Gain and Bandwidth Optimization of Compact UWB Tapered Slot Antennas

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Abstract **– A method is presented which is aimed at increasing the gain and bandwidth of the tapered slot antenna by just finding the optimum tapering profile of the antenna without the need to increase its size. The result of the analysis indicates that a slightly negative tapering gives the optimum gain and bandwidth performance. A positive tapering causes a sharp reduction in the gain and bandwidth, assuming a constant width and length for the antenna. The result of analysis is utilized by designing and manufacturing a tapered slot antenna which has an ultra wideband performance (bandwidth from 3.1 GHz to 10.6 GHz) and a maximum possible gain. The dimension of the antenna is 65 mm × 65 mm. The simulated and measured results show that the antenna covers the 3.1 GHz to more than 11 GHz band with a gain which varies between 4.5 dBi at 3 GHz and 12 dBi at the high frequency band (9-11 GHz).**

Index Terms-**Tapered slot antenna, ultra wideband.**

I. INTRODUCTION

Recently, ultra wideband (UWB) systems have received a considerable amount of interest with respect to communication and medical applications. An antenna, which can efficiently radiate and receive UWB signals, is essential for successful operation of these systems. In some applications such as the biomedical imaging, high efficiency, light weight, compact size, and end-fire radiation characteristics are the important requirements that are required for these antennas [1]. The tapered slot antenna (TSA) is one possible candidate to meet such requirements. TSA has already been utilized in UWB radar. In this case, the TSA featuring a relatively high gain of 10-15dB is used. Such requirement translates into the large length of the antenna being several wavelengths at the centre frequency of a given band [2]. This design is unsuitable for biomedical applications, as they require the antenna to be of compact size.

In the present work, the possibility of increasing the gain of a compact size TSA antenna by changing the tapering profile is investigated. The effects of the tapering profile on the beamwidth, sidelobe level and radiation pattern have already been extensively studied but no specific recommendations with respect to the gain are given [2-6]. The following investigations are concentrated on the TSA covering the UWB, i.e. 3.1-10.6 GHz.

II. ANALYSIS

In order to study effect of the tapering profile on the gain and bandwidth of the tapered slot antenna an exponential tapering shape was assumed. The value of the exponent is to be changed so that a wide range of tapering profile can be covered. To this purpose, a tapering parameter *B* is introduced. The analysis includes the following steps;

Step 1: The length and width of the radiating element, which is the tapered slot, are chosen to be equal to the effective wavelength calculated at the lowest frequency of operation. Given the lowest frequency of operation (f_l), thickness of the substrate (h) and its dielectric constant (ε_r), the width (w) and length (l) of the antenna

structure, excluding the feeder is calculated using the following equation:

$$w = l = \frac{c}{f_l \sqrt{(\varepsilon_r + 1)/2}} \quad (1)$$

where c is speed of light.

Step 2: The tapering profile of the antenna is assumed to be according to the following equation;

$$y = A \exp\{B(|x| - s/2)\} - A \quad (2)$$

for $s/2 \le |x| \le w/2$, where ;

$$A = \frac{l}{\exp(B(w-s)/2) - 1} \quad (3)$$

and *B* is the tapering profile parameter , *s* is width of the slotline feeder which is designed to give 50Ω terminal impedance. The equation for *A* is chosen such that the opening of the TSA is constant and equal to *w* for any value of the tapering profile parameter *B,* see Fig.1. Note that the case *B*=0 in (2)-(3) indicates a linear tapering, after solving (2) using the theory of limits.

The TSA performance can now be evaluated for different values of the tapering parameter *B* assuming a certain substrate for the antenna.
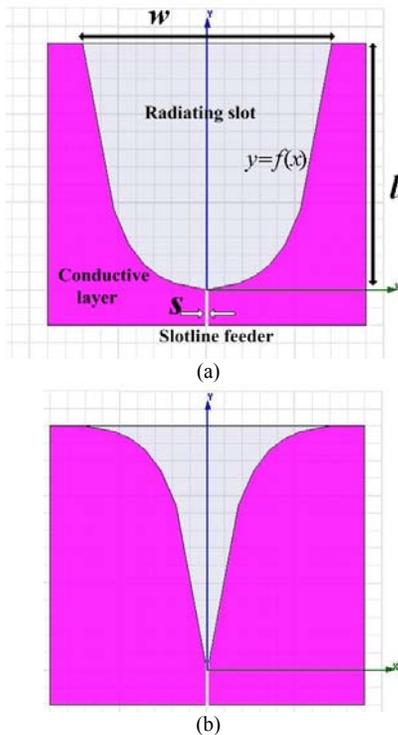

Fig.1   The tapered slot antenna. (a) Positive tapering, and (b) negative tapering.

III. RESULTS

The TSA design was assessed for different values of *B* assuming Rogers RO4003 ($\varepsilon_r = 3.38$, thickness=0.508mm) as a substrate. This task is performed using the frequency domain finite element method. The calculated values of the average gain and bandwidth is shown in Fig.2. In this figure the required 7.5GHz bandwidth for UWB applications is shown. The result indicates that the antenna has a maximum gain (11.7 dBi) when *B*=0. In turn, a maximum bandwidth is obtained when *B*=-0.25. For a positive tapering (*B* is positive), the gain and the bandwidth decrease rapidly. To compromise between the highest possible gain and the required BW (7.5 GHz in the present case), the optimum value for the parameter *B* is chosen as -0.12 (this is the intersection of the two graphs).
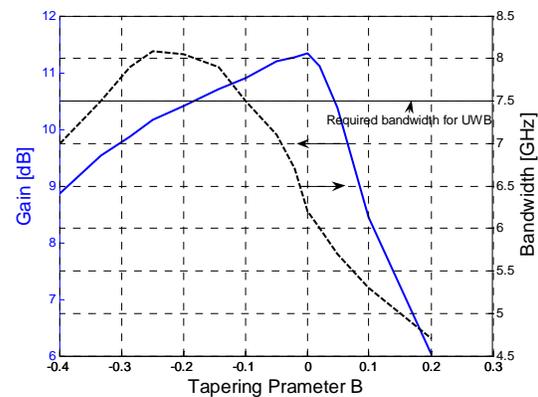

Fig.2   Variation of the average gain and bandwidth with *B*.

In order to develop and test a tapered slot antenna using the optimum value of *B*, it is preferred to alter the feeding structure of the antenna so that a microstrip feeder can be used instead of the slot line. It is well known that the microstrip line is the most common form of printed transmission line used for feeding a tapered slot antenna element. Therefore, the developed antenna was modified in order to use a microstrip line as a feeder. A microstrip line, being formed by a conductive metal strip on one side of a dielectric substrate and a conductive ground plate on other side of the substrate, is an unbalanced line [7]. This is opposite to the slot line, which is a balanced transmission line. Because of this situation, feeding a TSA with a microstrip line

requires a wideband balanced-to-unbalanced transition (balun) to avoid compromising the broadband performance.

Different methods for the microstrip line feeding arrangement for the TSA were presented in [7]-[9]. In this paper, the following arrangement was used. The slot line was terminated in an open circuit by adding a relatively large circular patch at the end of the slot line, and the microstrip line was shorted by using a circular patch, which effectively acts as a shorting via. Due to the above mentioned arrangement, a balun is created at the crossover which matches the unbalanced microstrip line to the balanced slot line of the antenna element. This electromagnetic coupling arrangement permits signal transmission from the microstrip transmission line to the slot line (for feeding the antenna). In general, the stronger the electromagnetic coupling, the better is the transition. Fig. 3 shows the type of balun which was used for the developed antenna. This configuration has no inherent bandwidth limitation other than parasitic inductances and capacitances.
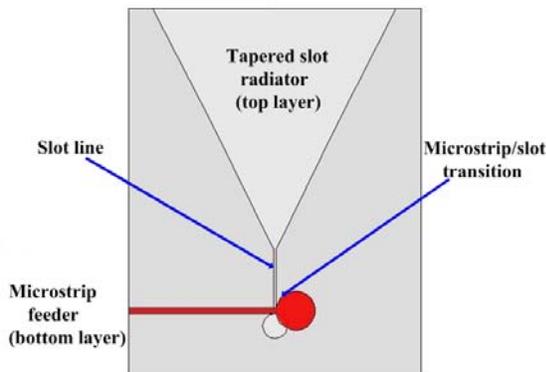

Fig.3   Configuration of the microstrip/slot line transition as a method to feed the antenna using a microstrip line.

The validity of the presented analysis was tested by designing an antenna with *B*=-0.12 in order to cover the UWB frequency band from 3.1GHz to 10.6GHz using Rogers RO4003C as a substrate. Dimension of the developed antenna is 65 mm × 65 mm. A photo for the manufactured antenna is shown in Fig.4.
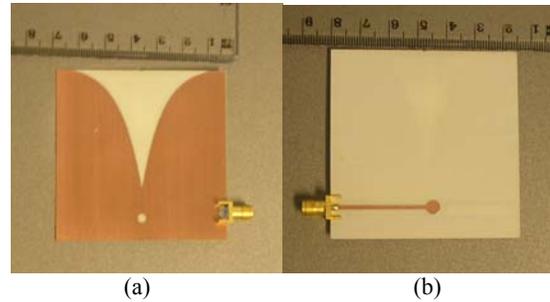

(a)   (b)

Fig.4   The manufactured antenna. (a) Top layer revealing the radiator and the transition, and (b) bottom layer showing the microstrip feeder.

Fig. 5 shows the simulated and measured return loss of the manufactured planar tapered slot antenna. As can be seen from Fig.5, the 10dB return loss of this antenna extends from 3.1GHz to over 11GHz. This result agrees well with the result of calculation shown in Fig.2, where the 10 dB bandwidth was expected to be more than 7.5 GHz when *B*=-0.12.
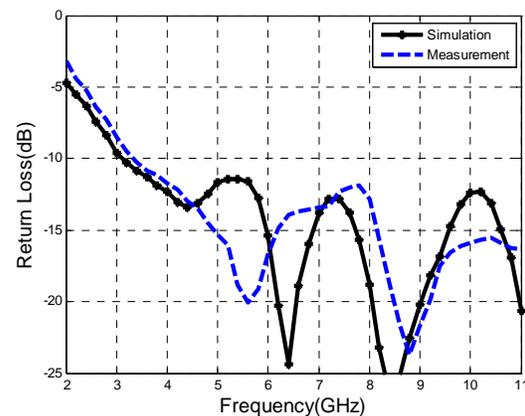

Fig.5   Variation of the measured and simulated return loss with frequency.

The measured far-field radiation patterns of the antenna in the two principle planes are shown in Fig.6 at three frequencies (4, 7 and 10 GHz). The measured patterns reveal that the front-to-back ratio of the antenna is greater than 12 dB indicating directive properties.

The variation of the measured and simulated gain with frequency is shown in Fig.7. The simulated gain for the antenna for the frequencies between 3 and 11GHz shows that the gain increases with frequency and is around 13 dBi at 11GHz. The measured gain of the antenna also increases with

frequency. It is between 4.5 dBi at 3 GHz and 12 dBi at the frequency band 9 GHz to 11 GHz. The simulated and measured results agree with each other, and both of them agree with the expected value shown in Fig.2 for *B*=-0.12.
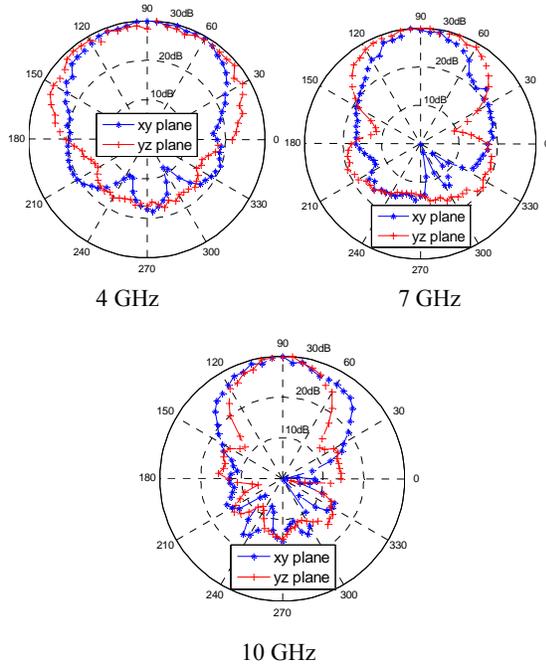

4 GHz   7 GHz

10 GHz

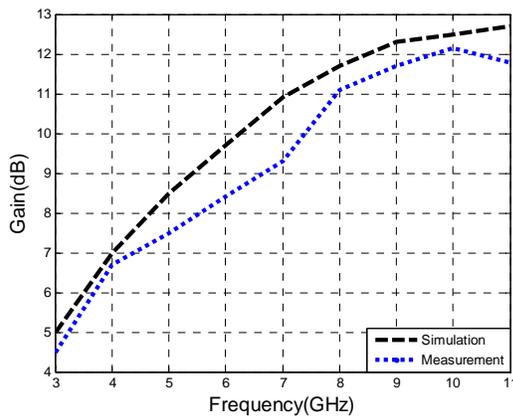Fig.6 The measured radiation pattern three frequencies.

Fig.7 Variation of the measured and simulated gain with frequency.

IV. CONCLUSION

A method has been presented which aimed at increasing the gain and bandwidth of the tapered slot antenna by just changing the tapering profile of the antenna without the need to increase its size. The result of analysis has indicated that a slightly negative tapering is the optimum choice for the tapered slot antenna with ultra wideband performance and compact size. The method has been utilized by designing and manufacturing a tapered slot antenna which has an ultra wideband performance (bandwidth from 3.1 GHz to 10.6 GHz) and a maximum possible gain. The simulated and measured results show that the antenna covers the 3.1 GHz to more than 11 GHz band with a gain which varies between 4.5 dBi at 3 GHz and 12 dBi at the high frequency band (9-11 GHz).

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