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# Alternative Device for Non-Ionizing Radiation Detection

Adedayo Kayode[a], Ashidi Ayodeji[a,*], Oloruntoke Oluseye[a], Ewetumo Theophilus[a]

[a] *Department of Physics, Federal University of Technology, Akure, PMB 704, Akure, Nigeria*

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**Abstract**

Detection of non-ionizing electromagnetic radiation is central to managing health and environmental hazards resulting from its exposure. This research focused on the design and development of a non-ionizing electromagnetic radiation detector that is sensitive to the medium frequency of 50Hz to 30MHz and their corresponding power density. The device consists of the sensing, amplifying, filtering and microcontroller sections. The sensing section is made up of a coil wound on a ferrite rod, it detects radiations from the surroundings and converts it to a voltage signal. The voltage produced is then fed to the operational amplifiers in the amplifying section. Afterwards, the output signal is fed to the filtering section where unwanted signals are eliminated. The analogue signal output from the active filter is then fed to the microcontroller section where it is converted to a digital signal through the analogue to digital converter (ADC). The ADC then presents the converted signal in a readable form to be displayed on the liquid crystal display (LCD). The developed equipment was calibrated (in $\mu W/cm^2$) using an existing detector EMF DT 1130. With an average calibration coefficient value of 2.32, the detector was found to perform excellently well at both medium and low-frequency ranges.

**Index Terms:** Non-ionizing radiation, electromagnetic field, operational amplifier, electrical appliances, radiation detector.



* Corresponding author.
E-mail address: agashidi@futa.edu.ng

## 1. Introduction

Electromagnetic radiation (both ionizing and non-ionizing) are ubiquitous, but the same cannot be said of their detectors. For instance, a very good percentage of urban dwellers are inundated with streams of invisible non-ionizing electromagnetic radiation (NIR) from multiple sources like radio, television, desktop and laptop computers, microwave oven, mobile phones and so on. This translates to the fact that either at home or at work; indoor or outdoor; daytime or nigh time; we are continuously “swimming” in the pool of invisible electromagnetic radiation. Although as at today, no clear-cut health hazard has been attributed to non-ionizing radiation (unlike its ionizing counterpart), yet studies abound that suggest the need for caution as far as exposure to NIR is concerned. Exercising caution requires, among other things, the ability to measure and quantify this invisible radiation, which will then form the benchmark for recommendation of necessary precautionary measures to all and sundry. A non-ionizing electromagnetic radiation detector, designed to convert the induced energy from electromagnetic radiation sources to their corresponding power density and frequency is hereby proposed. Its electronic circuitry changes the induced current to voltage and thereafter to power density.

Over the cause of the past decade, various electromagnetic field sources have become the focus of health and research concerns. They include power lines, microwave ovens, computer systems, television sets (TV screens), security devices, radars and most recently mobile phones and their base stations [1, 2]; and these appliances are commonly found at work and at home [3, 4]. Since NIR is ubiquitous [5, 6, 7], its detectors are equally expected to be commonplace. Unfortunately this is not the case as availability of NIR detectors pale in comparison to its existence and spread [7, 8]. This forms one of the cardinal reasons for undertaking this study. Another compelling factor is that NIR detecting devices are not being manufactured locally but imported, after manufacturers have carefully concealed the fabrication technology. This implies that the locally available NIR detectors are relatively expensive and difficult to maintain. These reasons prompt the need to develop a non-ionizing radiation detector - from locally sourced electronic components, portable, affordable and easy-to-maintain. Consequently, this work exploits existing technology discussed in [9, 10, 11, 12]; for the design and development of a low-cost alternative device for detecting and measuring non-ionizing electromagnetic radiation for domestic and industrial applications.

## 2. Review of Relevant Literature

Studies on the possible health risks associated with different NIR sources have been undertaken by (Eltiti et al., [1]; and Oscar and Sabella [2] among others; and their widespread nature have been reported as well in the studies carried out by Eileen [3], Tricas and Grill [4], Garaj-Vrhovac & Kopjar [5], Dadachova et al., [6] and Koehler & Som, [7] to mention just a few. The contrary trend of detectors availability to radiation abundance was equally reported in the works of Koehler & Som [7] and Hietanen [8]. Although many electromagnetic radiations related health and environmental hazards have been recorded, they were mainly adduced to ionising radiations. But it has not yet been exhaustively established that non-ionising electromagnetic radiation is not responsible for any of such cases [13, 14, 15, 16, 17].

Particularly, Hässig et al., [18] reported that non-ionizing radiation (NIR) resulted in changes in the enzyme activity among ten randomly chosen cows of different ages and at different stages of gestation. According to the work, certain enzymes were disabled and others enabled by NIR and the activity of glutathione peroxidase (GSH-PX) was reported to have increased whereas that of superoxide dismutase (SOD) decreased. Also, the effect of the electromagnetic field on the mass of earthworms was investigated by Ogunjo et al., [19]; with the authors reporting observable variations before and after exposure. Similar observations were reported by [5, 8]. This and many similar reports suggest the need for further investigation on the safety or otherwise of NIR to humans and animals alike.

Central to the determination of possible health risks of non-ionizing electromagnetic radiation is its detection and intensity measurement. Globally a good number of NIR detectors are in use following different design models proposed by various authors such as Laneo and Metz [9]; Bassen and Smith [10]; Harrison [11]; Martin [12] and Yehoshua [20]. Each model has its uniqueness and comparative advantage ranging from design complexity, portability, affordability to ease of use and maintenance. But there is still the need to fabricate a homegrown NIR detector with the aforementioned relative advantages.

## 3. The NIR Detector

In search of a hazard-free environment, non-ionizing radiation detectors whose circuitry requires a sensor capable of descrying electromagnetic radiation from electronic devices have become a key point of interest in recent times [8]. The wave that comprises of electromagnetic radiation can be imagined as a self-propagating transverse oscillating wave of the electric and magnetic field whose relationships are described by equations (1) to (5) according to Miskon [21] and Gupta [22]:

$$E = E_o \sin(kx - \omega t) \tag{1}$$

$$B = B_o \sin(kx - \omega t) \tag{2}$$

where E and B represent the root mean square of the electric and magnetic field strength; $E_o$ and $B_o$ are their respective amplitudes; and *$(kx - \omega t)$* is the phase angle of each.

The magnitudes and the amplitudes of the electric and magnetic fields in the electromagnetic waves are related by equation 3 as:

$$\frac{E}{B} = \frac{E_o}{B_o} = \frac{\omega}{k} = c = \frac{1}{\sqrt{\mu_o \varepsilon_o}} \tag{3}$$

where ω is the angular velocity, k is the wave constant; c is the speed of light; $\mu_0$ and $\varepsilon_0$ are the absolute permeability and absolute permittivity of free space respectively.

The power density S, and energy density U associated with electromagnetic waves are described by equation 4 and 5 below:

$$S = \frac{E^2}{z} \tag{4}$$

$$U = \tfrac{1}{2}\varepsilon_o E^2 + \tfrac{1}{2}\tfrac{1}{\mu_o} B^2 \tag{5}$$

where Z is the impedance of free space and its equal to 377 Ω.

The NIR detector model proposed by this paper consists basically of a sensing unit, an amplification stage, filtering section and the microcontroller unit. The device uses an adapted electromagnetic field (EMF) sensor for collecting energy from the nearby radiating sources, with the sensory apparatus consisting of one mutually orthogonal oriented detector developed with ferrite rod. It produced an output voltage in proportion to the input current induced from the inducting coil. The feedback reduces the effective input impedance and directs the small input current through a very lager feedback resistor and small capacitor such that a reasonable voltage is produced at the output. The output of the sensing element is converted to DC voltage and sent to the operational amplifier which amplifies the low input voltage to high output voltage. The filtering section is made of high-pass and low-pass filters, whose output (analogue signal) is fed to the microcontroller section. In the micro-controller, the analogue signal is converted to a digital signal through the analogue to digital converter (ADC) where the measured values are presented in a readable format through the liquid crystal display (LCD). The schematic diagram of this instrument is displayed in figure 1.

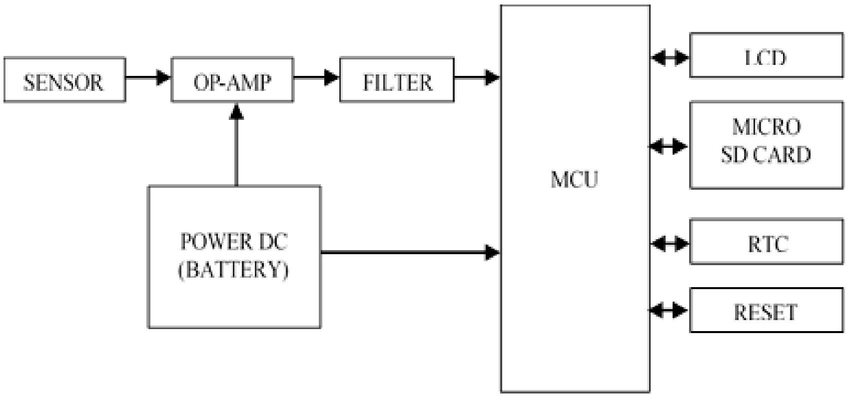


Fig. 1. A schematic block diagram of the developed non-ionizing electromagnetic radiation detecto

## 4. Research Method

In order to achieve the objective of this work, the electronic circuit of the device was designed, the off-the-shelve components were assembled, and each section was fabricated and coupled.

The sensing section is made up of a coil wound on a ferrite rod called the probe. This inductor coil was obtained by winding about 1200 turn of standard wire gauge of 30 Cu wire of a 34 mm x 5 mm around a ferrite rod, containing a 5mm x 1.2 mm x 0.05 mm core with a gauge of 0.32 and reactance of 18850 Ω. The sensor was used based on its ability to detect radiations from the surroundings and then convert same to a voltage signal. The voltage produced was then sent to the amplifying section. The EMF probe uses an inducting coil to locate stray electromagnetic fields around the devices, it responds to both changing magnetic and electric fields as each induces a voltage in the inductor. The detector circuit produces an output voltage in proportion to the input current induced from the inducting coil. From the circuit layout in figure (2), the 470 kΩ resistor, R1, reduces the effective input impedance and directs the small input current through a very large feedback resistor and a small capacitor such that a reasonable voltage is produced at the output. In order to convert the small current into a reasonable voltage, a large resistance and small capacitor were used.

The circuit, displayed in figure (2) is built around a quad low noise operational amplifier (op-amp). The first op-amp is the input stage which is directly coupled to the probe and the output (capacitive) is coupled via $C_3$ to the next op-amp which is for signal amplification.

The output is coupled to capacitor $C_5$ which is used to block the dc signal and then passed to transistor $Q_1$ which is used to amplify the voltage. The voltage at the collector is high enough to bias diode $D_1$ and $D_2$ which act as a full wave rectifier whose output is fed into the filter and $C_6$ has a large value so that the detector can respond to low frequencies. Capacitors $C_1$ and $C_2$ help to smoothing variations in the voltage, while switching S1; and resistors $R_9$ and $R_{10}$ act as a voltage gain; and resistors $R_5$ and $R_1$ act as a voltage divider. Resistors $R_8$ and $R_2$ act as input impedance that help to linearize the gain.

The control unit is anchored by the Arduino UNO ATmega328 microcontroller which many authors including Suresh & Ahmad [23] and others [24, 25, 26] have employed; and reported its versatility and suitability for a wide range of applications. The program for accepting the filtered analog input signal from the EMF sensor circuit, counting the number of pulses, computing the radiation concentration, display the computed value on the display and log the data to Secure Digital (SD) card is written, compiled, tested and then uploaded to the microcontroller using the Arduino Integrated Development Environment (IDE) software. The programmed microcontroller is then embedded in the circuit for the instrument.

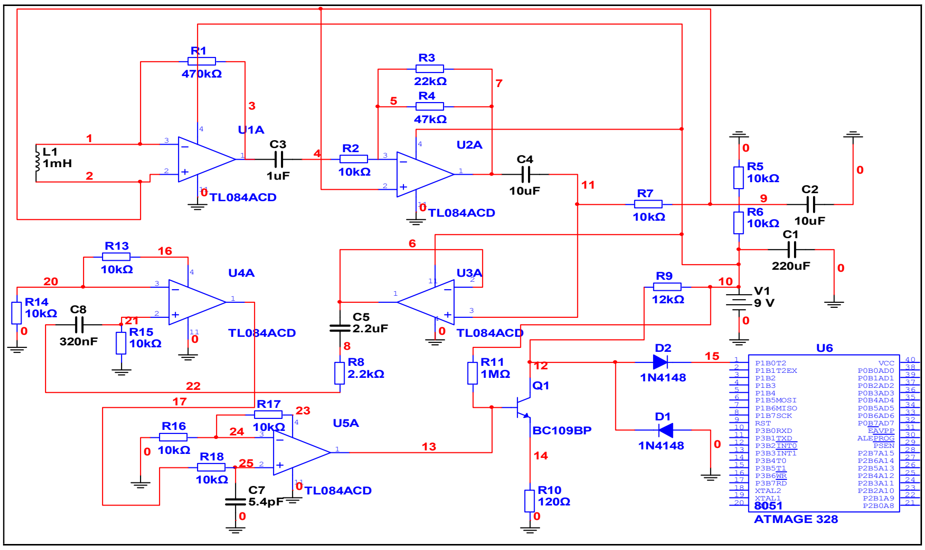


Fig. 2. Circuit diagram of the developed non-ionizing electromagnetic radiation detector (designed using multism 10. (Martin 2011)

Figure 3 shows the sectional circuit diagram of the micro-controller unit where the analog signal is being converted to digital via the ADC and the measured values are being presented in a readable format through the liquid crystal display (LCD). The microcontroller, the LCD, SD micro card and other associated components such as diodes, resistors and capacitors constitute the control circuit.

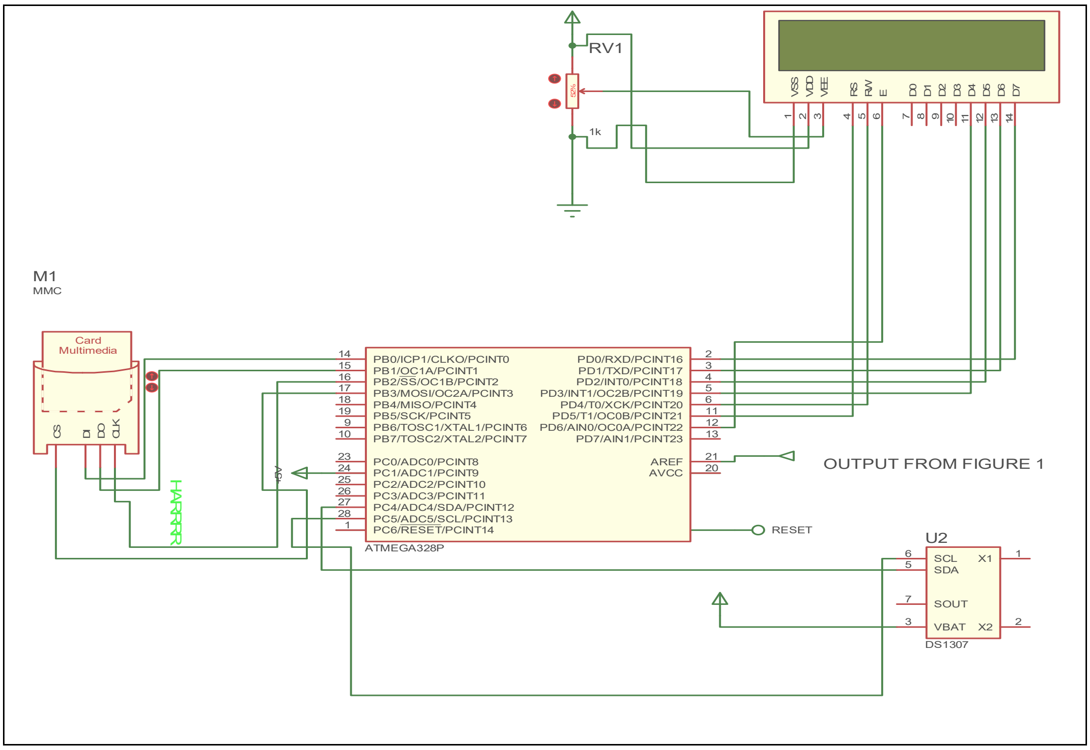


Fig. 3. Sectional circuit diagram of the microcontroller stage (designed using protex 7.1 based on the arduino functionality)

## 5. Results and Discussion

Following the development of the device, performance evaluation was carried out for its calibration. A comparative measurement of NIR from a wide range of appliances using the developed device and an existing NIR detector (EMF DT1130). The readings obtained from the two instruments are herein presented. A wide range of electrical and electronic appliances were measured in order to determine the suitability of the developed instrument over a reasonable range of radiation spectrum. Also, a conversion factor was calculated for each pair of readings obtained from the two instruments for every appliance measured. Table 1 shows the values and conversion factor obtained from the concurrent measurement of the electric field strength of randomly selected electrical and electronic appliances. The average of the conversion factors (2.32) is adopted as the calibration coefficient of the instrument. Table 2 shows the values of the electric field strength and power density for selected appliances. They were obtained when the developed instrument was embedded with the calibration coefficient. It is evident that the post-calibration readings of the developed NIR detector compares excellently well with measurement from the EMF DT 1130.

For proper visual perspective, trend of the electric field strength measured from the remaining electrical appliances using both instruments are shown in figure 4. We observed sharp skips in the trend line of the EMFDT 1130 for measurement of Wi-Fi modem, 2.4 KVA inverter and microwave oven, but this was absent in the trend line for the developed instrument for the same appliances. This suggests that the developed NIR detector exhibits higher stability relative to the EMFDT 1130 at those power density ranges. Although a mild skip was also observed in the trend line of the developed detector for the measurement of fluorescent desk lamp, it only confirms that such attributes are not uncommon with radiation detectors. The strong similarity in the trend lines of the two instruments suggests that both exhibit mutual measurement characteristics. This implies that the developed NIR detector performs favourably well in comparison with its counterpart EMF DT 1130. Consequently, the developed NIR detector can be safely utilised for measurement of non-ionizing electromagnetic radiation from a wide range of electrical appliances.

Table 1. Estimated conversion factor from the comparative measurement of the electric field strength of randomly selected appliances

| Appliances | EMF DT1130 (mV/cm) (X) | Developed instrument (mV/cm) (Y) | Conversion factor, a $a = \frac{X}{Y}$ |
|---|---|---|---|
| Electric socket on | 64.0 | 30.6 | 2.1 |
| Wi-Fi modem | 69 | 37.2 | 1.9 |
| Sony phone 345 | 78 | 46.8 | 1.7 |
| Mini multimedia projector | 92 | 47.2 | 1.9 |
| Clothes dryers | 387 | 109.2 | 3.5 |
| Dishwashers | 406 | 113.6 | 3.6 |
| LG 1000W Home Theater | 678 | 174.0 | 3.9 |
| Ups non-charging(1.2kva) | 876 | 228.0 | 3.8 |
| Portable heater | 964 | 249.0 | 3.9 |
| 3 Phase power supply | 1109 | 250.0 | 4.4 |
| Electric fan | 1242 | 295.6 | 4.2 |
| Toasters | 1374 | 335.0 | 4.1 |
| Soldering iron | 1383 | 335.6 | 4.1 |
| Hair dryer | 1387 | 335.8 | 4.1 |
| Coffee maker | 1467 | 393.0 | 3.7 |

In order to statistically quantify the level of reliability of the developed NIR detector, the linear relationship between the post-calibration measurements of the two instruments is plotted and shown in figure 5. Coefficient of determination; which shows the relationship between any two parameters on a scale of 0 to 1 (0 being "no relationship" and 1 being "perfect relationship") for this comparison is 0.9754 at 95% confidence interval. This is a statistically significant value, signifying a very strong relationship between the two instruments and implying a reliability level of about 97% in the developed NIR detector.

Table 2. Typical values obtained from concurrent measurement of electrical characteristics of randomly selected appliances using EMF DT 1130 and the Developed unit after calibration.

| Appliances | Electric Field Strength (mV/cm) | | Power Density (μW/cm$^2$) | |
|---|---|---|---|---|
| | EMF DT 1130 | Developed system | EMF DT 1130 | Developed system |
| Dell mini laptop | 47 | 46.9 | 5.9 | 5.8 |
| HP Compaq NC 6400 | 62 | 63.1 | 10.2 | 10.6 |
| Powered electric socket | 64 | 64.0 | 10.9 | 10.9 |
| Tecno Y6 (mobile phone) | 71 | 72.6 | 13.4 | 14.0 |
| Sony 345 (mobile phone) | 78 | 78.6 | 16.1 | 16.4 |
| Nokia 5234 | 105 | 106.7 | 29.2 | 30.2 |
| Samsung | 123 | 123.2 | 40.1 | 40.3 |
| 4g wireless router | 167 | 166.9 | 74.0 | 73.9 |

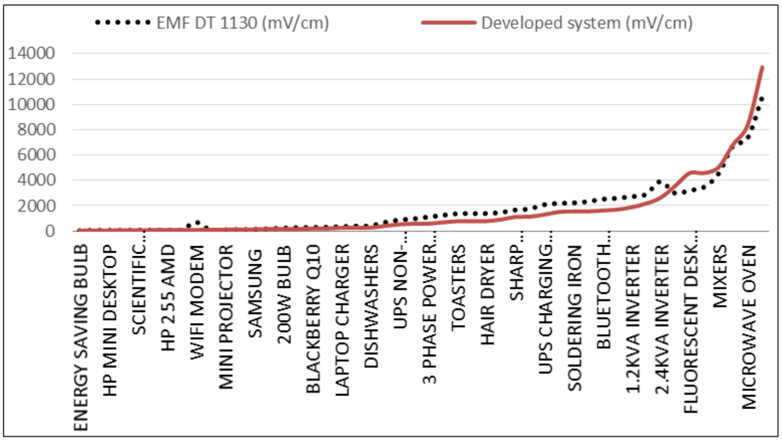


Fig. 4. Electric field strength measurement from both the EMF DT 1130 and Developed Instrument (mV/cm)

Using the relationship that exists between power density, electric field strength and magnetic field strength; the energy associated with the electromagnetic field measured by the developed detector and EMFDT 1130, for various appliances are shown in figure 6. With this feature, the power density and energy associated with any non-ionizing radiation (NIR) emanating from any home or office appliance (within the coverage of the detector) can be determined. The levels of such radiation can be known so that preventive and precautionary steps can be taken against any harm. Although the NIR energy measured from all the electronic appliances in this work are too low to split the atomic structure of any human cell, as all the measurement values are within the safe range of 5-10 W/m$^2$, excessive exposure to such radiations should still be avoided to guarantee absolute safety. This is because prolonged exposure to high radiations can affect both human and materials [8, 6, 27]; since at high-enough excitation state, electrons have sufficient energy to jump their boundary thereby causing displacement in the structure of materials. From the measurements, energy saving bulb has the minimum radiation in power density of 1.7 µW/cm$^2$ while circular saw has the highest radiation in power density of 0.44 W/cm$^2$.

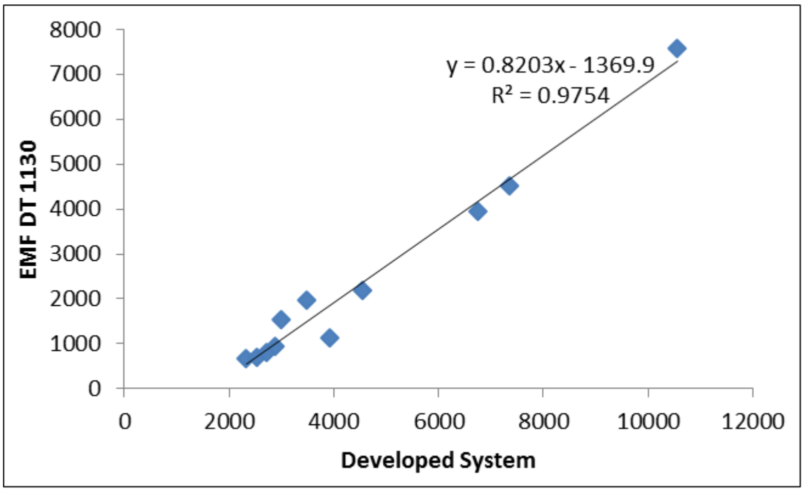


Fig. 5. Linear relationship between measurements of Electric Field using EMF DT 1130 and the Developed Instrument

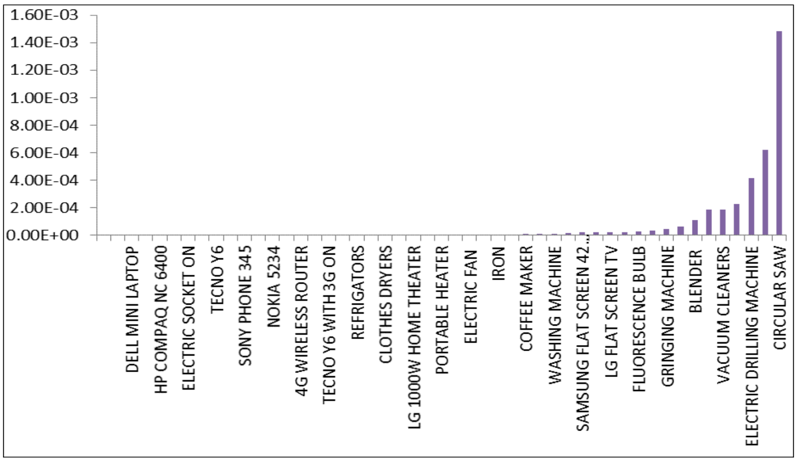


Fig. 6. Energy associated with electromagnetic radiation of the Source (J/V)

## 6. Conclusion

This work has reported the design and development of an alternative device for detecting and measuring non-ionizing radiation. The relationship between power density, electric field strength, magnetic field strength and energy associated with the electromagnetic field has been employed to facilitate the circuitry design. The knowledge of the power density and energy associated with any non-ionizing radiation (NIR) from home and office appliances can help to check excessive exposure to high intensity and harmful radiations [8, 6]. This device performs excellently well in comparison with an existing EMFDT 1130 used for its calibration. The conversion factors from the concurrent measurement of the electric field strength of randomly selected appliances using the two instruments have been shown, and a calibration coefficient calculated. Values of electric field strength and power density obtained when the developed instrument was embedded with the calibration coefficient was seen to have a very good agreement with measurements of the existing device. This is further established by $R^2$ value of 0.97. A wide range of measurement shows that energy saving bulb has the minimum radiation in power density of 1.7μW/cm$^2$ while circular saw has the maximum radiation in power density of 0.44 W/cm$^2$. The measurement of non-ionizing electromagnetic radiation energy associated with the appliances shows that all the devices measured are within safe range, but prolonged exposure to these radiations should still be avoided to prevent adverse health effects. The non-ionizing electromagnetic radiation detector developed in this work is only sensitive to the medium frequency range of 50Hz to 30MHz and their corresponding power density; future studies can be devoted to expanding the frequency range for more effective radiation detection.

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**Authors' Profiles**

**K. D. Adedayo** is a Professor with the Department of Physics, Federal University of Technology, Akure. He holds a Bachelor of Technology (B.Tech), Master of Technology (M.Tech) and Doctor of Philosophy (PhD) degrees in Physics from the same institution. His field of research is in electronic measurement, instrumentation and radio communication.

**Ashidi A. G.** is a young scientist with the Department of Physics, Federal University of Technology, Akure. He holds a Bachelor of Technology (B.Tech) and Master of Technology (M.Tech) degrees in Physics from the same institution and He is at an advanced stage on his PhD. His field of research is in Communication Physics and Radio Science.

**Oloruntoke H. O.** is a Technical expert with Industrial Development Center (IDC), Ondo State, Nigeria. He holds a Bachelor of Science (BSc) degree in Industrial Physics and Electronics form Nnamdi Azikiwe University, Awka, Nigeria; and a Master of Technology (M.Tech) degree from The Federal University of Technology Akure. He is currently pursuing a PhD degree in Electronic Measurement and Instrumentation.

**Ewetumo T.** is with the Department of Physics, Federal University of Technology, Akure. He holds a Bachelor of Technology (B.Tech), Master of Technology (M.Tech) and Doctor of Philosophy (PhD) degrees in Physics from the same Institution. His field of research is in electronic measurement, instrumentation and control.

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