Modelling and Development of a Frequency Modulated Field Strength Indicator

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ABSTRACT

Measuring instruments are inevitable in the world of Science and Engineering. Most often than not Field Strength Indicator (FSI) equipment are imported at a very expensive rate giving the economic situation currently in the developing county like Malaysia. Therefore, an inexpensive and reliable method of ascertaining the desired result becomes the motivating factor, coupled with the challenge of translating theory into concrete terms hence serving the needs of humanity. The FM Field strength meter (FSM) otherwise known as radiation tester, is a special receiver designed to measure the field strength of an electromagnetic wave (EM Wave) radiated by any transmitter transmitting in the same frequency ranges, and displaying either on a calibrated scale or LED readout. The concept of frequency tuning using resonance LC circuit is employed to receive signals while the other sub-circuits are used to filter out the RF signals from the received signal to have only an FM signal. This FM signal is then amplified and displayed on the LED readout. At the end of the design and development of the system, the performance objective that is basically to detect an appropriate level of signal within the range of frequency specified for the operation of the FSI was achieved.

KEYWORDS

Frequency Modulation, Field Strength, Received Signal Strength, Indicators, Electromagnetic Waves.

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1. INTRODUCTION

Measurement consists of representing relationship between physical quantities with another quantity which is directly accessible to the terminal element of a measuring device. Electrical signals may be obtained either by a physical quantity generating an

electrical quantities such as speed, heat etc. which generate an electrical quantity as in the thermoelectricity, or indirectly when a variation of an intermediate quantity with some modification of intense properties of the sensitive device (conductivity, permeability, permittivity) [l].

Electrical signal measurement has been made easy by electronic means, whose advantages are numerous and beyond doubts. The values of the electrical quantities need to be determined, using an appropriate measuring instrument. Such instruments refine or supplement human activities and abilities to sense, perceive, determine or evaluate quantities. One of the major building blocks in this respect is the transducer whose primary function is to convert some physical variables to electrical variable.

The field strength meter (FSI), otherwise known as radiation tester, is a special receiver designed to measure the field strength of an electromagnetic wave (EM Wave) radiated by any transmitter transmitting in the same frequency ranges, and displaying either on a calibrated scale or LED readout [2]. The circuitry is basically divided into six parts which includes; the tuned front end, RF amplifier, low noise amplifier, Diode pump and transistor staircase. The reception of satisfactory signal from a given broadcasting station by the FSI at any given point depends on (1) Percentage modulation of the carrier wave and directivity of the antenna, (2) Distance between the point of the reception and transmission of the signal and the resultant attenuation which the signal undergoes as it travels between the two points, (3) Strength of interference at the receiving end, (4) Fading as produce by direct and indirect signal and (5) Quality of the receiver system and its ability to filter out local noise or interference, adjacent channels interference and to convert the receiver RF signal into electrical signal without appreciable distortion.

The field strength meter today is the most common electronic equipment (device) found everywhere around the globe. Therefore the, need arises to produce those devices at low cost so as to enable Base Transceiver Station (BTS) engineers acquire it. The use of these devices will provide easier way of aligning FM transmitter and improve performance of FM radio stations. The aim of this research is to design and implement a measuring instrument capable of measuring or monitoring the magnitude (strength) of the signal at a point. This system has three features; it's a field strength meter, hidden bug detector, and an aid for testing detuned transmitters. The said meter is particularly essential when designing and building transmitter and expected range. Measuring instruments are inevitable in the world of engineering. Most often than now this equipment are imported at a very expensive rate giving the economic situation currently in the county. Therefore, an inexpensive and reliable method of ascertaining the desired result becomes the motivating factor, coupled with the challenge of translating theory into practice hence serving the needs of humanity. The designed indeed is the prototype that combines low cost, reliable and portable components to achieve the aim of the system. As a prototype opportunities for improvement thus exist in order to adopt same to various signal needs in telecommunication engineering. For this system development, based on the understanding of transducer operation, the tuned Radio frequency receiver has been designed as a transducer.

For clarity and neatness of presentation, the article is outline in to five (5) sections. The First Section gives a general introduction of a field strength meters. Theory and definition of terms is presented in Section Two. In Section Three, we outline the design

and analysis procedures. Section Four presents the system construction, results and discussion of the results. In Section Five, we conclude the work with some recommendations. Finally, the references are presented at the end of the paper.

2. THEORY AND DEFINITION OF TERMS

This section describes and defines the most important terms, theory of components and module used for the development of this system.

2.1. Frequency Modulation (FM)

Frequency modulation (FM) is a form of modulation that represents information as variations in the instantaneous frequency of a carrier wave. Contrast this with amplitude modulation, in which the amplitude of the carrier is varied while its frequency remains constant. In analog applications, the carrier frequency is varied in direct proportion to changes in the amplitude of an input signal. Digital data can be represented by shifting the carrier frequency among a set of discrete values, a technique known as frequency-shift keying [3].

FM is commonly used at VHF radio frequencies for high-fidelity broadcasts of music and speech. Normal (analog) TV sound is also broadcast using FM. A narrowband form is used for voice communications in commercial and amateur radio settings. The type of FM used in broadcast is generally called wide-FM, or W-FM. In two-way radio, narrowband or narrow-FM (N-FM) is used to conserve bandwidth. In addition, it is used to send signals into space. FM is also used at audio frequencies to synthesize sound. This technique, known as FM synthesis, was popularized by early digital synthesizers and became a standard feature for several generations of personal computer sound cards.

2.1.1 Theory

If the signal to be transmitted is

$$xm(t) \tag{1}$$

Restricted in amplitude to be

$$[xm(t)] \leq 1 \tag{2}$$

And the sinusoidal carrier is

$$xc(t) = A_C \cos(2\pi fct) \tag{3}$$

Where f_c is the carrier's base frequency in hertz and A_C is arbitrary amplitude, the carrier will be modulated by the signal as in:

$$xc(t) = A_C \cos\left(2\pi \int_0^t f(T)dT\right) = A_C \cos\left(2\pi \int_0^{[t]} t[fc + f_\Delta x_m(T)]dT\right) \tag{4}$$

Where, $f(t) = f_c + f_\Delta x_m(t)$ (5)

In this equation, *f(t)* is the *instantaneous frequency* of the oscillator and $f_\Delta x_m(t)$, is the *frequency deviation*, which represents the maximum shift away from f_c in one direction, assuming $x_m(t)$ is limited to the range ±1. Although it may seem that this limits the frequencies in use to $f_c \pm f_\Delta$ this neglects the distinction between *instantaneous*

frequency and *spectral frequency*. The frequency spectrum of an actual FM signal has components extending out to infinite frequency, although they become negligibly small beyond a point. For a simplified case, the harmonic distribution of a sine wave signal modulated by another sine wave signal can be represented with Bessel functions - this provides a basis for a mathematical understanding of frequency modulation in the frequency domain.

Frequency-shift keying refers to the simple ease of frequency modulation *by* a simple signal with only discrete slates, such as in Morse code or radio-teletype applications.

Manchester encoding may be regarded as a simple version of frequency shift keying, where the high and low frequencies are respectively double and the same as the bit rate and the bit transitions are synchronous with carrier transitions. When used in supervisory signaling in telephony, the term frequency-change signaling has been used to describe frequency modulation [4].

2.1.2. Modulation Index

As with other modulation indices, in FM this quantity indicates by how much the modulated variable varies around its unmodulated level. For FM, it relates to the variations in the frequency of the carrier signal as:

$$h = \frac{\Delta f}{f_m} = \frac{f_\Delta |x_m(t)|}{f_m} \qquad (6)$$

With a tone-modulated FM wave, if the modulation frequency is held constant and the modulation index is increased, the (non-negligible) bandwidth of the FM signal increases, but the spacing between spectra stays the same. If the frequency deviation is held constant and the modulation index increased, the bandwidth stays roughly the same, but the spacing between spectra decreases [3].

2.2 FM Measurement

Seeing the importance and complexity of electromagnetic waves such as FM signal, arises a need of simple measuring device to detect the presence and strength of this signal to allow designers and technicians to compare and estimate the efficiency of transmitters and their expected range. One way of getting this result is to make a field test but this sometimes require traveling various distances with radio receiver and compare attenuation levels. So the easier way is to get results on a bench by using a piece of equipment such as a RF power meter. The power meter is normally connected to antenna of the transmitter to perform the measurement. But it is difficult to place a measuring device (such as power meter) in the antenna circuit without it absorbing and upsetting the energy being radiated.

When dealing with frequencies in the 100MHz range, the signal flows over and through any device placed in the antenna circuit. Some of the signal is absorbed in the measuring device so that the reading may not be a true indication of the output. At the Same time, the performance of the transmitter is reduced such that it’s difficult to interpret the results. A much more accurate way of detecting the RF energy is to use device that can be placed at a point far or near the radiation source (antenna) so that it does not interfere with transmission. This is the advantage of FSI. It is placed at a point far or near the antenna and detects energy at a distance. A Frequency-Modulated field

strength meter (FSI) is perhaps the simplest piece of RF test equipment that can be built and used for checking the performance of the FM transmitters, antenna experimentation, and testing RF oscillators. The performance of the FSI depends to some extent on the precision and selectivity of the designed meter and some parameters of transmitting antenna apart from other environmental consideration. Despite the complexity of this equipment, an attempt is made in this research to construct the equipment within the available electronic components such as transistor, fixed and variable capacitors, inductor, diodes etc.

2.3. Radio Antenna

An antenna or aerial is an electronic component designed to transmit/receive radio signals (and, more generally, other electromagnetic waves). Antennas are for transmission of radio wave energy through the natural media (i.e., air, earth, water, etc.) for point-to-point communication or for the reception of such transmitted radio wave energy. Antennas are primarily designed for transmission of radio wave energy through free space or any space where the movement of energy in any direction is substantially unimpeded, such as interplanetary space (such as the interplanetary medium or interstellar medium), the atmosphere, the ocean (and other large bodies of water), or the earth. Antennas are used for communicating and conveying information specifically in larger systems, such as the radio, telephone, and the telegraph.

Physically, an antenna is an arrangement of conductors designed to radiate (transmit) an electromagnetic field in response to an applied alternating voltage and the associated alternating electric current, or to be placed into an electromagnetic field so that the field will induce an alternating current in the antenna and a voltage between its terminals.

2.4. Antenna Parameters

There are several critical parameters that affect an antenna's performance and can be adjusted during the design process. These are resonant frequency, impedance, gain, aperture or radiation pattern, polarization, efficiency and bandwidth. Transmit antennas may also have a maximum power rating, and receive antennas differ in their noise rejection properties [5-7].

2.4.1. Resonant Frequency

The *resonant frequency* and *electrical resonance* is related to the electrical length of the antenna. The electrical length is usually the physical length of the wire multiplied by the ratio of the speed of wave propagation in the wire. Typically an antenna is tuned for a specific frequency, and is effective for a range of frequencies usually centered on that resonant frequency. However, the other properties of the antenna (especially radiation pattern and impedance) change with frequency, so the antenna's resonant frequency may merely be close to the center frequency of these other more important properties.

2.4.2. Gain

In antenna design, *gain* is the logarithm of the ratio of the intensity of an antenna's radiation pattern in the direction of strongest radiation to that of a reference antenna. If the reference antenna is an isotropic antenna, the gain is often expressed in units of decibels over isotropic.

2.4.3. Bandwidth

The *bandwidth* of an antenna is the range of frequencies over which it is effective, usually centered on the resonant frequency. The bandwidth of an antenna may be increased by several techniques, including using thicker wires, replacing wires with *cages* to simulate a thicker wire, tapering antenna components (like in a feed horn), and combining multiple antennas into a single assembly and allowing the natural impedance to select the correct antenna. Small antennas are usually preferred for convenience, but there is a fundamental limit relating bandwidth and efficiency.

2.4.4. Impedance

Impendence is analogous to refractive index in optics. As the electric wave travels through the different parts of the antenna system (radio, feed line, antenna or free space) it may encounter differences in impedance. At each interface, depending on the impedance match, some fraction of the wave's energy will reflect back to the source, forming a standing wave in the feed line. The ratio of maximum power to minimum power in the wave can be measured and is called the standing wave ratio (SWR). A SWR of 1:1 is ideal.

2.4.5. Polarization

The *polarization* of an antenna is the orientation of the electric field (E-plane) of the radio wave with respect to the Earth's surface and is determined by the physical structure of the antenna and by its orientation. It has nothing in common with antenna directionality terms: "horizontal", "vertical" and "circular". Thus, a simple straight wire antenna will have one polarization when mounted vertically, and a different polarization when mounted horizontally. Electromagnetic wave polarization filters are structures which can be employed to act directly on the electromagnetic wave to filter out wave energy of an undesired polarization and to pass wave energy of a desired polarization [8].

2.4.6. Efficiency

Efficiency is the ratio of power actually radiated to the power put into the antenna terminals. A dummy load may have a SWR of 1:1 but an efficiency of 0, as it absorbs all power and radiates heat but not RF energy, showing that SWR alone is not an effective measure of an antenna's efficiency. Radiation in an antenna is caused by radiation resistance which can only be measured as part of total resistance including loss resistance. Loss resistance usually results in heat generation rather than radiation, and therefore, reduces efficiency [9].

3. SYSTEM ANALYSIS AND DESIGN

The FSI circuitry is basically divided into six parts, which includes: The tuned front end, RF amplifier, low noise amplifier, diode pump and transistor staircase. Despite the complexity of this equipment, an attempt is made in this work to construct the equipment within the available electronic components such as transistor, fixed and variable capacitors, inductor, diodes etc. The circuit's block diagram is presented below in Fig. 1.

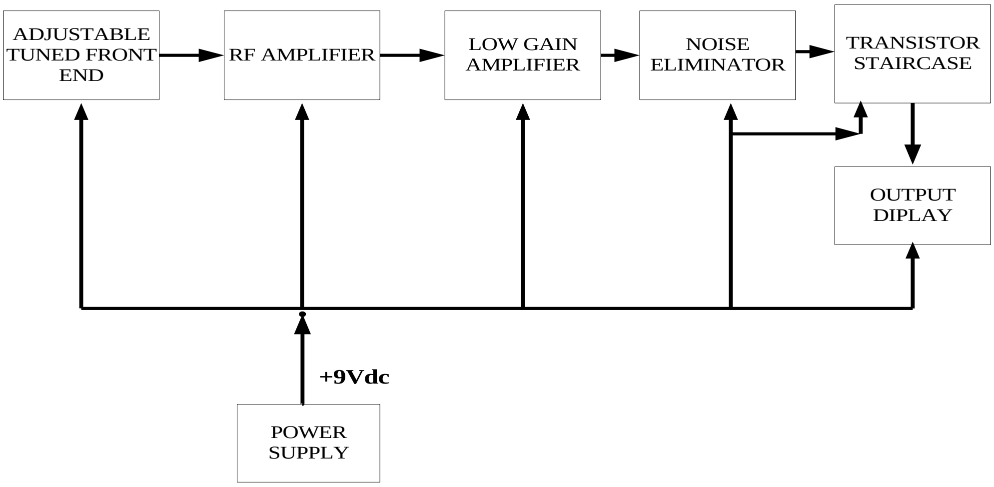

Fig. 1: A Generalized block diagram of FSI

3.2 TUNED FRONT END

This unit comprises of a capacitor and inductor connected either in series or parallel, preference is being given to the parallel connection for this system or design.

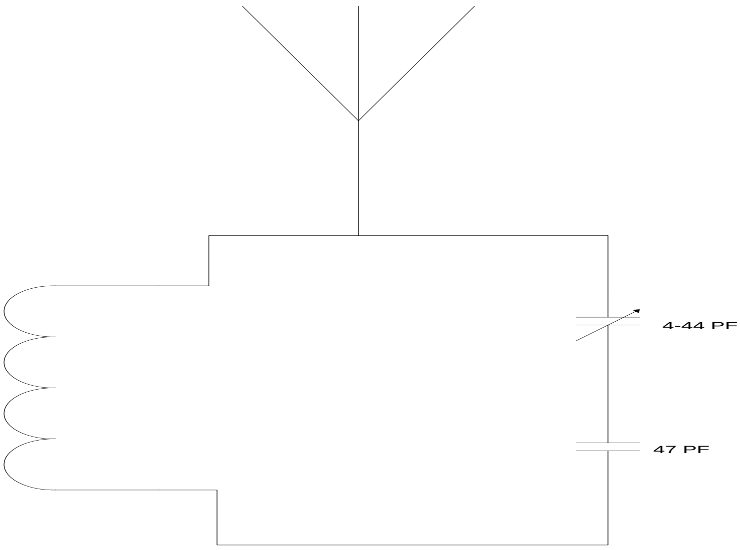

Fig. 2: A tuned front end

An antenna is normally coupled to this circuit to enhance receiver's reception capability. The 5cm-antenna picks up RF energy and passes it to a tuned circuit where all the frequencies, except one are lost in the coil capacitor combination. The only frequency to appear at the output of the tuned circuit is the one that is equal to the natural resonant frequency of the tuned circuit. The 5cm-antenna is connected to the parallel combination of inductor and capacitor (fixed and variable). Variation of the capacitors

changes the resonance frequencies of the tuned circuit, thus discriminating frequencies other than its natural resonance frequency. This unit is used for tuning the receiver to desired station of interest.

By employing the basic knowledge of RLC circuit analysis, the behavior of the tuned circuit is thus examined. A circuit is said to be in *resonance* if inductive reactance X_L and capacitive reactance X_C of the circuits are equal, and:

$$X_L = 2\pi frL \quad \text{where, } fr = \text{Re}\, sonancy \tag{7}$$

$$Xc = \frac{1}{2\pi frC} \tag{8}$$

Therefore at resonance $X_L = X_C$

And $2\pi frL = \frac{1}{2\pi\sqrt{LC}}$

3.3. Radio Frequency Amplifier

The signal is passed to the RF amplifying stage where it is amplified. This stage is designed to increase the level of the incoming RF signal in the 100MHz range and thus improve upon the sets sensitivity. A circuit showing the connection of this module is shown in Fig. 3 below.

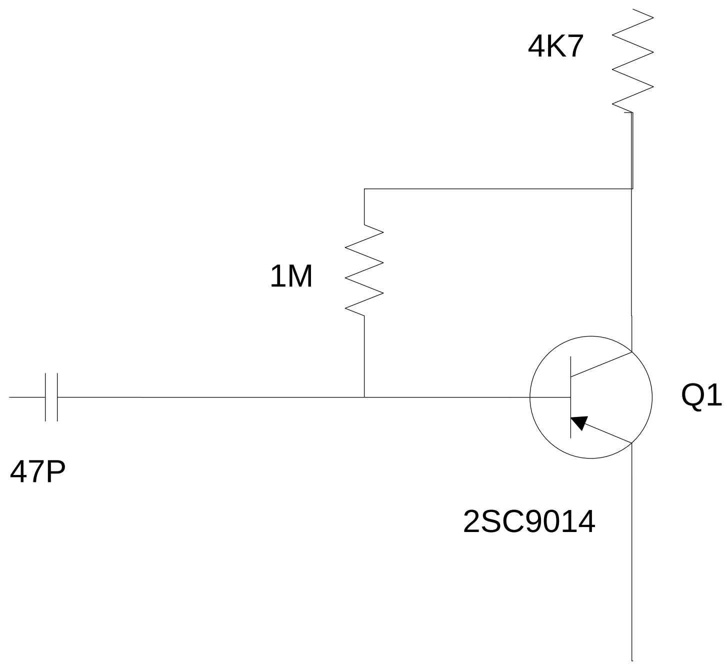

Fig. 3: A radio Frequency Amplifier

The high transistor is employed to perform the amplification and the output appears at the collector.

3.4. Low Gain Amplifier

The amplification is performed at this stage to increase the strength of the signal so it is large enough to be fed into a diode pump. Only signals above a certain threshold on the

base of Q3 appear on the collector (see Fig. 5). This signal is rectified by a signal diode and led into an l00nF reservoir capacitor.

3.5. Transistor Staircase

The first transistor in the staircase (Q1) starts to turn ON when 0.6V is present on the reservoir capacitor. As the voltage rises to 0.65V the LED connected to the collector of Q1 gets brighter and brighter. Due to the slight voltage drop across the 1k base bias resistor, the voltage on the reservoir capacitor needs to be slightly higher than 0.65v and once the first transistor in the staircase is turned ON fully, the next transistor (Q2) will begin to turn ON as the voltage on the reservoir capacitor (1nF) rises slightly above 1.3V (0.65V + 0 .65V).

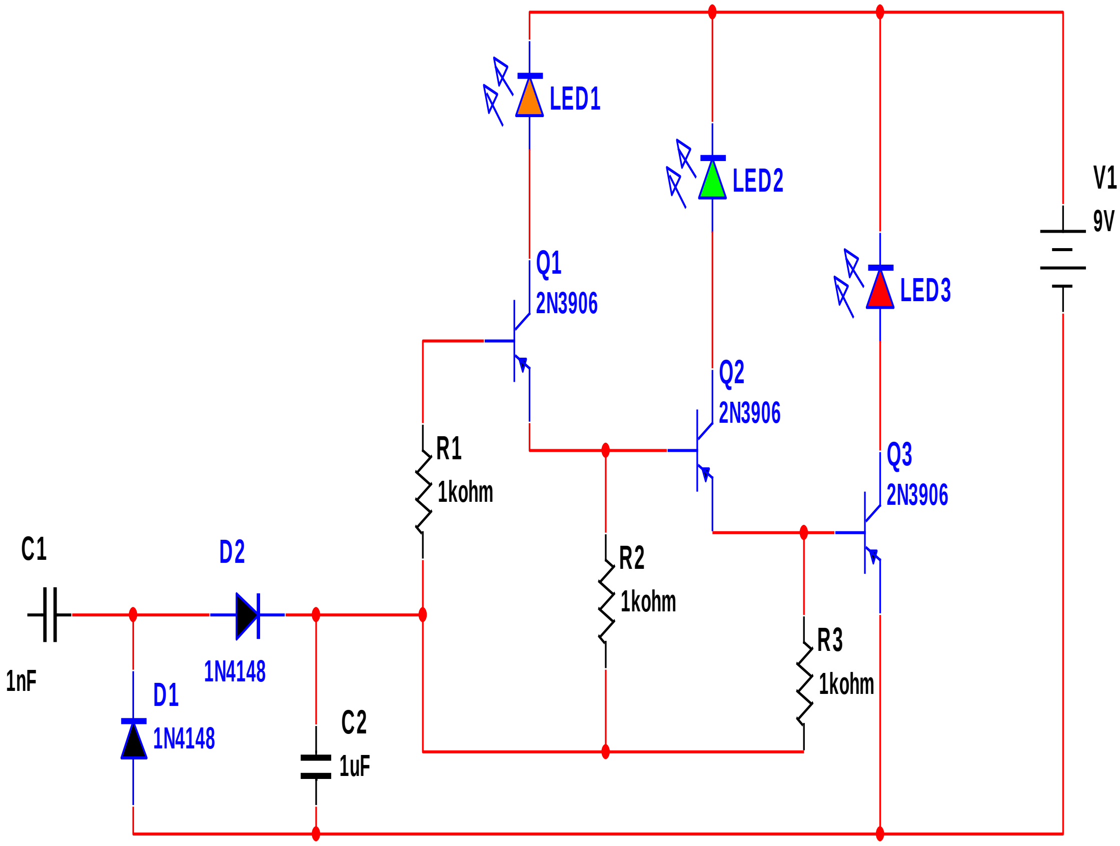

Fig. 4: A Transistor Stair Case

This process continues with the middle LED getting brighter and brighter until it is fully turned ON. As the voltage on the reservoir capacitor increases, the top LED will come ON and illuminate fully. It is important to know that the lower transistor (Q1), turns ON the rest and as the voltage on the reservoir capacitor increases, Q2 then Q3 turns ON and all this occur in rapid succession.

3.6. Generalized Circuit Diagram

The generalized circuit diagram is the combination of all the stages analyzed in the preceding sub-sections.

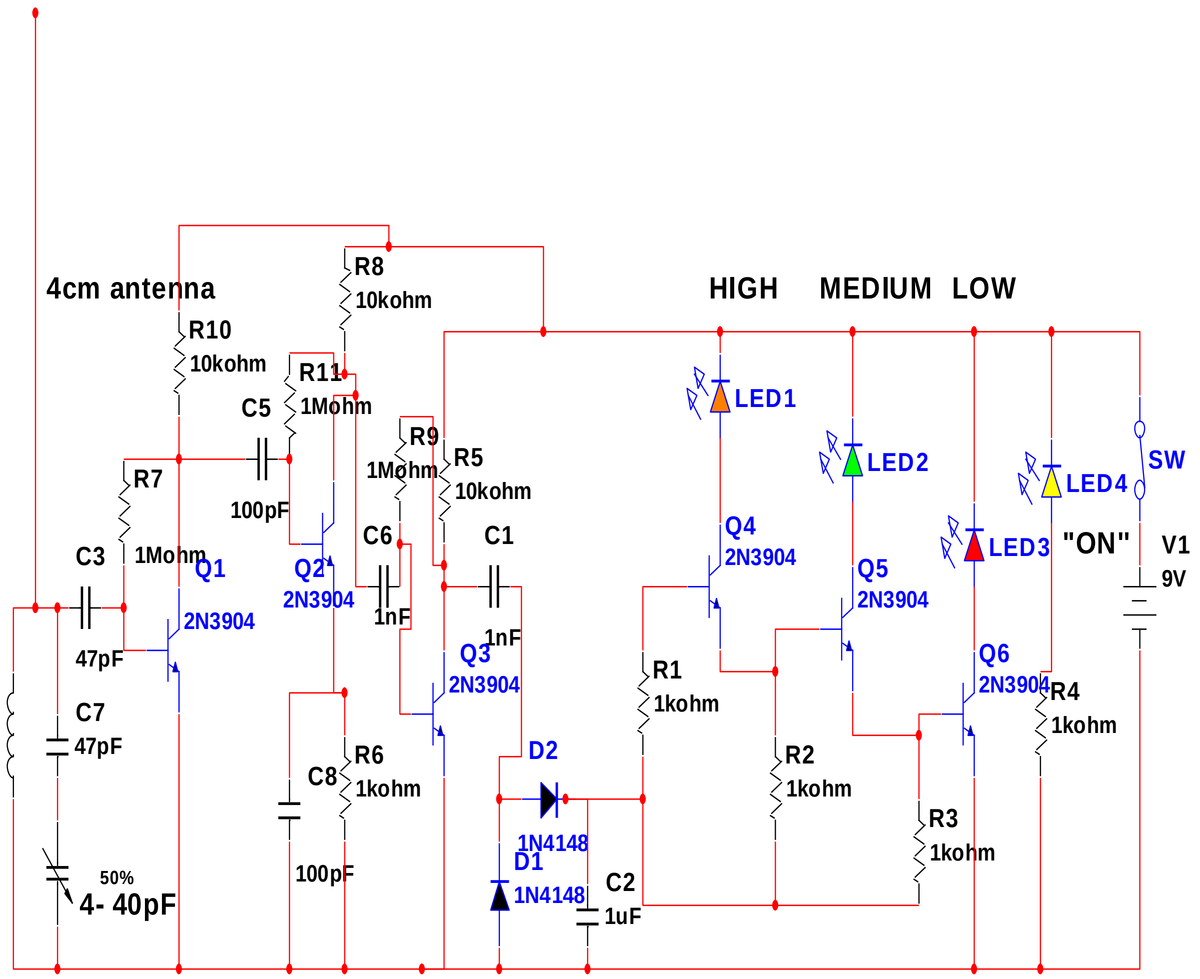

Fig. 5: A generalized Circuit Diagram of FSI

4. SYSTEM CONSTRUCTION AND TESTING

The objective of any designer is to see to the successful operation of the system so designed. This can he confirmed after performance checks have been carried out on the system and the result conform to the design specification. After the design stage, the next stage towards system construction is the selection of the system components as dictated by the calculated values in the design stage. In the event that correct component values cannot be found, equivalent or mean equivalent values are selected while also making necessary adjustments in order to neutralize the variation in voltage, current or frequency levels that might have been caused by these change(s). This procedure may be repeated until the required system working condition is established in the circuit then transferred from the bread board to the Vero board for final assembly.

4.1. Component Selection

The components used in construction of FSI were carefully selected and used based on specifications presented their data sheets. Table 1 show the list of components used for the circuit design.

Table 1: List of Components

S/N	Component	QTY
1	100 Ω –Resistor	1
2	330 Ω –Resistor	1
3	470 Ω –Resistor	1
4	1k Ω –Resistor	1
5	47k Ω –Resistor	4
6	10k Ω –Resistor	1
7	47k Ω –Resistor	1
8	100k Ω –Resistor	1
9	1M Ω –Resistor	2
10	2.2M Ω –Resistor	1
11	47pfCeramic Capacitor	2
12	100pf Ceramic Capacitor	2
13	1nf Ceramic Capacitor	2
14	100nf mono-block capacitor	1
15	4-40pf air trimmer capacitor	1
16	47uf electrolytic capacitor	1
17	1N4148 Diode	2
18	BC547 Transistor	5
19	PN3563 Transistor	1
20	3mm red LEDs	4
21	SPDT Switch	1

4.2. Bread Board Construction

A bead board is essentially used as a preconstruction board without soldering the component so as to ensure that the system conforms to its designed specifications. It is

also at that stage that any necessary adjustment is made in the event that the exact values of some of the components could not be found. A bread board is wired internally and has perforations on the surface to bring the components into electrical contact with the internal wiring. There is usually continuity on the vertical length of the board, while the longer length on the horizontal side of the board has no continuity. The components were simply cleaned and mounted on the board through the perforations.

4.3. Vero Board Construction

After the system must have satisfied design specification when tested on the bread board, the components were removed and cleaned in preparation for mounting on the Vero board, continuity test was carried out using a meter and it was confirmed that there were no short circuit. The components were then placed one by one onto the Vero board. Finally, the components were placed on new board.

4.4. Soldering

Soldering was carried out using a 40w 220/240v soldering iron. Excessive heat was avoided when soldering and also care was taken not to place the soldering iron on one particular point for a long time so as not to burn-out the components. Care was also taken to separate or melt down touching ends.

4.5. Tools Used

A number of tools were used in the construction process some of which are:

(i) Soldering iron

(ii) Multi meter

(iii) Lead

(iv) Breadboard for preconstruction

(v) Jumper wires

(vi) Vero board and (vii) Cutters

4.6. Assembling of FSI

The connected circuit was then assembled in a case made from plastic. The plastic casing gives a shielding effect against interference from external bodies to the input, and also provides a good insulation from static electricity to prevent damage to the component. Small holes were created for the LED indicators and finally gum and screws were used to secure the cover on to the casing.

4.7. Testing

In an attempt to test the efficacy of the said meter, the FSI is tuned to 91.2 MHz the transmitting frequency of crystal radio Minna and drive test was conducted from the base station in Maitumbi to Bosso campus of the Federal University of Technology, Minna, Nigeria and the following result was obtained and tabulated as shown in Table 2.

Table 2: Results for different distance

SN	Approximate distance from the Radiating source (KM)	Signal Level		
		Low LED	Medium LED	High LED
1	0.50	Fully ON	Fully ON	Fully ON
2	1.00	Fully ON	Fully ON	Fully ON
3	2.00	Fully ON	Fully ON	Fully ON
4	3.00	Fully ON	Fully ON	Partial ON
5	4.00	Fully ON	Fully ON	OFF
6	5.00	Fully ON	Fully ON	OFF
7	6.00	Fully ON	Partial ON	OFF
8	7.00	Fully ON	OFF	OFF

5. CONCLUSIONS

The aim of the system development which is basically the design, construction and testing of an FM field strength meter has been carried out and presented. The design approach was based on the basic principle of EM induction and the concept of frequency selection using resonant tune circuit. Within the given specification, the performance objective which is basically to detect an appropriate level of signal within the range of frequency specified for the operation of the FSI was achieved. On tuning, an appreciable signal level was detected on a typical test carried out. It was also noticed that the signal level was much stronger during night hours than during the day. From the result obtained, it can be verified that the developed device function satisfactorily in accordance with its specifications. The construction was done in such a way that it makes maintenance and repairs an easy task and affordable for the user should there be any system breakdown. All components were soldered on one Vero-board which makes troubleshooting easy. In general, the system was designed, and the real time implementation done with a photo-type of the model.

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