Design and Construction of FM Field Strength Meter

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DEDICATION

This thesis is dedicated to my ever-loving parents, my father Alhaji Muslim Mohammed for leading me to the intellectual pursuit and to my mother Hajiya Hauwa`u Muslim for the inspiration, support and prayers.

DECLARATION

I Muslim Abubakar Atiku declare that this work was carried out by me and has never been presented elsewhere for award of a degree. I also hereby relinquish the copyright to the FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

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ABSTRACT

Measuring instruments are inevitable in the world of Science and Engineering. Most often than not Field Strength Meter (FSM) 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 concrete terms hence serving the needs of humanity.

The FM Field strength meter (**FSM**), other wise 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 this project, the performance objective which is basically to detect an appropriate level of signal within the range of frequency specified for the operation of the FSM was achieved.

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CHAPTER ONE

1.1 GENERAL 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). [1]

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 faculties 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.

For this project, based on the understanding of transducer operation, the tuned Radio Frequency receiver has been designed as a transducer.

1.2 STATEMENT OF PROBLEM

In a bid to meet the aim of this project, the following questions serve as a guide for optimum result.

(i) What is the field strength meter?

(ii) What is the project's aim and motivation?

(iii) What are the various methods of measurement and the most suitable method of performing the measurement with this meter?

(iv) Over what range of frequencies does the instrument perform correctly?

(v) How can the sensitivity of the instrument be enhanced?

1.3 DEFINATION

The field strength meter (**FSM**), other wise 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.[3] 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 FSM at any given point depends on the following:

(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.

(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 in to electrical signal without appreciable distortion

1.4 PURPOSE OF THE PROJECT

The aim of this project is to design and implement a measuring instrument capable of measuring or monitoring the magnitude (strength) of the signal at a point.

. This project 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 project. As a prototype opportunities for improvement thus exist in order to adopt same to various signal needs in telecommunication engineering.

1.5 SIGNIFICANCE OF THE PROJECT

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. At the end of this project understanding of Field Strength Meter and how some semiconductor devices work will be achieved. Also, assembling and construction of electronic equipments, such as FSM with output as LED readout will be appreciated

The use of these devices will also provide easier way of aligning FM transmitter and improve performance of FM radio stations.

1.6 PROJECT OVERVIEW

This project is presented: such that chapter II gives theoretical background supporting the project. The specification, design and overall analysis are presented in chapter III. Testing, Result and Discussion in chapter IV, while conclusion, possible improvements and problems encountered in chapter V.

CHAPTER TWO

LITERATURE REVIEW

2.1 FREQUENCY MODULATION (FM)

Frequency modulation (FM) is a form of modulation which 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[5].

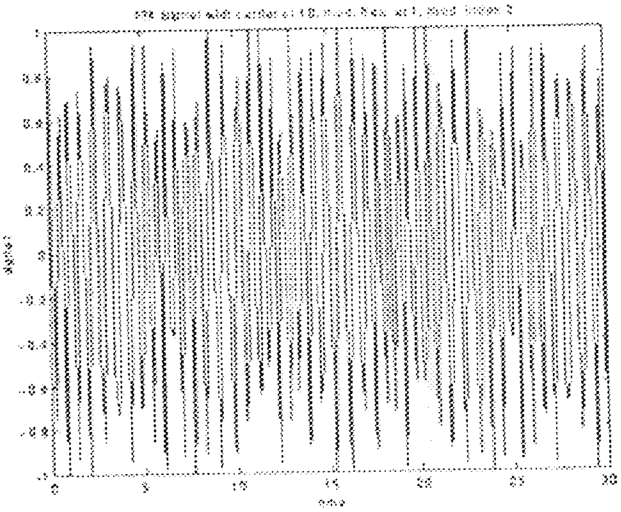

Fig 2.1: Frequency modulation (FM) with modulating frequency 1, carrier frequency 10 and modulation index 2

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

$$x_m(t)$$

Restricted in amplitude to be

$$|x_m(t)| \leq 1$$

And the sinusoidal carrier is

$$x_c(t) = A\cos(2\pi f_c t)$$

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

$$x_c(t) = A\cos\left(2\pi\int_0^t f(\tau)\,d\tau\right) = A\cos\left(2\pi\int_0^t \left[f_c + f_\Delta x_m(\tau)\right]d\tau\right)$$

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

In this equation, $f(t)$ is the *instantaneous frequency* of the oscillator and f_Δ 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.

A rule of thumb, *Carson's rule* states that nearly all (~98%) of the power of a frequency modulated signal lies within a bandwidth of

$$2(f_\Delta + f_m)$$

Where f_Δ is the peak deviation of the instantaneous frequency $f(t)$ from the center carrier frequency f_c (assuming $x_m(t)$ is in the range ±1) and f_m is the highest modulating frequency of $x_m(t)$.

But the frequency modulation can be regarded as a special case of phase modulation where the carrier phase modulation is the time integral of the FM modulating signal.

Frequency-shift keying refers to the simple case of frequency modulation by a simple signal with only discrete states, 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[9].

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:

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

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. [2]

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 some times require traveling various distances with radio receiver and compare attenuation levels. So an 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 placed at a point far or near the radiation source (antenna) so that it does not interfere with transmission. This is the advantage of FSM. It is placed at a point far or near the antenna and detects energy at a distance.

A Frequency-Modulated field strength meter (FSM) 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 **FSM** 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 project 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 transceive 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. [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].

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 dBi (decibels over isotropic)

2.4.3 BANDWIDTH

The "*bandwidth*" of an antenna is the range of frequencies over which it is effective, usually centered around 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, size and efficiency.

2.4.4 IMPEDANCE

"*Impedance*" is analogous to refractive index in optics. As the electric wave travels through the different parts of the antenna system (radio, feed line, antenna, 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 acts directly on the electromagnetic wave to filter out wave energy of an undesired polarization and to pass wave energy of a desired polarization. [4]

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[6].

CHAPTER THREE

1 CIRCUIT DESIGN AND ANALYSIS

The FSM 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 project to construct the equipment within the available electronic components such as transistor, fixed and variable capacitors, inductor, diodes etc. The circuit is presented in block diagram below:

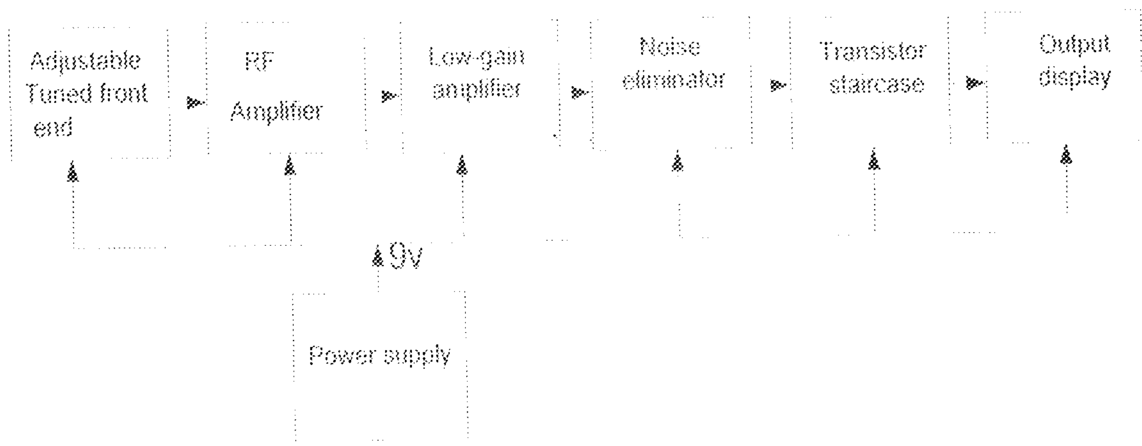

Fig. 3.1 A generalized block diagram of FSM

.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 project or design.

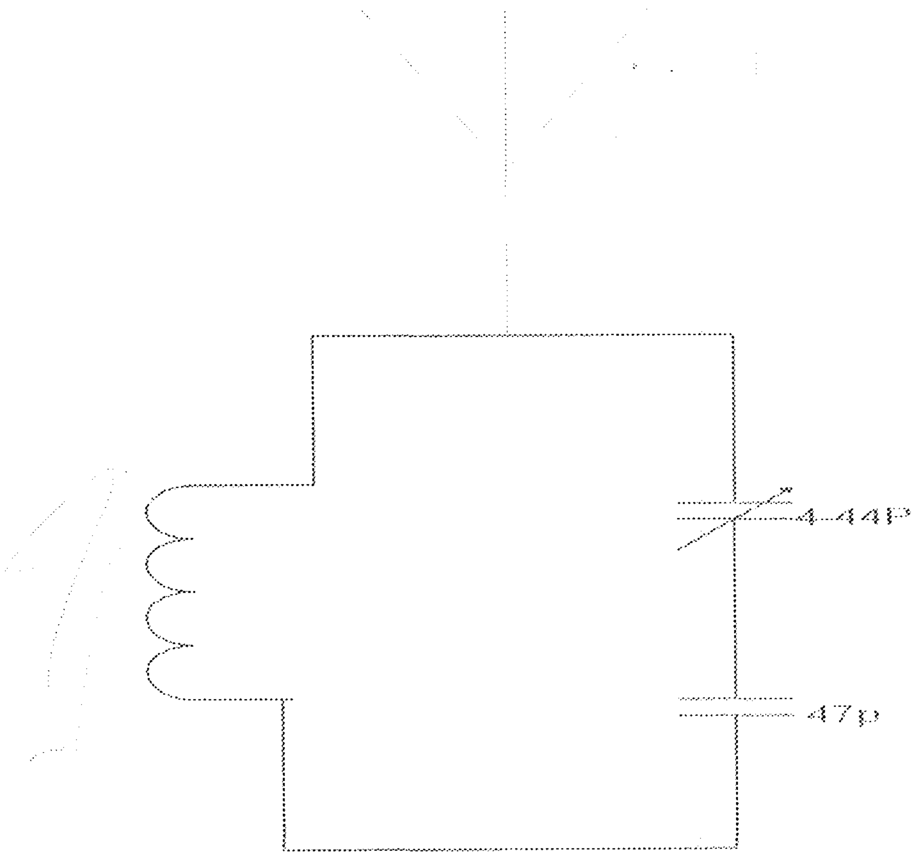

Fig. 3.2 A Tuned Front end

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 circuit are equal

$$X_L = 2\pi f_r L$$ Where f_r = Resonant Frequency

$$X_C = 2\pi f_r L$$

Therefore at resonance $X_L = X_C$

$$2\pi f_r L = \frac{1}{2\pi f_r C}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

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.

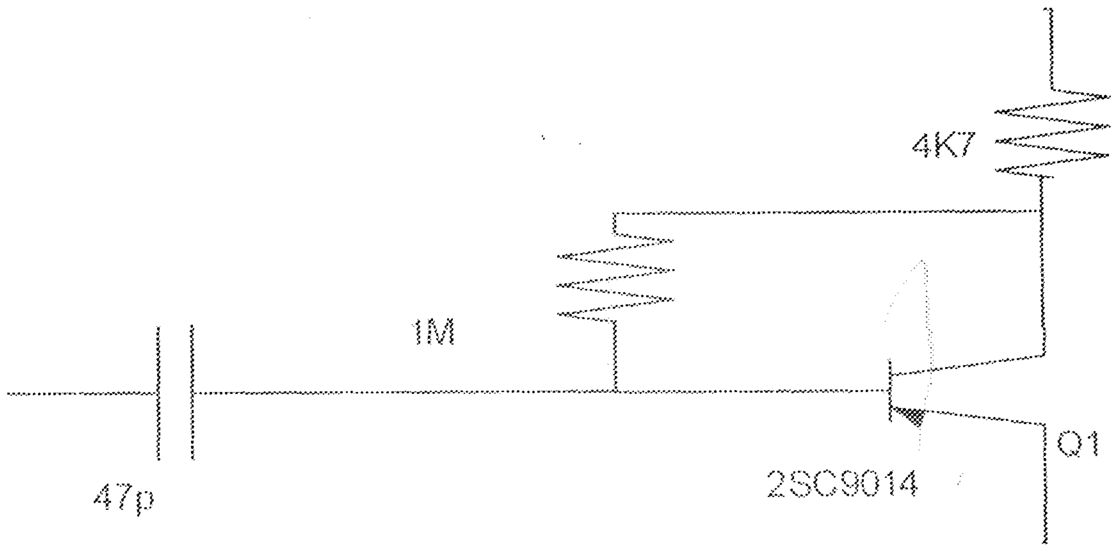

Fig 3.3 A radio Frequency Amplifier

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

3.4 LOW GAIN AMPLIFIER

Further amplification is performed at this stage to increase the strength of the signal so that 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. This signal is rectified by a signal diode and fed into a 100n reservoir capacitor.

3.6 TRANSISTOR STAIRCASE

The first transistor in the staircase (Q4) 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 Q4 gets brighter and brighter. Due to the slight voltage drop across the 47k 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 (Q5) will begin to turn on as the voltage on the reservoir capacitor (100n) rises slightly above 1.3v (0.65v + 0 .65v)

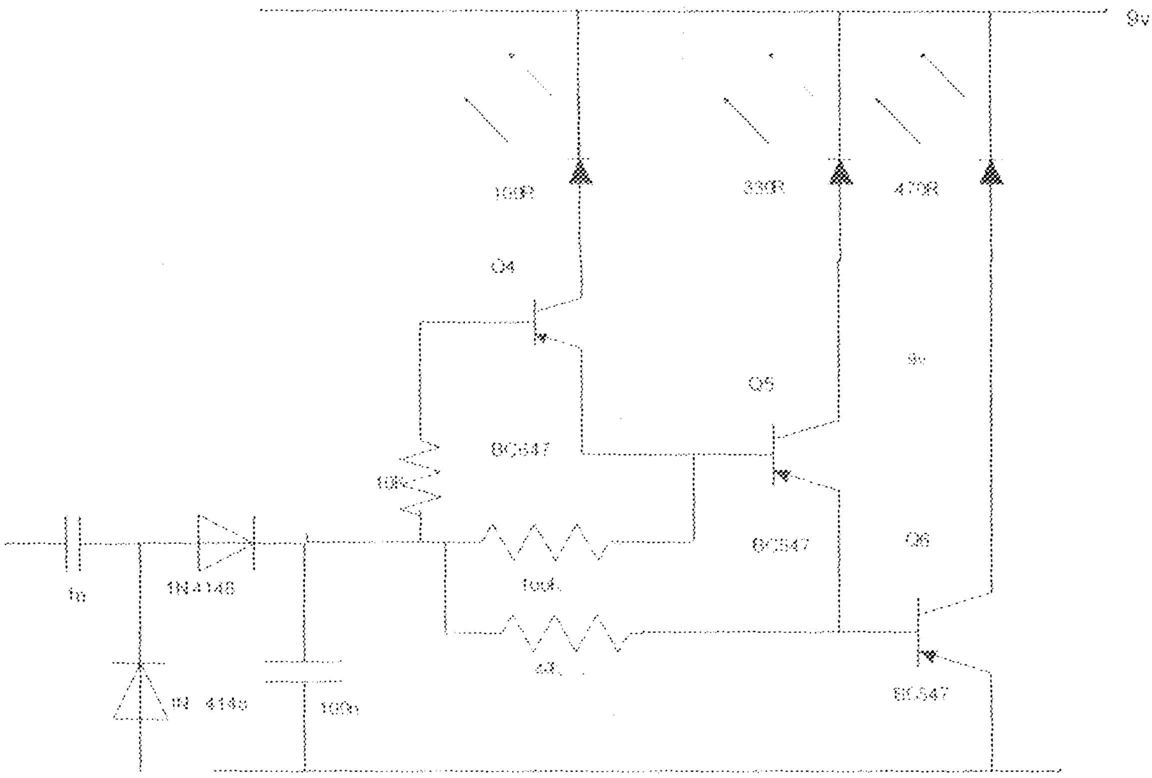

Fig 3.6 A transistor Stair Case

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 (Q4), turns on FIRST and as the voltage on the reservoir capacitor increases, Q5 then Q6 turns on and all this occur in rapid succession.

3.7 GENERALIZED CIRCUIT DIAGRAM

The generalized circuit Diagram is the combination of all the stages analyzed in the preceding section of this chapter.

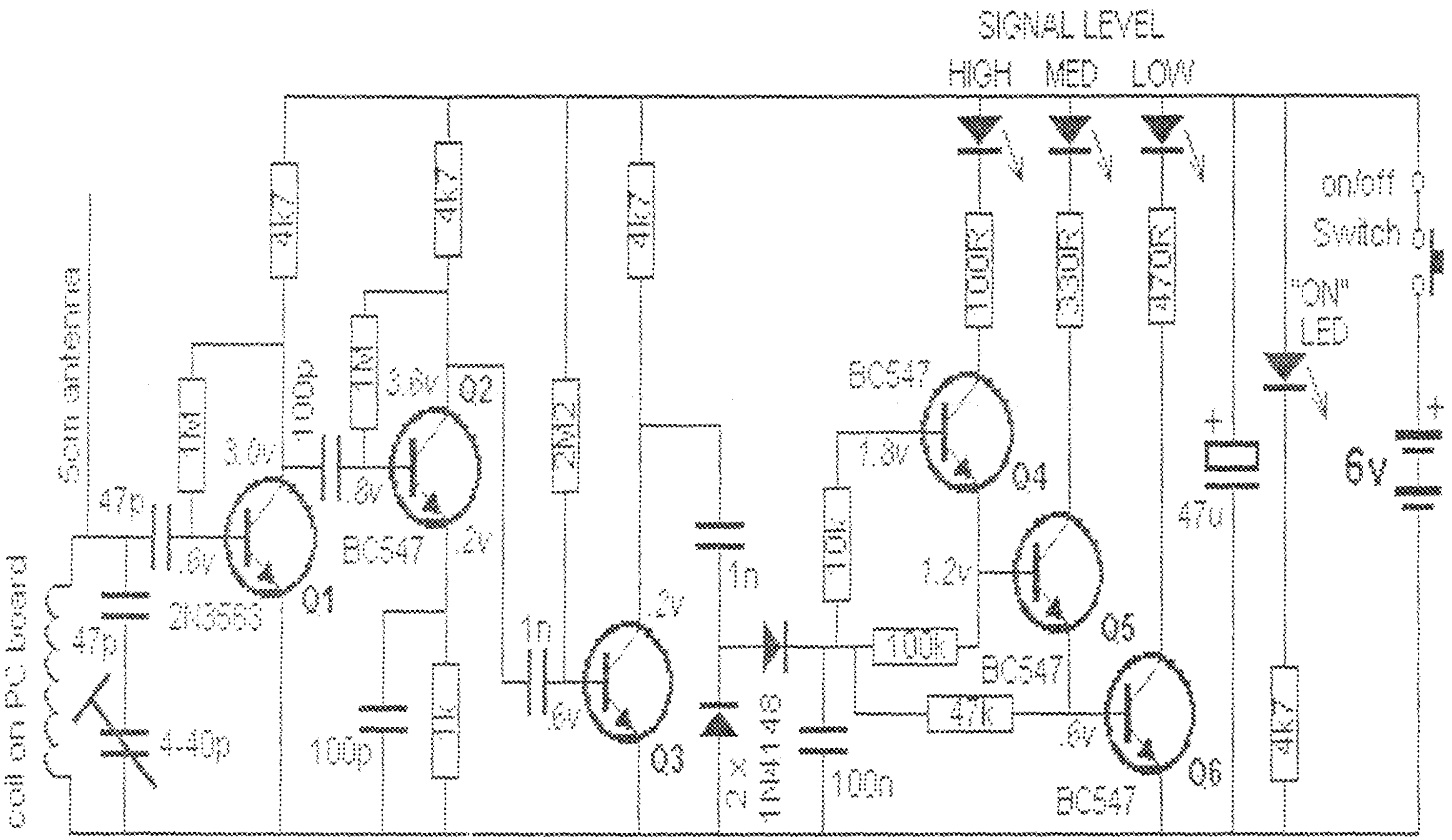

Fig. 3.1 A generalized Circuit diagram of FSM

CHAPTER FOUR

4.1 CIRCUIT CONSTRUCTION AND TESTING

The objective of any designer is to see to the successful operation of the system so designed. This can be 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.

4.2 COMPONENT SELECTION

The components used in construction of FSM were carefully selected and used based on specifications presented thier data sheets.

LIST OF COMPONENTS

S/N	COMPONENT	QTY
1	100Ω -Resistor	1
2	330Ω –Resistor	1
3	470Ω -Resistor	1
4	1kΩ- Resistor	1
5	47kΩ -Resistor	4
6	10kΩ – Resistor	1
7	47kΩ - Resistor	1
8	100kΩ Resistor	1
9	1MΩ Resistor	2
10	2.2MΩ Resistor	1
11	47pf Ceramic 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	47µf electrolytic Capacitor	1
17	1N4148 Diode	2
18	BC547 Transistor	5
19	PN3563 Transistor	1
20	3mm red LEDs	4
21	SPDT Switch	1

Table 4.1 List of component

4.6 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

(vii) Cutters

4.7 ASSEMBLING OF FSM

The connected circuit was then assembled in a case made from plastic .The plastic casing gives a shielding effect against interfere 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 to fit the LED indicators and finally gum and screws were used to secure the cover on to the casing.

4.8 TESTING

In an attempt to test the efficacy of the said meter, the FSM 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 and the following result was obtained and tabulated

S/N	Approximate distance from the Radiling souce (KM)	Signal Level		
		Low LED	Medium LED	Hih 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	Partial On
4	3.00	Fully On	Fully On	Partial On
5	4.00	Fully On	Fully On	Off
6	5.00	Fully On	Partial On	Off
7	6.00	Fully On	Partial On	Off
8	7.00	Fully On	Off	Off

CHAPTER FIVE

5.1 SUMMARY OF THE WORK

The aim of the project 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 FSM 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 than during the day.

5.2 LIMITATION

The biggest limitation of this equipment is that, it covers the range of 0 - 9km range from the transmitting station. The performance can be enhanced by using antenna with higher sensitivity and replacing 2SC9014 transistor with higher frequency transistor.

5.3 CONCLUSION

From the result obtained, it can be verified that the device constructed function satisfactorily in accordance with its specifications.

The construction process was really tedious and a lot of patience is needed. Also a very good understanding of how to apply theories learnt in the class is required.

The project apart from achieving its main objective has familiarized me in no small measure with some of the common problems encountered in electronic design work, steps taken in solving those problems, behavior of instruments and the general precautions which should be taken in design, construction and testing.

The project in fact exposed me with several challenges among which are:

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