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A Miniaturized Rectangular Notched Ultra-Wideband (UWB) Microstrip Patch Antenna

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ABSTRACT: This paper presents a design of a miniaturized single-notched ultra-wideband (UWB) patch antenna for wireless area network (WLAN) applications. The antenna was designed using an FR4-Epoxy substrate with a dielectric constant of ε_r =4.4 and a thickness of 1mm^3.The proposed antenna was analysed and simulated on AnsoftHigh Frequency Structure Simulator (HFSS). The UWB characteristics of the antenna were achieved by cutting a circular section of the radiating patch, truncating the top edges of the partial ground plane (PGP), and etching a simple rectangular slot at the centre of defected ground plane (DGP). The band-notched characteristics were obtained by etching an inverted T- Shaped miniature slot structure of different dimensions at the centre of the defected patch structure (DPS).The simulated and measured results shows that the proposed antenna has an operational bandwidth of 4.01-10.63 GHz for S_{11}< -10dB with notch band effect from (4.16-5.1 GHz) with *VSWR*<2, thus rejecting 5G Band (4.8-5.0 GHz) including International Satellite (INSAT) Band signals at (4.5-4.8 GHz). The antenna has significant advantages: its overall dimension is 18x12mm^2 and it is excited with a 50Ωmicrostripfeedline with a stable gain and radiation pattern. There is a good agreement between the simulated and measured data.

KEYWORDS: Keyword Rectangular Notched Band, Miniaturization, UWB Microstrip Antenna, Partial Ground Plane, Defected Patch Structure (DPS).

I. INTRODUCTION

The Federal Communication Commission's (FCC) licensing of the Ultra Wideband spectrum range from 3.1GHz to 10.6GHz in 2002 had a significant impact on commercial applications of this technology[1]. UWB technology has caught the interest of both academics and industries over the last two decades. UWB is a technology that employs a very low energy level for short-range, high-information transmission over a large bandwidth, often more than 500 MHz. Due to the short duration of UWB pulses, it is easier to engineer high-data-rates with low latency. This encourages the usage of UWB in sensor networks, wireless positioning systems, biomedical imaging, and high-data-rate short-range communications[2].

Antennas have a significant impact on the performance of UWB communication systems. As a result, the design of an antenna must meet its typical requirements, such as impedance matching, radiation stability, compact size, and low cost, which is quite challenging to achieve. Because of their lightweight, planar geometry, and ease of integration with other electronic components, these patch antennas are excellent candidates for UWB applications[3-4].The fundamental challenge in UWB communication is avoiding existing licensed and unlicensed wireless communication bands within the UWB spectrum, such as local area networks (WLAN) (IEEE802.11a, HIPERLAN/2), which operates at 5.15-5.825GHz, WiMAX (3.3–3.6 GHz), and X-band satellite communication (7.25–8.395 GHz). Filters are often utilized to reject unwanted bands in order to enhance communication quality. However, the use of filters increases the system's cost and volume, and also introduces insertion losses[5-6].Therefore, significant research has been devoted to the development of UWB antennas with band rejection capabilities in order to avoid potential interference from existing bands. Many notched band UWB antennas have been developed in previous research, applying distinctive approaches to avoid interference concerns. These band rejection techniques include etching slots in patches[7–9], split-ring resonators[10–12], electromagnetic bandgap (EBG) structures[13-15], and inserting a resonant cell in a microstrip line[16-17]. Some researchers achieved notched band capabilities by coupling parasitic elements to the radiator[18-19]. These techniques facilitate and make it much easier to design notch-band antennas. Hence, the design of a compact-sized rectangular notch UWB patch antenna with controllable notch bandwidth and frequency is needed.

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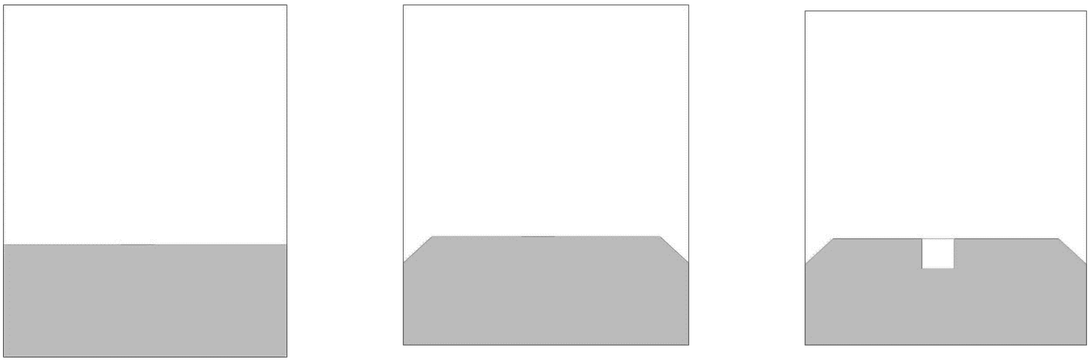
In this paper, a miniaturized, single-notched UWB patch antenna is proposed. The proposed antenna's band notched characteristics were achieved by etching an inverted "T"-shaped miniature slot at the center of the DPS, which is inserted on the radiating patch. The optimized parameters of the design have been obtained by simulating the antenna design onAnsoft HFSS. This paper's outline is as follows: Section II describes the UWB antenna configuration and design procedures. The proposed UWB antenna with band notch effects is explained in Section III. Section IV presents the simulation results and discussions. Finally, the paper is concluded in section V.

II. DESIGN PROCEDURES

2.1 UWB Antenna Configuration

The UWB antenna design evolved from the simulation of a conventional monopole rectangular patch antenna with PGP (Case I) to achieve the UWB characteristics shown in Fig.1 (a).The simulated S_{11} <-10dB (Return Loss)of this antenna plotted in Fig.2 shows that at (6.92 to 8.23 GHz), the antenna in Case I did not meet the UWB characteristics. In (Case II), the upper ends of the UWB antenna were truncated into diagonal edges to improve the impedance matching, as illustrated in Fig.1 (b). The S_{11} of the designated antenna illustrated in Case II is greater than-10dB at (7.38 to 7.59 GHz) and still does not match UWB characteristics within the working bandwidth.

Finally, to achieve good impedance matching properties, a simple rectangular slot is etched at the centre of the DGP in Case III, as shown in Fig. 1(c). Therefore, Case III is used as our reference UWB antenna. The wideband operation of the UWB antenna has been achieved by optimizing the dimension of the radiating patch and ground plane to achieve S_{11}<-10dB as illustrated in Fig.2.



(a) Case I (b) Case II (C) Case III

Fig. 1.The Design Evolution of UWB Patch antenna

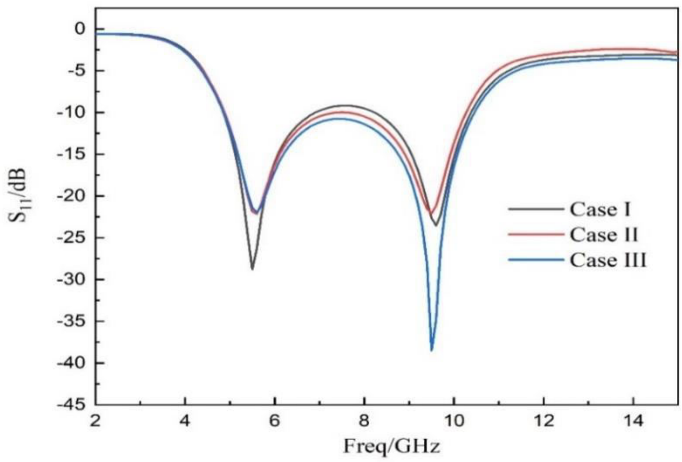


Fig. 2: The S_{11} Results of UWB Patch Antenna Evolution for Three Different Cases.

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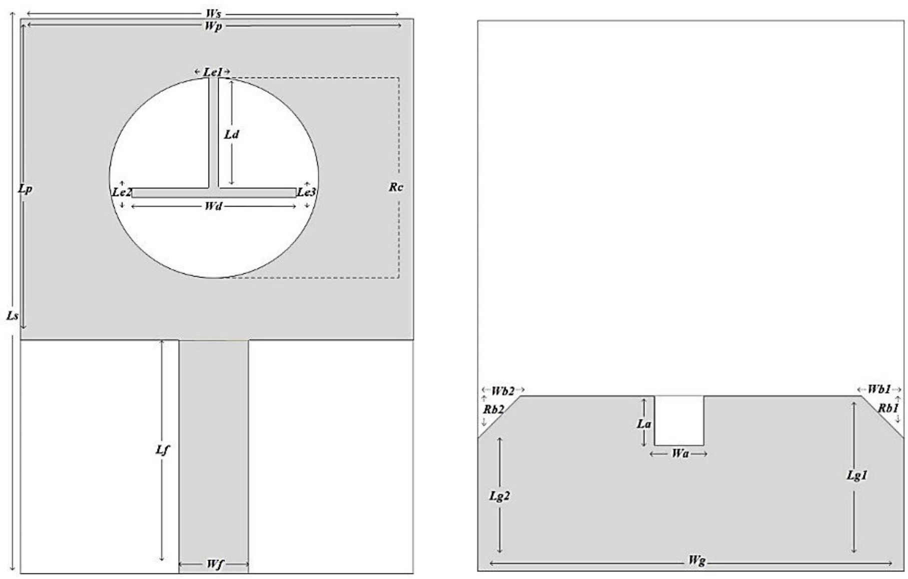
III. PROPOSED UWB ANTENNA WITH BAND NOTCHED FILTER

The geometry and detailed design parameters of the proposed UWB notched antenna are shown in Fig. 3. The antenna consists of a modified rectangular patch with an inverted T-shaped miniature slot etched in DPS. The UWB characteristics of the antenna were achieved by removing a circular section R_c of the radiating patch, truncating the upper corners of the PGP into diagonal edges as mentioned in Fig.1 (b) Case II, and having a simple rectangular slot etched at the centre of the DGP in Fig.1 (c) Case III. The use of slot structure is motivated by the ease of design and the simplification of the antenna. The antenna was designed using FR4_Epoxy substrate with dielectric constant of (ε_r = *4.4and tanδ = 0.02*), 1mm^3 thickness, with length $L_s$and width W_s. On AnsoftHFSS 20, the proposed antenna was analysed and simulated to get the desired performance in terms of the return loss and bandwidth over a wide frequency range. The overall size of the compact antenna is 18x12 mm^2 and it is fed through the feedline with a characteristic impedance of 50Ω. The optimized dimensions of the antenna are as follows:

TABLE 1: OPTIMIZED PARAMETERS OF PROPOSED ANTENNA

Symbol	**Size (mm)**	**Symbol**	**Size (mm)**	**Symbol**	**Size (mm)**
Ls	18mm	W_P	12 mm	L_d	5.2mm
Ws	12mm	L_{g1}	4.9mm	R_c	3.9mm
hs	1mm	L_{g2}	3mm	W_d	6.6mm
L_f	7.3mm	W_g	12mm	R_{b1}=R_{b2}	2mm
W_f	2mm	L_a	3.5mm	W_{b1}=W_{b2}	1.6mm
L_P	10.7mm	W_a	1.3mm	L_{e1}=L_{e2}=L_{e3}	0.2mm



(b) Top View (a) Back View

Fig 3: Geometry of proposed UWB antenna

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The antenna was excited by a 50Ω microstripfeedline whose width was calculated by using microstrip design equations. By inserting an inverted T-shaped slot branch of the dimensions 5.2mm x 6.6mm x length and 0.2mm width at the centre radius R_c of DPS, a notched frequency band from 4.16–5.1 GHz is created. The slot length impacts both the notch centre frequency and the notch bandwidth, whereas the slot width impacts just the notch bandwidth. It is easy to design a specificnotch-band range by adjusting the slot size[20-21]. The proposed antenna can be tuned to operate within the UWB band by selecting the optimal parameters listed in the table. Fig.4 shows the return loss characteristic of the proposed antenna with respect to Fig.1(c) Case III, as well as the effect of the modifications in the range of 4.01-10.63 GHz.

IV. RESULTS AND DISCUSSION

In this section, the desired performance of the proposed antenna was simulated and measured with the Ansoft HFSS tool. Figs.4 and 5 illustrate the simulated results of return loss for the proposed antenna with and without slot. It means that the antenna has a wide bandwidth ranging from 4.01 to 10.63 GHz. The overall target of the proposed UWB antenna design is to achieve good output with a return loss of -10dB. The inverted T-shaped slot rejects the frequency band of 4.16–5.1 GHz, so frequency interference caused by 5G Band (4.8–5.0 GHz) and INSAT Band signals at 4.5-4.8 GHz can be avoided.

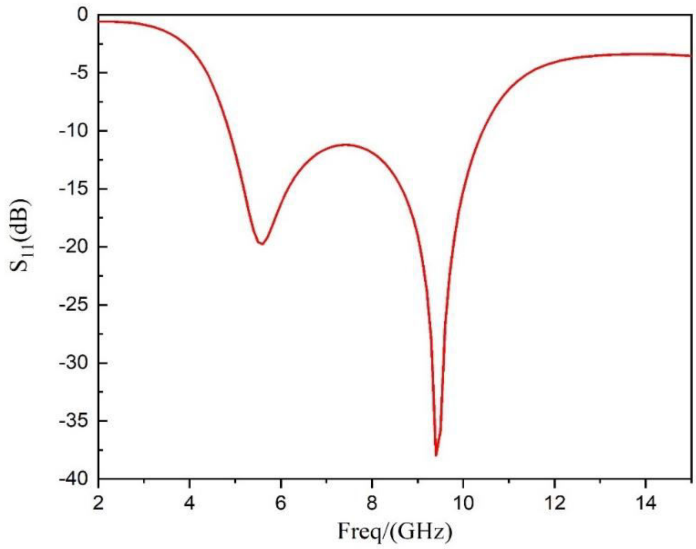

Fig 4. RL of UWB Antenna without Notch band behaviour

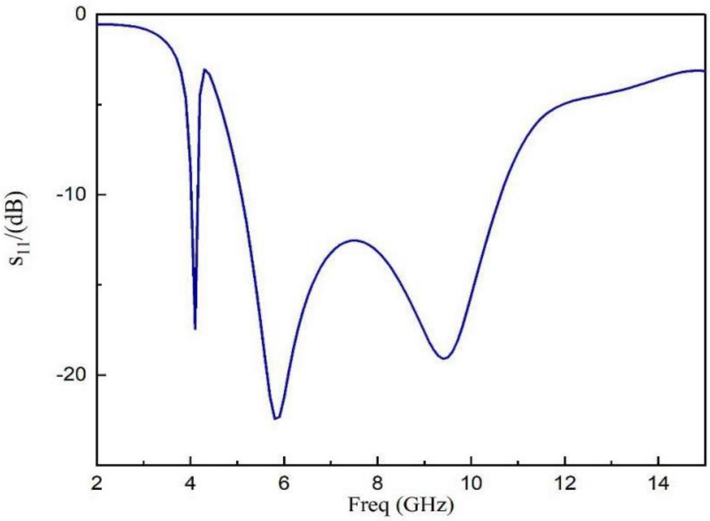

Fig 5. Simulated Return Loss of the antenna with Notched band behaviour

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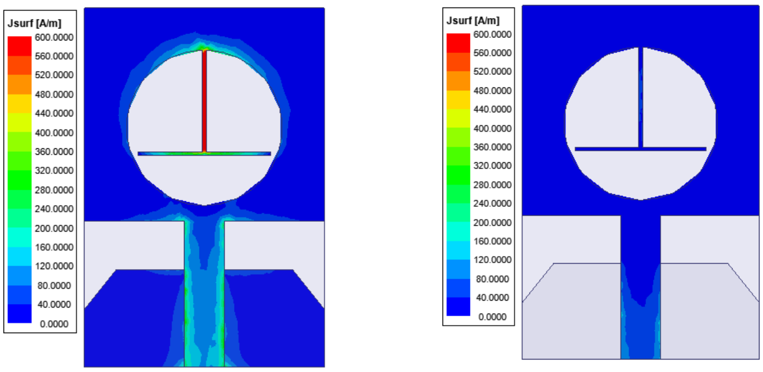
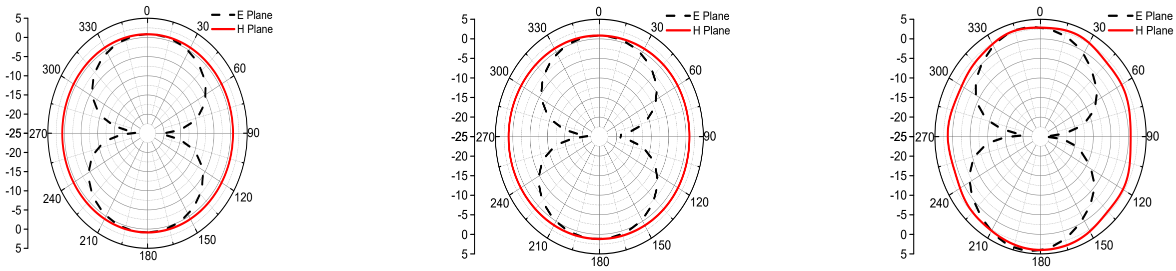
The surface current distribution determined by AnsoftHFSS on the radiating patch on the top side and the microstrip feed line on the bottom side of the substrate is shown in Fig.6 at 4.5 GHz and 6.0 GHz, respectively. In Fig.6 (a), a significant amount of current has accumulated around the inverted T-shaped structure, causing a notch at 4.5 GHz. In this frequency band, the antenna is unable to effectively convert the current into electromagnetic waves. In Fig.6 (b), it is obvious that at a frequency of 6.0 GHz, far away from the band notched frequency, the antenna radiates as usual.



(a) 4.5GHz (b) 6.0GHz

Fig. 6. Simulated surface current distributions of the antenna with theinverted T-Shaped filter.

The radiation patterns of the proposed antenna are simulated at 4.5 GHz, 6.0 GHz, and 9.5 GHz frequencies along both the E-plane and the H-plane as shown in Fig.7 (a), (b), and (c) respectively. In the view of UWB applications, the radiation pattern of the antenna should be omnidirectional. The results show that the radiation pattern of the proposed antenna at various frequencies (4.5 GHz, 6.0 GHz, and 9.5 GHz) demonstrates that the radiation pattern is nearly omnidirectional with a change in frequency across its operating bandwidth.



(a) 4.5GHz (b) 6.0GHz (c) 9.5GHz

Fig 7.The antenna radiation pattern of E Plane and H Plane.

As shown in Fig.8, the modelled antenna was fabricated on an FR-4 substrate (1 mm^3) for experimental verification. The impedance and radiation characteristics of the designed antenna were measured by an Agilent vector network analyser (VNA).

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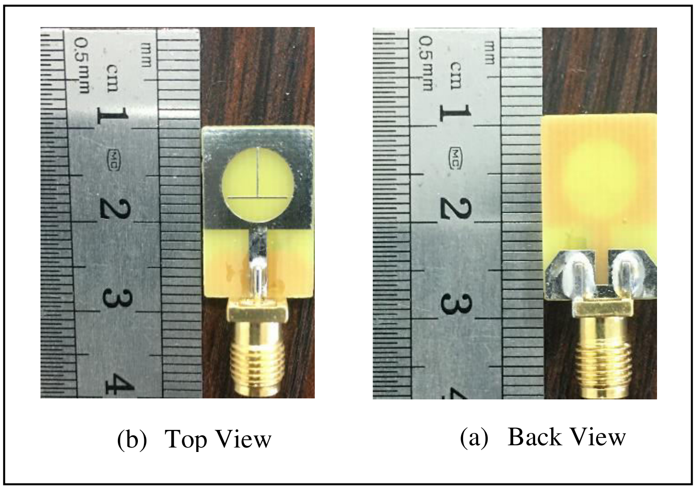

Fig.8 Physical Structure of The fabricated Proposed UWB antenna.

Fig.9 shows the simulated and measured impedance characteristics. The measured and simulated results are well-matched. The antenna showed good impedance matching characteristics throughout the entire UWB spectrum (4.01–10.63 GHz), with the exception of the notch band (4.16–5.0 GHz), which was rejected to avoid interference. There is a difference between simulated and measured S_{11} results, especially at high frequencies. The measured overall working bandwidth moves towards a high frequency, which is mainly affected by the test environment.

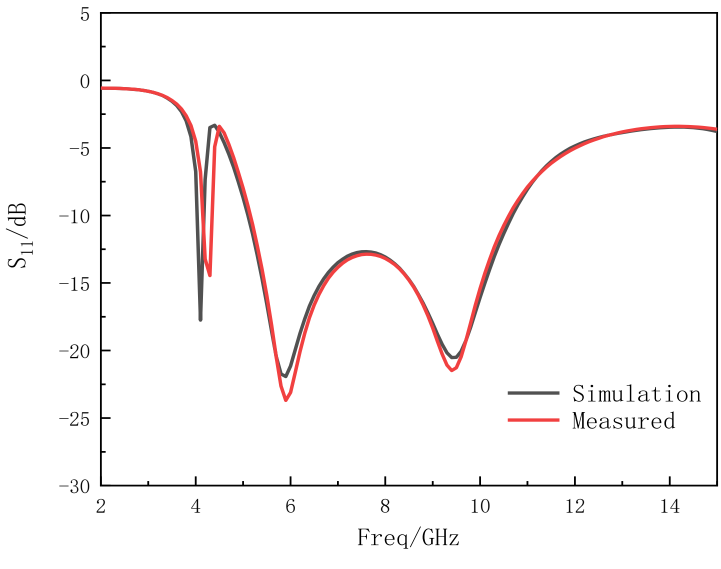

Fig.9 The simulation and measurement comparison of S_{11}.

IV. CONCLUSION

The design of a miniaturized single-notched UWB patch antenna with PGP for UWB applications with an overall compact size of 18 x 12 x 1 mm^3 is presented. The proposed UWB antenna is printed on an FR4-Epoxy substrate with band notched rejection capabilities. A simple rectangular slot and truncated diagonal edges have been etched on the ground plane with DPS on the radiating patch to produce a good impedance match from the 4.01 GHz to 10.63 GHz frequency range with a return loss of S_{11}< -10dB**.** The notched band characteristics have been achieved by inserting an inverted T-shaped miniature slot at the centre of the radiating patch to create a notch band effect from 4.16 GHz to 5.1 GHz, thus rejecting the frequency interference from the 5G Band (4.8-5.0 GHz) and INSAT Band signals (4.5-4.8 GHz). The good performance of the proposed UWB antenna structure makes it suitable for future UWB communication applications. A reasonable agreement has been achieved.

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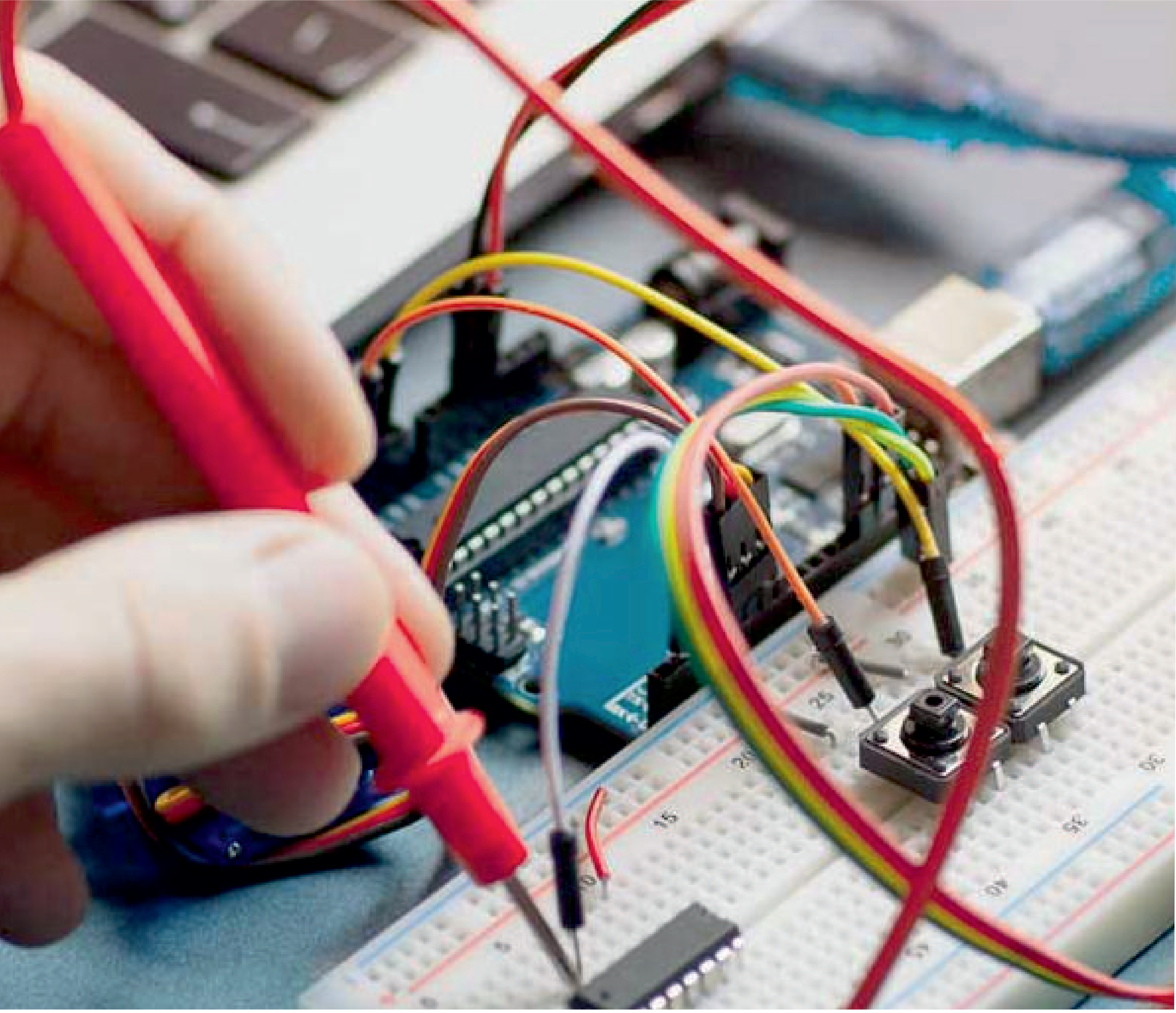

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