214-0055-01-01_00

R.F. Book

RF Note #54

September 27, 1979
S. Francis

"Improved"Fast Phase Shifter and Peak Detector

Fast Phase Shifter

Many changes have been made is the fast phase shifter since D. Birkett's RF Note #43, so I shall attempt to document this progress here.

During part of the 6 months that we had the pleasure of working with him, A. Laisne´ made various changes (improvements) in the design of the fast pahse shifter. The first change was to replace the MOSFET Q3 in Figure 1 RF #34 with 150 ohms, as shown in Figure 1 here. I show only the part of the circuit reflecting the changes as I provide a more complete schematic of the current phase shifter in Figure 3. This change resulted in giving us a higher output level than did Birkett's circuit, and eliminated one VMP4. Table 1 provides the performance of this arrangement.

Next we tryed to take the output off the drain of the MOSFET's, taking advantage of the gain of the transistors in order to obtain a higher output amplitude without distorting the signal. The quiescent current through the transistors was increased to about .12A (counting both transistors) by reducing the common source resistance to 75Ω, as in figure 2. These modifications did give us an increased output level with a quite acceptable level of distortion. Table II presents data for this "version" for two frequencies, 30 MHz and 10 MHz. Unfortunately, more data is not available for these prototypes, mais c'est la vie.

Figure 3 represents the current state of the fast phase shifter, in all of its glory. The F1, F1 inputs have been modified to be frequency dependent voltage dividers, compensating for the fact that the transistor gain falls off with frequency in order to obtain output levels that are fairly constant over our frequency range. The commom source resistance has been decreased to 27Ω (8W) increasing the quiescent current to 4A. Since the transistors themselves now dissipate 4 W each, it is necessary to mount them on heat sinks, but this is no problem. I also wound a new transformer for the output, M. Laisne' not having had the advantage of J. Riedel's lectures on the art of making a transformer. Also, the d.c. bias arrangement for the transistor gates has been modified by reducing the gain of two op amps to .27 so that the dynamic range of the phase shifter is utilized with an input range of +6 to -8 V dc.

The fast phase shifter will now put out 5 V nominal for the RF input levels equal to 5V. But since we will probably never need the full 5V out, I ran my tests on the shifter for input levels of 1.0 Vrms and 3.0 Vrms. It turns out, as one would hope, that the phase of the output signal relative to the rf input F1 is not dependent upon the amplitude of the rf inputs.

Another important characteristic of the phase shifter is the mean phase shift of the device vs. frequency. On the graph of same I have plotted 3 curves (one of which is a straight line). The first, labelled $\Delta\phi_o$ is the phase shift of the output of the device relative to F1 for a control voltage (Vin) of 0 volts. The second, which I call $\overline{\Delta\phi}$ is the arithmetic mean of the maximum and minimum phase shift for each frequency. Curiously enough, these two are not identical, although they are close enough that the descrepancy may be inconsequential. Anyway, the point is that we would like the mean phase shift through the device to be linear with frequency, so that it acts like a length of transmission line capable of lengthening or shortening itself, thereby effecting a $\Delta\phi_o \pm \Delta\phi$(Vin) phase transmission characteristic. Actually, we want the phase shift through every device in the RF system "chain" to look like it comes from a length of coax, but this seems like a subject for a different rf note. Suffice it to say that the mean phase shift of the shifter is reasonably close to being linear with frequency, close enough that I have chosen an effective cable length of the shifter, ℓ=1.778 m. Two graphs are given showing phase shift vs. control input (Vin); one for the absolute phase shift vs. Vin (ϕ(Vin)), one for the phase shift relative to a length of coax of ℓ=1.78 m ($\phi(\mathrm{Vin})-\omega\ell/\upsilon_p$).

Table III and following graphs contain all this information, Vin being the control voltage, PHASE represents the phase of the output with respect to the input F1, PHASE-CD is that phase minus the cable delay mentioned above, V out(3), V out (1) are the output voltages for rf input levels of 3 Vrms, and 1 Vrms. respectively.

In conclusion I say that the phase shifter works quite well, gives a phase shift of $\pm$ 40 degrees at all frequencies and provides quite ample output amplitude without distortion. The frequency response of the shifter is still what it was when D. Birkett measured it, having a break point at 100 KHz. I noticed that the phase shifter does require some time to warm up, there being a small difference in the operation of the device when it is cold from the operation of it after it has come to its operating temperature. This is only a small difference, and poses no problem as it only takes 5 minutes for the temperature of the shifter to stabilize. Since the transistors and source resistors dissipate a total of (.4A) x(30V)=12 watts, we must give some thought to the heatsink, airflow, etc.

Peak Detector

Due to the fastidious requirements of the amplitude regulator (as outlined in RF# 53) a new peak detector has been built with much better frequency response than the simpler original one. The old one had a 20 pf. filter capacitor which, being loaded by 100K resulted in a 2 μs time constant, giving it a break frequency of $f=1/2\pi RC \simeq 80KHz$. According to J. Riedel's computer program, this is not good enough, so we designed a peak detector using a two-stage Π filter using a total of only 6 pf. as shown in Figure 4. The op amp is a fancy 100 MHz job from Datel (AM 500GC), but actually I found it has unity gain closer to 50 MHz. The frequency response of this buffered peak detector has been examined and appears to be adequate, the response being fairly flat up to (and a bit beyond) 1 MHz. I present graphs of the amplitude and phase frequency response of the circuit and shall leave it at that. The filter does let some second harmonic through, but the amplitude of the ripple on the output, about 1/100 of the RF amplitude (at 9 MHz which is the worst case), which we can probably live with, the gain of the other stages of the amplitude regulator chain being quite low at these second harmonic frequencies.

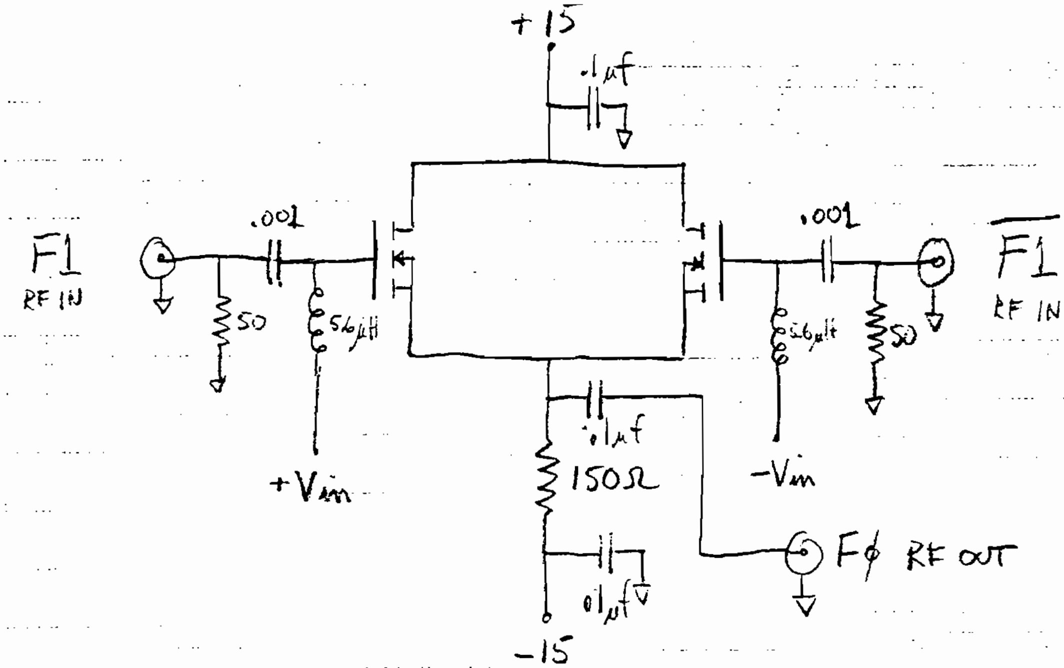


FIGURE 1

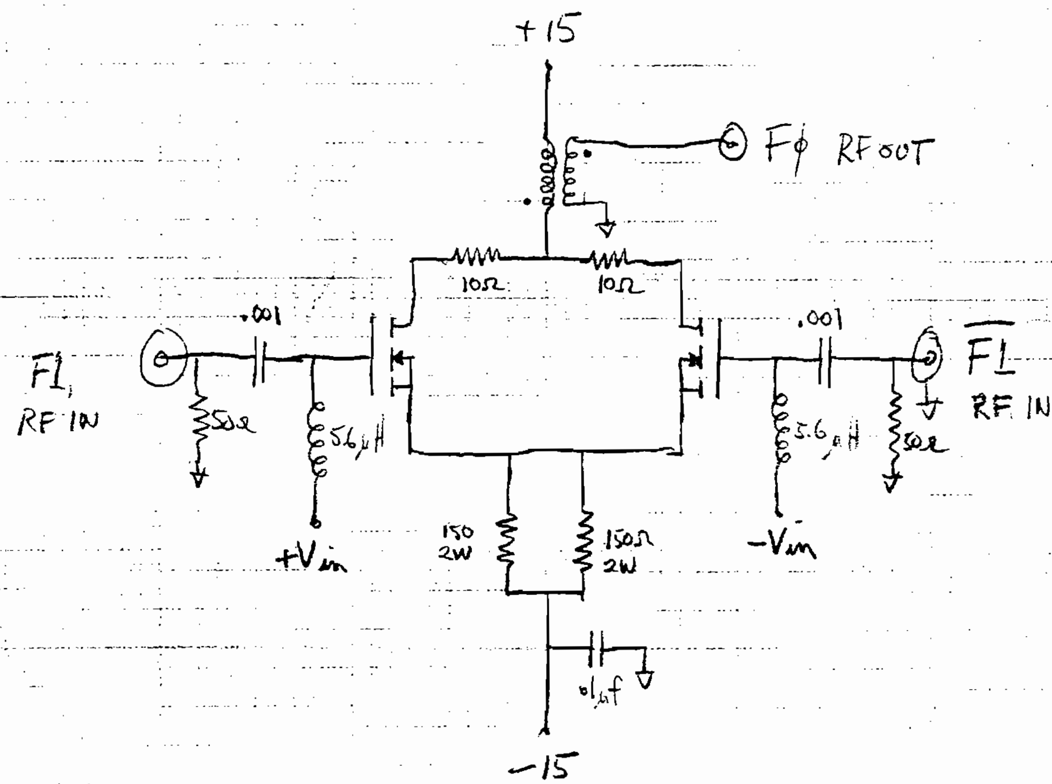
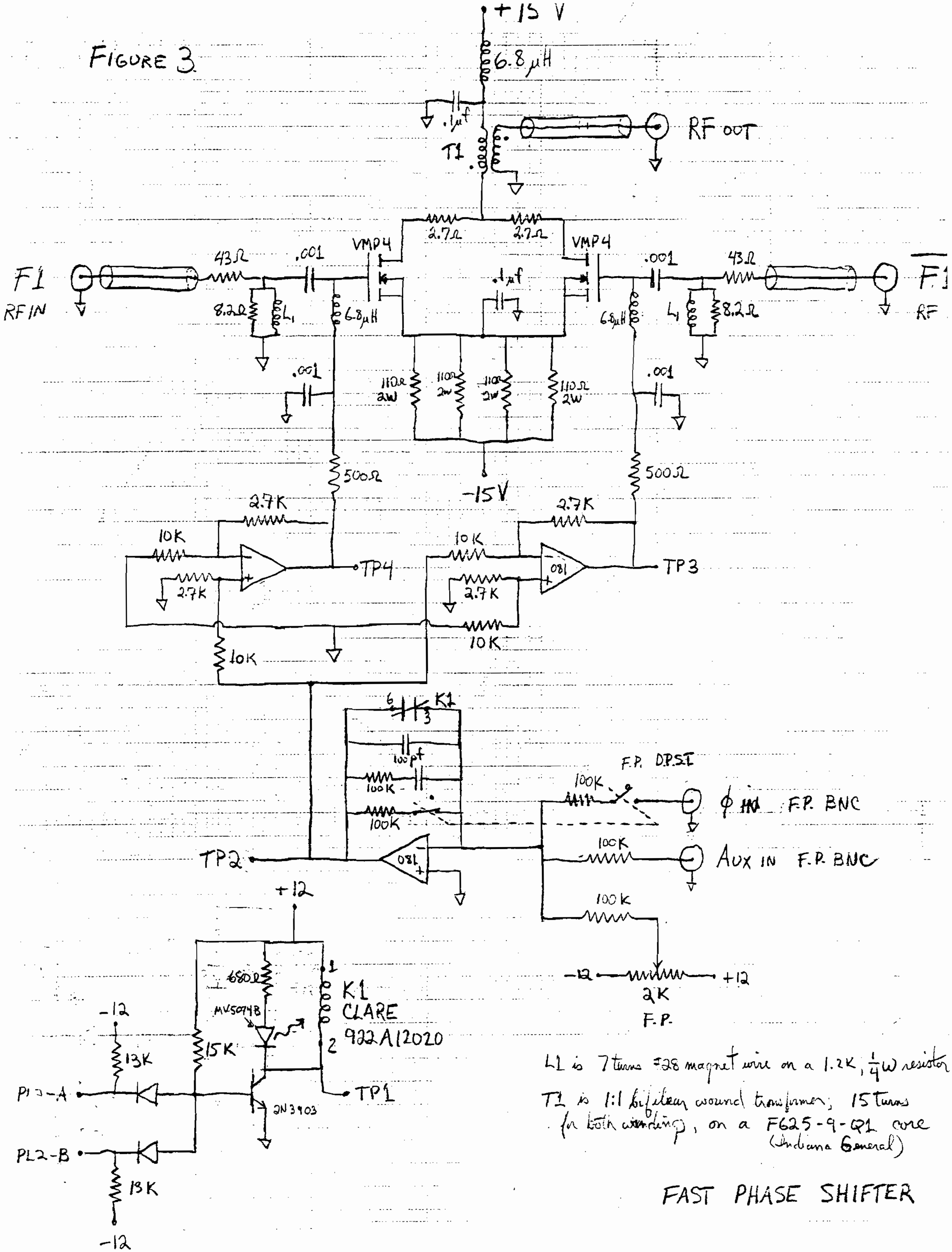


FIGURE 2

FIGURE 3



L1 is 7 turns #28 magnet wire on a 1.2K, ¼W resistor

T1 is 1:1 bifilar wound transformer; 15 turns for both winding, on a F625-9-Q1 core (Indiana General)

FAST PHASE SHIFTER

Table I

	30 MHz		
V_{in}	V_{ref}	V_{OUT}	$\phi_{out} - \phi_{FL}$
[illegible]	V_{rms}	V_{rms}	degrees
.709	.440	.355	−95
.380	.426	.300	−85
.226	.420	.275	−75
.088	.412	.260	−65
−.060	.408	.258	−55
−.203	.402	.263	−45
−.362	.400	.275	−35
−.556	.395	.300	−25
−1.76	.385	.334	−16
	14.3 MHz		
1.27	.446	.365	−98
.885	.446	.355	−95
.645	.445	.330	−90
.435	"	.305	−80
.283	"	.280	−70
.144	"	.275	−60
.006	"	"	−50
−.[illegible]6	"	.280	−40
−.224	"	.295	−30
−.463	"	.300	−20
−.721	430	.315	−10
−1.76	"	—	−7

Table II

30 MHz

V_{in} dc	V_{in} RF	V_{out}	$\phi_T - \phi_{F1}$
Vdc	V_{rms}	V_{rms}	
[illegible]	.465	2.11	-75°
.710	"	"	-75°
.615		2.10	-80°
.445		2.07	-90°
.315		2.08	-100
.175		2.08	-110
.025		2.10	-120
-.130		2.09	-130
-.273		"	-140
-.420		2.20	-150
-.597		2.20	-160
-.767		2.26	-165

$\phi_0 \approx -122°$

Table II cont

10 MHz

Vin dc / Vdc	Vin (FI) / Vrms	Vout (Fϕ)	ϕout - ϕFL °
.790	~.450	1.98	-10°
.613		"	-15°
.520		"	-20
.390		2.00	-30
.265		2.04	-40
.130		2.08	-50
-.030		2.11	-60
-.195		2.11	-70
-.343		2.11	-80
-.485		2.12	-90
-.650		2.20	-100
-.790		2.20	-102.5

$\phi_0 = -58°$

TABLE III

16:00 AUG 23 PHSHA10... f = 10 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-7	23.9516	55.9516	2.36790	.795000
-6.50000	19.9138	51.9138	2.36069	.795172
-6	15.6034	47.6034	2.39517	.803793
-5.50000	11.2931	43.2931	2.42224	.808707
-5	7.08333	39.0833	2.45333	.816750
-4.50000	3.33333	35.3333	2.48333	.830000
-4	0	32.0000	2.51000	.840000
-3.50000	-3.01205	28.9880	2.54012	.849036
-3	-5.90426	26.0957	2.55819	.855000
-2.50000	-8.56383	23.4362	2.55287	.855000
-2	-11.0648	20.9352	2.57130	.861389
-1.50000	-13.3796	18.6204	2.61759	.875278
-1	-15.6562	16.3438	2.65131	.885656
-.500000	-17.8434	14.1566	2.65569	.887843
0	-20.0281	11.9719	2.66000	.890000
.500000	-22.0329	9.96712	2.66000	.890000
1	-24.0377	7.96231	2.66000	.890000
1.50000	-26.1304	5.86957	2.65774	.890000
2	-28.3043	3.69565	2.65339	.890000
2.50000	-30.5392	1.46078	2.64676	.888922
3	-32.9902	-.990196	2.63206	.884020
3.50000	-35.5056	-3.50562	2.61798	.878989
4	-38.3146	-6.31461	2.60674	.873371
4.50000	-41.2500	-9.25000	2.59250	.870000
5	-44.3750	-12.3750	2.57375	.870000
5.50000	-48.2258	-16.2258	2.57000	.863548
6	-52.0290	-20.0290	2.56594	.857971
6.50000	-55.3285	-23.3285	2.56131	.855328
7	-57.1533	-25.1533	2.56861	.857153
7.50000	-58.9781	-26.9781	2.57591	.858978

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    420 HALT
>

 CLEAR
>LOAD SWITCH1
>WEAVE PHSHA14
>RUN
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TABLE III CON'T

16:02 AUG 23 PHSEA14... f = 14 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-8	5.30719	50.1072	2.79516	.937582
-7.50000	3.01961	47.8196	2.78863	.934314
-7	.732026	45.5320	2.78209	.931046
-6.50000	-3.26923	41.5308	2.78654	.936538
-6	-7.62295	37.1770	2.81098	.945246
-5.50000	-11.9444	32.8556	2.83778	.953889
-5	-16.4407	28.3593	2.86441	.964322
-4.50000	-20.5263	24.2737	2.90526	.977105
-4	-23.8158	20.9842	2.93816	.990263
-3.50000	-26.9512	17.8488	2.98122	1.00476
-3	-30	14.8000	3.03000	1.02000
-2.50000	-32.7778	12.0222	3.05778	1.03111
-2	-35.4717	9.32830	3.08660	1.04094
-1.50000	-37.8302	6.96981	3.11962	1.04566
-1	-40.1723	4.62773	3.15034	1.05034
-.500000	-42.3256	2.47442	3.15465	1.05465
0	-44.4789	.321102	3.15896	1.05896
.500000	-46.7401	-1.94013	3.17044	1.06000
1	-49.0358	-4.23581	3.18421	1.06000
1.50000	-51.1983	-6.39835	3.18041	1.06000
2	-53.2645	-8.46446	3.16388	1.06000
2.50000	-55.4167	-10.6167	3.15000	1.05917
3	-58.0208	-13.2208	3.15000	1.05396
3.50000	-60.6250	-15.8250	3.14625	1.05000
4	-63.2292	-18.4292	3.13063	1.05000
4.50000	-66.0390	-21.2390	3.11584	1.04792
5	-69.2857	-24.4857	3.10286	1.04143
5.50000	-72.5325	-27.7325	3.10000	1.04000
6	-75.8451	-31.0451	3.10169	1.04000
6.50000	-79.3662	-34.5662	3.10873	1.04000

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     420 HALT
>

 CLEAR
>LOAD SWITCH1
>WEAVE PHSEA18
>RUN
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TABLE III CON'T

16:04 AUG 23 PHSHA18... f = 18 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-7.50000	-16.1875	41.4125	3	1.00237
-7	-19.3125	38.2875	3	1.00862
-6.50000	-22.9104	34.6896	3	1.01000
-6	-27.1154	30.4846	3.01692	1.01423
-5.50000	-31.7544	25.8456	3.05053	1.02702
-5	-36.0484	21.5516	3.09935	1.04210
-4.50000	-40.0806	17.5194	3.20935	1.05032
-4	-44.1129	13.4871	3.17710	1.06645
-3.50000	-47.6000	10	3.20640	1.08560
-3	-50.7865	6.81348	3.24944	1.10157
-2.50000	-53.5955	4.00449	3.28315	1.10719
-2	-56.1792	1.42075	3.31179	1.11472
-1.50000	-58.5377	-.937736	3.33538	1.12415
-1	-60.8903	-3.29035	3.35690	1.13356
-.500000	-63.2334	-5.63336	3.38233	1.14293
0	-65.5199	-7.91986	3.40208	1.15000
.500000	-67.6331	-10.0331	3.41053	1.15000
1	-69.7464	-12.1464	3.41699	1.15000
1.50000	-71.9130	-14.3130	3.42000	1.15000
2	-74.0870	-16.4870	3.42000	1.15000
2.50000	-76.4356	-18.8356	3.41426	1.15000
3	-78.9109	-21.3109	3.40436	1.15000
3.50000	-81.3861	-23.7861	3.39446	1.14723
4	-83.8614	-26.2614	3.38455	1.14228
4.50000	-86.8750	-29.2750	3.38750	1.13625
5	-90.3125	-32.7125	3.40000	1.13000
5.50000	-93.4375	-35.8375	3.40000	1.13000
6	-96.3889	-38.7889	3.40556	1.13556
6.50000	-99.1667	-41.5667	3.41667	1.14667

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     420 HALT
>

 CLEAR
>LOAD SWITCH1
>WEAVE PHSHA22
>RUN
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TABLE III CON'T

16:06 AUG 23 PHSHA22... f = 22 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-7	-36.0204	34.3796	3.03796	1.02000
-6.50000	-41.0165	29.3815	3.03407	1.02204
-6	-45.5645	24.8355	3.05339	1.03226
-5.50000	-49.5968	20.8032	3.07758	1.04839
-5	-53.8136	16.5864	3.11051	1.05000
-4.50000	-58.0508	12.3492	3.14441	1.06220
-4	-62.0769	8.32308	3.18492	1.07631
-3.50000	-65.6818	4.71818	3.23091	1.09273
-3	-68.5227	1.87727	3.27636	1.10409
-2.50000	-71.3483	-.948315	3.32157	1.11539
-2	-74.1573	-3.75730	3.36652	1.12663
-1.50000	-76.6204	-6.22037	3.38648	1.13648
-1	-78.9352	-8.53519	3.39574	1.14574
-.500000	-81.1936	-10.7936	3.40955	1.15000
0	-83.4041	-13.0041	3.42723	1.15000
.500000	-85.6156	-15.2156	3.44000	1.15000
1	-87.8299	-17.4299	3.44000	1.15000
1.50000	-90.0439	-19.6439	3.43982	1.15000
2	-92.2368	-21.8368	3.43105	1.15000
2.50000	-94.4298	-24.0298	3.42228	1.15000
3	-96.9072	-26.5072	3.41237	1.15000
3.50000	-99.4845	-29.0845	3.40206	1.15000
4	-102.247	-31.8472	3.40000	1.15000
4.50000	-105.061	-34.6610	3.40000	1.15000
5	-108.110	-37.7098	3.40000	1.15000
5.50000	-111.080	-40.6795	3.41080	1.15216
6	-113.920	-43.5205	3.43920	1.15784
6.50000	-116.476	-46.0762	3.46476	1.16295
7	-118.857	-48.4571	3.48857	1.16771

420 HALT

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```
 CLEAR
>LOAD SWITCH1
>WEAVE PHSHA27
>RUN
```

TABLE III CON'T

16:08 AUG 23 PHSHA27... f = 27 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-7	-56.4865	29.9135	2.96703	1
-6.50000	-59.8649	26.5351	2.96027	1
-6	-63.8095	22.5905	3.00571	1.01524
-5.50000	-68.4314	17.9686	3.04059	1.02686
-5	-72.5758	13.8242	3.06030	1.04030
-4.50000	-76.5789	9.82105	3.07947	1.05316
-4	-80.7143	5.68571	3.11000	1.06143
-3.50000	-83.9610	2.43896	3.15545	1.06792
-3	-87.1795	-.779487	3.18308	1.07672
-2.50000	-90.2913	-3.89126	3.20233	1.09056
-2	-92.7184	-6.31845	3.22175	1.09544
-1.50000	-95.1395	-8.73953	3.24112	1.10028
-1	-97.4651	-11.0651	3.25972	1.10493
-.500000	-99.7907	-13.3907	3.27833	1.10958
0	-101.996	-15.5956	3.28000	1.11000
.500000	-104.189	-17.7886	3.28000	1.11000
1	-106.364	-19.9636	3.28000	1.11000
1.50000	-108.528	-22.1281	3.28000	1.11000
2	-110.777	-24.3767	3.28000	1.10845
2.50000	-113.204	-26.8039	3.28000	1.10359
3	-115.677	-29.2771	3.28000	1.10000
3.50000	-118.281	-31.8812	3.28000	1.10000
4	-120.966	-34.5659	3.28000	1.10000
4.50000	-123.807	-37.4068	3.28000	1.10000
5	-126.908	-40.5079	3.28000	1.10000
5.50000	-130.185	-43.7852	3.28074	1.10037
6	-133.272	-46.8716	3.29309	1.10654
6.50000	-135.965	-49.5649	3.31351	1.11772
7	-138.158	-51.7579	3.34421	1.13526

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    420 HALT
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 CLEAR
>LOAD SWITCH1
>WEAVE PHSHA32
>RUN
```

TABLE III CONT

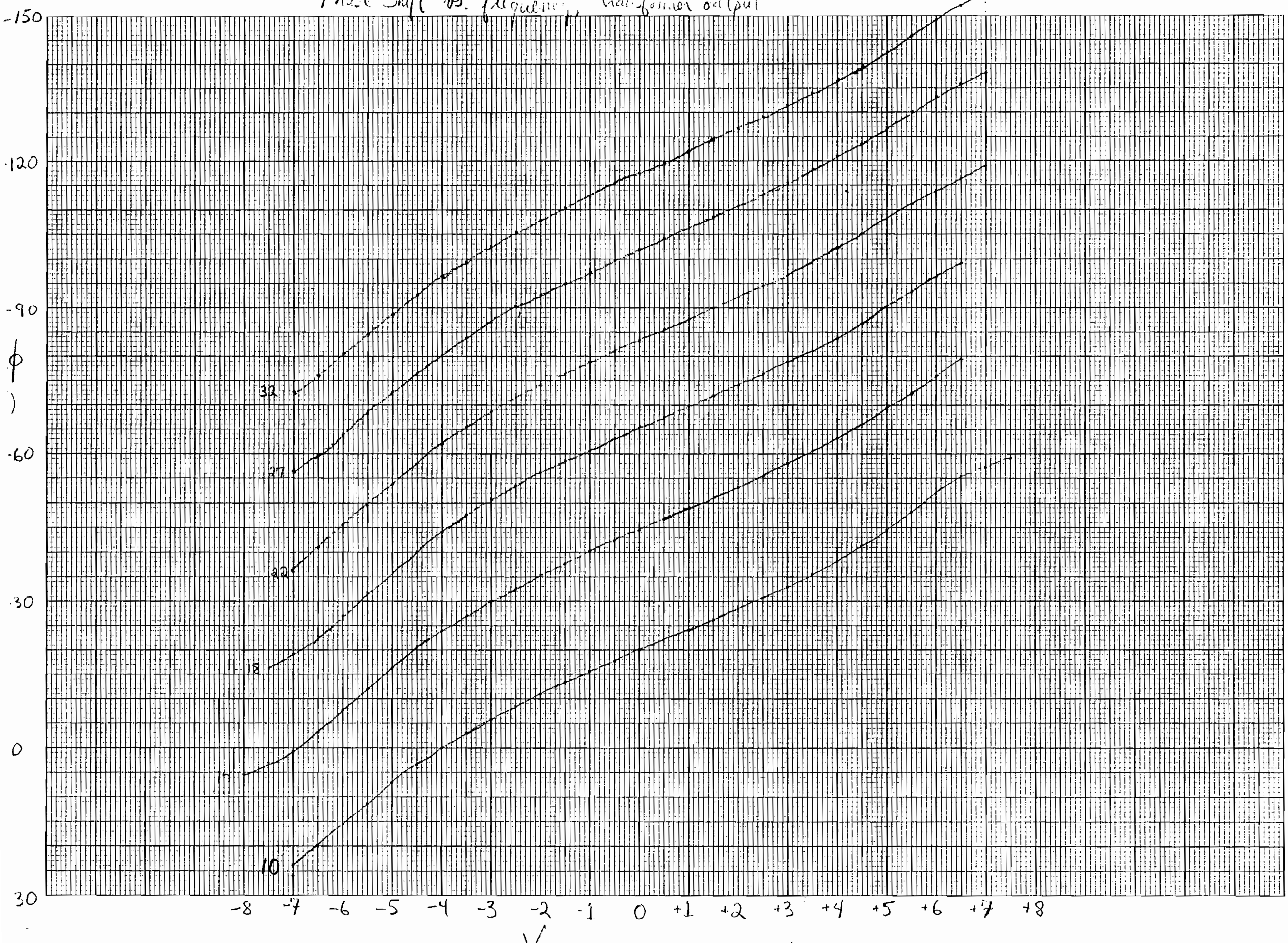
16:10 AUG 23 PHSHA32... f = 32 MHz

V IN	PHASE	PHASE-CD	V OUT(3)	V OUT(1)
-7	-72.8161	29.5839	2.86000	.967816
-6.50000	-76.0714	26.3286	2.88143	.968929
-6	-80.5085	21.8915	2.95186	.965506
-5.50000	-84.7458	17.6542	2.88407	.969746
-5	-88.7903	13.6097	2.89516	.977581
-4.50000	-92.7344	9.66562	2.92187	.985469
-4	-96.3291	6.07089	2.94532	.990000
-3.50000	-99.4937	2.90633	2.95797	.990000
-3	-102.593	-.192593	2.98074	1.00296
-2.50000	-105.529	-3.12885	3.00317	1.01553
-2	-107.933	-5.53269	3.01760	1.01793
-1.50000	-110.354	-7.95369	3.03142	1.02000
-1	-112.882	-10.4817	3.04153	1.02000
-.500000	-115.357	-12.9565	3.05000	1.02000
0	-117.557	-15.1572	3.05000	1.02000
.500000	-119.758	-17.3579	3.05000	1.02000
1	-122.051	-19.6507	3.05000	1.01590
1.50000	-124.355	-21.9548	3.05000	1.01129
2	-126.714	-24.3143	3.04314	1.01000
2.50000	-129.095	-26.6952	3.03362	1.01000
3	-131.535	-29.1347	3.02079	1.00693
3.50000	-134.010	-31.6099	3.00594	1.00198
4	-136.744	-34.3442	3	1
4.50000	-139.651	-37.2512	3	1
5	-142.785	-40.3848	3.00557	1
5.50000	-146.000	-43.6000	3.01800	1.00200
6	-149.333	-46.9333	3.04467	1.00867
6.50000	-152.041	-49.6408	3.07041	1.02633
7	-154.592	-52.1918	3.09592	1.04673

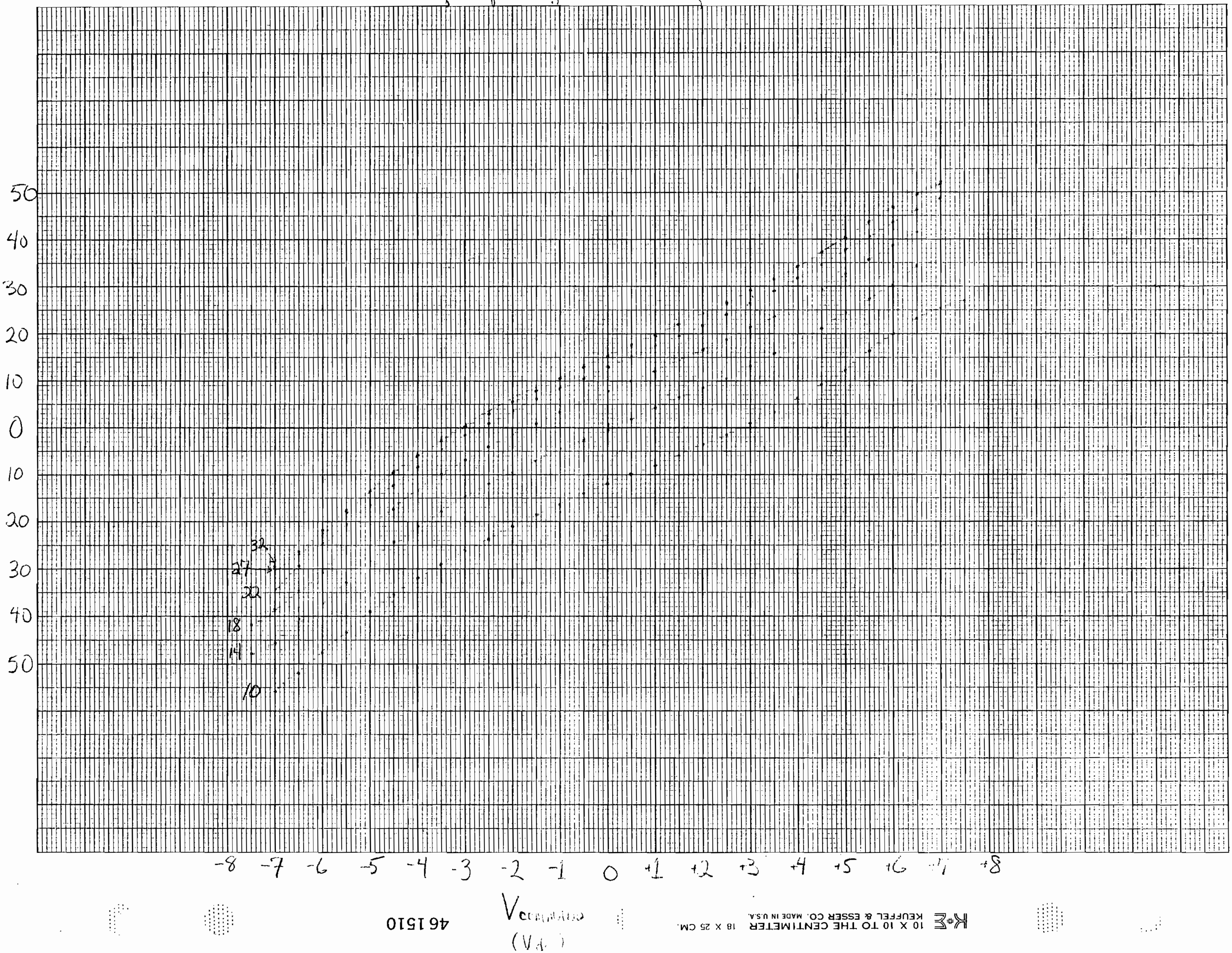
420 HALT

>

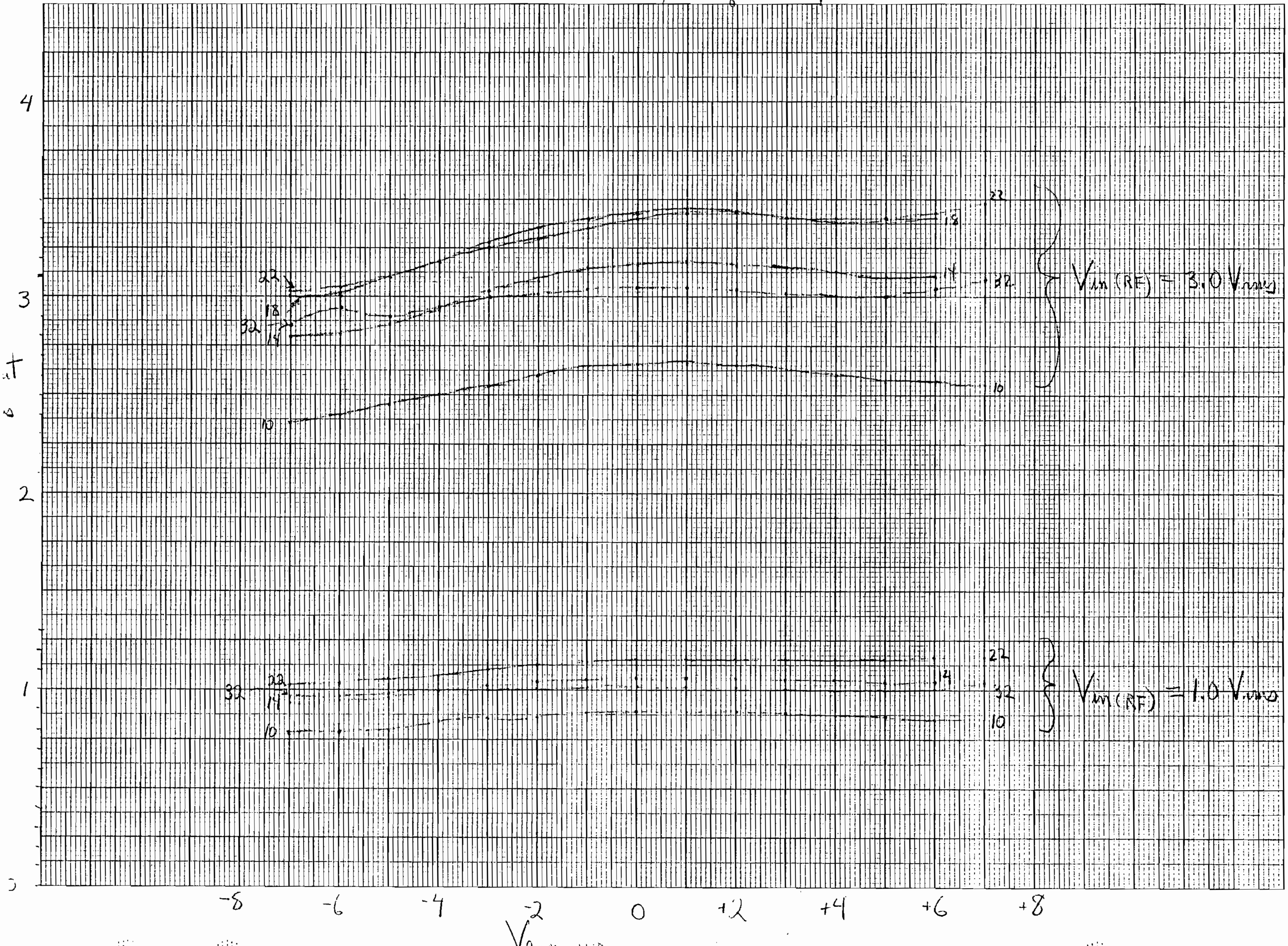
Phase Shift vs. frequency, transformer output

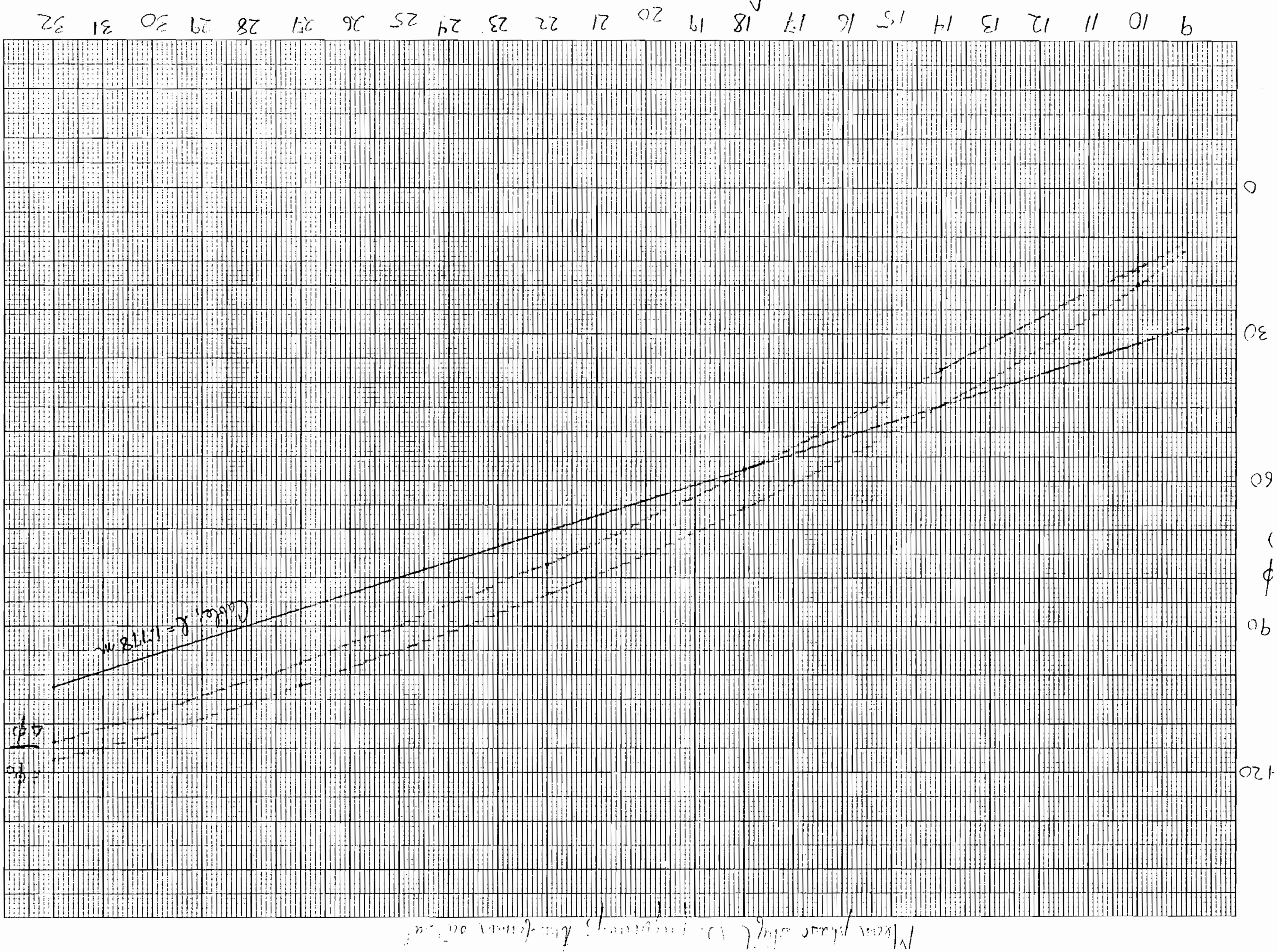


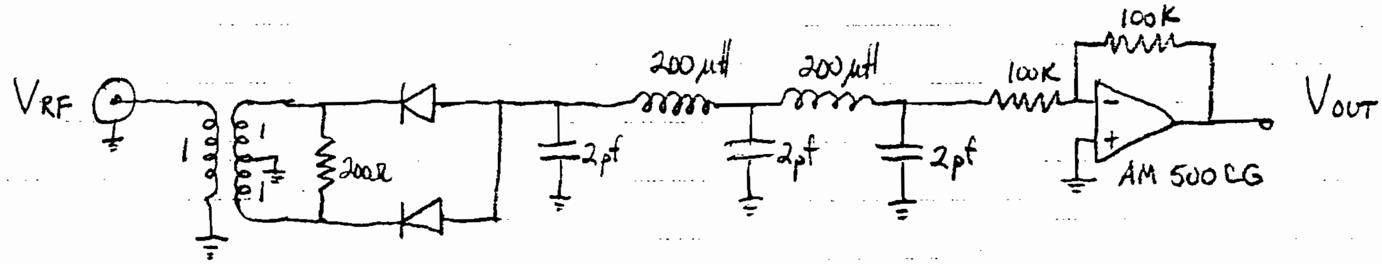
Phase Shift of Tran[illegible] [illegible]ed shifter relative to cable; l = 1.778 m



Vout vs. Vcommand, Transformer output



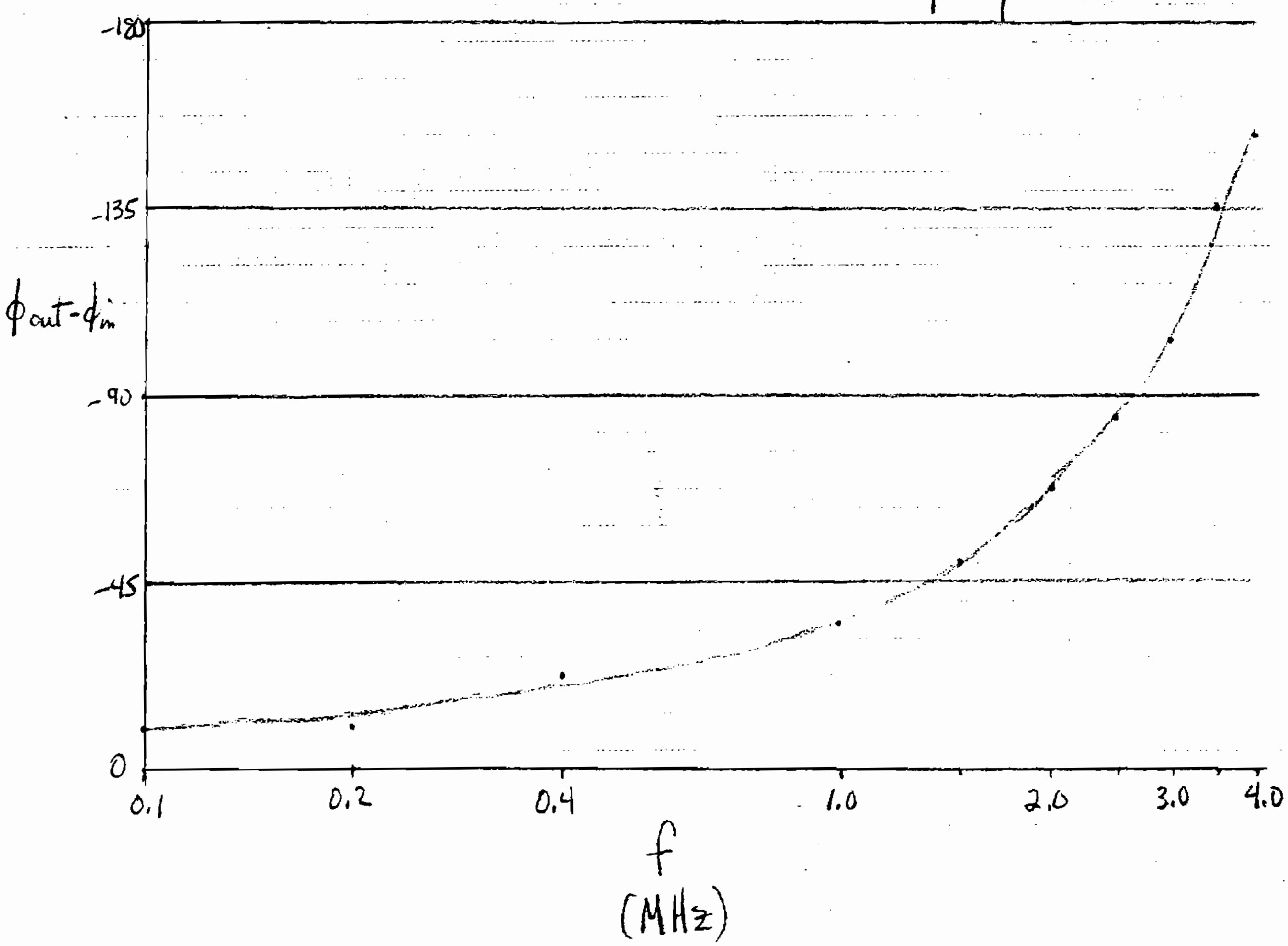

f (MHz)
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
φ
0
30
60
90
120
Cable,



CHOKES ARE 15 TURNS # 32 MAGNET WIRE
ON F625-9-TC9 CORES (IND. GEN.)
TRANSFORMER IS HOME WOUND (BALANCED CAPACITY) ON SAME CORE

FIGURE 4

Peak Detector Phase Frequency Response



Peak Detector Amplitude Frequency Response