DESIGN AND CONSTRUCTION OF A NONCONTACT RESISTIVITY MEASUREMENT INSTRUMENT

William R. Hamilton
5th Year Microelectronic Engineering Student
Rochester Institute of Technology

ABSTRACT

An Eddy-Current Gauge was fabricated from the design of G. L. Miller, D. A. H. Robinson and J. D. Wiley [1]. The electronics involved was mounted on a printed circuit board and the header assembly was successfully machined and housed in Lucite. The calibration and testing confirmed the instrument's linear properties for measuring conductivity.

INTRODUCTION

Accurate measurement of bulk resistivity is an important concern in all microelectronic fabrication processes. Traditionally, resistivity has been obtained using the four point probe technique, as shown in Figure 1. This involves physically contacting four equally spaced probes to the surface of a wafer. A current is forced through the two outer probes and the voltage created across the two middle probes is measured. Using these two values, one applies them to appropriate equations that account for dimensional specifications of the sample and obtain the wafer's bulk resistivity. The drawback to this technique is that it is damaging to the contact area. In addition, the device's accuracy depends upon the amount of current used for testing[2]. Despite its imperfections, it is predominantly used in the semiconductor business simply because it is an inexpensive and well established means of measuring bulk resistivity.

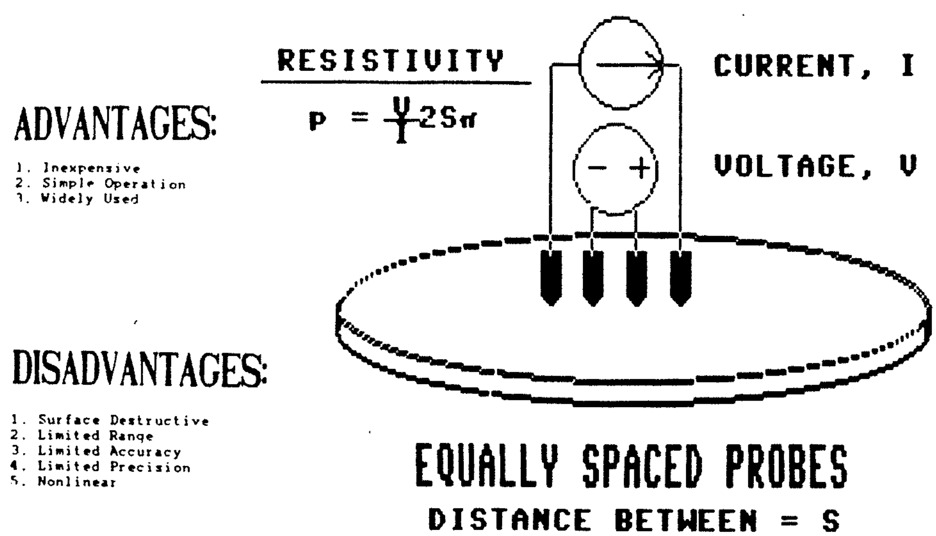

Figure 1: Four Point Probe

The Eddy-Current Gauge, shown in Figure 2, offers several obvious advantages to the four point probe. The most recognizable of these advantages are that: it is nondestructive, it has high precision and accuracy, it maintains perfect linearity and, finally, it can be range sensitive. Range sensitive means a sample having too high or too low a value of conductivity to be measured will trigger an electronics warning circuit to alert the experimenter.

Eddy-Currents are created when a conductive object moves through a stationary magnetic field. These currents obey the right-hand-rule to the magnetic field and exist within the passing conductor. The Eddy-Current Gauge utilizes an oscillating magnetic field containing a stationary conductor and then measures the amount of power absorbed by that semiconductor, through eddy-currents. The power absorbed is characterized by Equation 1:

$$Ps = (E_T^2/8\pi n^2)t\sigma \qquad [1]$$

where E is the primary rms voltage, n is the number of primary turns on the core, σ is the semiconductor's conductivity and t is the semiconductor's thickness.

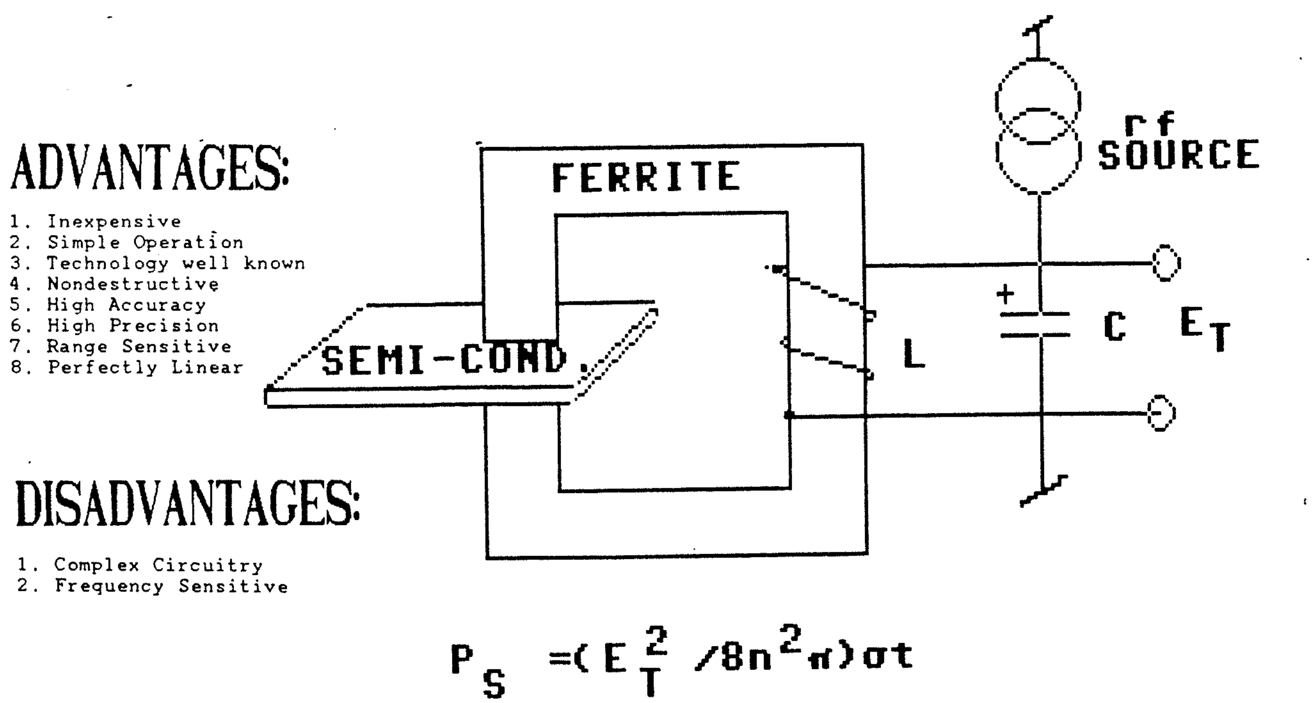

Figure 2: Eddy-Current Gauge [1]

To create the oscillating magnetic field involves several components. The first component is the rf tank. This tank is composed of a split ferrite pot core transducer having about two coils on either side. The area separating the transducer halves is where the wafer is placed for resistivity measurement. This apparatus is depicted in Figure 3.

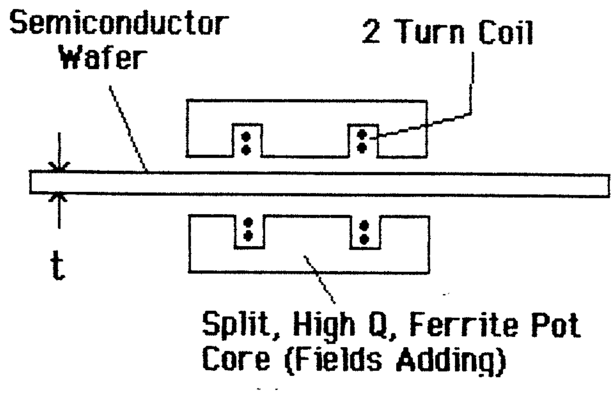

Figure 3: Split Core Inductor [1]

The number of coils employed serves as a means of defining the range capability of the measuring instrument. This is directly due to the dependence of the range scaling to $1/n^2$. The main advantage of the range scaling is that the coil inductance also increases with n^2. As expected, the operating frequency will be proportional with $1/n$, provided that the tank capacitance (C) remains constant. This characteristic is important to satisfy the skin depth criterion for use in measuring high conductivity samples. The value of n also bears heavy consequence on the fringing field created by the split pot core. confinement of the field was achieved through fitting each of the halves with a seamless aluminum cup covered with conducting paper at the opening.

To create the oscillating magnetic field, the tank is supplied with a current from an rf self-excited oscillator. One problem is that the wafer's absorption of power affects the electric field created by the transducer. This makes the electric field a variable and complicates power measurement. To correct for this, a feedback circuit can be employed to maintain a constant electric field independent of the power level of the semiconductor absorption. This feedback circuit senses changes within the electric field of the transducer and sends an appropriate booster signal to the oscillator. Once the power absorption is maintained constant, all that's left to do is measure the proportional rms voltage at the circuit's output.

This project was entirely based upon the designs presented in Reference [1]. The purpose was to recreate a the device conceived by Robinson, Wiley and Miller.

ELECTRONICS

Referring to Figure 4 shows a detailed diagram of the circuit required for this instrument. In this case, a Robinson Oscillator[1] design was used with a resonance of 10MHz to minimize any "skin-effect". Once the parts were gathered, construction was a simple matter of creating the printed circuit board (PCB). An acetate sheet was used with each side coated with copper metal. The pattern was hand drawn to the 115x160mm board with an etchant resistive ink.

Mounting holes 1/64" in diameter were created with the use of a drill press. The pattern was etched at room temperature with a mild solution of ferric chloride during constant agitation. Finally, the parts were soldered in place with standard rosen core solder, using 8-pin sockets for the Operational Amplifier integrated circuits.

HEADER ASSEMBLY

The mounting frame was constructed of Lucite plastic. To define the spacing between the two core halves, three pieces of sheet lead, each measuring 0.008" in thickness, were combined and placed appropriately before the transducer. An exploded view of this assembly can be seen by Figure 5.

RESULTS/DISCUSSION

A DC analysis of the circuit was completed using SPICE. These simulated results were compared to measured values to confirm the device was operating properly. In addition, the AC component driving the magnetic field was also noted to ensure an operating oscillator. At this point the device was properly zeroed and set for wafer thickness.

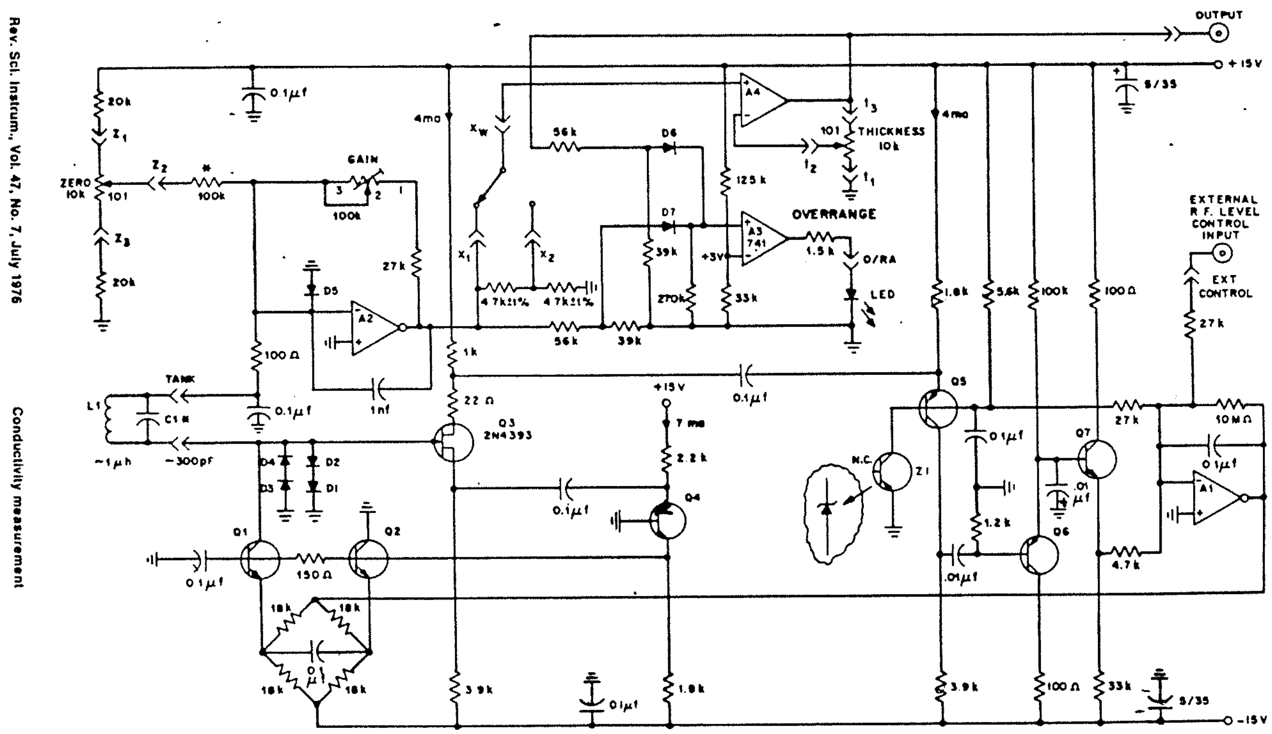

FIG. 1 Complete schematic of the conductivity measuring system. Resistors are 0.25 W ± 5% unless otherwise specified. Diodes are 1N4154. NPN transistors are 2N3904; PNP transistors are 2N3906. *, Select.

Figure 4: Electronics Schematic [1]

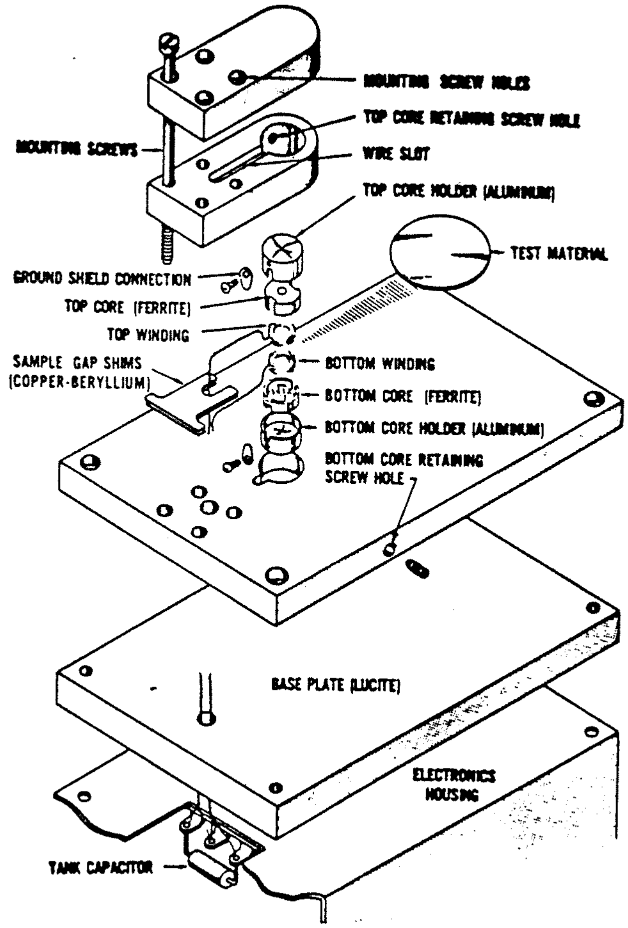

Figure 5: Header Assembly [1]

Four wafers, each approximately 15 mils thick and of various resistivities, were tested with the device. Figure 6 depicts the output voltage values for the four resistivity values of: 0.5, 3.0, 4.0 and 10 ohms/square. Point A, 10 ohms/square, distinctly shows a inconsistency with the linearity of the output voltage. This was the point where the device began functioning erratically with an inconsistent value for the AC current. The wafer having a resistivity of about 18ohms/square attained a dc output of 14.73 volts. This voltage value existed near the rail voltage of 15 volts. Upon checking for an AC voltage value in any part of the circuit revealed all AC activity had ceased. It is suspected that the oscillator circuit began to fail during the measurement of point A and had been completely lost to the 18ohm/square wafer measurement.

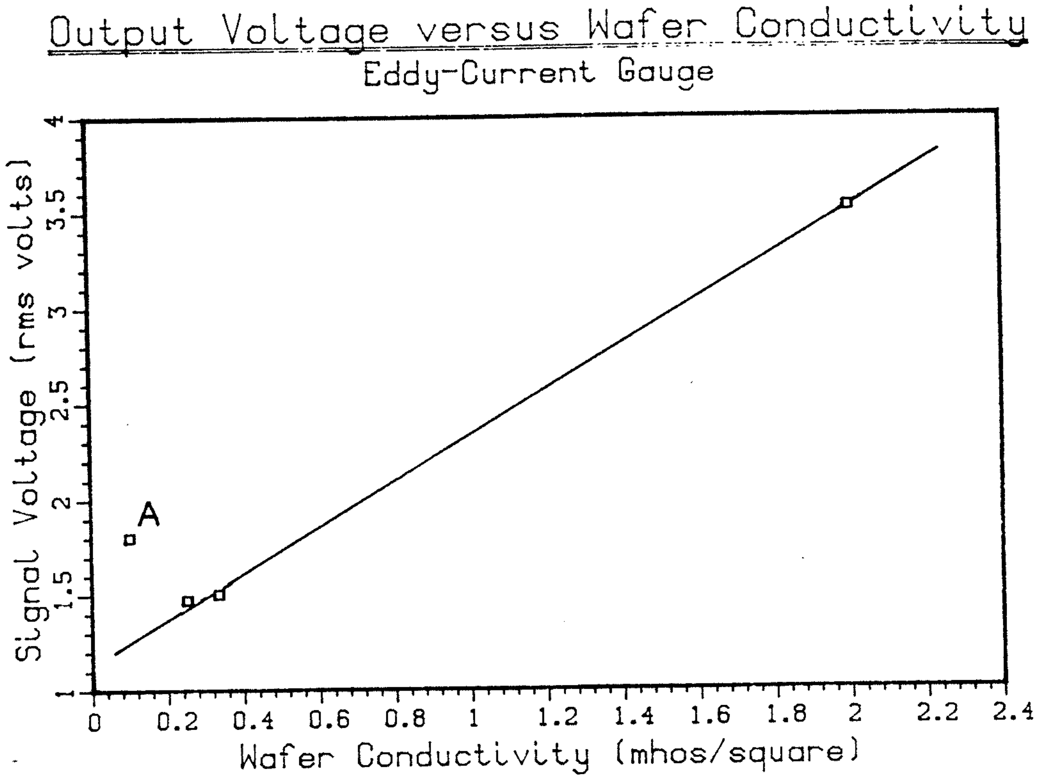

Figure 6: Graphical Analysis

CONCLUSIONS

The Eddy-Current Gauge was successfully constructed. Initial testing showed the device to operate in a linear fashion. The ECG still requires calibration and electronic repairs are needed for the oscillator. An improvement into the design might be to utilize a programmable, low impedance pattern generator as the driving power source. In addition, in stead of having the resulting signal analyzed, an oscilloscope could be used to measure the change in impedance of the inductor. In this suggestion, rather than the construction of a full PCB circuit, an experimenter could use laboratory equipment, properly connected to the header assembly, to attain the wafer's resistivity value. All that must be consistent is that Equation 1 be used as a base for the set up.

ACKNOWLEDGMENTS

Special Thanks go to Dave Hathaway and Lynn Bishop of the RIT Mechanical Machine Shop Department for their efforts in the Lucite Header Assembly. Additional thanks go to Michael Jackson, Dr. Richard Lane and to the RIT Microelectronics department for their assistance and support.

REFERENCES

[1] G.L. Miller, D.A.H. Robinson, and J.D. Wiley, Rev. Sci. Instrum. 47, 799 (1976).

[2] ASTM Standards, Designation: F 673 - 80.