POLYCONDUCTOR THERMAL WATTMETER

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In Partial Fulfillment
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Master of Science
Electrical Engineering Department

by
James Gordon Maciejko
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ABSTRACT

The thesis presents a thermal wattmeter which using a new matal oxide type of polyconductor (Moxie) for the sensing elements and which could be incorporated in a watthour meter for remote reading of on line energy consumption of a load. The basic feature of this semiconductor is that its terminal resistance can vary by many orders of magnitude for a small change in input power during transition, thus accounting for the high sensitivity of the wattmeter. The sensing circuit makes use of the approximate square law characteristics of two polyconductors to provide the necessary multiplication of the instantaneous current and voltage required in wattmeter operation. In order to correct for ambient temperature fluctuations in the wattmeter circuit investigated,a novel temperature compensation network is incorporated and which generates heating pulses with frequency determined by the ambient temperature. The main drawback associated with the accuracy of the experimental meter is due to the hysteresis phenomenon inherent in the polyconductor used and is partially overcome by the manner in which the pair of polyconductors are used resulting in a uncertainty of 1.0%. Other factors are also investigated such as

transient power pulse, step temperature fluctuations and harmonic content of the line power.

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CHAPTER I

INTRODUCTION

Many electrical engineers are constantly engaged in a struggle to improve existing electrical equipment with newly developed devices and novel ideas. Their efforts have led to many intriguing developments in electromagnetic field, control, satellite and space communication and telemetry technology. Inspite of these advances it is astonishing to realize how electric power is metered in domestic and industrial installations. Current meters require the employment of manually recorded readouts to control and monitor power flows. In addition, these power recordings serve no value as real time information sources. Any effort to economically solve this problem will be of great interest to those engaged in power generation, distribution, and consumer billing industry.

The first universal application automatic remote meter reading and load control system was developed by the Plessey Electronics Group (1). The system alters the existing induction type watthour meter with a mechanical to electrical device which changes state after a "unit" of energy has been consumed. The state of the device is interrogated regularly, and frequently enough to count every unit consumed. Louisiana Power and Light Company have an experimental residential load control system (2) AMRAC (acronym for automatic meter reading and control) similiar to the Plessey Group system. Steps are taken in converting to remotely read meters but an average annual meter-reading cost of one dollar per meter per year is too small a quarry to justify only automatic power meter reading (3), as was the economic situation fourteen years ago but with time the economics will overrule the meter man in favour of automatic remote meter reading (18).

The scope of this thesis is to investigate the use of a new device in a power metering instrument. The new wattmeter in this study was investigated in hopes of developing a meter which would easily lend itself to remote meter reading applications. In this case, the output of the meter is to be already in a electrical form thus not necessitating the use of mechanical to electrical convertors currently employed. The new device investigated has associated problems with which original designs and ideas were needed to complete the study. The philosophy employed in this thesis is to utilize a semiconductor device (Moxie,Metal-Oxide) to sense a portion of the power flowing in the line. In this sense it is similiar to the transformerless and transformer type thermal wattmeters developed by Hagan (4) and Lincoln Electric (5) which are discussed in Chapter 3.

The device used is a Moxie, which is a trade name for a polyconductor (vanadium dioxide, VO_2) film which undergoes a change of several orders of magnitude in its terminal resistance for typically a few degrees °C. change from ambient temperature. The device is non-linear but its terminal resistance vs temperature characteristic can be approximated piecewise to exhibit three logarithmically linear ranges, the second of which gives the square law response required in a wattmeter. The basic characteristics of Moxie devices are discussed in Chapter 2.

The original design details incorporated in this study include a novel method of ambient temperature fluctuation compensation and utilization of the polyconductor in a thermal wattmeter which are presented in Chapter 4.

The device has an approximate square law response which is also found in other thermoelements currently manufactured. Substitution of this device for the others mainly stems from the large sensitivity as discussed in Chapter 3.

To date there has been no other attempt to employ Moxies in a thermal wattmeter but numerous thermal wattmeters employing conventional thermoelements have been investigated and a brief summary is also presented in Chapter 3.

The instrument presented in Chapter 4 and results of which we presented in Chapter 5 is designed and constructed by the author in search of a meter which would solve some of the problems inherent in present meters and one which unfortunately introduces new problems not realized with conventional instruments. The problems related to accuracy and their suggested solutions are discussed in Chapter 6 and Chapter 7. Some of these could not be overcome due to the present inadequate technological state of manufactured Moxies. The Moxie devices employed were far from ideal but nevertheless were utilized in the testing of the instrument.

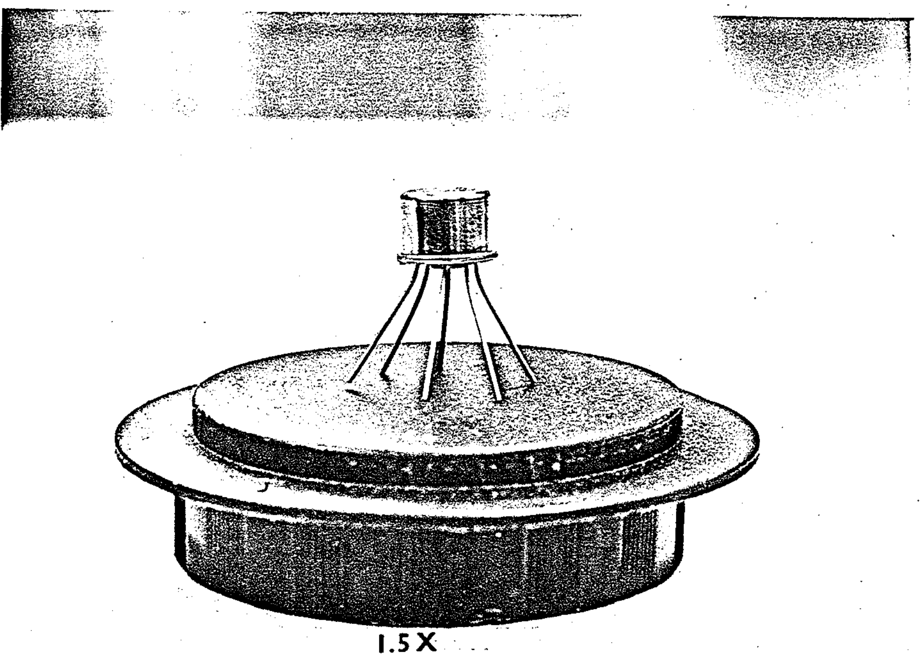
CHAPTER 2

TRANSITION METAL POLYCONDUCTORS

2.1 General Characteristics

Transition Metal Polyconductors, more commonly called Moxies, are solid state devices (see Fig. 2.1) which exhibit changes in physical properties due to a phase change in the polyconductor crystal structure (6). The physical property which has been exploited is that of resistance, specifically, the resistance of a typical device which will switch from 200KΩ to 300Ω when subjected to thermal energy. An ideal terminal resistance vs temperature characteristic is shown in Fig. 2.2. The three logarithmically linear regions (pre-transition, transition post transition) are clearly illustrated. The region of most interest is the transition region where a linear relationship is evident. The value R_b is the resistance value before transition and R_c is the value after transition. T_b and T_c are the temperatures at which switching from a low conductivity state to a high conductivity state begins and ends respectively. These four values (R_b, R_c, T_b, T_c) can be controlled by commercial manufacturing processes.

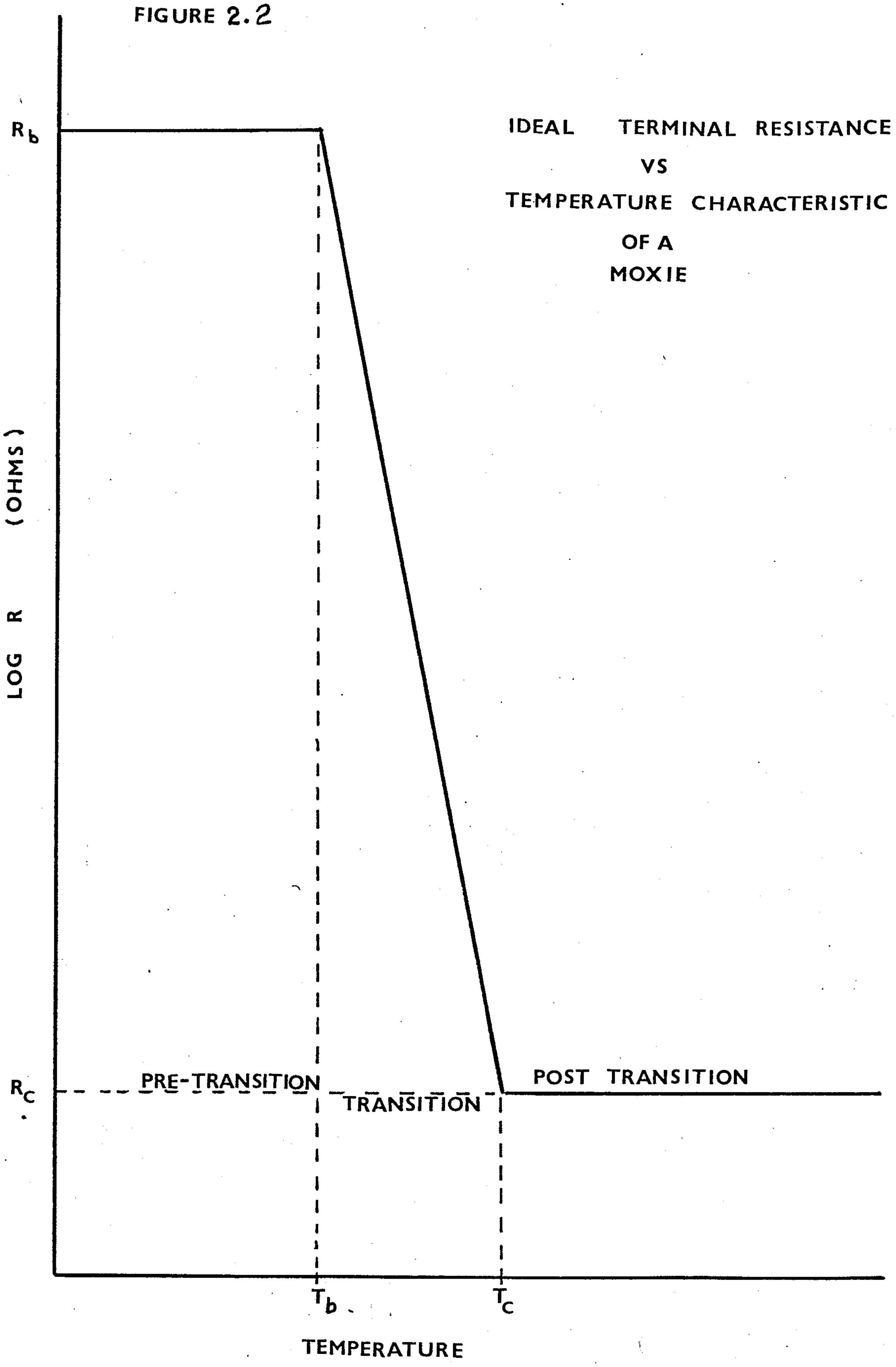
FIGURE 2.1



1.5X

DUAL TC1-F 5v MOXIE

FIGURE 2.2


IDEAL TERMINAL RESISTANCE
VS
TEMPERATURE CHARACTERISTIC
OF A
MOXIE
R_b
R_C
LOG R (OHMS)
PRE-TRANSITION
TRANSITION
POST TRANSITION
T_b
T_C
TEMPERATURE

The power required for switching a Moxie device is approximately 150 mw (7) when the Moxie chip is the 65°C. switching temperature type and ambient air is at room temperature. When the air temperature increases the input power required decreases as the Moxie is "pushed" further towards total transition.

The Moxies are currently being manufactured with transition temperatures of 57,65,75,85 and 140°C. The switching from a low to high conductivity varies from a high speed "on-off" action to a slow transition requiring substantially longer switching time. As the device returns to low conductivity state (after being switched), it does so by tracing a hysteresis (temperature lag) as illustrated by the typical plot of terminal resistance vs temperature curve shown in Fig. 2.3, (6). This graph illustrates a high speed polyconductor with its transition from high to low, or viceversa, requiring only a few degrees C to complete.

The commercial fabrication of the device involves deposition of the polyconductor, in the form of a thin film onto a suitable substrate (Fig. 2.4) as sapphire, protection of the film by means of a passivation layer of silicon dioxide, the attachment of contacts (Fig. 2.5) and final packaging in either a hermetically sealed tin header or ceramic package. The sensitivity of such a device to changes in temperature is dependent on the combined heat

FIGURE 2.3 TYPICAL TERMINAL RESISTANCE VS TEMPERATURE CHARACTERISTIC OF A MOXIE

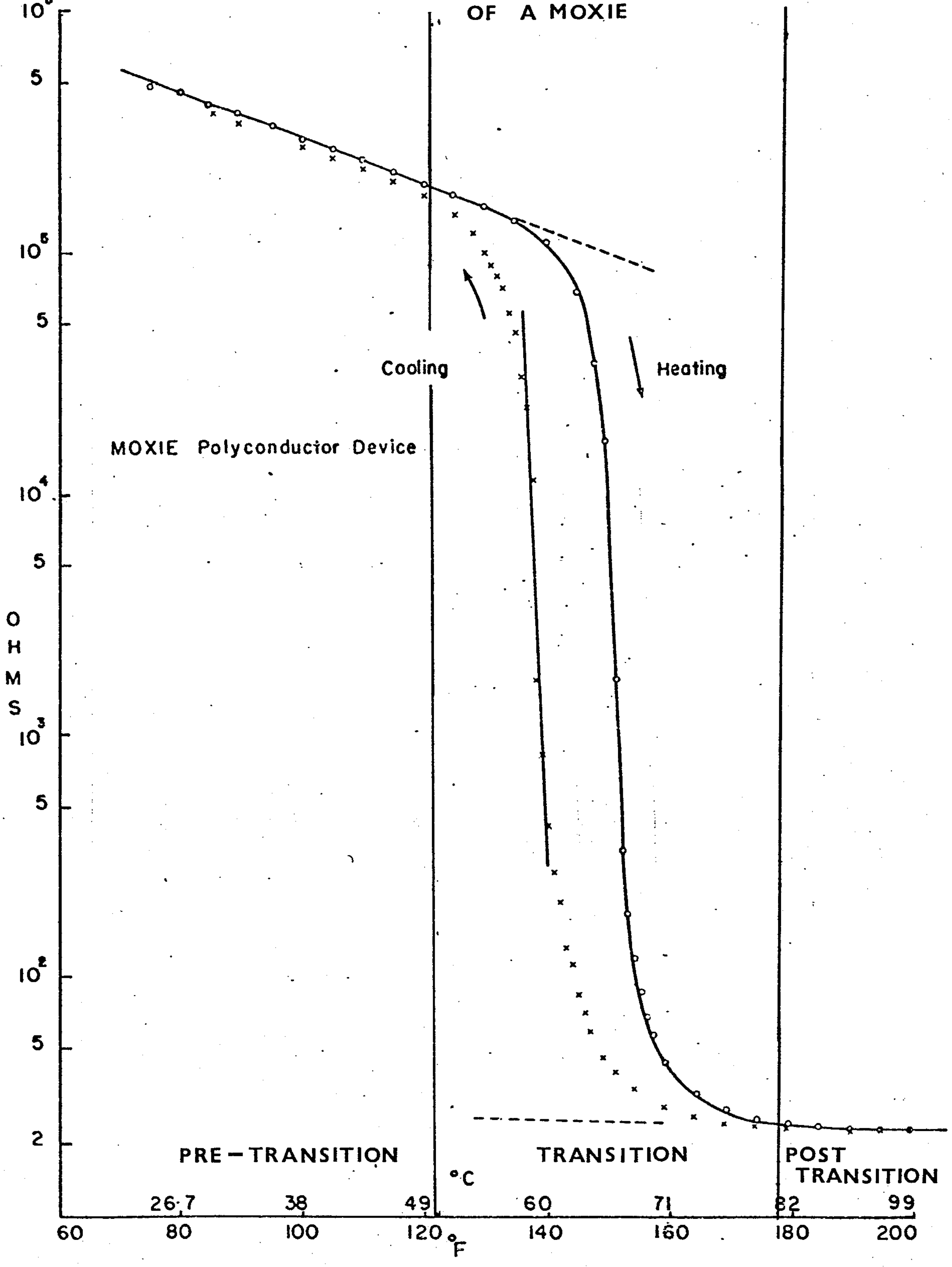
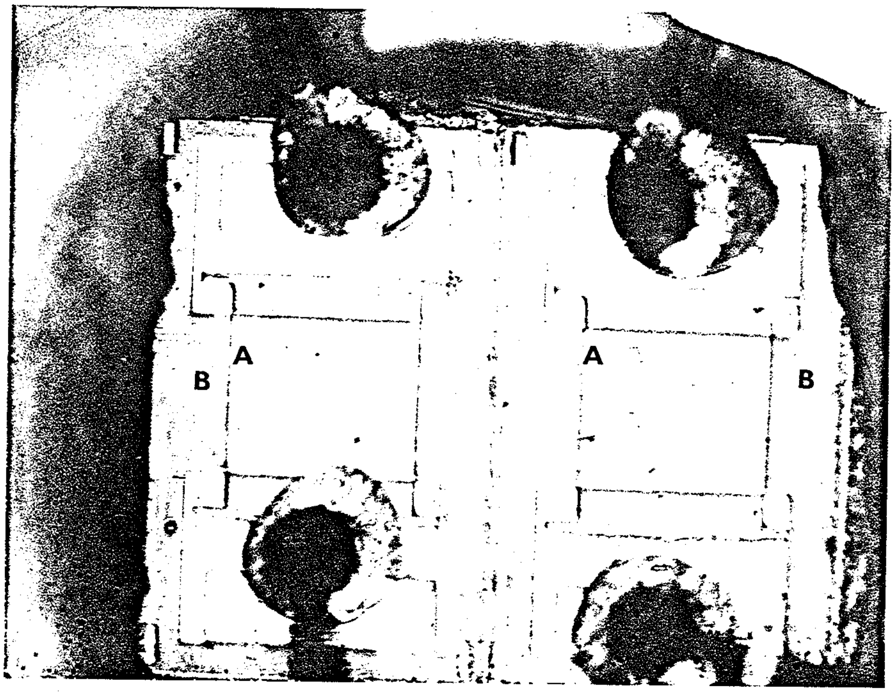


FIGURE 2.4

VO2 POLYCONDUCTOR FILMS

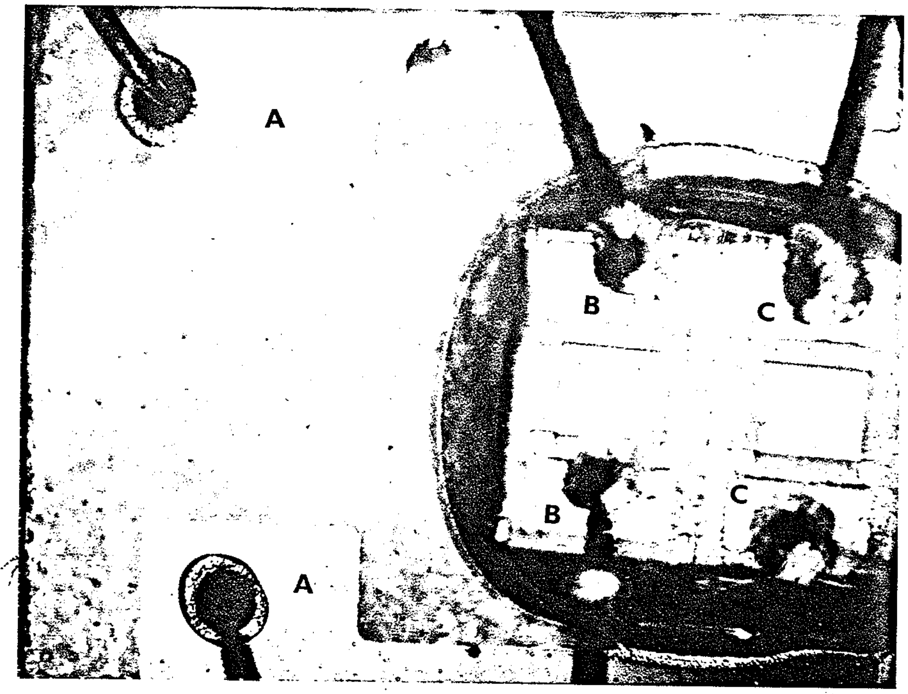


170 X

A - VO2 FILMS
B - SUBSTRATE

FIGURE 2.5

DUAL TCIF-5V MOXIE



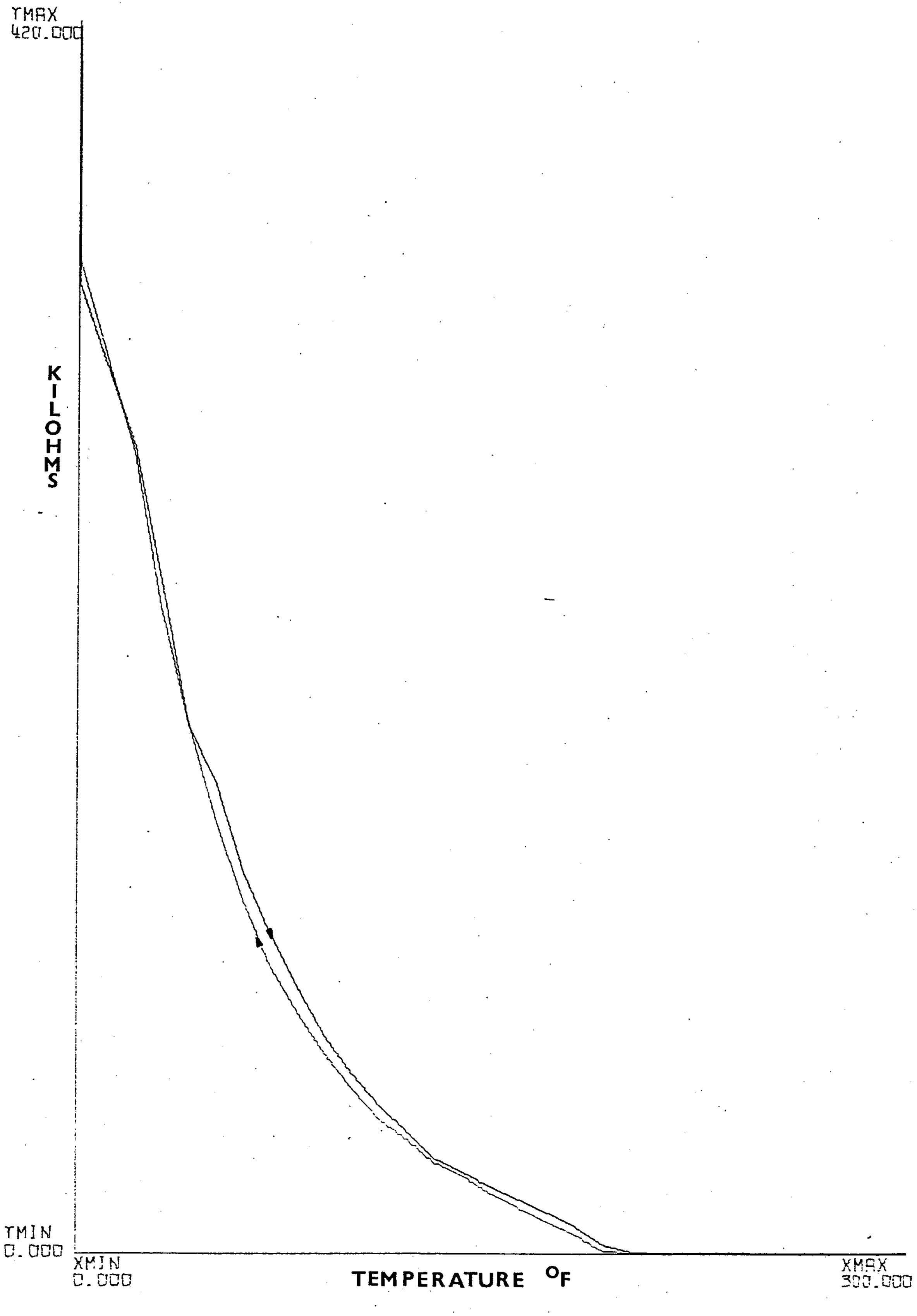
101 X

A- HEATER CONTACTS
B- VO2 FILM CONTACTS
C- VO2 FILM CONTACTS

capacity and thermal conductivity of the film, the substrate, the contact leads and the mass of the package with which the substrate is in intimate contact. The switching speed of the polyconductor is dependent on heat flow through and heat loss by the various materials used in mounting and packaging the film. Thermal coupler Moxie devices have heaters in contact with the substrate to provide the thermal energy required for a state change. In this case, because the heater and the substrate are in immediate contact, the speed of response of the film depends mainly on heat flow through the substrate. The extremely fast switching thermal couplers have a thin film resistive heating element deposited directly on top of the very thin silicon dioxide passivation layer covering the polyconductor. Switching speeds in the low microsecond range have been observed with high peak pulse power supplied to the heater. Various heater resistances can be obtained from the manufacturer, but are typically manufactured for 5,12, and 24V operation.

One of the fundamental drawbacks of Moxie devices is the hysteresis effect previously mentioned which limits its application in precision instrumentation. A linear axis plot of the polyconductor temperature hysteresis graph is shown in Fig. 2.6. This graph was experimentally obtained from the dual TC1-F 5V Moxies employed in this

FIGURE 2.6 TEMPERATURE HYSTERESIS CURVE



investigation. The upper curve illustrates the heating portion and the lower the cooling portion. The extreme lower portion of the curve is narrow. The transition region is stretched out as it goes through a greater order of magnitude change in this region. The main requirement of the Moxie device in this investigation is a slow switching characteristic which will produce an expanded transition region, thus enlarging the monitoring range available for instrument operation. The peak value reached for the dual TC1-F 5V Moxie tested is 420 KΩ at 0°F and the minimal value of 60Ω is reached at 300°F. This device therefore goes through an enormous magnitude change when exposed to a few hundred °F temperature variation.

The hysteresis curve of interest would naturally be the portion corresponding to above room temperature. This part of the curve is shown in Fig. 2.7 with the hysteresis curve plotted against the power applied to the heater of the Moxie device. The useful range is from 90 KΩ to 1 KΩ where the device still exhibits a substantial magnitude of transition.

2.2 Typical Applications

Most of the existing applications of Transition

FIGURE 2.7 HYSTERESIS CURVE OF MOXIE