Design and application of a microwave moisture meter

by Joseph Lacy Kowalski

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Electrical Engineering
Montana State University

Abstract:
A specific application of microwave techniques to the measurement of moisture content of fuel materials of the forest floor is discussed in this paper. The principle of absorption of electromagnetic energy passed through a layer of water is used to derive the equation for calculating the moisture content of a given sample. Detailed experimental and theoretical study showed the attenuation of microwave energy in water is a strong function of the temperature of the water. A plot of calculated attenuation verses temperature and a table of the derived multiplying factor (k) used in the moisture meter equation are given and compared to experimental results.

It was observed experimentally that the method used for oven drying as a check on the moisture meter was not consistant. It was found to be necessary to remove the moisture from the air in the oven to allow the sample materials to dry out completely. This was achieved by placing a drying agent (calcium sulfate) in the oven. The drying agent absorbed the moisture, in the air and allowed the sample material to dry out completely.

Methods of further study to determine the accuracy of the meter and improvements that could be made on the moisture meter are. given in the last two chapters of this paper.

In presenting this thesis in partial fulfillment of the requirements for an advanced degree at Montana State University, I agree that the Library shall make it freely available for inspection. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by my major professor, or, in his absence, by the Director of Libraries. It is understood that any copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Signature Joseph Lang Kowalski

Date July 12, 1974

DESIGN AND APPLICATION OF A MICROWAVE MOISTURE METER

by

JOSEPH LACY KOWALSKI

A thesis submitted to the Graduate Faculty in partial
fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Electrical Engineering

Approved:

Head, Major Department

Chairman, Examining Committee

Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 1974

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Professor Bruce McLeod for his many suggestions, encouragement, and guidance during the course of this graduate work and thesis research.

He is grateful for the financial support provided by his parents and that provided by the Electrical Engineering Department of Montana State University in the form of Graduate Research Assistantship.

The author's very special appreciation is expressed for the help received from Mrs. Sally Jean Peters who contributed in her own special way to make this thesis possible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

A specific application of microwave techniques to the measurement of moisture content of fuel materials of the forest floor is discussed in this paper. The principle of absorption of electromagnetic energy passed through a layer of water is used to derive the equation for calculating the moisture content of a given sample. Detailed experimental and theoretical study showed the attenuation of microwave energy in water is a strong function of the temperature of the water. A plot of calculated attenuation verses temperature and a table of the derived multiplying factor (k) used in the moisture meter equation are given and compared to experimental results.

It was observed experimentally that the method used for oven drying as a check on the moisture meter was not consistant. It was found to be necessary to remove the moisture from the air in the oven to allow the sample materials to dry out completely. This was achieved by placing a drying agent (calcium sulfate) in the oven. The drying agent absorbed the moisture in the air and allowed the sample material to dry out completely.

Methods of further study to determine the accuracy of the meter and improvements that could be made on the moisture meter are given in the last two chapters of this paper.

CHAPTER I

INTRODUCTION

The need for accurate, continuous moisture monitoring equipment in the production of paper, textile, flour and various other products has brought about the use of microwave techniques to measure moisture levels where direct contact with the material is undesirable [1,2].

The technique of measuring moisture is based on the fact [3] that the amount of microwave energy absorbed is a function of the amount of water present. Therefore, by transmitting microwave energy through a sample and measuring the difference in transmitted and received energy, the moisture content of the sample can be determined.

This investigation was undertaken to determine how the absorption of microwave energy behaved as a function of moisture content of several particular materials. Also, part of the work was concerned with finding other variables that would have to be considered to obtain a portable microwave moisture meter that could be used by the Forest Service to measure moisture content of fuels on the forest floor with at least as good if not better accuracy than methods presently being used.

CHAPTER II

PRINCIPLE AND DESIGN OF MICROWAVE MOISTURE METER

This chapter discusses the principle of the absorption of electromagnetic energy in water and how this principle is applied in the design of a moisture meter.

A. Microwave Absorption in Water

1. Absorption at Resonance Frequency

The absorption of microwaves in water is due to a resonance of the water molecule with the microwave signal [4]. Several authors have shown that microwave absorption in water peaks out about 22,000 MHz [3,5]. The shape of the absorption peak was first determined by Becker and Aulter [5] for water vapor. It has been shown that the attenuation for pure water is 40 dB/cm at a frequency of 10,000 MHz [6]. Above 10,000 MHz the conductivity of water is independent of its salt content and therefore the absorption of electromagnetic energy is independent of salt content [6]. Figure (1) gives a plot of the loss factor of pure water verses frequency [4]. It is seen then from Figure (1) that the choice of frequency to obtain a high loss factor and hence good sensitivity for the meter would be in the microwave frequency range.

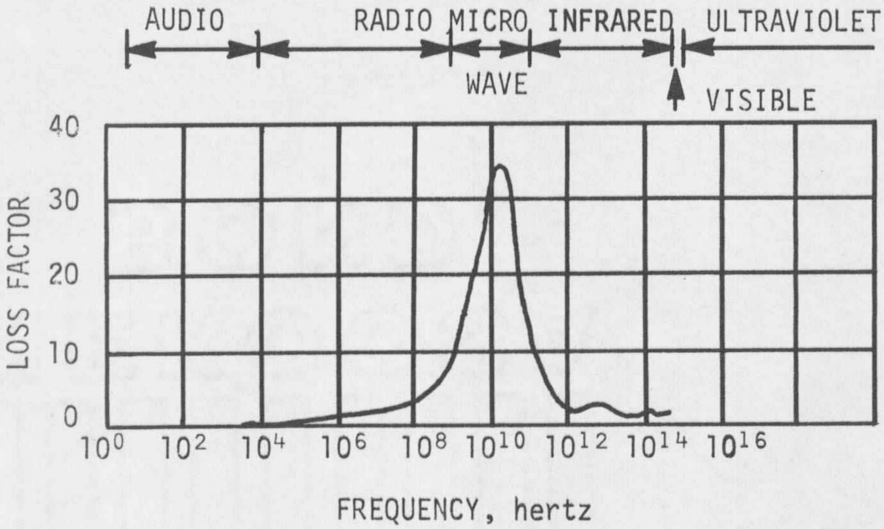

Figure 1. Loss Factor for Pure Water vs. Frequency.

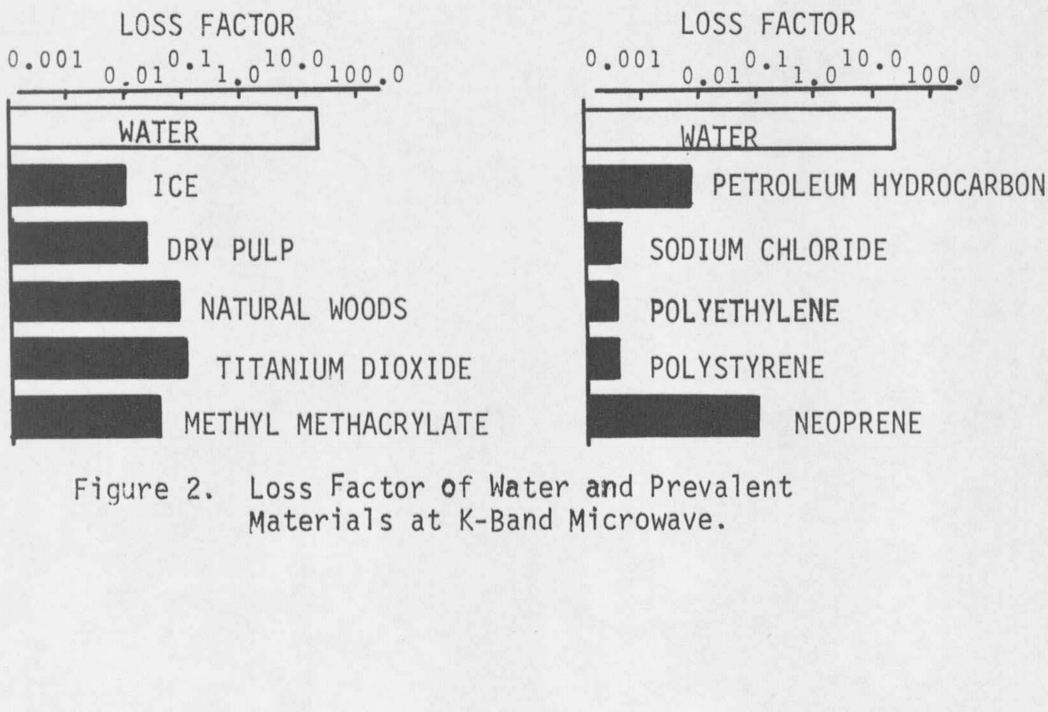

Figure 2. Loss Factor of Water and Prevalent Materials at K-Band Microwave.

2. Absorption of Microwaves in Materials Containing Water

Since the interest of this study was measuring moisture content of materials, the question of how electromagnetic waves were attenuated by water contained in specific materials was raised. If the attenuation of microwaves due to water contained in specific materials was much greater than the attenuation due to the materials themselves the amount of water present could be related directly to the attenuation measured.

The fact that the absorption of microwaves in materials is proportional to the loss factor of the material [4] implies that the loss factor of water is much higher than that of the specific materials of interest. Figure (2) compares the loss factor of water to various other materials [4]. The figure shows that a ratio of 100 to 1 between water and base materials should exist. This means that a similar ratio should exist for the absorption of water and the base material.

Theoretically then the moisture content of a sample of material could be determined from the attenuation of a microwave signal passed through it. Therefore, for a moisture meter, a source of microwave signal plus a means of guiding the signal through the sample material and measuring the received signal at the other side of the sample is needed.

B. Components of Moisture Meter

1. Microwave Components

The heart of the microwave moisture meter is its source of microwave energy. The requirement that the moisture meter be portable placed restrictions on the choice of microwave source. The source had to be small, lightweight, and most of all had to be powered by a dc voltage source. A Gunn oscillator was chosen as the source because it is small, lightweight and requires only a 12 volt dc power supply. The Gunn oscillator chosen operates at 10,525 MHz. This frequency was selected so that the effects due to salts in the water could be ignored as previously stated.

Microwave horns are used to transmit and receive the microwave signal. The horns are placed approximately 2 inches apart. Each horn has an apature area of 2.5" x 2.25" = 5.625 square inches, and each has a gain of approximately 9 db over a dipole antenna.

For detection of the microwave signal a standard 1N23 silicon diode detector is used. The diode detector rectifies the microwave signal and has a dc voltage output proportional to the microwave input level.

A precision rotary vane attenuator is used to set the level of microwave signal that is transmitted into the sample. The accuracy of the attenuator is $\pm 2\%$ of db reading or ± 0.1 db whichever is greater over a 0 to 50 db range. The scale on the attenuator can be read to the nearest tenth of a db in the 10 to 50 db range.

2. Electronic Components

The electronics of the meter are composed of a modulator, amplifier, and power source (two six volt batteries connected in series). The modulator supplies a 1 KHz square wave with its low level at 0 volts and high level at 12 volts. The modulator drives the Gunn oscillator which in turn outputs a 10,525 MHz signal modulated by a 1 KHz square wave. The diode detector then has a 1 KHz square wave output. This output is fed to the amplifier (tuned to 1 KHz) which has a variable gain of 0 to 40 db. The amplifier in turn drives a current meter which is used to set a reference level on the received signal.

Appendix I contains pictures of the Gunn oscillator, horns, diode detector, precision attenuator, modulator and amplifier. Appendix II contains the schematics and specifications of the modulator and amplifier.

C. Construction Details of Moisture Meter

Figure (3) is a block form representation of the moisture meter in terms of its microwave and electronic components. Several authors show similar diagrams of moisture meters that work on the same principle of attenuation measurements [6,7,8].

The moisture meter being discussed in this investigation was designed and built by Dr. Bruce R. McLeod, of Montana State University. The first model was rather large and difficult to carry in the field.

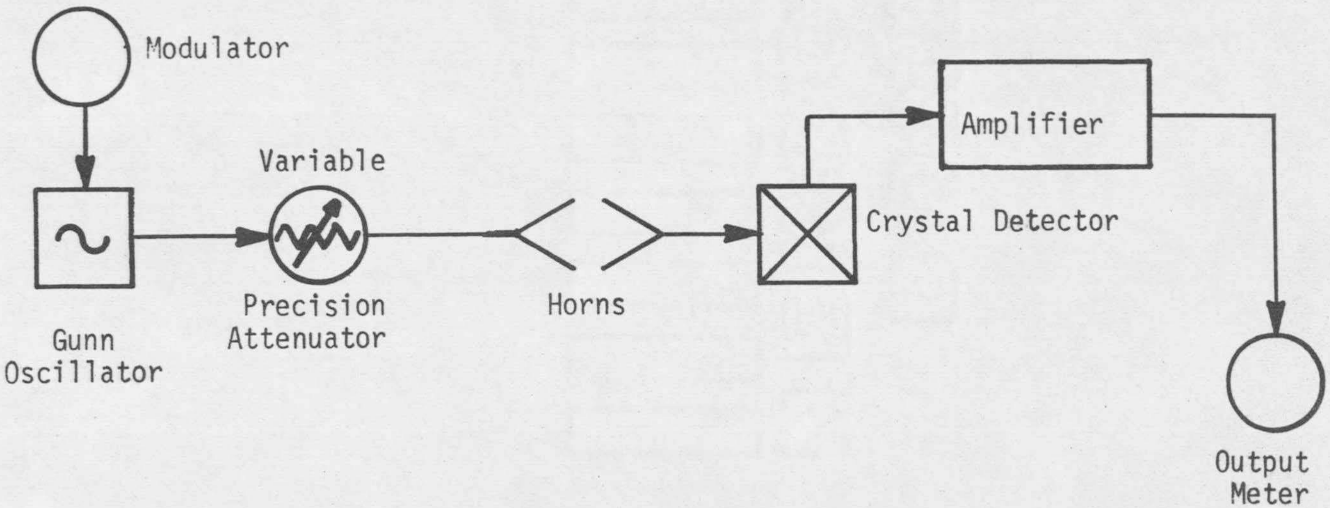

Figure 3. Block diagram of microwave moisture meter.

The second model shown in Figure (4) was built approximately 2 years later in 1973. It is much smaller and easier to carry in the field. Figure (5) shows a rear view of the front panel and inside view of the case with batteries in place. A design convenience of the moisture meter is that all the parts are attached to the removable top panel making repairs very easy. Since it is important that the measurement be consistant from sample to sample, a guide is attached to the bottom of the case in which the sample box fits. Thus, the sample box is held in very nearly the same place for every measurement.

It was found experimentally that glass tape was the best way of fastening the front and back faces to the sample box. Epoxy and various other glues were tried but none held up as long as the glass tape. The sample box dimensions are 5" x 5" x 2".

D. Calculation of % Water from Attenuation and Weight

The equation for relating the moisture content of a sample material to its weight and attenuation of microwave energy was derived by Dr. Bruce R. McLeod. The derivation of the equation given below can be found in Appendix III.

$$\% \, H_2O = \frac{100}{k \frac{w}{x} - 1} \qquad (1)$$

where k = Multiplying Factor
w = Weight of Sample
x = Measured Attenuation