Design and Performance of an UWB Antenna for a Mono-static Microwave Radar System

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Abstract — In this research work, design and performance of an ultra wideband (UWB) microwave antenna is described. The antenna is backed by a reflector and fed through the image ground plane. Intersection of two circular areas of different radius of curvature makes up the antenna element. Antenna element is made of Aluminum. Bandwidth is determined by the radius of curvature of lower circular section of the antenna element. The UWB antenna is suitable for detection of ultra-short electric pulses as given by the measured VSWR from 0.1 GHz to 20 GHz (Percent bandwidth of 198%). The UWB antenna is used in a mono-static radar system. Analysis and performance details are described for the resistive duplexer. Measurement results are presented for the far-field radiation of the antenna using ultra-short pulses. Average error in distance measurement using the mono-static system was measured to be 1.59% at a distance of 1 meter.

Keywords — mono pulse radar; position measurement; pulse radar; radar detection; UWB antenna.

I. INTRODUCTION

UWB antenna is used for receiving and transmitting sub-nanosecond electromagnetic pulses in a pulsed microwave radar system. This is known as pulse-echo radar [1]. The distance of the object is calculated from the received signal by using time-of-flight principle [2]. A bi-static configuration of the UWB microwave radar, with spatial separation of the transmitter and receiver antenna elements, can be found in [3]. In a bi-static system two antennas are used, one as transmitter and other as receiving antenna. In the present work, mono-static configuration is used, as shown in Fig. 1, where single antenna element is used for transmitting and receiving the pulses. In case of mono-static configuration, prior knowledge of the object angle to the antenna plane is not necessary for determining distance of the object, this is suitable for determination of buried objects inside another material. Mono-static configuration is reduced in size, and suitable for antenna array.

II. MONO-STATIC UWB MICROWAVE RADAR SYSTEM

In Fig. 2, the system blocks of the mono-static microwave radar system is described. Antenna is connected through the broadband duplexer.
Basic clock signal is provided by the stabilized 20 MHz quartz oscillator, which feeds a frequency divider circuit. A CMOS IC which has selectable output from 20 kHz to 10 MHz sets the pulse repetition frequency of the radar. Frequency divider output is amplified by an avalanche pulse. Step recovery diode (SRD) is used for shaping the transmitted pulses (FWHM: 140 ps, Rise time: 100 ps) with maximum pulse amplitude of 7 V. A broadband duplexer is used for separating the transmitted and received pulses. Outputs from two RC charging circuits are compared, and comparator output is followed by a second SRD based pulse sharpener, output of which is used for sampling of the received pulses. Received signal is sampled with the sampling aperture of 50 ps. Extended-time sampling is used to down-convert the received picosecond pulses into the millisecond range. Received pulses are fed directly into a high-gain trans-impedance amplifier. Target range information from the received signals are extracted using a computer.

Figure 3. The schematic of the resistive duplexer.

**A. Broad-band Resistive Duplexer**

The resistive duplexer (Fig. 3) is designed on the basis of bridge-reflectometer concept [4]. The three port divider contains lossy components to improve simultaneous matching of all ports. The divider consists of symmetrical resistive films deposited on ceramic substrate. The circuit was realized on planar microstrip transmission line. Measurement and simulation results of the reflection and transmission coefficients of the divider are shown in Fig. 4 and Fig. 5, respectively. Optimization of the circuit has been performed using electromagnetic field simulator. Transmission coefficient is shown in Fig. 5. Measured transmission is decreased beyond 10 GHz due to parasitic effects at the microstrip to coaxial transitions [5].

Figure 4. The eigen reflection coefficients of the signal divider at port 1.

Figure 5. The transmission coefficients of the signal divider.

**B. A novel rugby-ball antenna for pulse radiation**

Wideband matching of the antenna is needed for radiating electrical pulses of sub-nanosecond region. Also simple and cost-effective fabrication of the antenna is desired.

For wideband applications a bow-tie antenna was proposed in [6]. Problems with the bow-tie configuration is that additional loading (capacitive or resistive) is needed to reduce unwanted reflections from the drive point. Planar ‘trapezoidal’ antenna was proposed in [3]. Planar Trapezoidal antenna is useful only for bandwidth of 1 GHz to 5 GHz. In another attempt, ‘Planar Inverted Cone Antenna (PICA)’ was proposed in [7] for radiating ultra wideband signals. In the present approach, antenna element consists of intersecting areas of two circles of different radius of curvature. The antenna is termed as Rugby-ball antenna for the similarity of its shape with Rugby-ball [8]. The advantage of the new antenna is improved impedance bandwidth and VSWR performance in the frequency range from 0.1 GHz to 20 GHz compared to the previous UWB antennas. It is seen in Fig. 6 that the lower circular contour of the antenna has smaller diameter compared to the upper part of the antenna.
The UWB antenna was simulated using a 3D electromagnetic field simulator. In Fig. 6, the diagram of the shape of the antenna and surface mesh elements are shown. Aluminium plate of thickness 2 mm is used to fabricate the antenna element, reflector and ground plane.

The placement of feed point have significant effect on the antenna impedance. The height between ground plane and antenna element was chosen such that it optimises the input matching of the antenna. The VSWR was further optimised using the 3D electromagnetic field simulation to obtain VSWR, impedance, and percent bandwidth. The reference plane for the measurements was set at the SMA connector feed point which is just underneath the image ground plane. The measurements were carried out using a vector network analyzer (HP 8510). Simulation and measured VSWR of the antenna from 0.1 GHz to 20 GHz as shown in Fig. 7.

From broadside radiation of antenna, it can be seen that maximum peak pulse amplitude is attained at an angle of $\theta$ equal to 60° (Fig. 8). Radiation decreases gradually towards zero degree.

III. EXPERIMENTAL RESULTS OF THE UWB RADAR

Fig. 9 shows the measured reference and reflected pulse from the target. A metallic target was used as object in the mono-static radar system. First pulse is the reference pulse and the second is the reflected pulse from the target. Distance between antenna and target is determined by time-of-flight principle.

In Fig. 10, measured distance error of the object is plotted in case of mono-static configuration. Measurements were performed equipped with the UWB antenna. Average difference is shown together with
maximum and minimum difference of 10 measurements. Average error is found to be 1.59 % for mono-static system.

Figure 10. Measurement result of UWB mono-static microwave radar system using the UWB antenna.

IV. CONCLUSION

Design details of a new UWB antenna and a wideband diplexer is presented for a mono-static pulsed microwave radar. Low VSWR performance is achieved for the frequency bandwidth from 0.1 GHz to 20 GHz by optimizing the upper and lower radius of curvature of the antenna element, which is suitable for transmission of UWB pulses. Extended-time-sampling method was used in the receiver of the radar system, which reduces the hardware cost of the system, as the signal processing is performed in the low frequency region. Using the mono-static pulsed microwave radar system, low (1.59%) average error in near range (1m) distance measurement is achieved.

REFERENCE