the unwanted early time and late time arrival signal. The statistical errors can be reduced by an internal averaging function of the digital sampling oscilloscope. The averaging number is up to 2,048 in the HP 54120B digitizing oscilloscope mainframe. For example, the noise level is reduced by the factor of $\sqrt{n}$, that is, 18 dB reduction for $n = 64$. The wavelet technique can also be applied to denoise the time-domain measurement data [8,9]. Figure 4 shows the noise reduction when the wavelet technique is applied to the measured time-domain signal.

The inverse scattering imaging algorithms for the NDE systems include nonlinear iterative algorithms such as DBIM [3,4] and LSF [5,6], linear first order algorithm diffraction tomography [10]. The nonlinear iterative algorithm can account for the multiple scattering phenomenon which is a nonlinear effect of the scattering mechanism of the test targets. The linear algorithm is much faster although it does
not account for the multiple scattering phenomenon. The DBIM and LSF methods have been applied successfully to process the data from a plastic pipe and a small metallic cylinder embedded in a concrete block [1]. Here, we show the diffraction tomography reconstruction image result from a larger tested target. Figure 5 shows the diffraction tomography reconstruction image of a metallic cylinder (5 cm diameter) embedded at 15 cm beneath a cement slab.
CONCLUSIONS

We have presented a prototype ultra-wideband time-domain microwave NDE system developed at the University of Illinois at Urbana-Champaign. This microwave NDE system has several features different from other commercial systems on the market, such as low power and ultra-wideband frequency bandwidth. The system can achieve high resolution image with test targets located in air or in shallow subsurface. Its ultra-wideband frequency bandwidth can provide much more information for target sensing, classification, and evaluation purposes.

REFERENCES


Figure 5. The diffraction tomography reconstruction image of a metallic cylinder embedded in a cement slab.
