RF NOTE #6 214-0007-01-01_00 April 22, 1977
by Jack Riedel

1. The purpose of this visit was to consummate the test of the current carrying capacity of a finger. The operating test current per finger is 10 amps rms at 80 MHz. The plan was to be able to go as high as 30 amps rms at 21 MHz, using Heath Kit CB equipment. As should have been expected, this was a mistake. There must be a reason for my long contumely of Hams and CB'ers. Anyhow, after Herculean efforts we managed to modify the Heath Kit CB so that it would produce 80 watts at 21.5 mHz. Then, concordantly, a super-human effort was necessary to get an operable vacuum system. Finally this was achieved, but barely. I would like to measure the pumping speed of this petite vacuum system, as I suspect it is minuscule. However, after all this toil and trouble, the unfortunate vicissitudes of almost each moment, and after actually finding 6 coax cables, I got the equipment hooked up and ready to perform the test. Amazingly, at exactly 10 amps something went wrong, as evidenced by a CW output of the photomultipliers and an increase in the vacuum pressure -- from 10^{-5} mm to 3×10^{-5} mm of Hg. The system was opened up and it was found that the aluminum return strap had burned up and that a supposedly polystyrene insulator had melted. Good -- we were doing something.

However the finger itself was in fine shape. So we reassembled the apparatus and tried to repeat the test. The CB equipment failed, the Tectronix scope failed -- but I didn't shoot myself yet. I simply gave up. If a person can live long enough, he can solve all such problems. Anyhow, this test is not finished. Hopefully, D. Birkett will get the equipment working properly so that on 5/8/77 we can complete the test.

(A note to myself or someone else. I goofed! Yes! I found that I had failed to turn off the H.V. supply to the photomultipliers when I opened the apparatus to air and thus to light. The voltage was 2200V. I hope the PM's are not ruined.)

2. H. Blosser has decided that 80 mHz is out; that operation on the fundamental, 2, 3, 4, 6, 8, 9th harmonics are in and that therefore the 3 dees will not be tied together, mechanically or electrically, and that in fact they will have to work at $\pm 120^{\circ}$ phase relationship. O.K. Without much thought I had previously said that would be no problem!

So I read Bob Smith's and Ken Mackenzie's paper of 1956 on the subject of powering 3 dees 120° apart in phase. And lo and behold, it says there (and of course this is like gospel) that the problem of servoeing the phase and amplitude control of the three dees was "insuperable" until they had neutralized the dee to dee capacity. Well! They were working at a fixed frequency and this neutralization via loop coupling and $\lambda/2$ lines between the stems was simple. At MSU with our 4 to 1 frequency range this would not be so simple.

3. Meanwhile we measured the dee to dee capacity, using the electrolytic tank set-up that Bishop had made to study the orbit geometry in the injection region. It was 0.5 pf. A truly miraculous number. This number has many strange and hopefully benign significances. (Sometimes I wonder why I make any measurements or experiments. I "felt" that this capacity would be .5 pf, just like I "feel" that 30 amps is the maximum that my finger can carry!)

Now .5 pfs, at 60 MHz stores 3.77 x 10^6 volt amperes of circulating energy. This is 2% of the circulating energy of each dee system and therefore one can say that the .5 pf strongly couples the dees. Weak coupling would obtain if the fraction of energy in the coupling was less than 1 part in Q, or less than .05%.

Now, unlike the case with MacKenzie's dees, the problem of neutralizing our dee to dee capacity over a 4 to 1 frequency range is insuperable! And shielding the dees to reduce the coupling is probably out as well because we need to decrease the capacities by a factor of 100 or even 1000.

So we ask: Why did Smith and Mackenzie say neutralization was necessary? The answer is that they could not achieve stable servo loops for phase and amplitude control. However some progress has been made since 1956 on understanding servoe problems; we now have opamps, and we have ECAP and similar computer programs to solve open and closed servoe responses and I, J. Riedel, assert that there is no fundamental reason why stability cannot be achieved even with strong coupling, it is merely that the servoe amplifier transfer functions need be designed right! After all, it is a linear system, and with Q's of 5000 nothing can change very much in a few hundred cycles, so that we have a few microseconds to correct for errors, and as T. Coor (of PAR) says, almost anything can be done in a microsecond. So it is proposed that we make a computer analysis of the problem and hopefully so demonstrate that a solution is possible, and that we build a model specifically designed to prove that we can close stable servo loops for amplitude and phase rf regulation.

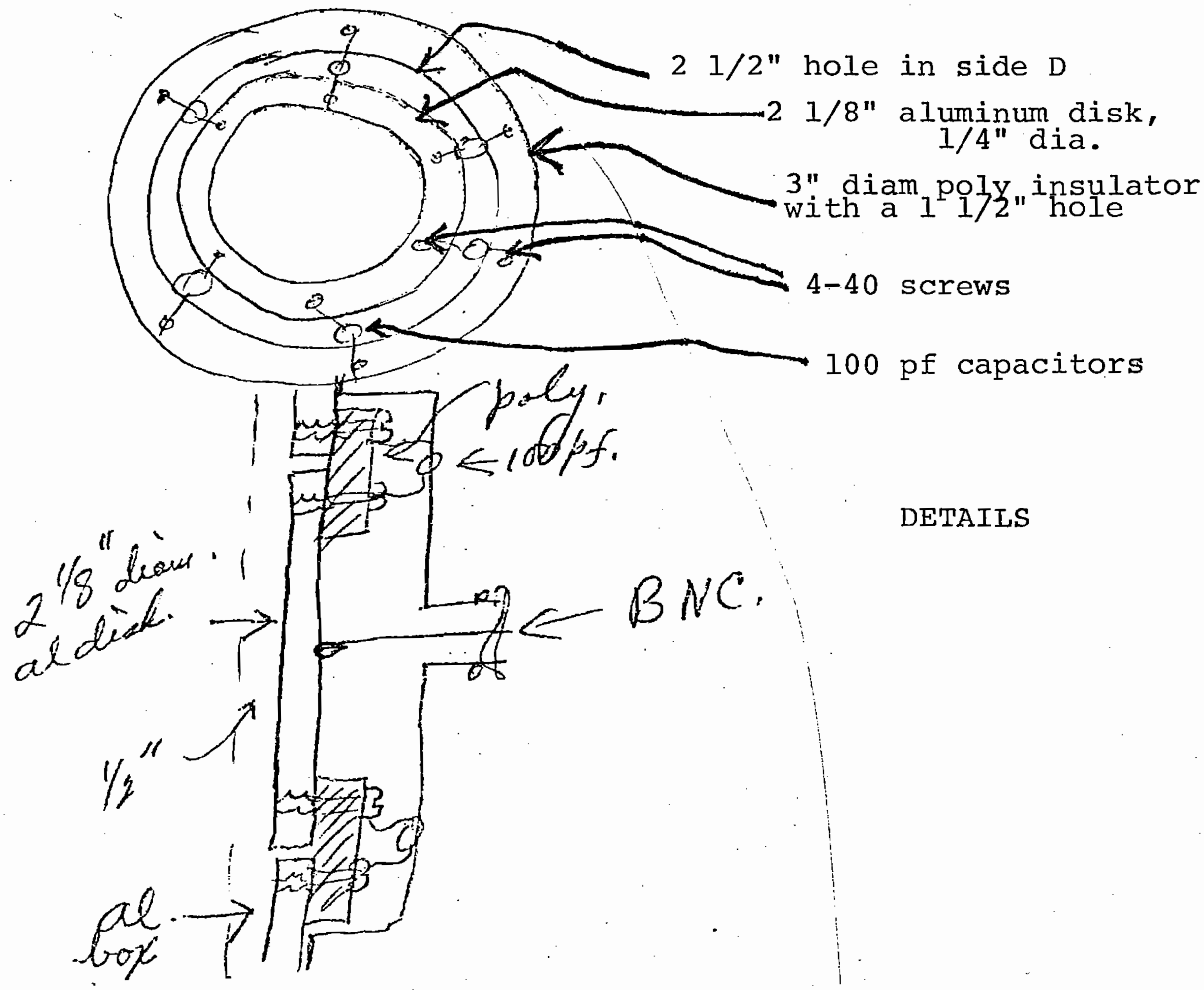
Stability Model

It is proposed that we build a model that will work at 50 mHz ± 5 mHz. using full scale stems (about 3 ft. long) and a lumped capacitance to achieve the same characteristic and shunt impedances as the actual dees (and thus the same Q). The tuning of the dees will be via hydraulically driven vacuum variable capacitors (5±1 pf). The amplitude and phase detectors should have inputs of about 5 volts rms into 50 ohms, or 1/2 watt each. This means that in order to avoid having the detectors affect the Q, that the power into the dees should be about 10 watts each, or a voltage of about 1200V rms.

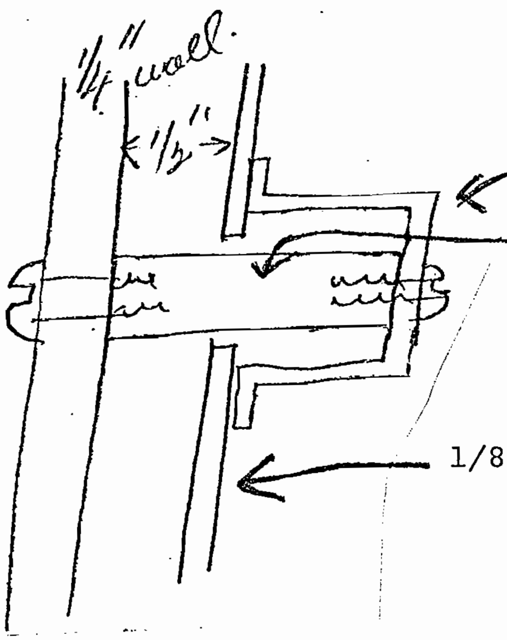
Another important requirement is that the mechanical arrangement be stable and immune to vibrations etc. So it will be a substantial mechanical device. It is felt that the 15" x 15" x 15" box constructed 1/4" thick aluminum will be sufficiently stable, although 1/2" would be better.

Capacities

At 50 mHz, the 50.1Ω stems, .74 meters long require a capacitor of 88 pf's to achieve resonance. We arbitrarily settle on a 1/2" air gap and thus find that we need an area of 14 x 14 in sq. for the capacitor, and that is why we choose a 15" x 15" x 15" box. The divider for reading the dee voltage will be 200 to 1 or 500 pf to 2 1/2 pf. The 2 1/2 pf will come via a 4.25" diam hole in the center side of D of the 15 x 15 x 15" boxes and a disk (2 1/8" diam) mounted flush with the surface supported by a polystyrene 1/4" 3" diam disk. 5-100 pf mica capacitor to ground complet the divider, which then feeds a BNC connector.



The 80 pf capacitors are aluminum square plates 13" x 13" held 1/2" from the D surfaces by 4 ceramic staked off insulators. Use 1" long insulators that penetrate clearance holes in the plate as below.



The 1/2 pf coupling capacitors are 1/2 pf ceramic or mica capacitors which connect directly to the dees thru 1/2" holes in the D side.

The drive capacity of approximately 1 1/3 pf, but variable will be achieved by using a 6" long 50 ohm copper line which can have a 2" diam plate on its end and its position can be adjusted by pulling it in and out. See detail of side C. A tee at the entrance and a small box can permit one to put 200Ω to the monitor BNC to get a 4 to 1 ratio for the feeder voltage monitor.

Sides B will support the Moog hydraulic servo actuator and the 20 pf Jennings Vacuum capacitor. Sides A will be removable via 16 screws for assembly and inspection. The aluminum boxes can be either screwed together or welded, whichever is cheaper.

It is presumed that this test fixture will exist by June 1, 1977.

Electronics & Measurements

In order to perform the desired tests it will be necessary to fabricate the following electronics devices:

1. A servo amplifier for the Moog actuators with unity gain at 10 Hz and a gain of 10^5 at .0001 Hz.
2. Phase detectors with response better than 1 MHz, amplitude independent.
3. Electronic phase shifters with response better than 1 mHz, amplitude independent.
4. A peak detector with response better than 1 mHz.
5. A linear electronic attenuator for frequencies above 15 mHz with response better than 1 mHz and not producing phase shifts.
6. Servo amplifiers for 3 amplitude and phase controller -- total of 9.

It is fortunate that we know how to build these devices and that we have six weeks to do it in!

Schedule

Mechanical things completed by June 15; 1st grid dip tests, June 15.
Completion of modified mechanical system, July 1.
Moog electronics working by June 15.
Phase detectors by July 1.
Phase shifters by July 1.
Phase and amp. servoes by July 1.
First modifications to electronics completed by August 1.
First serious tests on servo loop closures, August 1.
By September 1, 1977, hopefully, we will have positive answers, then we will take a vacation, regardless of what the answers are! It is beforehand presumed that the answer is not no. Maybe, maybe!

Actually what was originally known to be a bag of worms has become more wormy and baggier to boot.

*Note: The referred to drawings are on the back of a computer printout of what, to me, is the actual MSU rf system. Maybe someone else will someday take the trouble to understand it!