Effects of the Span of the Calibrating Frequency Scan on Resolution of Microwave Electronic Distance Measurements

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Abstract-In microwave electronic distance measurement (EDM) sensors, the accuracy of results depends on the resolution of the measurements. This paper deals with the effects of calibrating frequency span on the resolution of microwave measurements. The isolated parameter is reflection coefficient (S_{11} dB) of wide band horn antenna and the reflecting materials selected are copper and water because of the higher reflectivity. A number of reflections measurements have been performed between horn and copper plate and when the same antenna is placed in front of water in PVC pipes for different range of calibrating frequency spans. The results show that the resolution of measurements improves with the enhancement of calibrating frequency span.

Keywords-Horn, S_{11} dB, EDM and Frequency Span

I. INTRODUCTION

At September 2014, the possible trend of measurements systems is remote sensing [i-iii]. These sensors collect a large amount of 3-D coordinate data from visible objects in the range and can be used in a wide variety of automation applications, including object shape acquisition, mobile robot navigation [iv, v] and medical diagnosis of Tumor detection [vi, vii]. Some market based sensors for electronic distance measurements (EDM) can be found in [viii-x]. These sensors work on the principle of microwave reflections from the object whose distance has to be measured. The total time of flight is calculated from the source to the object and then this time is converted to distance domain. But the main issue in all such sensors is the accuracy of the measurements which varies from sensor to sensor and application to application.

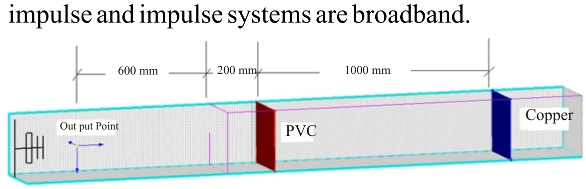
Our intent in these simulations and experimental work is to find out the factor effecting the accuracy of the measurements of microwave sensors. It has been observed in this research that this factor is the span of calibration band width and it for this reason that this research work will help makers of microwave sensors in the market to compete for better sensors production and capture the costumers.

II. METHODOLOGY

Two different types of situations have been selected for performing these experiments. In first case horn antenna was placed at varying distances (Horizontal) from the copper and Polyvinyl Chloride (PVC) plate. These two types of plates were so selected just to have different levels of reflection due to the difference in their electrical conductivity. While in second set of measurements a real time application of water flowing inside a PVC pipe was selected and horn antenna was placed at varying distances (Vertical) from different water levels inside. The difference of electrical conductivity in this case also holds true.

III. SIMULATION RESULTS FOR THE FIRST CASE

As mentioned in first scenario copper plate was placed behind a PVC plate in front of a plane wave excitation and the simulation package used was CST Microstripes. The setup is shown in Fig. 1. It is important to mention here that the scenario used and impulse and impulse systems are broadband.



Dimensions of Plates: 250x250x3 (cubic mm)

Fig. 1. Placement of copper and PVC plates in front of plane wave excitation

In this system the transducer will emit energy towards the pair of PVC plates and according to the literature larger amount of energy will be reflected if in case the incident wave impinges on a surface with greater characteristic impedance than the one in which it is propagating. Similarly larger amount of energy will be transmitted if in case the incident wave impinges on a surface with lower characteristic impedance than the one in which it is propagating. So it is expected that in this case copper plates will have more reflections than transmission and vice versa for PVC plates due to higher electrical conductivity of copper metal. The dimensions of the plates were large enough to avoid the unnecessary diffraction at the edges of the plates. The simulation results for the above setup are given in Fig. 2.

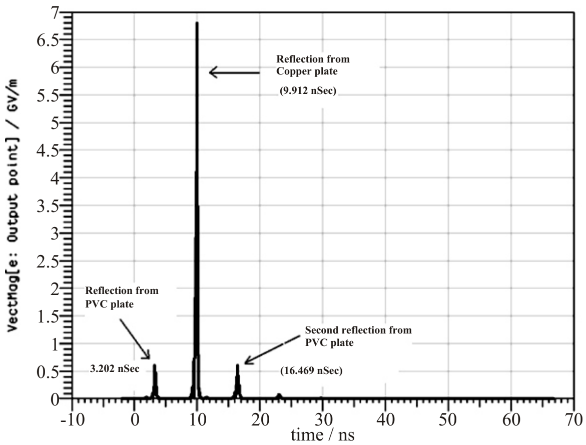


Fig. 2. Reflections from copper and PVC plates

It is clear from Fig. 2 that two types of reflections were achieved in the process. First reflection was from PVC plate and the other one was from copper plate. The occurrence of reflection for PVC was at 3.202 nSec and for copper plate was at 9.912 nSec. It is important to clarify here that this time corresponds to the total time of flight from transducer to plate and from plate back to the observation point. After doing the necessary calculations, 3.202 nSec time equates to a distance of 0.961m while the actual distance was 0.985m, which contributes an error of approximately 2.43% in the measurements. The error in measuring the distance of copper plate was approximately 2.3%.

IV. EXPERIMENTAL RESULTS FOR THE FIRST CASE

The experimental rig was created and the setup for the first case are constructed the way it is shown in Fig. 3.

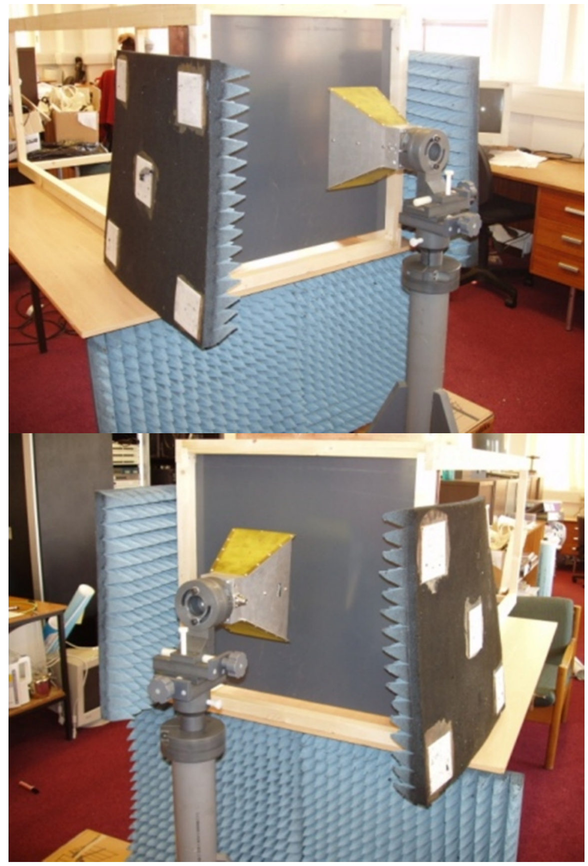


Fig. 3. Experimental setup for first case

As can be seen in Fig. 3 the PVC plate was fixed at one side while copper plate was made moveable at the back while horn antenna was used to illuminate the system. The metallic plate was moved over a distance of 200mm in 25mm intervals. Step reflection was used to measure the distance of the plates and the measured results are shown in Fig. 4. A vector network analyser MS2028 was used in these experiments. As mentioned before the isolated parameter of antenna was return loss i.e. S_{11} dB, which is the ratio of transmitted and reflected energy.

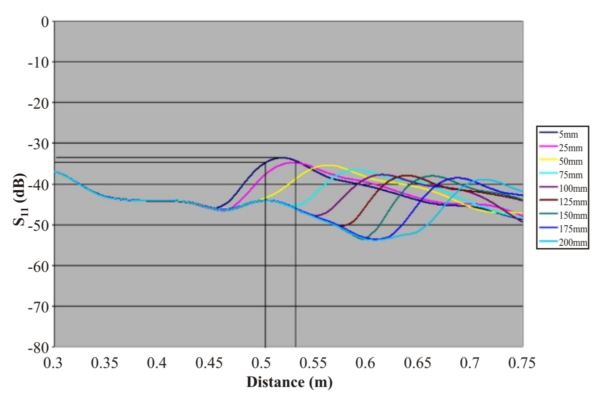


Fig. 4. Distance domain reflections from different distances of copper plate from the horn antenna

Comparing Fig. 4 with the simulations, it can be observed that in general the response curves are more rounded (lower rate of change) in the measurements. The main factor causing this is the simulation has much greater bandwidth than the measuring device. These rounded curves create problems in measuring the actual distance of the copper plate from the horn, as measured value for an actual distance of 515mm, will have a range of 500-530mm.

This problem made our way to do some more experiments to derive the effects of calibrating frequency span on the resolution of the measurements.

However, the results gave some useful information that the peak result is $\approx$ *-33dB* down on the source. This provides a voltage ratio of 0.0223872. Therefore at this range the returned voltage would be $\frac{1}{50}$*th* of the voltage used to excite the antenna. The dynamic range of the signal in less than 5*dB*.

V. SIMULATION RESULTS FOR SECOND CASE

As mentioned before that a real time application of water flowing inside PVC pipes has been considered for second set of experiments. This application was selected because of the simplicity as the experimental rig can be easily made for measurements and also there are many sensors available in the market to find the height of water inside tanks or pipes.

A PVC pipe with different levels of water was simulated using CST Microstripes. This simulated PVC pipe was 1m long with a radius of 0.2m (200mm). A plane wave excitation was given vertically from the top. The setup is shown in Figure 5. The results are shown in Fig. 6.

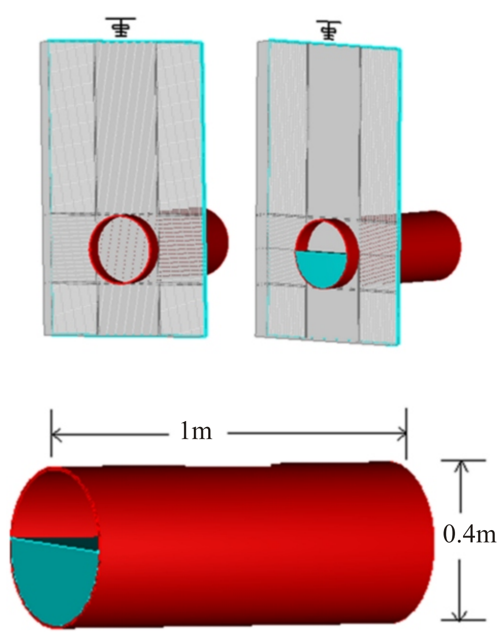


Fig. 5. Simulation setup of second case

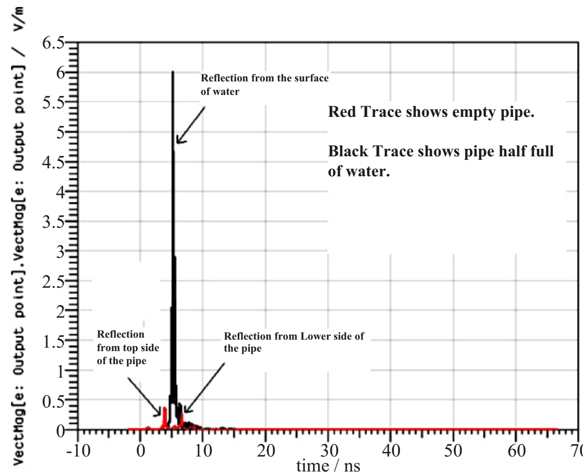


Fig. 6. Reflections from two different levels of water inside PVC pipe

Results given in Fig. 6 shows that since the measurements are broad band so the peaks of the reflections are crisp and pointed to time scale. These narrow reflections helps in calculating the distance more precisely and accurately.

VI. EXPERIMENTAL RESULTS FOR SECOND CASE

The experimental setup used for the second case is shown in Fig. 7. This is a real time application of the sensors for finding the levels of water inside the plastic pipes.

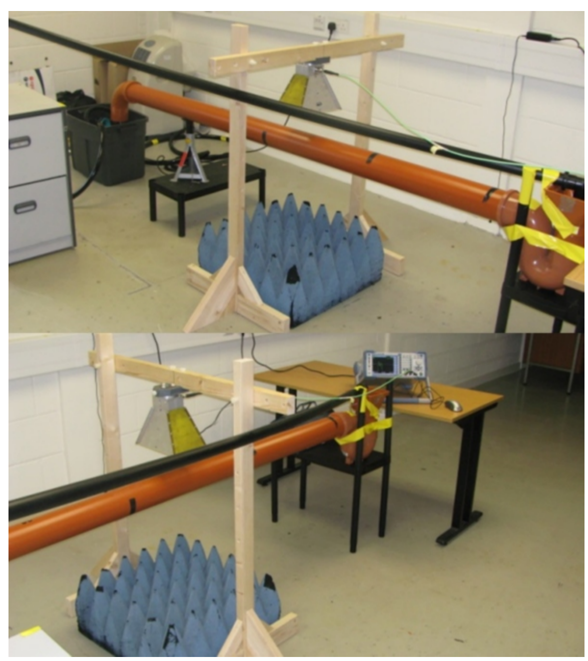


Fig. 7. Experimental rig for the calculation of water levels in plastic pipes

Wideband horn antenna, RF absorbers at the bottom and the instrument used was R&S ZVL13 [xi] from Rhodes and Schwarz, which was able to produce results in time domain. The bandwidth of the frequency scan of this machine was 9kHz to 13.6GHz. For comparison purpose measurements were performed for an empty pipe for several frequency spans to find out the reflections from upper and lower side of the pipe. The results are given in below Fig. 8. It can be seen that a frequency span of 9KHz to 12GHz allows easy recognition of all peaks whilst for a span of 4GHz to 6GHz only one reflection was seen in which it was difficult to observe the reflections from individual surfaces. The minimum frequency span concluded from these measurements was of 1GHz to 9GHz, but in general the bigger the frequency span the better the results will be.

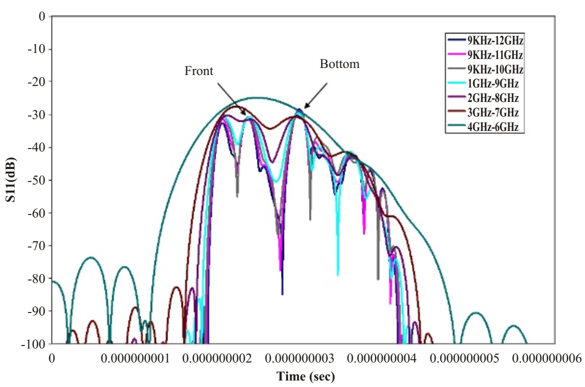


Fig. 8. Information of the frequency span on resolution of the measurements

It is clear from Fig. 8 that poor resolution we get for the calibration frequency span of 4GHz to 6GHz (top most curve) in fact there are no peaks what so ever. When the frequency span was increased the peaks of the reflections from upper and lower side of the pipe starts to appear and the best result was achieved for the frequency span of 9KHz to 12GHz (Blue line). In this particular case the reflections gave better resolution for the measurements of the water levels inside the pipe.

CONCLUSIONS

This paper deals with the research work done to find out the effects of calibration frequency span on the resolution of the measurements. Results show that the boundary returns in experiments are much less distinct than in simulation. This is because the measurement systems used had much lower bandwidth than the simulations. Detection of the peak of the pulse would require some signal processing.

Although most of the measurements and simulations in this research have been taken/measured using the pulse method, in implementation the broadband nature of this technique would make the device relatively expensive. Wideband filters, splitters and circulators are all likely to be needed for this option. However, this method does offer the best resolution and might allow an instrument the capability to measure concentrations of other materials below the water surface measured. Further, a larger data set in terms frequency range would allow more sophisticated signal processing to be used for level detection and the subtraction of noise.

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