DESIGN AND CONSTRUCTION OF A STANDING WAVE RATIO METER

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MINNA, NIGER STATE, NIGERIA.

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THIS PROJECT IS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF ENGINEERING (B.ENG) DEGREE IN THE DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING,

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FEBRUARY, 2002.

CERTIFICATION

I hereby certify that this project on the "Design and construction of a STANDING WAVE RATIO METER for 1.5-70MHZ radio waves, was executed by LONGJOHN DABOTA KOLO [95/4474]. It was supervised by Engr. Attah of the department of Electrical and Computer Engineering of the school of Engineering and Engineering Technology, Federal University of Technology Minna, Niger State.

Attah

Supervisor
Engr. Paul Attah

28/2/2002
Date

Head of Department
Engr Y.A. Adediran

Date

External Examiner

Date

DECLARATION

I LONGJOHN DABOTA KOLO [95/4474] hereby declare that the studies reported in this project were carried out by me. The work has not been previously published or accepted else where for the award of a degree. All work opinions and ideas other than mine have been fully acknowledged in the references.

LONGJOHN DABOTA
Name Of Student

Signature

DEDICATION

I dedicate this project to the ALMIGHTY GOD, my creator, sustainer and strength, who has enabled me to achieve all I have by HIS infinite wisdom.

ACKNOWLEDGEMENT

My utmost thanks goes to the Almighty God, the creator of the heavens and the earth, who has given me life, wisdom, strength and the ability to be educated even to the point of writing and completing this project.

I wish to express my profound gratitude to my supervisor, Engr. Attah for his help, advice and encouragement.

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Also, lots of thanks and appreciation to a dear friend, Ogbonnaya Okogeri [OGB] who made sure that I did the right thing. Thank you very much.

ABSTRACT

This project is designed as a measuring or instrument which measures the efficiency of an antenna system by determining how closely the impedance of the antenna matches the impedance of the transmitter. This meter can also be used separately to measure the transmitters field strength. This scale helps to position the antenna for best output coverage. It can also provide the data needed to plot a map of the transmitters power around the antenna. When coupled between the transmitter and the coaxial antenna feed cable, the meter monitors how effectively the transmitters output is transferred to the antenna. The comparison of the power sent to the antenna with power reflected back to the transmitter is known as the STANDING WAVE RATIO or SWR.

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CHAPTER ONE

1.1 INTRODUCTION

1.1.0 PREAMBLES

Transmission lines are used in a variety of applications, one common use is to feed an antenna. Usually one cannot locate the oscillator or radio transmitter, exactly at the antenna point. In these instance, it is necessary to locate the transmitter some distance away, which could be few meters to a few miles and to use a transmission line to carry power to the antenna.

Transmission lines may consist of parallel wires although coaxial cables are more frequently used. Some of the characteristics of transmission lines are:

1) Velocity factor
2) Characteristic impedance
3) Standing wave radio ratio

But based on this project, reference will be made on only the standing wave ratio.

1.1.1 STANDING WAVE RATIO

When a transmission line is terminated at an impedance different from it's characteristics impedance; some of the forward signal wave is reflected back. This reflected wave mixes with the forward wave, and the resultant amplitude at any point is the algebraic sum of the amplitude of the two waves as shown in figure 1.1

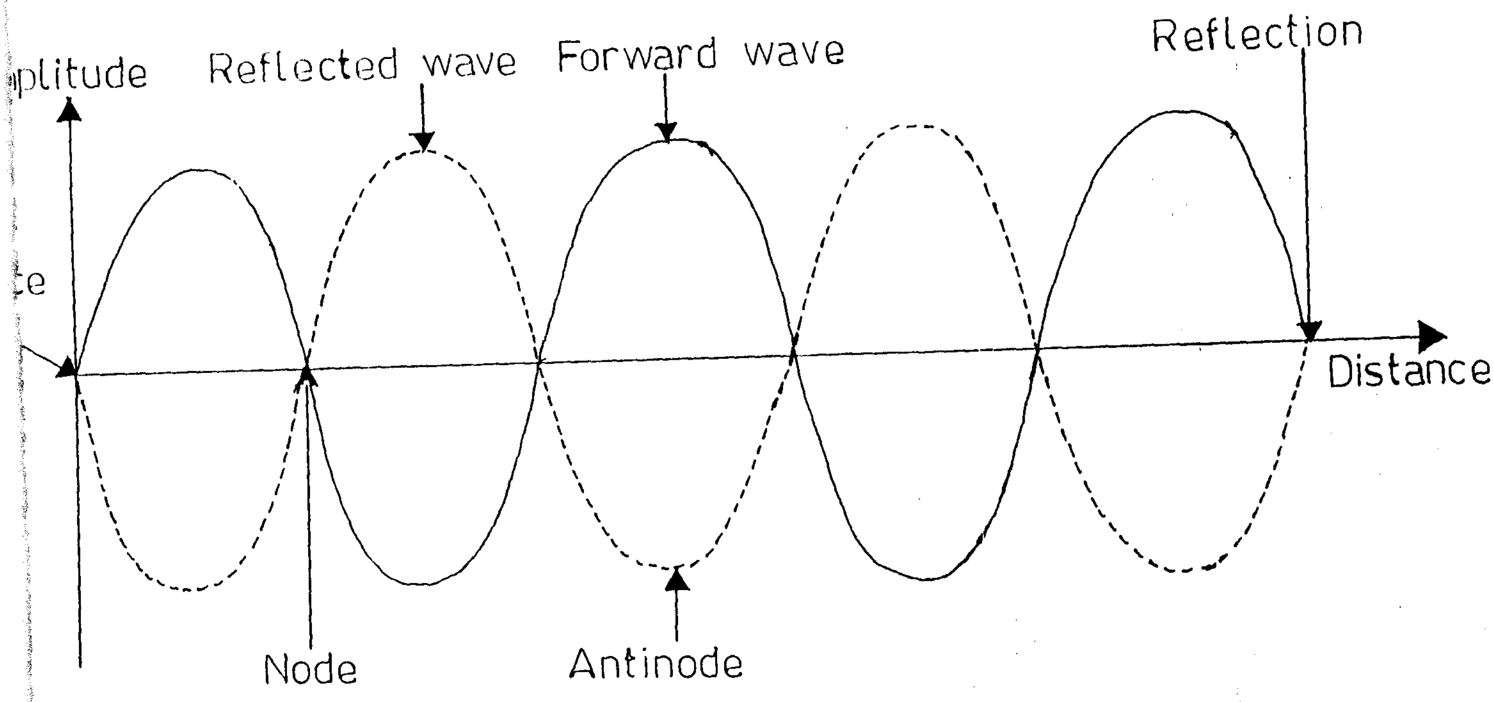

Fig. 1.1 ILLUSTRATION OF A STANDING WAVE

The nodes and antinodes do not move relative to the transmission line, that is they are stationary, and the wave are called standing waves.

An important consideration in transmission line and antenna design is the standing wave ratio and this is illustrated using fig. 1.2, which represents standing wave on a line.

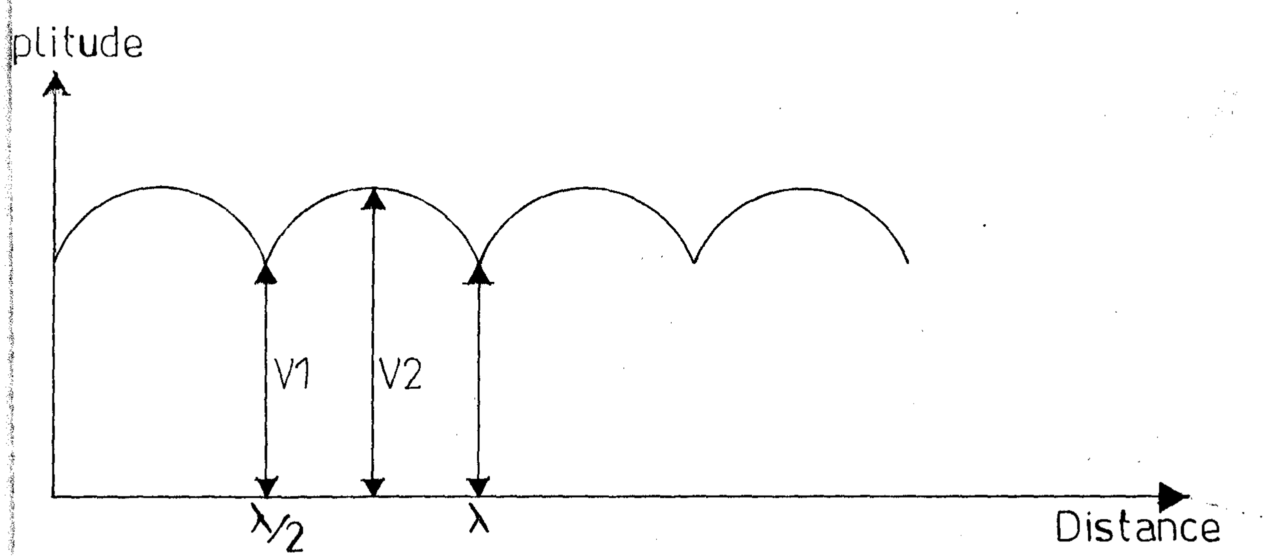

Fig. 1.2 ILLUSTRATION OF A STANDING WAVE RATIO (SWR=V2/V1)

If the line is open circuited or short circuited (load impedance being infinite or zero respectively), then all the forward wave is totally reflected back to the source and V_1 is zero. For an open circuited line, the antinodes are located at half wavelengths along the line, starting back from the open circuited point. For a short-circuited line the nodes are located at half wavelengths, starting back from the short-circuited point. Therefore, although open and short-circuited lines give identical standing wave patterns, they are shifted relative to the position of the nodes and the antinodes.

In most systems some of the forward wave will be absorbed by the load, for example in the case of an antenna some of the forward energy is radiated into space. Therefore the reflected wave, resulting in a standing wave similar to that of fig. 1.2. The standing wave ratio (SWR) is then given by the ratio of the maximum and minimum amplitude of this wave. Both voltage and current ratios can be used, and these are referred to as VSWR and ISWR respectively.

The standing wave ratio (SWR) is one of the most fundamental parameters as it checks for mismatch between the transmitter, transmission line and antenna. The SWR varies with frequency, since the impedance of the source, line load are likely to change by the same amount with frequency, so the SWR should always be measured at several frequencies.

Most low cost instruments use voltage or current as the measurement parameter. These instruments give correct readings only when the load is not too reactive, that is the SWR ratio being measured is low. The meters must also be connected to take readings at the load feed point, or at half wave from load. This usually means that the transmission line needs to have a length, which is an integral value of its electrical length.

SWR meters based on power measurements give results, which are independent of length

1.1.2 STANDING WAVE RATIO (SWR) METER

A standing wave ratio (SWR) is a meter radio frequency (RF) power Monitoring, instrument. It is often connected permanently between the transmitter/receiver rig and coax cable to the antenna. During transmission, it provides a relative indication of transmitter power, as well as an indication of the ratio of the forward RF power (i.e. the power fed to the antenna) to the reflected RF power (i.e. the power reflected into the transmitter owing to a mismatch at some point in the transmission line). It is used to measure the efficiency of an antenna system and transmitter field strength, which can help to position the antenna for best output coverage. It can also provide the data needed to plot a map of the transmitter power around the antenna.

SWR meter is aimed at delivering the maximum power to the antenna. The antenna is usually located some distance from the transmitter and requires a feedline to transfer power between the two. If the feedline has no loss, and matches both the transmitter output impedance and the antenna input impedance then and only then will maximum power be delivered to the antenna?

In this case, the SWR will be 1:1 and power will be constant over the whole length of the feedline. Any deviation from the situation will cause a standby wave to exist on the line.

The ideal SWR reading is 1:1 or a meter reading of 1 on the upper SWR. However, this measurement is obtainable only under lab conditions. Actual antenna installations are likely to have higher readings.

There are a number of ways SWR or its effects can be described and measured. Different terms such as reflection coefficient, return loss, reflected power and transmitted power loss are but a few. They are difficult concepts to understand, they are different ways to saying the same thing. The most accurate method of determining SWR is to measure the forward power and reflected power and then calculating the SWR ratio.

1.2 LITERATURE REVIEW

The standing wave ratio meter is a meter that measures the efficiency of the antenna system by determining how closely the impedance of the antenna matches the impedance of the transmitter. It is connected permanently between the transmitter receiver rig and coax cable to the antenna. During transmission, it provides a relative indication of the transmitted power, as well as an indication of the ratio of the forward RF power to the reflected RF power.

Assuming a stone is thrown into a quiet pond, there will be a splash and a series of concentric circles spreading out from where the stone entered in the water. This is an analogy that can help demonstrate RF waves and how they act. This happens around an antenna when RF is applied to it, and RF can also be measured by using an SWR meter, to see just how much energy is going in two different directions in the coax and what the antenna is using in amount of power. As the two traveling waves pass on opposite directions, they set up an interference pattern call standing wave. At certain places on the feedline the power will add producing a power maximum and their relative phase difference will cause a power minimum to exist on the feed line.

ROBERT MCGRAWC (1999) reported that these maximum and minimum points occur ¼ wavelength apart. In the days when open wire feed lines was used, these points could easily be measure with simple indications. Coax cables however present another problem since the inside of the cable is not readily available for measurement. Consequently, SWR measurements in coax are usually made at the transmitter end of the feedline. Therefore, you are presented with the SWR of the entire system, which includes all losses associated with the entire system.

Also, Andrew Cody (1998) also reported that the more energy that goes away from the antenna as it transmits, the better. However, RF is a tricky phenomenon that also leaves energy behind as it radiates from the antenna. This energy returns to the radio and how much of it, and the condition of this energy affects the overall performance of the antenna system, and hence the SWR of the system.

L.B Cebik, (1999) reported that SWR is directly related to the impedance of the load and the impedance of the feedline connected to it. Because it can be measured, it has become the standard measure of a meter or mismatch between the load (usually an antenna) and the feedline. Transmission lines are almost (but not quite) purely resistive.

SWR is a relative value, which is determined by comparing values. The most accurate method of determining SWR is to measure forward power and reflected power and then calculate the SWR ratio.

1.3 PROJECT OBJECTIVE/MOTIVATION

The objective of this project is to design and construct a meter that can Measure the reflected power between a transmitter and an antenna. This is the proportion of incident power, which is reflected back toward the transmitter due to a mismatch antenna.

This is also called a standing wave ratio and is determined by the reflection coefficient at the antenna.

With the increasing demand in communication, it has become a necessity to improve on communication technology with the use of a standing wave ratio meter the signals that are transmitted from the transmitter to the antenna can be monitored to give the desired SWR ratio, which will greatly improve transmitted signals being received.

1.4 PROJECT LAYOUT

Chapter One gives a broad overview of the project. It consist of an Introduction and literature review. This deals with basic concepts earlier researched. Project objective/motivation, which were set out as guidelines for design and construction.

Chapter two deals with introduction to the systems design, and system design / analysis.

Chapter three is about the construction, testing and the results obtained from the tests, and also discusses on the results obtained during the tests.

Chapter four deals with recommendation, conclusion, suggestion, appendix and reference. This chapter contains the student's view of what has been achieved and goals met in the execution of this project, recommendations for more technological projects.

Books and other materials consulted are in the reference. Calculations are in the appendix.

CHAPTER TWO

SYSTEM DESIGN

2.1 INTRODUCTION

The circuit diagram of the present SWR meter is conventional. The forward and reflected powers induce RF voltages in a toroid inductor L_1, which is positioned around a short length of coax cable. The cable is grounded at one side of the instrument only (a coax cable grounded at both ends does not radiate).

The RF voltage supplied by the transmitter is capacitively coupled via C_1 to serve as a kind of reference against which the forward and reverse powers are measured. The coupling capacitor is connected to a tuned circuit L_2-L_3-C_3-C_2, that serves to balance the measurement circuit at higher frequencies (in the 6m band and possibly the 4m band also).

The forward and reflected voltages are rectified by two diodes, D_1 and D_2, to establish the relative powers and thus the SWR. The AA119s used are low capacitance point contact germanium diodes with a low threshold voltage of about 0.2V. A toggle switch, S_1 allows the user to select a (relative) forward power indication or reflected power relative to forward power. The circuit is presented in figure 2.1.

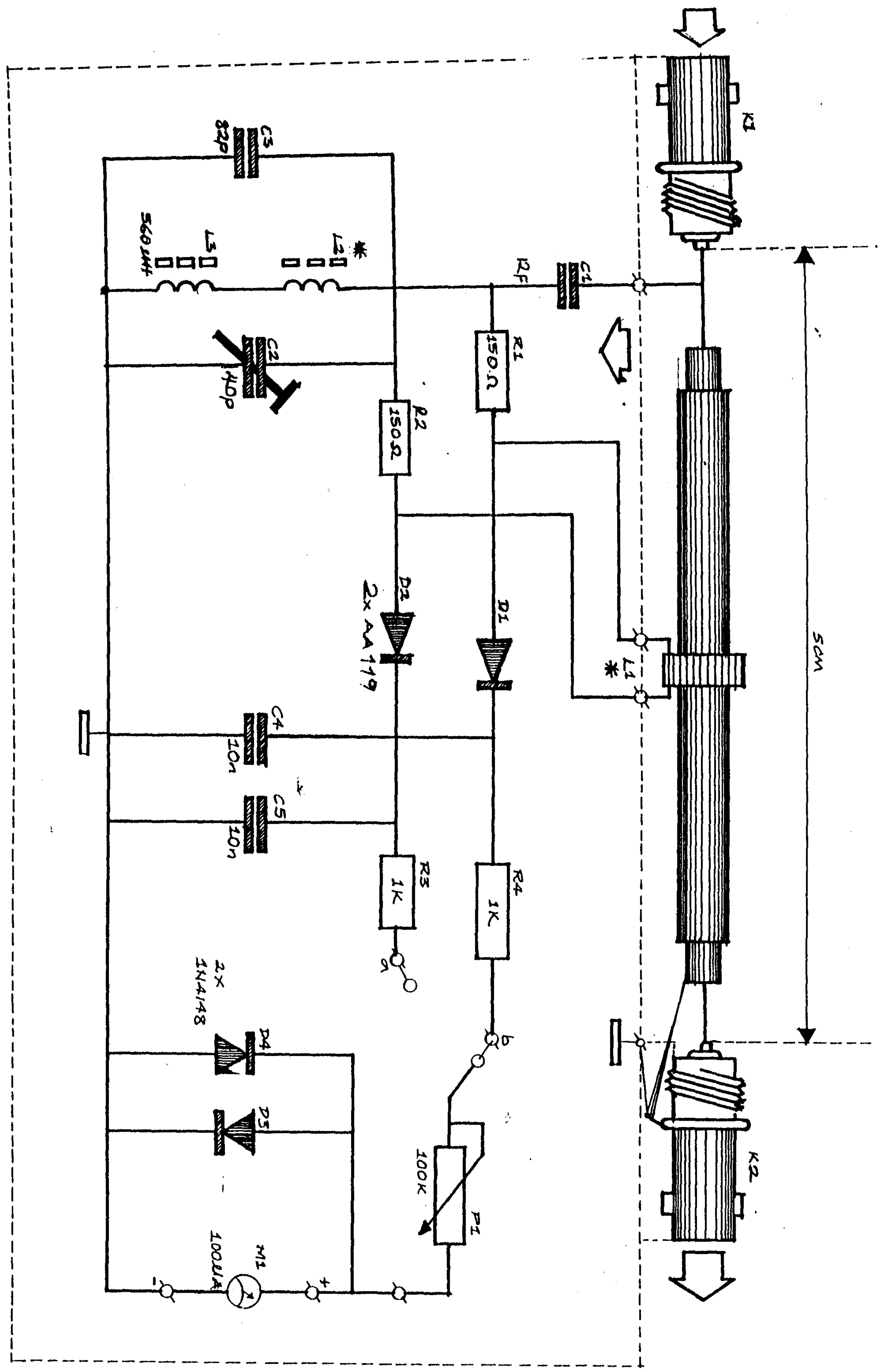

Figure No. 2.1 Circuit Diagram Of The SWR Meter

2.2 SYSTEMS DESIGN / ANALYSIS

The forward signal from the transmitter to the antenna picked up by wire is coupled by a capacitor C_1 sometimes called blocking capacitor since it blocks DC couples the signal into the circuit. Resistors R1, R2 and the tuned circuit absorb this signal. In operation the RF signal on the pick wires will be rectified by diodes D_1 or D_2 smoothed by capacitors C_4 or C_5 then applied as DC to the indicator. D_3 and D_4 acts as current limiting diodes to the coil meter.

L_1 is a Toriod Inductor, which is induced by the forward and reflected Power and is used to power the circuit. To calculate the inductance L_1.

Given the following parameters:

Number of turns for Inductor L_1	= 30
Core diameter	= 0.2mm
Length L_1	= 317mm
Relative permitivity for ferrite	= 20
Magnetic flux density	= $4\pi * 10^{-7}$

Inductor L $= 4\pi * 10^{-7} * UrN^2A/L$ ....(2.2)

Where, Ur =

N = Number of turns

A = Area of core

L = Length of core

$$A = \pi d^2/4 \quad \ldots\ldots(2.3)$$

$$= \pi (0.2)^2/4$$

$$= 3.14 * 10^{-2}\text{mm}^2$$

Therefore,

$L_1 = 4\pi * 10^{-7} * UrN^2A/L$

$= 4\pi * 10^{-7} * 10 * (30)^2 * 3.14 * 10^{-2}/317$

$\therefore L_1 = 112uH$

To calculate the inductance L_2,given the following parameters:

Number of turns L_2 = 6

Core diameter = 0.2mm

Length L_2 = 63.4mm

Relative permitivity for ferrite = 20

Magnetic flux density = $4\pi * 10^{-7}$

$L = 4\pi * 10^{-7} * UrN^2A/L$ .... (2.2)

$L_2 = 4\pi * 10^{-7} * 10 * (6)^2 * 3.14 * 10^{-2}/63.4$

$\therefore$ $L_2 = 22.41uH$

Considering the tuned circuit

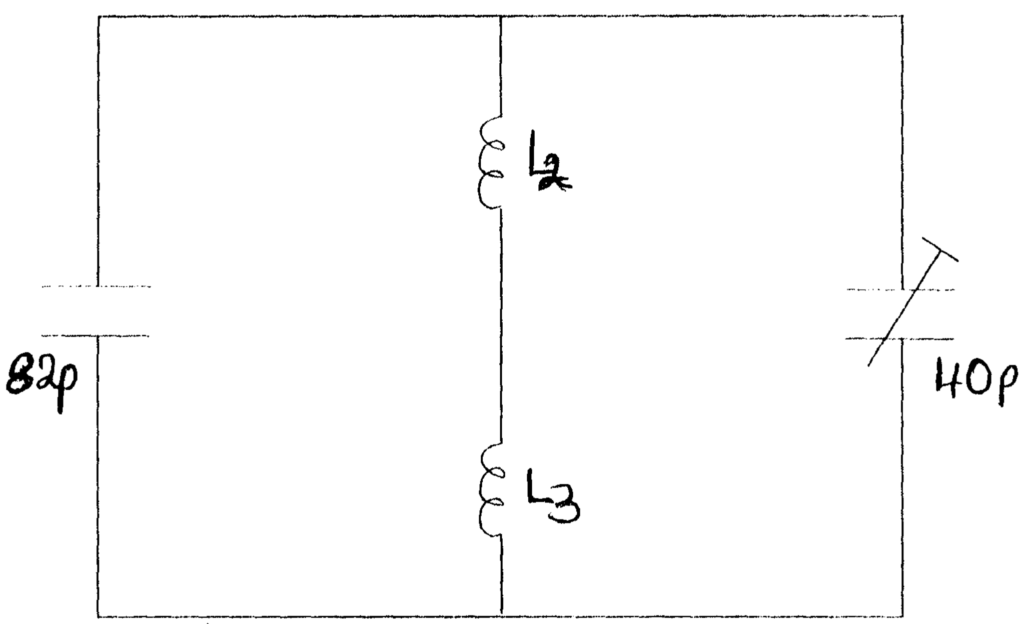

Figure No. 2.2 Tuned Circuit

Contained in the tuned circuit is Capacitor C_2 connected in parallel with Capacitor C_3 which is called a trimmer or vericap used to regulate or tune the reflected power.

Considering Capacitors C_2 and C_3 connected in parallel

The equivalent capacitance Ceq is given as

Ceq = $C_2 + C_3$ .... (2.1)

= (82 + 40) pF

Where

Ceq = 122pFS

Therefore

Inductor equivalent Leq = $L_2 + L_3$

Leq = $_2 + L_3$

= $(22.41 + 560) * 10^{-6}$

= $582.41 * 10^{-6}$

= 582.41uH

The frequency Fo of the tuned circuit is

Fo = 1/2π√Leq Ceq .... (2.4)

= $1/2\pi\sqrt{(682.41 * 10^{-6})\ (122 * 10^{-12}}$

Fo = 59.71KHz

The voltage across the inductor is

V = LdI/dt .... (2.5)

V = 112 * 10-6 dI/dt

At 1.6mHz the output voltage of the transmitter was found to be 15.88v

The peak voltage across D1 and D2 is

V_{D1} = √2 * Vo .... (2.6)

= √2 * 15.88

V_{D1} = 22.46V

From the manufacturers data sheet, the movement resistance R_m of the 100UA meter was found to be 2000Ω

R_4 or R_3 is in series with P_1 and in parallel with resistance of the meter.

$R_{3or4} = 1K\Omega$ $P_1 = 100\ K\Omega$ $R_m = 2\ K\Omega$

$R_{3or4} + P_1 = (1 + 100)\ 10^3$ .... (2.7)

$= 101K$

$R_1 \quad = 101 * R_m/101 + R_m * 10^3$ .... (2.8)

$= 101 * 2/101 + 2 * 10^3$

$R_T \quad = 2.96\ K\Omega$

Therefore time constant is,

$R_{TC} = 1960 * 10 * 10^{-9}$

$= 190bus$

Discharge time, td = 1/F .... (2.9)

$= 1/50$

therefore td $= 0.025$

The peak –to-peak voltage is

$V_{P\ P} = V_{D1}\ (1 - e^{td/Rmc})$ .... (2.10)

$= 22.46\ (1 - e^{-(0.02/19.6*10-6)})$

$= 22.45V$

The DC voltage at the output of each diode is

$V_{dc} = V_{D1} - (V_{p\text{-}p}/2)$ .... (2.11)

$= 22.46 - 22.46/2$

$V_{dc} \quad = 11.23V$

CHAPTER THREE

CONSTRUCTION, TESTING AND RESULTS

3.1 CONSTRUCTION

In the construction of the standing wave ratio (SWR) meter, at each stage the design specification of each component was followed strictly.

The construction was completed on a Vero board by connecting the different components according to the design after a test drive had been done on a breadboard.

The meter is powered from the power flowing from the transmitter output. This is done by the use of a BNC (Baby-N-Connector) sockets connected by a short length of thin 75Ω coaxial cable of which the screening braid is connected to the socket and the board at the antenna side only. C_1 is then connected to the coaxial cable by the use of a jumper wire.

All soldering was done on the conducting side of a 9 x 6cm Vero board using transformer wires and in between the board where the component was soldered was cut slightly to stop continuity between the ends of the components. Continuity was checked using a digital multimeter. Conducting jumper wires were used in accordance with color-code, i.e. negative or ground black and white and blue for connecting signal terminals to one another.

R_1, D_1 and R_4 were connected in series on the Vero board. C_4 is in parallel with the above-mentioned components, C_4 is connected to the other components with jumper wire after soldering it on the Vero board so also is C_1. This link forms the forward terminal.

C_4, L_2, L_3 and C_2 were connected in parallel and soldered; jumper wires linked them to each other.

L_1 is linked between R_1, D1 and R_2, D_2 with jumper wires.

The meter is linked to the circuit by connecting jumper wires behind the meter and soldering it to the Vero board. D_4 and D_3 are connected in parallel to each other and in parallel to the meter and linked by jumper wires.

The entire circuit system was housed in a wooden casing for protection. The casing was constructed with a ½ inch wood and plywood. The plywood makes up the top section while the ½ inch wood was used for the base.

The side and top were drilled to make room for the switch and BNC sockets and moving coil meter at the top.

3.2 TESTING

One side of the completed SWR meter was connected to an AM source of 4wt and a dummy load of 75Ω

Transmitting at a continuous output for 10us on the forward terminal, it was then switched to the reflected terminal for the same period of time at the same power.

The variable resistor was used to vary the incoming dc voltage until a reasonable deflection was obtained. The trimmer C_2 was used to indicate the required full-scale deflection on the reflected terminal.

3.3 RESULTS

When 17v/40mHz was pass through the meter for 10us the following results were obtained;

Forward voltage = 576.6mv (deflection)

Reflected voltage = 576.5mv (deflection)

The standing wave ratio (SWR) is given by the ratio of the maximum and minimum amplitudes of this wave. Both voltage and current ratio can be used and these are referred to as VSWR and ISWR respectively and are given by;

$$VSWR = V_2/V_1 \quad \text{.........................} \quad (3.1)$$

$$ISWR = I_2/I_1 \quad \text{.........................} \quad (3.2)$$

$$SWR = \frac{V_F + V_R}{V_F - V_R} \quad \text{....................} \quad (3.3)$$

Where V_F is forward voltage, and V_R the reflected voltage

Therefore

$$SWR = \frac{(576.6)\,10^{-3} + (576.5)\,10^{-3}}{(576.6)\,10^{-3} - (576.5)\,10^{-3}}$$

$$SWR = \frac{1.1531}{0.000100}$$

The ratio is 1:0

Where 1.1531 approximately 1 is the forward voltage, and 0.000100 approximately 0 is the reflected voltage.

The equation used in getting the SWR is shown in great detail in the appendix.

3.4 DISCUSSION OF RESULTS

The SWR results obtained for the ratio of the forward and reflected Voltage is 1:0, where 1 is the forward voltage and 0 is the reflected voltage. This result shows that all power from the transmitter output is being absorbed by load at the other end and there is no reflected power.

According to Andrew Cody (1999), the ideal SWR reading is 1:1 or a meter reading of 1 on the upper SWR scale. This measurement is obtainable only under laboratory conditions. Actual antenna installations are likely to have higher readings.

We can therefore conclude that the result obtained from this test is an ideal one since a ratio of 1 was obtained on the upper scale.

CHAPTER FOUR

RECOMMENDATION AND CONLUSION

4.1 RECOMMENDATION

I will recommend that two coil meters be used to make the reading of the reflected and forward power easier for individual use instead of one coil meter and switching to take readings to avoid error for one who is not familiar with the procedures.

It is recommended that the school as a whole and individual departments organize private sectors and other interested parties to take active parts carrying out researches and finding standard final year projects for students.

Research should be embarked on and students encouraged participating in them from their 100 levels so as to prepare them for their final year projects and the practical world after school.

4.2 CONCLUSION

In conclusion, this project as was its aim to measure the ratio of forward power to reflected power has been successful.

A ratio of 1:0 was achieved, this means that the entire signal sent from the transmitter is being used up by the load at the output.

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APPENDIX

The Standing wave ratio is given by

$$SWR = \frac{Z_C}{Z_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

(for $Z_C > Z_L$)

or

$$SWR = \frac{Z_L}{Z_C} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

(for $Z_L > Z_C$)

Where Z_C is the characteristics impedance of the transmission line and Z_L is the characteristics impedance of the load.

$$SWR = \frac{1 + (P_R/P_F)^{1/2}}{1 - (P_R/R_F)^{1/2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where P_f is the forward power from the source to the load and P_r is the power reflected back from the load.

$$SWR = \frac{1 + V_R/V_F}{1 - V_R/V_F} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$SWR = \frac{V_F + V_R}{V_F - V_R} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where V_F is the voltage component of the forward wave and V_R is the voltage component of the reflected wave.