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MET.O.15 INTERNAL REPORT

No 18

An assessment of the performance of the pressure element of the NAVAID dropsonde

by

A F Lewis and P Ryder

1979 Cloud Physics Branch (Met.O.15)

Pressure element for the NAVAID dropsonde

1.1 Introduction A dropsonde is being developed in Met.O.15 for use from the MRF C130 aircraft. This replaces an earlier radar reflector dropsonde which was used in the Scillonia project. The latest version has been designated the NAVAID dropsonde, as the method of obtaining horizontal position, and hence wind data, depends upon a re-transmission from sonde to aircraft of NAVigational AID transmissions, specifically Loran C. This has several advantages over the former radar tracking method; flexibility of use, larger operational area, etc. but does require a separate height finding system for full 3 co-ordinate position fixing.

1.2 Specification Temperature and humidity will be measured on the sonde so that in principle at least it is not too important whether geometrical height above some fixed surface (sea-level) or pressure height is measured. The accuracy required of this measurement is still a matter for some discussion and depends, for example, upon the maximum wind shear which is likely to be observed and the representivity of any particular observation. Thus strong wind shears require high accuracy if the horizontal wind field is to be closely defined but the amplitude of sub-grid scale perturbations impose a limit on the accuracy to which the height of a feature can justifiably be specified. Nevertheless, whilst this question is being resolved, it is clear that the desired accuracy is probably in the range $\pm$ 1 - 3 mb, over a height range of 300 to 1030 mb, and that this is to be achieved over a temperature regime of -30°C to +30°C. The problem is complicated by the fact that the sondes may have a long shelf life and will certainly experience a pressure shock ~ 500 mb and a physically shock of 26 g for 20 milliseconds at ejection.

1.3 Possible solutions Despite an intensive search in U.K. and abroad we had not been able to find a manufacturer capable of meeting this specification at a reasonable price. However, Dr. Levanon, late of the University of Wisconsin, and now of Meeda Scientific Instrumentation Ltd., Israel, has produced a radio altimeter which will provide height to $\pm$ 10 m, $\pm$ 0.05% from ~ 1,500 ft above a flat surface to our operational ceiling around 30,000 ft. The beam width is quite large so that small scale perturbations such as sea surface waves are not too important. This device has been tested up to 20,000 ft and appears to meet the specification. The system is relatively expensive constituting ~ 25 - 30% of the cost of the sonde, and requires deployment of a downward facing aerial. The search for a suitable pressure element has continued and it now appears that a device produced by National Semiconductor Corporation shows promise of meeting our specification at a reasonable cost; ~ £24 for 100's off.

1.4 National Semiconductor LX 1602A pressure transducer.

The transducer is a hybrid circuit which consists of a ceramic substrate with laser trimmed thick film resistors, an operational amplifier chip and the transducer chip itself. The latter is basically a Wheatstone bridge arrangement of four piezo resistors diffused into a silicon chip. The silicon chip is a 25 µm thick pressure diaphragm that has been etched out of one wall of a cavity. The rest of the cavity has a wall thickness of 300 µm. A reference pressure cavity is formed by etching the rear surface of the chip to 275 µm and then bonding a 300 µm thick backplate to it. The process is carried out in a vacuum to form a vacuum reference cell. Temperature compensating diodes, bridge balancing resistors and a zener regulator for the bridge power supply are also formed on this chip by standard IC production methods. As part of the manufacturing process a power transistor is generated in the centre of the sensor bridge and the base emitter diode thus formed can be used to monitor the bridge temperature.

As can be seen from the attached product selection guide the LX 1602A is designed to operate from 0 to 15 psi (0 to 1033 mb) giving outputs of 2.50 ± 0.15v and 12.50 ± 0.15v at these pressures, at a temperature of 21°C and an excitation voltage of 15.00 ± 0.15 volts. The device sensitivity is therefore approximately 10 mV per mb, so that the spread in the high and low pressure points about the nominal 12.5 and 2.5 volts is ± 15 mb. The maximum residual temperature error is ~ 0.5 mb/°C and without calibration the device is clearly not capable of meeting the specification of 1 - 3 mb over the 300 to 1040 mb range. However, the combined linearity and hysterisis error is stated to be ± 5 mb and the temperature sensing diode provides the possibility of correcting for temperature drifts. Furthermore, the form of construction provides a reasonable expectation that the device will not be degraded by the ejection shock. Therefore an evaluation sample of 3 LX 1602A transducers was purchased, with the expectation that, at least, a two point calibration and a temperature compensation / calibration would be necessary.

2. Experimental arrangement

In use in the NAVAID dropsonde the transducer will operate over a 300 to 1040 mb pressure regime and a likely environmental temperature range of -30°C to +30°C. (The actually temperature cycle experienced by the transducer will almost certainly be less than this). Therefore the device was mounted in a simple 'Tufnol' holder to provide mechanical restraint for the wiring. This was placed in a bell jar connected to a vacuum pump for low pressure measurements. The bell jar was also connected to a simple mercury manometer, and screened cabling was provided through a pressure seal to the drive and measuring electronics. The bell jar and/or device could be either placed in a refridgerator capable of operating down to $-20^{\circ}C$ or in the laboratory at up to $+20^{\circ}C$. Atmospheric pressure was also monitored by a Meteorological Office Precision Aneroid Barometer Mk. 2.

An excitation voltage of 15.00 volts was chosen and this was derived from a stabilised 18 volt supply driving a μA 723 voltage regulator. Initially temperature compensation of the pressure transducer was attempted. The base emitter diode was forward biased through the 1.5 MΩ resistor to provide a voltage of ~ 0.6 volts at V_t (see figure 1). This is amplified by an amount determined by experiment and added to the transducer output V_p. The amplification of V_t was determined by requiring the same output for a given pressure (~ 1000 mb) at $-16^{\circ}C$ and $+23^{\circ}C$. Although this was successfully achieved (see Section 3) it was discovered that a different amplification was necessary at low pressure. Therefore, subsequently V_p and V_t were measured and the temperature correction was applied in the analysis. V_p and V_t were measured using Solatron LM 14202 digital voltmeters.

3. Results obtained

3.1 Temperature compensation at approximately 1000 mb

Element number 333 was used in this experiment. The serial number signifies that the device was manufactured during the 33rd week (second and third digits) of 1973 (first digit). At a temperature of 23°C and pressure of 1003.4 mb, V_p = 11.92 volts and V_t = − 0.495 volts. At a temperature of −16°C and pressure of 1003.4 mb, V_p = 12.14 volts, V_t = −0.564 volts. Thus $\frac{\Delta V_F}{\Delta T} \sim +1.8$ mV/°C in good agreement with the expected temperature sensitivity of a forward biased silicon diode. $\frac{\Delta V_P}{\Delta T} \sim -5.6$ mV/°C as compared with the predicted ± 5 mV/°C error band of the transducer output. Hence by amplifying V_t by a factor of 5.6/1.8 = 3.15 and adding the result to V_p we expected to remove much of the temperature sensitivity of V_p. This was done using the circuit of figure 1 and the results obtained during several temperature cycles at constant pressure are shown in figure 2. Some of these cycles were achieved by plunging the device into the refridgerator with an insulating jacket around the transducer. No significant difference in the variation of V_p with temperature was observed, which suggests that the sensing diode is well positioned to monitor the important temperature variations. There is a slight but obvious non linearity in the V_p temperature characteristic over the range −18 to +23°C leading to the residual variation shown in figure 2. Nevertheless even over this large temperature excursion, the errors are less than ± 2 mb; a factor of 10 less than in the uncorrected V_p. The residual variation also appears to be repeatable to ± 1 mb or better between different temperature cycles.

3.2 Temperature sensitivity over the pressure range 300 to 1000 mb.

The outputs of element 333 were then monitored as the device experienced a pressure decrease from 300 mb to 1000 mb at room temperature and in the refridgerator. The device transfer characteristics are shown in figure 3. The relationship between V_p and pressure appears to be quite linear for this particular element but clearly the transducer temperature coefficient varies with pressure so that the simple circuit of the type shown in figure 1 is not adequate over the full pressure range.

Therefore it was decided not to attempt to correct V_p for temperature effects electronically but to apply corrections in the analysis. The simplest assumption to make is that the derived pressure is given by $P = A' + B' V_p$ + higher order terms in Vp as necessary and that the coefficients A', B' etc. are linearly dependent upon temperature as exemplified by Vt.

Thus $A' = A\,(1 + \alpha\,(Vt - Vt_0))$, $B' = B\,(1 + \beta\,(Vt - Vt_0))$, etc.

This assumption is tested and shown to be reasonable in figure 4 (a), (b) where A' and B' have been derived by least-squares fitting polynomials to V_p vs pressure data obtained at constant temperature. The data used were obtained over a period extending from 15 to 30 Nov 1973. The coefficients A, B, α and β were derived from figure 4 where Vt_0 was arbitarily chosen at about room temperature. The relationship between V_t and temperature is shown in figure 5. The R M S error, $\langle \Delta^2 p \rangle$ (where Δp is the difference between the barometer measured, and calculated pressure) of the various runs is shown in figure 6 (a). The RMS error of the barometer measured pressure is estimated to be ± 0.4 mb.

As tests continued it became apparent that the mean deviation during a pressure calibration run was not zero. The RMS deviation about the mean however remained much as before. To investigate this further, calibrations at room temperature and at low temperature were performed during one day (7 January 1974). The results are shown in figure 4. The obvious conclusion is that α, β and B have remained essentially constant but that A has drifted with time.

It is believed that, in operational use, a one point calibration is entirely feasible as part of the sonde check-out procedure in the aircraft. Accordingly the data were re-examined assuming that B, α and β remained constant but that A could be derived for a given calibration run by using the measured pressure and V_p at about 750 mb (the expected pressure inside the aircraft). The calibration procedure was also changed so that data were obtained on any given day at both room and low temperature. The warm, 750 mb data were used to determine A. This, of course, then tests the assumption that α remains constant with time and models the expected use. The values of A and the RMS deviation of Δ_p are shown in figure 6 (b) and (c) as a function of time. With the experience gained during the testing of the first device, serial number 333, the other devices, 339 and 340 were calibrated. Both these devices were found to be sufficiently non-linear to require expressions of the form

$$P = A' + B' V_p + C' V_p^2$$

Again in an attempt to model the likely operational procedure the coefficients A, B, α, β, C and γ were derived from a single warm/cold calibration run and A was derived on a day to day basis as described above. The results obtained so far are shown in figures 7 and 8.

3.3 Effects of mechanical shock on the transducer

The velocity of the sonde at ejection from the C130 aircraft has been measured to be 15 ft/sec. This velocity is achieved by accelerating the sonde over a distance of 2.5 inches. In a simple experiment to duplicate these effects the device was dropped from a height of ~ 5 ft (the impact velocity is therefore ~ 18 ft/sec) into a foam rubber lined box. Initially 1 inch thick rubber was used but as no detectable change (< 0.5 mb) was observed between the device outputs before and after the shock the thickness was reduced gradually to ~ 1/16 inch when a 1 mb change was occasionally observed in one of the two transducers tested. As this effectively exceeded the expected shock magnitude by a factor of not less than 40 it is thought reasonable to assume that sonde ejection will not significantly change the device calibration.

3.4 Effect of supply voltage variations on the transducer output.

A typical device sensitivity to supply voltage variation is given in the manufacturers electrical specification. It is suggested that both the output offset, V_{po}, and constant of proportionality, S, (between output volts, Vp, and pressure, P) are voltage sensitivity. Thus

$$\frac{\partial V_p}{\partial V} = \frac{\partial V_{po}}{\partial V} + \frac{\partial S}{\partial V}.P$$

At 15 volts $\frac{\partial V_{po}}{\partial V} \simeq 0$ and $\frac{\partial S}{\partial V} \simeq$ 0.26 volts per bar per volt

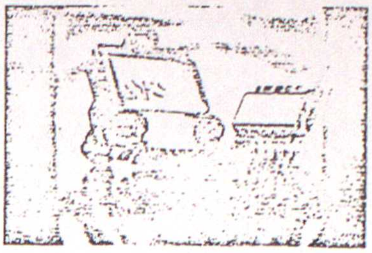
As the error is proportional to pressure the maximum value will be obtained at high pressure where the predicted sensitivity is equivalent to ~ 26 mb per volt. This implies that the supply regulation should be better than ~ 40 millivolts to achieve a < 1 mb error.

The effect of varying the supply voltage to device 333 is shown in figure 9. Measurements were made at high and low pressure over a supply voltage range of 10 - 20 volts to determine $\frac{\partial V_{p_0}}{\partial V}$ and $\frac{\partial S}{\partial V}$. Although good agreement was obtained between the manufacturers predictions and the measured sensitivity at 15 volts the device tested showed a significant increase in $\frac{\partial S}{\partial V}$ below ~12.5 volts and a rather larger than expected $\frac{\partial V_{p_0}}{\partial V}$.

4. Conclusions.

From the results of tests carried out on 3 LX 1602A pressure transducers, provided that each device is calibrated over a range of pressure and at two temperatures spanning the expected variation and that a single point calibration is made just before use, RMS deviations of the device measured pressure from the barometer measured pressure are likely to be in the range 1 - 2 mb. The calibrations appear to be insensitive to the expected ejection shock.

MAY 1973



LX1601A/LX1602A/LX1603A, LX1701A/LX1702A/LX1703A absolute LX1601G/LX1602G/LX1603G/LX1604G, LX1701G/LX1702G/LX1703G/LX1704G gage LX1601D/LX1602D/LX1603D/LX1604D differential pressure transducers 0–30psi

general description

These rugged devices are highly accurate, completely field interchangeable, temperature compensated linear pressure transducers.

All of the basic transduction elements are incorporated in one hybrid package. A totally useful pressure transducer is shown in the block diagram below—the diaphragm and pressure reference, piezoresistive sensor, signal discriminator, and signal amplifier and processor. The first three functional elements are contained in a single silicon die and the fourth is provided by standard National linear IC operational amplifiers.

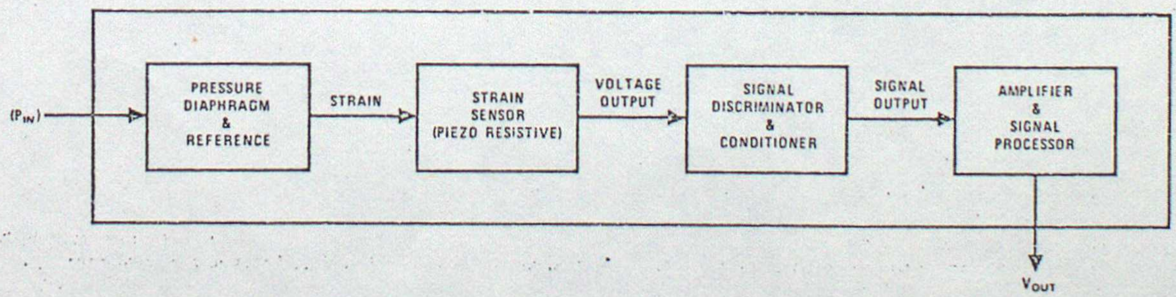
applications

- Medical electronics
- Altimetry, air data, and meteorology
- Computer pneumatics
- Fluid system proportional control
- Hydraulics
- Pneumatic controls
- Heating, ventilation, refrigeration and air conditioning controls
- Automotive emission control, safety, and diagnostic systems

features

- Field interchangeability—by using computerized laser trim all units meet one guaranteed characteristic curve.
- Accuracy—maximum calibration error band of ±1.5% of span
- Temperature compensated—transducer temperature effects offset by computerized laser trimming
- Flexibility—arithmetic functions, digital format and multiplexing are easily attainable because of the single ended op amp configuration
- Input overvoltage and output short circuit protection
- Low mass, no moving parts, good frequency response
- Temperature measurement capability at point of pressure sensing
- Available from local National distributor

block diagram



Total Useful Pressure Transducer

PRODUCT SELECTION GUIDE

absolute maximum ratings

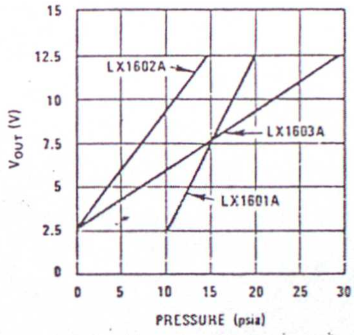
Excitation Voltage	30 V_{DC}
Output Current	5 mA
Temperature Sensing Current	100μA
Operating and Storage Temperature Range	−40°F to +240°F
Bias Current at 15V Excitation	15 mA
Lead Temperature (Soldering, 10 sec)	572°F

(See Note 5 and 6)

nominal characteristics (+70°F, 15V excitation)

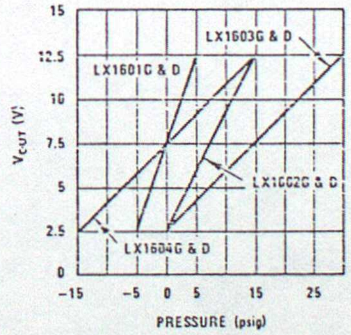
ABSOLUTE TRANSDUCERS

OUTPUT VOLTAGE		CALIBRATED PRESSURE RANGE (psia)		
±1.5% Span (±150 mV)		LX1601A LX1701A	LX1602A LX1702A	LX1603A LX1703A
2.5V	Low Pressure End Point	10	0	0
7.5V	Mid-Range	15	7.5	15
12.5V	High Pressure End Point	20	15	30
Maximum Allowable Over-Pressure		40	40	50



GAGE AND DIFFERENTIAL TRANSDUCERS

OUTPUT VOLTAGE		CALIBRATED PRESSURE RANGE (psig)			
±1.5% Span (±150 mV)		LX1601G LX1701G LX1601D	LX1602G LX1702G LX1602D	LX1603G LX1703G LX1603D	LX1604G LX1704G LX1604D
2.5V	Low Pressure End Point	−5	0	0	−15
7.5V	Mid-Range	0	7.5	15	0
12.5V	High Pressure End Point	+5	15	30	+15
Maximum Allowable Over-Pressure		30	40	50	40



Note 1: All nominal characteristics calibrated with 15V excitation and +70° Farenheit.

Note 2: The 17 series package is available for absolute and gage units only.

Note 3: Refer to the physical specifications, page 4, for the proper pressure connections to all differential units.

Note 4: To maintain the specified tolerances, the power supply must be regulated to within ±1%. These transducers can be calibrated for any excitation voltage from 10V to 30V.

Note 5: The unit may not withstand corrosive working fluid. In addition to standard die passivation a chemical coating is added to permit use with many common non-conductive working gas and liquids. For specific requirements, consult the factory.

Note 6: The transducers are not electrically isolated from the working fluid.

definition of terms

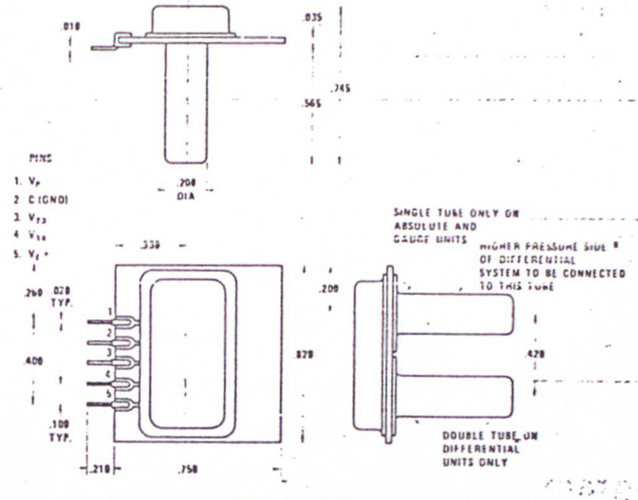
Span Voltage: The difference between output voltages at maximum calibrated pressure and minimum calibrated pressure. For all transducers described herein span voltage is 10V.

Absolute Pressure Transducer: Measures all pressure relative to a self-contained vacuum reference (LX16XXA or LX17XXA).

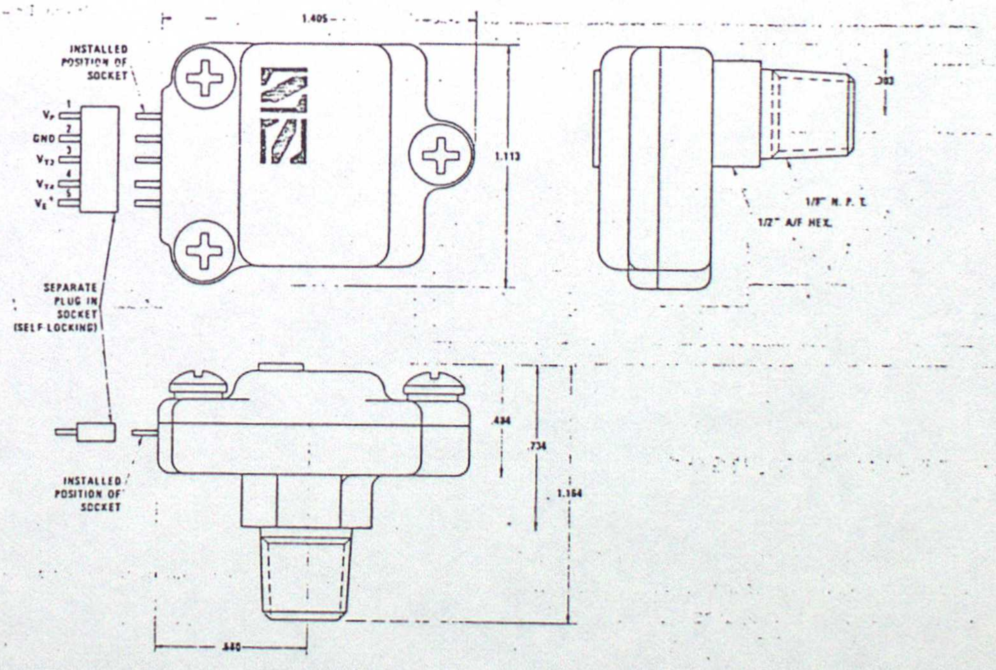
Differential Pressure Transducer: Measures the difference between two pressure inputs (LX16XXD). Note: Higher pressure input connection is important—*MUST* follow instructions shown below.*

Gage Pressure Transducer: A differential pressure transducer that measures a pressure input relative to local ambient pressure (LX16XXG or LX17XXG).

physical dimensions



Order Number LX16XXX



Order Number LX17XXX

Manufactured under one or more of the following U.S. patents: 3083262, 3189758, 3231797, 3303356, 3317671, 3323071, 3381071, 3408542, 3421025, 3426423, 3440498, 3518750, 3519897, 3557431, 3560765, 3566218, 3571630, 3575609, 3579059, 3593069, 3597640, 3607469, 3617859, 3631312, 3633052, 3638131, 3648071, 3651565, 3693248.

National Semiconductor Corporation
2900 Semiconductor Drive, Santa Clara, California 95051, (408) 732-5000/TWX (910) 339-9240

National Semiconductor GmbH
8080 Fuerstenfeldbruck, Industriestrasse 10, West Germany, Tele. (08141) 1371, 1372, 1373, 1374,1484/Telex 527-649

National Semiconductor (UK) Ltd.
Larkfield Industrial Estate, Greenock, Scotland, Tele. 33251/Telex 778-632

ELECTRICAL SPECIFICATIONS

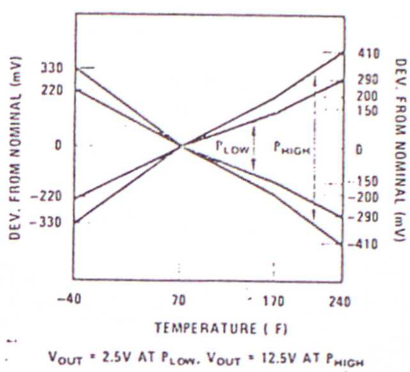
combined linearity and hysteresis

±50 mV (±0.5% Span)

output voltage temperature tolerance

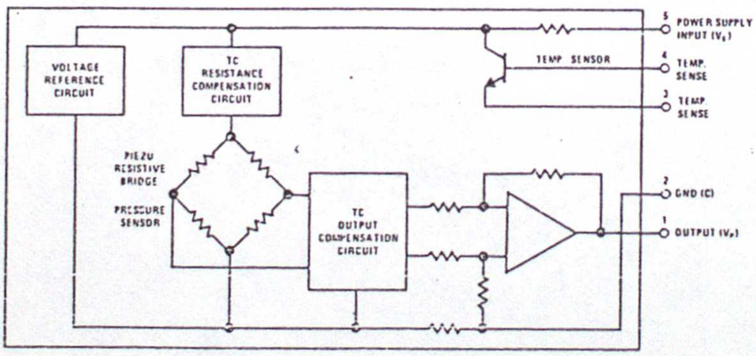
NOMINAL OUTPUT VOLTAGE		MAX TEMP COEFFICIENT mV/°F	MAX ERROR OVER TEMP RANGE mV	MAX ERROR OVER TEMP RANGE % SPAN
Calibrated Temp Range +70°F ≤ T ≤ +170°F				
2.5V	Low Pressure End Point	1.5	150	1.5%
12.5V	High Pressure End Point	2	200	2%
Full Temp Range −40°F ≤ T < 240°F				
2.5V	Low Pressure End Point	2	290	3%
12.5V	High Pressure End Point	3	410	4%

Temperature Error Band

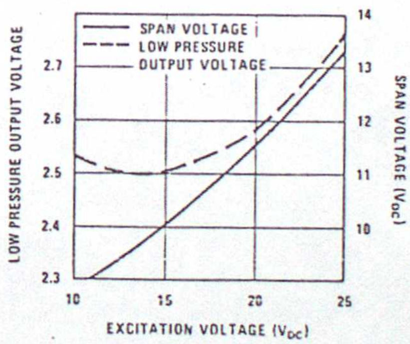


V_{OUT} = 2.5V AT P_{LOW}, V_{OUT} = 12.5V AT P_{HIGH}

connection diagram



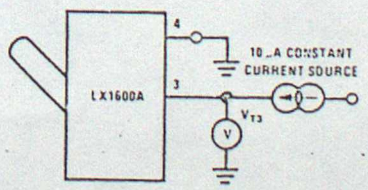
Typical Excitation Voltage Tracking



temperature sensor

The temperature sensor of the transducer is activated by grounding pin 4 and connecting pin 3 to a 10μA constant current source as shown. Then V_{T3} measured with a 10 MΩ voltmeter indicates the temperature being sensed. With measurements at several different known temperatures the unit is easily calibrated. When connected in this fashion the typical reference voltage is 7V with a sensitivity of 1.1 mV/°F.

Temperature Sensing Connection



Note: 70°F = 21°C, 170°F = 78°C, 240°F = 116°C, −40°F = −40°C, 572°F = 300°C, 1 mV/°F = 1.8 mV/°C,
1 psi = 51.71 TORR (mmHg) = 2.036 in Hg = 27.67 in H_2O = 2.307 ft H_2O = 68.95 mbar.

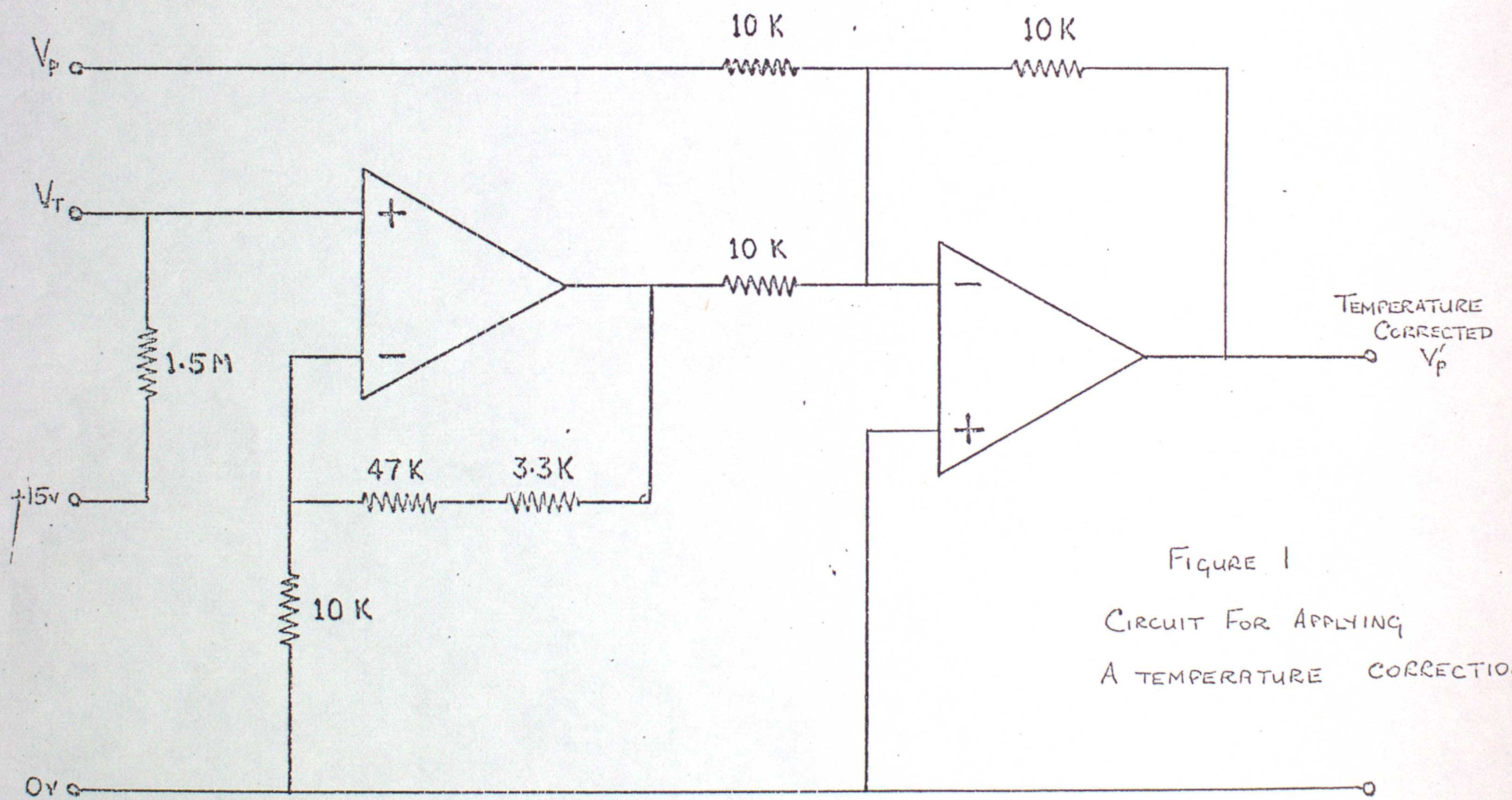


Figure 1

Circuit for applying a temperature correction

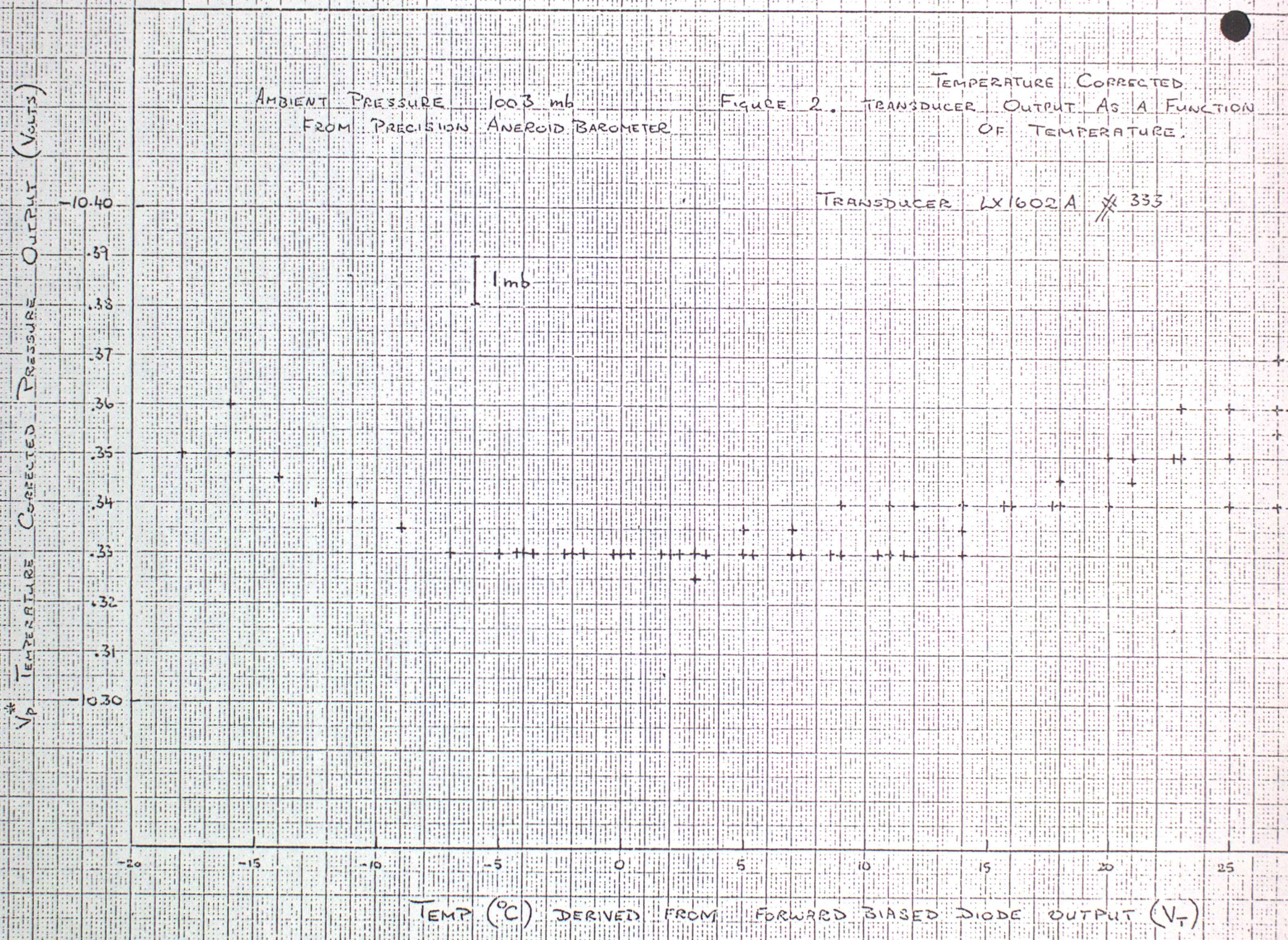


Figure 2. Temperature Corrected Transducer Output As A Function Of Temperature.

FIGURE 3.

TRANSDUCER OUTPUT CHARACTERISTICS (X 333)

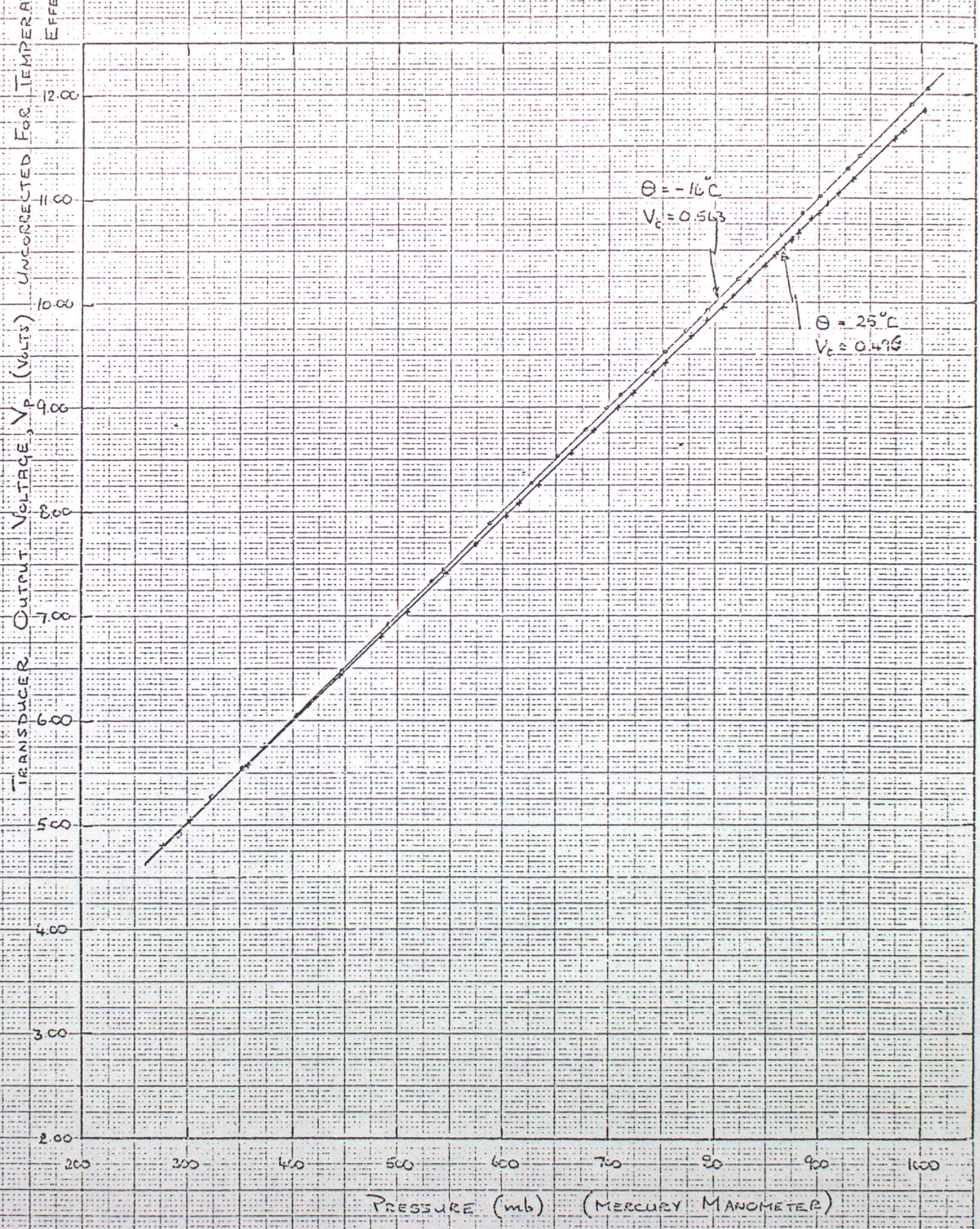


FIGURE 4(a) VARIATION OF THE CONSTANT, A', WITH THE OUTPUT OF THE TEMPERATURE SENSING DIODE, V_T. (# 333)

$$P = A' + B'V_P$$

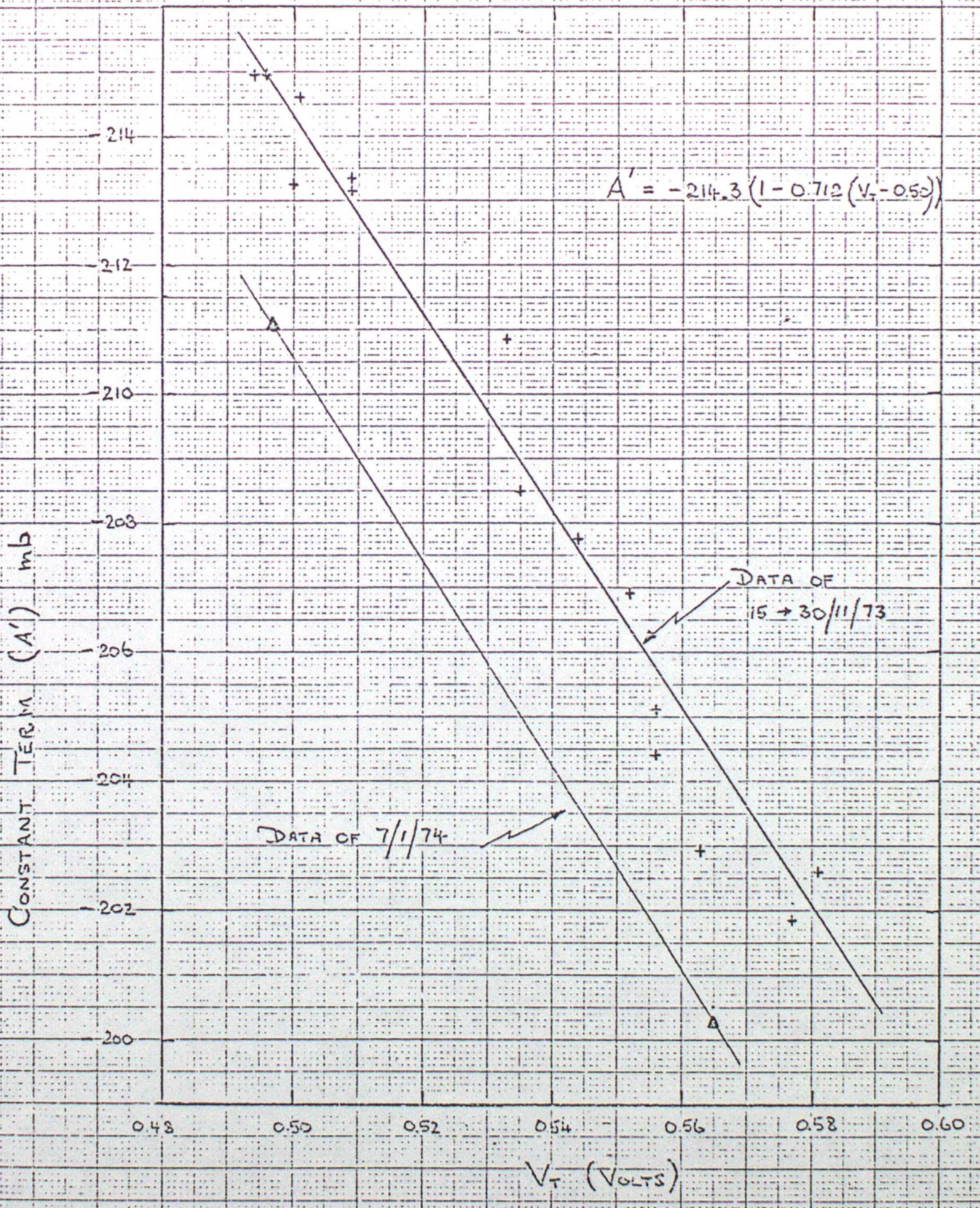


FIGURE 4(b). VARIATION OF THE GRADIENT TERM, B′, WITH THE OUTPUT OF THE TEMPERATURE SENSING DIODE, V_T (#333)

$$P = A' + B'V_p$$

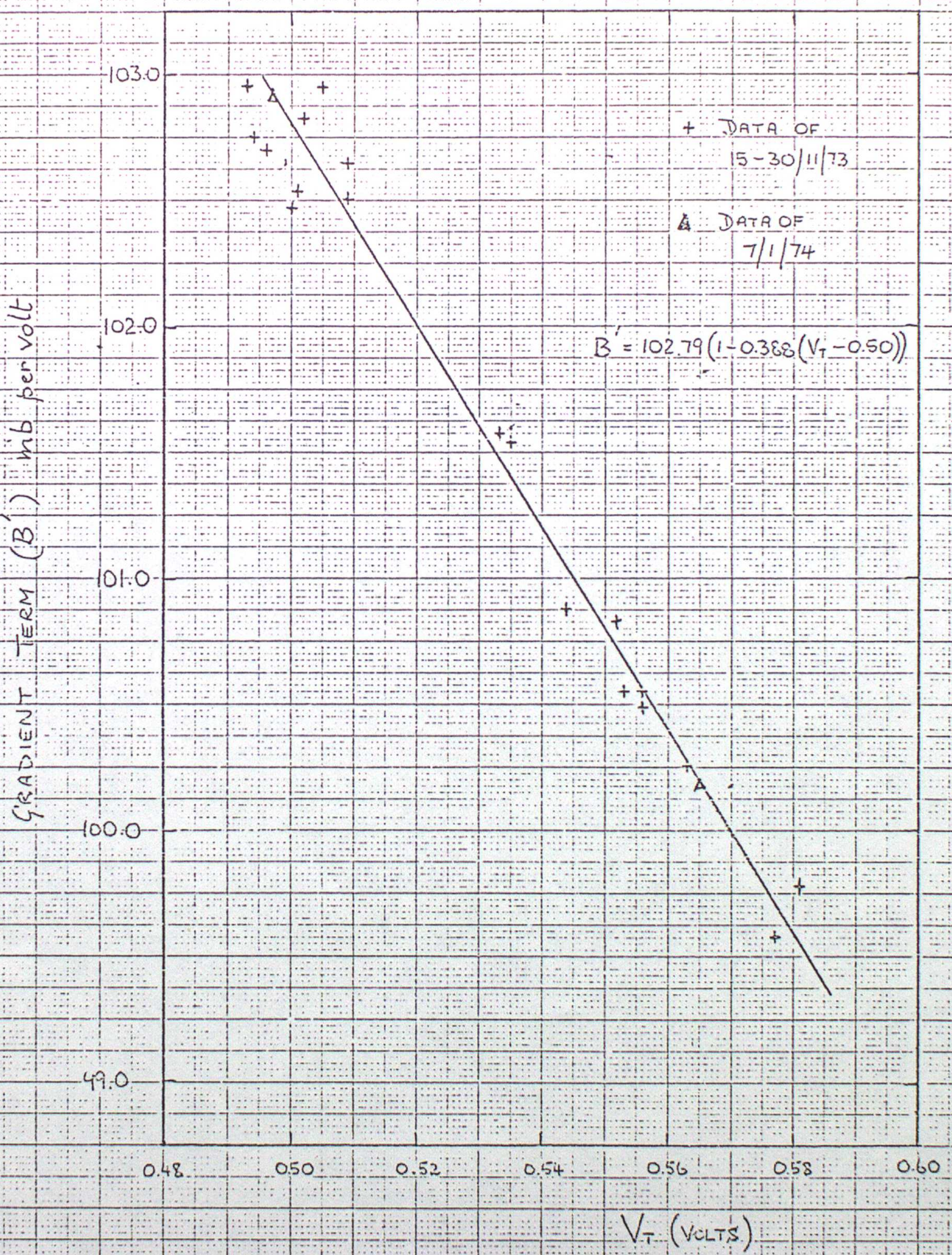


Figure 5. Variation of Temperature Sensing Diode Output, V_T, with Temperature

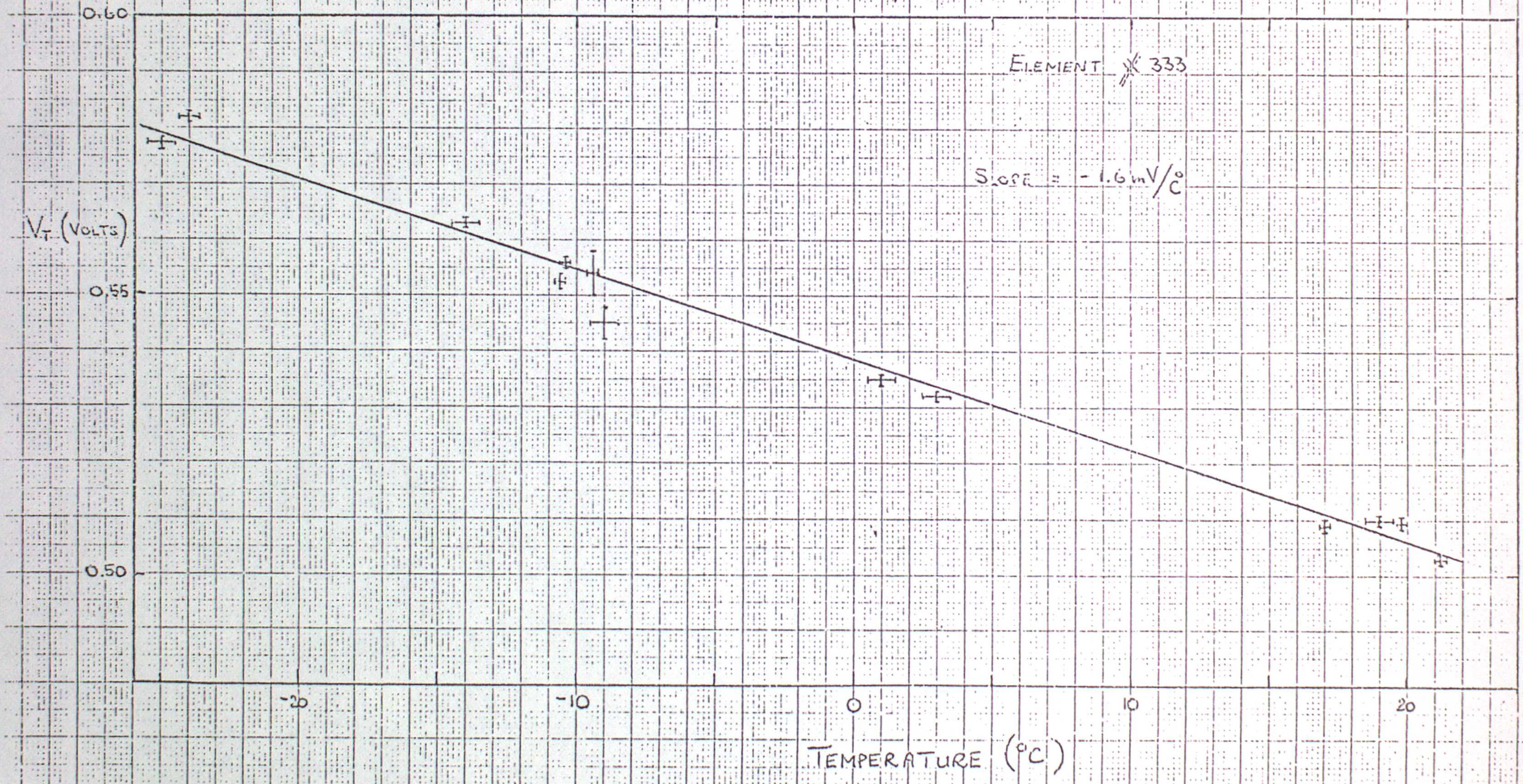


FIGURE 6. VARIATION OF <Δp²>, AND THE COEFFICIENT, A, WITH TIME. (# 333)

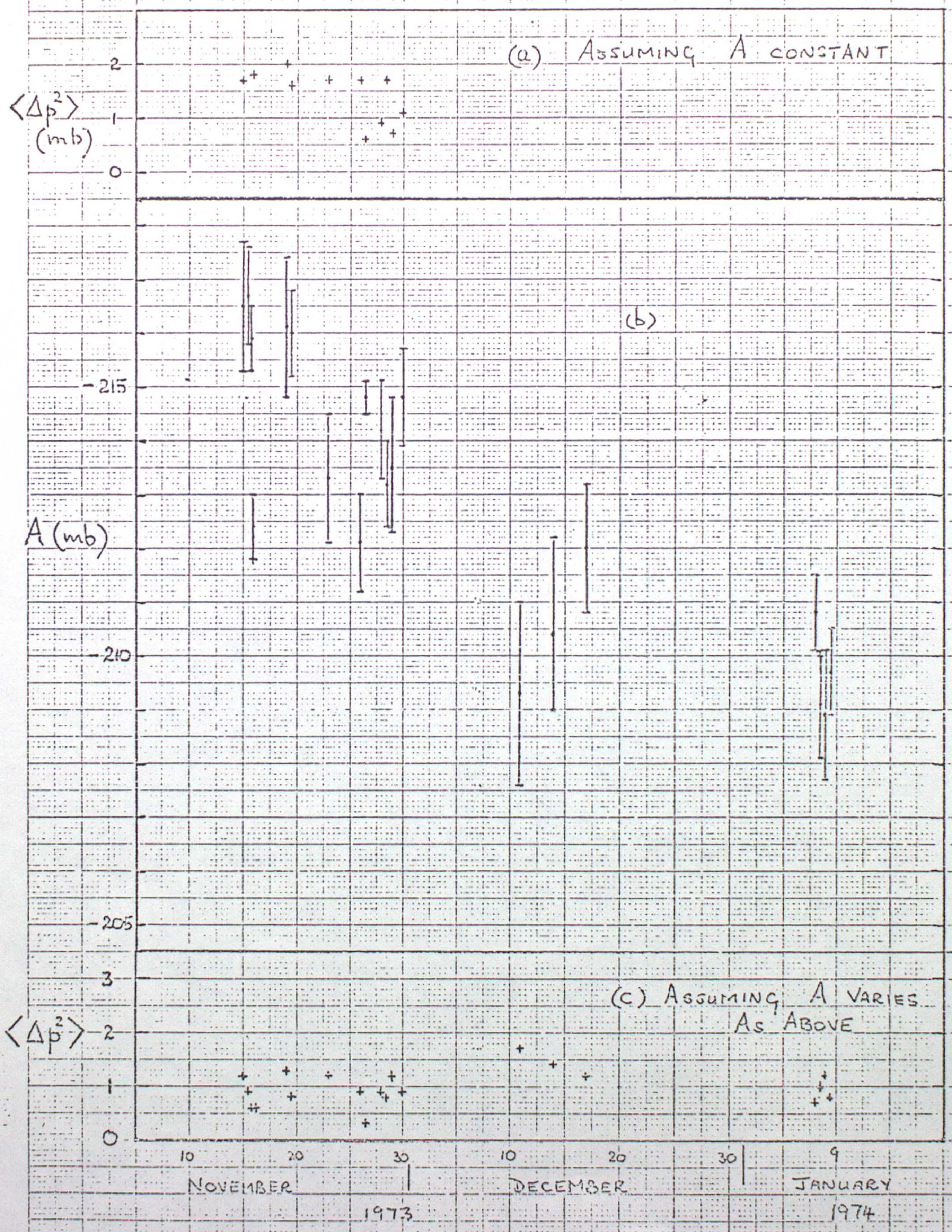


FIGURE 7 TIME VARIATION OF $<\Delta p^2>$
AND THE COEFFICIENT A (#339)

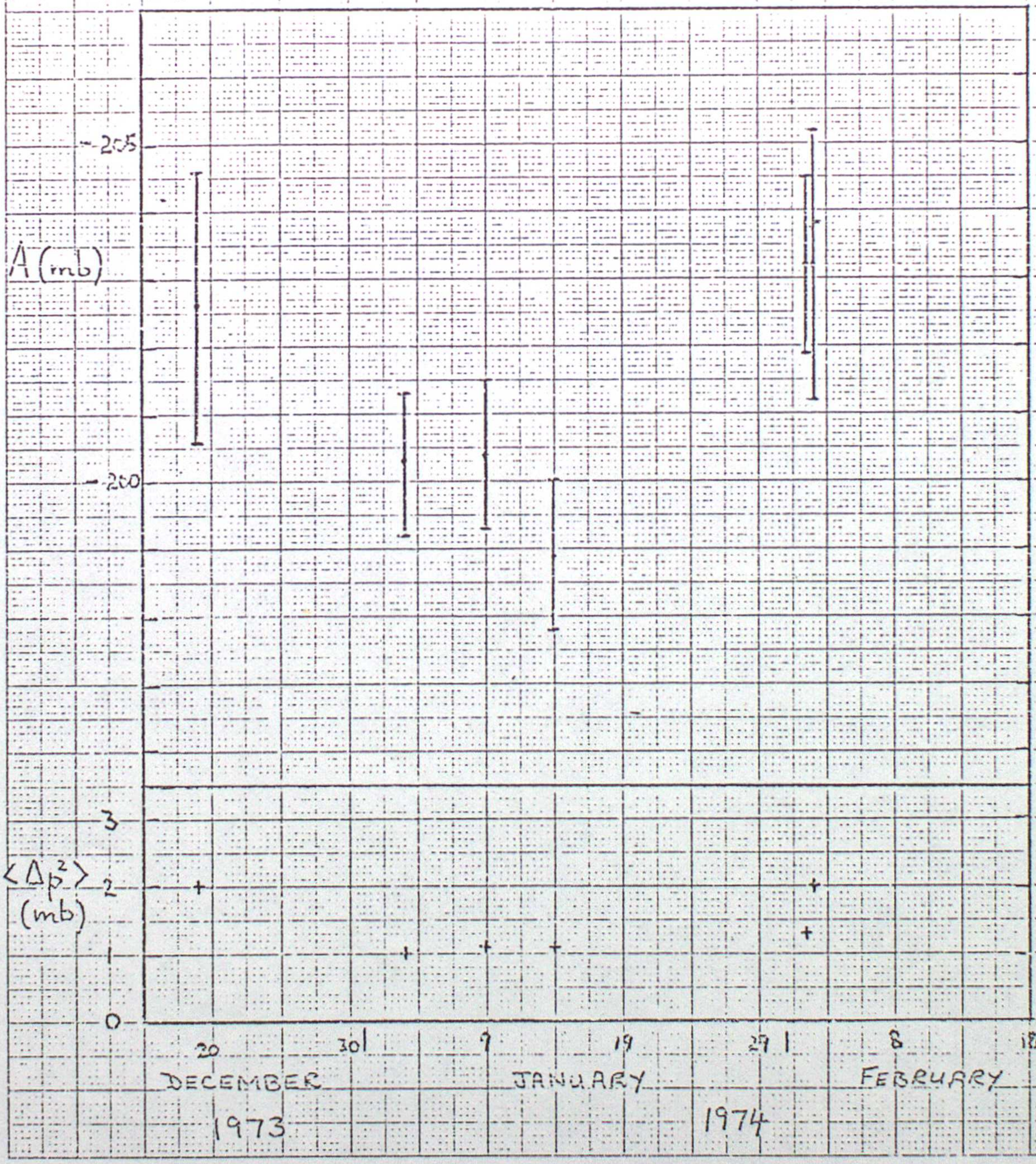


FIGURE 8. TIME VARIATION OF $\langle \Delta p^2 \rangle$

AND THE COEFFICIENT A (✱340)

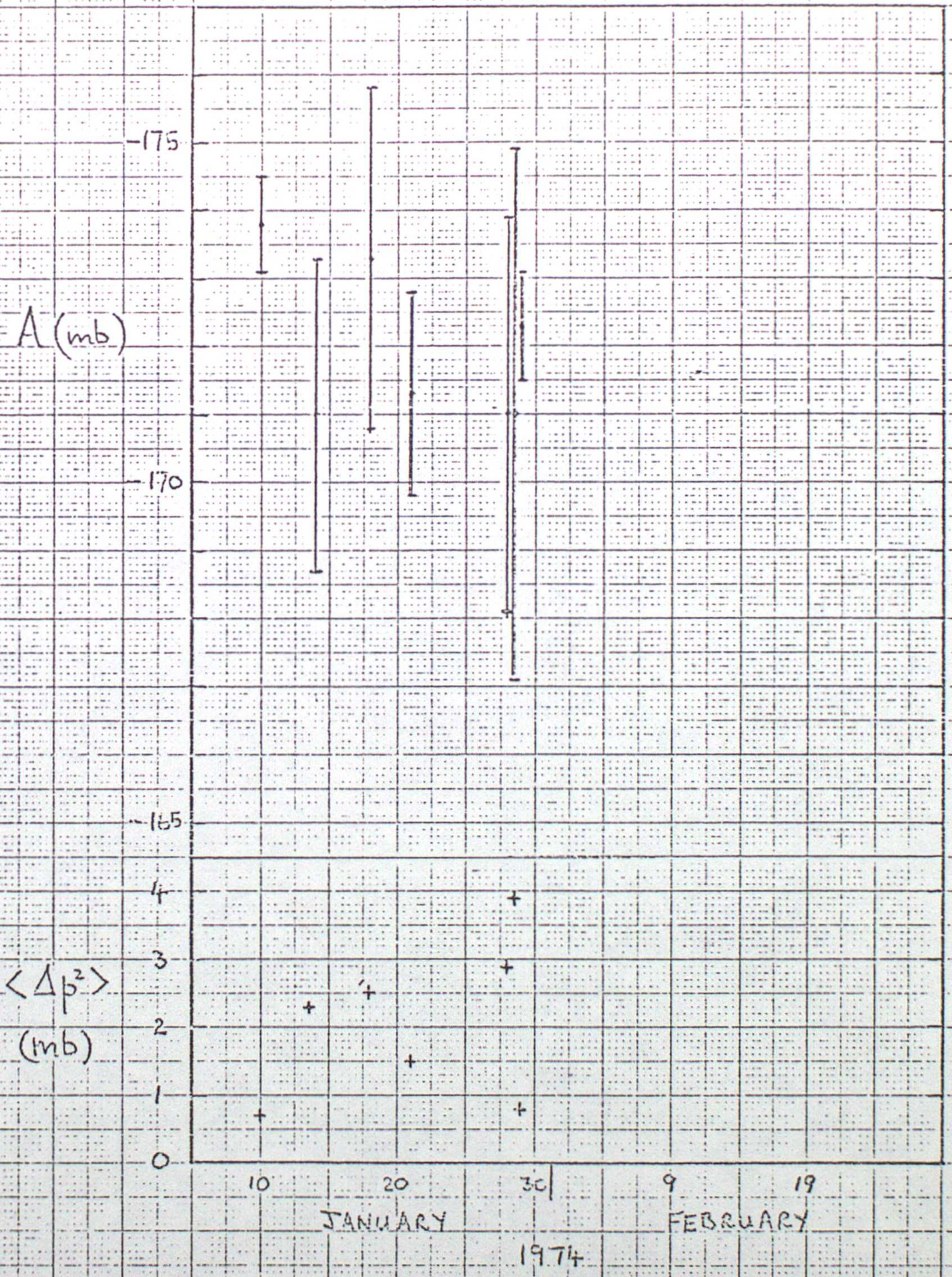


FIGURE 9. SENSITIVITY OF THE DEVICE OUTPUT TO SUPPLY VOLTAGE VARIATIONS