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Optimizing Diversity Selection Techniques in Rayleigh/ Rician Fading Channels: A BER Performance Analysis

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ABSTRACT: In wireless communication systems, the reliability of data transmission is significantly impacted by the characteristics of the fading channel. This paper presents an in-depth performance analysis of diversity selection combining techniques in Rayleigh and Rician fading environments. By focusing on Bit Error Rate (BER) as a key performance metric, we evaluate the effectiveness of various selection combining methods in mitigating the adverse effects of multipath fading. Our study includes a comparative analysis of the performance of these techniques under different channel conditions, highlighting the trade-offs and benefits associated with each method. Simulation results demonstrate that optimizing diversity selection can significantly enhance signal quality and robustness, thereby improving overall system performance. The findings of this research provide valuable insights for the design and optimization of resilient wireless communication systems operating in complex fading environments.

KEYWORDS: Fading Channel, BER, Diversity Combining

I. INTRODUCTION

Multiple propagation channels exist in an ordinary radio communication context due to scattering caused by various barriers between the transmitter and receiver [1]. As a result, distinct signal versions following various pathways may experience varying attenuation, distortion, delays, and phase changes. Both positive and destructive interference can happen at the receiver end. Destructive interference is the reason behind the considerable reduction in signal power. Fading is the term used to describe this observed phenomenon[1]. When delivering a signal over a radio communication channel, fading is a serious issue. The fading is brought on by the transmitted signal's multipath propagation. Multiple signals might interfere with one another either beneficially or detrimentally. The wireless channel's execution is deteriorated by fading. Various fading channels encounter different kinds of fading. Numerous fading model channels are suitable for various environmental kinds. For small-scale fading, models with Rayleigh and Rician components were examined. In order to transmit the signal effectively, it becomes imperative to negate its effect. In this paper, the effects of Fading are countered by using the Direct Combining Diversity Technique, Maximal Ratio Combining (MRC), Selective Combining (SC), Equal Gain Combining (EGC), and Maximal Ratio Combining (MRC) with QPSK for Rayleigh Channel and Rician Channel. We use the simplest method and the fewest computations possible to accomplish these strategies.

The fading effects of wireless communications are a characteristic. Large-scale fading is an indication of average signal power attenuation or route loss brought on by widespread motion. According to [2], minor variations in the spatial separation between a transmitter and receiver can cause rapid shifts in the amplitude and phase of the signal, which is referred to as small-scale fading.

II. RESEARCH BACKGROUND

Various researchers have measured the detector's signal-to-noise (SN) interference ratio and closed-form bit error rate (BER) expressions. In addition to the high SNR approximation, the error rate efficiency and outage likelihoods of the MMSE detector are also analyzed. Based on the MMSE receiver output's Gamma distribution approximation[3], which incorporates various modulations and applies the Rician and Rayleig multipath phenomena, MIMO technology is used

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separately. For instance, [4]use the Rician method to find that the BER likewise lowers if the parameter K, which represents the Line of Sight (LOS) power ratio, is reduced.

The following modulations are employed by the researchers in their examination of these phenomena: QPSK (quadrature amplitude modulation), QAM (binary shift phase modulation), and BPSK (binary shift phase modulation). By altering the phase of a reference signal, also known as a carrier wave, the PSK phase shift keying mechanism delivers data or information.

The demodulator's job is to take the received signal's phase and convert it back to the symbol that corresponds to that phase. The keying technique modulates the phase of a reference signal, also known as a carrier wave, in order to convey information or data. Demodulators work by determining the phase of incoming signals and re-assigning them to the symbols they represent [5].

According to [2], the BPSK modulation technique is a way to modulate two distinct phases of a carrier signal, or a reference signal, with a 180° separation between each phase. When compared to a typical BPSK system, QPSK can double data throughput while preserving signal bandwidth or retain BPSK data rate while reducing required bandwidth by half[6]. Two amplitude-modulated, 90° out-of-phase radio frequency carriers are used in quadrature amplitude modulation (QAM), a type of modulation. Phase and amplitude shifts are combined to improve transmission efficiency and facilitate the passage of information[2].

According to[7], the BER performance of BPSK, QPSK, and 16-QAM in OFDM, for example, shows that the three distinct modulation schemes—BPSK, QPSK, and 16-QAM—have varied BER probability performances. Using the BPSK modulation system improves the BER probability performance in RS-encoded (Rician Shadowed) OFDM communication systems; however, according to [6], the BER of QPSK is exactly the same as the BER of BPSK, and choosing otherwise is a prevalent chaos when evaluating or explaining QPSK. Yet, [8]claim that QSPK is superior when bigger bandwidths are needed, particularly when utilizing MIMO schemes like the one they tested, which carried out the study utilizing a 2x2 MIMO scheme and Long Term Evolution (LTE) technology.

The BER response using a BPSK modulation against the power conveyed through the Rician channel is more effectively, according to [9] than it is using a Rayleigh fading channel. For this reason, in this work, we aim to accurately compare and perform a more approximate measurement of BER using QPSK modulation with various Diversity Combining techniques.

III. RICIAN FADING CHANNEL MODEL

Rician fading is a channel model used to describe environments where there is a strong line-of-sight (LOS) path in addition to multiple scattered paths [10]. This model is particularly useful for scenarios where the signal transmission involves a direct, dominant component along with several weaker, reflected signals.

Key Parameters

1. **K-Factor**: The Rician K-factor is the ratio of the power of the direct path to the power of the scattered paths. A high K-factor indicates a strong LOS component, while a low K-factor means the channel behaves more like a Rayleigh fading channel (with no dominant LOS path).

$$K = \frac{\text{Power of LOS path}}{\text{Power of scattered paths}} \quad (1)$$

2. **Amplitude Distribution**: The amplitude of the received signal in a Rician fading channel follows a Rician distribution, which can be expressed as:

$$f_R(\mathrm{r}) = \frac{r}{\sigma 2}\exp\left(-\frac{r^2+A^2}{2\sigma^2}\right)I_0\left(\frac{\mathrm{Ar}}{\sigma^2}\right) \quad (2)$$

Where:

- r is the amplitude of the received signal.
- A is the amplitude of the LOS component.
- σ^2 is the variance of the scattered components.
- $I_0(\cdot)$ is the modified Bessel function of the first kind and zero order.

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Mathematical Model

The received signal in a Rician fading channel can be modeled as:

$$R = \sqrt{A^2 + 2\sigma^2} + R_c \quad (3)$$

Where:

- A represents the LOS component.
- R_c is the complex Gaussian component representing the scattered paths.

The total received signal can be expressed as a combination of the LOS and scattered components:

$$R(t) = R_{LOS}(t) + R_{Scattered}(t) \quad (4)$$

$R_{LOS}(t) = Acos\,(2\pi f_c t + \theta)$ is the LOS element.

The sum of N scattered components is $R_{Scattered}(t) = \sum_{i=1}^{N} \alpha_i \cos(2\pi f_i\, t + \emptyset_i)$

Here, α_i is the amplitude, f_i is the frequency and $\emptyset_i$ is the phase of the scattered waves.

We have simulated the Rician fading channel by generating the LOS component and the scattered multipath components, using MATLAB 2018.

The performance of diversity selection combining techniques in Rician fading and Rayleigh Fading channels is evaluated by measuring metrics such as Bit Error Rate (BER) under (different signal-to-noise ratios (SNR). This involves: Generating Rician Fading Samples, Applying Diversity Combining Techniques maximal ratio combining (MRC, SC, DC and EGC), to assess their impact on signal quality and Evaluating Performance Metrics i.e. analyzing BER.

RAYLEIGH FADING CHANNEL MODEL

Rayleigh fading is a statistical model used to describe the effect of a propagation environment on a signal, particularly in scenarios where there is no dominant line-of-sight (LOS) path[11]. It is commonly used to model wireless communication in urban areas where the signal undergoes multiple reflections, diffractions, and scattering before reaching the receiver.

Key Parameters

1. **Amplitude Distribution**: In a Rayleigh fading channel, the amplitude of the received signal follows a Rayleigh distribution. This distribution is used when there is no dominant LOS component, and the received signal is composed of many multipath components with independent and identically distributed complex Gaussian random variables.

$$f_R(\mathrm{r}) = \frac{r}{\sigma 2} \exp\left(-\frac{r^2}{2\sigma^2}\right),\ \mathrm{r} \geq 0 \quad (5)$$

- r is the amplitude of the received signal.
- σ^2 is the variance of the underlying Gaussian process.

2. **Phase Distribution**: The phase of the received signal is uniformly distributed between 0 and 2π.

Mathematical Model: The received signal in a Rayleigh fading channel can be represented as:

$$R = R_I + jR_Q \quad (6)$$

R_I and R_Q are the in-phase and quadrature components of the received signal, respectively.

R_I and R_Q are Gaussian random variables with zero mean and variance σ2.

III. DIVERSITY COMBINING TECHNIQUES

Diversity combining techniques are used in wireless communication systems to improve signal quality and reliability by combining multiple copies of the received signal. These copies are obtained through different paths or antennas, and the diversity techniques help mitigate the adverse effects of fading and other channel impairments.

Direct Combining

Combine all signals of branches directly and then compensates the overall phase shift.

Maximal Ratio Combining (MRC)

Maximal Ratio Combining (MRC) is an optimal diversity combining technique used in wireless communication systems to maximize the signal-to-noise ratio (SNR) at the receiver. MRC achieves this by weighting each received signal branch according to its SNR and then coherently combining these weighted signals. This method fully utilizes all

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available diversity branches, providing the best performance among diversity techniques in terms of SNR improvement [12].

Process of MRC

Signal Reception: Multiple antennas or branches receive the signal. Each received signal can be represented as:

$$r_i = h_i s + n_i \quad (7)$$

The received signal at the i[th] branch is r_i. Chanel gain is h_i , n_i *is* noise and s is the transmitted signal.

Weighting: Each received signal is weighted according to its channel gain. The weight for the i[th] branch is typically the complex conjugate of the channel gain h_i^*.

Combining: The weighted signals are summed coherently to produce the combined signal:

$$r_{MRC} = \sum_{i=1}^{N} h_i^* r_i \quad (8)$$

Where, N is the number of diversity branches.

Output: The combined signal is processed for further decoding and demodulation.

Selection Combining (SC)

Selection Combining (SC) is a diversity combining technique used in wireless communication systems to improve signal reliability and quality by selecting the best signal from multiple received copies. Unlike other combining techniques that require combining and weighting of multiple signals, SC simply selects the branch with the highest Signal-to-Noise Ratio (SNR) or the strongest signal for further processing.

Signal Reception: Multiple antennas or branches receive the signal. Each received signal can be represented as equation (7).

SNR Measurement: The SNR or signal strength of each branch is measured.

Selection: The branch with the highest SNR or the strongest signal is selected:

$$i^* = b \arg\max(SNR) \quad (9)$$

Output: The selected signal is then processed for further decoding and demodulation:

$$r_{SC} = r_{i^*} \quad (10)$$

Equal Gain Combining (EGC)

Equal Gain Combining (EGC) is a diversity combining technique used in wireless communication systems to improve signal quality and reliability[13]. EGC combines multiple received signal branches by adjusting their phases to be coherent (in-phase) and then summing them with equal weights. This technique is a compromise between the simplicity of Selection Combining (SC) and the optimal performance of Maximal Ratio Combining (MRC).

Signal Reception: Multiple antennas or branches receive the signal. Each received signal can be represented as equation 7.

Phase Adjustment: The phase of each received signal is adjusted to align them coherently. The phase-adjusted signal for the i[th] branch is:

$$r_i' = \frac{r_i}{|r_i|} \quad (11)$$

Equal Weighting: Each phase-adjusted signal is given an equal weight of 1. The equal-weighted signal for the i[th] branch is:

$$w_i r_i' = r_i' \quad (12)$$

Combining: The equal-weighted, phase-aligned signals are summed to produce the combined signal:

$$r_{EGC} = \sum_{i=1}^{N} r_i' \quad (13)$$

Where, N is the number of diversity branches.

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IV. RESULTS ANALYSIS

Performance Metrics

The performance of diversity combining techniques is typically evaluated using metrics such as:

- **Bit Error Rate (BER)**: The rate at which errors occur in the received data. Lower BER indicates better performance.
- **Signal-to-Noise Ratio (SNR)**: The ratio of signal power to noise power. Higher SNR indicates better signal quality.

Table 1: Simulation Parameters

Parameters	Values
Modulation Scheme	QPSK
Multipath phenomenon	Rayleigh/Rician
Noise	AWGN
Number of Antenna (MIMO)	2 Transmitting and 2 Receiving
SNR	1-9 dB

The SNR is set within the range of 0 and 9dB, the BERs of each diversity combining technique SC, EGC, and MRC, DC are calculated accordingly. Figure 1 shows that BER performance of Rician channel is better than Rayleigh channel, due to the presence of LOS (line of sight). Figures below show the BER value with respect to the Signal to Noise Ratio (SNR or Eb/No), in decibels (dB) of the configurations according to parameters of table.

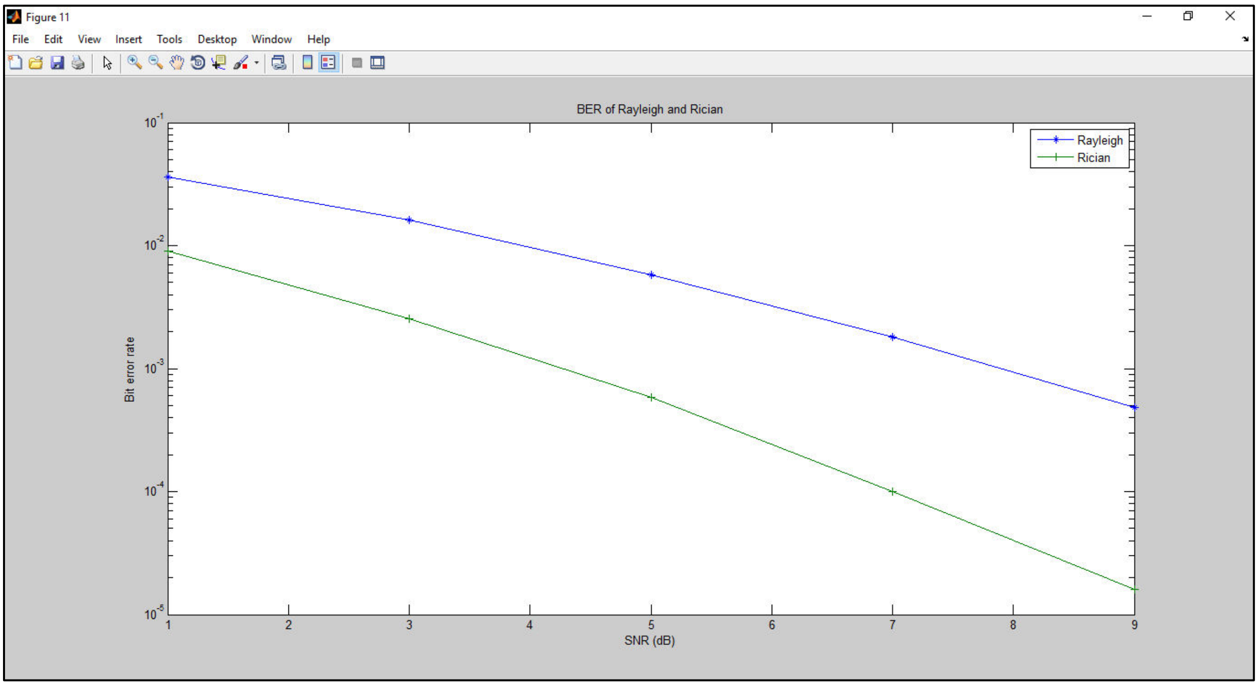

Figure 1: BER of Rayleigh and Rician Fading Channel

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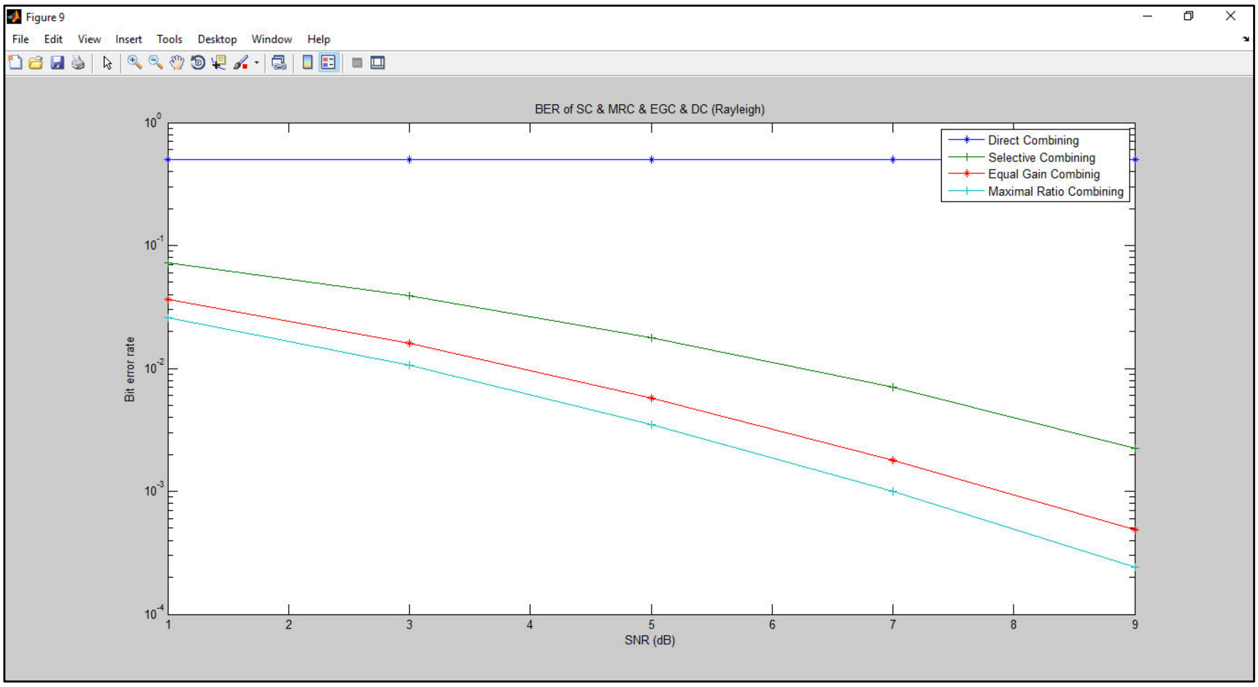

Figure 2: BER of Diversity Combining Techniques (Rayleigh)

Figure 2 and Figure 3 shows that MRC gives best performance for Rayleigh channel and Rician channel respectively.

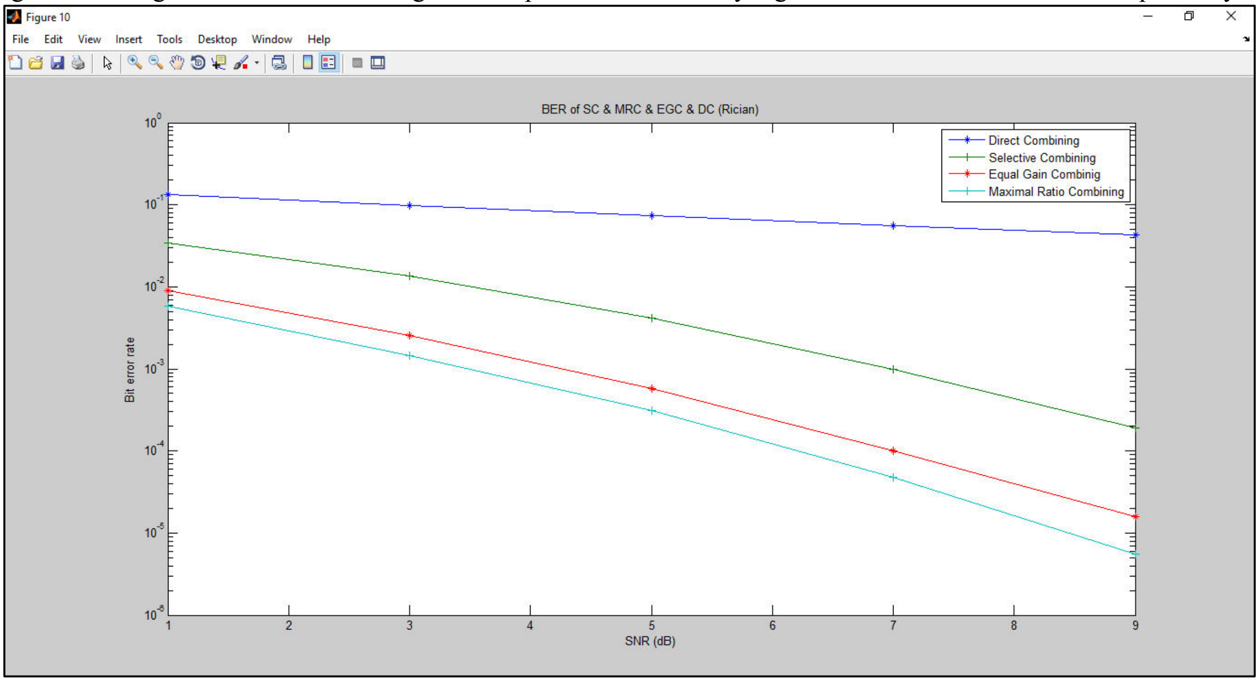

Figure 3: BER of Diversity Combining Techniques (Rician)

V. CONCLUSION

In this study, we used Rician and Rayleigh Multipath channels to evaluate the capacity of massive MIMO communications systems. We found that a 2x2 MIMO setup is the most effective setup, meaning that as the number of antennas increases, the BER would decrease. The most efficient channel turns out to be the Rician channel. As a result, this paper offers a comprehensive analysis of the BER (bit error rate) efficiency in wireless communication systems, taking into account the effects of various modulation strategies, multiple input multiple output (MIMO) setups, and the fading phenomena of Rayleigh and Rician. The results indicate that the 2x2 MIMO arrangement, especially when

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combined with the Rician channel, is the most effective configuration, exhibiting notably lower BER values. Notably, the study presents a new statistic that offers a more comprehensive view of transmission excellence: the multivariate correlation component. The integration of machine learning for real-time adaptability, security implications in different MIMO setups, cross-layer optimization for enhanced efficiency, and user-centric examines to customize systems to changing needs should be the main areas of future wireless communication research. Field studies will validate these research directions' practical usefulness and sturdiness in the real world. Lastly, the study can be constrained by its simulation-based methodology, which lacks the intricacies of the actual world. Furthermore, not every deploy situation may be represented by the scenarios that were selected. Results may not generalize as well to larger communication environments. Subsequent research endeavors to address constraints by the integration of empirical data, diversification of scenarios, and integration of extra factors to enhance comprehension and enhance generalizability.

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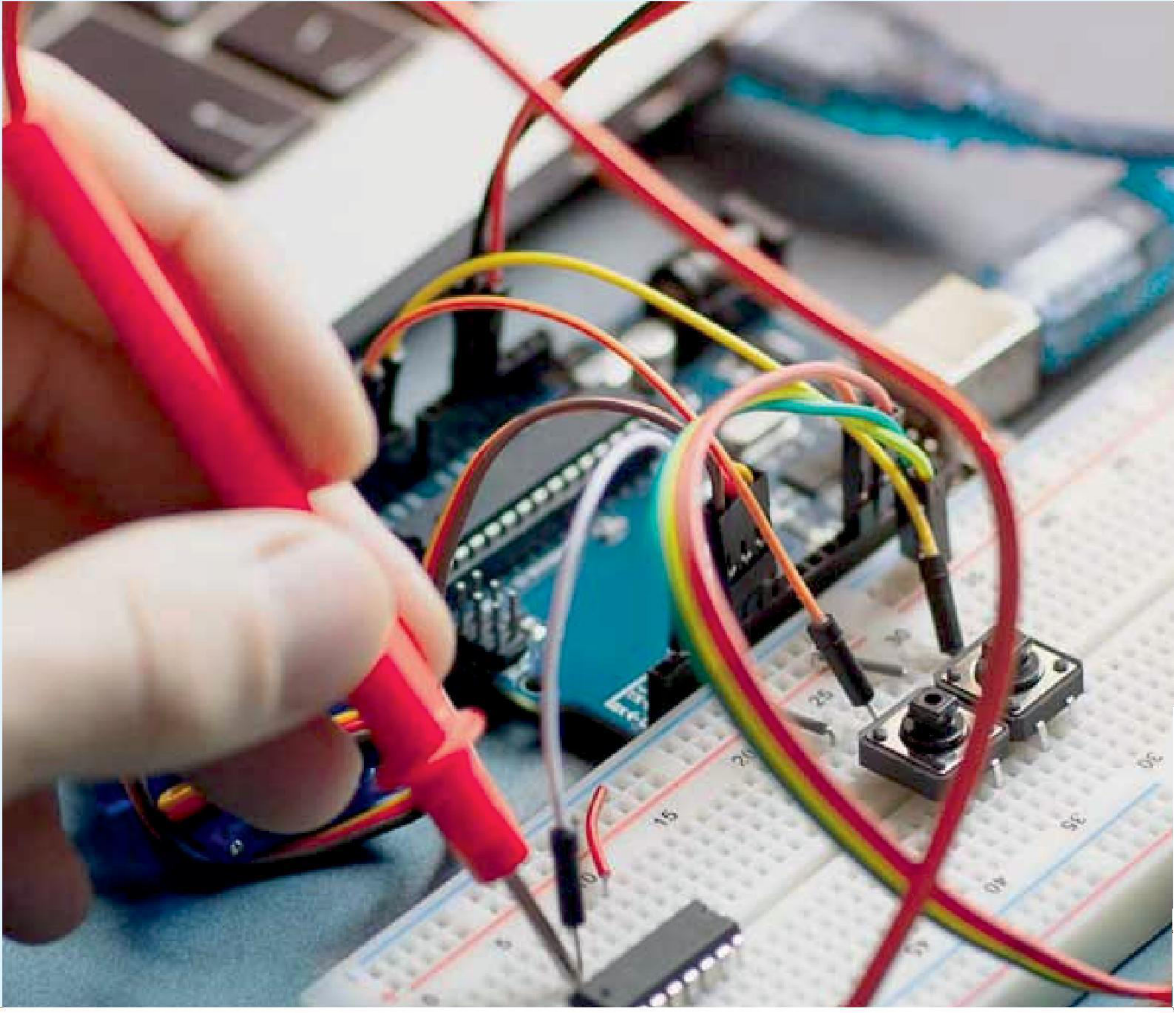

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