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Microstrip-fed tap monopole antenna with ultra-wideband performance for IoT and 5G applications

Antena monopolo tipo Tap alimentada por microcinta con rendimiento ultraancho para aplicaciones en IoT y 5G

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***Abstract*—In this paper, a planar microstrip-fed tab monopole antenna is designed and presented for ultra-wideband (UWB) wireless communication applications. The impedance bandwidth of the antenna is enhanced by adding a slit on one side of the monopole, introducing a tapered transition between the monopole and the feed line, and incorporating a two-step staircase notch in the ground plane. The proposed antenna would be printed on an Epoxy FR4 substrate, has a small size of 16×19mm, and provides an ultra-wide bandwidth from 1.2 to 20.8 GHz with a low VSWR level and good radiation characteristics, satisfying the requirements of current and future wireless communications systems.**

***Index Terms*—Ultra wideband, IoT, microstrip-fed, monopole antenna.**

***Resumen*—En este artículo se diseña y presenta una antena monopolo en tapa con alimentación Microstrip para aplicaciones de comunicaciones inalámbricas de ultrabanda ancha (UWB). El ancho de banda de impedancia de la antena se mejora mediante la adición de una ranura en un lado del monopolo, la introducción de una transición gradual entre el monopolo y la línea de alimentación, y la incorporación de una muesca escalonada de dos niveles en el plano de tierra. La antena propuesta se imprimiría sobre un sustrato de Epoxy FR4, tiene un tamaño reducido de 16×19 mm y proporciona un ancho de banda ultraancho desde 1.2 hasta 20.8 GHz, con un bajo nivel de VSWR y buenas características de radiación, lo que satisface los requisitos de los sistemas de comunicaciones inalámbricas actuales y futuros.**

***Palabras Claves*—Ultra Banda Ancha, Iot, Alimentación Microstrip, Antena monopolo.**

I. Introduction

THE technologies for wireless communications always need additional improvements to meet higher resolution and data requirements. That's why the Federal Communications Commission (FCC) reviewed ultra-wideband communications systems covering 3.1 GHz to 10.6 GHz in February 2002, which are currently under development. There is always an increasing demand for smaller sizes, higher capacities, and transmission speeds, which will undoubtedly require a higher operating bandwidth in the near future. Planar tap monopole antennas have been extensively adopted and studied for UWB communications systems due to their numerous features, including a wide impedance bandwidth, a simple structure, a small size, a low profile, and omnidirectional radiation patterns. A variety of wideband tap monopole configurations, including rectangular, elliptical, pentagonal, and hexagonal, have been proposed for UWB applications. Wide impedance bandwidth of (1:1.7), (1:2.25), and (1:7.9) for VSWR=2, and a small antenna size of 16:30 and 16 mm are reported in [1]-[6], respectively. These reported results demonstrate the ongoing research and development efforts aimed at optimizing UWB antenna designs, with a focus on achieving wider bandwidths and miniaturization. The challenge lies in balancing these performance requirements with practical considerations such as cost-effectiveness and ease of integration into devices [7], [8]. This document presents a proposal for a modified printed tap monopole antenna for UWB applications. The presented antenna exhibits an ultra-wide impedance bandwidth of (1:7.9), and a small approximate size of 16 mm, which is less than or equal to the antennas presented in [9].

II. Parameters For Antenna Design

The proposed antenna has a small size, with approximate measurements of 16 x 19 mm, and would provide an ultrawide bandwidth with a low VSWR level. Fig. 1 illustrates the design of the top layer, which features a Rectangular Patch, Slit, Tapered Transition, and Feedline. Fig. 2 shows the design of the Bottom layer, where the Ground Plane with Notch is located. This antenna was created with FR4 Epoxy substrate.

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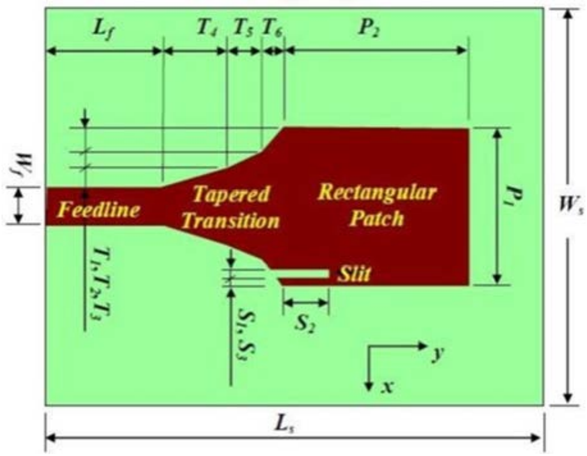

Fig. 1. The geometry and parameters of the proposed planar tap monopole antenna on the top layer.

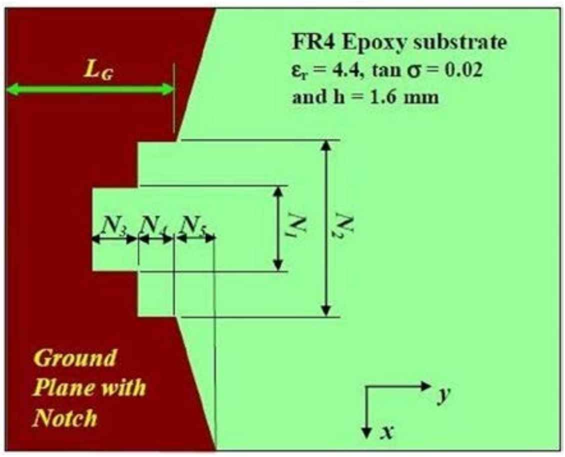

Fig. 2. The geometry and parameters of the proposed planar tap monopole antenna on the bottom layer.

III. Antenna Geometry

The patch is connected to a feed line of width W_f and length L_f through a tapered transition, which is defined by the parameters T_1 to T_6, as shown in Fig. 1. The tapering produces a smooth transition, which reduces the reflections resulting from the sudden change from the feedline width to the patch width. On the other side of the substrate, a conducting ground plane of width (W_s) and length (L_G) is placed. The truncated ground plane plays a crucial role in the broadband characteristics of this antenna, as it helps match the patch to the feedline over a wide frequency range [10], [11]. This is because the truncation creates a capacitive load that neutralizes the inductive nature of the patch, producing nearly pure resistive input impedance. To further enhance the matching, a two-step staircase notch is embedded in the truncated ground plane. The notch is defined by the parameters N_1 to N_4 as depicted in Fig. 2.

IV. Numerical Analysis

The initial dimensions of the antenna are as follows: (1) Substrate: $W_s = 16$, $L_s = 19$, (2) Patch and Slit: $P_1 = 7$, $P_2 = 9$, $S_1 = 0.3$, $S_2 = 2.5$, $S_3 = 0.5$, (3) Tapered Transition: $T_1 = 1$, $T_2 = 0.75$, $T_3 = 0.75$, $T_4 = 4$, $T_5 = 1$, $T_6 = 1$, (4) Feedline: $W_f = 2$, $L_f = 3$, and (5) Ground and Notch: $L_G = 4$, $N_1 = 7$, $N_2 = 5$, $N_3 = 1.5$, $N_4 = 1$, $N_5 = 0$ mm. In this study, the parameters T_4:T_6 and S_2 are presented in figures from Fig. 3 to Fig. 8, respectively, to illustrate the effect of the tapered transition [12], [13] and the slit on the VSWR of the antenna. The VSWR is computed over a large bandwidth, from 2 to 21 GHz, using the commercial computer software package Ansys from Ansoft.

Fig. 3, 4, and 5 show the effects of T_4, T_5, and T_6, respectively. Generally, increasing these parameters improves the overall VSWR level because the transition from the feedline to the monopole becomes smoother. The parameter T_4 has more effect in the middle range. Additionally, increasing T4 decreases the upper operating frequency, resulting in a decrease in bandwidth after T4 reaches 5 mm [8]. The parameter T_6 can be used to enhance the VSWR at higher frequencies, thereby improving the bandwidth. The maximum bandwidth occurs at $T_6 = 1.5$ mm.

The slit length S_2 and the slit distance from the edge S_3 control the VSWR level at 11.5 GHz. This is mainly because these two parameters control the impedance of the arm to the right of the slit, which can be considered an open circuit stub [14], [15].

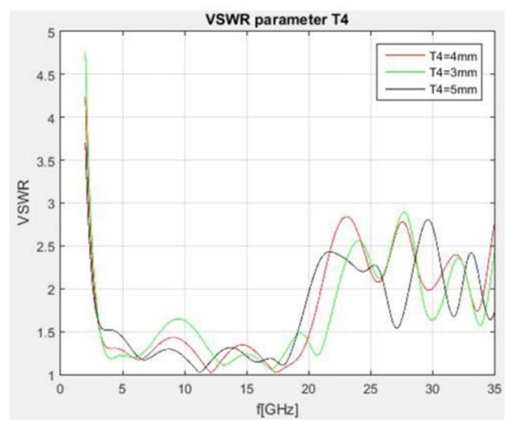

Fig. 3. The effect of the tapered transition parameter T_4.

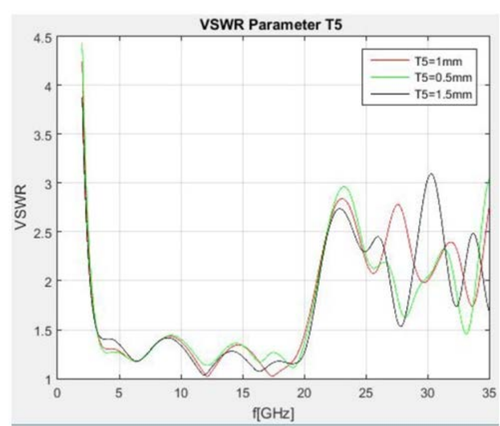

Fig. 4. The effect of the tapered transition parameter T_5.

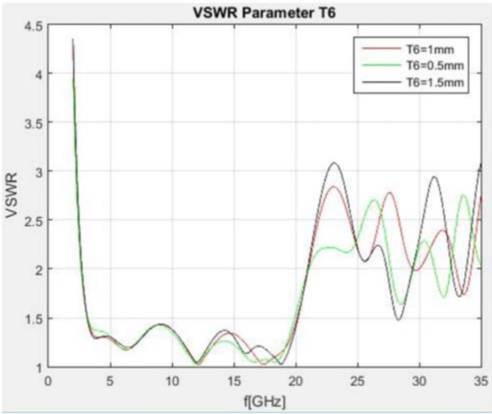

Fig. 5. The effect of the tapered transition parameter T_6.

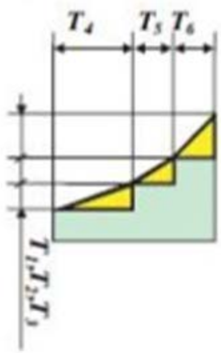

Fig. 6. The effect of the tapered transition parameters exposed previously.

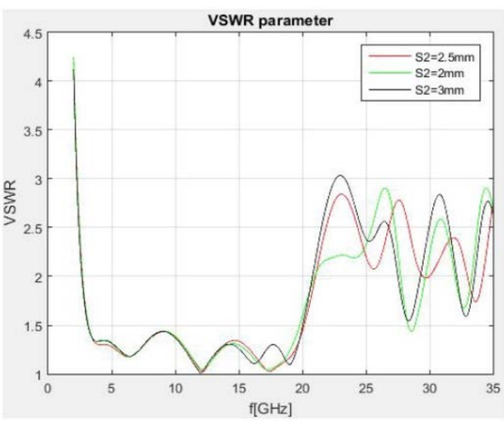

Fig. 7. The effect of the tapered slit parameter S_2.

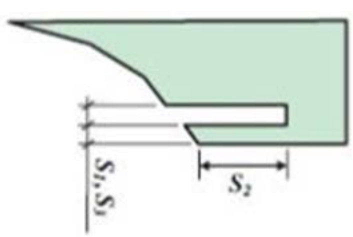

Fig. 8. The effect of the tapered slit parameters *S*.

V. Final Design

The best bandwidth and VSWR level are achieved for the antenna with N_2 = 4 mm, where the antenna remains functional up to 15 GHz. Therefore, the VSWR is re-computed up to 18 GHz using Ansys. The results show that the antenna operates over a wide range that extends from 2 to 21 GHz, which is (1:7.8). The VSWR level is less than 1.5 in almost the entire operating band. The low VSWR level is achieved through the tapered transition and the good matching provided by the two-step staircase notch, as shown in Fig. 9. The average value of the real part of the resulting input impedance is approximately 50 ohms. In contrast, the imaginary part fluctuates slightly around zero. This supports the aforementioned explanation of how truncating the ground plane and introducing a staircase notch within it produces an almost pure resistive input impedance.

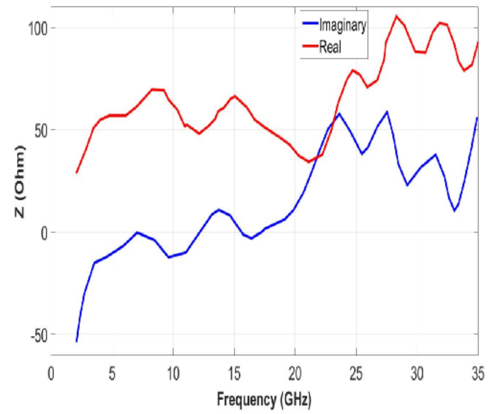

Fig. 9. The computed Z parameter in its real and imaginary parts.

The E-plane radiation patterns for the 3D simulated monopole tap antenna are shown in Fig. 10, while Figs. 11 and 12 present the results for the antenna implemented using the spectrum analyzer [16], [17].

Fig. 12 shows the area of interest that goes from 0 to 90 degrees, with a HPBW of 40 degrees, while Fig. 13 shows the reflection coefficient. As can be observed, there are two pronounced dips at 12 and 17 GHz.

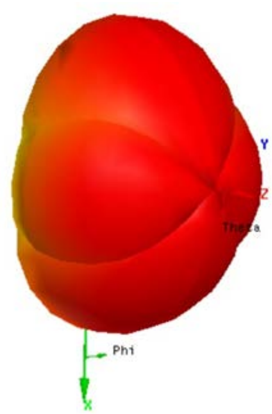

Fig. 10. The computed radiation pattern in the E theta and E phi in dB, at 0 degrees and 90 degrees.

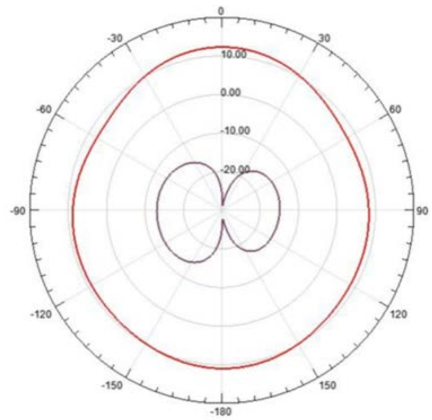

Fig. 11. The real radiation pattern in the E phi in dB, at 0 degrees and 90 degrees.

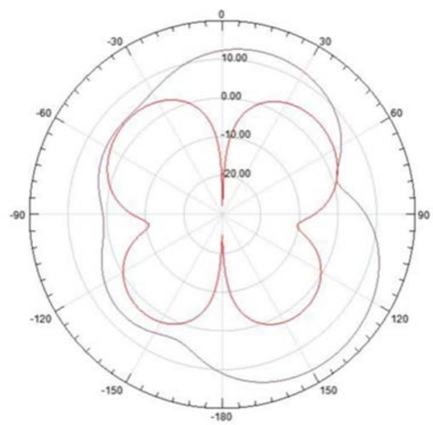

Fig. 12. The real radiation pattern in the E theta in dB, at 0 degrees and 90 degrees.

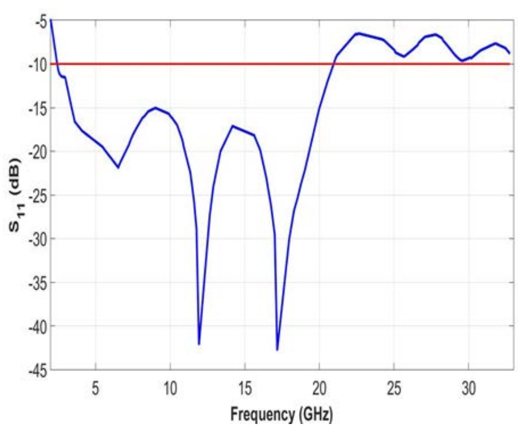

Fig. 13. The S parameter that indicates the bandwidth is from 2 to 21 GHz.

VI. Measurements

The block diagram in Fig. 14 represents the antenna measurement, which connects the transmitting antenna via the SMA connector to the generator model MG3692C, spanning frequencies from 0 to 20 GHz. The signal range was configured to verify the gain within the bandwidth in which the antenna operates. The same procedure is performed with the receiving antenna connecting it to the spectrum analyzer Anritsu model MS2724C from 9 kHz to 20 GHz, the measurements were performed inside the semi-anechoic chamber available at the Faculty of Informatics and Electronics of the ESPOCH, to avoid external interference from the environment, in FAR FIELD in steps of 0.1 obtaining 180 points frequency vs. gain to verify the simulated bandwidth.

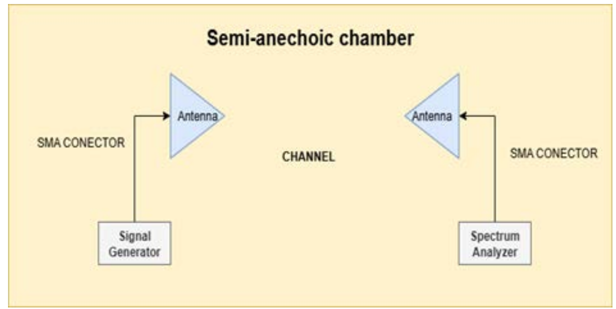

Fig. 14. Block diagram used in the measurement of the antenna.

VII. Implementation And Results Analysis

Once the antenna is optimized, we proceed to the physical construction of the antenna. For this, the dielectric used is FR4, with a thickness of 1.5 mm and dimensions of 16 mm and 19 mm in length and height, respectively. An SMA connector is connected to the patch and the antenna ground, as shown in Fig. 15. As can be seen, the antenna is so small that it resembles the size of a penny coin. In the results, we observe a slight variation compared to the simulation results. Three frequencies do not work correctly. This is due to the incorrect implementation of the slit, because in the print, this slit is not visible. This is the reason why Figure 16 shows three very low peaks at 5.3 GHz, 17.8 GHz, and 18.2 GHz.

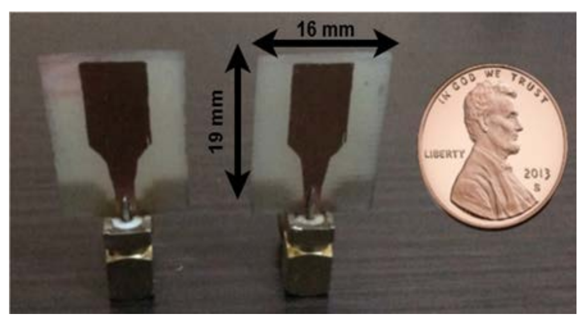

Fig. 15. Microstrip-Fed Tap Monopole Antenna implemented.

As shown in Fig. 16, the frequency of 12.3 GHz exhibits a good gain. Assuming the same time spectrum analyzer selects a suitable width for this frequency band, the graphics are similar to those obtained in Ansys.

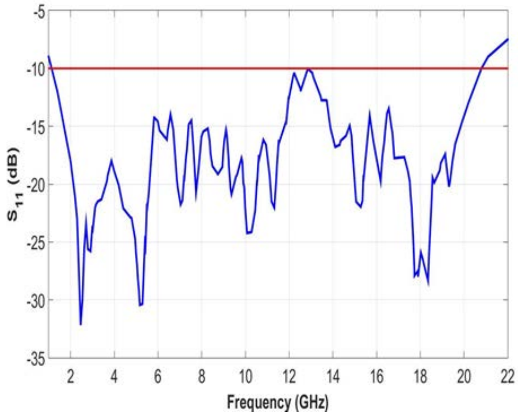

Fig. 16. The *S* parameter of the implemented antenna indicates that the bandwidth is from 1 to 21 GHz.

VIII. CONCLUSIONS

This paper presents a design of a printed tap monopole antenna with a small size for UWB wireless communications applications. A slit, tapered transition, and two-step staircase notch are implemented to obtain the ultra-wide bandwidth of the antenna. The presented antenna exhibits an ultra-wide impedance bandwidth of 1:7.8, with a low VSWR level of less than 1.75, and a small size compared to the UWB antennas investigated. This antenna is a good candidate for handheld UWB applications. A slot within a plane conductor forms the microstrip-fed tap monopole antenna. Widely used in the microwave field. The electric field at the ends of the extremities, while the current flows in the metal, is minimal in the middle and high in the extremities.

Thanks to software, we can determine the exact point of coupling between the antenna through an analysis of the impedance and reflection coefficient results. In the simulation, it was appreciated that the antenna has a bandwidth of 2.7 to 21 GHz. At the time of implementation, with the help of the spectrum analyzer, it was possible to verify that the antenna effectively operates within a bandwidth of 1 to 21 GHz. This is because the Slit had changed its location and size slightly on the board.

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