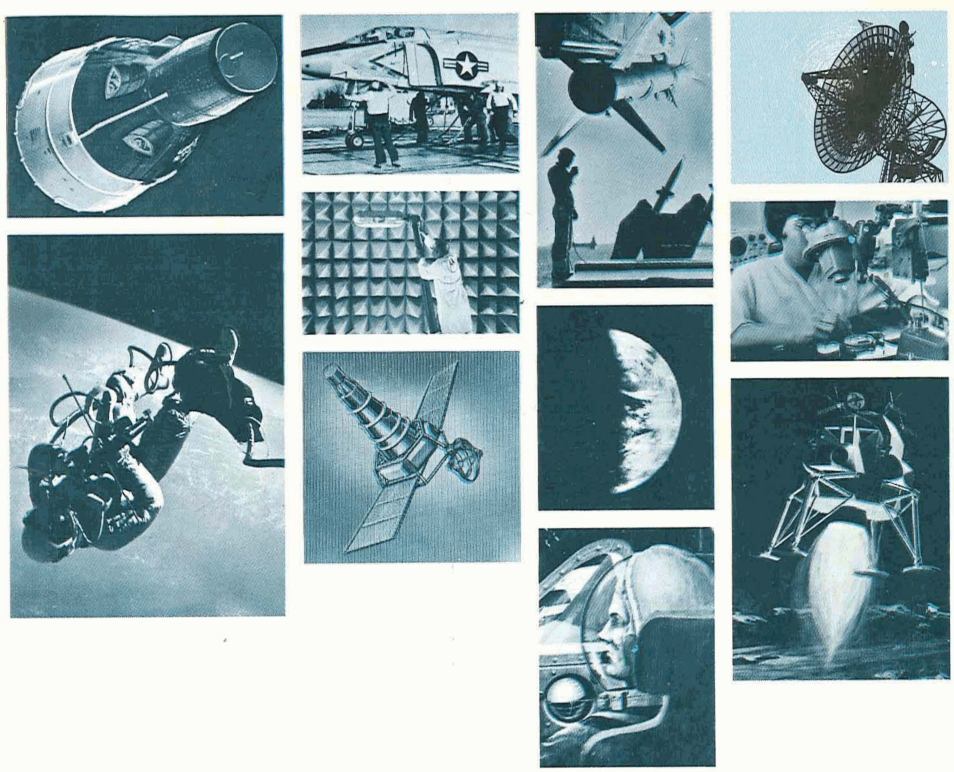
MOTOROLA Government Electronics Division

SCOTTSDALE, ARIZONA 85252



Prepared by: George Borst
George Borst
Project Leader

Approved by: Ken Porter
Ken Porter, Chief Engineer
Space Systems Laboratory

3 March 1969

ENGINEERING FINAL REPORT
FUNCTION GENERATOR
PROTOTYPE CIRCUITS

CASE
COL

Contract No. NAS 8-30032

Prepared For
George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TABLE OF CONTENTS

1.0 INTRODUCTION

This final engineering report covers the work at Motorola, Inc., Government Electronics Division, in the development and fabrication of the Function Generator. The program was to produce 10 prototype circuits.

This report documents the major efforts spent during the program and the performance of the delivered circuits.

2.0 CIRCUIT FABRICATION

2.1 CIRCUIT DESIGN

The circuit design selected to perform this generator function is best described as an analog servo. This design was a closed loop servo response to approximate the desired function. Figure 2.0 is the schematic diagram of the final circuit.

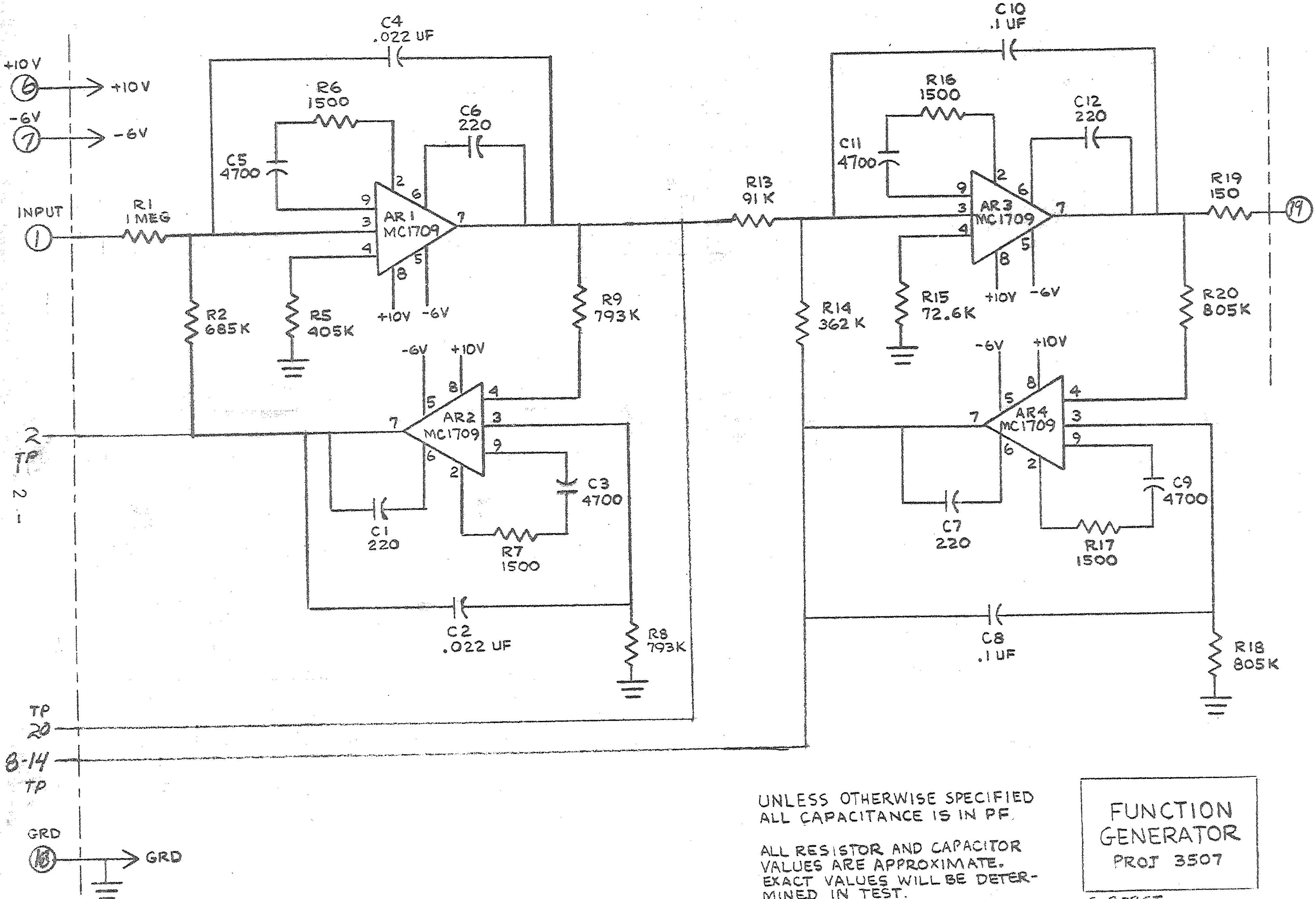
Figure 2.1 is a pictorial layout of the parts inside the package at a 10 to 1 scale.

Figure 2.2 is a drawing of the package used for these Function Generators.

2.2 FABRICATION

The general approach to the fabrication of these circuits was to make up a kit of parts for each circuit. These kits were made up by first selecting and measuring C2, C4, C8 and C10 for each circuit. A calculation was then made to determine the exact values of R2, R8, R14 and R18. R1 was set a 1 Meg ohm and R13 at 91K ohm.

The operational amplifiers, AR1, 2, 3 and 4 were purchased as packaged units and the exact values of R5, R9, R15 and R20



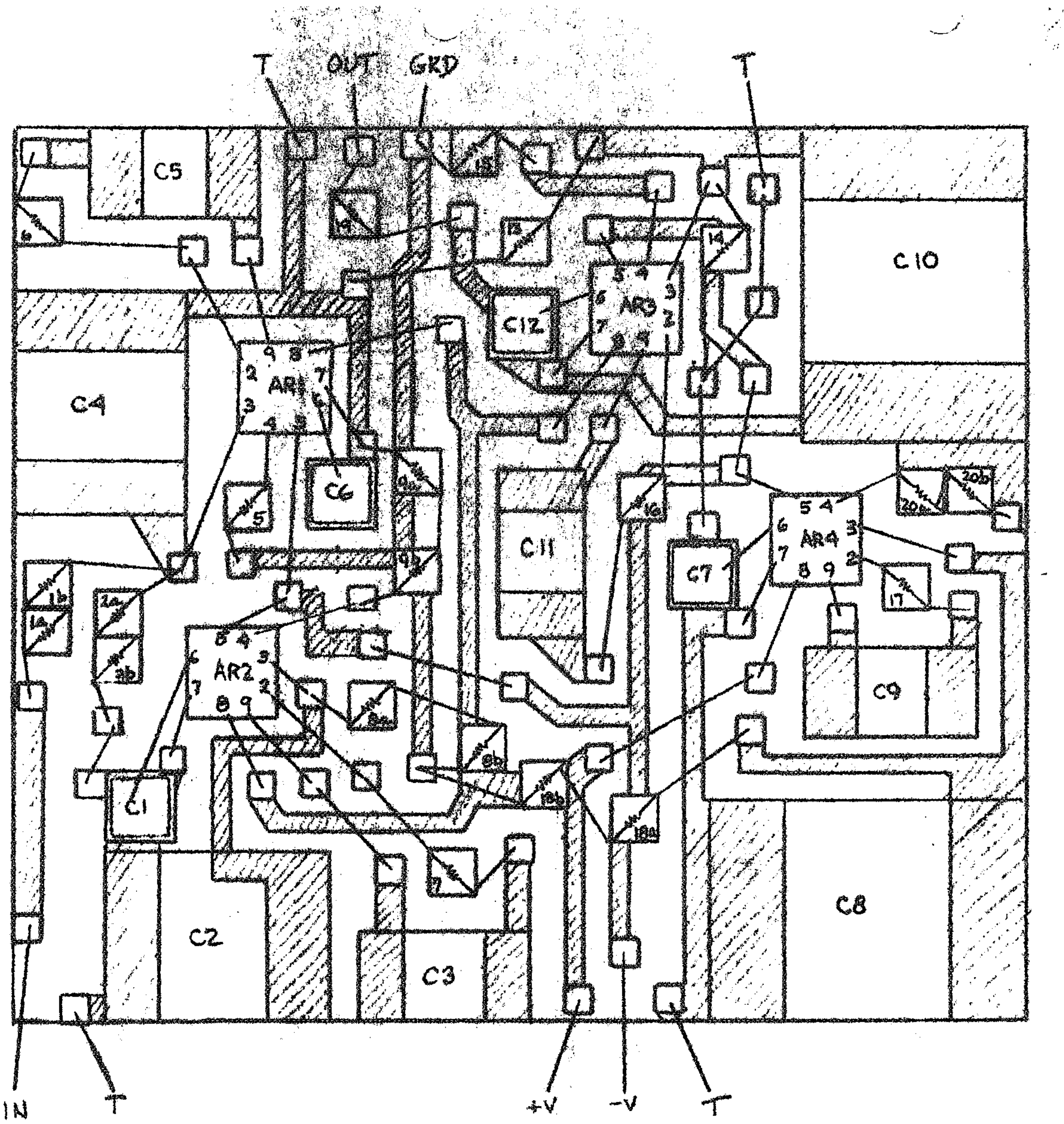
UNLESS OTHERWISE SPECIFIED ALL CAPACITANCE IS IN PF.

ALL RESISTOR AND CAPACITOR VALUES ARE APPROXIMATE. EXACT VALUES WILL BE DETERMINED IN TEST.

FUNCTION GENERATOR
PROJ 3507

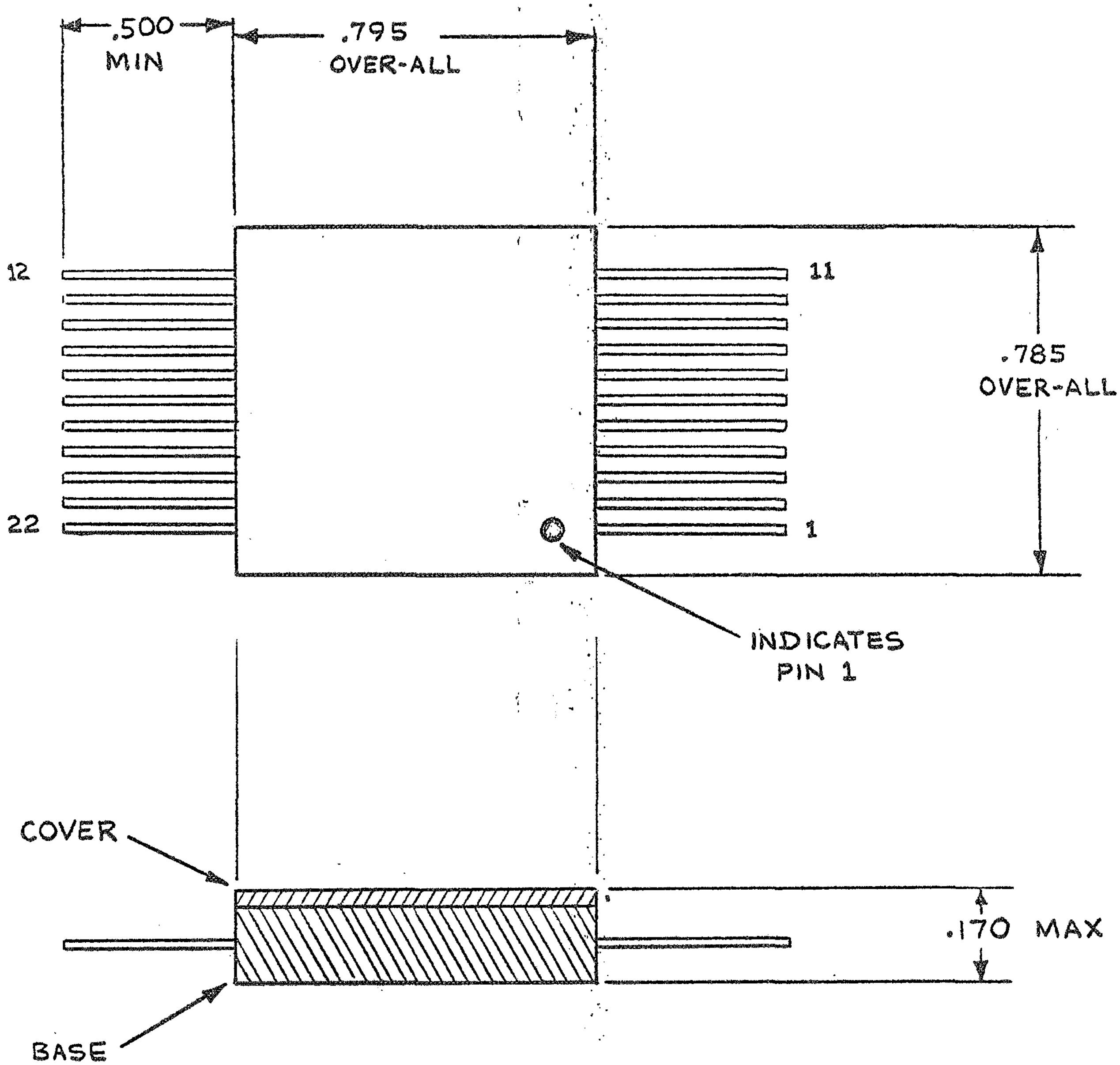
G. BORST

Fig 2.0


T
OUT
GRD
T
C5
C10
C12
AR3
C4
AR1
C6
C11
AR4
C7
AR2
C9
C1
C8
C2
C3
IN
T
+V
-V
T

9-10-68

Fig. 2.1



PREPARED BY MOTOROLA INC.
FOR GEORGE C. MARSHALL
SPACE FLIGHT CENTER, NASA
MARSHALL SPACE FLIGHT CENTER
ALABAMA

MOTOROLA INC. Government Electronics Division AEROSPACE CENTER 8201 EAST McDOWELL ROAD SCOTTSDALE, ARIZONA	SIZE A	CODE IDENT NO. 94990	Fig. 2.2 PACKAGE OUTLINE 70-22459 F
	SCALE	REVISION	SHEET 1 of 1

V-2-A -199H

were determined in a test fixture by using the previously calculated values of resistance for the other components. The remaining components do not enter into the output function determination and were, therefore, measured to meet nominal tolerance specifications only.

2.3 CERAMIC CAPACITORS

A discussion of the effects of temperature on ceramic capacitors is contained in Appendix I. This is an excerpt from an application note which was published by Electro Materials Corporation.

This type of capacitor was used for C2, C4, C8 and C10.

The capacitors which were assembled in the Function Generators had an aging characteristic which was slightly higher than the manufacturer had predicted. The Function Generator output waveform exhibits a shift relating to the capacitor aging. This shift is primarily in timing and not an amplitude change. The positive and negative peaks will each change approximately 0.5% in amplitude as the circuit ages from 1000 to 10,000 hours. A zero crossing shift of approximately 1.5 milliseconds can be expected during this same time period. These numbers have been predicted by using the best aging data available on the capacitors and computing the time response from the transfer function. Preliminary aging data shows that these are valid numbers. This aging characteristic is logarithmic with time. Therefore, these same changes can be expected to take place between 100 and 1000 hours and between 10,000 and 100,000 hours. This aging cycle is started over each time the unit is heated to greater than +115°C. It is therefore recommended that the maximum temperature be limited to +80°C.

3.0 CIRCUIT PERFORMANCE

3.1 TEST DATA SHEETS

Each unit was tested according to the Acceptance Test Procedure (Motorola Document No. 12-22458F01) and the data recorded. This procedure is attached as Appendix II. The data sheets for these units are included here for reference.

3.2 CORRELATION WITH COMPUTER DATA

A program was written which used our SDS engineering computer to plot the output time function from the actual resistor and capacitor values in the circuit.

The results of this program were very useful in enabling us to predict the effects of changes in the various component parameters. This program was not 100% effective, however, probably because the ceramic capacitor and stray substrate leakage currents were not taken into account. For this reason, we were not able to predict the effect of component changes accurately enough to allow us to "trim in" the output function.

3.3 PACKAGE SEALING

It was planned to seal the covers on these units with soft solder. Several units were sealed by this method but a problem developed in doing this and all but one of the units had to be opened. The remaining units were sealed with an epoxy with which we have had experience. All of the units were tested to be hermetic to an equivalent leak rate of 10^{-5} atmosphere cc/sec of Helium.

4.0 CONCLUSIONS

This program has demonstrated that the multichip hybrid type of construction is well suited to this circuit. By using the circuit fabrication techniques as outlined here, there were no major problems in producing these circuits. Circuits fabricated by this construction technique have been demonstrated to be machanically rugged and electrically stable.

The largest single objection to circuit performance is the aging type of variation in the output function. This aging is predictable and decreases with time to a negligable amount. The ceramic capacitors used in the timing circuits are the primary contributor to this variation. As a result of these changes the circuits must be aged at least 1000 hours after their last exposure to temperatures greater than 115°C to meet the stability requirements.

5.0 RECOMMENDATIONS

The effects of capacity aging should be reduced in these circuits. This can be accomplished by increasing the resistor values and decreasing the capacity values in the RC timing networks.

This action, combined with selecting a more stable capacitor, should yield circuits with adequate performance stability.

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 2
Date 12-19-68
Operator C. R. Clevenger
Q.A. (M)
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LOW (Volts)
0	+0.006	+0.57	-0.57
20	+2.391	+2.97	+1.83
40	+3.803	+4.47	+3.33
60	+2.521	+3.27	+2.13
80	+0.440	+1.07	-0.93
100	-0.971	-0.53	-1.67
120	-1.481	-0.98	-2.12
140	-1.483	-0.93	-2.07
180	-1.120	-0.58	-1.72
240	-0.506	0.00	-1.14
320	-0.044	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.004
20	+2.248
40	+3.733
60	+2.685
80	+0.714
100	-0.788
120	-1.407
140	-1.480
180	-1.167
240	-0.569
320	-0.075

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR OUTPUT FUNCTION TESTS +45°C

Unit # 3
Date 12-14-68
Operator [illegible]
Q.A. (M)
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LIMITS LOW (Volts)
0	+0.014	+0.57	-0.57
20	+2.440	+2.97	+1.83
40	+3.924	+4.47	+3.33
60	+2.572	+3.27	+2.13
80	+0.316	+1.07	-0.93
100	-1.137	-0.53	-1.67
120	-1.560	-0.98	-2.12
140	-1.465	-0.93	-2.07
180	-1.055	-0.58	-1.72
240	-0.471	0.00	-1.14
320	-0.021	+0.52	-0.61

OUTPUT FUNCTION TESTS +25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.012
20	+2.330
40	+3.886
60	+2.705
80	+0.526
100	-1.000
120	-1.525
140	-1.486
180	-1.089
240	-0.539
320	-0.052

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 4
Date 12-19-68
Operator C. L. Clevenger
Q.A. (M)
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS	
		HIGH (Volts)	LOW (Volts)
0	+0.001	+0.57	-0.57
20	+2.500	+2.97	+1.83
40	+4.000	+4.47	+3.33
60	+2.480	+3.27	+2.13
80	+0.096	+1.07	-0.93
100	-1.306	-0.53	-1.67
120	-1.597	-0.98	-2.12
140	-1.422	-0.93	-2.07
180	-1.028	-0.58	-1.72
240	-0.471	0.00	-1.14
320	-0.038	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.001
20	+2.346
40	+3.928
60	+2.663
80	+0.389
100	-1.117
120	-1.553
140	-1.438
180	-1.055
240	-0.544
320	-0.070

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 7
Date 12-19-68
Operator C. L. Clevenger
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LOW (Volts)
0	+0.005	+0.57	-0.57
20	+2.482	+2.97	+1.83
40	+4.051	+4.47	+3.33
60	+2.521	+3.27	+2.13
80	+0.096	+1.07	-0.93
100	-1.323	-0.53	-1.67
120	-1.620	-0.98	-2.12
140	-1.419	-0.93	-2.07
180	-1.024	-0.58	-1.72
240	-0.471	0.00	-1.14
320	-0.038	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.001
20	+2.386
40	+3.992
60	+2.683
80	+0.355
100	-1.171
120	-1.587
140	-1.449
180	-1.051
240	-0.536
320	-0.068

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 8
Date 2-19-68
Operator C. L. Clevenger
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LIMITS LOW (Volts)
0	+0.013	+0.57	-0.57
20	+2.635	+2.97	+1.83
40	+4.212	+4.47	+3.33
60	+2.748	+3.27	+2.13
80	+0.244	+1.07	-0.93
100	-1.314	-0.53	-1.67
120	-1.683	-0.98	-2.12
140	-1.512	-0.93	-2.07
180	-1.114	-0.58	-1.72
240	-0.522	0.00	-1.14
320	-0.045	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.007
20	+2.476
40	+4.136
60	+2.886
80	+0.498
100	-1.135
120	-1.616
140	-1.510
180	-1.120
240	-0.581
320	-0.076

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 13
Date 12-19-65
Operator [illegible]
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LIMITS LOW (Volts)
0	-0.002	+0.57	-0.57
20	+2.546	+2.97	+1.83
40	+3.946	+4.47	+3.33
60	+2.611	+3.27	+2.13
80	+0.435	+1.07	-0.93
100	-1.033	-0.53	-1.67
120	-1.558	-0.98	-2.12
140	-1.562	-0.93	-2.07
180	-1.181	-0.58	-1.72
240	-0.535	0.00	-1.14
320	-0.050	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	-0.001
20	+2.403
40	+3.982
60	+2.866
80	+0.764
100	-0.807
120	-1.477
140	-1.571
180	-1.266
240	-0.641
320	-0.101

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 13
Date 12-19-68
Operator C. L. Clevenger
Q.A. (M) 2515
Gov't. Insp. (M) NASA 975

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LOW (Volts)
0	-0.006	+0.57	-0.57
20	+2.361	+2.97	+1.83
40	+3.709	+4.47	+3.33
60	+2.430	+3.27	+2.13
80	+0.392	+1.07	-0.93
100	-0.953	-0.53	-1.67
120	-1.435	-0.98	-2.12
140	-1.439	-0.93	-2.07
180	-1.092	-0.58	-1.72
240	-0.506	0.00	-1.14
320	-0.064	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	-0.004
20	+2.204
40	+3.646
60	+2.608
80	+0.674
100	-0.746
120	-1.341
140	-1.424
180	-1.141
240	-0.580 ~~-0.100~~
320	-0.100

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 14
Date 12-19-68
Operator C. Z. Clevenger
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LIMITS LOW (Volts)
0	-0.023	+0.57	-0.57
20	+2.508	+2.97	+1.83
40	+3.950	+4.47	+3.33
60	+2.447	+3.27	+2.13
80	+0.096	+1.07	-0.93
100	-1.281	-0.53	-1.67
120	-1.565	-0.98	-2.12
140	-1.413	-0.93	-2.07
180	-1.074	-0.58	-1.72
240	-0.509	0.00	-1.14
320	-0.070	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	-0.030
20	+2.376
40	+3.883
60	+2.550
80	+0.281
100	-1.159
120	-1.527
140	-1.400
180	-1.079
240	-0.560
320	-0.103

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 15
Date 12-19-68
Operator C. T. Clevenger
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LIMITS LOW (Volts)
0	+0.009	+0.57	-0.57
20	+2.510	+2.97	+1.83
40	+3.993	+4.47	+3.33
60	+2.636	+3.27	+2.13
80	+0.419	+1.07	-0.93
100	-1.071	-0.53	-1.67
120	-1.602	-0.98	-2.12
140	-1.591	-0.93	-2.07
180	-1.168	-0.58	-1.72
240	-0.501	0.00	-1.14
320	-0.026	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	+0.006
20	+2.371
40	+3.927
60	+2.705
80	+0.683
100	-0.868
120	-1.515
140	-1.577
180	-1.208
240	-0.571
320	-0.057

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # 16
Date 12-19-68
Operator C. L. Clevenger
Q.A.
Gov't. Insp.

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LOW (Volts)
0	-0.026	+0.57	-0.57
20	+2.505	+2.97	+1.83
40	+4.010	+4.47	+3.33
60	+2.682	+3.27	+2.13
80	+0.482	+1.07	-0.93
100	-1.020	-0.53	-1.67
120	-1.580	-0.98	-2.12
140	-1.480	-0.93	-2.07
180	-1.132	-0.58	-1.72
240	-0.589	0.00	-1.14
320	-0.084	+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	-0.036
20	+2.320
40	+3.922
60	+2.560
80	+0.787
100	-0.793
120	-1.492
140	-1.604
180	-1.296
240	-0.691
320	-0.145

MOTOROLA INC. Government Electronics Division AEROSPACE CENTER 8201 EAST McDOWELL ROAD SCOTTSDALE, ARIZONA	SIZE A	CODE IDENT NO. 94990	ACCEPTANCE TEST PROCEDURE 12-22458F01
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APPENDIX I

APPENDIX I

Section II: Temperature Effects

Barium titanate ceramics are crystalline in structure. As the temperature of a high K barium titanate capacitor element is changed over the range of -55°C to +150°C, the measured capacitance value will change considerably. Figures 2 and 3 show the typical curve of percent capacitance change (% Δ C) vs temperature for K12003 dielectrics. This capacitance change is due to changes in the crystalline structure of the material. At approximately 115°C to 125°C (at a point know as a "Curie point") the crystalline structure changes from tetragonal to cubic and the dielectric constant drops sharply, resulting in a sharp decrease in capacitance. (The capacitance change at any temperature is always referenced to the value measured at 25°C while making a single run from the low end to the high end of the operating temperature range, unless otherwise specified.) In general, the higher the "K" of the ceramic, the more pronounced the capacitance change will be over a given temperature range.

Once the Curie temperature of a high K ceramic capacitor has been reached or exceeded, it will not exactly retrace the capacitance vs temperature curve it followed on its initial run. This phenomenon is referred to as an "aging characteristic" and is due to the fact that the crystalline structure of the ceramic dielectric requires a finite time to reestablish its stable state after having been changed due to heating. This effect will always result in an increase in the capacitance value measured at a given temperature; immediately after heating above the Curie point of the material. (This refers to the effect of temperature alone and does not take into account the voltage effects of combined voltage-temperature effects discussed in succeeding sections of these notes.) The "stabilized" value of capacitance for high K dielectrics has arbitrarily been established as the value of capacitance measured 1000 hours after the material has last been heated above its Curie point. K12003 dielectric "ages" at an average rate of -1.75% capacitance change per decade of time. That is, between 0.1 hour and 1.0 hour after being heated above the Curie point, the measured capacitance will decrease by 1.75%. Between 1.0 hour and 10 hours, it will drop another 1.75% and from 10 hours to 100 hours another 1.75%, etc. This is an average figure and the actual aging will vary from lot to lot of materials. Aging may range from less than 1% per decade to 2.0% per decade. This effect is taken into account when capacitors or chips are graded for capacitance value. Limits are set so that the parts will be in tolerance when received by the user and will not have aged out of tolerance when the 1000 hour "stable" point is reached. This explains why parts shipped on a "rush" basis may occasionally measure slightly above the high tolerance limit when received. It must be noted that this aging cycle starts all over again each time the dielectric is heated to or above its Curie point. Figures 4, 5, 6 and 7 are typical capacitance aging curves for K12003 dielectrics. These curves were drawn from data obtained in the first 72 hours of the aging period, and extrapolated to the 1000 hour point. Figures 6 and 7 have the actual capacitance measurements at 1000 hours plotted on the curves for comparison. Aging curves are normally plotted over the full 1000 hour period. These particular curves are included to demonstrate that the aging effect is predictable within the limits of accuracy normally required of high K materials. Higher K dielectrics exhibit increased capacitance aging effects as the K increases. Contrarily, over an operating temperature range of -55°C to +150°C, the capacitance aging of NPO dielectric is so small it is not measurable and can be completely ignored.

APPENDIX II

APPLICATION	
EXT ASSEMBLY	USED ON
	63-22446F01
	70-22459F

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED
-	Initial Release	12-13-6[illegible]	[illegible]

EV / HEET

EV STATUS F SHEETS | REV | SHEET

TERPRET DRAWING IN ACCORDANCE WITH STANDARDS PRESCRIBED BY | FOR PARTS LIST SEE

NLESS OTHERWISE SPECIFIED ALL DIMENSIONS ARE IN INCHES AND END USE. FOR TOLERANCES SEE NOTE	DR BY [illegible]	MOTOROLA INC. Government Electronics Division / AEROSPACE CENTER 8201 EAST McDOWELL ROAD SCOTTSDALE, ARIZONA
	CHK BY	
	MFG / PROJ NO.	ACCEPTANCE TEST PROCEDURE
ATERIAL:	CONTR NO.	
	RELEASE NOTICE	
	APPROVED DATE	SIZE A / CODE IDENT NO. 94990 / 12-22458F01
	APPROVED DATE	SCALE / SHEET 1 OF 5

-1-A

1.0 Test Procedure:

The test procedure shall be as follows:

1.1 Resistor Tests

After the components are assembled in the package and all the resistors are wired, measure each resistor to determine that it is within the tolerance specified. Record this data as an aid to future circuit check out.

1.2 Open Loop Tests

After the monolithic amplifiers (AR1,2,3,and 4) have been wired, perform open loop DC tests to determine that each amplifier is functioning.

1.3 Pre-Seal Test and Adjustment

After the loops have been closed, measure the output function with a 5 volt square wave input. Adjust the resistors as necessary, to produce the proper output function. Use the computer to predict the effect of each specific adjustment on each circuit, if necessary, to reduce the number of adjustments needed.

1.4 Post-Seal Tests

After the circuits have been sealed, the following tests will be performed.

1.4.1 Gross Leak Test

All units must pass a gross leak test in 60°C Isopropyl Alcohol

1.4.2 Electrical Test

The following procedure will be followed for the final electrical test. Using the test setup of Figure 1.4.1 measure the amplitude of the output function at 0, 20, 40, 60, 80, 100, 120, 140, 180, 240, and 320 milliseconds after the input wave form goes to +5.volts. Use the Type W plug-in to determine amplitude. Extreme care must be used in establishing the zero voltage point with the Type W plug-in because of drifts.

The input wave should be calibrated for a positive 5 volt transition using the Type W plug-in. The rise time of the input wave form should be much less than one millisecond.

The data from these tests is to be recorded on the data sheets provided (Figure 1.4.2) and be within the tolerances listed.

The tests are to be repeated at +25°C ± 5°C and +45°C ±5°C.

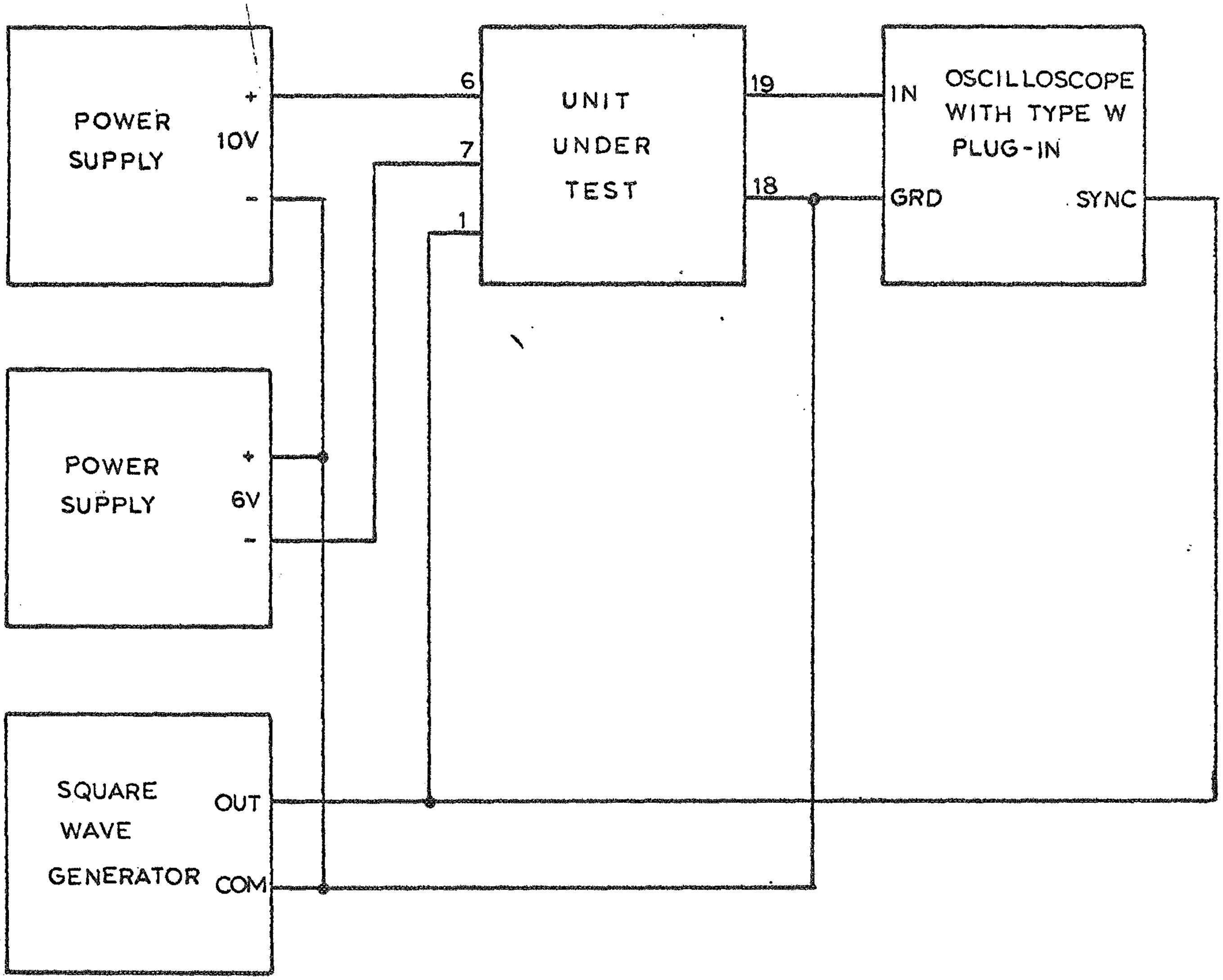
POWER SUPPLY
+
10V
-
POWER SUPPLY
+
6V
-
SQUARE WAVE GENERATOR
OUT
COM
6
7
1
UNIT UNDER TEST
19
18
IN
GRD
OSCILLOSCOPE WITH TYPE W PLUG-IN
SYNC

Figure 1.4.1

Figure 1.4.2 - DATA SHEET

FUNCTION GENERATOR
OUTPUT FUNCTION TESTS
+45°C

Unit # ____
Date ____
Operator ____
Q.A. ____
Gov't. Insp. ____

TIME (milliseconds)	VOLTAGE (Volts)	LIMITS HIGH (Volts)	LOW (Volts)
0		+0.57	-0.57
20		+2.97	+1.83
40		+4.47	+3.33
60		+3.27	+2.13
80		+1.07	-0.93
100		-0.53	-1.67
120		-0.98	-2.12
140		-0.93	-2.07
180		-0.58	-1.72
240		0.00	-1.14
320		+0.52	-0.61

OUTPUT FUNCTION TESTS
+25°C

TIME (milliseconds)	VOLTAGE (Volts)
0	
20	
40	
60	
80	
100	
120	
140	
180	
240	
320	