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EMR AEROSPACE SCIENCES DIVISION

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NASA STI FACILITY
INPUT BRANCH

ELECTRO-MECHANICAL RESEARCH, INC.
COLLEGE PARK, MARYLAND

Technical Progress Report No. 2

for

Airborne Electronic Reset Fuse

(23 August 1968 - 18 October 1968)

Contract No: NAS 5-11559

Prepared by

EMR-Aerospace Sciences
EMR Division
Weston Instruments, Inc.
College Park, Maryland

for

Goddard Space Flight Center

Greenbelt, Maryland

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SECTION 1
GENERAL PROJECT STATUS

1.1 OBJECTIVE

This report has been prepared in accordance with Article II of contract NAS 5-11559.

The purpose of this report is to inform the GSFC Technical Officer of the progress on the Airborne Electronic Reset Fuse through 18 October 1968.

1.2 PROJECT SUMMARY

The breadboard has been completed and is delivered with this report. The following modifications and/or optimizations have been incorporated:

a. The change from a +7V supply voltage to +12V has not been incorporated. To maintain the power dissipation at the present low level, while increasing the supply voltage, is not feasible. The 70 percent increase in supply voltage would require a power dissipation increase of approximately 35 percent. In addition, this would change the stress on several components making it necessary to change their voltage ratings with a consequent increase in size.

b. The breadboard is capable of demonstrating a fuse of any rating from $\frac{1}{16}$ amp to 3 amps. In particular, ratings of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{2}$, and 3 amps will be demonstrated.

c. Energy storage is provided to allow circuit operation for 1.0^{+} seconds in the event the 7V line were suddenly decreased or shorted.

d. Capability of ground commands to open or close the relay, even in the event of a collector emitter short on Q9, is provided.

e. The time delay versus temperature is significantly improved.

f. The fusing point accuracy versus temperature is stabilized.

g. The time delay variation versus supply voltage changes is reduced.

The modifications/optimizations of the circuit have been incorporated only after careful consideration of their effect on reproducability, manufacturing operations, reliability, power consumption, size, and cost factors.

1.3 CONCLUSION

The GSFC evaluation will find that the improved circuit exceeds the specifications. Recommendations from GSFC as a result of this evaluation will be incorporated into the thick film circuit as applicable.

SECTION 2
TECHNICAL DISCUSSION

2.1 MODIFICATIONS

The schematic diagram, Figure 1, shows the original circuit before the modifications/optimizations. Figure 2 is the schematic diagram of the improved circuit. Where possible, the desirable electrical characteristics (i.e., simplicity, low power consumption, reliability) of the original circuit have been preserved, while its capabilities and environmental performance have been enhanced.

2.1.1 Fuse Rating

For the capability of adjusting the fuse to $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, or 3 amp ratings, there are two basic design approaches.

1. Adjust the bias current through the sense winding of the transformer for each fuse rating.

2. Use a basic $\frac{1}{16}$ amp fuse circuit configuration, and use precision shunts to shunt the additional fused current around the control winding for higher fuse ratings.

Approach 1 above has several disadvantages:

a. The power drain of the circuit increases with the bias current.

b. The transformer for currents of $\frac{1}{2}$ amp and greater would have to be of greater cross sectional area (more iron).

c. The temperature compensation of the JFET would probably have to be changed for each bias current.

RELEASED BY ENR DATE
OCT 21 1965

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

INPUT 1

T1 (1, 2, 6, 7, 8, 5, 4, 3)

K1 (RESET, SET)

2 OUTPUT

CR3 IN645 — 3 RESET

CR4 IN645 — 4 SET

5 +V

Q1 2N2605 — R24 1.5K — C1 .04mf — R1 62K

Q2 2N2605 — R25 1.5K — C2 3300pf — R2 220K

R3 33K — C3 120pf — R6 200

R7 68K — C4 120pf — R5 200

Q3 2N2524

Q4 2N2524

R4 1.1K — C5 1.2pf — R25 82K — R8 20K — C6 3300pf — Q5 2N2524

CR2 IN645 — R26 2.2K

R9 120K — C7 820pf — R10 20K — Q6 2N2605 — R11 20K — Q7 2N2605

R12 39K — R13 240K

R15 100K — Q9 2N3638A — R16 6.2K — C8 .68mf — R29 22K — R28 20K — Q8 2N2524 — C9 .68pf

R17 3.3K — Q10 2N2524

R19 33K — Q11 2N2524

R22 56K

Q12 2N3459 FET — R27 TBD — R23 TBD

6 COMMON

GD

LAST CIRCUIT SYM. USED:

R29
Q12
C9
CR4
T1
K1

CIRCUIT SYM. NOT USED:

CR1
R18
R20
R21

LIST OF MATERIAL — EMR 03-19-103

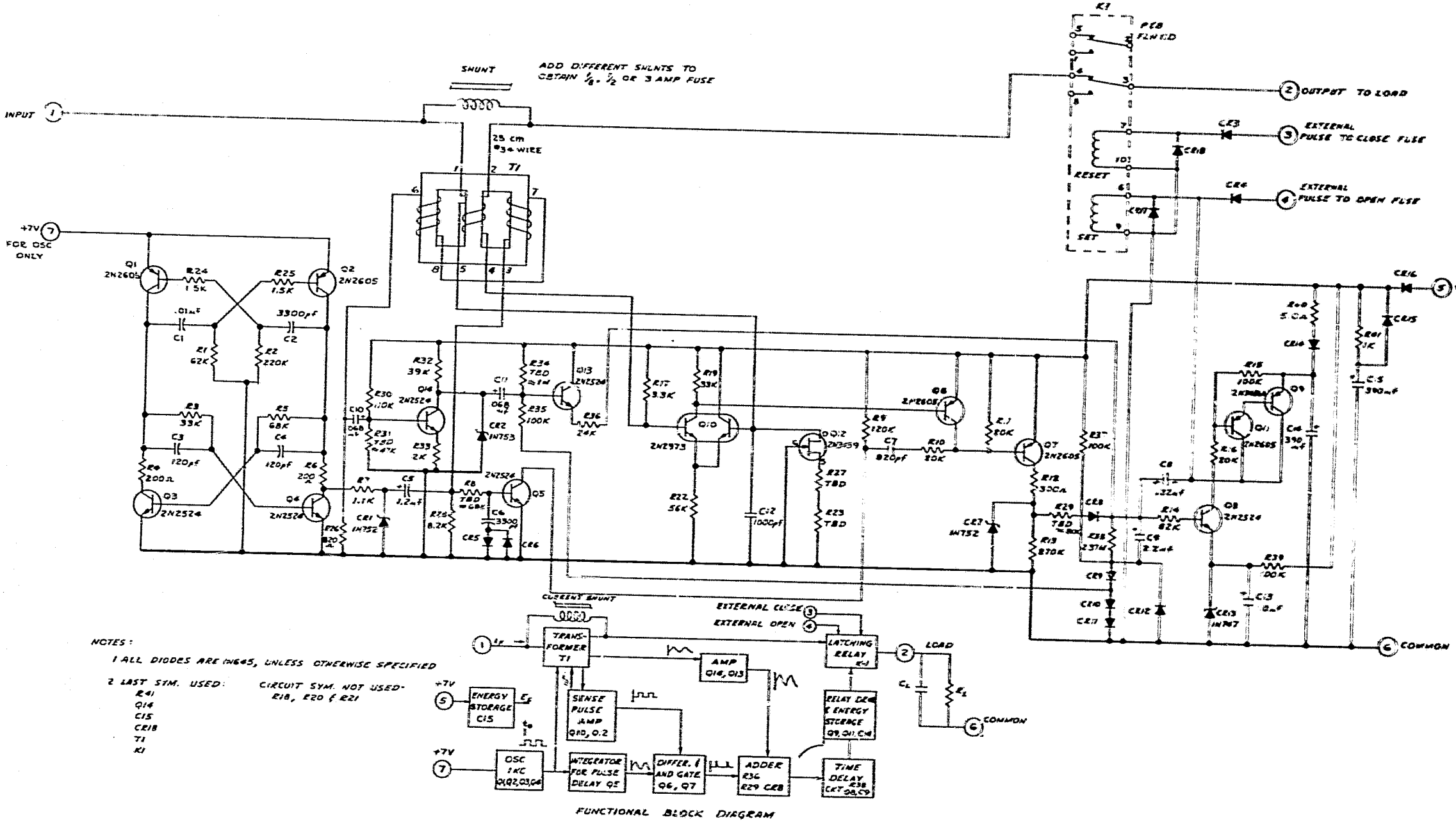
ELECTRONIC FUSE SCHEMATIC

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

03-19-100 — F511

GD

FIGURE 1 SCHEMATIC



NOTES:

1 ALL DIODES ARE IN645, UNLESS OTHERWISE SPECIFIED

2 LAST SYM. USED:
R41
Q14
C15
CR18
T1
K1

CIRCUIT SYM. NOT USED- R18, E20 & R21

FUNCTIONAL BLOCK DIAGRAM

FIGURE 2

Design approach 2 is used and allows a basic $\frac{1}{8}$ amp circuit configuration to handle currents up to the capability of the latching relay. With this configuration, a shunt, which has been calculated and/or adjusted to give the desired fusing point, is simply inserted in parallel with the control winding. Since the control winding is magnetically coupled to an a.c. circuit (1kHz) the shunt must present an inductive reactance which is much greater than the inductive reactance of the control winding turns. This makes it necessary to insert a high permeability material in the shunt. Thus, for each fuse rating a shunt wound on a toroid is used to give the desired fusing point. This approach gives great versatility to the fuse since there is simply a basic $\frac{1}{8}$ amp fuse circuit, and the rating is changed with different shunts.

The shunts are of magnet wire having a length equal to that of the control winding, but with a cross sectional area proportional to the increase in fusing point desired. Thus, if the control turns wire is 25 cm long and 40 circular mils gives a $\frac{1}{16}$ amp fuse, in order to obtain a $\frac{1}{2}$ amp fuse requires that the circular mils total be 8 x 40 = 320 cir mils. Subtracting the 40 cir mils already on the control winding gives 280 circular mils to be added in shunt and of length 25 cm. When wire selections are such that 280 circular mils is not conveniently obtained, the length of the shunt is adjusted to obtain the proper shunt resistance.

2.1.2 Energy Storage

Two capacitors, C_{15} and C_{14}, have been added to the original circuit. C_{15} provides storage of energy to operate the fuse circuit for approximately one second following a supply voltage failure. C_{14} provides energy storage to operate the relay after the circuit has operated through the time delay. The storage capacitor for the relay is inserted in the circuit so as not to aid capacitor C_{15} in operating the circuit. Thus, C_{14} remains fully charged until the time delay period has been completed and then delivers its full energy to the relay coil. The values for C_{15} and C_{14} are as follows:

$$C_{15} = \frac{2\ Pc\ tc}{V_0^2 - V_1^2} \qquad C_{14} = \frac{2\ Pr\ tr}{V_0^2 - V_1^2}$$

where Pc = Power requirement of the circuit (3.4×10^{-3}W)

tc = Time circuit must operate (1.0 seconds)

Pr = Power requirement of relay

tr = Time power must be applied to relay (5×10^{-3} sec.)

V_0 = Voltage capacitor is charged to initially (7.0V)

V_1 = Voltage capacitor is allowed to discharge to in tc or tr (5.5V)

Thus

$$C_{15} = \frac{2\ (3.4)\ 10^{-3}\ (1.0)}{49 - 30} = 358\ \mu fd$$

$$C_{14} = \frac{2\left(\frac{49}{67}\right) 5\ 10^{-3}}{19} = 383\ \mu fd$$

In the circuit each capacitor is 390 μfd.

An interesting consideration is: When the 7V drops suddenly or significantly, will the overload current be of such magnitude that the time delay would always be 0.1 second or less. If so, the capacitor C_{15} need only supply energy for 0.1 second (tc). Then C_{15} could be reduced to one-tenth of that calculated above with a considerable saving in the size of the capacitor. Or capacitor C_{14} could supply this energy by adding a diode in parallel with resistor R_{40}, with its cathode at E_s and anode on the Q_9 emitter. The diode (CR_{14}) is then not necessary.

2.1.3 Command Operation

Provision to ensure the capability of remotely opening or closing the fuse by commands has been incorporated. R_{40} is added to ensure that the fuse may be remotely closed in the event of a failure (collector-emitter short) of Q9.

2.2 OPTIMIZATIONS

It is noted in Figure 2, that diodes have been used in all cases to temperature compensate the circuit. This has several advantages over sensistors or thermistors:

a. The change in forward voltage of a diode with temperature will approximately track the Vbe of the transistor which is causing the temperature dependance.

b. Thick film or thin film is more feasible with diodes than sensistors/thermistors.

c. Diodes are less expensive and more reliable.

2.2.1 Time Delay Versus Temperature and Overload Current

The delay time required to open the fuse as a function of temperature and overload current has been improved and a curve of the circuit characteristic is shown on Figure 3. The circuit configuration is such that this characteristic may be conveniently modified to change: the curves' slope, its minimum time delay, and the overload at which the time delay begins to decrease. Compensation of this time delay with temperature is dependent on several components:

a. Vbe of Q_8 - (nominally $\frac{2mV}{^oC}$)

b. Temperature coefficient of C9 - (nominally $\frac{400 \text{ parts}}{\text{million } ^oC}$)

c. Vbe of Q_7 - ($\frac{2mV}{^oC}$)

d. Frequency change in the oscillator

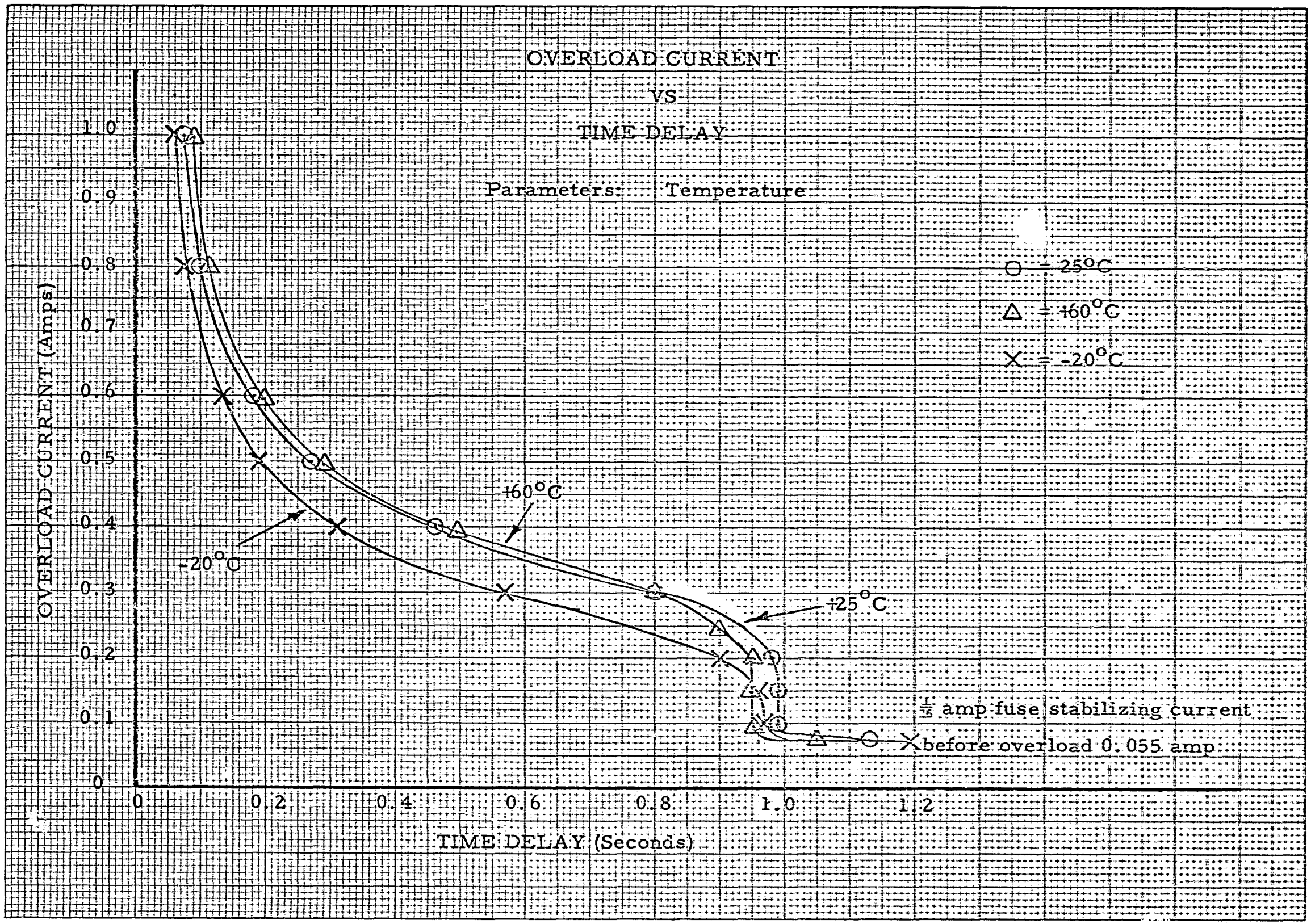
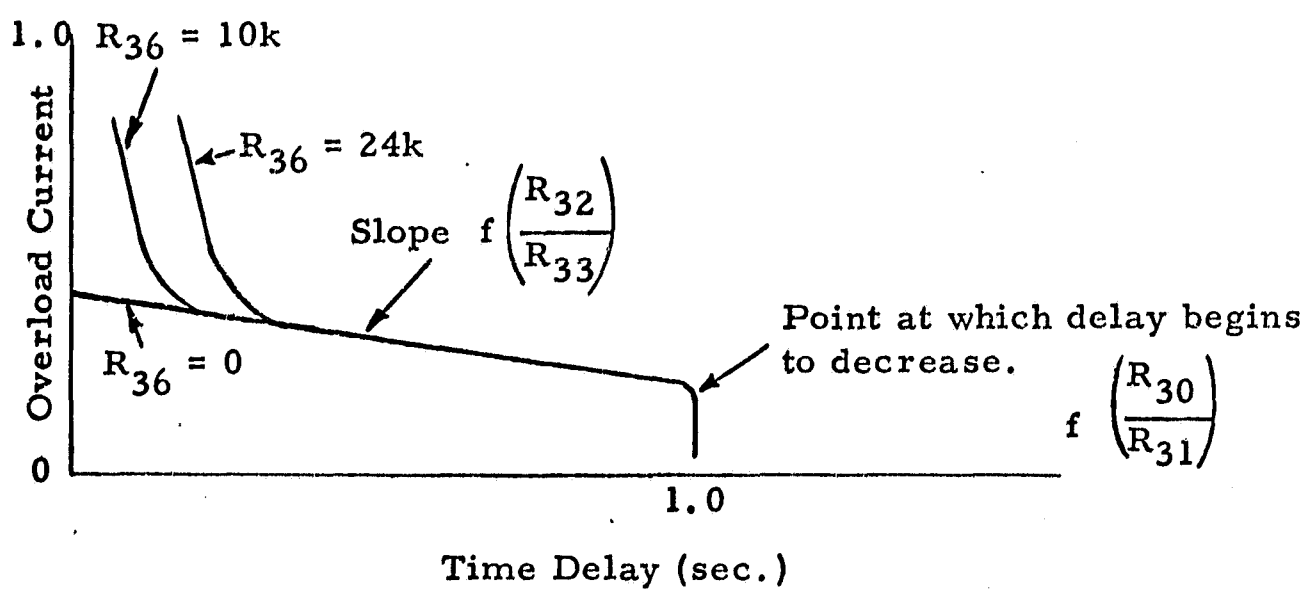

OVERLOAD CURRENT
VS
TIME DELAY
Parameters: Temperature
○ = 25°C
△ = +60°C
X = -20°C
OVERLOAD CURRENT (Amps)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
+60°C
-20°C
+25°C
1/5 amp fuse stabilizing current
before overload 0.055 amp
0
0.2
0.4
0.6
0.8
1.0
1.2
TIME DELAY (Seconds)

FIGURE 3

Compensation of these variables is obtained using diodes CR_9, CR_{10}, and CR_{11}. In some situations, only two of the three diodes may be necessary. This is dependent on the amount of compensation required. To provide the inverse time delay with overload current it is necessary to amplify and provide control of the d.c. level of the signal fed back from R_{26}. This added amplifier provides convenient control over the i_f versus t_d characteristic.

Transient Response

The circuit has a feature incorporated to allow high current transients through the fuse without opening. This provision is a function of resistor R_{36}, which establishes the minimum time delay at high overload currents. The sketch below shows the effect of R_{36}. This is considered a very valuable feature in that it may be easily adjusted to meet the need of a particular experimenters transient requirements.



Accuracy

Since the transformer is the component which detects the current overload, the fusing point accuracy is affected by the transformer hysteresis. The bias current flowing in the sense winding magnetizes the transformer center core. A residual magnetism will remain in this core, even with the bias current removed due to the coercive force of the magnetic material.

Current overloads applied for a sufficient period of time will negate some of the magnetization due to the bias current and thus lower the point (overload current) at which the fuse will open. Laboratory tests of this effect show that with the time delays of 1.0 seconds or less, the effect is approximately 5 percent.

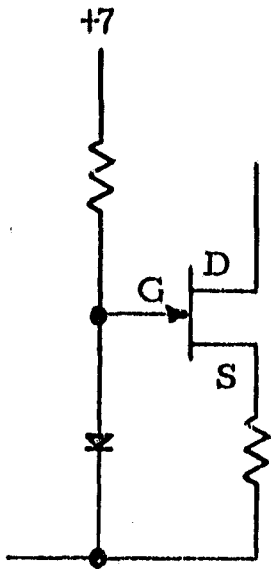
2.2.2 Time Delay Stability Versus Supply Voltage Changes

To compensate the circuit against changes in supply voltage, several voltage reference diodes were added. The choice here was to either regulate the input voltage which would increase the power drain or regulate the individual circuit signals. The latter technique was employed.

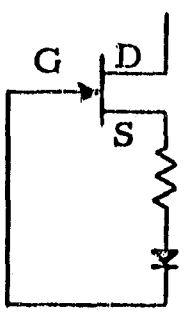
2.2.3 Fusing Point Accuracy Versus Temperature

The fusing point is affected by changes in the bias current through the sense winding of the transformers. The JFET (2N3459) Q_{12} is a constant current source and must either be biased where its temperature coefficient is zero or be temperature compensated. JFET's exhibit a temperature characteristic where for high currents (i_d) the temperature coefficient is negative and for low currents it is positive.

In the circuit application, the bias current (i_b) is low ($\approx 20\mu A$) and the FET temperature coefficient is positive. Without compensation, the fusing point will increase with increasing temperature, if other effects may be neglected. To compensate for this effect, diode compensation may be added as shown below:



If the net effect of other variables is to decrease the fusing point with temperature, the FET may be compensated as shown below:



An interesting and perhaps valuable consequence of this compensation is that almost any fusing point characteristic versus temperature may be obtained. Since many of the equipments to be fused in a spacecraft draw increasing current with increasing temperature, a positive slope to the fuse characteristic may be desirable and can be easily obtained.

Conversely, if a negative slope is desired, it may easily be obtained. If a single diode greatly over compensates the FET, then sensistors/thermistors must be used. The amount of compensation required is a function of the individual FET. The variation of temperature coefficients between FET's within the family of 2N3459's has not yet been established. The particular FET in the circuit does not need compensation; however, a sufficient sample to establish its relationship to the family has not been evaluated.

SECTION 3
PACKAGING

3.1 PHYSICAL SIZE OF FUSE

The physical size of a fuse is dependent on the desired current rating. The largest of the components for a fuse are:

a. The relay
b. The storage capacitors
c. The transformer
d. Transformer shunts

The relay used on the breadboard (P&B FLH 11D) has a 5A rating and is physically large. For a $\frac{1}{16}$ amp fuse, a smaller relay normally would be used. Such a relay would be the size of a TO-5 transistor can.

The two storage capacitors are large, but necessarily so if this feature is to be retained.

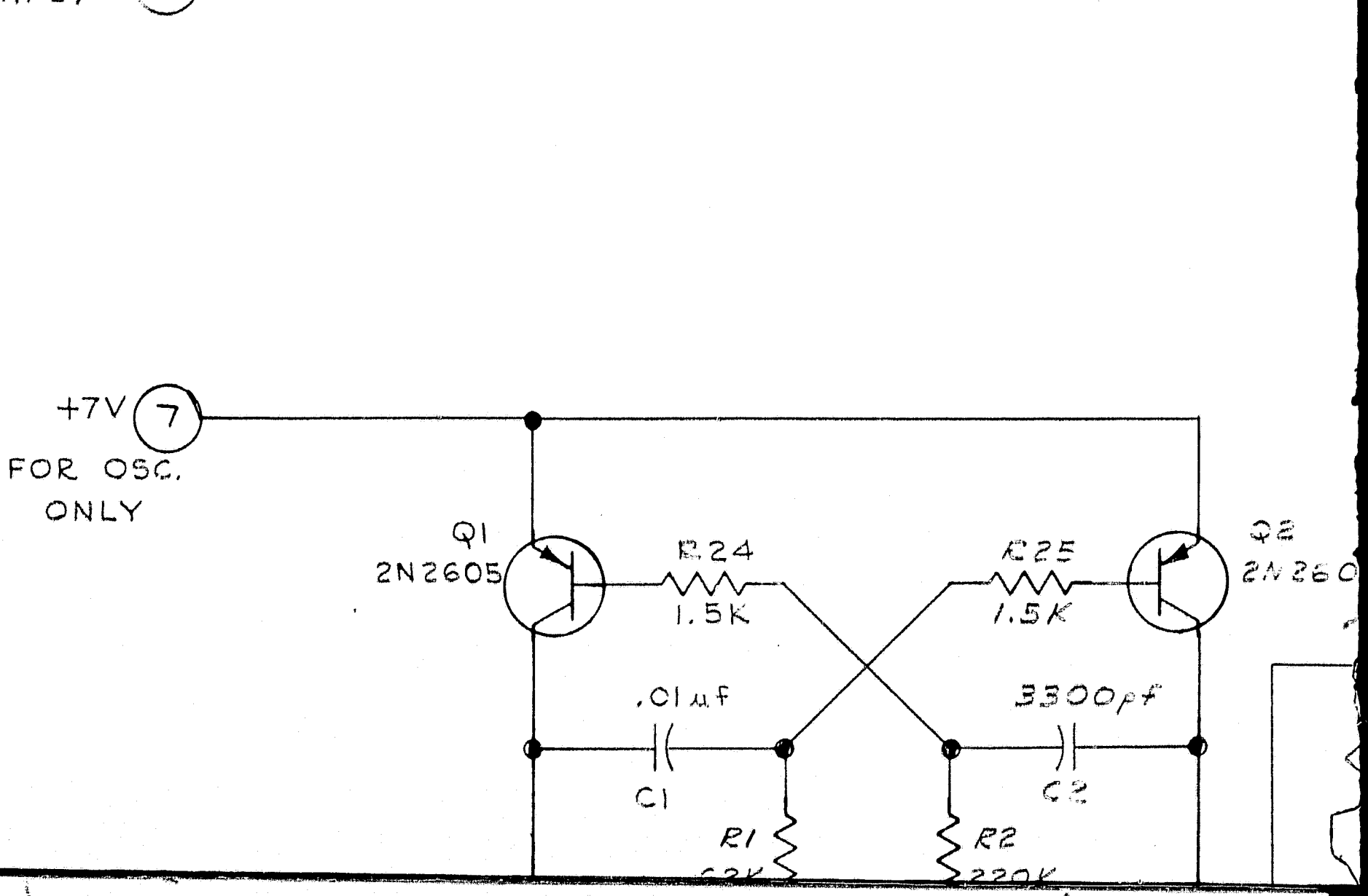
The transformer size is as small as feasible. Also, the size of the toroids for the shunts are essential, unless the transformer is made larger. The toroids supplied with the breadboard are not of optimum size. The window area need only be large enough for 6 to 8 turns of wire. Thus, the toroids could be reduced by a factor of 3 to 5 times.

3.2 THICK FILM PROCESS

The thick film packaging will reduce the circuit size considerably; however, large components listed in paragraph 3.1 must be mounted externally. Also, in order that the thick film circuit may be adjusted to give the proper

characteristics, critical components to be determined at test will be added externally to the package. This is necessary since the thick film components will have temperature characteristics different from those used in the breadboard. In addition, slight changes in the transformer characteristics will require circuit adjustments. When several thick film circuits and transformers have been manufactured and the variation of parameters have been established, the TBD components could be reduced.

FOLDOUT FRAME 1



Fold a Frame 2

FOLD

SHUNT

ADD DIFFERENT SHUNTS TO
OBTAIN ½ ¼ OR FAME PUN

25 cm
#24 WIRE

T1

1 2 6 7 8 5 4 3

Q2
2N2605

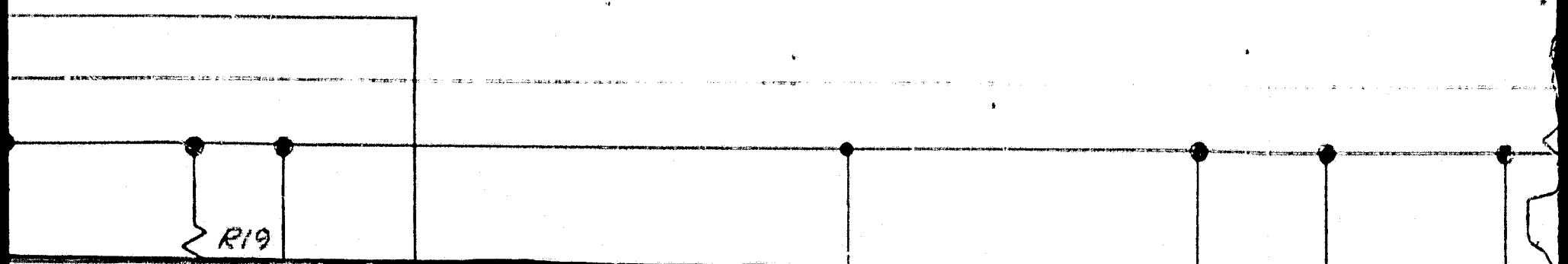
R32

R34

Q3

FOLDOUT FRAME 3

FOLDOUT FRAME



REVISIONS	
SYM	DESCRIPTION

FOLDOUT FRAME

FOLDOUT FRAME

K1

5

2

1

4

3

6

9

RESET

SET

P1-5
FLM IID

(2) OUTPUT

CR3

(3) EXTERNAL
PULSE T

CR5

IC

CR4

(4) EXTERNAL
PULSE TO

CR7

R40
51 OHM

CR14

R15
100K

Q2
2N3484

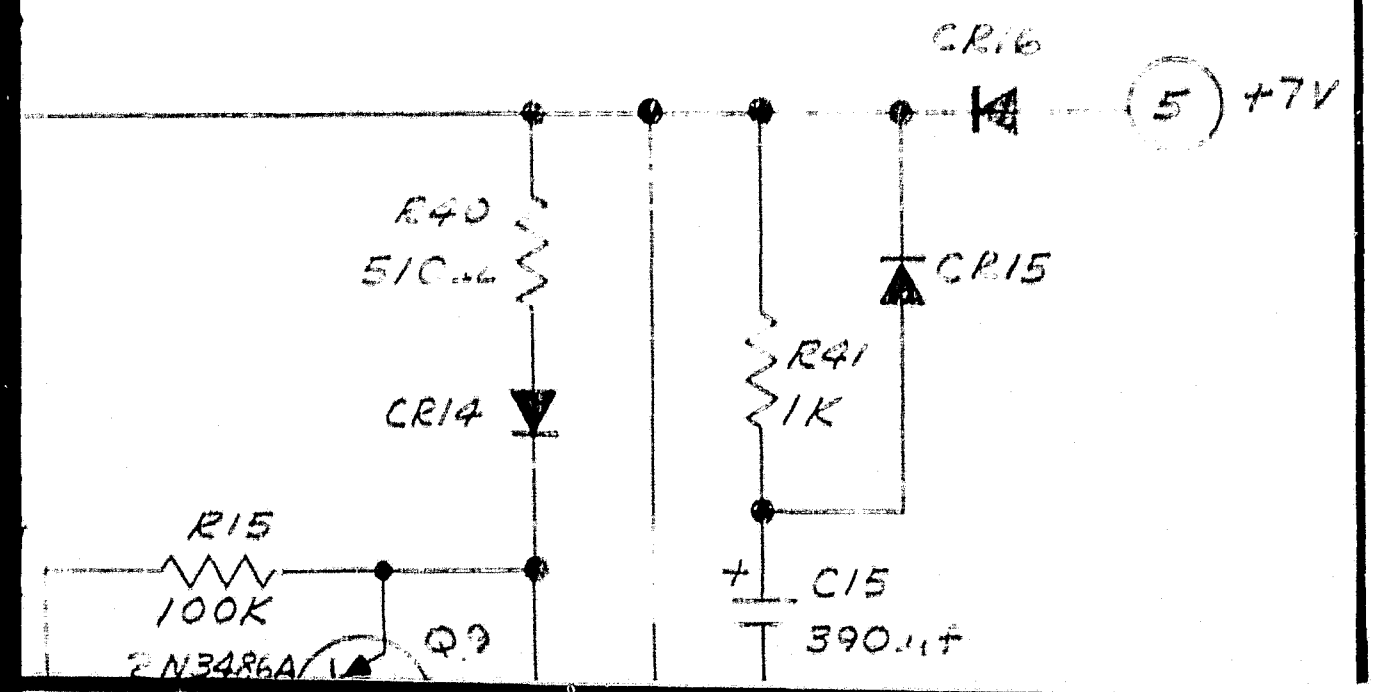
REVISIONS		
DESCRIPTION	DATE	APPROVED

FOLDOUT FRAME 5

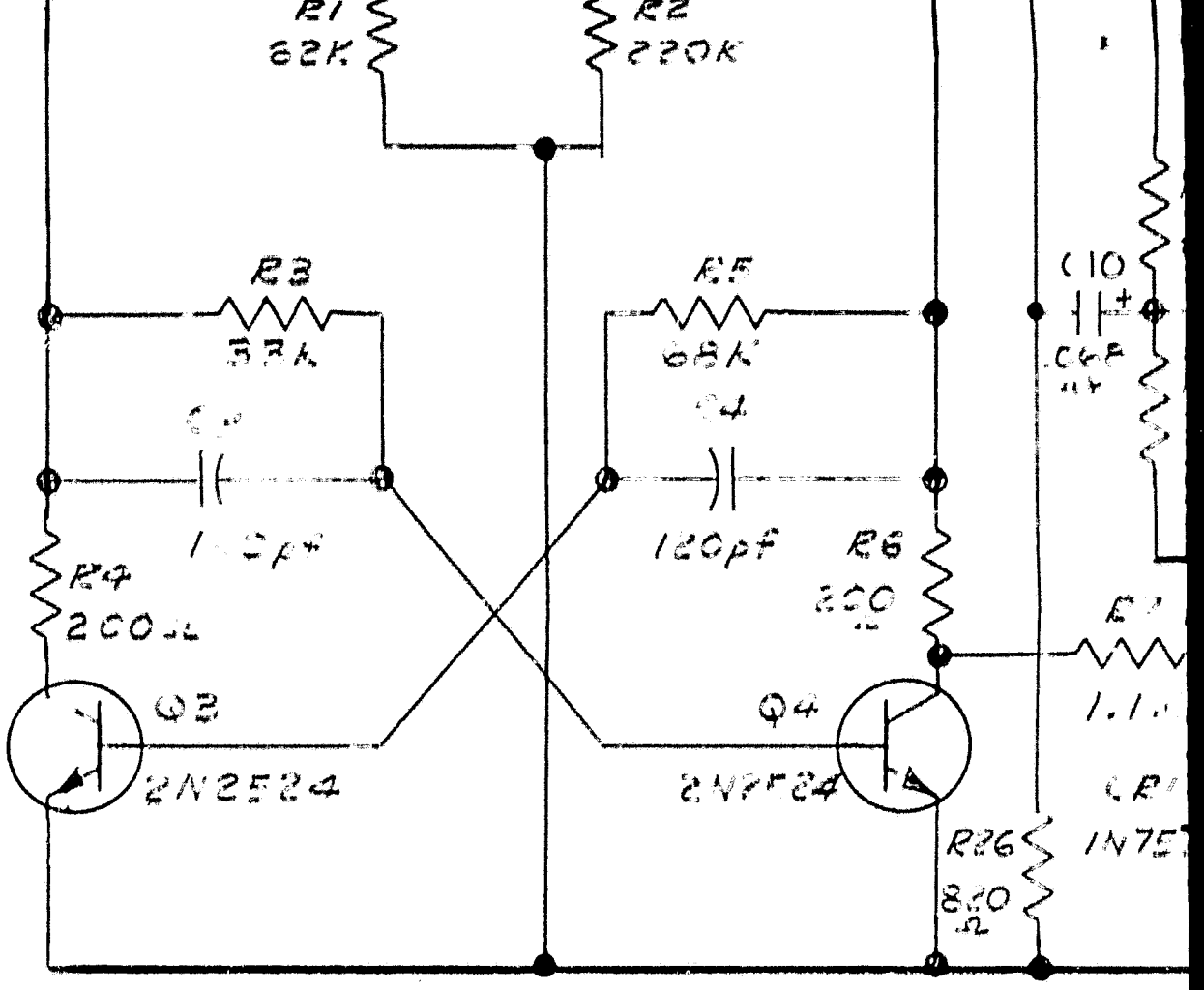
(2) OUTPUT TO LOAD

CR3 EXTERNAL
(3) PULSE TO CLOSE FUSE

CR4 EXTERNAL
(4) PULSE TO OPEN FUSE



FOLDOUT FRAME

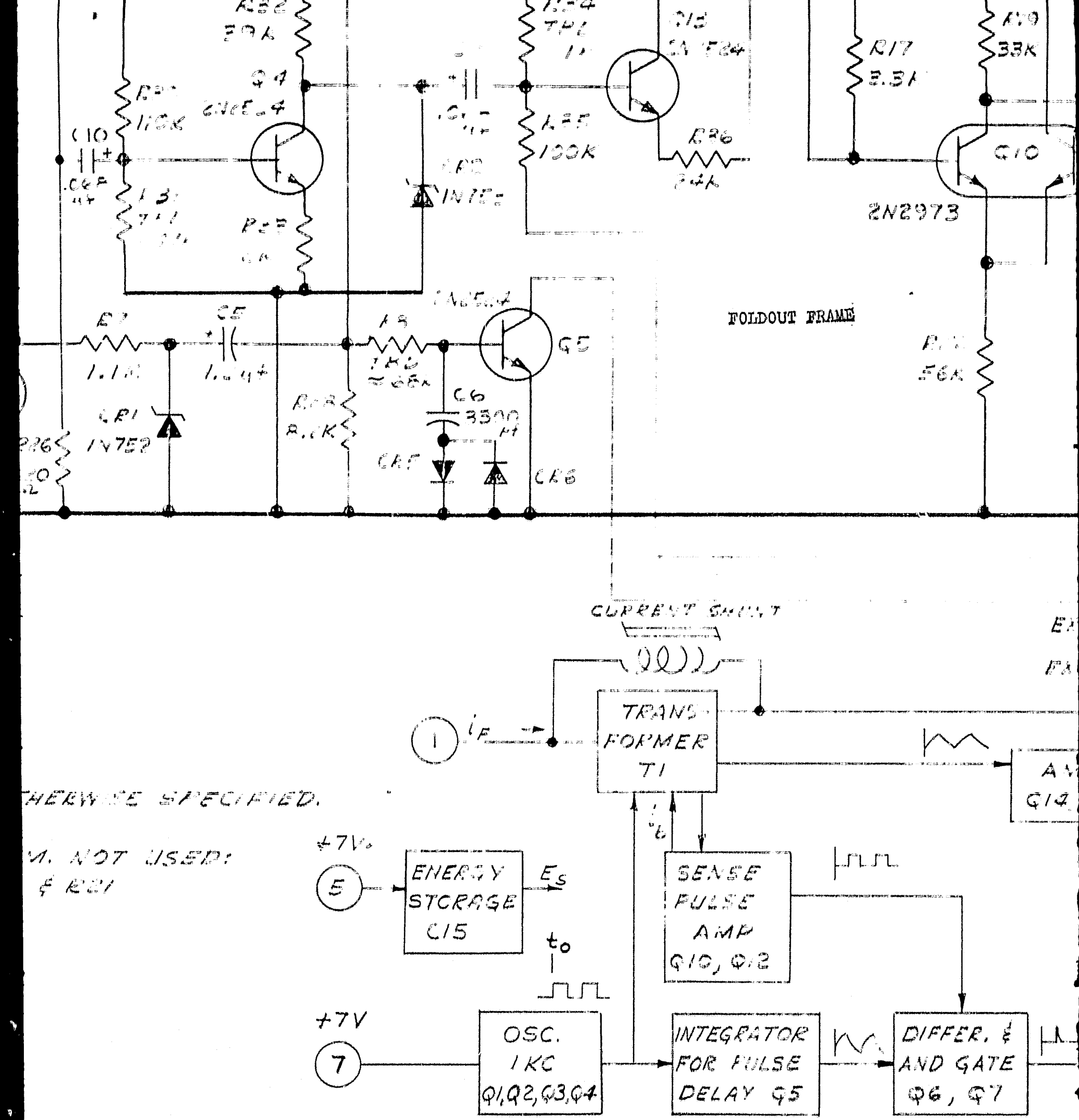


NOTES :

1. ALL DIODES ARE IN645, UNLESS OTHERWISE

2. LAST SYM. USED: CIRCUIT SYM. NOT
R41 R18, R20 & R21
Q14
C15
CR18
T1
K1

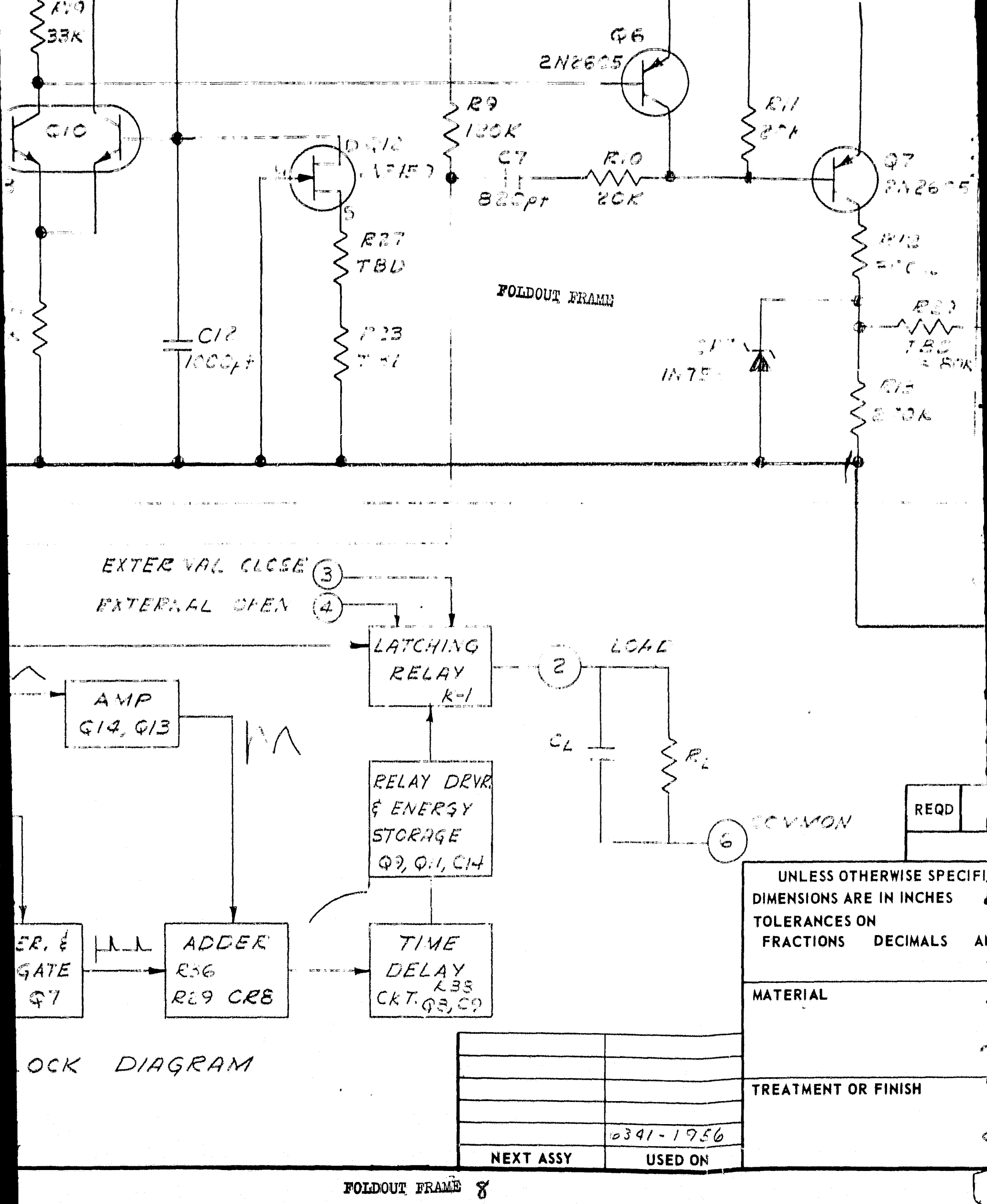
Clearprint 1000H-8 Muth Co.

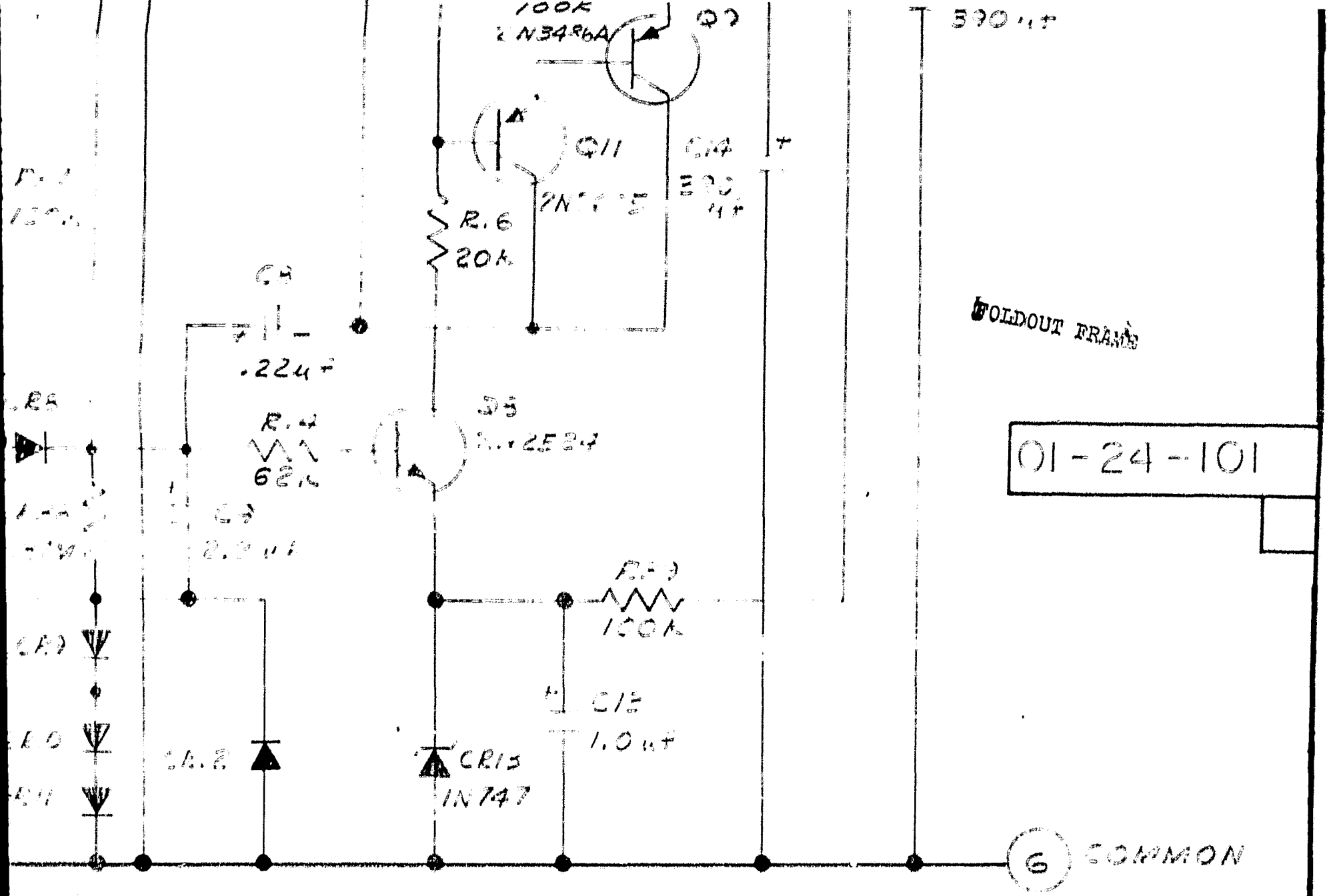


THERWISE SPECIFIED.

M. NOT USED:
& REV

FUNCTIONAL BLOCK D


R19
33K
Q10
R9
130K
Q6
2N2605
R11
C7
820pf
R10
20K
Q7
2N2605
R27
TBD
FOLDOUT FRAME
C12
1000pf
R23
IN753
R15
EXTERNAL CLOSE
3
EXTERNAL OPEN
4
LATCHING
RELAY
K-1
2
LOAD
AMP
Q14, Q13
RELAY DRVR.
& ENERGY
STORAGE
Q2, Q11, C14
C_L
R_L
6
COMMON
ADDER
R36
R29 CR8
TIME
DELAY
CKT. Q8, C9
R38
OCK DIAGRAM
REQD
UNLESS OTHERWISE SPECIFI
DIMENSIONS ARE IN INCHES
TOLERANCES ON
FRACTIONS DECIMALS A
MATERIAL
TREATMENT OR FINISH
0341-1956
NEXT ASSY
USED ON



01-24-101

PRELIMINARY COPY

PART NO.	ITEM	DESCRIPTION	SYM

LIST OF MATERIALS

DRAWN BY M. BELKOSIAN	DATE 10-15-68	EMR-AEROSPACE SCIENCES DIVISION ELECTRO-MECHANICAL RESEARCH, INC. COLLEGE PARK, MARYLAND
CHECKED T.R. Burnett	10-17-68	
ENGINEER	17 Oct 68	ELECTRONIC RESETTABLE FUSE SCHEMATIC
APPROVED	17 Oct 68	
APPROVED K. G. [illegible]	10/17/68	

CODE IDENT NO.	SIZE	
06141	D	01-24-101

SCALE ~ SHEET

FOLDOUT FRAME 9