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TRW SYSTEMS

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

NASA CR 65986

STUDY

HIGH DIELECTRIC CONSTANT THIN FILM CAPACITOR MATERIALS

MATERIALS REPORT

DELIVERABLE HARDWARE PROCESS SPECIFICATIONS AND TEST DATA

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Prepared for
NASA MANNED SPACECRAFT CENTER
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ILLUSTRATIONS

SCOPE

This document describes the items of deliverable hardware required under NASA Contract Number NAS 9-5592, "Study - High Dielectric Constant Thin Film Capacitor Materials". The hardware consists of numerous substrates containing sodium niobate capacitors and substrates containing the sodium niobate dielectric material only. The materials and processes used in fabricating the hardware are delineated. Various tests performed on the hardware, such as temperature coefficient of capacitance, frequency response, D. C. leakage, voltage breakdown, and stability are described and the test results shown. In addition, the capacity and dissipation factor of all substrates are indicated along with the dielectric thickness and the calculated dielectric constant.

HARDWARE

Capacitors

The hardware delivered in fulfillment of contractual requirements for NASA Contract Number NAS 9-5592 consists of fourteen capacitor substrates containing a total of 199 unshorted capacitors (between twelve and sixteen unshorted capacitors per substrate), and three substrates containing the dielectric material only. The capacitor configuration is as shown in Figure 1, Page 5. Each capacitor contains an effective counter electrode area of 0.016 cm^2. The capacitor numbering system is indicated in Figure 1 for convenience of referencing with the data sheets. The capacitor substrates delivered are as follows:

Run Number	Substrates	Number of Unshorted Capacitors
N3	A, B, C, D	58
N6	A	15
N7	A	12
N17	A	13
N19	B, C, D	43
N20	A, B, C, D	58

All of the capacitors contain aluminum base-electrodes and aluminum counter-electrodes. The substrate material is quartz (0.460" x 0.460" x 0.060") and the dielectric material is sodium niobate. The capacity and dissipation factors were read on a General Radio Model 1650-A impedance bridge at a test frequency of lkc. The initial readings of the capacity and the dissipation factor for all capacitors appear in Tables I(a) - I(f), Pages 6 through 11.

The dielectric thickness for each run has been determined and appears on the data sheets, Tables I(a) through I(f). Using this dielectric thickness and an average capacitor value for the run, the dielectric constant for each run has been calculated and also appears in Tables I(a) through I(f).

Dielectric Samples

The three dielectric samples are designated as run N21, substrates A, B, and C. They consist of sodium niobate evaporated on quartz substrates. The geometric configuration is identical to that of the dielectric deposition on the capacitor substrates. The dielectric thickness as measured on this run is 1460 Å.

DEPOSITIONAL APPROACH *

The approach used for depositing of sodium niobate dielectric has been designated the "Molten Sphere Technique". The process involves powder feeding sodium carbonate powder on to an electron beam heated sphere of molten niobium (Figure 2, Page 12).

The equipment, materials, and procedure are all delineated on Pages 13 through 16.

STABILITY

Upon completion of the capacitor substrates, all were stored at room temperature in a dessicator. After thirty days, all capacitors were reread for capacity and dissipation factor. The results are tabulated in Tables II(a) - II(f), Pages 18 through 23.

The average capacity and dissipation factor for each substrate were calculated for both the initial readings and again after thirty days. These numbers are indicated in Table III, Page 24, along with the per cent change in capacity and dissipation factor for the thirty day storage period.

* - Reference: Letter from George C. Thompson, TRW Systems, to Marvin F. Mathews, NASA, dated March 10, 1967, "Interim Report of New Technology Under NASA Contract NAS 9-5592"

TEMPERATURE COEFFICIENT OF CAPACITANCE

Representative substrates were selected from each of the runs being delivered as hardware for the performance of temperature coefficient tests. In general, the actual capacitors tested are not those being delivered, since the series of tests culminated in a destructive voltage breakdown test. In the case of run N3 and N20 where all four substrates from the run are being delivered, all tests were performed on the deliverable hardware with the exception of the D. C. leakage and voltage breakdown tests.

The temperature coefficients were determined for the temperature range of 20°C - 100°C and the results appear on Graph I, Page 25. It will be noted that the T. C.'s range from a low of 631 ppm/°C (N7-C5) to a high of 7875 ppm/°C (N6-B12). Note the change of scale for N3-D7.

FREQUENCY TEST

Utilizing the test set up indicated in Figure 4, Page 26, the capacity and dissipation factor of the test capacitors were examined as a function of frequency in the range of 300 cps to 40,000 cps. The results are depicted in Table 4, Pages 27 through 29. The 1kc ratings have been blocked out for ease of reference. It will be noted that the dissipation factor decreases drastically as a function of increasing test frequency. The capacity also experiences a decrease with increasing frequency, but not nearly so drastically as the dissipation factor.

D. C. LEAKAGE AND BREAKDOWN VOLTAGE TEST

The test samples were monitored for D. C. leakage as a function of increasing voltage with the test set up shown in Figure 5, Page 30. The results appear in Table 5, Page 31. The voltage was increased until failure occurred. It will be noted that this failure occurs in the range of two to three volts. Since all of these capacitor substrates from runs N3 and N20 are being delivered, this test was not performed on samples from these two runs.

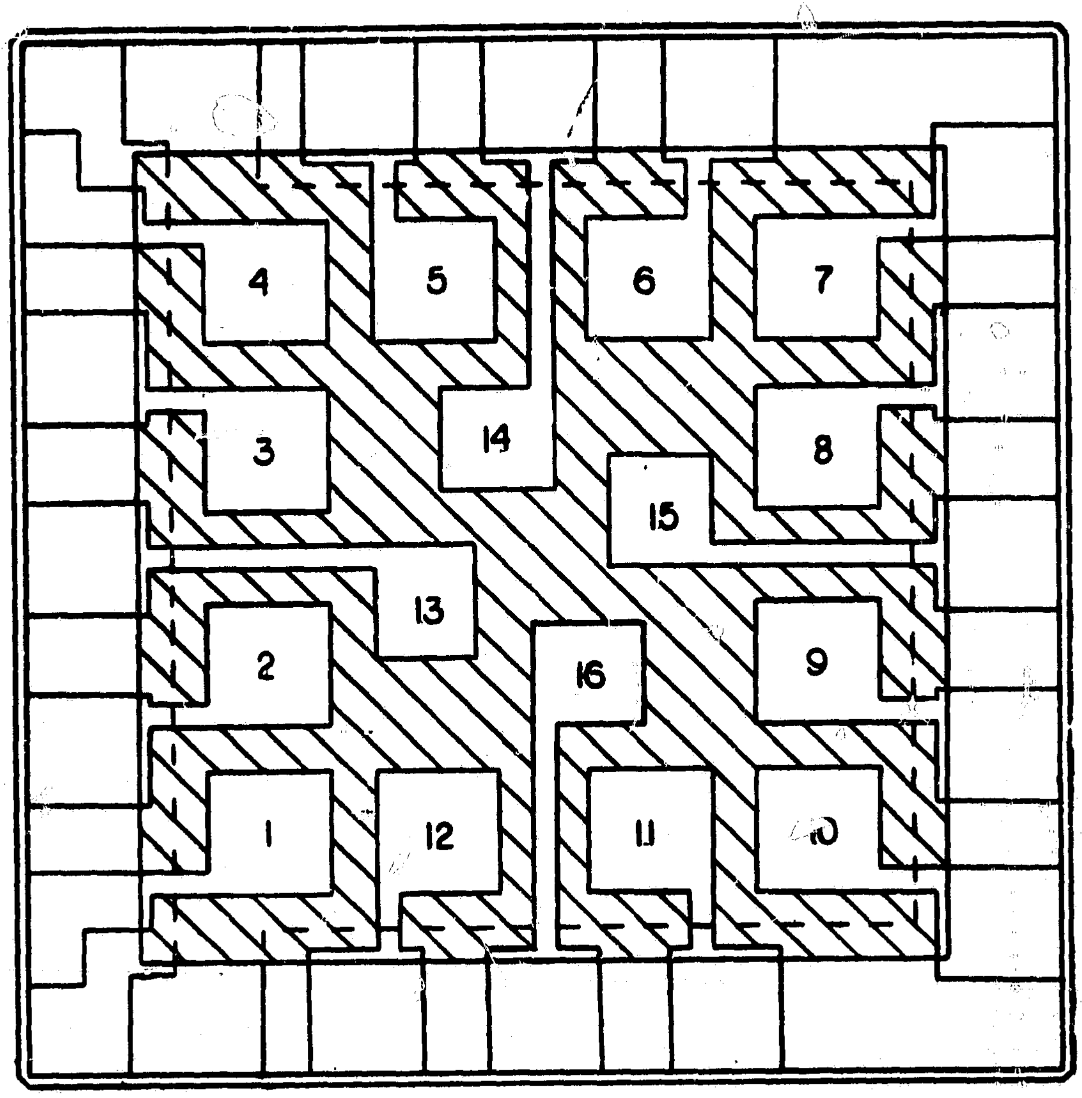


Figure 1. Capacitor Test Pattern

Run No. N3

Thickness = 5300 Å
"k" = 477
Cap. of Calc. = 15.5 nf

TABLE I(a)
$NaNbO_3$ Capacitors
Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	12.6	0.32	14.5	0.24	17.4	0.16	14.2	0.27
	2 - 6 -10 -14	Short		15.7	0.19	16.9	0.17	16.3	0.21
	3 - 7 -11 - 15	Short		16.2	0.18	16.5	0.16	18.4	0.19
	4 - 8 -12 - 16	10.6	0.37	16.9	0.18	14.8	0.20	16.3	0.19
B	1 - 5 - 9 - 13	15.7	0.14	15.6	0.20	14.8	0.17	17.0	0.29
	2 - 6 -10 - 14	15.8	0.14	16.7	0.27	16.4	0.12	17.5	0.33
	3 - 7 -11 - 15	15.7	0.17	15.6	0.13	16.2	0.19	18.2	0.36
	4 - 8 -12 - 16	14.2	0.21	15.2	0.19	15.8	0.17	17.1	0.28
C	1 - 5 - 9 - 13	15.2	0.11	15.4	0.11	15.7	0.14	16.2	0.18
	2 - 6 -10 - 14	15.7	0.15	15.4	0.12	15.0	0.17	16.0	0.14
	3 - 7 -11 - 15	15.7	0.14	15.4	0.13	Short		16.7	0.15
	4 - 8 -12 - 16	15.4	0.12	15.9	0.12	15.2	0.13	16.4	0.19
D	1 - 5 - 9 - 13	15.4	0.14	15.8	0.17	Open		Short	
	2 - 6 -10 - 14	16.0	0.16	14.3	0.13	14.8	0.14	15.5	0.18
	3 - 7 -11 - 15	16.2	0.18	14.3	0.18	15.6	0.13	16.3	0.18
	4 - 8 -12 - 16	15.1	0.18	15.5	0.14	16.3	0.13	17.4	0.30

Run No. N3

Run No. N6

Thickness = 3800 Å
"k" = 61
Cap. of Calc. = 3 nf

TABLE I(b)
$NaNbO_3$ Capacitors
Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	1.61	.024	2.65	.08	3.20	.03	2.45	.026
	2 - 6 -10 -14	1.62	.024	Open		2.85	.03	3.[illegible]2	.150
	3 - 7 -11 - 15	1.62	.024	3.15	.028	2.43	.028	3.54	.030
	4 - 8 -12 - 16	Short		3.35	.026	5.80	.08	2.8	.030
B	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								

Run No. N6

Run No. N7

Thickness = 4500 Å
"k" = 52
Cap. of Calc. = 2 nf

TABLE I(c)
$NaNbO_3$ Capacitors
Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	2.05	.039	1.93	.026	2.07	.024	1.98	.024
	2 - 6 -10 -14	1.98	.038	Short		2.20	.034	Short	
	3 - 7 -11 - 15	1.96	.034	Short		2.05	.028	Short	
	4 - 8 -12 - 16	1.92	.029	2.07	.022	2.03	.030	2.10	.028
B	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								

Run No. N7

Run No. N17

Thickness = 3800 Å
"k" = 110
Cap. of Calc. = 5 nf

TABLE I(d)

$NaNbO_3$ Capacitors

Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	4.7	.10	4.7	.10	5.5	.10	Short	
	2 - 6 -10 -14	4.55	.085	4.7	.092	5.4	.10	5.2	
	3 - 7 -11 - 15	4.56	.10	5.8	.135	5.0	.08	Open	
	4 - 8 -12 - 16	4.55	.128	5.15	.085	4.9	.08	Short	
B	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								

Run No. N17

Run No. N19

Thickness = 3680 Å
"k" = 48
Cap. of Calc. = 2.25 nf

TABLE I(e)
$NaNbO_3$ Capacitors
Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13								
	2 - 6 -10 -14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
B	1 - 5 - 9 - 13	2.13	.041	2.05	.040	2.07	.034	2.16	.040
	2 - 6 -10 - 14	2.12	.048	2.03	.036	2.16	.037	2.09	.036
	3 - 7 -11 - 15	2.05	.038	2.11	.033	2.10	.036	2.14	.036
	4 - 8 -12 - 16	2.03	.044	2.06	.030	Short		2.17	.039
C	1 - 5 - 9 - 13	Short		2.31	.044	2.29	.044	2.36	.044
	2 - 6 -10 - 14	2.24	.044	2.33	.042	2.37	.042	2.38	.045
	3 - 7 -11 - 15	2.37	.044	2.47	.041	2.32	.14	2.43	.043
	4 - 8 -12 - 16	2.35	.042	2.40	.044	Short		Short	
D	1 - 5 - 9 - 13	2.30	.055	2.24	.042	2.33	.05	2.30	.046
	2 - 6 -10 - 14	Short		2.27	.044	2.37	.051	2.40	.050
	3 - 7 -11 - 15	2.17	.04	2.43	.05	2.28	.056	2.52	.050
	4 - 8 -12 - 16	2.20	.04	2.42	.052	2.23	.044	2.38	.052

Run No. N19

Run No. N20

Thickness = 5250 Å
"k" = 67.3
Cap. of Calc. = 2.2 nf

TABLE I(f)
$NaNbO_3$ Capacitors
Initial Readings

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	2.30	.050	2.08	.037	2.15	.036	Short	
	2 - 6 -10 -14	2.19	.052	2.04	.034	2.19	.037	2.18	.036
	3 - 7 -11 - 15	2.17	.040	2.14	.036	2.17	.045	2.33	.036
	4 - 8 -12 - 16	2.04	.039	2.18	.037	2.11	.040	Short	
B	1 - 5 - 9 - 13	2.27	.039	Short		2.17	.033	2.35	.037
	2 - 6 -10 - 14	2.23	.038	2.18	.033	2.22	.033	2.33	.032
	3 - 7 -11 - 15	2.22	.041	2.25	.033	2.22	.036	2.30	.036
	4 - 8 -12 - 16	2.18	.038	2.22	.036	2.22	.037	2.34	.040
C	1 - 5 - 9 - 13	2.12	.055	2.15	.055	2.12	.053	2.27	.061
	2 - 6 -10 - 14	2.20	.070	2.13	.053	2.11	.050	2.20	.048
	3 - 7 -11 - 15	2.17	.060	2.20	.059	2.17	.044	2.23	.048
	4 - 8 -12 - 16	2.12	.051	2.19	.063	2.23	.077	2.25	.062
D	1 - 5 - 9 - 13	2.30	.051	2.25	.063	2.27	.060	2.33	.048
	2 - 6 -10 - 14	2.29	.051	Open		2.54	.099	Short	
	3 - 7 -11 - 15	2.22	.051	2.33	.060	2.46	.090	2.44	.063
	4 - 8 -12 - 16	2.23	.055	2.34	.062	2.37	.070	Short	

Run No. N20

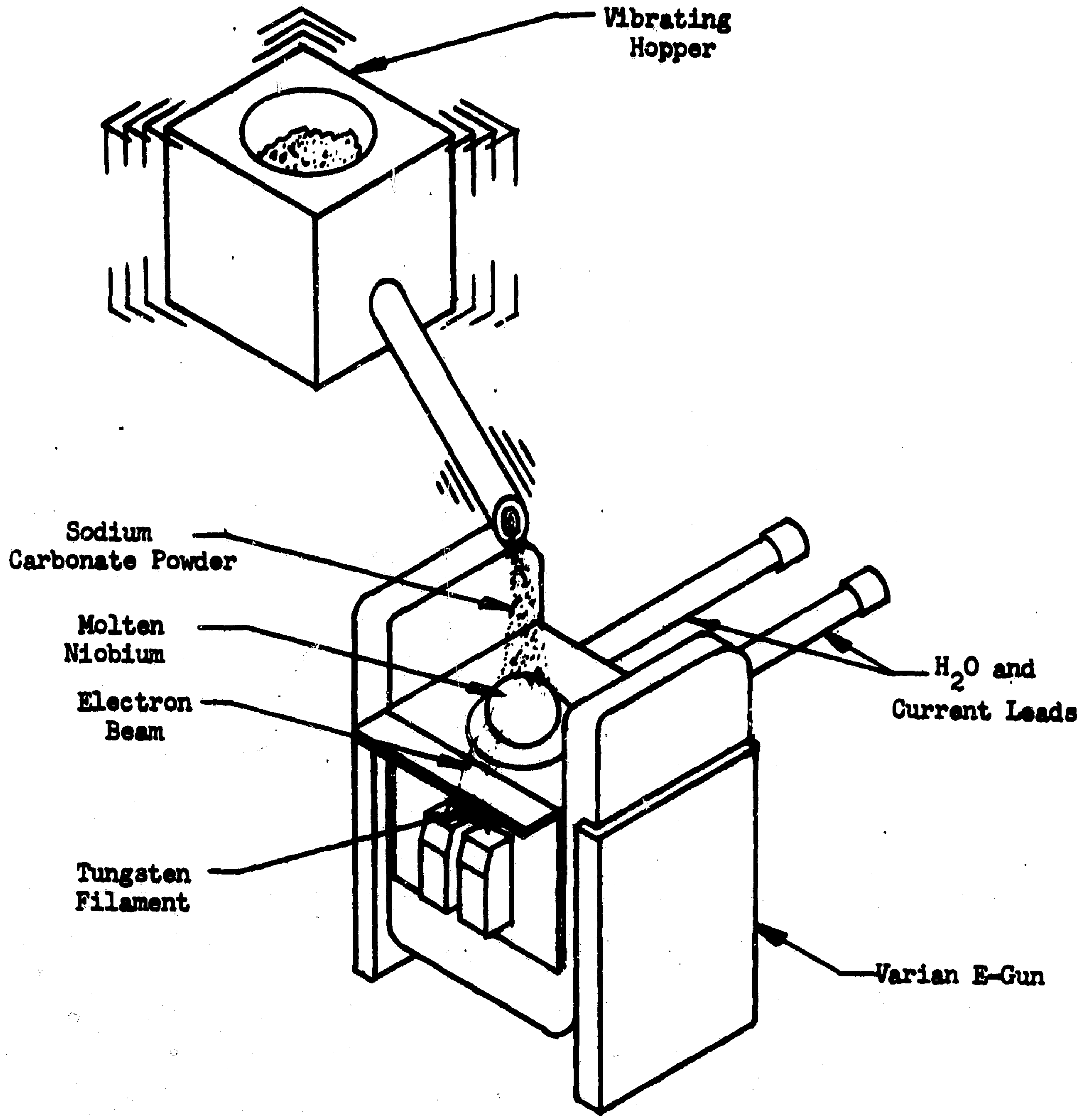


Figure 2. "Molten Sphere Technique"

* - Reference: Letter from George C. Thompson, TRW Systems, to Marvin F. Mathews, NASA, dated March 10, 1967, "Interim Report of New Technology Under NASA Contract NAS 9-5592"

$NaNbO_3$ DEPOSITION PROCESS

Equipment

High vacuum system with 18" x 30" bell jar and feedthrough collar

Varian "e" gun, Model Number 980-0001

Varian "e" gun power supply, Model Number 922-0020

Powder feed mechanism, per attached drawing (Figure 3)

Substrate holder, mask holder, and appropriate masks

Substrate heater (capable of achieving 450°C substrate temperature)

Pressure regulator, Granville Phillips, Model Number 213001

Oven (temperature up to 500°C), Hevi-Duty, Model Number 051-PT or equivalent

Materials

Niobium metal - 0.040" diameter wire, 99.5%, Electronic Space Products, Inc., No. K3654D

Na_2CO_3 - Analytical Reagent Grade, Mallinckrodt Chemical Company

Aluminum metal - 0.023" diameter wire, 99.999%, Electronic Space Products, Inc., Number K234K

Quartz - 0.046" x 0.046" x 0.060", General Electric, Number ESPJ

Tungsten resistance source, R. D. Mathis Company, Number B12B or equivalent

Bottled oxygen supply

Labtone glass cleaner, Van Waters and Rogers, Inc.

PROCEDURE

I. Substrate Cleaning

1. Scrub in D.I. water and labtone cleaner with soft brush.
2. Rinse with D.I. water.
3. Rinse with Reagent Grade Methyl Alcohol.
4. Dry in hot air stream.

II. Aluminum Base Electrode Deposition

1. Place 8" of 0.023" diameter aluminum wire in W basket source.
2. Place substrates in holder, mask holder, and appropriate mask directly over source at a source-to-substrate distance of 25 cm.
3. Close shutter between source and substrate.
4. Evacuate system to $< 8 \times 10^{-6}$ torr.
5. Turn on substrate heater and bring substrate temperature to 280°C.
6. Fuse aluminum charge and outgas. Leave shutter closed until pressure drops to $<8 \times 10^{-6}$ torr.
7. Open shutter.
8. Evaporate to completion ($\approx$ 20 sec.).
9. Turn off substrate heater.
10. Cool to <100°C ($\approx$ 20 min.).
11. Close high vacuum valve, bleed to atmosphere, remove substrates and holder from system.

III Dielectric Deposition *

1. Fill powder feed hopper with $NA_2\ CO_3$.
2. Load ≈ 2.0 gm of rolled up Niobium wire on e-gun hearth.
3. Load Substrate Holder - Mask Holder over e-gun (Source - Substrate distance = 20 cm).
4. Evacuate System to 5×10^{-5} torr.
5. Bring Substrate temperature up to $350^{\circ}C$.
6. Turn on e-gun power supply.
7. Raise "Emission Adjust" knob until Niobium metal just becomes molten. (≈ 50 - 60 ma).
8. Turn on powder feed power supply. Feed $Na_2\ CO_3$ at maximum rate which will not produce ionization. (Approx. 0.05 gm/min.) - Continue for ten minutes.
9. Admit O_2 through pressure controller to pressure of 1×10^{-4} torr.
10. Adjust "Emission Adjust" knob to achieve current 10 ma above that used in Step Number 7 (i.e., 60 - 70 ma).
11. Deposit for 180 minutes.
12. Turn off Powder Feed and e-gun power.
13. Raise Substrate temperature to $450^{\circ}C$ while maintaining O_2 pressure at 1×10^{-4} torr.
14. Maintain for thirty minutes at $450^{\circ}C$ temperature.
15. Turn off substrate heater.
16. Cool in high residual O_2 for thirty minutes.
17. Close high vacuum valve, bleed to atmosphere, and remove substrates from system.

* - Reference: Letter from George C. Thompson, TRW Systems, to Marvin F. Mathews, NASA, dated March 10, 1967, "Interim Report of New Technology Under NASA Contract NAS 9-5592"

IV. Heat Treatment

1. Place substrates, still in substrate holder, in high temperature oven.

2. Heat in air for sixteen hours at 450°C.

3. Remove from oven.

V. Aluminum Counter-Electrode Deposition

1. Repeat all of II (see II, "Aluminum Base-Electrode Deposition," steps 1 through 11).

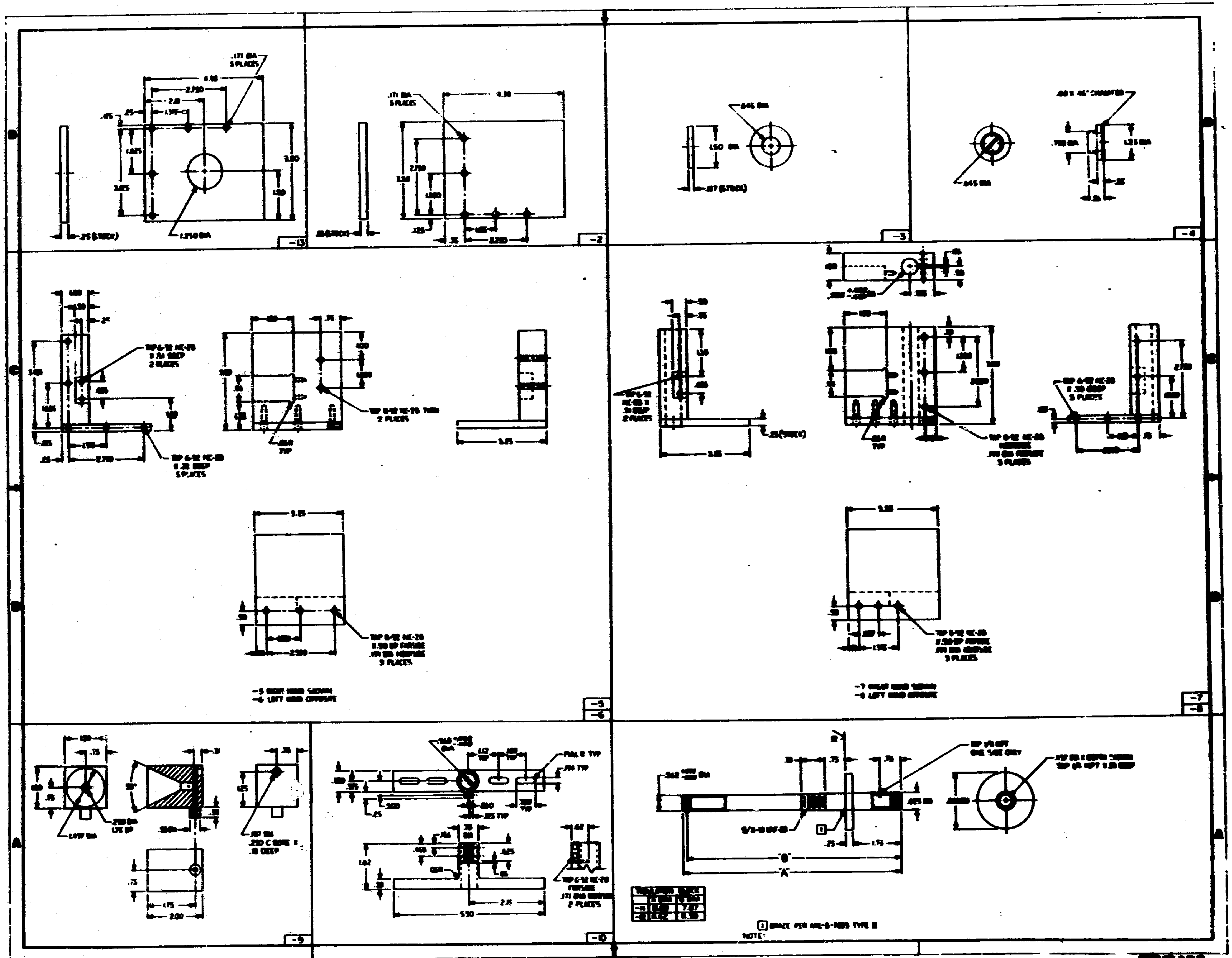


Figure 3. Powder Feed Mechanism

Run No. N3

TABLE II (a)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	9.9	.33	10.5	.27	12.0	.19	10.6	.30
	2 - 6 -10 -14	Short		11.1	.20	11.7	.18	11.4	.22
	3 - 7 -11 - 15	Short		11.4	.19	11.4	.18	12.7	.22
	4 - 8 -12 - 16	8.0	.36	11.7	.19	10.9	.24	11.6	.23
B	1 - 5 - 9 - 13	12.9	.19	12.0	.29	11.7	.28	Short	
	2 - 6 -10 - 14	12.8	.20	12.8	.31	12.5	.20	13.7	.37
	3 - 7 -11 - 15	12.2	.21	12.1	.24	12.6	.22	14.0	.41
	4 - 8 -12 - 16	10.9	.28	11.8	.28	12.6	.21	13.5	.32
C	1 - 5 - 9 - 13	11.6	.11	11.7	.15	11.1	.18	12.2	.19
	2 - 6 -10 - 14	11.4	.14	11.1	.18	10.4	.18	12.0	.17
	3 - 7 -11 - 15	11.5	.14	11.0	.21	Short		12.2	.18
	4 - 8 -12 - 16	11.5	.13	11.4	.19	11.6	.13	12.1	.21
D	1 - 5 - 9 - 13	11.5	.12	11.3	.17	Open		Short	
	2 - 6 -10 - 14	11.6	.17	11.0	.12	11.4	.11	11.7	.19
	3 - 7 -11 - 15	11.6	.20	11.1	.13	11.3	.12	12.2	.19
	4 - 8 -12 - 16	10.7	.16	11.7	.11	11.6	.13	13.2	.40

Run No. N3

Run No. N6

TABLE II (b)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	1.60	.021	Short		3.15	.026	2.40	.024
	2 - 6 - 10 - 14	1.60	.023	2.61	.066	2.81	.024	3.06	.13
	3 - 7 - 11 - 15	1.60	.021	3.07	.026	2.37	.024	3.49	.024
	4 - 8 - 12 - 16	1.63	.023	3.30	.022	5.61	.071	2.74	.024
B	1 - 5 - 9 - 13								
	2 - 6 - 10 - 14								
	3 - 7 - 11 - 15								
	4 - 8 - 12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 - 10 - 14								
	3 - 7 - 11 - 15								
	4 - 8 - 12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 - 10 - 14								
	3 - 7 - 11 - 15								
	4 - 8 - 12 - 16								

Run No. N6

Run No. N7

TABLE II (c)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	2.25	.070	2.22	.090	2.14	.052	2.16	.072
	2 - 6 -10 -14	2.19	.075	Short		2.37	.070	Short	
	3 - 7 -11 - 15	2.19	.082	Short		2.23	.072	Short	
	4 - 8 -12 - 16	2.14	.068	2.16	.054	2.18	.057	2.27	.079
B	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								

Run No. N7

Run No. N17

TABLE II (d)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	4.67	.097	Short		5.80	.11	4.90	.083
	2 - 6 -10 -14	4.59	.088	4.81	.095	5.71	.12	5.32	.086
	3 - 7 -11 - 15	4.71	.11	5.80	.14	5.01	.076	Open	
	4 - 8 -12 - 16	Short		5.47	.079	4.88	.084	5.30	.085
B	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
C	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
D	1 - 5 - 9 - 13								
	2 - 6 -10 - 14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								

Run No. N17

Run No. N19

TABLE II (e)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13								
	2 - 6 -10 -14								
	3 - 7 -11 - 15								
	4 - 8 -12 - 16								
B	1 - 5 - 9 - 13	2.11	.034	2.05	.036	2.06	.031	2.14	.038
	2 - 6 -10 - 14	2.10	.045	2.01	.031	2.16	.030	2.07	.036
	3 - 7 -11 - 15	2.02	.036	2.09	.028	2.08	.032	2.15	.037
	4 - 8 -12 - 16	2.02	.036	2.04	.026	Short		2.17	.036
C	1 - 5 - 9 - 13	Short		2.23	.035	2.23	.031	2.31	.034
	2 - 6 -10 - 14	2.14	.030	2.23	.032	2.30	.041	2.32	.040
	3 - 7 -11 - 15	2.20	.032	2.42	.044	2.3	.23	2.37	.036
	4 - 8 -12 - 16	2.24	.034	2.32	.041	Short		Short	
D	1 - 5 - 9 - 13	2.45	.036	2.25	.049	2.38	.067	2.30	.044
	2 - 6 -10 - 14	Short		2.32	.056	2.41	.062	2.47	.069
	3 - 7 -11 - 15	2.19	.049	2.57	.076	2.36	.077	2.53	.061
	4 - 8 -12 - 16	2.22	.045	2.45	.060	2.21	.042	2.43	.064

Run No. N19

Run No. N20

TABLE II (f)
$NaNbO_3$ Capacitors
Thirty Days After Deposition

Substrate	Capacitor No.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.	C (nf)	D. F.
A	1 - 5 - 9 - 13	2.37	.058	2.14	.051	2.26	.061	Short	
	2 - 6 -10 -14	2.27	.059	2.05	.038	2.27	.053	2.22	.052
	3 - 7 -11 - 15	2.15	.057	2.25	.055	2.48	.080	2.47	.064
	4 - 8 -12 - 16	2.07	.047	2.25	.051	2.17	.055	Short	
B	1 - 5 - 9 - 13	2.33	.044	Short		2.15	.034	2.39	.042
	2 - 6 -10 - 14	2.30	.042	2.17	.034	2.20	.032	2.31	.034
	3 - 7 -11 - 15	2.28	.050	2.23	.034	2.22	.038	2.30	.039
	4 - 8 -12 - 16	2.22	.037	2.22	.043	2.25	.044	2.38	.049
C	1 - 5 - 9 - 13	2.34	.12	2.36	.095	2.37	.085	2.52	.12
	2 - 6 -10 - 14	2.55	.14	2.27	.085	2.30	.087	2.33	.086
	3 - 7 -11 - 15	2.36	.11	2.47	.105	2.15	.073	2.34	.085
	4 - 8 -12 - 16	2.26	.095	2.47	.11	2.75	.15	2.55	.13
D	1 - 5 - 9 - 13	2.48	.092	2.90	.14	2.65	.10	2.54	.084
	2 - 6 -10 - 14	2.38	.087	Open		3.54	.189	Short	
	3 - 7 -11 - 15	2.43	.088	2.96	.14	3.13	.16	2.80	.11
	4 - 8 -12 - 16	2.54	.11	2.74	.13	2.69	.11	Short	

Run No. N20

Table III. Na NbO_3 Capacitors 30 Day Aging Data

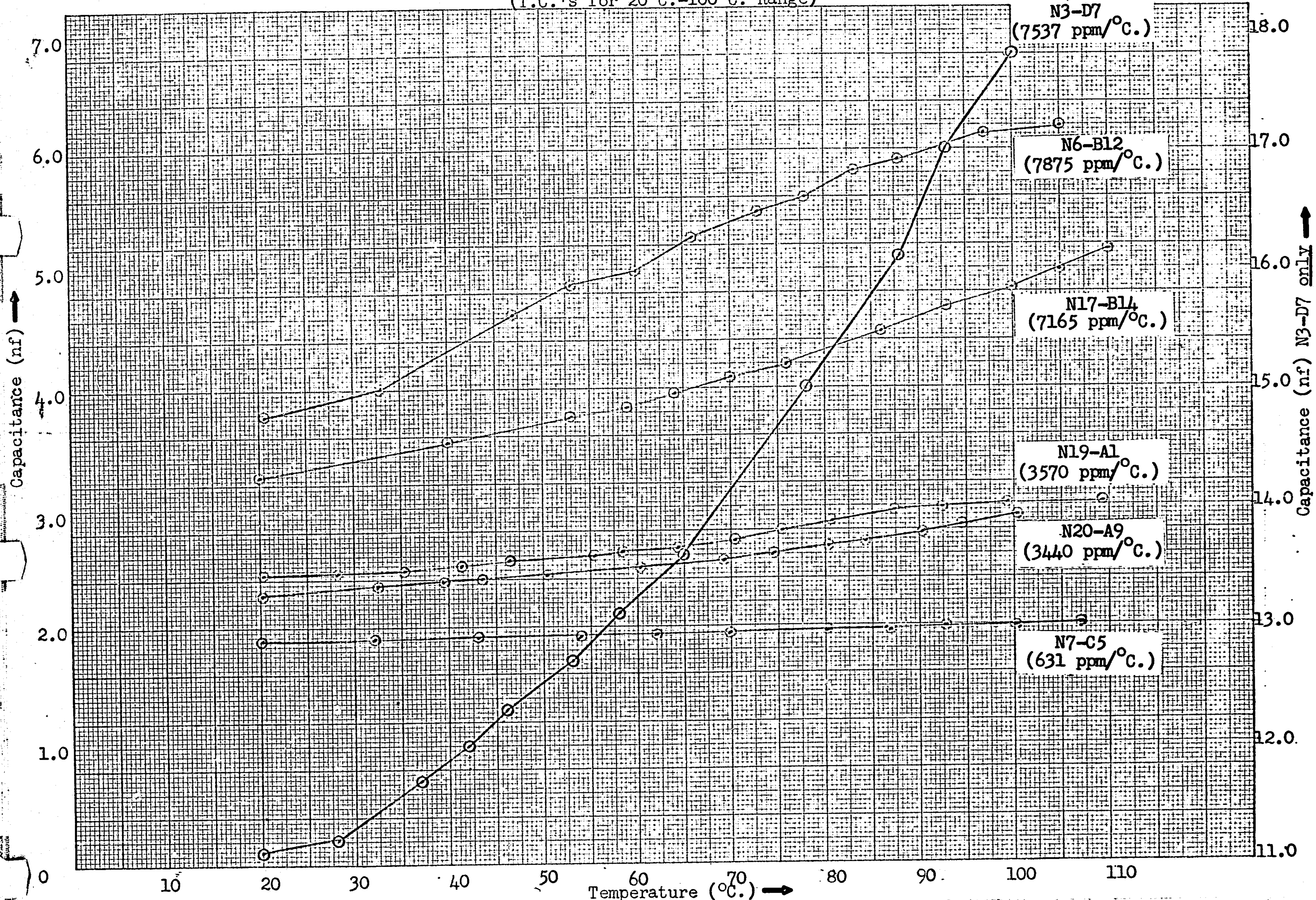
Run Number	Substrate	Initial		After 30 Days		Percent Change	
		Capacity (nf)	D.F.	Capacity (nf)	D.F.	Capacity (nf)	D.F.
N3	A	15.5	.22	11.1	.24	-28	+9
	B	16.0	.21	12.5	.27	-22	+3
	C	15.7	.14	11.5	.17	-27	+2
	D	15.6	.17	11.6	.17	-26	0
N6	A	2.89	.041	2.83	.026	-2.1	-4
N7	A	2.03	.030	2.21	.070	+8.9	+1
N17	A	5.04	.095	5.16	.099	+2.4	+4
N19	B	2.10	.038	2.08	.034	-.95	-2
	C	2.36	.051	2.28	.035	-3.4	-3
	D	2.32	.048	2.37	.057	+2.2	+9
N20	A	2.16	.040	2.24	.056	+3.7	+3
	B	2.25	.036	2.26	.040	+.44	+2
	C	2.18	.057	2.40	.099	+10.1	+7
	D	2.34	.063	2.75	.12	+17.5	+9

Graph 1

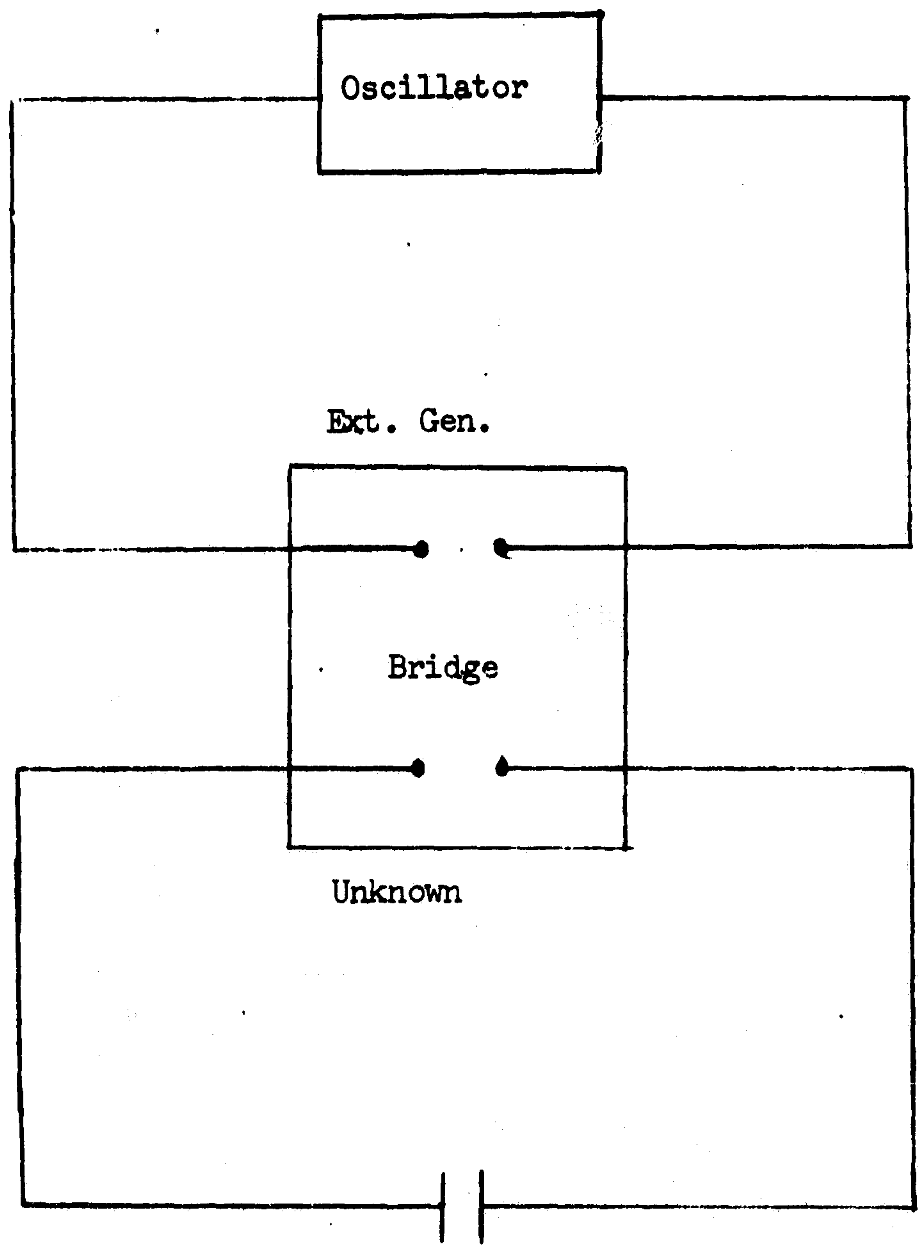
$NaNbO_3$ CAPACITORS

CAPACITANCE VERSUS TEMPERATURE

(T.C.'s for 20°C.-100°C. Range)



$NaNbO_3$ Capacitors
Frequency Test



Bridge:	General Radio Model 1650-A
Oscillator:	Hewlett Packard Model 200 CD

Figure 4.

TABLE IV

$NaNbO_3$ Capacitors

Frequency Test

Run-Substrate	N3-D							
Capacitor No.	5		6		7		8	
Frequency (Kc)	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.
.3	11.9	.69	11.1	.47	11.1	.63	11.9	.52
.5	11.4	.44	10.8	.34	10.6	.42	11.6	.35
1.0	10.8	.25	10.4	.22	10.0	.25	11.0	.22
2.0	10.1	.13	9.5	.12	9.0	.13	10.2	.13
3.0	9.5	.090	9.0	.085	8.5	.089	9.4	.090
5.0	8.6	.055	8.2	.050	7.6	.050	8.7	.055
11.0	7.4	.024	7.1	.022	6.7	.021	7.3	.023
25.0	6.4	.009	6.2	.008	6.0	.008	6.4	.009
40.0	5.9	.006	5.8	.005	5.6	.005	5.9	.005

Run-Substrate	N6-C				N7-C			
Capacitor No.	7		8		5		16	
Frequency (Kc)	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.
.3					1.88	.13	2.16	.056
.5	3.33	.52			1.83	.09	2.14	.039
1.0	3.07	.22	3.53	.56	1.83	.045	2.13	.018
2.0	2.87	.073	2.90	.16	1.82	.013	2.11	.009
3.0	2.78	.038	2.70	.076	1.84	.006	2.10	.006
5.0	2.72	.018	2.58	.030	1.84	.003	2.10	.004
11.0	2.62	.006	2.47	.008	1.82	.002	2.07	.002
25.0	2.53	.002	2.43	.002	1.81	.001	2.06	.002
40.0	2.45	.001	2.35	.001	1.78	.001	2.03	.001

TABLE IV

- continued -

Run-Substrate	N17-B			
Capacitor No.	5		6	
Frequency (Kc)	Cap. (n.f.)	D.F.	Cap. (n.f.)	D.F.
.3				
.5	5.68	.29	6.50	.19
1.0	5.45	.10	6.27	.098
2.0	5.25	.045	6.05	.047
3.0	5.11	.027	5.88	.029
5.0	5.00	.015	5.70	.018
11.0	4.86	.006	5.47	.008
25.0	4.66	.002	5.23	.004
40.0	4.54	.001	4.93	.001

Run-Substrate	N19-A							
Capacitor No.	7		8		11		12	
Frequency (Kc)	Cap. (n.f.)	D.F.	Cap. (n.f.)	D.F.	Cap. (n.f.)	D.F.	Cap. (n.f.)	D.F.
.3	2.55	.46	2.34	.55	2.28	.28	2.34	.33
.5	2.43	.15	2.25	.14	2.23	.092	2.26	.11
1.0	2.34	.064	2.19	.055	2.18	.038	2.22	.046
2.0	2.28	.028	2.16	.021	2.15	.017	2.18	.020
3.0	2.25	.016	2.14	.011	2.13	.010	2.16	.013
5.0	2.22	.009	2.12	.006	2.12	.006	2.13	.007
8.0	2.18	.005	2.11	.003	2.10	.003	2.11	.004
14.0	2.16	.002	2.08	.002	2.07	.002	2.07	.002
25.0	2.13	.001	2.06	.001	2.06	.001	2.06	.001
40.0	2.10	.001	2.07	.001	2.04	.001	2.05	.001

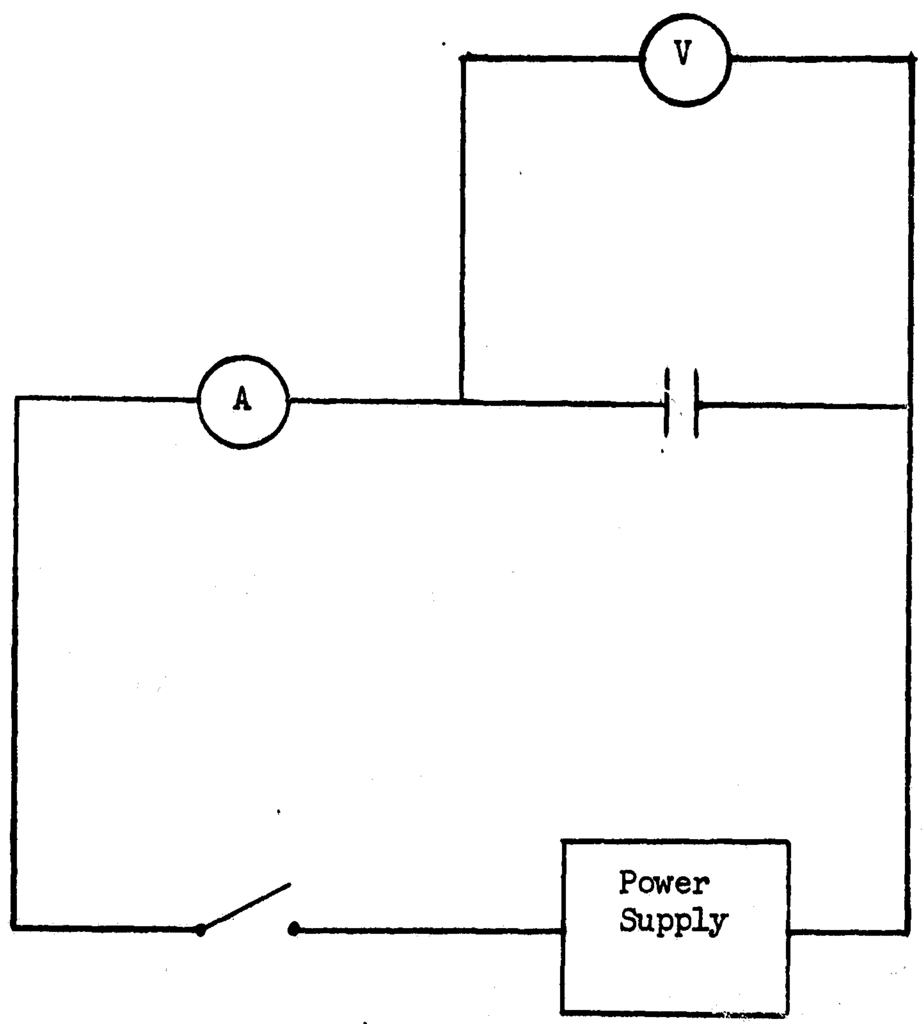
TABLE IV

- continued -

Run-Substrate	N20-A							
Capacitor No.	9		10		11		12	
Frequency (Kc)	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.	Cap.(n.f.)	D.F.
.3	2.37	.19	2.34	.17	2.60	.23	2.23	.22
.5	2.31	.12	2.32	.11	2.54	.15	2.18	.12
1.0	2.24	.060	2.26	.051	2.46	.082	2.13	.055
2.0	2.18	.029	2.21	.024	2.37	.043	2.08	.024
3.0	2.14	.019	2.18	.016	2.31	.028	2.05	.015
5.0	2.10	.010	2.14	.009	2.24	.017	2.03	.008
11.0	2.04	.004	2.10	.003	2.14	.007	1.97	.004
25.0	2.00	.001	2.06	.001	2.04	.003	1.94	.001
40.0	1.97	<.001	2.03	<.001	2.00	.001	1.91	<.001

NaNbO$_3$ Capacitors

D. C. Leakage and Breakdown Voltage Test



Voltmeter:	Hewlett Packard	- Model 410 C
Ammeter:	Simpson Meter	- Model 262
Power Supply:	Hewlett Packard	- Model 723 A

Figure 5.

TABLE V

Na NbO_3 Capacitors
DC Leakage and Breakdown Voltage

N6-B					
Capacitor No. 6		Capacitor No. 7		Capacitor No. 8	
Volts	I (μa)	Volts	I (μa)	Volts	I (μa)
.15	0	.1	1	1.0	5
.2	0	.3	4	1.5	8
.5	1	.6	8	2.0	13
.9	3	.9	13	2.5	18
1.2	5	1.1	17	2.7	*
1.5	6	1.3	21		
1.9	9	1.5	26		
2.5	14	1.8	35		
3.0	*	2.0	42		
		2.3	52		
		2.5	62		
		3.0	*		

* - Failure

N7-C					
Capacitor No. 2		Capacitor No. 5		Capacitor No. 6	
Volts	I (μa)	Volts	I (μa)	Volts	I (μa)
1.0	0	.5	0	.5	0
2.0	0	1.0	1	1.0	0
2.1	*	1.5	1	1.5	0
				2.0	*

* - Failure

N17-B			
Capacitor No. 5		Capacitor No. 14	
Volts	I (μa)	Volts	I (μa)
.5	1	.6	0
1.0	0	1.0	0
1.2	1	1.5	2
1.5	1.5	1.8	7
1.6	2	1.9	12
1.7	5	2.0	*
1.8	18		
1.9	47		
2.0	*		

* - Failure

N19-A					
Capacitor No. 1		Capacitor No. 3		Capacitor No. 5	
Volts	I (μa)	Volts	I (μa)	Volts	I (μa)
.5	0	.5	0	1.0	0
1.0	0	1.0	0	1.5	0
1.5	0	1.5	0	1.6	0
1.8	2	1.7	*	1.8	0
1.9	3			2.1	0.5
2.0	6			2.2	1
2.1	12			2.3	*
2.2	*				

* - Failure