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A Broadband Double U-Slot Loaded Rectangle Patch Antenna for 5G Applications

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ABSTRACT: -In this paper a microstrip antenna loading with double U-slot loaded rectangle patch antenna is designed. Here, the shape of patch is rectangular and partial ground plane is used. The antenna designing is done by using HFSS simulation tool. Feeding is done by using microstrip feed line. After designing antenna we see the effect of variation in the dielectric material of substrate, width and length of U-shaped slot, feed position and ground plane variation on antenna bandwidth is analyzed. Finally, the proposed antenna design gives optimum impedance bandwidth of 10 GHz operating over a frequency range of 4.1 to 14.1 GHz with VSWR < 2. These characteristics make the designed antenna suitable for various ultra wideband applications.

KEYWORDS:-Microstrip Antenna, U-shaped slot, Partial ground plane,5G.

I. INTRODUCTION

Consider the term "ultra-wideband" (5G) as a relatively new term to describe a technology, which had been known since the early 1960's. The old definition was referring to "carrier-free", "baseband", or "impulse" technology. The fundamental concept is to develop, transmit and receive an extremely short duration burst of radio frequency (RF) energy, like a short pulse. The pulse typically has duration of a few tens of picoseconds to a few nanoseconds. These pulses represent one to only a few cycles of an RF carrier wave; therefore, as for resultant waveforms, extremely broadband signals can be achieved. Often it is difficult to determine the actual RF center frequency for an extremely short pulse; thus, the term "carrier-free" comes in. The amount of powertransmitted is a few milliwatts, which, when coupled with the spectral spread, producesvery low spectral power densities. The Federal Communication Commission (FCC) specifies that between 3.1 and 10.6 GHz, the emission limits should be less than -41.3 dBm/MHz, or 75 nW/MHz. The total power between these limits is a mere 0.5 mW.
The entire paper has been partitioned into five parts. In II, microstrip patch antennas have been discussed. In III, antenna design for double U-slot rectangle patch antenna hardware structure is discussed. In IV, result and discussion has been discussed. In V, conclusions and future scope of the paper work has been presented.

II. MICRO-STRIP ANTENNA

Microstrip antennas consist of a very thin ($t \ll \lambda o$ where λo is the free space wavelength) metallic strip (patch) placed a small fraction of a wavelength ($h \ll \lambda 0$, usually $0.003\lambda o \le h \le 0.05\lambda o$) above ground plane. The micro strip patch is designed so its pattern maximum is normal to the patch (Broadside radiator) this is accomplished by properly choosing the mode (field configuration) of excitation beneath the patch.

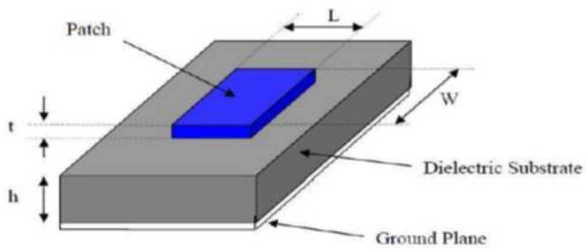

Figure 1: Rectangular patch antennas

The strip and the ground plane are separated by a dielectric sheet (referred to as the substrate) as shown in figure 1.

There are numerous substrate that can be used for the design of microstrip antennas and their dielectric constants are usually in the range of 2.2<= ε r <=12. The ones that are most desirable for good antenna performance are thick substrate whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound field for radiation into space. Thin substrates with higher dielectric constants are desirable for microwave circuitry because they require tightly bound field to minimize undesired radiation and coupling, and lead to smaller element sizes; however, because of their greater losses, they are less efficient and have relatively smaller bandwidth. Often microstrip antennas are also referred to as patch antennas. The radiating elements and the feed lines are usually photo etched on the dielectric substrate.

Dielectric Material for Microstrip Antenna

Dielectric constant of the substrate gives mechanical strength to the microstrip patch antenna. In order to predict the resonant frequency, resonant resistance and other antenna parameter, the propagation constant for a wave in the microstrip substrate must be accurately known. This can be done by accurately estimating the dielectric constant of the substrate materials, and the temperature tolerance of the permittivity.

There is no one ideal substrate; the choice rather depends on the application. Substrate choice and evaluation is an essential part of the design procedure. Many substrate properties may be involved in these considerations; dielectric constant and loss tangent and their variation with temperature and frequency, thermal coefficient and temperature range. Low frequency application requires high dielectric constants to keep the size small. For high power application of microstrip patch antenna, a thick cladding is desirable. microstrip patch antennas used low dielectric substrates.

In this project, we have used RT duroid 5880 substrate with dielectric constant 2.5 and this substrate has following features

- High thermal conductivity
- Low loss tangent
- Thermally stable low profile and reverse treated copper foil
- Advanced filler system

USB Microstrip Antenna

In the recent rapid research of ultra-wideband (UWB) technology, the UWB antenna is one of the most essential components for an UWB system. Many applications such as local network, imaging radar, and communication employ UWB technology. Therefore, developments of UWB antennas become important and complex for system and antenna designers. In conventional UWB systems, the antenna radiates in the preferred direction with high gain performance and operates over a broad impedance-matched bandwidth. One of the examples would be log-periodic antennas; they have broadband impedance matching and reasonable gain in the desired direction. However, due to their dispersive properties on broadband waveform radiation, extra compensations and complexities are required. Another type of broadband antenna would be the TEM horn. To have lower dispersive rating, bi-conical antennas are a good choice for broadband systems. Bi-conical antennas have a broadband impedance match and tend to generate non-dispersive waveforms. However, when applying UWB systems to portable devices, conventional UWB antennas are not suitable. This is mainly due to their bulky size and directional properties. Monopole and dipole antennas are good options for portable UWB devices. They have great features such as broadband impedance matching, small size and omni-directional radiation. However, from a system design point of view, fabrication may not be easy because those antennas require a perpendicular ground plane. Therefore, planar or printed-circuit board (PCB) antennas are much more suitable in terms of manufacturing complexities. Also, when designing UWB antennas, designers must make new considerations based on new UWB standards.

III. ANTENNA DESIGN

In this paper, antenna is designed by using ANSOFT HFSS (High Frequency Structural Simulator) [4]. Method of finite element solver is used. Rectangular patch is 11.964 mm wide and 16 mm long. Dielectric material of substrate is varying and it is 30 mm wide and 30 mm long and height of the substrate is 1.5 mm. We take different types of substrate such as glass, FR4 epoxy, mica and Bakelite. Feeder position is varied at 0 mm, 1.5mm, 2.5 mm from the symmetrical position. . Ground plane is partial providing good impedance match with width 30mm mm and varying length. At different lengths of partial ground plane i.e. 7mm, 7.4mm, 7.8mm, 8mm, 8.4mm, 8.8mm and 9mm, effect on antenna bandwidth is observed. Double U-shaped slot is used to decrease the overall impedance. It provides good impedance matching and higher bandwidth.

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Table 1:shows the dimension of various parameters of antenna

S.No	Parameters	Dimensions	Material
1	Substrate	W_{sub}=30 mm L_{sub}=30 mm H_{sub}= 1.6mm	Varying
2	Rectangular patch	L_p= 16 mm W_p= 11.964mm	Copper
3	Ground Plane	W_g= 16 mm L_g= varying	Copper
4	U-Slot	L_{Hs}= Varying W_s= Varying	-
5	Feed line	W_f= 3.01mm L_f = 8 mm	Copper

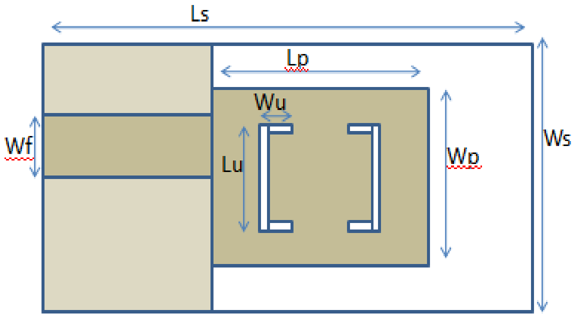

Figure 2: Design of Double U-slot loaded Rectangle Patch Microstrip Antenna

Width of microstrip antenna is simply given as

$$W = \frac{c}{2f_0\sqrt{\frac{\varepsilon_r+1}{2}}} (1)$$

Where,

W= Width of Patch

ε_r= Dielectric constant of the substrate

Actual length of microstrip antenna is given as

$$L_{actual} = L_{eff} - \Delta L \ (2)$$

Where,

L_{eff}= Effective length of the patch.

ΔL = Extended electrical length

Effective length of the patch is simply given by

$$L_{eff} = \frac{c}{2f_0\sqrt{\varepsilon_{reff}}} (3)$$

Where,

ε_{reff}= Effective dielectric constant

For low frequencies the effective dielectric constant is essentially constant. At intermediate frequencies its values begin to monotonically increase and eventually approach the values of dielectric constant of the substrate. Its value is given by,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}[1 + 12\frac{h}{W}]^{-\frac{1}{2}} (4)$$

h = thickness of the substrate

In microstrip antenna, radiation occurs due to the fringing effects. Due to fringing effects electrical length of patch is greater than its physical length. This fringing depends on the width of patch and height of substrate [7].Now the extended electric length is given by

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.8)} (5)$$

The width of microstrip line in microstrip antenna is given as follows:

For

$$\frac{W_{eff}}{h} \geq 2$$

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$$W_{eff} = \frac{2h}{\pi}\left\{\frac{\varepsilon_r - 1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - 0.\frac{61}{\varepsilon_r}\right] + B - 1 - \ln(2B-1)\right\}$$

And for

$$\frac{W_{eff}}{h} \le 2$$

$$W_{eff} = \frac{8he^{A}}{e^{2A} - 2} \quad (6)$$

$$W_f = W_{eff} - \frac{t}{\pi\left[1 + \ln\left(\frac{2h}{t}\right)\right]} \quad (7)$$

Where, A and B are given as follows

$$A = \frac{Z_{ol}}{60}\left(\frac{\varepsilon_r + 1}{2}\right)^{0.5} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}(0.23 + 0.11/\varepsilon_r)$$

$$B = \frac{377\pi}{2Z_{ol}\sqrt{\varepsilon_r}} \quad (8)$$

IV. RESULTS AND DISCUSSION

The results shown here are simulated on HFSS software. In HFSS, rectangular patch and partial ground plane are made up of PEC (Perfect Electrical Conductor) and air or vacuum can be used for the radiation box.

Firstly, the effect of varying length of partial ground plane on bandwidth of antenna is analyzed.Return loss gives us amount of power being reflected by the input port. For 5G antenna, return loss below -10 dB is considered to be quite efficient.Figure 3 shows return loss v/s frequency curve at different length of ground plane.

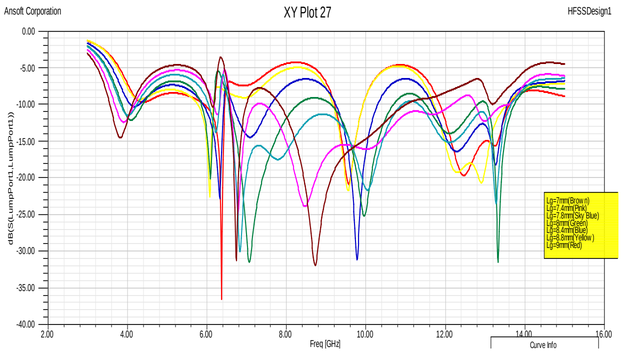

Figure 3: Return loss v/s frequency curve for varying length of ground plane

Table 2: Bandwidth at Different Length of Ground Plane

Length of Ground Plane	Frequency Range	Bandwidth	Fractional Bandwidth
7mm	7.8-11.01 GHz	3.21 GHz	44.58%
7.4mm	6.5-12.22GHz	5.72GHz	79.44%
7.8mm	6.5-13.6GHz	7.1GHz	98.6%
8mm	6.5-13.7GHz	7.2GHz	100%

8.4mm	9.2-10.33GHz	1.13GHz	15.69%
8.8mm	9.17-9.94GHz	0.77GHz	10.69%
9mm	9.22-9.92GHz	0.7GHz	9.72%

From the figure 3 and table 2 it is clear that optimum bandwidth is achieved when length of ground plane is 8mm. Now, we see the effect of U-slot width on bandwidth of antenna.Figure 4 shows return loss v/s frequency curve at different width of ground plane.

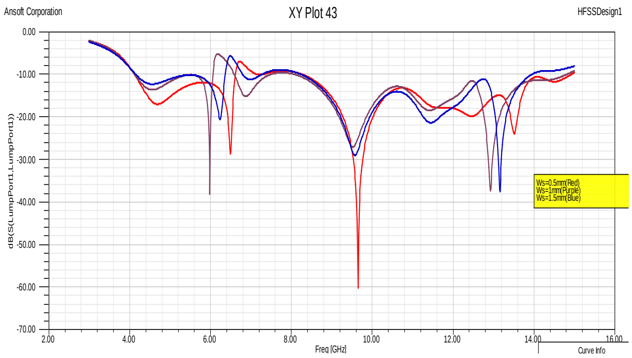

Figure 4: Return loss v/s frequency curve for varying width of U-slot

The E-plane is defined as the plane containing the electric field vector and the directions of maximum radiation while the H-plane is the plane containing the magnetic field vector and the direction of maximum radiation. The x-z plane elevation plane with some particular azimuth angle φ is the principle E-plane. While for the x-y plane azimuth plane with some particular elevation angle θ is principle H-plane. Figure 5 and figure 6 shows 2D E-plane radiation pattern at different frequencies with in the band 4.1-14.1 GHz.

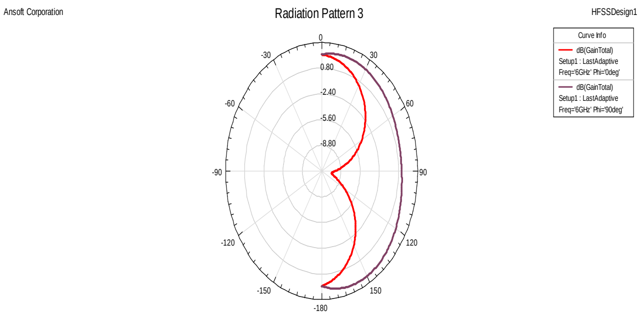

Figure 5: 2D E-plane Radiation Pattern at 6 GHz

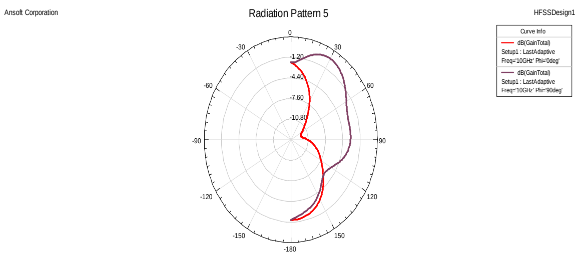

Figure 6: 2D E-plane Radiation Pattern at 12 GHz

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Figure 7 and figure 8 shows 2D H-plane radiation pattern at different frequencies with in the band 4.1-14.6 GHz.

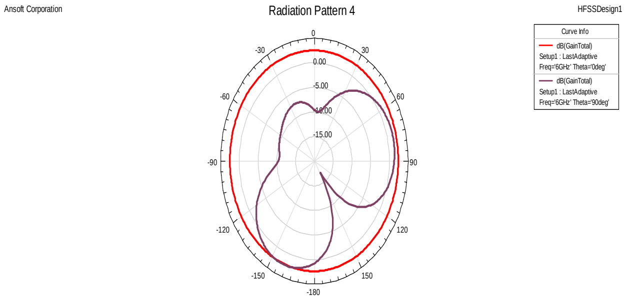

Figure 7: 2D H-plane Radiation Pattern at 6 GHz

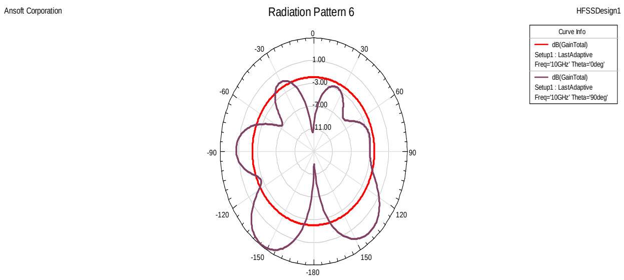

Figure 8: 2D H-plane Radiation Pattern at 12 GHz

Figure 9 and figure 10 shows 3D radiation pattern at different frequencies within the band 4.1-14.6 GHz

Figure 9: 3D Radiation Pattern at 6 GHz

Figure 10: 3D Radiation Pattern at 12 GHz

V. CONCLUSION

It is observed that double U-slot loaded rectangle patch microstrip antenna provided optimum bandwidth when length of partial ground plane is 8mm (6.5-13.7 GHz i.e. 7.2 GHz), U-slot width is 1mm (6.5-14.8 GHz i.e. 8.3GHz), and feeding position is 2.5mm from symmetrical position (6.5-14.8 GHz i.e. 8.3 GHz). Finally, we saw the effect of dielectric material on bandwidth and got optimum bandwidth by using FR-4 epoxy substrate (6.5-14.8GHz i.e. 8.3 GHz), and when length of U-slot is 12mm (6.5-14.8 GHz i.e. 8.3 GHz). Finally, we design antenna having ground plane length 8mm, U-slot width 1mm, feeding position 2.5 mm from symmetrical position, substrate material is FR-4 epoxy, length of U-slot is 12mm then we get bandwidth (S11<-10 dB) 10.5 GHz (4.1-14.6 GHz). The proposed design of the antenna can be used for a variety of 5G applications including high speed data transfers, wireless connectivity between 5G-enabled devices and a variety of medical applications.

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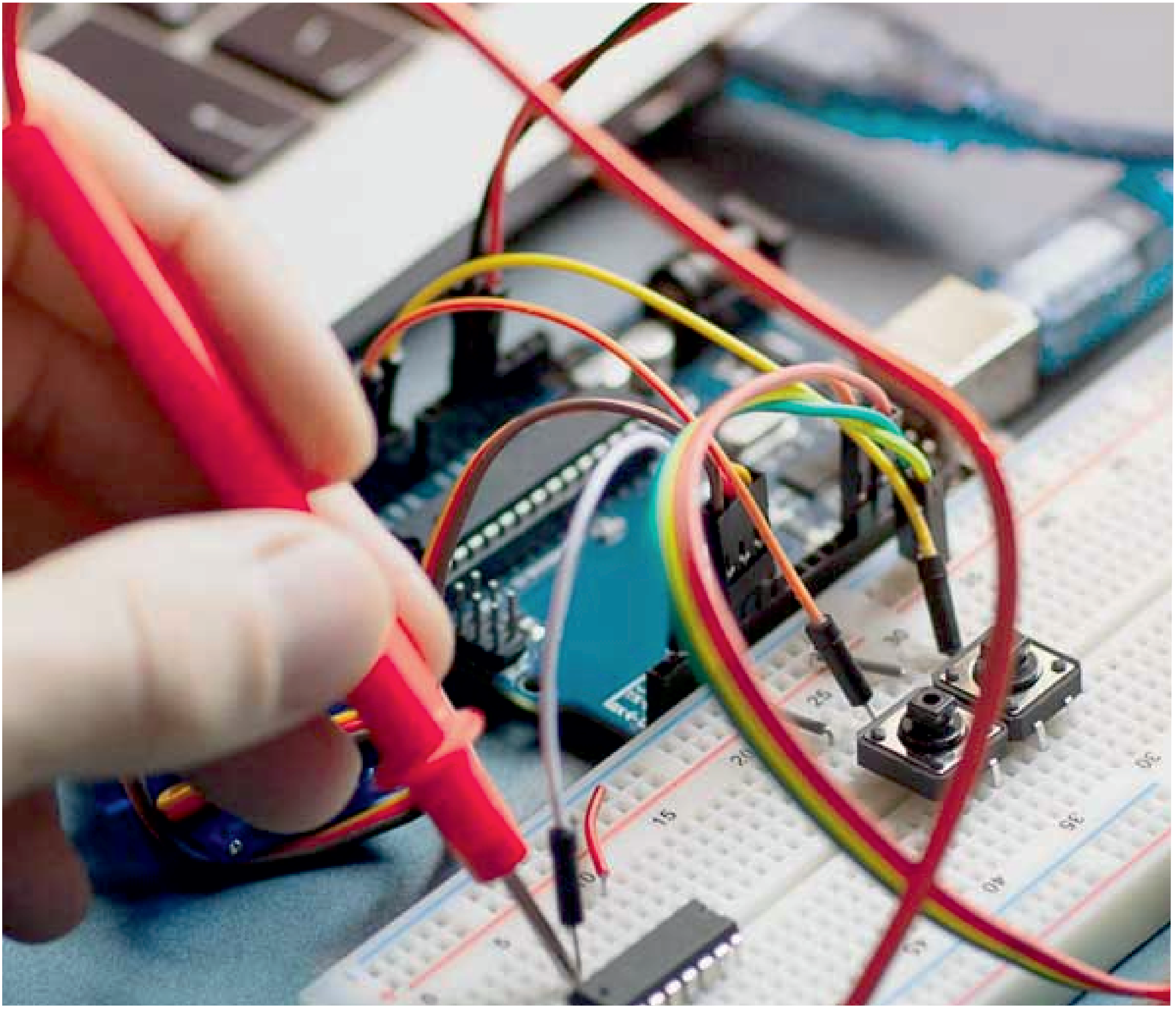

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