NATIONAL RADIO ASTRONOMY OBSERVATORY
GREEN BANK, WEST VIRGINIA

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DESIGNS OF 300-1000 MHz UPPER SIDEBAND CONVERTE

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NATIONAL RADIO ASTRONOMY OBSERVATORY

DESIGNS OF 300-1000 MHz UPPER SIDEBAND CONVERTERS

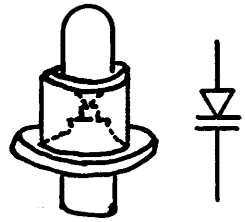
Albert Wu

Introduction

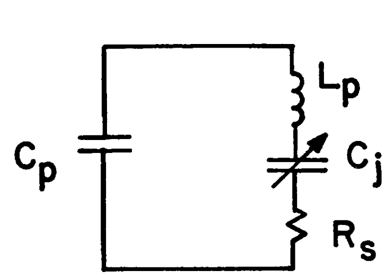
The purpose of this report is to describe the design and performance of the upconverters used in the 300-1000 MHz receiver box. The noise contribution of the upconverter to the system, theoretically, is negligible, which we have found to be quite accurate. There were three sets of such upconverters designed and working in our traveling feed receiver. One set of upconverters operate from 300 to 400 MHz with approximately 10 dB of gain. A second set of upconverters work from 500-700 MHz with approximately 7 dB of gain. A third set of upconverters operate from 700-1000 MHz with approximately 5.5 dB gain.

Manley and Rowe derived a set of general relationships of power and frequencies in an ideal (non-resistive) non-linear reactance which basically shows that, given two high-frequency generators feeding power to a non-linear reactive element will give rise to several other frequencies from the non-linear reactance. The impedance of the non-linear reactive element will appear negative; therefore, if we send a signal into it we will find gain. The gain of the upper sideband upconverter can be calculated by the voltage and current relationships given in the Manley and Rowe matrix, but the end result will be described by an equation that contains the characteristics of the reactive element, in our case the varactor diode.

The varactor diode is a device that has a capactive reactance that changes with the voltages impressed upon it. Although a varactor is not a purely non-linear capacitor, it does have other characteristics which will be shown in the equivalent circuit, Figure 1B.



1A: Varactor Diode Symbol



1B: Equivalent Circuit

FIGURE 1

Table 1

Upconverter Frequency		Gain max (dB)	Noise Temperature [1] (°K)	Noise Temperature [2] (°K)	R_g Maximum Gain (ohms)
.35	D_1 *	10.87	9.84	.66	26.29
	D_2 *	10.69	16.17	1.08	31.57
.60	D_1 *	8.53	13.72	.92	19.87
	D_2 *	8.30	22.62	1.51	23.88
.85	D_1 *	6.91		1.14	16.79
	D_2 *	6.63	28.37	1.89	20.19

*D_1 = f_{C6} = 2 50 *D_1 R_s = 0.8246 Ω

D_2 = f_{C6} = 1 50 D_2 R_s = 1.6224 Ω

[1] Varactor at 300°K.

[2] Varactor at 20°K.

As long as the varactor diode is in reverse bias, the above equivalent circuit can be considered accurate enough for analysis.

An upconverter will have three major frequencies involved. For instance, the signal frequency range in our case is 300-400 MHz. The pump frequency is at 4.2 GHz. Out output frequency is the sum of the signal and the pump frequency; in this case it would be 4.5-4.6 GHz.

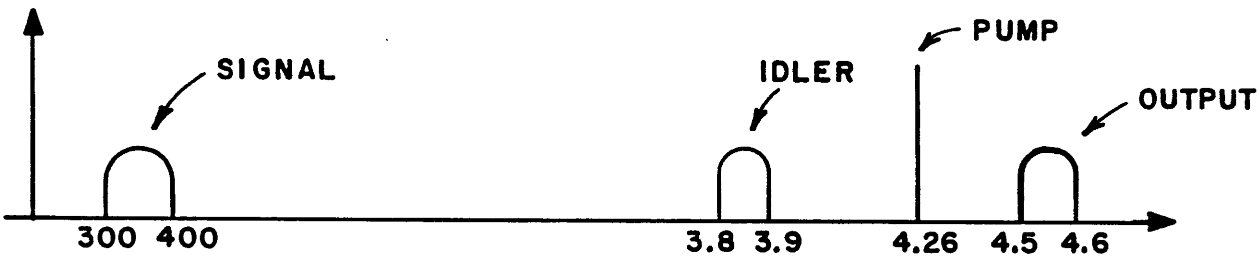


FIG. 2

In an upper sideband converter we will try to suppress the idler frequencies which is the difference between the pump and the signal frequencies, called the idler. This idler is what is enhanced in a parametric amplifier that would give us a large amount of gain. Whereas the upper sideband upconverter will have gains in direct ratio of the signal and pump frequencies modified by the varactor characteristics, namely, resistive losses. It turns out that the gain of the upconverter depends somewhat on the Q or the losses in the varactor diode.

The lower the R_s in the varactor the higher the Q of the varactor. There is, however, a trade off here because if we made Q of the varactor very high we will approach the theoretical gain of $(F_p + F_s)/F_s$, but the bandwidth would suffer because the Q is so high we will have a very narrow band of very high gain at the center of the signal frequency and the fall-off is too fast. So, to compromise, we select a varactor with a Q of about 100. We find that we can have about 25% to 35% bandwidth at the signal frequency.

Design Considerations

Varactor specifications:

In order to tune the signal circuit to resonance, we must have an inductor in series with the varactor diode. For 300 MHz, we will have a relatively large inductor, so I bought the highest capacitance diode I could find, which is about 1.0 pF. An 0.2 μH inductor was necessary to resonate the signal circuit. With the capacitance of the varactor determined, we use an analysis routine on the 9825A calculator to find the gain and noise of the upconverter. The equations for the 9825A program were entirely from the book by Blackwell and Kotzbue entitled Semiconductor-Diode Parametric Amplifiers.

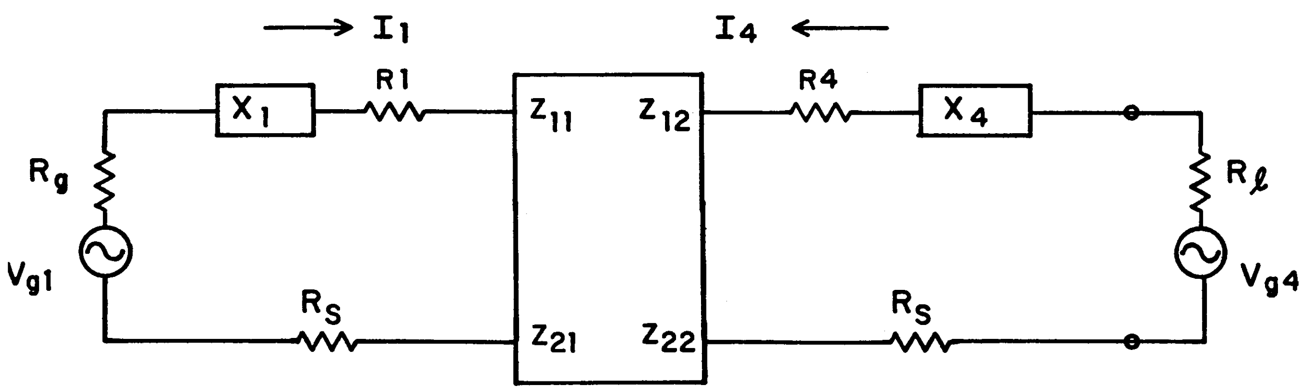


FIG. 3

Power output $= |I_4|^2 R\ell$

Power input $= |V_{g_1}|^2/4 R_g$

Z_{T_1} = Total external circuit impedance at f_1

$= X_1 + R_g + R_s + R_1$

Z_{T_4} = Total external circuit impedance at f_4

$= X_4 + R + R_s + R_4$

Transducer gain $g_t = \dfrac{4 R_g R_\ell |I_4|^2}{|V_{g_1}|^2}$

$$= \frac{4 R_g R_\ell |Z_{21}|^2}{\left|\left(Z_{11} + Z_{T_1}\right)\left(Z_{22} + Z_{T_4}\right) - Z_{12} Z_{21}\right|^2}$$

At mid-band, assuming

$$-X_1 = Z_{11} \ , \quad X_4 = Z_{22}$$

This means the matched input and output

$$g_t = \frac{4 R_g R_\ell \delta^2}{\left(\omega_1 C\right)^2} \cdot \frac{1}{\left[R_{T_1} R_{T_4} + \dfrac{\delta^2}{\omega_1 \omega_4 C^2}\right]^2}$$

To simplify, assume

$$R_{T_1} = R_g + R_s \ , \quad R_{T_4} = R_\ell + R_s$$

and

$$g_t = \frac{4 R_g R_\ell}{\left[\left(R_g + R_s\right)\left(R_\ell + R_s\right) \dfrac{\omega_1 C}{\delta} + \dfrac{\delta}{\omega_4 C}\right]^2}$$

For maximum gain

$$R_g = R_\ell$$

and

$$R_g = R_s \sqrt{1 + \frac{\delta}{\omega_1 \omega_4 C^2 R_s^2}}$$

since $1/\omega C R_s$ is defined as the effective Q of the varactor

$$R_g = R_s \sqrt{1 + \frac{\omega_1}{\omega_4} (\delta Q)^2}$$

With R_g as given above, we find

$$g_t = \frac{\omega_4}{\omega_1} \cdot \frac{\omega_1\ \omega_4 (\delta Q)^2}{1 + \sqrt{1 + \omega_1/\omega_4\ (\gamma Q)^2}\ ^2}$$

Let $\omega_1/\omega_4\ (\delta Q)^2 = \chi$

$$g_t = \frac{\omega_4}{\omega_1} \cdot \frac{\chi}{[1 + \sqrt{1 + \chi}\ ^2}$$

(This is maximum gain at center of band.)

The impedance of the varactor is given by

$$Z_{in} = Z_{11} - \frac{{}_{12}\ \ {}_{21}}{Z_{22} + Z_{T_4}}$$

$$= \frac{1}{j\ \omega_1\ C} + \frac{\delta^2}{\omega_1\ \omega_4\ C^2\ \ Z_{T_4}\ \ \ \frac{1}{j\ \omega_4}}$$

At resonance, all reactive components disappear and we get

$$Z_{in} = \frac{\delta^2}{\omega_1\ \omega_4\ C^2\ R_{T_4}}$$

and by symmetry

$$Z_{out} = \frac{\delta^2}{\omega_1\ \omega_4\ C^2\ R_{T_1}}$$

Varactor Specifications (continued):

The cut-off frequency of a varactor diode is defined as

$$f_{C(v)} = \frac{1}{2\pi R_s C_{j(v)}}$$

$$Q = \frac{1}{2\pi f C_j R_s}$$

$$\delta = \frac{C_{j(max)} - C_{j(min)}}{2 (C_{j(max)} + C_{j(min)}}$$

$C_{j(max)}$ and $C_{j(min)}$ are usually defined, by the manufacturer, to be the capacitance at zero bias ($C_{j\ max}$) and 6 V reverse bias for ($C_{j\ min}$); for a GaAs varactor is usually 0.25.

With our decision made on an output frequency of 4.55 GHz and the first set of upconverters covering 300 MHz, we calculate the Q of the varactor at somewhere around 350 MHz. We find that we will have a Q of over 300. Faced with such high Q's, we must be limited to the bandwidths we can get at the input frequencies

$$BW = \frac{\omega_0}{Q} \qquad \omega_0 = \text{center frequency}$$

According to this equation, with a single tuned input to our upconverter, the maximum bandwidth would be $\sim$ 7 MHz. We were able to match into the upconverter with one-eighth wave distributed parameter transformers and some lumped constant shunt stubs to coax about 25 % bandwidth from the upconverter. In fact, at the higher frequencies the input Q of the varactors are lower. We were able to get up to 35% bandwidths from the upconverts.

Table 2

Analysis of Upconverters at Cryogenic Temperatures

Up Converter	Up Converter	Up Converter
Sig Freq(Ghz)	Sig Freq(Ghz)	Sig Freq(Ghz)
.35	.6	.85
Pump Freq(Ghz)	Pump Freq(Ghz)	Pump Freq(Ghz)
4.2	4.05	3.75
Cj0(pf)	Cj0(pf)	Cj0(pf)
1.156	1.156	1.156
Cj6(pf)	Cj6(pf)	Cj6(pf)
.505	.505	.505
Fc6(Ghz)	Fc6(Ghz)	Fc6(Ghz)
275	275	275
Diode temp(K)	Diode temp(K)	Diode temp(K)
20	20	20
Ambient temp(K)	Ambient temp(K)	Ambient temp(K)
300	300	300
Diode parameters	Diode parameters	Diode parameters
Rs(ohm)= 1.1460	Rs(ohm)= 1.1460	Rs(ohm)= 1.1460
Qd= 343.2402	Qd= 200.2235	Qd= 141.3342
Fc0(Ghz)= 120.1341	Fc0(Ghz)= 120.1341	Fc0(Ghz)= 120.1341
For Max Gain	For Max Gain	For Max Gain
Rg(ohm)= 27.2989	Rg(ohm)= 20.6382	Rg(ohm)= 17.4443
Rin & Rout= 26.1529	Rin & Rout= 19.4921	Rin & Rout= 16.2983
Gain(db)= 10.7746	Gain(db)= 8.4102	Gain(db)= 6.7619
F(db)= 0.0132	F(db)= 0.0184	F(db)= 0.0230
NT(K)= 0.8795	NT(K)= 1.2284	NT(K)= 1.5378
For Min Noise	For Min Noise	For Min Noise
Rg(ohms)= 98.3476	Rg(ohms)= 57.3770	Rg(ohms)= 40.5095
Rin & Rout= 7.4770	Rin & Rout= 7.2556	Rin & Rout= 7.2737
Gain(db)= 5.1894	Gain(db)= 4.6601	Gain(db)= 4.1346
F(db)= 0.0068	F(db)= 0.0118	F(db)= 0.0168
NT(K)= 0.4559	NT(K)= 0.7881	NT(K)= 1.1257

Table 3

Analysis of Upconverters at Room Temperature

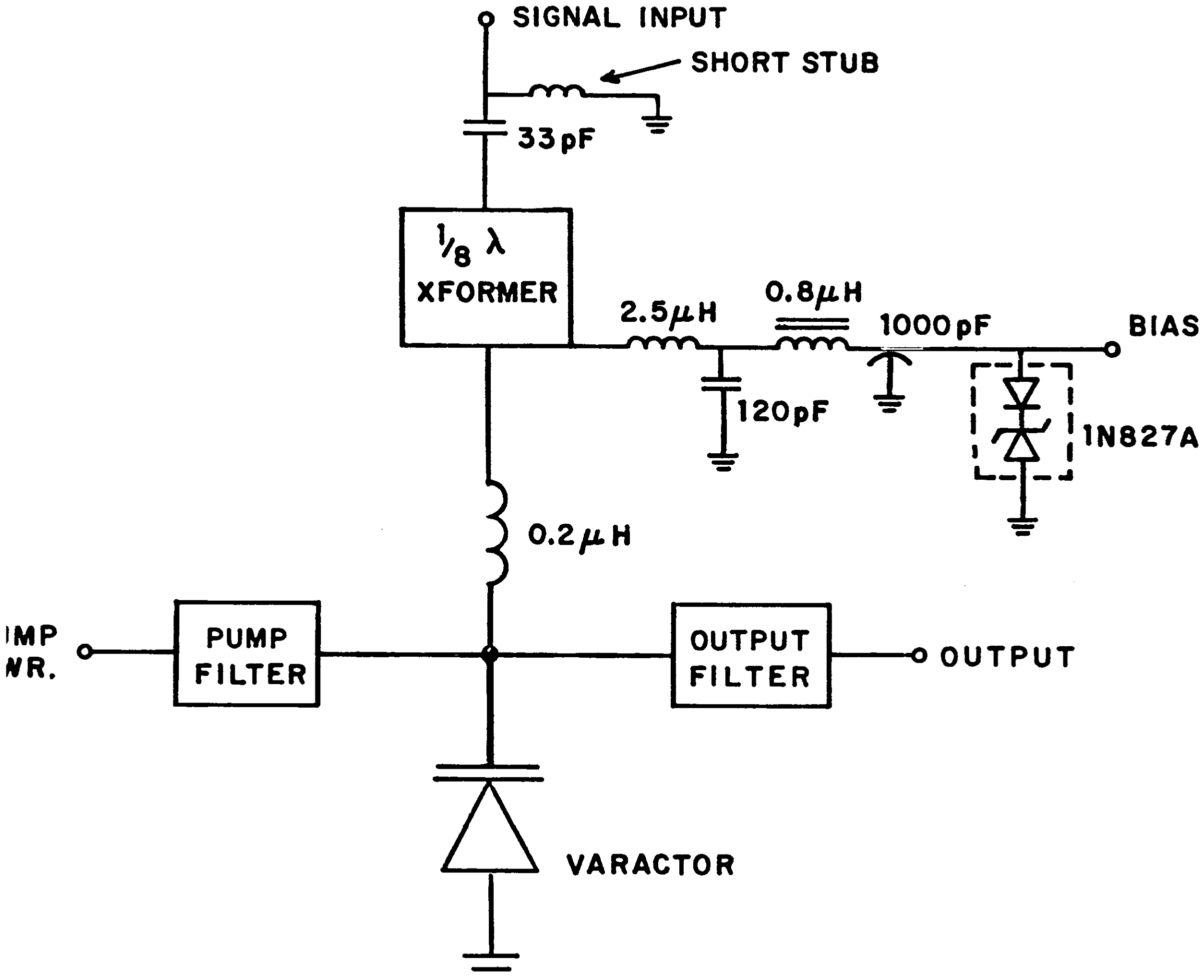
	Up Converter	Up Converter	Up Converter
Sig Freq(Ghz)	.35	.6	.85
Pump Freq(Ghz)	4.2	4.05	3.75
Cj0(pf)	1.156	1.156	1.156
Cj6(pf)	.505	.505	.505
Fc6(Ghz)	275	275	275
Diode temp(K)	300	300	300
Ambient temp(K)	300	300	300
Diode parameters			
Rs(ohm)=	1.1460	1.1460	1.1460
Qd=	343.2402	200.2235	141.3342
Fc0(Ghz)=	120.1341	120.1341	120.1341
For Max Gain			
Rg(ohm)=	27.2989	20.6382	17.4443
Rin & Rout=	26.1529	19.4921	16.2983
Gain(db)=	10.7746	8.4102	6.7619
F(db)=	0.1932	0.2675	0.3324
NT(K)=	13.1930	18.4258	23.0676
For Min Noise			
Rg(ohms)=	98.3476	57.3770	40.5095
Rin & Rout=	7.4770	7.2556	7.2737
Gain(db)=	5.1894	4.6601	4.1346
F(db)=	0.1012	0.1735	0.2458
NT(K)=	6.8383	11.8208	16.8861

In conclusion, we want a lower Q varactor diode for large bandwidths but high Q diodes for lower noise contribution. The gain variation is minimal in our case, so we disregarded the gain as a factor in our selection of the varactor diodes. As a matter of fact, we chose varactors with relatively low cut-off frequencies and large capacitances. The large capacitance for signal frequency resonance with relatively small inductances while the low cut-off frequencies to get as much bandwiths as possible.

Circuit Design

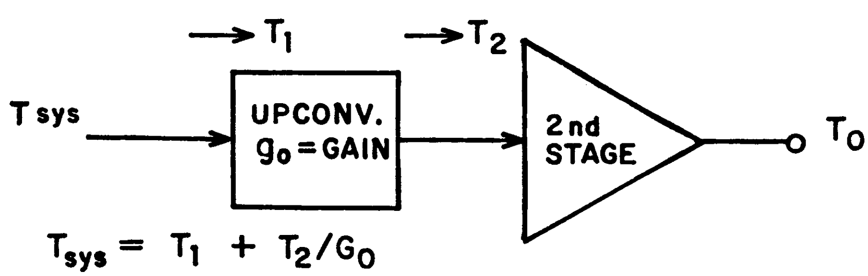
We plug our varactor parameters into the equations given by Blackwell and Kutzbue, Semiconductor-Diode Parametric Amplifiers, and find that for maximum gain the input impedance for the 300-400 MHz upconverter would be 25 Ω. A distributed parameter one-eighth wavelength with a shunt stub reactance compensation would provide up to 100 MHz bandwidth.

The pump frequency for this upconverter would be 4.2 GHz which will set our output at 4.5-4.6 GHz. The varactor diode in our case is not a frequency selective element; therefore, if we send in signal frequencies and a pump frequency we will get the sums and the differences of the pump and the signal frequencies. Since in an upconverter the sum frequencies are what we want and not the difference frequencies, we must suppress the propagation of the difference frequencies with very sharp filters. A side effect of the propagation of the difference frequencies would be instabilities in the upconverters; that is another reason why we must have very sharp pump filters as well as the output filters to select the wanted outputs from the undesired outputs and their side effects. So the upconverter would have three connections. The signal input port, the pump port and the output port. All three ports are connected to a common point on the varactor diode.



SIGNAL INPUT
SHORT STUB
33pF
1/8 λ XFORMER
2.5μH
0.8μH
1000pF
BIAS
120pF
1N827A
0.2μH
IMP
WR.
PUMP FILTER
OUTPUT FILTER
OUTPUT
VARACTOR

FIG. 4



T1
T2
T sys
UPCONV.
g0 = GAIN
2nd STAGE
T0
Tsys = T1 + T2/G0

FIG. 5

Since the pump frequencies, output frequencies, and the difference frequencies of the signal and pump frequencies are in the GHz range, and the inductive reactance in the signal circuit is very high, we can neglect the possibility of an unwanted signal propagating in the signal line.

Using the given equations in Blackwell and Kotzbue, I made some analyses of the upconverters on the computer, as shown in Tables 2 and 3. One set of the computer printout is for room temperature operation and another set for 20°K operation. Of course, these analysis only assumes losses in the varactor diode but no loss in the matching and filtering networks. In our analysis there are two outputs, one set is for maximum gain of the upconverter and another set for minimum noise contribution by the upconverters. In all cases, we find it is more advantageous to build the upconverters for maximum gain and not for minimum noise because we know that an amplifier following the upconverter will have some noise contribution, and this contribution equation is as shown in Figure 5.

In any case, the system temperature would be the lowest if we can minimize the second stage noise contribution to the system, because the second stage noise contribution is high in our case. Let us take, for example, the 350 MHz upconverter. For the maximum gain case, we have noise contributed by the upconverter of about 1°K, gain of 10.8 dB (which is a ratio of approximately 12) and, assuming a second stage contribution of 20°K, the T_{sys} = 1 + 20/12 = 2.7°K. Whereas, if we assume the same noise in the upconverter, we will have 0.5°K upconverter contribution and gain of 5.2 dB (which is a gain ratio of 3.3). This assumes the same 20°K second stage contribution T_{sys} = 0.5 + 20/3.3 = 6.54°K. Therefore, the maximum gain case could be more advantageous.

The pump filter is very sharp and is a narrow-band, coupled-microstrip, double-pole filter. The loss through it is relatively high, approximately 2 dB. The output filter is a single-pole and relatively broad-band with approximately 0.75 dB loss. The output filter on the upconverter circuit board is really not sufficient to reject the pump frequency at the upconverter output, so we went to a commercial multipole filter at the output to give us pump attenuation. Both of these on-board filters were built with matching the output of 50 Ω to the lower impedance of the diode in mind. The diode-driving impedances for the various upconverters are on the computer printouts listed.

The circuit board is made of Epsilam-10 material which is a polystyrene resin loaded with some very high dielectric powder, such as rutile, to make it into a substrate with dielectric constant of 10.3, clad with 2 ounces of copper on both sides. After the circuit board is made, it is mounted on an aluminum slab and into an aluminum case. The aluminum slab where the substrate is mounted has a mounting hole for the varactor which is gold plated to avoid corrosion caused by dissimilar metals. After the diode is mounted, it is soldered onto the substrate with low temperature silver solder. All solder joints on the substrate is soldered with low temperature silver solder. Biasing the varactor diode is done with a 0.008 diameter phosphor bronze coil of wire solder directly to the low impedance point on the signal transformer, approximately at the same point where the inductance is soldered for signal resonance with the varactor diode. This inductor is also the .008 dia. phosphor bronze wire with enamel coating. The biasing coil is connected to a low-pass filter. All three ports of the upconverter is accessed through SMA connectors mounted on an aluminum case. The bias lead is brought out through a feedthru capacitor.

The performance of the upconverters were measured with a mixer measurement set up. At room temperature we measured about 40°K with 7 dB gain from the prototype upconverters built in the 300-400 MHz range. Subsequently, we have built two more of these upconverters that went into the traveling feed receiver which is cryogenically cooled. The gains of these upconverters are a little over 9 dB and the noise contribution is on the order of 4°K to 5°K. Currently these upconverters are on the telescope operating with a system temperature of about 20°K at the input flange. See Figures 6 and 7 for gain and noise plot of the upconverters. See Figures 8 and 9 for receiver noise performance.

Conclusion

Upconverters are built for the traveling feed receiver at 300-400 MHz, 500-700 MHz, and 700-1000 MHz. The higher frequency upconverters have a little less gain as shown in the computer analysis. Therefore, the system temperature is higher but the application of the upconverters for radio astronomy is still the most desirable device in comparison to other existing amplifiers in regard to bandwidth and noise performance.

We have encountered some mechanical problems where the substrate coefficient of thermal expansion is much greater than the mounting case, but this was remedied by screwing down the substrate with additional screws. The mechanical rigidity of the coils was very poor with copper wires when they are cooled to cryogenic temperatures. We went to 0.008 diameter phosphor bronze wires to remedy the problem. There were very large sheer streeses on the varactor diode package that caused many varactor failures, but all we did was to enlarge the mounting holes through the substrate to allow for movements of the substrate with respect to the mounting slab. See Figure 10.

Conclusion (continued):

The last batch of upconverters had been in cool-down cycles for more than a dozen times and seem to be doing very well under such conditions. One of the 500-700 MHz upconverters seems to have lost a great deal of gain, as shown in Figure 9 where the noise performance is very poor. This is an earlier mechanical model which will be modified for greater mechanical stability.

Specifications/Vendors

On the following pages are specification sheets for all of the materials that go into the upconverters and also a list of vendors for these materials.

Bibliography

[1] J. M. Manley and H. E. Rowe, "Some General Properties of Nonlinear Elements, Part I: General Energy Relationships", IRE Proc., July 1956, pp. 904-913.

[2] J. M. Manley and H. E. Rowe, "Some General Properties of Nonlinear Elements, Part II: Small Signal Theory, IRE Proc., May 1958, pp. 850-860.

[3] Getsinger and Matthaei, "Some Aspects of the Design of Wide-Band Up-Converters and Nondegenerate Parametric Amplifiers, IEEE MTT, January 1964, pp. 77-87.

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[5] G. L. Matthaei, "A Study of the Optimum Design of Wide-Band Parametric Amplifiers and Up-Converters, IEEE MTT, January 1961, pp. 23-38.

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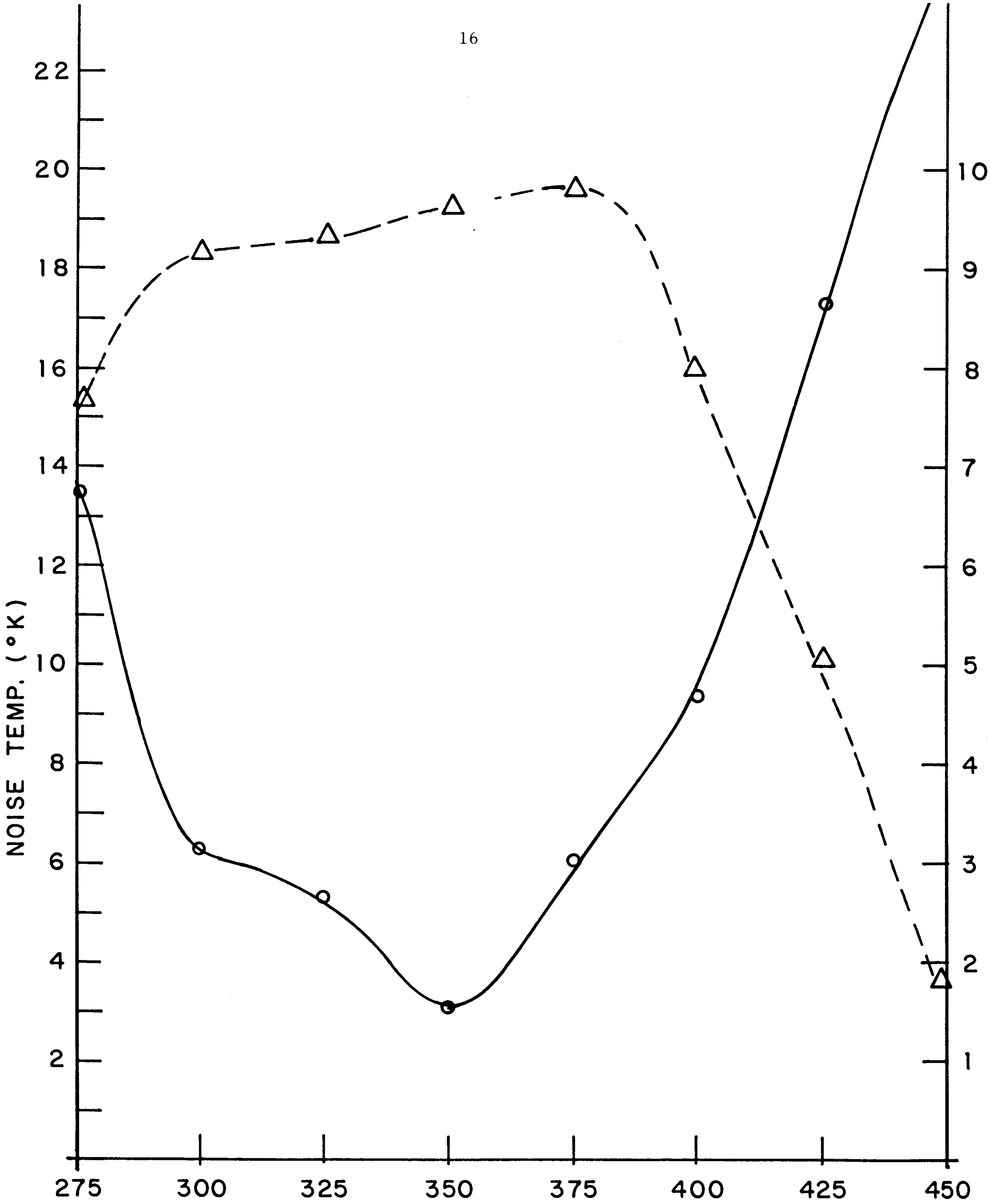
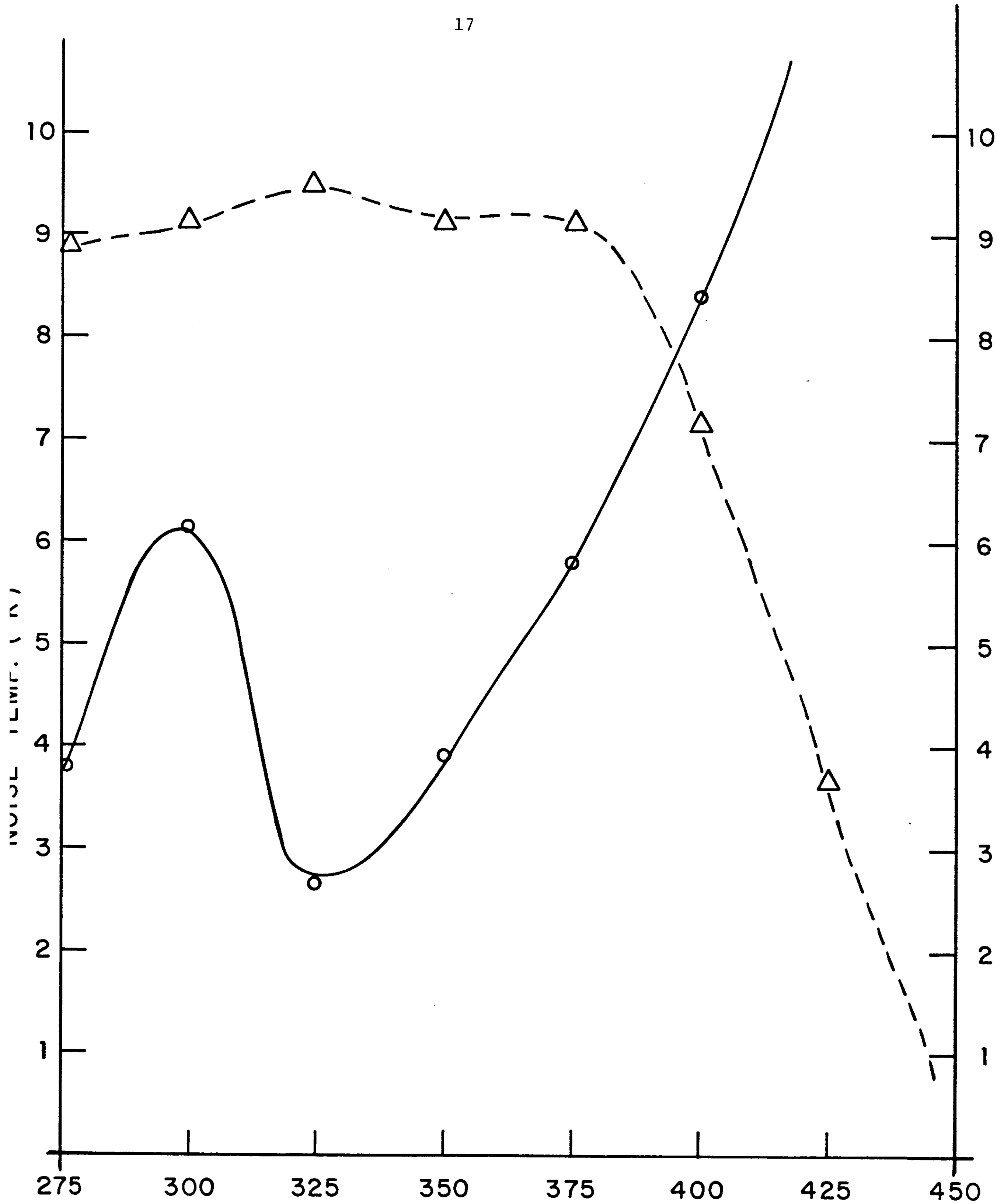
[7] L. A. Blackwell and K. L. Kotzebue, Semiconductor Diode Parametric Amplifiers, Prentice-Hall: Englewood Cliffs, NJ, 1961.



UPCONVERTER GAIN & NOISE TEMPERATURE VS FREQUENCY
FIG. 6



UPCONVERTER No. 1 NOISE TEMPERATURE VS FREQUENCY
FIG. 7

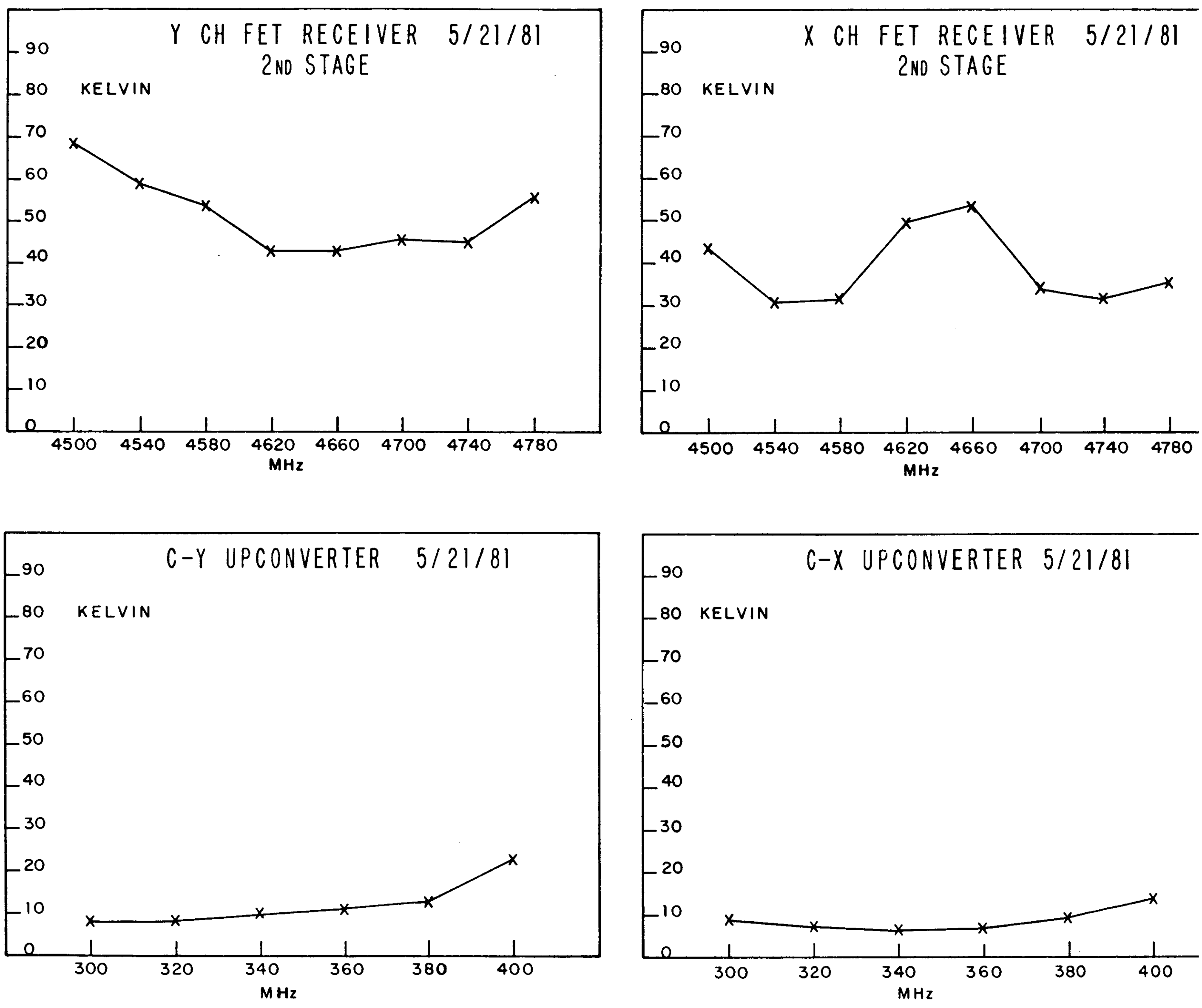

Y CH FET RECEIVER 5/21/81
2ND STAGE
KELVIN
90
80
70
60
50
40
30
20
10
0
4500
4540
4580
4620
4660
4700
4740
4780
MHz
X CH FET RECEIVER 5/21/81
2ND STAGE
KELVIN
90
80
70
60
50
40
30
20
10
0
4500
4540
4580
4620
4660
4700
4740
4780
MHz
C-Y UPCONVERTER 5/21/81
KELVIN
90
80
70
60
50
40
30
20
10
0
300
320
340
360
380
400
MHz
C-X UPCONVERTER 5/21/81
KELVIN
90
80
70
60
50
40
30
20
10
0
300
320
340
360
380
400
MHz

FIG. 8

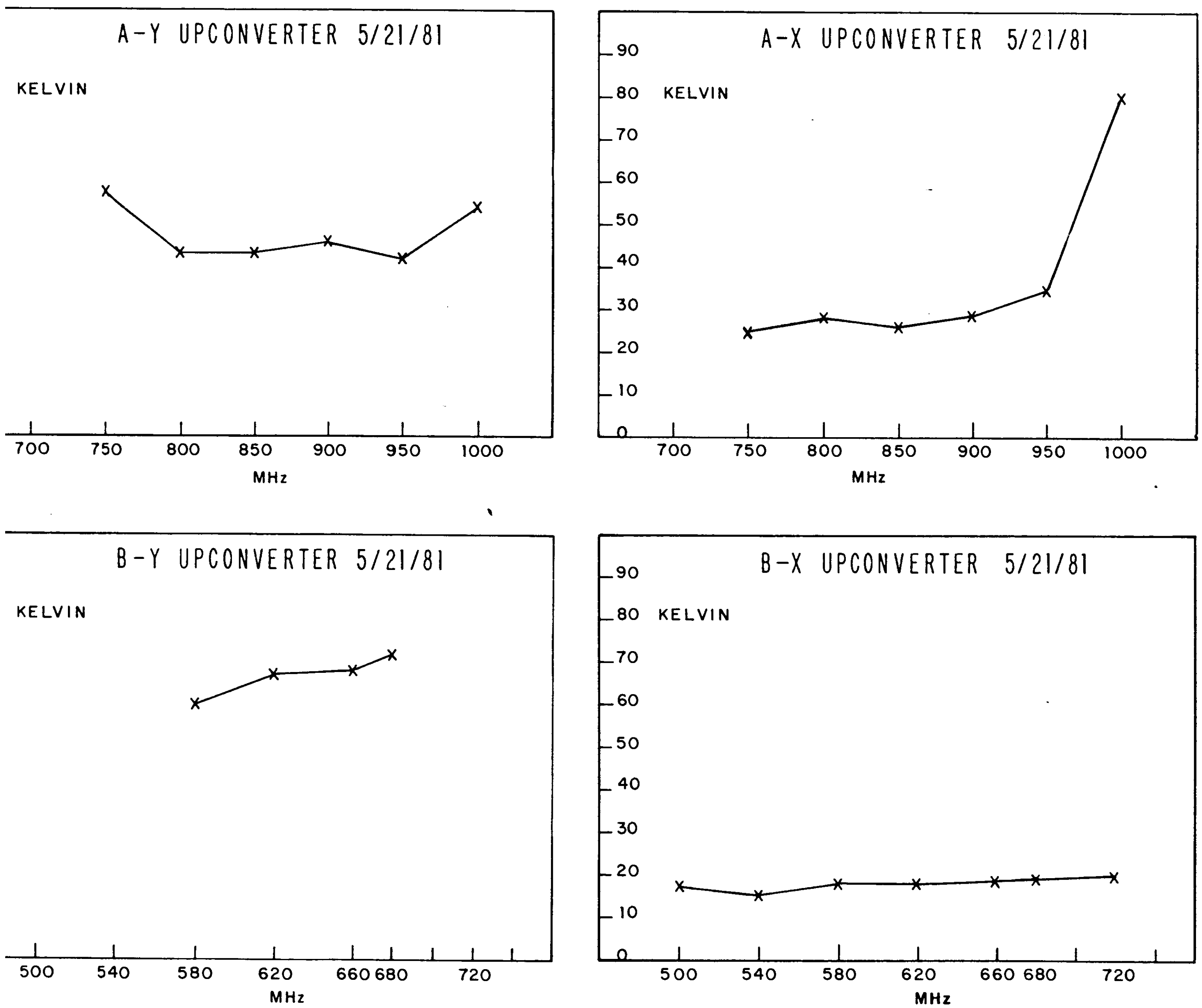

A-Y UPCONVERTER 5/21/81
KELVIN
700 750 800 850 900 950 1000
MHz
A-X UPCONVERTER 5/21/81
KELVIN
0 10 20 30 40 50 60 70 80 90
700 750 800 850 900 950 1000
MHz
B-Y UPCONVERTER 5/21/81
KELVIN
500 540 580 620 660 680 720
MHz
B-X UPCONVERTER 5/21/81
KELVIN
0 10 20 30 40 50 60 70 80 90
500 540 580 620 660 680 720
MHz

FIG. 9

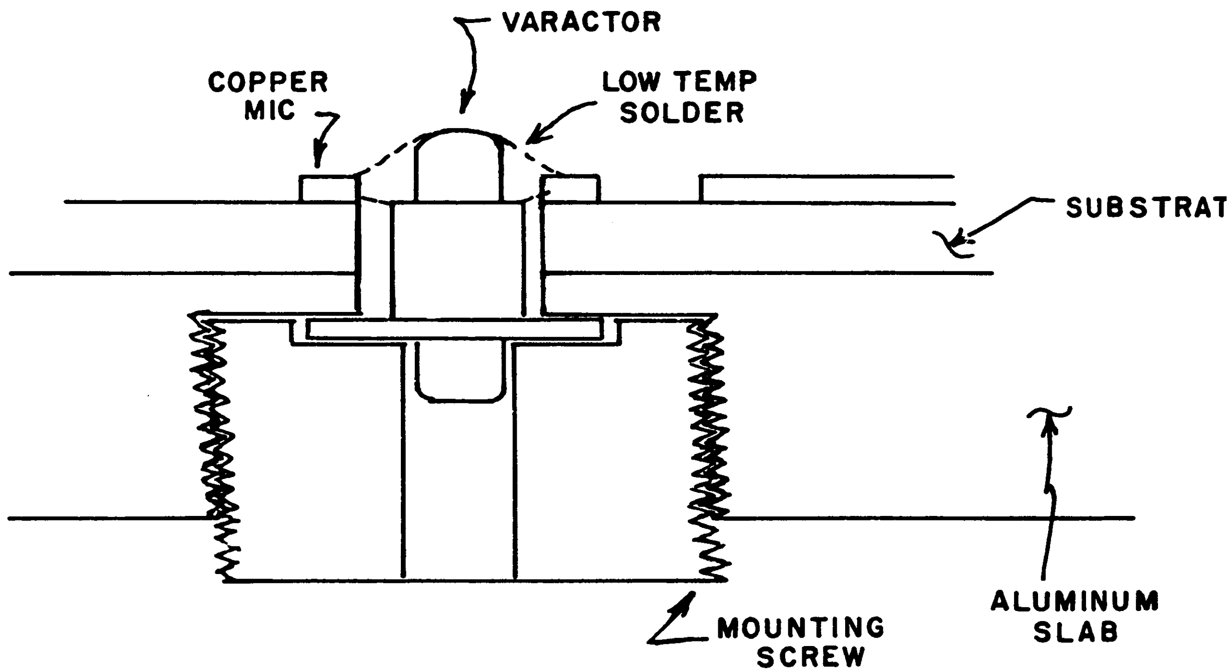


FIG. 10

Acknowledgement

Thanks to Jim Coe and Marion Pospieszalski for their suggestions and encouragement. Also, thanks to Ron Monk and Brown Cassell for graphic support, Tony Miano for drafting and Carolyn Dunkle for typing.

Specifications

Manufacturer	Materials
Sigmund Cohn Corporation	0.008 diameter phosphor bronze wire, cold drawn with enamel.
Omni Spectra	Part No. 2502-0000-00, Model No. 251
3M	Epsilam-10 microwave substrate, 2 oz. copper clad both sides, 9" x 9" x 0.050" T'k
Dielectric Labs, Inc.	M17AH121JPS Chip capacitors, 120 pF M11AH330JPS Chip capacitors, 33 pF
Alpha Industries	GaAs varactor diodes #DVE 4556-71 V_b = 6 V min, $C_j\delta$ = 0.9-1.0 pF, f_{C6} = 250 GHz, 4°K screened.
Indium Corporation of America	Indalloy #104 silver bearing solder.

List of Vendors

Alpha Industries
20 Sylvan Road
Woburn, MA 01801
617-935-5150

Dielectric Labs, Inc.
69 Albany Street
Cazenovia, NY 13035
315-655-8710

Indium Corp. of America
P. O. Box 269
Utica, NY 13503
315-797-1630

Omni Spectra
140 Fourth Avenue
Waltham, MA 02254
617-890-4750

Sigmund Cohn Corporation
121 S. Columbus Avenue
Mt. Vernon, NY 10553
914-664-5300

3M
3M Center
St. Paul, MN 55101
612-733-1110

	L		W		THICKNESSES	
SIZE 11 =	.050″	X	.050″	X	.050″	— CUBE
					.035 MAX	— MID
					.020 MAX	— THIN

DLI CAPACITORS

WORKING VOLTAGES (WVDC) IN THICKNESSES AVAILABLE

CAP (pf)	PART NO.	TOLERANCE	CUBE WVDC MAX	MID WVDC MAX	THIN WVDC MAX
0.1	11AH0R1	B	50	50	
0.2	11AH0R2	B			
0.3	11AH0R3	B			
0.4	11AH0R4	B			
0.5	11AH0R5	B, C			
0.6	11AH0R6	B, C			
0.7	11AH0R7	B, C			
0.8	11AH0R8	B, C			
0.9	11AH0R9	B, C			
1.0	11AH1R0	B, C			
1.1	11AH1R1	B, C			
1.2	11AH1R2	B, C			
1.3	11AH1R3	B, C			
1.4	11AH1R4	B, C			
1.5	11AH1R5	B, C			
1.6	11AH1R6	B, C			
1.7	11AH1R7	B, C			
1.8	11AH1R8	B, C			
1.9	11AH1R9	B, C			
2.0	11AH2R0	B, C			
2.1	11AH2R1	B, C			
2.2	11AH2R2	B, C, D			
2.4	11AH2R4	B, C, D			
2.7	11AH2R7	B, C, D			
3.0	11AH3R0	B, C, D			
3.3	11AH3R3	B, C, D			
3.6	11AH3R6	B, C, D			
3.9	11AH3R9	B, C, D			
4.3	11AH4R3	B, C, D			
4.7	11AH4R7	B, C, D			
5.1	11AH5R1	B, C, D			
5.6	11AH5R6	B, C, D	50	50	

WORKING VOLTAG (WVDC) IN THICK NESSES AVAILABL

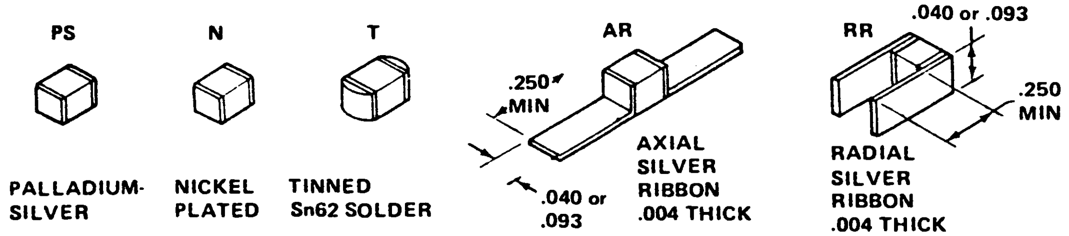
CAP (pf)	PART NO.	TOLERANCE	CUBE WVDC MAX	MID WVDC MAX	THI WVI MA
6.2	11AH6R2	B, C, D, G, J	50	50	
6.8	11AH6R8	B, C, D, G, J			
7.5	11AH7R5	B, C, D, G, J			
8.2	11AH8R2	B, C, D, G, J			
9.1	11AH9R1	B, C, D, G, J			
10	11AH100	F, G, J, K			
11	11AH110	F, G, J, K			
12	11AH120	F, G, J. K			
13	11AH130	F, G, J, K			
15	11AH150	F, G, J, K			
16	11AH160	F, G, J, K			
18	11AH180	F, G, J, K			
20	11AH200	F, G, J, K			
22	11AH220	F, G, J, K			
24	11AH240	F, G, J, K			
27	11AH270	F, G, J, K			
30	11AH300	F, G, J, K			
33	11AH330	F, G, J, K			
36	11AH360	F, G, J, K			
39	11AH390	F, G, J, K			
43	11AH430	F, G, J, K			
47	11AH470	F, G, J, K			
51	11AH510	F, G, J, K			
56	11AH560	F, G, J, K			
62	11AH620	F, G, J, K			
68	11AH680	F, G, J, K		50	
75	11AH750	F, G, J, K		25	
82	11AH820	F, G, J, K		25	
91	11AH910	F, G, J, K		25	
100	11AH101	F, G, J, K		25	
110	11AH111	F, G, J, K		25	
120	11AH121	F, G, J, K	50	25	

DIELECTRIC LABORATORIES, INC.

TOLERANC

B	=	± 0.1
C	=	± 0.2
D	=	± 0.5
F	=	± 1
G	=	± 2
J	=	± 5
K	=	± 10
M	=	± 20

TERMINAL CONFIGURATIONS



AW=AXIAL WIRE, SIZE=NO. 26 AWG   RW=RADIAL WIRE, SIZE NO. 26 AWG

CONSULT FACTORY FOR OTHER AVAILABLE TERMINATION STYLES

LASER MARKING AVAILABLE

INDIUM CORPORATION OF AMERICA

Guide to Research Solder Kits

This chart identifies the Indalloy® solders in each Research Kit, and indicates the basic design characteristics of each solder. In all cases, Kit alloys come in wire form (approx. 4' of .047 diameter). But all are available in preforms, ribbon, foils, ingots, shot, rods, pellets, powders and spheres, as well. All high indium alloys are highly resistant to corrosion in alkaline media.

Kit #1 — Indalloy Research Solder Kit
Kit #2 — Microelectronics Research Solder Kit
Kit #3 — Special Joining Research Solder Kit
Kit #4 — General Purpose Research Solder Kit
Kit #5 — Non-metallic Bonding Kit

Indalloy® No.	Composition	Liquidus °C/°F	Solidus °C/°F	Plastic Range	Density lbs./cu.in.	Electrical Conductivity % of Copper	Thermal Conductivity Watts/CM C at 85 C	Thermal Coeff. of Expansion Micro in/ C at 20 C	Tensile Strength P.S.I.	Bond Holding Strength	Kit No. 1	2	3	4	5
136	49Bi 21In 18Pb 12Sn	58/136	58/136	Eutectic	0.3252	2.43		12.8	6300				■		
8	44In 42Sn 14Cd	93/200	93/200	Eutectic	0.2693		0.36	24			■		■	■	
1E	52In 48Sn	118/244	118/244	Eutectic	0.2635	11.7	0.34	20	1720	1630			■		■
1	50In 50Sn	125/257	118/244	7°C/13°F	0.2635	11.7	0.34	20	1720	1630	■			■	■
13	70In 15Sn 9.6Pb 5.4Cd	125/257 (MP)			0.2754		0.39	27		2000	■				
290	97In 3Ag	143/290	143/290	Eutectic	0.2664	23.0	0.73	22	800			■	■		■
181	51.2Sn 30.6Pb 18.2Cd	145/293	145/293	Eutectic	0.3050		0.35	24.4						■	
2	80In 15Pb 5Ag	149/300	142/290	7°C/10°F	0.2834	13.0	0.43	10	2550	2150	■	■	■	■	
4	100In	157/313	157/313	Eutectic	0.2640	24.0	0.78	29	575	890	■	■	■		■
9	70Sn 18Pb 12In	162/324 (MP)			0.2812	12.2	0.45	24	5320	4190	■			■	
204	70In 30Pb	174/345	160/320	14°C/26°F	0.2956	8.8	0.38	28	3450			■		■	
104	62.5Sn 36.1Pb 1.4Ag	179/354	179/354	Eutectic	0.3036	11.6	0.31	25.2	7000					■	
5	37.5Sn 37.5Pb 25In	181/358	134/274	47°C/84°F	0.3040	7.8	0.23	23	5260	4300	■				
106	63Sn 37Pb	183/361	183/361	Eutectic	0.3032	11.5		25	7700					■	
205	60In 40Pb	185/365	174/345	15°C/20°F	0.3077	7.0	0.29	27	4150			■			
7	50In 50Pb	209/408	180/356	29°C/52°F	0.3198	6.0	0.22	27	4670	2680	■	■	■	■	
121	96.5Sn 3.5Ag	221/430	221/430	Eutectic	0.2657	16.0	0.33	30.2	2860					■	
206	60Pb 40In	225/437	195/383	30°C/54°F	0.3355	5.2	0.19	26	5000			■			
3	90In 10Ag	237/459	141/285	96°C/174°F	0.2722	22.1	0.67	15	1650	1600	■		■		■
133	95Sn 5Sb	240/464	232/450	8°C/14°F	0.2617	11.9	0.28	31.1	5900					■	
10	75Pb 25In	264/508	250/482	14°C/26°F	0.3599	4.6	0.18	26	5450	3520	■	■	■	■	
150	81Pb 19In	280/536	270/518	10°C/18°F	0.3707	4.5	0.17	27	5550			■		■	
6	92.86Pb 4.76In 2.38Ag	300/572 (MP)			0.3982	5.5	0.25	25	4560	2830	■				
164	92.5Pb 5In 2.5Ag	300/572 (MP)			0.3978	5.5	0.25	25	4560	2830		■	■	■	
165	97.5Pb 1.5Ag 1Sn	309/588	309/588	Eutectic	0.4072	6.0	0.23	30.4	4420					■	
12	90Pb 5In 5Ag	310/590	290/554	20°C/36°F	0.3971	5.6	0.25	27	5730	3180	■				
171	95Pb 5Sn	314/597	311/592	3°C/5°F	0.3980	8.8	0.23	29.8	3400					■	
11	95Pb 5In	314/598	293/558	21°C/40°F	0.3980	5.1	0.21	29	4330	3220	■				

MP = Melting Point

OMNI SPECTRA

OSM MINIATURE COAXIAL CONNECTOR
PANEL AND BULKHEAD MOUNT

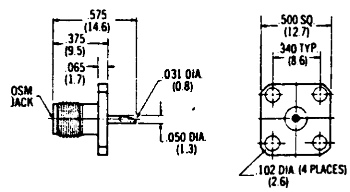
OSM Panel and Bulkhead Mount Connectors are designed to meet requirements for coaxial transitions to components, cavities, waveguides and strip transmission lines.

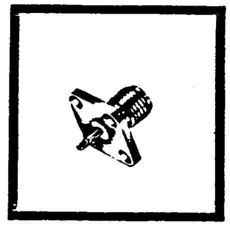
Certain types make use of a captured center contact, while others are supplied with a separate, removable center contact to facilitate assembly. Some types may be supplied with a choice of center contact on special order; with or without capturing.

PANEL AND BULKHEAD MOUNT • SOLDER POT TERMINAL

FLANGE MOUNT JACK RECEPTACLE

CAPTURED CENTER CONTACT SOLDER POT TERMINAL	
PART NUMBER	2052-0000-00
MODEL NUMBER	215

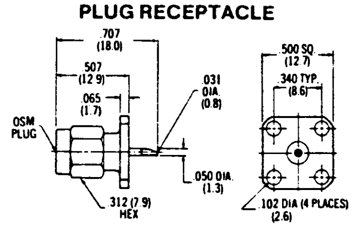


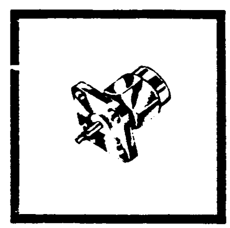


See footnote #1

FLANGE MOUNT PLUG RECEPTACLE

CAPTURED CENTER CONTACT SOLDER POT TERMINAL	
PART NUMBER	2051-0000-00
MODEL NUMBER	214-7871

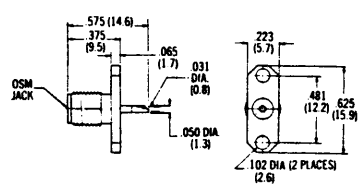


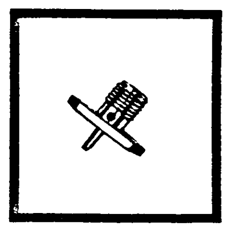


See footnote #1

TWO HOLE FLANGE MOUNT JACK RECEPTACLE

CAPTURED CENTER CONTACT SOLDER POT TERMINAL	
PART NUMBER	2052-1350-00
MODEL NUMBER	—

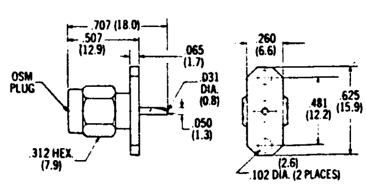


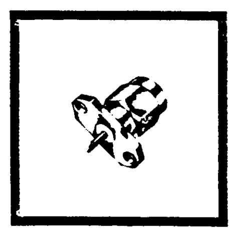


See footnote #1

TWO HOLE FLANGE MOUNT PLUG RECEPTACLE

CAPTURED CENTER CONTACT SOLDER POT TERMINAL	
PART NUMBER	2051-1350-00
MODEL NUMBER	—





See footnote #1

1. For passivated stainless steel finish versions, change the suffix "00" to "02" in the part number or add suffix "SF" to the model number.

SIGMUND COHN CORPORATION

Bronze Wire

PURE BASE METALS

	REF.	PURITY % or COMPOSITION	RESISTIVITY (Ω/cmf 0°C) Hard	Annld.	TEMP. COEFF. OF RESISTANCE (0-100°C) Hard	Annld.	TENSILE STRENGTH (PSI x 1000) Hard	Annld.	ELON-GATION (Percent) Hard	Annld.	MELTING POINT (Solidus) °C	DENSITY (g/cm³)	FORMS AVAILABLE S	W	R
Iron		99.9+%	61	54	.0062	.0065	180	34	2	40	1536	7.9	—	✓	✓
205 Nickel		99%	60	54	.0044	.0048	130	60	2	36	1440	8.9	—	✓	✓
270 Nickel		99.97%	40	38	.0064	.0067	95	48	2	36	1452	8.9	—	✓	✓
RT Nickel CP Ni	(E)	99.98%	39.4	37	.0064	.00676	100	48	2	36	1452	8.9	—	✓	✓
Tungsten	(F)	99.98+%	39	33	.0036	.0048	320	160	1.5	16	3410	19.3	—	✓	—
Copper		99.98%	9.44	9.24	.0041	.0043	76	32	1.5	46	1083	8.93	—	✓	✓

COPPER BASE ALLOYS

	REF.	PURITY % or COMPOSITION	RESISTIVITY (Ω/cmf 0°C) Hard	Annld.	TEMP. COEFF. OF RESISTANCE (0-100°C) Hard	Annld.	TENSILE STRENGTH (PSI x 1000) Hard	Annld.	ELON-GATION (Percent) Hard	Annld.	MELTING POINT (Solidus) °C	DENSITY (g/cm³)	FORMS AVAILABLE S	W	R
Copper-Silver		Ag-15% Cu	13.8	12.2	.0028	.0031	96	64	2	18	780	10.2	—	✓	✓
Phosphor Bronze Grade A		Cu 95%-Sn 5%	66	65	.00072	.00074	130	60	2	58	950	8.86	—	✓	✓
Phosphor Bronze Grade C		Cu 92%-Sn 8%	89	84	.00058	.00063	150	70	2	60	880	8.8	—	✓	✓
Beryllium Copper #10		Be 0.6%-Cu 96.9%-Co 2.5%	44	16	.001	.0028	113	64	2	20	1050	8.75	—	✓	✓
Beryllium Copper #25		Be 2%-Cu 97.75-Co 0.25%	71	38	.00085	.0015	210	100	2	28	870	8.23	—	✓	✓

3M

EPSILAM-10 MICROWAVE SUBSTRATE

EPSILAM-10® TYPICAL PROPERTIES

EPSILAM-10® TYPICAL PROPERTIES		TEST METHODS
*Effective Dielectric Constant (C Band Microstrip) 25 mil 50 mil	 10.2 ± .5 10.6 ± .5	3M
*Z Direction Dielectric Constant **(1 to 10 GHz)	10.0 ± 0.2	3M
*Water Absorption (24 hr. H_2O)	0.7 - 1.0%	MIL-P 13949E
*Copper Adhesion (lbs/in.)	8 min. (ED Copper)	MIL-P 13949E
*Etching Shrinkage With all copper and aluminum removed With 1 oz. copper ground plane With aluminum ground plane	 4 - 5 mil/in. 0.3 - 0.5 mil/in. ± 0.0	3M
*Dissipation Factor	.002	3M
Temperature Coefficient of Єr (ppm/°C)	570 (−50° C to +170° C)	
Coefficient of Thermal Expansion (ppm/°C)	20 - 25 (est.)	D-696
Tensile Strength (psi)	1400	D-229
Specific Gravity	2.98 gm/Cm³	D-792
Thermal Conductivity (cal/sec. - cm°C)	8.9 x 10 - 4	D-696
Elongation at Break	> 6%	—
Tensile Modulus (psi)	35,000	—
NASA Outgassing and Condensables	0.04% and 0.00%	—
Shore Hardness	D-65	—
Bonding Process	Direct—no interlayer	—
Processing	Standard printed circuit methods	—
Solderability	At least 520° F—stands red hot hand soldering	—
Fabrication	Can be machined, drilled, sheared and punched—the limitation on bonding and forming is the elongation of the copper.	—
Substrate Color	Gray	—
Substrate Thickness	.010", .025", .050", .075" and .100"	—
Sheet Size	9" x 9"	—
Attenuation per db/wavelength (λ) (50 ohm microstripline on 25 mil E-10)	= db/λ from 1-6 GHz .18	—
Unloaded Q	145	—

E-10® Typical properties continued on back

Test data for aluminum clad Epsilam-10® is based on the .063" aluminum thickness.

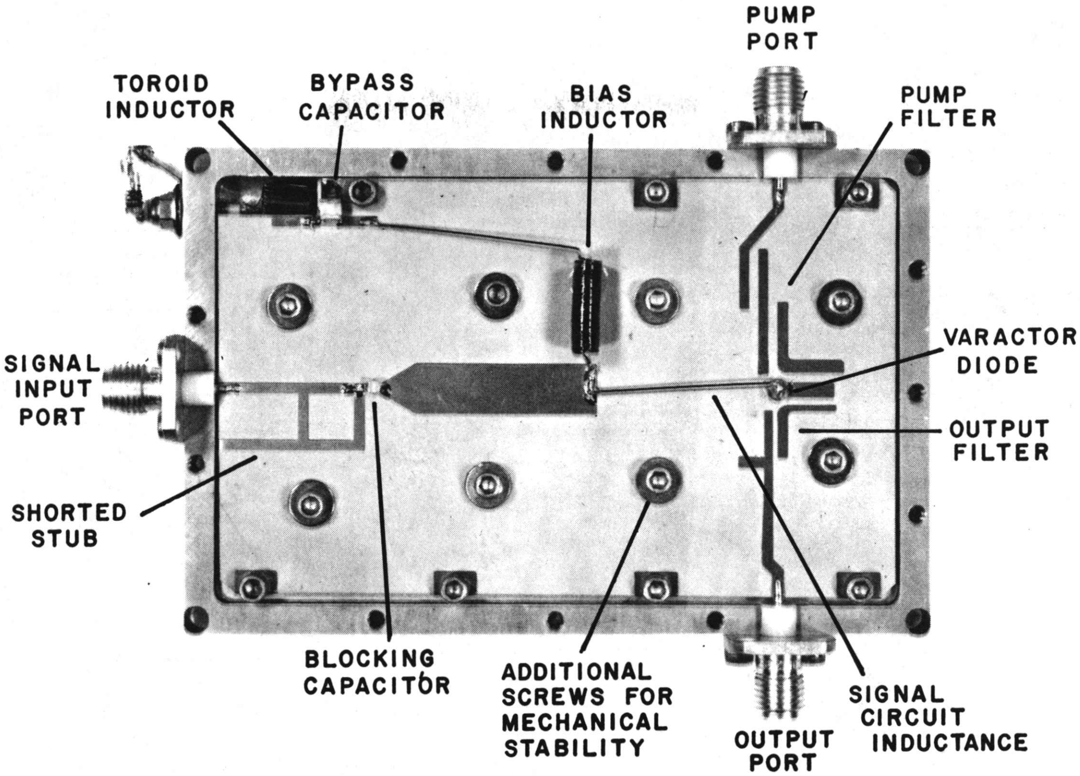
*Specification Values
Product is supplied in accordance with these values.

**Plated Disk Test

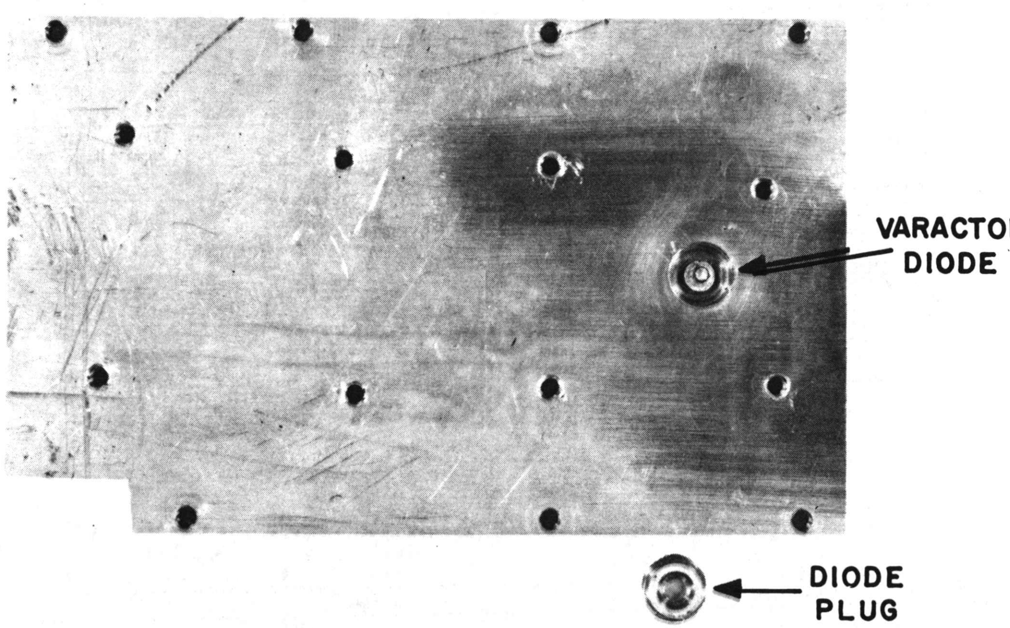
†Clamping pressure should be properly distributed to avoid indenting the E-10®.

EPSILAM-10® TYPICAL PROPERTIES

EPSILAM-10® TYPICAL PROPERTIES		TEST METHODS
Specific Heat	.2 cal/gm °C (determined from specific heats of ingredients)	—
Change in єr with frequency (1-12 GHz)	negligible	—
Change in Dielectric Constant with Temp. (−50° C to +170° C)	≈1%	—
50 ohm line width on 50 mil ground plane 25 mil ground plane	40 mils 20 mils	—



Shown here is the back side of the aluminum slab into which the varactor diode is screwed. The microstrip board would be mounted on the other side of this slab.



This is the complete assembly of a 500-700 MHz upconverter with the circuit board mounted on the aluminum slab and then in turn mounted in the upconverter case.