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Electronic System for Optical Signal Processing and Amplification

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ABSTRACT: High frequency signals have wide range varying from 3MHz to 300GHz. Fibre optic Sensors (FOS) make use of such high frequency signals for their operation. The optical signal is converted to analog voltage signal at the receptor end using photodiode in transimpedance stage. This voltage signal is a low magnitude, high frequency signal which further needs processing before digitization. The first stage of processing is amplification but proper attention needs to be given on circuit design, board layout before obtaining the final result as these signals are prone to noise pick-ups and may not give the desired output. Points that help in preparing a good board layout for such circuits have been described in this paper. The circuit has been designed and simulated first to check its functioning. PCB layout was prepared following the criteria and was fabricated. The hardware results were obtained and are reported in the paper. This amplifier circuit if properly designed can be utilized for FOS and is very economical.

KEYWORDS: Optical Signals, Fibre Optic Sensors, Amplifiers, Noise.

I.INTRODUCTION

According to the International Telecommunication Union (ITU) the various operating frequencies are limited in bands starting from lowest frequency band to the highest operating band. Each of these frequency bands have their own significance and applications.

The high frequency signal bands ranging from 3MHz to 300GHz are used in various communication systems for data transmission, broad band reception, radar communication. The ultra sound, digital X-rays, digital spectrum analyzers, digital oscilloscopes, etc. also utilize high frequency [1].

High frequency offers wide bandwidth which is one of the major requirements of the optical signals. These signals are being utilized in the field of Instrumentation for sensing various physical parameters like temperature, pressure, acoustics etc. These sensors are known as fibre optic sensors(FOS).

II.FIBRE OPTIC SENSORS

The basic block diagram of FOS Fig1. system includes the light source which may be LASERs, LASER diodes or other light sources. This light passes through the fibre and any variation in the physical parameter to be measured causes the property of light to change which could be in terms of changes in intensity, wavelength, phase, etc. [2]. This light then falls on the detector circuit which is a photodiode followed by certain signal processing. The analog signal is then digitized for further digital signal processing required to obtain the correct information about the physical parameter change.

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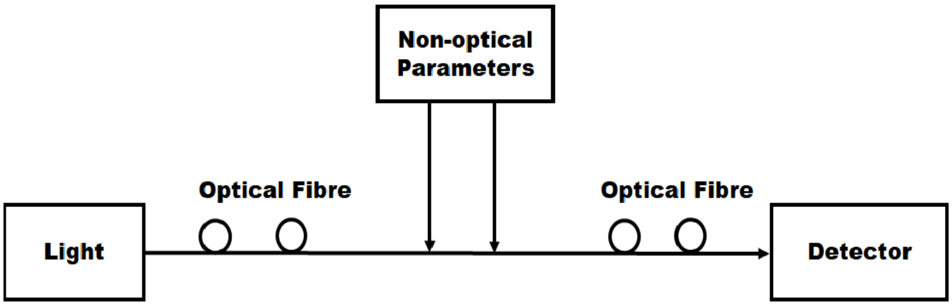

Fig 1. Basic Block Diagram of FOS

As high frequency signals are prone to noise proper design considerations, board layout and fabrication method are important in order to obtain desired results. This paper describes the important criteria to be implemented while designing the hardware of the amplification circuit, it also presents the simulation result and the hardware result of the amplifier circuit designed for FOS applications. The circuit designed is very cost effective, caters to the need of optical signal processing by providing a wide bandwidth and adequate gain.

III.ANALOG SIGNAL PROCESSING

The light that travels the optical fibre is sensed by the photodiode which converts this signal into the corresponding current signal. The amplitude of this current signal is very small, for example, in nano to micro ampere range as per the application, but the frequency can be very high. The current signal is then converted to voltage amplitude for further processing. This is done by employing an operational amplifier(op-amp) in transimpedance amplifier (TIA)configuration. Proper selection of photodiode and the op-amp for the TIA stage is very crucial as they decide the overall accuracy of the detector circuit.

The output of the TIA is in microvolts to millivolts range having a high frequency. The signal further needs amplification to obtain a signal that can be fed to the digitization board. The op-amps used for amplification of such signals should have the high gain bandwidth product.

Several integrated circuits (ICs) are available that could be utilized for such applications namely AD8009, AD811, LTC6268 etc.

IV.SIMULATION RESULTS

The simulation was performed using NI-Multisim. A two stage non-inverting amplifier employing IC AD8009 was designed each with a gain of 5. The overall gain of the system was 25. The Fig 2. displays the implemented amplifier circuit layout using IC AD8009. The circuit was specifically tested with square wave input as many times the higher frequency light output corresponds to the light flashes having fast rise time and a small duration.

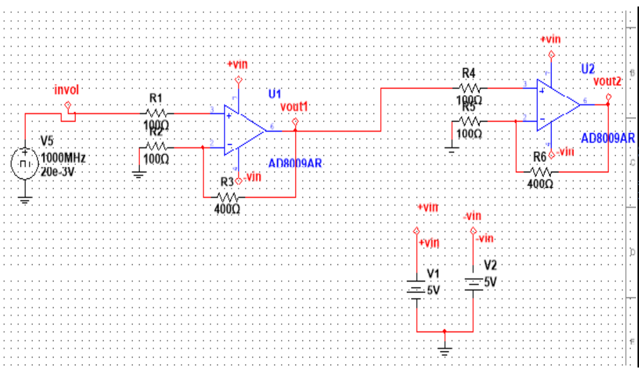

Fig 2: Simulation Circuit Layout

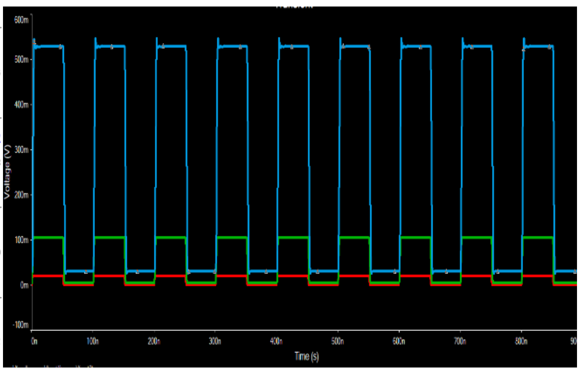

Fig 3: Output waveforms for 10MHz

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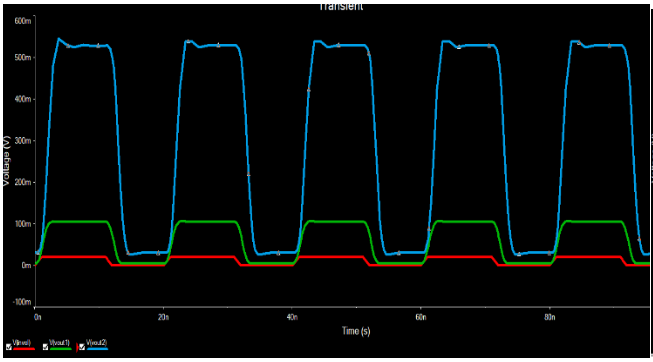

Fig 4: Output waveforms for 50MHz

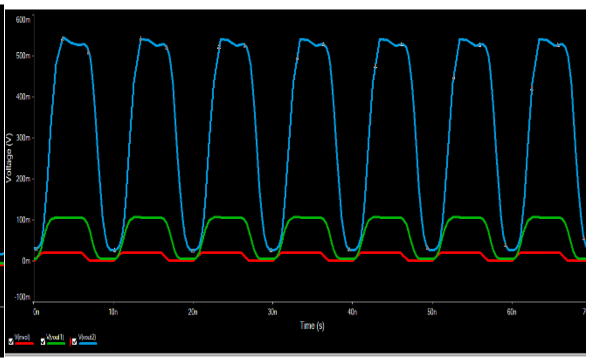

Fig 5: Output waveforms for 100MHz

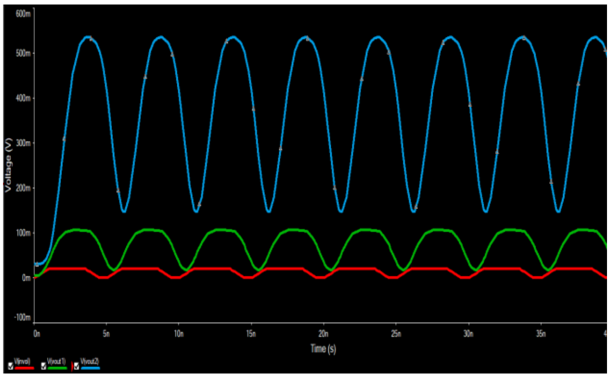

Fig 6: Output waveforms for 200MHz

For 20mv square wave input signal(that corresponds to the red colour in the figures) the first stage amplified output was 100mv(that corresponds to green colour in the figures) which was further amplified with a gain of 5 and thus the amplifier output of 2nd stage was 500mv(corresponds to waveform in blue colour). Figures 3, 4, 5 and 6 display the simulated output waveforms for the frequencies of 10MHz, 50MHz, 100MHz and 200MHz respectively. It was observed from the simulation results that the circuit gave amplification results up to 200MHz and soon after that the gain factor started reducing till it reached a gain of 1 at 1GHz. It could also be seen that at 200MHz the output of first stage is still a square wave but because of finite rise time of the system the shape of the output at the second stageis distorted but the rise and fall time of the signal output is of the order of 2nanoseconds. Thus, with this amplifier circuit amplification for a wide frequency with rise time as small as 2nanoseconds can be achieved. After getting satisfactory results in the simulation, the board layout was prepared using Eagle software.

V. HARDWARE RESULTS

High frequency signal processing deals with certain design issues. These difficulties are caused due to electromagnetic interference, cross talks, utilization of high-speed op-amps, probe, noise, grounding systems etc. All these considerations have to be taken care while preparing the circuit board layout. A good printed circuit board (PCB) is the one which reduces these undesired effects and gives the high-quality output[3].Few considerations, crucial for a proper board layout which should be implemented during hardware design are mentioned.

To start with, a double layer PCB is the minimal requirement when dealing with high frequencies. A double layer PCB is one in which the bottom plane is used as a continuous large plane for ground. Itprovides a low ohmic resistance ground track for all the return signals. The supply voltage should be provided as the supply plane on the top layer [4].

Utilizing surface mount devices (SMD) on high frequency board helps to ensure the low terminal inductance, it also reduces the stray capacitance by providing a smaller and compact PCB. Use of sockets should be avoided [4].

Separate grounds should be provided for analog and digital circuits on the board. These grounds then should be brought to a common ground point which is usually the chassis ground of the device. This is termed as star ground [5].

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In order to protect the noise entering the op-amps, their supply terminals need to be bypassed. This implies that several capacitors should be connected between the supply terminals and the ground. By implementing this a low ac impedance path is created for a wide range of frequencies that ensures no noise interference with the op-amps [6]. Usually, an electrolytic capacitor of 10microfarad and a ceramic capacitor of 0.01 microfarad is sufficient enough to take care of broad frequency noise rejection. The capacitors should be placed very near to the op-amp. The other terminal of the capacitor should be connected to the ground plane with the shortest possible distance [7].

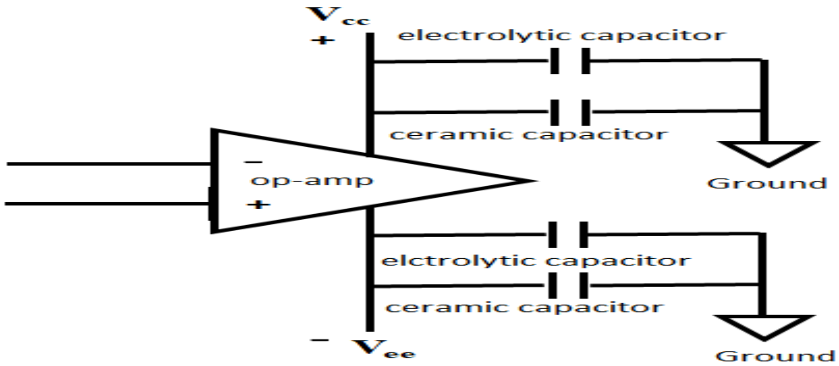

Fig 7.: Bypassing Supply terminals of op-amp

High frequency circuits are most affected by undesired stray inductances and capacitances invariably present in the circuit. These unwanted parasites can be reduced by the proper placing of the components i.e., the signal traces should be short enough.

The parasitic capacitance can be evaluated with the help of the formula represented by Eq.1[6]

$$C = \frac{\epsilon A}{11.3d} \text{pico farads} \qquad (1)$$

where C is the stray capacitance, A is the area of the plates in cm^2 , ϵ is the dielectric constant of the board material, d is the distance between the plates in cm. High value of C causes undesirable oscillations in the circuit.

Lack of ground plane and longer trace lengths causes strip inductance, a form of parasitic inductance given by the Eq.2[6]

$$I = 0.0002L\left(ln(\frac{2L}{(W+H)}) + 0.2235(\frac{W+H}{L}) + 0.5\right) micro\ Henry \qquad (2)$$

where
W= trace width (mm)
L = trace length (mm)
H = trace thickness (mm)

The utilization of vias should be minimized as they are also the cause of emergence of stray inductances and capacitances.

Transmission lines are the traces that are dependent on the frequency of the signals passing through it and the length of the trace. These lines can be made free from cross talks if a resistor is added in series to the output of the op-amp and placing a terminator resistor at the end of the transmission line.

The high frequency signal trace upholds a characteristic impedance of 50ohms to match the standard impedance of the cables used. There are two types of controlled impedance lines namely microstrip transmission line and strip line.

If the high frequency signal moves in a track that is immediately placed above a ground plane, then this style is known as microstrip transmission line. The return current then flows directly in the ground plane present below the track. The characteristic impedance of the microstrip line is dependent on three variables namely the trace width, its thickness and the dielectric constant of the board material. Its value is given by Eq.3[8]:

$$Z_o = \frac{87}{\sqrt{(\epsilon_r + 1.41)}} ln\left[\frac{5.98H}{(0.8W+T)}\right] \qquad (3)$$

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where
Z_o = characteristic impedance (ohms)
W = trace width (mils)
T = trace thickness(mils)
H = distance between the trace and the ground plane (mils)
ϵ_r = PCB board's dielectric
Using this equation, the value of W could be determined in order to match the impedance of the circuit. The capacitance of this transmission line is expressed by the Eq.4

$$C_o = \frac{0.67(\epsilon_r+1.41)}{ln\left[\frac{5.98H}{0.8W+T}\right]} \qquad (4)$$

where,
C_o = is the capacitance expressed as pF/in
Strip line technique is utilized in multilayer PCBs. In this, the signal trace is placed between the supply and ground planes [8].

At high frequency another phenomenon called skin effect also comes into existence. It is the incidence in which high impedance due to the inductive effect allows current to pass through only the top layer of the conductors. Skin depth is given by the Eq.5

$$\text{Skin Depth in cm} = \frac{6.61}{\sqrt{f}} \qquad (5)$$

f is the operating frequency in Hz. If the skin depth value is less than the conductor's thickness by 50% then this phenomenon becomes considerable [8].

After proper consideration of the important points the PCB for optical signal amplification was designed and fabricated. The circuit was designed for four stage amplification but only 2stages were utilized for testing each of gain ten in order to amplify the small value signals.

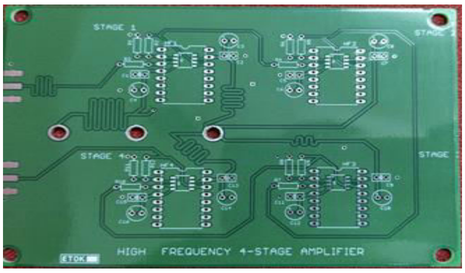

Fig 8.: Final Fabricated PCB

The PCB was soldered and tested for various inputs in the range of 2millivolts to 100millivolts square wave input for a frequency band of 100KHz to 10MHz (because of hardware restrictions).Few results regarding the performance of the amplifier are shown in the figures below:

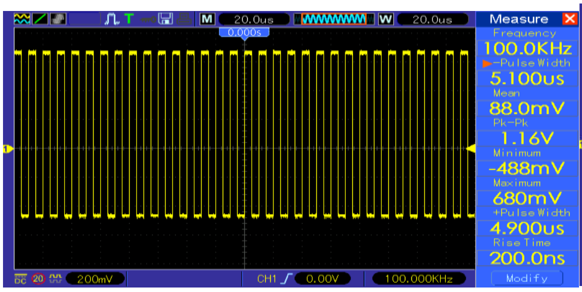

Fig 9.: Final Amplifier Output at 100KHz

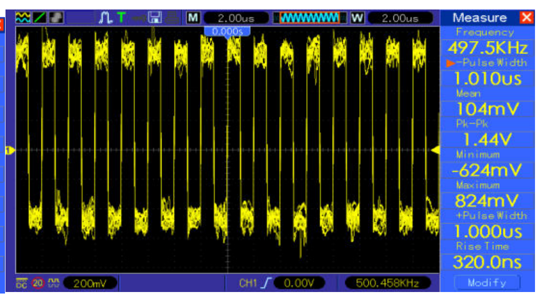

Fig 10.: Final Amplifier Output at 500KHz

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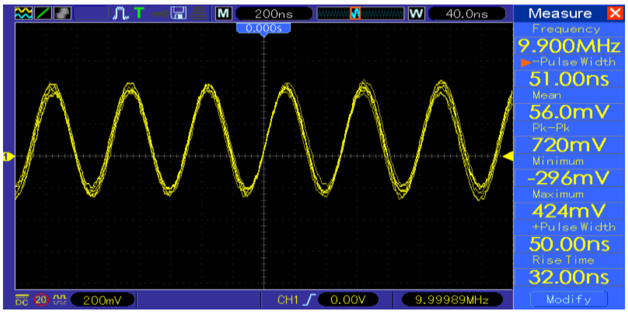

Fig 11.: Final Amplifier Output at 10MHz

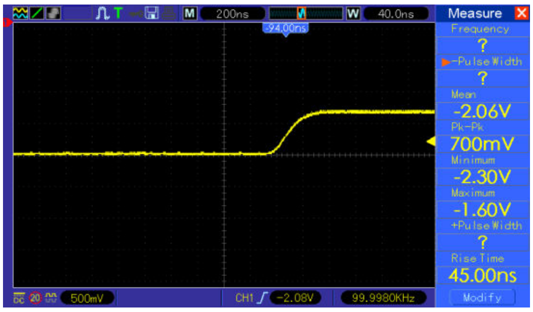

Fig 12.: Rise time of the output signal

The input signal was 10mv square wave which was varied for different frequencies, the output of first stage was 100mv which was further amplified at the second stage to obtain a signal of 1V. The output was satisfactorily obtained for various frequencies as shown in Fig 9, Fig10 and Fig11. Due to hardware limitations the frequency at 10MHz was distorted and similar waveforms were achieved for higher frequencies too. The rise time of the input signal was of the order of 45 nanoseconds and the rise time of the output signal was also 45nanoseconds as shown in Fig.12. This shows that the rise time is not getting degraded even by 1 or 2 nanoseconds which ascertains that the rise time of the amplifier would be very small in the order of 2nanoseconds as verified from the simulation.

VI. CONCLUSION

FOS deals with signals which are weak in amplitude eg microvolts signal but possess very high frequency. These signals are sensitive to noise and if not properly handled the signal is suppressed with noise that leads to erroneous output. Thus, proper care needs to be taken before hardware implementation of such high frequency signals. The important considerations for designing the high frequency board have been described in this paper. Simulation and hardware results for a high frequency amplifier circuit have been presented. This amplifier circuit design satisfies the requirements of FOS and is also cost effective.

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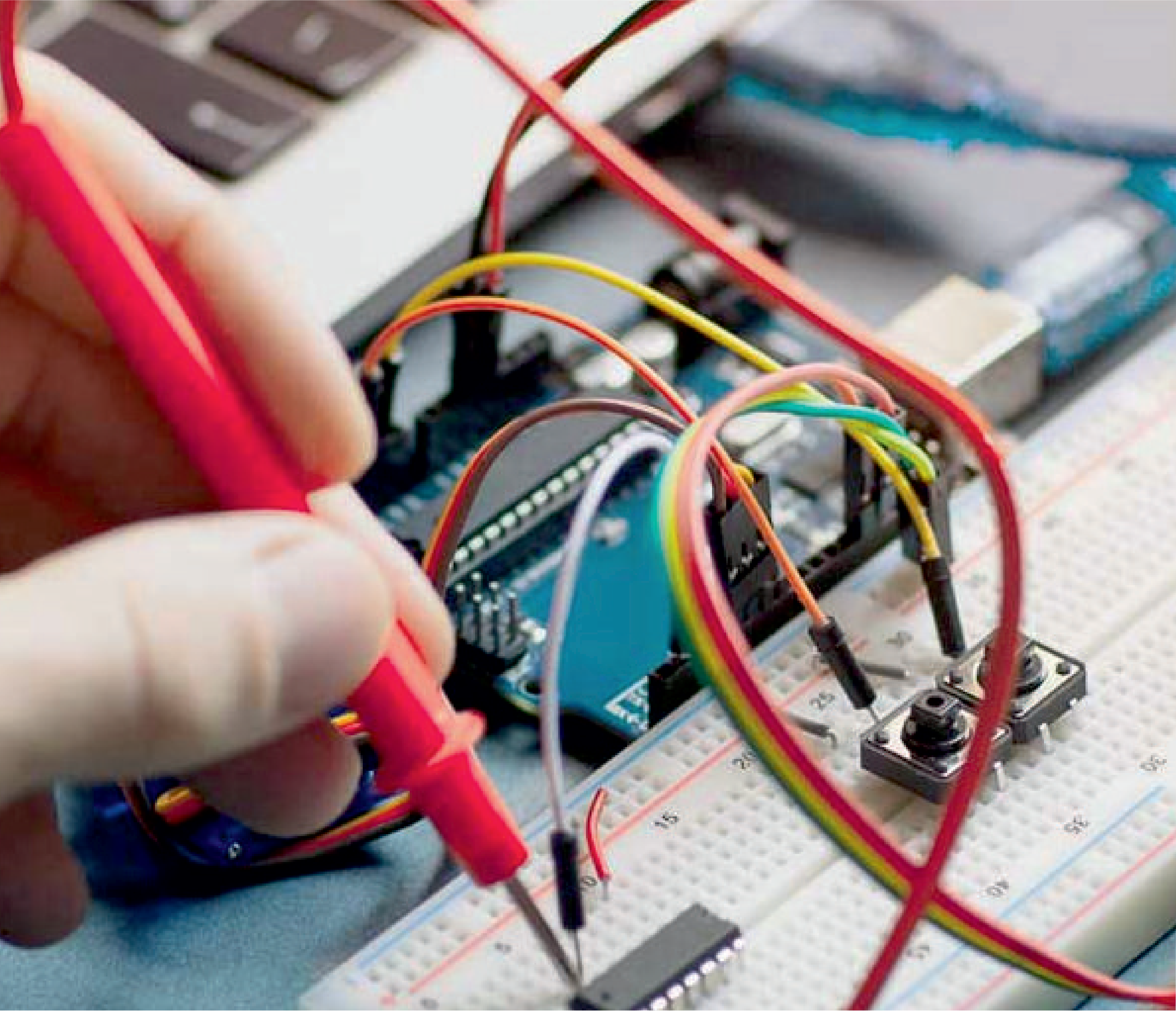

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