Quality Measurements of an UWB Reduced-size CPW-fed Aperture Antenna

M. Zolfaghari, N. G. Riley, M. Mehdawi, A. Fanan, M. Ammar and F. Meng

***Abstract* — The characterisation of compact ultra-wideband antennas is challenging due to the difficulty of presenting gain and efficiency results over the whole range of frequencies, elevation and azimuthal angles. This paper presents a characterisation of a compact co-planar wave guide (CPW)–fed slot loaded low return loss planar printed antenna designed for wireless communication and UWB applications. The antenna design, which includes a combination of corner features and loading slots to achieve higher bandwidth and size reduction, was implemented and simulated using Agilent's Advanced Design System (ADS). This paper concentrates on initial laboratory measurements of the antenna and discusses how an antenna quality metric based on time-domain S_{21} may be related to antenna quality metrics such as the System Fidelity Factor (SFF).**

***Keywords* — Antenna measurement, Antenna quality metric, CPW-fed, Microstrip antenna, Ultra-wideband.**

I. Introduction

Microstrip patch antennas are appropriate for use in wireless communication systems including ultra wideband (UWB) systems due to their attractive qualities of simple structure and low profile [1-5]. Ultra-wideband communications differs from conventional radio systems because it uses extremely narrow RF pulses and therefore occupies a very wide bandwidth. UWB technology is becoming widely used in radars, high data rate short range wireless communications, and identification/localization applications including UWB-RFID.

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The frequency range of operation for such antennas is generally defined as 3.1 GHz to 10.6 GHz (the Federal Communications Commission (FCC) bandwidth). The operational bandwidth of an antenna is usually defined as the frequency range over which the return loss S_{11} is less than 10% (-10dB) [6-10], although some papers present results in terms of VSWR.

In this work we have described the design of a novel UWB antenna [14] using ADS, analyzing the results in terms of S_{11} and then optimizing the design stage-by-stage to improve the bandwidth performance whilst reducing the overall patch size relative to the original design.

Our final design exhibits a -10dB S_{11} frequency range from approximately 2.9 GHz to above 12 GHz with a circuit board area which is 54% of the original. The fabricated antenna band width is shown to extend from 2.56 GHz to above the 9 GHz limit imposed by the available vector network analyzer (VNA).

Characterisation of the performance of such antennas, for example in terms of gain, presents a challenge [15] due to the wide range of frequencies and radiation angles involved.

Two methods of UWB antenna performance characterization (Time domain S_{21} and System Fidelity Factor (SFF)) are presented and compared, along with an example of measured results.

II. ANTENNA MODELLING

The industry-standard simulation software ADS 2012 based on the momentum method is employed to perform the design and optimization process.

A. Substrate

The antenna modeled here is a microstrip patch antenna implemented on single-sided FR4 circuit board, 1.5mm thick, whose substrate has relative permittivity of 4.1. The feed structure is a 50Ω CPW transmission line, whose end is terminated by a semi-circular tuning stub, similar to that used in [11]. This feed configuration appears similar to a mushroom shape, presenting a simple geometrical structure. The width of microstrip feed line is fixed at 3.6 mm to achieve 50Ω characteristic impedance.

B. Size reduction techniques

Work has previously been undertaken [12] to reduce the size of a patch antenna used for narrow-band applications. It has been found that some of these techniques including corner-cutting and the use of a series of slots to force an increased current path, resulting in an increased effective electrical size of the antenna, can also be applied in modified form to the UWB case.

III. SIMULATION

A. *Return loss*

Fig. 1 shows the optimized antenna design layout after approximately 70 iterations. The location and length of asymmetrical slots has been found to be critical in achieving the desired degree of size reduction whilst maintaining the required UWB frequency range. The overall size of the optimized design is 24mm perpendicular to the 9.75 mm length and 3.6 mm feed line width, which attached to a half a circle with radios 6 mm and the other outer dimension 22mm parallel to the feed. The slots width is differ from 0.40 mm to 0.30 mm and the gap between the feed section and the main section is 0.25 mm. the antenna fabricated on a FR4 substrate with dielectric constant ε_r of 4.3, and thickness 1.5mm.

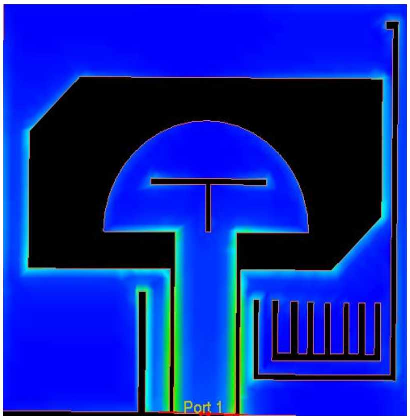

Fig. 1. Layout of Slot loaded CPW-FED Antenna and Current distribution for the frequency 6.80 GHz.

The calculated S_{11} amplitude and phase plots are shown in Fig. 2 and Fig. 3 where it may be seen that the -10dB bandwidth far exceeds the FCC UWB frequency range.

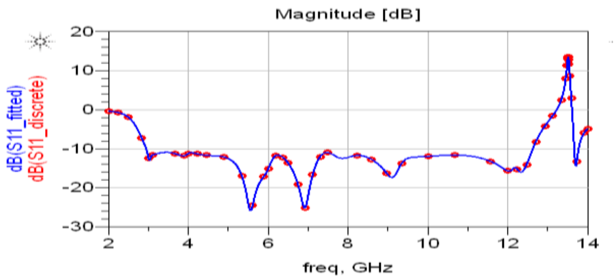

Fig. 2. The calculated S_{11} amplitude.

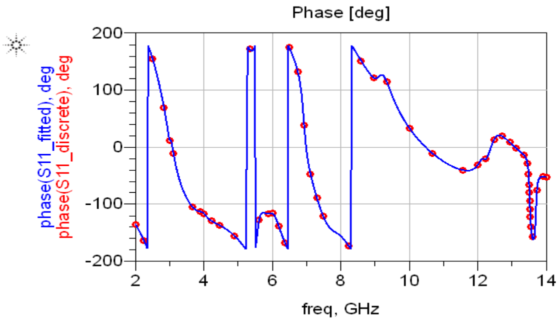

Fig. 3. The calculated S_{11} phase

B. *Current Distribution*

Fig. 1 also illustrates an example of the calculated current distribution for the optimised antenna, for a frequency of 6.80 GHz, chosen for illustrative purposes, since it is difficult to show current distribution as a function of frequency over the whole required band. Throughout the optimization process monitoring the current distribution has been the key factor in determination of slot location and length.

C. *Radiation pattern*

Fig. 4 shows three-dimensional plots of the predicted radiated E-field produced using the post processing Far-Field. Again, these have been produced for illustrative frequencies of 6.80 and 9.40 GHz. As expected from an electrically small structure, the radiation pattern is approximately omni-directional with a reduction in field in the plane of the substrate.

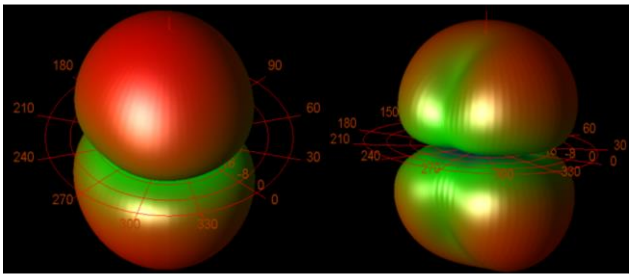

Fig.4. Radiation for 6.80 GHz (left) and 9.40 GHz (right).

IV. FABRICATED RESULTS

The fabricated antenna is shown in Fig. 5 which includes dimensional information.

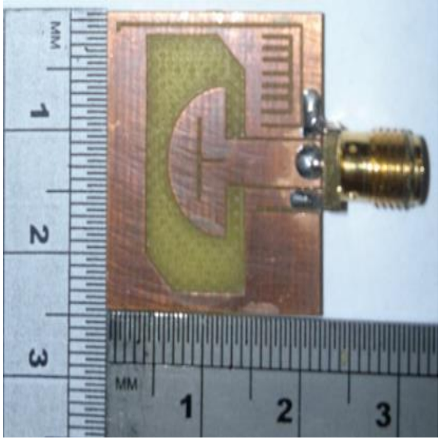

Fig.5. Dimensions of antenna.

The return loss of the fabricated antenna was measured using an Agilent 58358A 300 kHz to 9 GHz vector analyzer (VNA). Results are shown in Fig. 6. The results show a wider bandwidth from 2.56 GHz compared to simulated results of 2.8 GHz. Generally good agreement is seen between simulated and measured results, up to the 9 GHz limit imposed by the VNA.

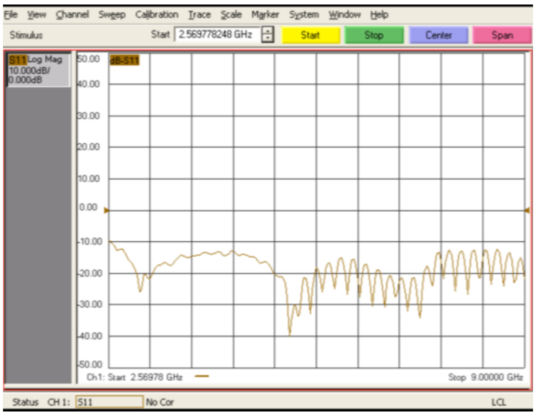

Fig.6. Return loss S_{11} measured by VNA.

V. MEASUREMENT SETUP

Practical measurements were carried out using two identical antennas (Transmit and Receive) and a vector network analyser (Agilent E8358A) over the frequency range 3 GHz to 9 GHz, which includes most of the FCC UWB band. The measurement setup is illustrated in schematic form in Fig. 7 and as a practical set up in Fig. 8. Radio absorbing material (RAM) was positioned to suppress reflections, although with the low power and consequent short range used, this is not found to be a particular problem.

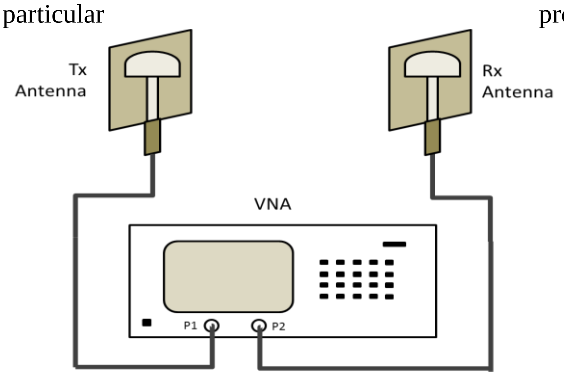

Fig. 7. Schematic view of measurement system.

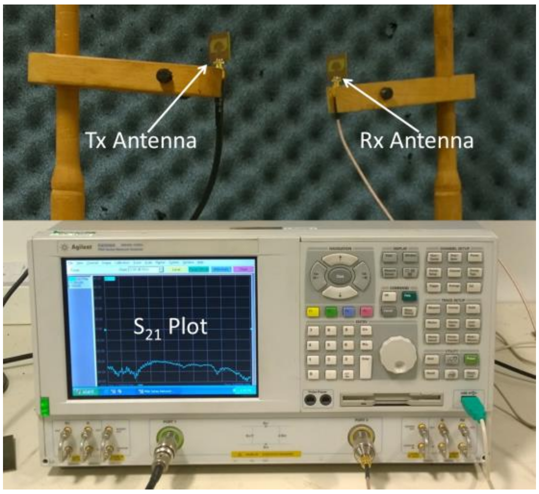

Fig. 8. Arrangement of antennas (Top) and Measurement system (bottom).

VI. MEASURED RESULTS

The measured results were downloaded from the spectrum analyser onto a memory stick for later processing. The raw data is in the form of an Excel file. For each of 401 data points, frequency and the amplitude and phase of S_{21} are recorded. An example of the amplitude data is shown in Fig. 9 for the antennas in a broadside condition, separated by approximately 100mm.

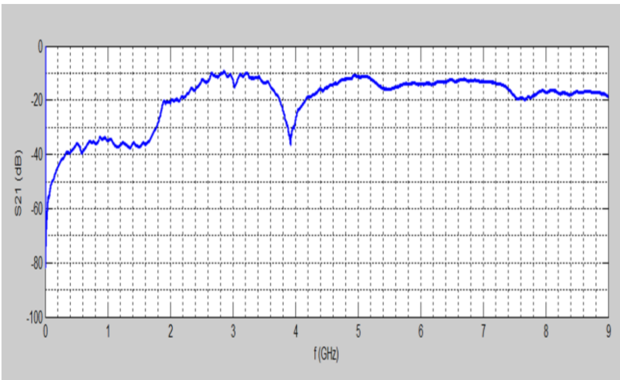

Fig. 9. S_{21} as a function of frequency for broadside antennas, d=100mm.

It should be noted that S_{21} in these measurements relates to the whole system between the spectrum analyser ports 1 and 2, including cable and connector losses as well as spatial attenuation.

VII. TIME DOMAIN ANALYSIS

The measurement data were converted from the frequency domain to the time domain using a MATLAB program to implement an Inverse Fast Fourier Transform (IFFT) algorithm with the result shown in Fig. 10. The horizontal timescale of Fig. 10 represents 20 nanoseconds and it can be seen that the time resolution is consistent with an upper frequency of 9 GHz. The delay of approximately 5 ns is equivalent to a total propagation range of around 1.5 m which is consistent with the length of connecting cables and distance between the antennas.

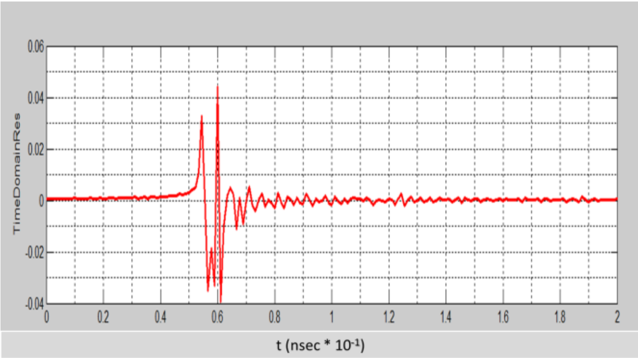

Fig. 10. Time domain analysis of the frequency domain measurements, 0 – 20 ns scale.

The time domain response amplitude is proportional to the total system loss, including antenna gains, cable loss and propagation loss. In order to characterise the antennas in absolute terms, it is necessary to calibrate the cables and accurately measure the propagation loss. If the antennas are assumed to be identical, it is then possible to determine antenna gain over the complete range of azimuth and elevation angles.

VIII. SYSTEM FIDELITY FACTOR

A further method of quantifying the performance of an UWB antenna is the System Fidelity Factor (SFF) [13] which compares the shape, in the time domain, of pulses before and after transmission through a system including transmit and receive antennas. The transmitted signal $T_s(t)$ and received signal $R_s(t)$ are both normalised to remove frequency-independent attenuation according to:

$$\hat{T}_s(t) = \frac{T_s(t)}{\left[\int_{-\infty}^{\infty} |T_s(t)|^2 dt\right]^{1/2}} \qquad (1)$$

and likewise for the received signal $\hat{R}_s(t)$. The SFF is then evaluated as the maximum value of cross-correlation between $\hat{T}_s(t)$ and $\hat{R}_s(t)$ at every point in time. Due to the normalisation, the SFF is a single number between 0 and 1, relating to particular relative orientations of transmit and receive antennas.

IX. SFF AND S_{21} IN TIME DOMAIN

At a given frequency, S_{21}, $T_s(f)$ and $R_s(f)$ are related by:

$$S_{21} = R_s(f)/T_s(f) \qquad (2)$$

which can be interpreted as the channel impulse response, $H(t)$, under these measurement conditions, to within the measurement time resolution. The SFF is defined [13] as:

$$SFF = \underbrace{max}_{n} \int_{-\infty}^{\infty} \hat{T}_s(t)\hat{R}_s(t+\tau)\, dt \qquad (3)$$

In the case where the transmitted signal is impulsive it can be seen that SFF reduces to an amplitude-normalised version of S_{21}. Our measurement method can therefore be seen to be equivalent to the SFF method provided cable losses and propagation loss can be taken into account. It should also be noted that SFF assumes, in its normalisation process, that propagation losses are frequency-independent.

X. CONCLUSIONS

The design and simulation of a novel compact UWB antenna has been reviewed. The antenna occupies only 54% of the board area of an established design [11] and has a bandwidth which exceeds the FCC UWB frequency range. Approaches to the problem of characterisation of such antennas over a wide range of frequencies and radiation angles have been investigated. Measured S_{21} results have been presented in the frequency domain and transformed to the time domain. It has been suggested that the method of derivation of these results is equivalent to the SFF method, to within a normalisation factor.

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