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FINAL REPORT

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To:

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FINAL REPORT

OBJECTIVE: To evaluate active and passive components and to develop circuit techniques that would be suitable for high temperature operation. The preliminary goal was 300-350 degrees centigrade.

The specific circuits that were evaluated were crystal oscillators and frequency dividers.

SUMMARY: This program had several rather independent lines of investigation and so they will be listed separately. This study is also not to be regarded as conclusive but rather as a state of observation that was reached at the time funding expired.

1. ACTIVE DEVICES

The active devices under investigation were limited to JFETS because preliminary work in this field has indicated that they were the only devices known that could be operated in the desired temperature range. After some investigation, the 2N3821 and the dual unit, the 2N5911, were selected for continued tests. This was based on good temperature performance, low threshold voltage and relatively high g_m at low currents. It was desirable to operate with a single +6V supply and with as little current drain as possible.

The bistable divider shown in Figure 3 worked very well

at the lower frequencies but could not operate at the desired oscillator frequency of 3 to 10 mHz.

A discussion with Mr. Bruce Draper of the Sandia Corporation revealed that McDonnell Douglas had a development program to produce GaAs JFETS which should be superior to the Si units that were being used. Dr. Reiner Zuleeg was contacted and donated 3 discrete samples for use in the program.

These units are indeed superior and make possible direct frequency division from the oscillator. A 10 MHz crystal oscillator was built from these units that operated at 250°C. At this time a random failure stopped the test, but 325 to 350°C operation is believed to be attainable.

2. PASSIVE DEVICES

a. Resistors.

Most resistors are unsuitable at 300°C but the MS220 type resistor made by Caddock Electronics Inc. showed excellent temperature stability and no ill effects from the 300°C operation.

b. Capacitors.

Glass capacitors such as the CY100 type made by Corning Electronics withstood the 300°C operation with no apparent damage. Stability tests were not made. The selection of suitable larger capacitors for decoupling was not addressed.

c. Inductors.

Their use was avoided until the last tests for the oscillator circuit. At that time ordinary magnet wire wound overlapping on a ceramic cone and coated with Q dope was used. The coil survived a one hour run at 250°C with no apparent damage. This needs further study.

3. CIRCUIT PERFORMANCE

The tests performed showed that operation from a 5 MHz oscillator to a divider chain at 300°C can definitely be built from discrete parts. 10 MHz operation is very probable.

The section on Laboratory Data has details on this matter and the section on Recommendations has further information.

4. CONSTRUCTION TECHNIQUES

These comments apply only for development and breadboard circuits:

Ordinary solder melts at these temperatures but if the leads are tightly twisted 3 or 4 times, the liquid solder will remain between the wires to maintain the connection. This is not suitable for repeated tests as the solder oxidizes and intermittent connections will develop.

Welding is the best technique, but this requires special equipment that is not always available.

Circuit boards made from Pyrolin by DuPont and Macor by Corning Glass will hold up very well. They can be machined

and made useful in that manner. If the correct size connector pin sockets are available they can be pressed into holes in the boards and the component then inserted in these pin sockets. Stitch welding is used for the interconnections.

The technique employed in the simple circuits shown in this report used #2 screws, nuts and washers to hold the parts together. A screw of suitable length is selected for each joint. Then each lead, with a half turn is placed between 2 washers and tightened with a nut. This will get out of hand for larger circuits, but worked well in this case and is very reliable.

RECOMMENDATIONS:

The GaAs JFETS developed by McDonnell Douglas are clearly superior to the silicon devices. There may be other sources of these JFETS and that should be investigated.

The McDonnell Douglas discrete GaAs JFETS are really samples cut from integrated circuits for tests and evaluation. They are very low power and low capacitance devices and much of their value is lost when they are operated as discrete units in a transistor case.

It is recommended that an integrated GaAs chip be developed that will suitably connect to the necessary passive elements to complete the circuit.

LABORATORY TESTS:

1. JFETS PROPERTIRES

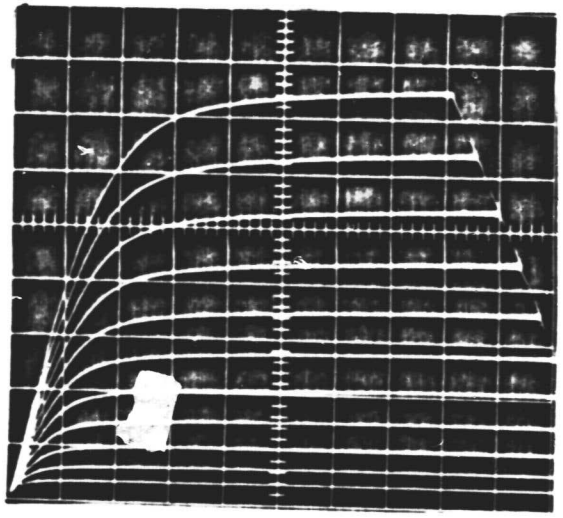
When a JFET, either Si or GaAs, is operated at elevated temperatures, an overall deterioration of the essential properties occurs. Figure 1 shows the results of a test on the 2N3821. The top trace is at 0V gate to source.

From 1B it is seen that the g_m is reduced by a factor of 2 at 200°C and the voltage to produce cut-off is increased. As the temperature is raised the bottom and top traces come closer together until the gate completely looses control and the JFET becomes a simple conductor. The knee of the curves has also moved further out requiring higher voltage for operation and the dynamic drain resistance is reducing, resulting in further loss of gain.

In addition to this the gate current is increasing rapidly. For these tests a 51K ohm resistor was placed in the gate lead. At 200°C the gate current was still small enough so that the resistor had no noticeable effect. At 255°C, however, the resistor has produced a serious loss of transconductance and cut off capability.

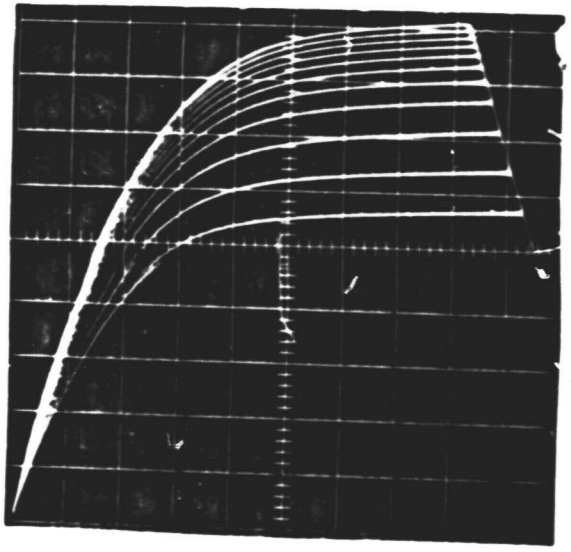
The GaAs JFETS have the same mode of failure but similar tests and photoes could not be taken because of problems with oscillations.

Figure 2 shows the test arrangement to obtain the data that is shown in Table I.

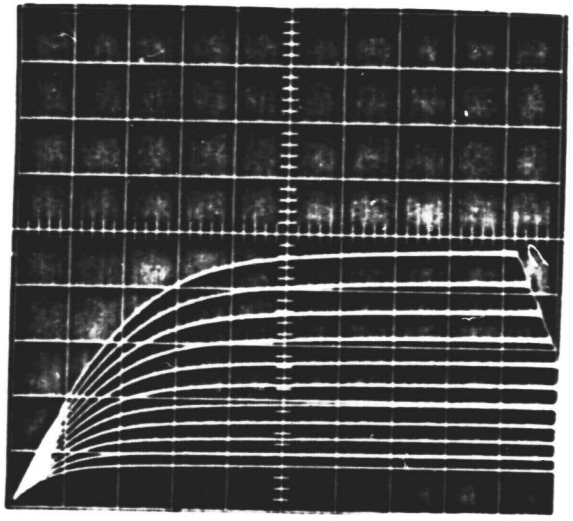


A 24°C

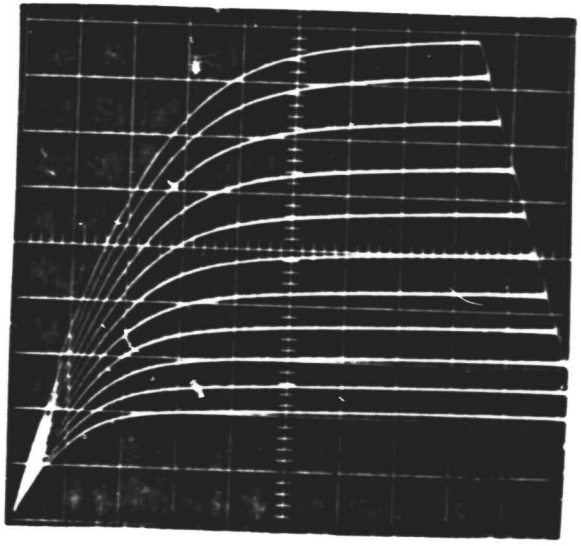
Base = 0.1V steps
I = 0.2mA/Sq.
E = 0.5V/Sq.



C 255°C 51K-Ω in
(0.1mA/Sq.)



B 200°C 51K-Ω no effect



D 255°C 51K-Ω shorted
(0.1mA/Sq.

Fig 1 2N3821 (51K-Ω in series with base)

TABLE I

CALUCULATED DATE

Unit	Temp.	Gain	g_m	r_d	I_g	E_g	I_D
GaAs #11	23°C	13.6	5.7m℧		0.12uA	-.091	1mA
	200	11.4	4.7		4	-.24	1
	250	11.4	4.7		12	-.28	1
	300	8.6	3.6		63	-.37	1
GaAs #1	23	11.3	4.7m℧		0.1μA	-.209	1mA
	200	10.4	4.3	2.49K	4.5	-.33	1
	250	9.6	4.0	4K	19	-.39	1
	300	6.9	2.9	3.56K	93	-.48	1
GaAs #2	23	8.1	3.4m℧		0.78μA	-.145	0.9mA
	200	7.8	3.25	4.14K	4.7	-.269	0.9
	250	6.7	2.8	3.8K	24.4	-.325	0.9
	300	5.3	2.2	5.3K	99.6	-.426	0.9
2N3821	25	3.19	1.33m℧	240K	0.4μA	-.418	0.68mA
	200	2.1	.87		.1	-.27	0.68
	250	1.9	.8		1.4	-.252	0.68
	305	2.1	.87		16.7	-.114	0.68

$$r_d = \frac{\Delta E_o \, R_L}{\Delta E_o - \Delta E_o} \qquad g_m \; (r_d >> R_L) = \text{gain}/R_L$$

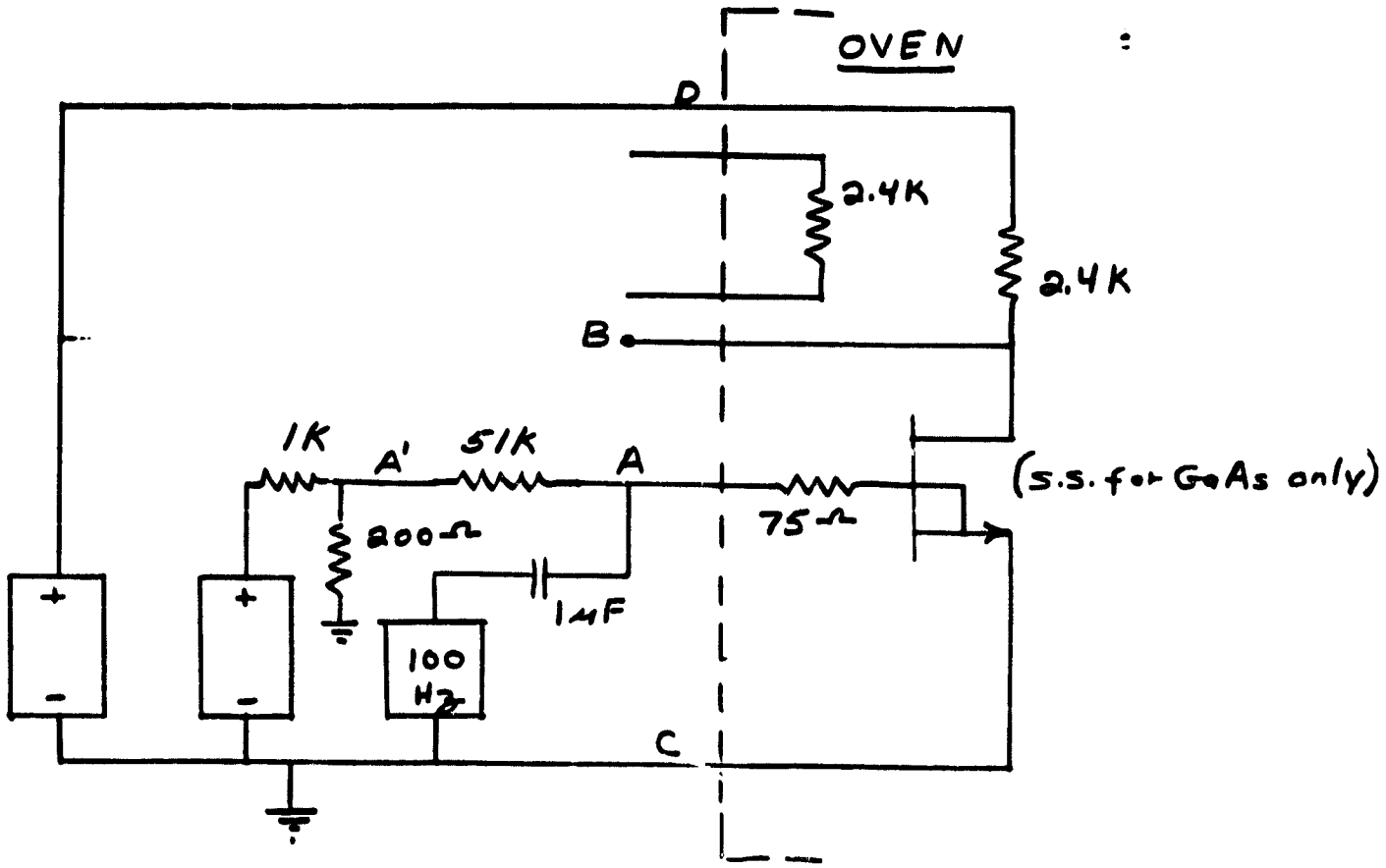


Fig 2 Test Connections for JFETS

The supply voltage at D was held constant at +5 volts except for data readings to obtain the drain resistance. Here a data point was taken at +6 volts to make the necessary calculation.

The calculations of g_m = gain/R_L results in higher than correct values because of the influence of r_d. Where r_d is

available, the correct calculations can be made from the expression

$$\text{gain} = \frac{-g_m R_L}{1 + R_L / r_e}$$

It is seen that the loss of g_m, with elevated temperatures, for Si and GaAs is about the same. It is just that the GaAs has about four times as much g_m as the Si unit. The gate leakage current of the GaAs JFET's was much higher than the Si JFET and no explanation is offerred for this. It will be stated, however, that the GaAs JFET was developed solely for cryogenic applications and the high temperature operation was not considered in its design.

Table II shows data that was taken on two types of Si diodes and a GaAs monolithic diode pair. The 2N4150 was useless at the first data point of 200°C.

TABLE II

Temp	1N4150 E_f	1N4150 I_R	FDH 300 E_f	FDH 300 I_R	GaAs(1) E_f	GaAs(1) I_R	GaAs(2) E_f	GaAs(2) I_R
22	.579V		.677V		1.249V		1.344V	
200	.197	93μA	.362	1.5μA	.838	5.4μA	.663	4.3μA
250	.099		.27	12	.698	24	.704	23.5
30	.045		.188	81	.592	75	.572	74

The FDH 300 is a special low leakage Si diode and did much better. Again, as with the JFETS the GaAs diodes were not developed with high operating temperatures in mind.

7. MULTIVIBRATORS

The basic circuit shown in Figure 3 was built and tested with various values of passive elements for both the Si and GaAs JFETS. The proper choice of drain inductor will raise the operating frequency by a factor of about 1.5. The circuit as shown with the 2N3821 could be driven by a maximum frequency of about 0.75 MHz.

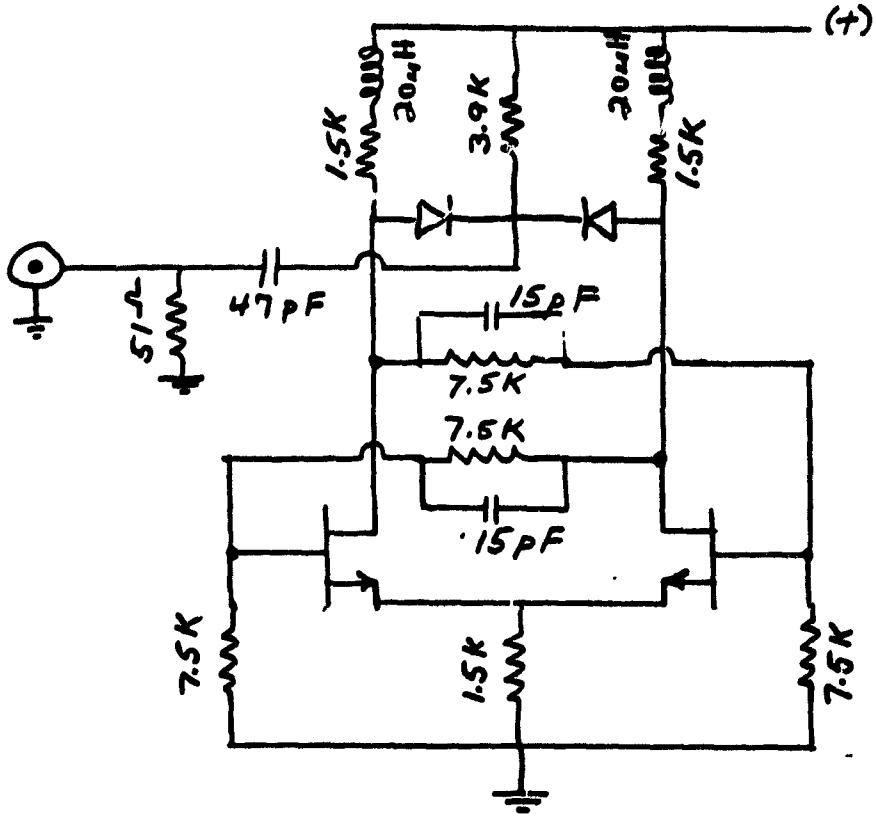


Fig. 3 Basic Multivibrator

The speed limitation in this type of simple circuit is primarily due to the influence of the triggering input on the divided output. This is shown in Figure 4. Here the derivative of the triggering signal is deliverately placed over the output pulse to show the interaction. The rising edge of the output is tracking part of the input while the falling edge of the output is attempting to reverse itself in an effort to lock on to the input pulse. As the frequency is raised, the influence of the input becomes more pronounced and will abruptly loose control of the multivibrator.

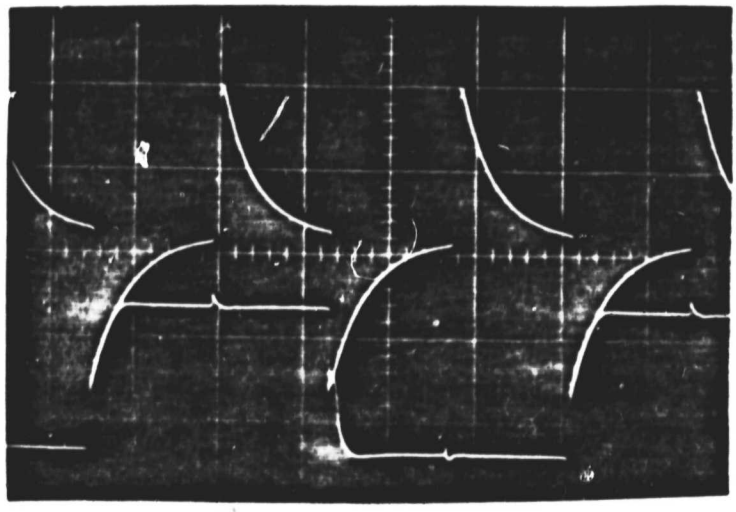


Figure 4. 2N3821

Figure 5 shows the wave forms of the same type of circuit with a GaAs JFET. A similar influence is shown by the notch in the rising edge of the output pulse.

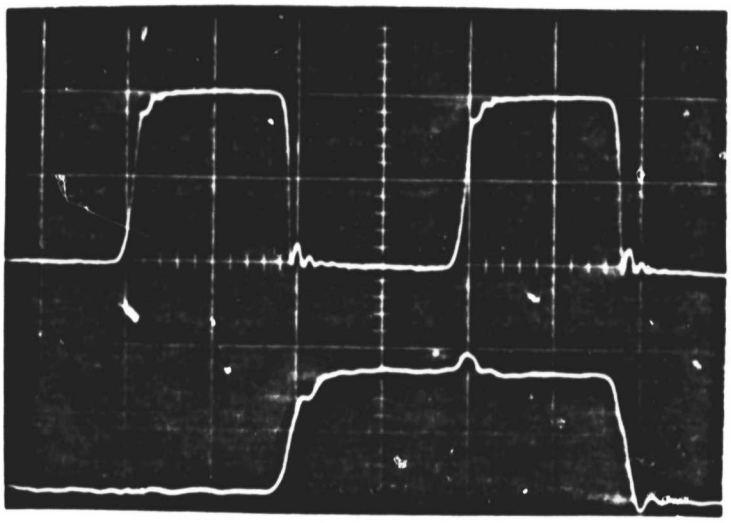


Fig 5 GaAs JFET

The superior frequency performance in this type of circuit, by the GaAs JFETS is due primarily to two factors: one is the higher g_m and the other is that the GaAs device requires less energy to trigger and therefore can operate with a derivative that is proportionally smaller.

For both the Si and GaAs devices, however, the shaping of the triggering signal is crucial to high frequency operation.

Test equipment was not available to trigger the GaAs flip-flop from a source greater than the 2.5 mHz used in Figure 5, so the upper limit of this circuit was not determined.

Using the GaAs devices in an integrated circuit where the trigger is isolated from the output produces a vastly different result. McDonnell Douglas has reported trigger fre-

quencies in excess of 500 mHz.

If discrete JFETS are used the circuits must be kept simple to keep the size down and to reduce the number of interconnections. It appears that the proper GaAs JFET can make the high frequency divisions down to about 0.5 MHz. After that the required performance is easily acquired at lower power levels, but the parts count still remains high.

If a suitable GaAs integrated chip can be obtained, this would definitely be the best method to produce the required oscillator and the succeeding divider chain.

3. CRYSTAL OSCILLATORS

Two types of crystal oscillators were tested. The first was the Pierce oscillator shown in Figure 6. This was selected because of its simplicity. The circuit worked well

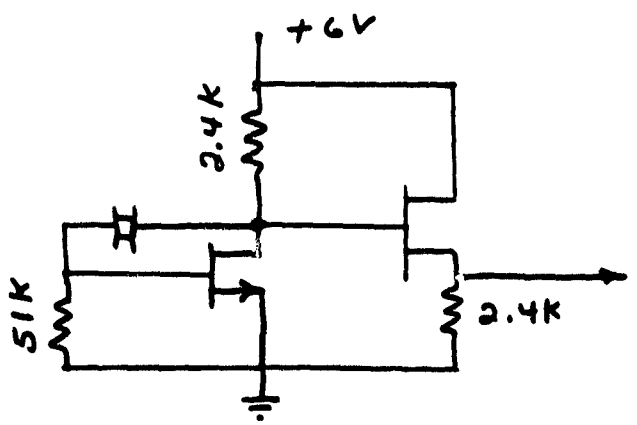


Fig 6 Pierce Oscillator

for the 2N3821 with a 5 MHz crystal at room temperatures. A

heat gun test indicated that the circuit would not work at the required temperature range. A negative bias voltage at the gate resistor would be of benefit, but not sufficient for 300°C operation.

The multivibrator circuit shown in Figure 7 was the second choice. This produced a strong 10 mHz oscillation with the 2N3821's but again they could not operate with the heat gun.

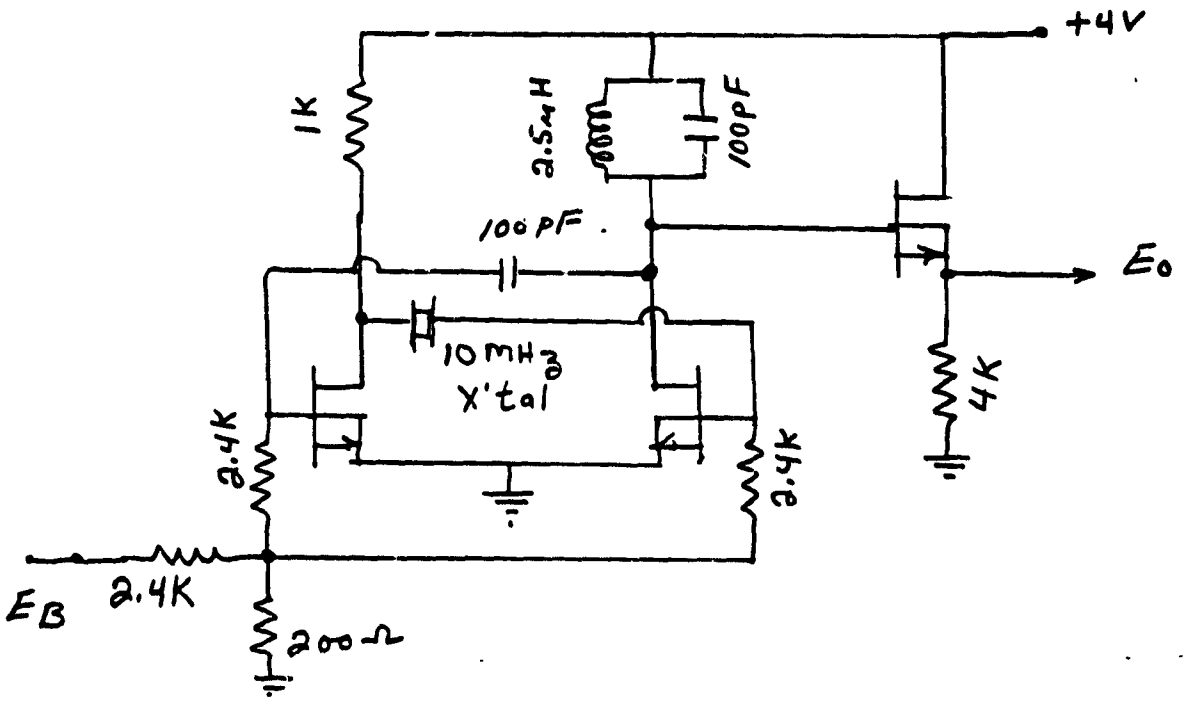


Fig 7 Multivibrator X'tal Oscillator (Colorado Crystal)

The circuit was used with the GaAs JFETS and oscillation was difficult to start. The reason for this is not clear but based on their subsequent failure it is possible that they were already operating in a damaged condition.

Table III shows data taken to 250°C where device

failure occurred. The nature of the failure or which of the JFETS had failed was not investigated. The circuit was rechecked with the 2N3821's and operated properly.

Figure 8 shows a plot of the data. It is clear that a change in slope had not started within this temperature range.

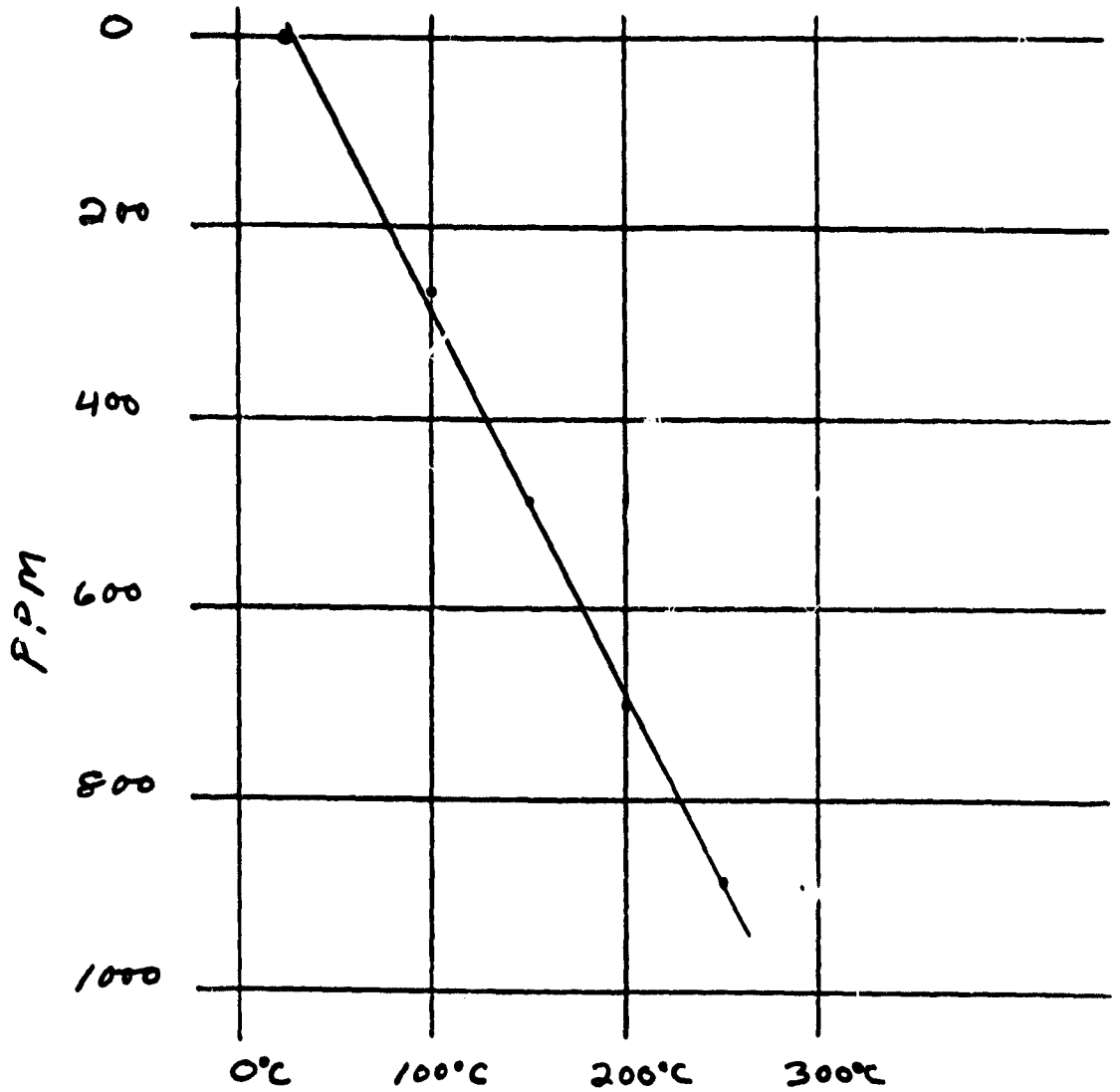


Fig 8 Frequency vs Temp. (Fig 7)

TABLE III

Temp. ^{o}C	f (KH_3)	E_{BIAS}	Eo pp	PPM change
23	9999.980	0V	0.6V	---
100	7.310	0	0.5	267
150	5.104	0	0.44	488
200	2.960	0	0.4	702
250	1.170	0		881