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June 23, 1978 KF BOOK
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Electronic and Manual Phase Shifter

Drawing number 5-RE-1K-E shows, in block diagram form, where the electronics phase shifter fits into the grand plan, although the relative positions of the phase shifter and the attenuator may be juxtaposed. The purpose of this "fast phase servoe" is to compensate for possible phase errors, or modulation, due to the fact that the fine tuner on the dees, with a response time of only about .2 seconds, may not be fast enough to overcome the effects of mechanical movement of the rf structures.

Possible ways of constructing a fast phase shifter have been discussed in previous notes, but they were either inordinately complicated and/or unsatisfactory in other ways. So here is presented a much simpler way of doing it. Figure 1 (page 2) is the circuit diagram.

Let the gate of Q2 have an rf drive of 2 Coswt volts and Q1 have 2 Sinwt and Q3 have -2 Sinwt volts. Let us assume, and hope, that the bias on Q4 can be adjusted so that the three currents add linearly to produce

$$V_{out} = V4 \; Coswt + (V3-V2) \; Sinwt$$

It is then possible to show that the opamp circuitry of Fig. 1 will result in producing an output voltage ACos(wt+θ) where, as the COMMAND IN varies from -5 to +5 volts, θ will vary from -53^{o} to $+53^{o}$, and A will vary by less than 5%.

Figure 2 (page 3) is a small computer program and printout that verifies this.

Phase Detectors

D. Birkett has assembled a circuit and made enough measurements to assure me that the phase detector scheme proposed in rf note # 19 will work fine. This scheme is shown in Fig. 3 below.

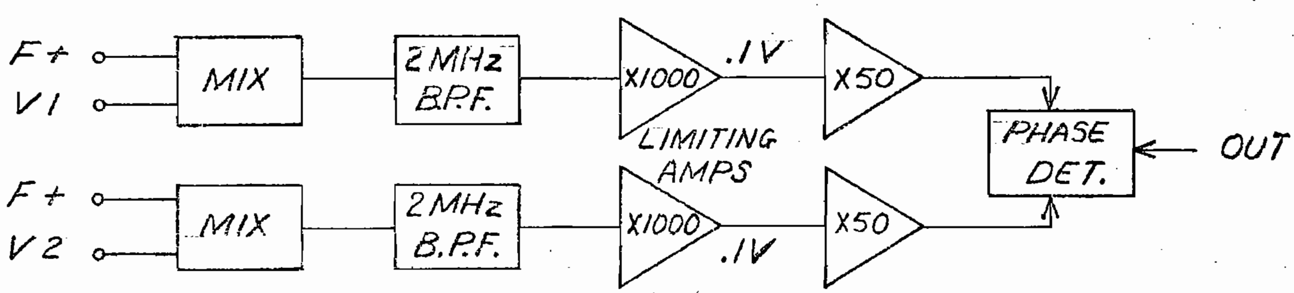
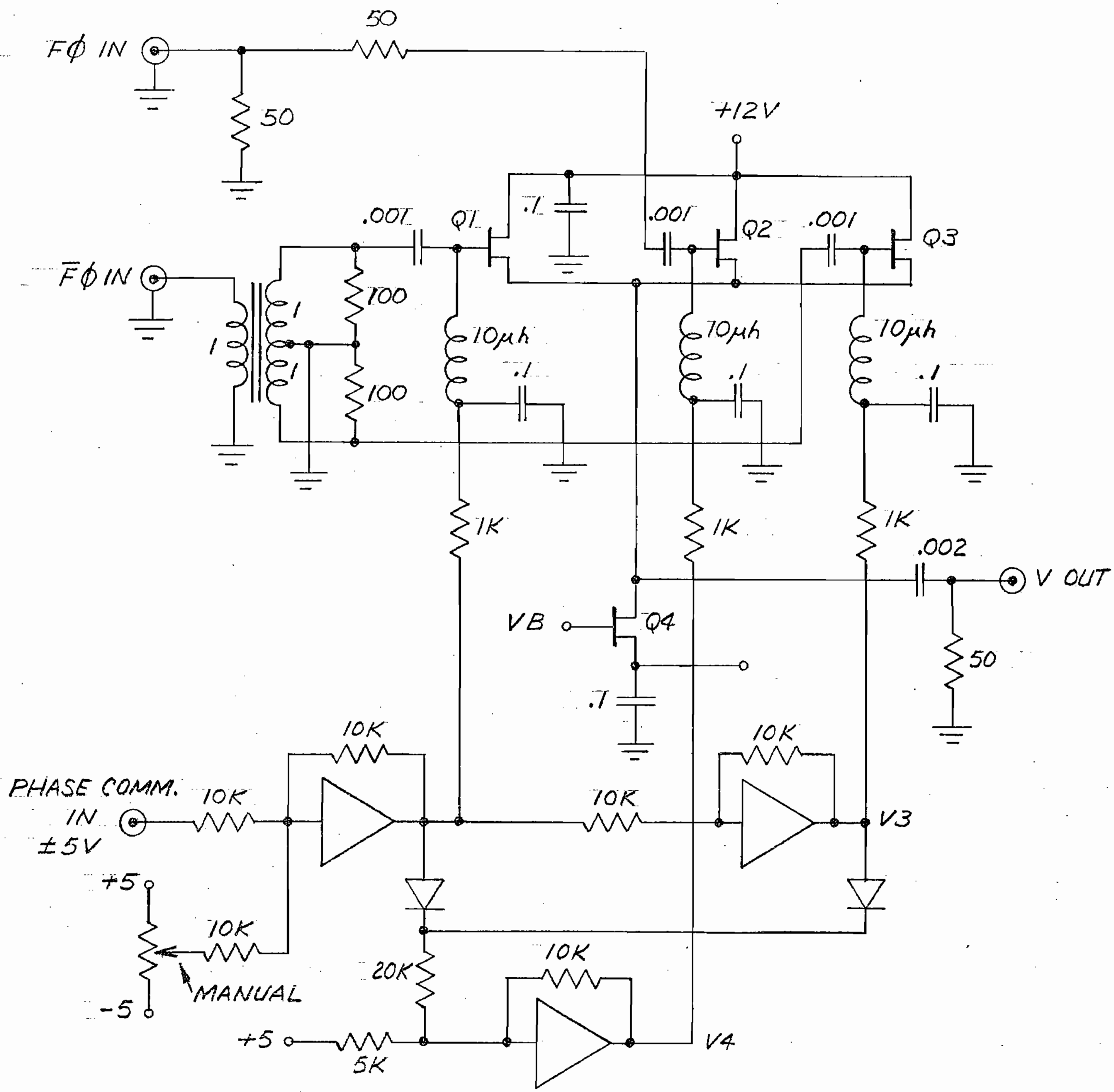


Figure 3.

If V1 and V2 are supposed to be in phase, or 180^{o} out of phase, then we will use $\overline{F+}$ into one of the channels. F+ and $\overline{F+}$ are 5 volt rms signals which turn the diodes in the mixers on and off hard. Thus



FAST PHASE SHIFTER

FIG. 1

```
LIST
 5  REM      STORED AS QUAD
 10 REM    PHASE SHIFTER BY ADDING QUADRATURE SIGNALS
 20 K=.5
 25 A=10
 30 FOR V2=-5 TO 5 STEP .5
 40 V3=-1*V2       \* INVERSION
 50 IF V2>=0 THEN 100
 60 V4=-K*V3+A
 70 GO TO 110
 100 V4=-K*V2+A
 110 V=SQR(V4**2+(V3-V2)**2)
 115 IF ABS(V4)>1E-6 THEN 120
 116 V4=1E-6
 120 P=ATN((V3-V2)/V4)
 150 PRINT V2,V4,V,DEG(P)
 160 NEXT V2
 200 END
>
```

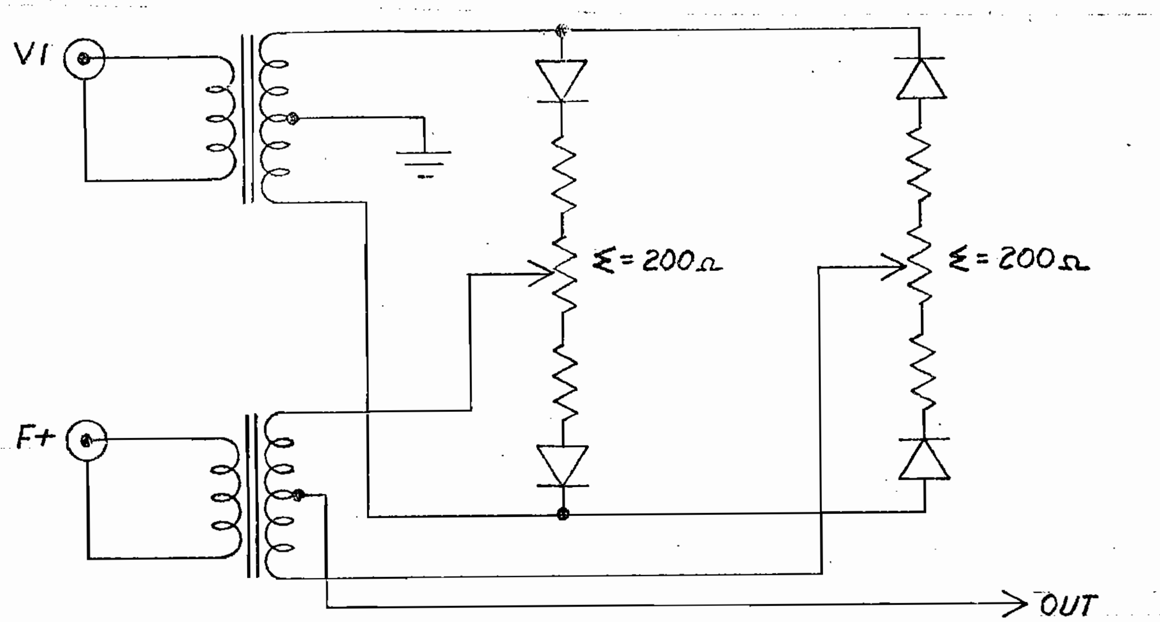
(handwritten column labels: V2, V4, Vout, Phase)

```
RUN
10:    JUN 21  QUAD...
-5             7.50000        12.5000        53.1301
-4.50000       7.75000        11.8770        49.2679
-4             8              11.3137        45.0000
-3.50000       8.25000        10.8195        40.3141
-3             8.50000        10.4043        35.2176
-2.50000       8.75000        10.0778        29.7449
-2             9              9.84886        23.9625
-1.50000       9.25000        9.72433        17.9691
-1             9.50000        9.70824        11.8887
-.500000       9.75000        9.80115        5.85601
 0             10             10             0
 .500000       9.75000        9.80115       -5.85601
 1             9.50000        9.70824       -11.8887
 1.50000       9.25000        9.72433       -17.9691
 2             9              9.84886       -23.9625
 2.50000       8.75000        10.0778       -29.7449
 3             8.50000        10.4043       -35.2176
 3.50000       8.25000        10.8195       -40.3141
 4             8              11.3137       -45.0000
 4.50000       7.75000        11.8770       -49.2679
 5             7.50000        12.5000       -53.1301

    200 HALT
>
```

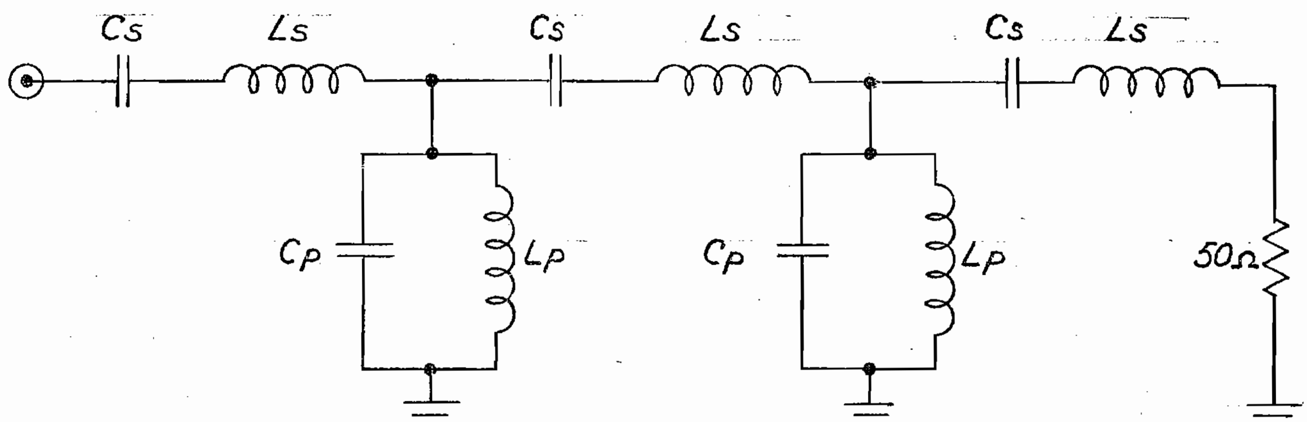
Fig. 2.

both V1 and V2 can be as small as 500 μv and the mixer outputs are linear with V1 and V2. The mixers look like this:



The transformers look like 8 pin DIP's, and are cheap.

The band pass filters are 10 element constant K filters whose configuration is schematized below:



This filter was chosen to have a band width of 2 MHz and a central frequency of 2 MHz, operating into 50 Ω. Fig. 4 is a computer printout of the response of this filter. Careful measurements have determined that the actual response agrees with the computed response.

The limiting amplifiers are 16 Pin DIP IC's MC1355 used in the phase lock loops of commercial television sets. For inputs over 100 μv the output is a square wave with rise and fall times of .02 μs.

The x 50 amplifiers are yet to be designed, but should offer no problems. The phase detectors, thus, with square wave inputs will be linear. The phase detectors are exactly like the mixers, except that the output will be through a low pass filter with cut-off at 1 MHz.

RUN
16:51 JUN 23 BANDP...

BAND PASS FILTER • 2 SECTIONS •

F0=2.00E+06 BW=2.00E+06 R0= 50.0 OHMS
LS=3.98E-06 CS=1.59E-09 LP=3.98E-06 CP=1.59E-09 C=1500?
L=4μH,
4143

FREQ	V OUT	P OUT	R IN	X IN	PHASE IN
1.00E+05	3.19E-07	447.	9.87E+11	995.	90.0
1.12E+05	5.71E-07	447.	7.79E+11	886.	90.0
1.26E+05	1.02E-06	446.	6.11E+11	788.	90.0
1.41E+05	1.83E-06	446.	4.74E+11	701.	90.0
1.58E+05	3.30E-06	445.	3.56E+11	623.	90.0
1.78E+05	5.95E-06	445.	2.50E+11	553.	90.0
2.00E+05	1.08E-05	444.	1.54E+11	491.	90.0
2.24E+05	1.96E-05	443.	7.67E+10	435.	90.0
2.51E+05	3.59E-05	443.	3.07E+10	385.	90.0
2.82E+05	6.62E-05	442.	1.04E+10	340.	90.0
3.16E+05	1.23E-04	441.	3.16E+09	300.	90.0
3.55E+05	2.33E-04	439.	9.07E+08	263.	90.0
3.98E+05	4.48E-04	438.	2.47E+08	230.	90.0
4.47E+05	8.84E-04	436.	6.39E+07	200.	90.0
5.01E+05	1.80E-03	434.	1.54E+07	173.	90.0
5.62E+05	3.84E-03	431.	3.38E+06	147.	90.0
6.31E+05	8.82E-03	428.	6.43E+05	122.	90.0
7.08E+05	2.27E-02	423.	9.68E+04	98.2	89.9
7.94E+05	7.39E-02	415.	9.16E+03	72.2	89.5
8.91E+05	.502	388.	199.	35.8	79.8
1.00E+06	.639	244.	123.	173.	35.3
1.12E+06	.648	216.	119.	62.5	62.3
1.26E+06	1.08	170.	43.0	53.7	38.7
1.41E+06	1.09	106.	42.0	895.	2.69
1.58E+06	.919	69.2	59.3	841.	4.03
1.78E+06	.941	38.1	56.5	342.	9.36
2.00E+06	1.00	.815	50.0	1.05E+04	.272
2.24E+06	.944	-36.7	56.1	-344.	-9.26
2.51E+06	.916	-67.9	59.5	-768.	-4.43
2.82E+06	1.08	-104.	42.8	-1.17E+03	-2.09
3.16E+06	1.10	-167.	41.6	-55.3	-36.9
3.55E+06	.659	-215.	115.	-61.1	-62.1
3.98E+06	.625	-242.	128.	-157.	-39.1
4.47E+06	.567	-385.	155.	-33.9	-77.7
5.01E+06	7.83E-02	-415.	8.16E+03	-71.0	-89.5
5.62E+06	2.37E-02	-423.	8.88E+04	-97.2	-89.9
6.31E+06	9.14E-03	-428.	5.98E+05	-121.	-90.0
7.08E+06	3.97E-03	-431.	3.17E+06	-146.	-90.0
7.94E+06	1.86E-03	-434.	1.45E+07	-171.	-90.0
8.91E+06	9.09E-04	-436.	6.04E+07	-199.	-90.0
1.00E+07	4.61E-04	-438.	2.34E+08	-229.	-90.0

50000 HALT
>

Figure 4.

Significance

So it seems that the phase detectors will give good phase information for inputs varying by a factor of 10^4. This means that the idea of turning on 100 volts of dee voltage to allow the various servoe loops (fine tuner, final grid coil, driver coil, plate moving short, and if necessary, dee stem short) to set themselves before we start the slow-fast turn on sequence can work. So we proceed with confidence with this plan. Now the controls can be designed. But there is a mountain of work ahead, and too little time to do it all right!

It also means that, with the aid of the fast phase shifters, we may be able to control the phases of the various dees of the various cyclotrons to 0.2 degrees.

Transmitter

The driver has been tested and works as calculated. 25 watts will be sufficient drive power, and the plate power will be only 2000 watts. Water cooling various surfaces has proven very effective.

The drawings for the screen bypass condenser are in the shop, and it is hoped that by next month at this time the anode circuit will be completely assembled with the exception of the blocker. The blocker is not due to arrive until October so we schedule to test the transmitter with stem in situ by October 15. Hopefully this will give us time to build controls and interlockery for these tests.

Testing Program

First, without the output transmission line, the transmitter circuit will be excited at instrument voltage levels to check for Q and Frequency and output loop voltages. Then we will borrow the 50 MeV cyclotron's final plate supply and excite the anode circuit to full rf voltage to check for voltage holding ability. The power will be less than 5 KW.

Then we will short out the anode rf circuit (with globars) and drive the final with the driver so that 10 amps of dc is modulated with the power supply set at 2 KV. This will prove that into a suitable load the transmitter could deliver 100 KW. Then we will power the test dees and stems.

R.F. Power Test Stand

Previously we had thought to test the transmitter by connecting it to the 50 MeV cyclotron dees and thus replacing the presently existing transmitter. However, it is my opinion that it is relatively unimportant to test the power delivering capability of the transmitter after the tests outlined above have been done. Instead, it is more important to test the voltage holding ability, and the current carrying capability of the dee stem insulator and moving short. So we will build a test fixture to accomplish this.

We start with a steel 36" diam by 20" high scattering chamber presently residing on the cyclotron shielding. We line this with copper (20 mil uncooled copper is satisfactory, soft solder joints o.k.). Inside we put a copper cylinder (20 mil is OK, cooling unnecessary) to simulate the dee capacity, 140 pf (70 pf for each half dee).

Then we use the real dee stems down to the insulator, the real insulator and the real hexagonal stems and real moving short. Don Lawton has a sketch showing this and will arrange to have this construction assembled alongside the magnet by Nov. 1, 1978. It will extend from the ceiling to the floor, a total length of some 45 feet.

<u>Details and problem areas</u>

Bob Gress is working on the synthesizer outputs and their multiplicity of buffered outputs. Due to the recent change in the requirements for the fast phase shifters we now need multiple outputs of:

$F\phi \rightarrow$ 9 to 60 mHz

$F\phi \angle 120^\circ \rightarrow$ "

$F\phi \angle -120^\circ$ "

$\overline{F\phi} \rightarrow F\phi$ shifted 90°

$\overline{F\phi \angle 120^\circ} \rightarrow$ " "

$\overline{F\phi \angle -120^\circ} \rightarrow$ " "

$F+ \rightarrow F\phi + 2$ MHz

$\overline{F+} \rightarrow F+$ shifted 90°

There will be 15 phase detectors, 3 amplitude detectors, and 3 phase shifters, necessitating 66 outputs. To simplify the nomenclature we should probably call these F1, F2, F3, $\overline{F1}$, $\overline{F2}$, $\overline{F3}$, F+, $\overline{F+}$. The buffer amps will be "damn fast" and the details of how to assemble these in NIM modules is yet to be worked out.

Then there are the controls. Very soon we will have to specify these and have the electronics shop build them.

Low Level

By low level, I mean the pseudosynthesizer, up-down circuits, buffer amplifiers, outputs of F, F^+, $\overline{F}$, $\overline{F}^+$ and their 3 phases, the phase detectors, amplitude regulators, manual and servoe phase shifters, servoe amplifiers for all of the above and control and interlock circuits. In industry this would keep a small army of engineers and technicians busy for years. We presume to do it all in six months with half a platoon. But we must get humping! If each of us works 30 hours per day, I think we may make it!