

NASA CR-65989

SECOND QUARTERLY REPORT

PHASE B

Thin-Film Personal Communications and Telemetry System (TFPCTS)

Contract No. NAS 9-3924

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MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Submitted to

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MANNED SPACECRAFT CENTER
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MELPAR, INC.

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FACILITY FORM 602

Second Quarterly Report

Phase B

THIN-FILM PERSONAL COMMUNICATIONS
AND TELEMETRY SYSTEM (TFPCTS)

For the period of June 24, 1966 to September 24, 1966

Contract No. NAS 9-3924

Submitted to

National Aeronautics and Space Administration
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Houston, Texas

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Melpar, Inc.
7700 Arlington Boulevard
Falls Church, Virginia

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1. INTRODUCTION

This report for the second quarter of Phase B is submitted in compliance with Contract NAS 9-3924 between NASA - Houston and Melpar, Inc. The ultimate task objective is to construct a thin-film personal communication and telemetry system. During Phase B, the objective is to design and construct the circuit modules that will be used in Phase C to package the total system. Each module is designed to incorporate thin-film circuitry to the greatest extent possible.

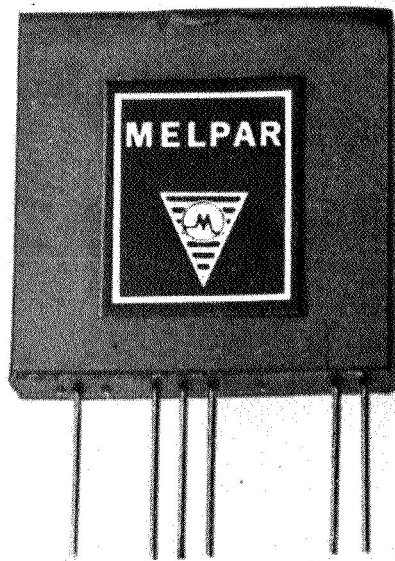
In general, progress in the design and fabrication of modules is satisfactory. The only modules scheduled for completion during this quarter were three twin-T modules and these were delivered three weeks ahead of schedule. In the initial program scheduling, it was anticipated that some of the modules might require redesign. For this reason, and because of the complexity of the processing, the schedule was tightened to aim for a 9-month completion date for the majority of modules. Some of the modules that are now in progress are behind schedule, but no problems which would affect the ultimate completion date are anticipated.

Development work has continued on high-frequency thin-film transistors, and although the work is not directly part of this program, successful results are of real interest. Tellurium transistors that show useful gain at 170 Mc when used as a tuned amplifier have been recently fabricated. They will be considered for use in the 100-Mc oscillators in the transceiver.

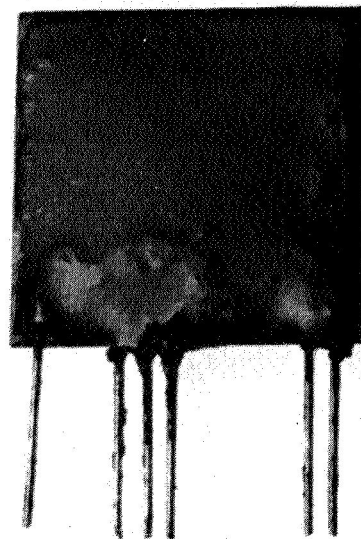
Packaging studies for Phase B have been successful in selecting coating materials that protect the substrates during normal handling, and at the same time, do not interfere with the circuit operation. An Apiezon

wax is used as a conformal coating and a molded epoxy is used to provide a rigid, shock-resistant outer package. Figure 1 shows a typical module in various stages of fabrication.

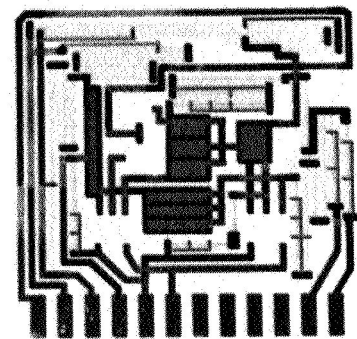
A breakdown of the thin-film and discrete-component parts is given later in this report. In general, all resistors, capacitors, diodes, and low-value inductors will be in thin-film form. Thin-film transistors will be used everywhere except in high-frequency and high-stability dc circuits. Discrete component inductors will be used for values over 0.1 microhenry or for values of Q over 100.



COMPLETED PACKAGE
MOLDED IN EPOXY



SUBSTRATE WITH LEADS
AND WAX COATING



THIN FILM SUBSTRATE

Figure 1. Module Packaging Sequence

2. TECHNICAL DISCUSSION

During this quarter, the major effort has been to reduce as many circuits as possible to a thin-film design. Except for the r-f diplexer circuit, all circuits processed have been in the transmitter audio and VCO subsystems. A complete schematic for this portion of the system is shown in figure 2. On the schematic, each module is bounded by dotted lines and the module pin numbers are circled. The circuitry has been considerably reduced from that shown in the first quarterly report by use of a high gain feedback amplifier. A spectrum analysis was made of the new system and the summation all spurious signals is less than 1.5 percent of the total VCO modulation energy.

Each processed circuit module will be discussed in the following paragraphs and the system performance will be analyzed.

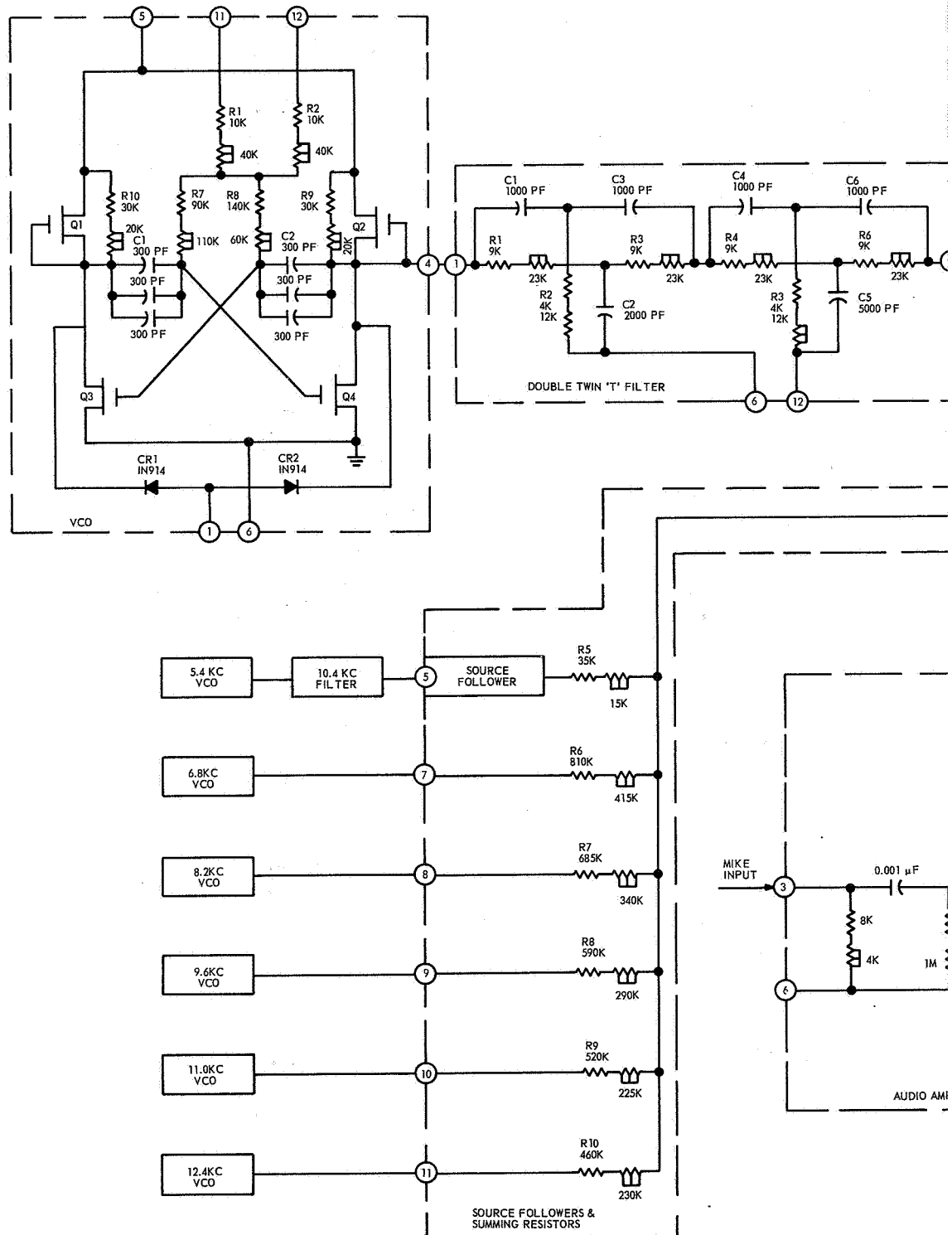
2.1 Transmitter Audio Amplifier Module

The specifications for this circuit are:

Input impedance	10 Kohms
Frequency response	250 cps to 2.3 Kc
Gain	200 to 2500, selectable
Undistorted output swing	5 V peak-to-peak
Output impedance	< 10 Kohms

This circuit receives its input from the voice microphone (test signal, 1.0 mV rms at 1 Kc) and is required to produce a signal that will modulate the transmitter. A 1-volt rms signal is sufficient to drive the modulation to 95 percent; this is the requirement for the secondary system. Melpar thin-film transistors will be used in this

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5-A

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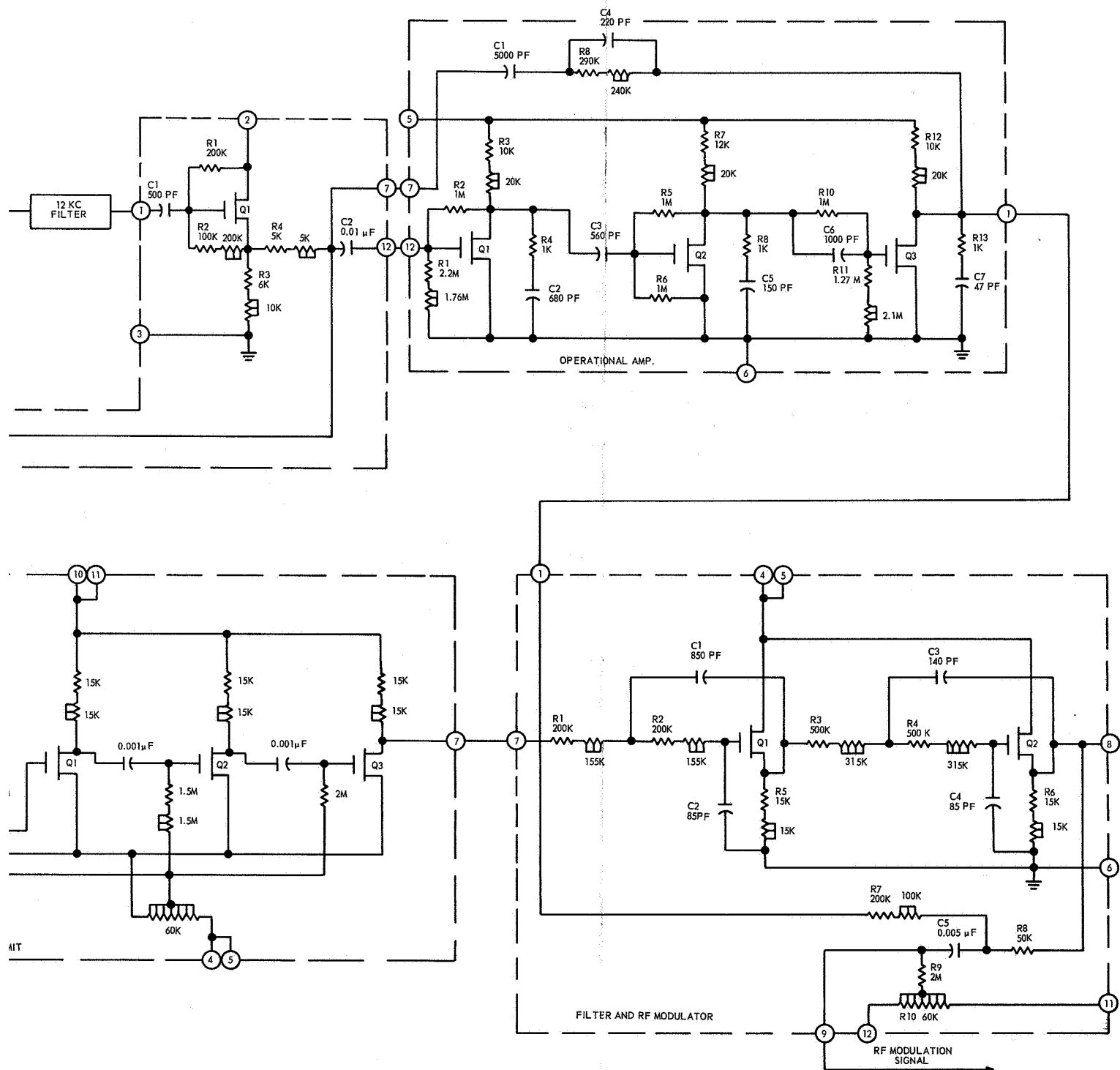


Figure 2. Schematic, VCO Sub-System

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circuit with a g_m of about 600. The minimum gain per stage, using a 15-Kohm load, is 9; the maximum gain is 18 per stage with a 30-Kohm load. Three stages are required to insure a total gain of 1000. Provision is made to reduce the gain to the correct level by use of a voltage divider on the first-stage input resistor. Further gain adjustment is possible by trimming the load resistors which are adjustable in five steps between 15 and 30 Kohms.

The audio frequency response is specified to be flat to within 1.5 dB from 250 cps to 2.3 Kc. Above 2.3 Kc, the frequency response is obtained by means of a filter; this is discussed in the next section. The lower frequency response is maintained in the RC coupling networks in the audio amplifier. An attenuation of -1.5 dB is equivalent to a voltage ratio of 0.84. Since three stages are used to obtain this attenuation, the loss per stage is:

$$\begin{aligned}\text{Attenuation per stage} &= (0.84)^{1/3} \\ &= 0.945\end{aligned}$$

For RC networks the transfer function for equal cascaded networks is:

$$T^N = \left(\frac{1}{\sqrt{1 + \left(\frac{1}{\omega RC}\right)^2}} \right)^N$$

In this case, $N = 3$, resulting in

$$\omega RC = \frac{1}{0.346}$$

$$\text{for } \omega = 2\pi \times 250$$

$$\text{and } R = 2 \text{ megohms}$$

$$\text{Then } C \geq 0.00093 \times 10^{-12} \text{ farads}$$

In the actual circuit the first and third stages have a 2-megohm and 0.001-microfarad capacitor coupling network. The second-stage network has a 1.5- to 3.0-megohm trimmable resistor so that the lower frequency response may be tailored to compensate for deposition and masking irregularities.

All three audio stages are returned to a common bias point which is provided by means of a 50-Kohm voltage divider. This simplified biasing arrangement is made possible by use of high-input-impedance active devices. Normally, a large bypass capacitor is required on the bias supply. In this case, the large 2-megohm resistors, in conjunction with the 50-Kohm voltage divider, introduce sufficient attenuation to prevent instabilities through undesired feedback without the use of a bypass.

2.2 Low-Pass Filter Module

In the primary system, the voice channel must be limited in high-frequency response to prevent interference with the data channels. The "roll-off" is specified at 24 dB/octave beyond 2.3 Kc. Using RC filters, it is possible to obtain 6 dB/octave/RC stage. There are several well-known filter characteristics that provide the necessary "roll-off"(i.e., a Bessel filter, which optimizes the phase shift vs. frequency response; a Chebyshev filter, which allows a finite amount of ripple in the amplitude-frequency response, but gives an initial, rapid roll-off; and a Butterworth filter, which has a maximally flat response with no ripple in the passband). The Butterworth design philosophy was chosen for the low-pass filter. Four stages of RC networks yield the required 24 dB/octave slope after the 3 dB point.

The transfer characteristic of a four-pole Butterworth low-pass filter is

$$T_B = \frac{1}{(s^2 + 0.7654s + 1)(s^2 + 1.8478s + 1)} \quad (1)$$

The circuit shown in figure 3 is a two-pole RC network with the following transfer characteristic:

$$T = \frac{+A}{s^2 R_1 R_2 C_1 C_2 + s [R_1 C_1 (1-A) + (R_1 + R_2) C_2] + 1}$$

When two such filters are used in cascade, the total transfer characteristic is

$$T \times T' = \frac{AA'}{\{s^2 R_1 R_2 C_1 C_2 + s [R_1 C_1 (1-A) + (R_1 + R_2) C_2] + 1\}} \times \frac{1}{\{s^2 R_1' R_2' C_1' C_2' + s [R_1' C_1' (1-A') + (R_1' + R_2') C_2'] + 1\}} \quad (3)$$

This is of the same form as equation (1) above. Equating the coefficients, we obtain the values of R's and C's assuming that the amplifier gain is 1, and that the input and output impedances of the amplifier are infinity and zero, respectively.

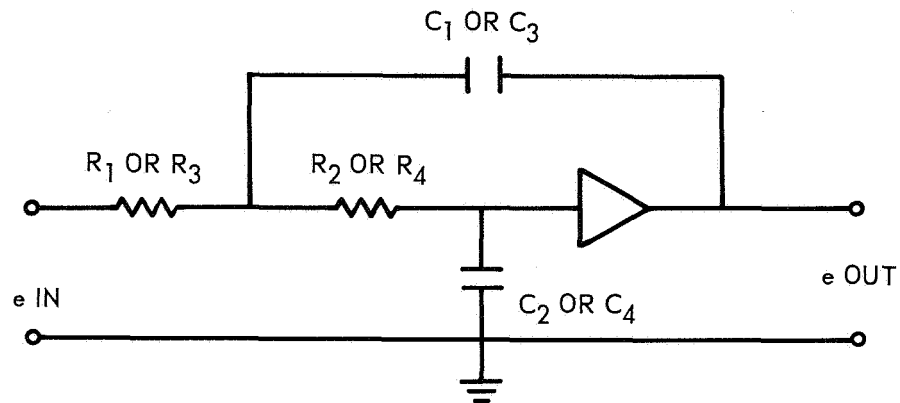
$$R_1 = R_2 = 267 \text{ Kohms}$$

$$R_3 = R_4 = 644 \text{ Kohms}$$

$$C_1 = 850 \text{ pfs}$$

$$C_2 = C_4 = 85 \text{ pfs}$$

$$C_3 = 140 \text{ pfs}$$



$$T = \frac{e_{OUT}}{e_{IN}} = \frac{A}{s^2 R_1 R_2 C_1 C_2 + [R_1 C_1 (1-A) + (R_1 + R_2) C_2] + 1}$$

Figure 3. Basic Two-Pole Network Used to Synthesize Four-Pole Butterworth Low-Pass Filter

The actual circuit that is now being processed in thin-film form is shown in figure 3. The unity gain amplifiers are source followers with very high input impedance and with an output impedance that is sufficiently low to neglect its effect on the circuit. When deposited in thin-film form, the capacitors will not generally be exactly as calculated. However, the resistors are made trimmable so that after the capacitor values are known, the resistor values can be recalculated and the resistor elements trimmed to the correct values. This procedure was used on a discrete-component version of the circuit and the experimentally determined transfer function matched the theoretically predicted response within the accuracy of the measurement equipment.

2.3 VCO Circuit Module

Seven voltage-controlled oscillators are required to convert voltage signals to frequency-modulated signals. Several circuit designs were attempted which were not successful. These included multivibrator circuits using a single RC timing circuit; conventional multivibrator circuits using FET transistors with resistor loads; and MOS transistors with resistor loads and also MOS transistors for the loads. In all cases, the linearity and/or the temperature drift were intolerable. The only MOS transistor that was available for circuit design in chip form was the General Instrument MEM 511, which includes a Zener diode across the gate-source electrodes.

The circuit which has been most successful to date is shown in the circuit diagram (figure 2). The linearity and temperature curves are shown in figure 4. In this case, we are using FET junction transistors both as the amplifying device and the load resistors. When used in this manner, the load transistor is made to compensate for temperature changes

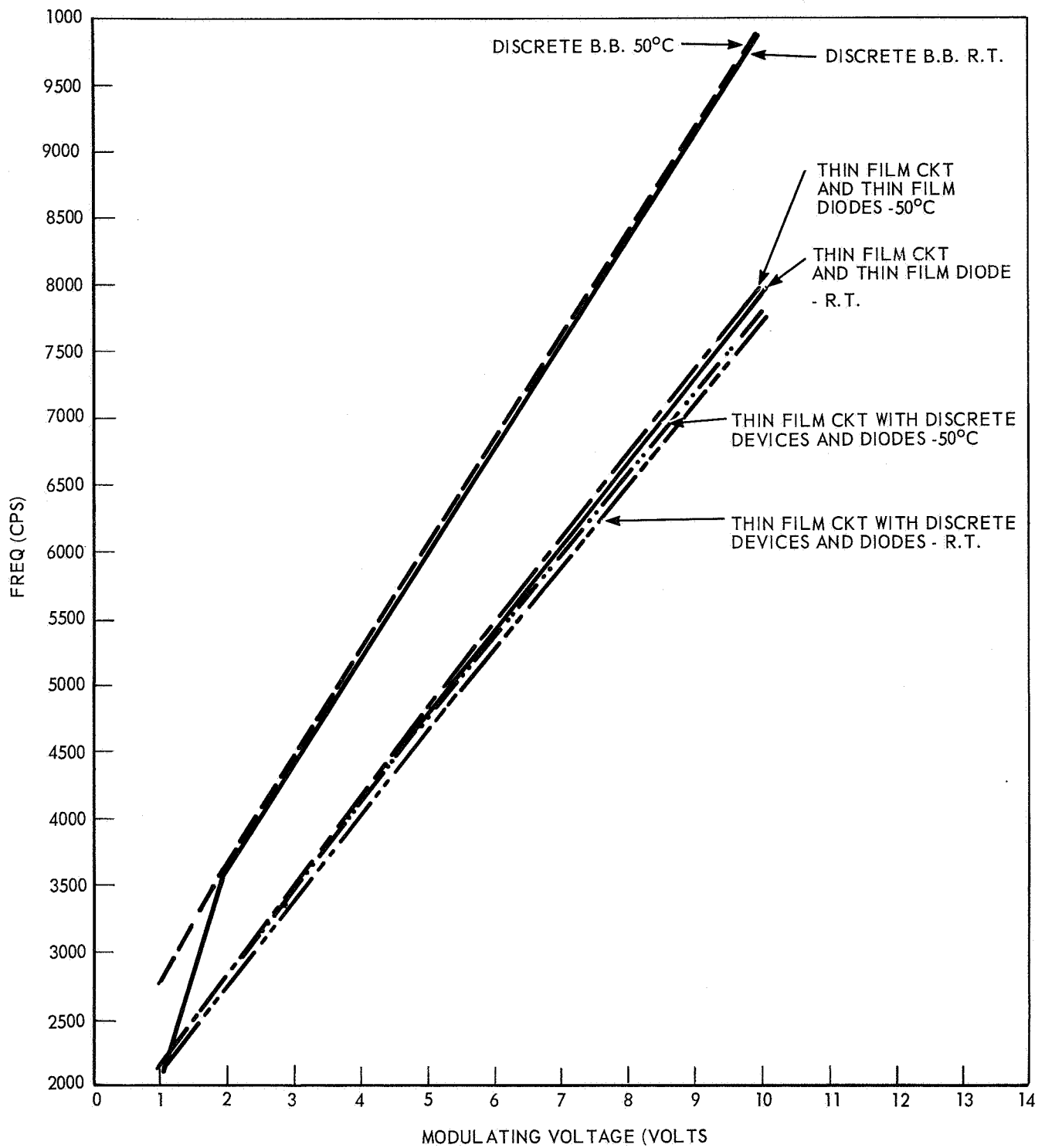


Figure 4. VCO Linearity and Temperature Characteristics

in the switching transistor. The choice of a transistor was based on the following:

- a. A field-effect transistor will be used so that when the stability of the thin-film devices is improved, the passive circuitry will be of the correct design to accommodate them.

- b. The transistor must be available in chip form.

- c. The temperature characteristics of the device must be predictable.

We have been fortunate in finding all of these characteristics in the Amelco 3071 FET junction transistor.

The output swing on the multivibrator is clamped at B^+ when the bottom transistor is OFF and clamped at $\approx +3$ volts by diode clamps when the bottom transistor is ON. The gate waveforms are very linear for modulating voltages above 2 volts. The linearity of frequency deviation with modulating voltage is well within the requirements. The temperature stability is within limits on the upper channels with no compensation required. A slight circuit modification will be made to adjust the temperature compensation on the lower channel VCO's.

Figure 3 shows the linearity and temperature stability of the VCO circuit when constructed in three ways:

- a. All discrete components.

- b. Thin-film substrate with attached discrete transistors and diodes.

- c. Thin-film substrate including thin-film diodes with attached discrete transistors.

In all three cases, the linearity is excellent over a very wide frequency range. For each circuit, there are two responses shown: one is at room temperature and the other is at $+50^{\circ}\text{C}$. It is possible to reduce the temperature coefficient either by use of a diode in the voltage divider for the modulating voltage or by use of more positive temperature coefficients in the RC components used for timing. The temperature coefficient of the power supply can also be adjusted to compensate for the VCO temperature coefficient.

Resistors and capacitors, which are used for frequency and bandwidth determination, are made trimmable so that one thin-film design is suitable for the seven VCO's.

2.4 Twin-T Filter Modules

The twin-T filters have been discussed in detail in previous reports. There are three such filters in the system, as shown in figure 1: two are in the 4-Kc channel and one is in the 5.4-Kc channel. The function of the filters is to remove from the low channel VCO's the harmonics that would interfere with the higher channels.

2.5 Summing Network Module

A resistor summing network is used to combine the seven VCO outputs into a single frequency-multiplexed signal. Because of the high output impedance of the twin-T filters, the two low channels require source followers between the filters and the summing resistors. The followers are included on the summing network module. The output of the summing network feeds an operational amplifier that is used to equalize the VCO outputs and to provide filtering for the four highest-frequency VCO's.

The seven summing resistors are determined by considering the gain required for each channel. The operational amplifier output for each channel is

$$e_o = \frac{Z_f}{R_{in}} e_{in},$$

where R_{in} is the summing resistor for a particular channel,
 e_{in} is the fundamental input voltage to the summing resistor, and
 Z_f is the feedback impedance in the operational amplifier.

Z_f is chosen to have a low-pass characteristic with a corner frequency at 2 Kc. The output voltage e_o should be the same for each channel and, since it will be mixed with the voice signal for modulation (1 volt rms - 100 percent modulation), e_o should be greater than 0.2 volts. A value of 420 mV was selected for e_o . Table 1 lists the values of R_{in} calculated by using experimentally determined values of e_{in} . The value of one summing resistor can be chosen to fix the value of Z_f . Since R_6 will be the largest, it was chosen to be 1 megohm; Z_f is then calculated to be a 200-pf capacitor

TABLE 1
SUMMING RESISTORS FOR VCO's

Frequency (KC)	e_{in} (V)	e_o (V)	Z_f (Kohms)	R_{in} (Kohms)
4	0.0176	0.4	177	7.75
5.4	0.141	0.4	138	49
6.8	3.58	0.4	122	1000
8.2	3.58	0.4	94.1	840
9.6	3.58	0.4	80.8	720
11.0	3.58	0.4	70.9	630
12.4	3.58	0.4	63.2	565

in parallel with 396 Kohms. All summing resistors are made trimmable to compensate for tolerances in fabrication.

2.6 Operational Amplifier

An operational amplifier is used to equalize the seven VCO outputs and to provide a low-pass filter for the VCO harmonic energies. The amplifier has three stages with a minimum gain of 1000. Because there is a very modest frequency response required in the amplifier, the high frequency roll-off on the basic amplifier is started at about 13 Kc with a 9-dB/octave slope.

The filtering action of the amplifier is produced by the capacitor C_4 in the feedback loop. As an example, we compute the amount of second harmonic of the previously unfiltered 6.8-Kc channel

$$e_o = \frac{Z_f}{R_6} e_{in}, \text{ where } Z_f \text{ and } e_{in} \text{ are at 13.6 Kc}$$

$$e_o = \frac{57 \times 10^3}{10^6} (0.3) = 17.2 \text{ mV}$$

This agrees with the value measured with a wave analyzer. There are approximately 15 such spurious signals between the highest VCO frequency and 40 Kc; however, the total energy in these responses is less than 1.5 percent of the VCO outputs.

The higher-order harmonics could be further reduced by use of a more complex filter in the operational amplifier, if this were required; however, the following analysis shows that, with a reasonable receiver, there should be no ambiguity in the received data. Assume a receiver with a 3 percent linearity. The receiver output can be expressed as:

$$e_o = a_1 e_{in} + a_2 e_{in}^2 \quad (4)$$

$$\text{where } e_{in} = A \sin \omega_1 t + B \sin \omega_2 t \quad (5)$$

$A \sin \omega_1 t$ and $B \sin \omega_2 t$ are two higher-order harmonics which can produce an interfering signal in the VCO frequency range if they are mixed in a nonlinear system. When equation (5) is substituted in equation (4), and A is assumed equal to B , the result is:

$$e_o = a_1 A(\sin \omega_1 t + \sin \omega_2 t) + a_2 A^2 \underbrace{\frac{1 - \cos^2 \omega_1 t}{2} + \frac{1 - \cos^2 \omega_2 t}{2}}_{\text{pure harmonics}} + \underbrace{\cos(\omega_1 - \omega_2) t}_{\text{difference signal}} - \underbrace{\cos(\omega_1 + \omega_2) t}_{\text{sum signal}} \quad (6)$$

The 3 percent linearity assumption implies that

$$\frac{a_2}{a_1} = 0.03,$$

which is the ratio of the difference signal (in equation 6) to the input signal. The difference frequency is then 30 dB below the harmonic signal, which, in turn (in the worst case), is 16 dB below the fundamental VCO signal for a total of 46 dB attenuation of undesirable signal.

3. PROJECT SCHEDULE

The objective for this phase of the project is to deliver a complete set of modules for the transceiver. Essentially all circuit design work has been completed. Exceptions to this are (1) VOX circuitry, which has not been fully specified, (2) portions of the r-f circuit, as far as thin-film geometry is concerned and (3) power-supply circuitry. All low frequency circuits in the transmitter have been reduced to a thin-film design and the modules are in the process of being fabricated. The receiver i-f, AGC and audio circuits are now being reduced to thin-film design.

The following revised list represents the complete set of modules that will be required for the transceiver along with notations on the progress made to date:

Module #1 - Transmitter audio amplifier

Thin-film layout completed.

Ready to have masks fabricated.

Module #2 - 2.3-Kc low-pass filter

Thin-film layout completed.

Ready to have masks fabricated.

Module #3 - Voice-operated switch

Waiting for information from NASA on function to be performed.

Module #4 - VCO 4 Kc

Module #5 - VCO 5.4 Kc

Module #6 - VCO 8.8 Kc

Module #7 - VCO 8.2 Kc

Module #8 - VCO 9.6 Kc

Module #9 - VCO 11 Kc

Module #10 - VCO 12.4 Kc

Several deposition runs have been made and there are approximately 10 substrates for evaluation. Discrete component transistors (2N3071) were found satisfactory and delivery is presently awaited on a larger quantity order. Thin-film transistors will also be evaluated in this circuit.

Module #11 - Staggered pair 8-Kc twin-T notch filters

Module #12 - Staggered pair 12-Kc twin-T notch filters

Module #13 - Staggered pair 10.8-Kc twin-T notch filters

These modules have been delivered.

Module #14 - Diplexer primary system - Xmit end

Module #15 - Diplexer primary system - Receiver end

Module #16 - Diplexer secondary system - Xmit end

Module #17 - Diplexer secondary system - Receiver end

Redesign is required on these modules to achieve better isolation.

Module #18 - Mixer operational amplifier

Deposition masks have been ordered for this module.

Module #19 - Transmitter r-f module

Module #20 - Receiver r-f module

These modules have been designed in discrete form but various geometrical designs will be attempted before a thin-film design is finalized.

Module #21 - I-F amplifier, first half
Module #22 - I-F amplifier, second half
Module #23 - Detector and AGC
Module #24 - Receiver audio amplifier

These four modules are ready for layout in thin-film form.

Module #25 - Summing resistor network

Deposition masks have been ordered for this module.

Module #26 - Power supply

Module #27 - Power supply

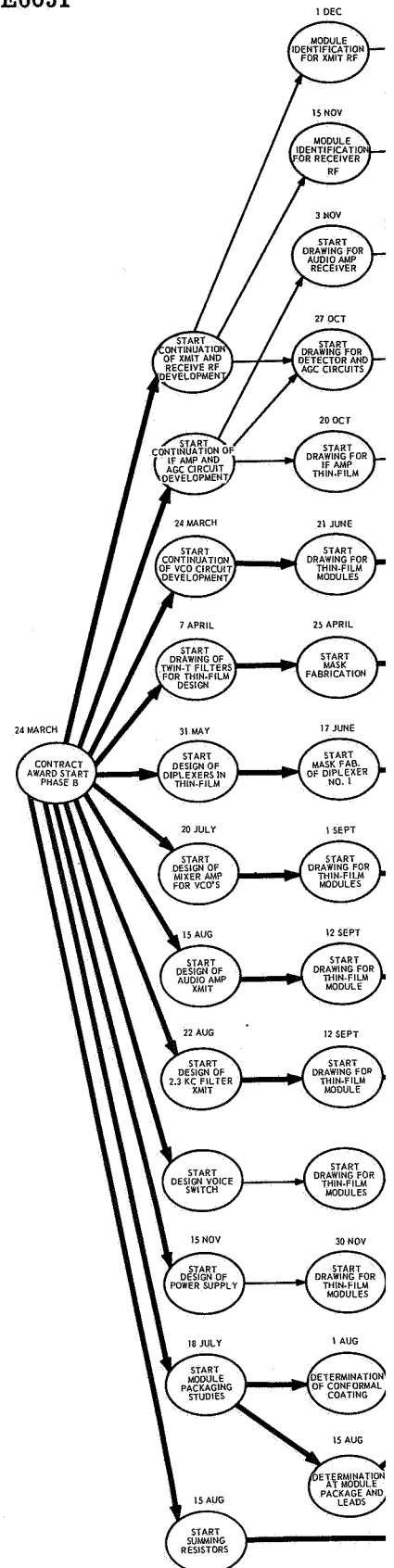
These modules will not be finalized until all other modules are reduced to thin-film form.

3.1 PERT Chart

A revised PERT chart is shown in figure 5. As was stated in the first quarterly report, the charts are used for scheduling and as an aid in reporting progress and problem areas. The target dates given in the first quarterly report have been changed to reflect what is now considered realistic. An effort is now being made to speed up the time interval required for obtaining masks.

Seven types of modules are now in the process of fabrication which will yield 16 of the 27 deliverable modules. Four additional modules will be started before the first week of November. The r-f and power-supply circuitry will be initiated in late November or early December.

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21-A

3.2 Estimate of Thin-Film Components

Table 2 shows the part count for the various types of components.

The current percentage of thin-film components is:

$$\frac{636 \text{ thin-film components}}{742 \text{ total parts}} = 86 \text{ percent}$$

This figure is somewhat lower than originally predicted because of the decision to use discrete transistors in the VCO's. This decision could be reversed if increased stability is obtained in the thin-film transistor. There is also a possibility of using thin-film transistors in the 100-Mc oscillators.

The total package will include approximately 40 modules within the design goal of 10 cubic inches.

TABLE 2

COMPONENT PARTS FOR THIN-FILM TRANSCEIVER

	Transistors		Coils		R T.F.	C T.F.	Diodes T.F.	Other
	Discrete	T.F.	Discrete	T.F.				
Transmitter audio ampl	3				7	3	14	
2.3-Kc filter	2				9	5		
VOX	2				6	2		
VCO's (7)	28				42	14	14	
Twin-T's (3)					18	18		
Diplexers				4		4		
Operational amplifier	3				13	7		
Transmitter r-f modules	7		3	6	15	20		1 crystal
Receiver r-f modules	5		2	4	11	19		1 crystal
I-F amplifiers	2	8			20	10		
Detector & AGC		9			23	16	1	
Receiver audio ampl		2			5	5	1	
Swimming resistors		2			13	3		
Power supply	5	3			15	10	8 discrete	
	47	34	5	14	197	136	16/8	2

NOTE: The power supply will require 4 discrete capacitors.

Audio ampl in receiver will require 1 discrete capacitor.

These figures are for the primary system. The totals for both systems are:

Transistors	66 discrete	61 thin-film
Coils	10 discrete	28 thin-film
Resistors	--	304 thin-film
Capacitors	10 discrete	225 thin-film
Diodes	16 discrete	18 thin-film
Crystals	4 discrete	--

4. MODULE PROCESSING INFORMATION

Appendix A contains the deposition mask drawings for the VCO module. Also included are tables that show the process steps and tolerances involved in the fabrication of the VCO, Diplexer and Twin-T filter substrates.

The charts show the types of material used for the resistors, capacitors, and conductors. Also presented are the resistivities, capacitances per unit area, and deposition thicknesses. The charts, in conjunction with the mask drawings, completely define the circuits. The mask drawings given are reproductions of the actual masking photographs.

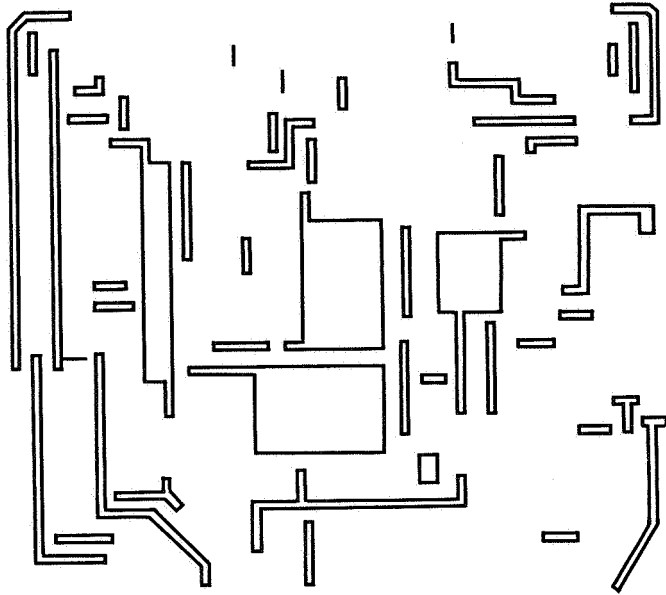
5. SUMMARY AND NEXT-PERIOD OBJECTIVES

Circuit design and fabrication have progressed satisfactorily during the past quarter. Some departures from the original PERT chart estimates have occurred. The delays are not serious and it is anticipated that the majority of the modules will be completed by the end of December.

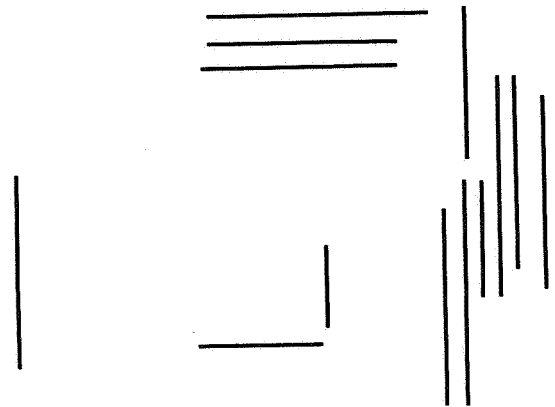
During the next quarter, the remaining modules will be started in thin-film form and partial system integration will be initiated.

APPENDIX A
VCO MASKS AND DEPOSITION CHARTS

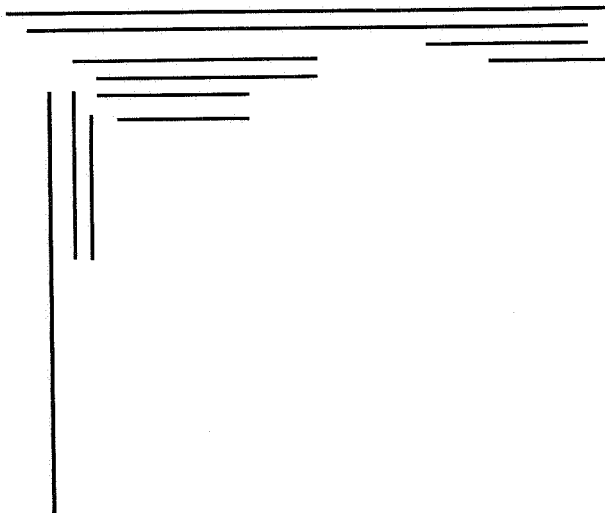
The VCO masks and deposition charts referred to in the body of this report appear on the following pages.



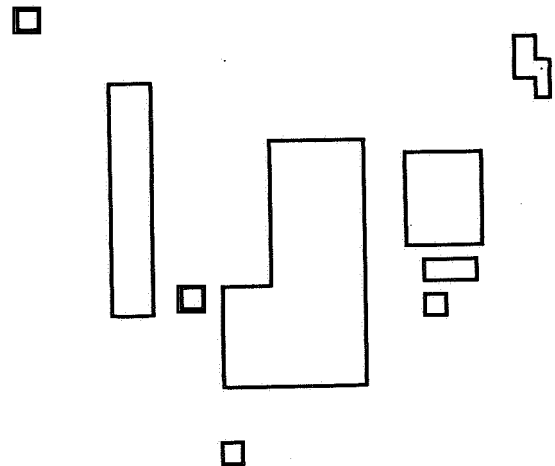
FIRST CONDUCTOR



RESISTOR (LOW VALUE)



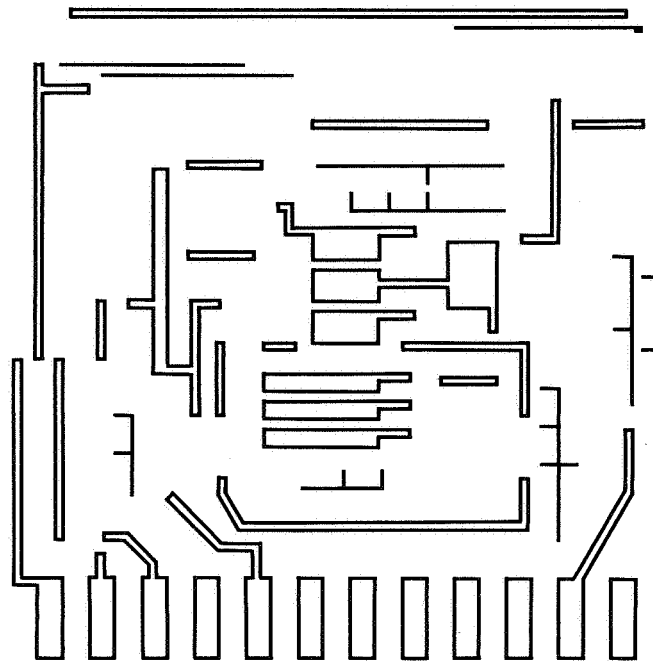
RESISTOR (HIGH VALUE)



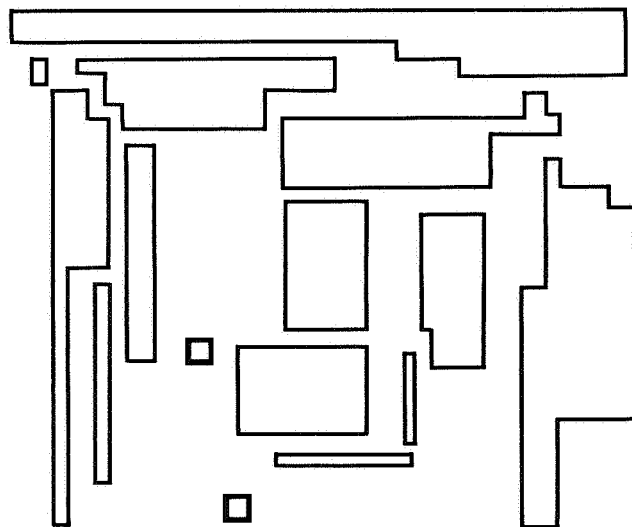
DIELECTRIC

Figure A-1. VCO Substrate Masks (Sheet 1 of 2)

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SECOND CONDUCTOR



PROTECTIVE COATING

Figure A-1. VCO Substrate Masks (Sheet 2 of 2)

Thin Film Circuit Vacuum Process Chart for Melpar, Model I
RD-1070

"TFC Vacuum Processing Plant"

CHART NO. 5006-7
DATE: 10 - 18 - 66

Circuit No. and Name: 5006-7 "Diplexer"

Substrate Description: Corning Code 0211 glass

$0.021 \pm 0.003 \times 1.000 \pm 0.010 \times 4.188 \pm 0.020$ inch

Mask Numbers:	Function
5006-7-1	A, B, C
-2	D
-3	E, F
5006-7-4	G

SPECIFICATIONS

- 1 Capacitor Tolerance $\pm 20\%$
- 2 $R_C \geq 1000 \text{ M } \Omega @ 1.5 \text{ VDC}$
- 3 $V_D \geq 30 \text{ VDC}$ continuous
- 4 D.F. $\leq 1\%$ for $1 \text{ Kc} \leq f \leq 100 \text{ Kc}$
- 5 Film spreadout $\leq .002$ inch

REF. NOTE: This circuit contains small value inductors + capacitors; circuit $Q \geq 40$ for $250 \text{ Mc} \leq f \leq 300 \text{ Mc}$.

Film Characteristics (in order of deposition)

Symbol	Circuit Function	Material	$R' = P \frac{L}{W}$ $\Omega/\text{sq.}$	$C' = C \frac{C}{A_2}$ $\mu\text{uf}/\text{cm}^2$	Thickness $\text{\AA}$
A	Adherence film for "B"	Cr			$500 \pm 20\%$
B	High conductance film for first cap. plates + conductors	Cu	.01 max		25000
C	First cap. plates + conductors (reqd. for low leak. cap.)	Al			$1100 \pm 20\%$
D	Cap. dielectric	70% SiO_2 30% B_2O_3		5000 $\pm 8\%$	7450
E	Second plate for non-trim. cap. + cond.	Al	.01 max		$1100 \pm 20\%$
F	High conductance film for "E"	Cu			25000
G	Second plates for trim-mable capacitors	Al	0.30 max		2200

NOTES: All specifications shall be satisfied for temperatures from
0 to $+50^\circ\text{C}$.

TFC VACUUM PROCESS CHART

RD-1047

CIRCUIT NO.: 5006-7 "DIPLER"

No.	Operations Chronological Order	Source Matl.	Mask Dash No.	Operation Duration Min.	SUBSTRATE HEAT			HEATER POWER			SOURCE HEAT FILAMENT POWER			BEAM POWER			MON. RES. AT CUT OFF WATTS OHMS
					MON. TEMP. °C	AMPS	VOLTS	WATTS	AMPS	VOLTS	WATTS	MA	KV	WATTS			
1	Dep. Adherence film	Cr	1	5.5 ± 0.5	200 ± 5		3.3			17.5 ± 0.5	10.7 ± 1	187	312	0.8	250 ± 5		
2	Dep. high cond. film #1	Cu	1	20 +1 -0	200 ± 5		3.3						375	0.8	300 ± 5		
3	Dep. Cap. plate #1	Al	1	5 ± 0.5	150 ± 5		2.0						400	0.8	320 ± 5		
4	Dep. Cap. Diel.	SiO ₂ /B ₂ O ₃	2	30 ± 0.3 total (NOTE 1)	150 ± 5		2.0						290	0.69	200 ± 5		
5	Dep. Nontrim. Cap. plate #2	Al	-3	5 ± 0.5	150 ± 5		2.0						400	0.8	320 ± 5		
6	Dep. high cond. film #2	Cu	-3	20 +1 -0	200 ± 5		3.3						375	0.8	300 ± 5		
7	Dep. Trim. Cap. plate #2	Al	-4	10 +1 -0	150 ± 5		2.0						400	0.8	320 ± 5		

NOTES: 1. 10 ± 0.1 min. from each of three 1.25-gm crucible loads.

2. Clearance between mask and substrates shall not exceed 0.001 in. when using -1 and -3 masks.

Thin Film Circuit Vacuum Process Chart for Melpar, Model I
RD-1070

"TFC Vacuum Processing Plant"

CHART NO. 5006-8 (REV. A)

DATE: 10 - 18 - 66

Circuit No. and Name: 5006-8 "Voltage Controlled Oscillator"

Substrate Description: Corning Code 0211 glass
0.020 ± 0.004 x 1.000 ± 0.010 x 1.000 ± 0.010 inch
with 1350 Å ± 20% thick Cu film on back

Mask Numbers:	Function
5006-8-1	A
-2	deleted
-3	B
-4	C
-5	D + E
5006-8-6	F

SPECIFICATIONS

- 1 $-70 \leq \text{TCR} \leq -170 \text{ PPM}/^\circ\text{C}$
 - 2 $+20 \leq \text{TCC} \leq +270$
 - 3 $R_c \geq 1000 \text{ M } \Omega @ 1.5 \text{ VDC}$
 - 4 $V_b \geq 30 \text{ VDC}$, continuous
 - 5 D.F. $\leq 2\%$
 - 6 Resistor tolerance $\pm 31\%$
 - 7 Capacitor tolerance $\pm 12\%$
- ($-150 \leq \text{TCRC} \leq +200 \text{ PPM}/^\circ\text{C}$)

Film Characteristics (in order of decomposition)

Symbol	Circuit Function	Material	$R' = \frac{P}{L/W}$ $\Omega/\text{sq.}$	$C' = \frac{C}{A^2}$ uuf/cm^2	Thickness $\text{\AA}$
A	Res. terminals, first cap. plates + conductors	Al	0.3 max		2200
B	Resistor film	Re	1100 $\pm 21\%$		~ 35
C	Cap. + crossover dielectric	70% SiO ₂ 30% B ₂ O ₃		9500 $\pm 8\%$	3925
D	Adherence film for circuit terminals	Cr			500±20%
E	Second capacitor plates + conductors	Al	0.3 max		2200
F	Protective coat	SiO			2000±20%

NOTES: All specifications shall be satisfied for frequencies from 3.8 Kc to 12.4 Kc and for temperatures from 0° to +50°C.

TFC VACUUM PROCESS CHART
RD-1047

CIRCUIT NO.: 5006-8 "Voltage Controlled Oscillator"

No.	Operations Chronological Order	Source Matl.	Mask Dash No.	Operation Duration Min.	SUBSTRATE HEAT			SOURCE HEAT			BEAM POWER			MON. RES. AT CUT OFF OHMS				
					MON. TEMP. °C	HEATER POWER		AMPS	VOLTS	WATTS	FILAMENT POWER	AMPS	VOLTS		WATTS	MA	KV	WATTS
1	Dep. #1 Cond. film	Al	-1	10 ⁺¹ -0	150 ± 5		2.3		17.5 ±0.5	10.7 ± 1	187	400	0.8	320 ±5	10 k ±0.2 k			
2	Dep. initial Res. layer	Re	-3	5.5	460 ± 5		8.8		"	"	"	155	4.6	710 ±5	9 k Ref			
3	Anneal above		"	5 or until Res. stable	550 ± 5		12.1		0					0	6.5 k ±.06 k			
4	Dep. & anneal final Res. layer	Re	"	10	"		"		17.5 ±0.5	10.7 ± 1	187	110	5.4	590 max	200 ±5			
5	Dep. cap. & cross dielectric	SiO B ₂ O ₃	-4	10.8 ± 0.2 total*	150 ± 5		2.0		"	"	"	290	0.69		0			
6	Anneal above		"	15 ± 1	300 ± 5		?		0						250 ±5			
7	Dep. adherence film	Cr	5	5.5 ± 0.5	150 ± 5		2.0		17.5 ±0.5	10.7 ± 1	187	312	0.8	320 ±5	100 ±5			
8	Dep. #2 conductor film	Al	"	10 ⁺¹ -0	"		"		"	"	"	400	0.8					
9	Dep. protective film	SiO	6	15 ± 1	"		"		"	"	"	200	0.5					

* 5.4 ± 0.1 min from each of two 1.25 gm crucible loads.

Thin Film Circuit Vacuum Process Chart for Melpar, Model I
RD-1070

"TFC Vacuum Processing Plant"

CHART NO. R65018-1

Circuit No. and Name: R65018-1 "Twin-T-Filter"

DATE: 10 - 18 - 66

Substrate Description $0.020 \pm 0.004 \times 1.000 \pm 0.010 \times 1.000 \pm 0.010$ inch,
Corning Code 0211 glass

Mask Numbers:	Function
R65018-1-0	A
-1	B
-2	C
-3	D
-4	E
R65018-1-5	F

SPECIFICATIONS	
1	$-100 \leq \text{TCR} \leq -200 \text{ PPM}/^\circ\text{C}$
2	$0 \leq \text{TCC} \leq +300 \text{ PPM}/^\circ\text{C}$
3	$R_c \geq 1000 \text{ M } \Omega @ 1.5 \text{ VDC}$
4	$V_b \geq 30 \text{ VDC}$, continuous
5	D.F. $\leq 2\%$
6	Resistor Tolerance $\pm 30\%$
7	Capacitor Tolerance $\pm 12\%$
$(-200 \leq \text{TCRC} \leq +200 \text{ PPM}/^\circ\text{C})$	

Film Characteristics (in order of deposition)

Symbol	Circuit Function	Material	$R' = \frac{P}{L/W}$ $\Omega/\text{sq.}$	$C' = \frac{C}{A_2}$ $\mu\text{uf}/\text{cm}^2$	Thickness $\text{\AA}$
A	Adherence film for circuit terminals	Cr			$500 \pm 20\%$
B	Resistor terminals lower cap, plates cond.	Al	0.3 max		2200
C	Resistor film	Re	$1103 \pm 21\%$		~ 35
D	Capacitor + cross. Diel + Res. Prot.	70% SiO_2 30% B_2O_3		9500 $\pm 8\%$	3.925
E	Upper cap. plates remaining conductors	Al	0.3 max		2200
F	Protective coat (Abrasion only)	SiO			$2000 \pm 20\%$

NOTES: All specifications shall be satisfied for frequencies between 4 KC and 12 KC and for temperatures between 0° and $+50^\circ\text{C}$.