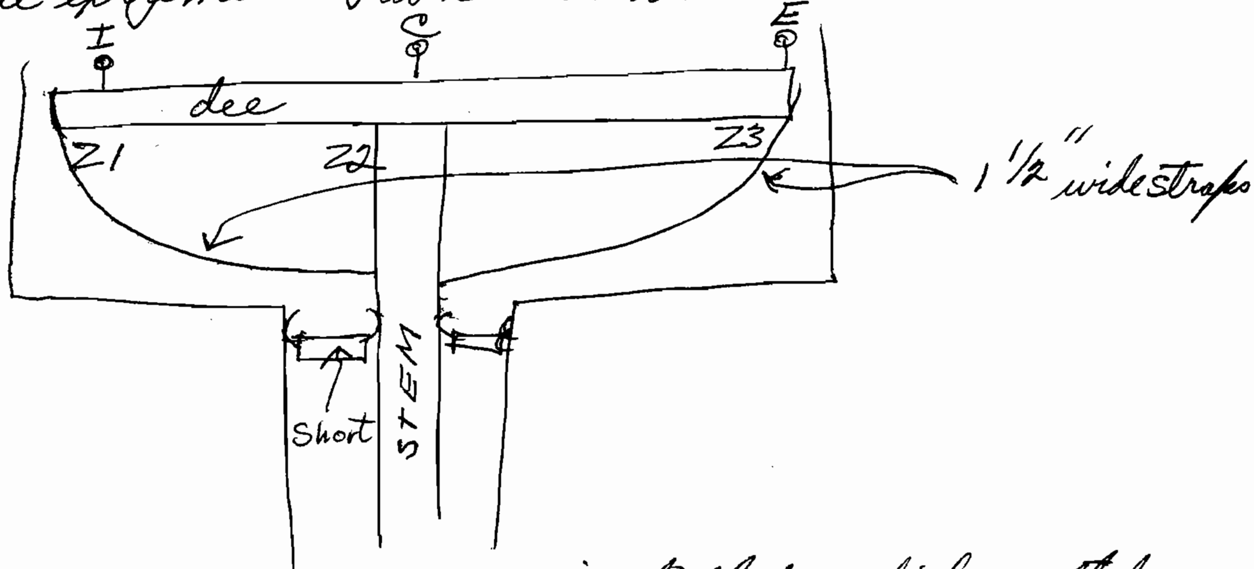
Note #3 by J. Riedel 10/8/76

Dee-Stem Configuration

Model Measurements

Measurements made on the 1/2 scale model on Sept 27, 1976 revealed two things: the top frequency was too low by 6%, and the voltage at extraction and injection radii was higher than at the central radius by 25%. Both these results were in fair agreement with calculations and therefore not surprising. Calculations had shown that both of these undesirable results could be remedied by adding straps between the dee stem and the dee extremeties as shown below.

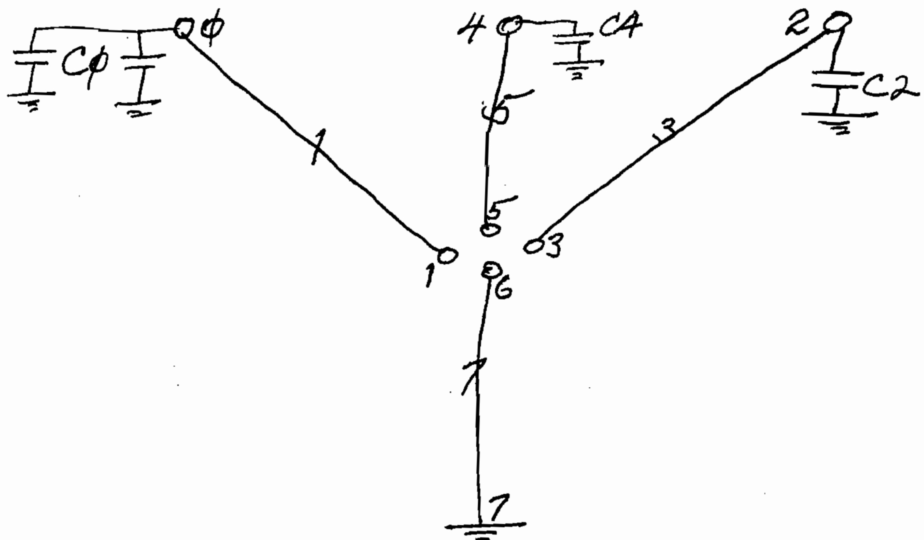


~~A~~ 1/2" wide straps were first installed, which resulted in reducing the radial voltage variation to 10% and raising the frequency by 8%. The straps were then changed to 1 1/2" and the frequency was raised to 165 mHz (from originally 150) and the voltages at points I, C, E on the above sketch were equal. Calculations showed that the ratios C/I and C/E could be made almost anything by suitably setting ~~[illegible]~~ Z2/Z1 and Z2/Z3, so the equality of the voltage ratios was a happy chance result.

Because it was easy to do, the Q of the model was measured and found to be only 1000, a factor of 3.5 less than calculations called for.

Calculations

Various configurations were calculated with a BASIC program called MSUDS, now spinning on the disk. The model calculated is as below.



where Cϕ = the lumped capacity of ½ the dee from the extraction radius to ½ way to the dee center, plus 1 pf for fine tuning, plus from 1 to 3 pfs, depending on frequency, for the coupling capacitor

C2 = the lumped capacity of ½ the dee from the injection radius to ½ the distance to the stem.

C4 = the rest of the lumped capacity of the dee.

1, 3, 5 & 7 ~~1 and 3~~ are transmission lines with a length and a Zϕ.

and points 0,1,2,3,4,5,6,7 are places where voltages, phase angles and currents are calculated.

~~line~~ line L(7) is of course the stem.

~~[illegible]~~

Because it may be of some interest, the method of performing the calculations will be very briefly mentioned.

$V\phi$ is assigned as ~~#~~ $10^5/\sqrt{2}$ (calculations in rms) ~~volts~~

$I\phi = V\phi\,\omega\,C\phi$

$P\phi = \operatorname{atn}(I\phi\,Z1/V\phi)$ is calculated

$\theta 1 = L(1)\,\omega/c$, the electrical length of the line 1 is calculated.

$$\left.\begin{aligned} V1 &= V\phi \cos\theta 1 - I\phi\, Z1 \sin\theta 1 \\ I1 &= V\phi \sin\theta 1/Z1 + I\phi \cos\theta 1 \end{aligned}\right\}\ \text{trans. line equations.}$$

and W1 and E1, the power and circulating energy in L1 are integrated.

V2, I2, V3, I3, P2, O2, W3, & E3 are similarly calculated then normalized to make $V3 \equiv V1$

the same with V4, I4, V5 etc.

then $I6 = I1 + I3 + I5$ and we calculate

$P6 = \operatorname{atn}(I6\,Z7/V6)$ permitting us to calculate L7 (the length of the stem to the short) and eventually W7, E7 and the sum of all the Ws & Es winding up with the total power W, the total circulating energy E and we calculate

$R_S = 6\,V\phi^2/W$ the equivalent shunt impedance of the three dees + 6 stems.

$Q = E/W$

$C = 6E/\omega V1^2$ the equivalent capacity

and repeat the above for selected frequencies.

One then studies the results, principally the ratios V1/V4 and V1/V2 and the power at 80 mHz.

It soon becomes manifest that if $C\phi = C2 = C4$ then to keep the above voltage ratios unity, the ratios ~~L1/Z1~~ L(N)/Z(N) should be equal. Since $L1 = 2.3 \times L5$ this means that Z5 should be $2.3 \times Z1$. But because ~~of the~~ $C\phi > C4$, then Z5 must be even larger than $2.3 \times Z1$.

After many runs with different choices of Z5 and Z3 it was ~~found~~ determined that any ratios of the three voltages could be achieved, but that to make them the same an iterative variation of Z3 & Z5 would be necessary to zero in on unity ratios.

this is fairly easy to do, but deferred because it is uncertain ~~to~~ as to how accurate the computer model is. Because of the complex geometry it is difficult to calculate the impedances and it is felt that an actual model should be built. But the computer calculations proved very usefull in revealing how things changed as the geometry was changed. For example: the program calculates Z_N and R_N, including the effect of the corner capacity for rectangular transmission lines, from the designated geometry, and the results show that if thin straps are used for L1 & L3 the power at 80 mHz can easily become excessive, being larger than for 13 mHz.

Conclusions from the calculations & measurements

The dee should be connected to the stem as ~~of~~ it emerges from the 9 inch hole in the iron by three pipes for L1, L3 and L5. L1 ~~sh~~ (to the outer radius) should be a 4 or 5 inch diameter pipe, thru which the dee cooling tubes and the cryogenic pumping hardware can pass. L3 should be smaller, perhaps a 3" pipe. L5, to the center, may be only 1" diameter. In order to determine what the diameters of L3 and L5 should be, and also to decide on the liner geometry an accurate 1/2 scale rf model should be constructed. This model should be built in such a way as to make it easily possible to replace L3 and L5 with different diameter pipes. Also, the connections should be made with screws or finger stock so that the Q will be appropriatly modeled. after a few measurements are made, an interaction between them and the computer calculations can permit the modification of the computer model so that the computer results agree with the measurements. Then an optimumizing program can select the final geometry, thus minimizing the number of changes that would be made on the 1/2 scale model.

Fine Tuning

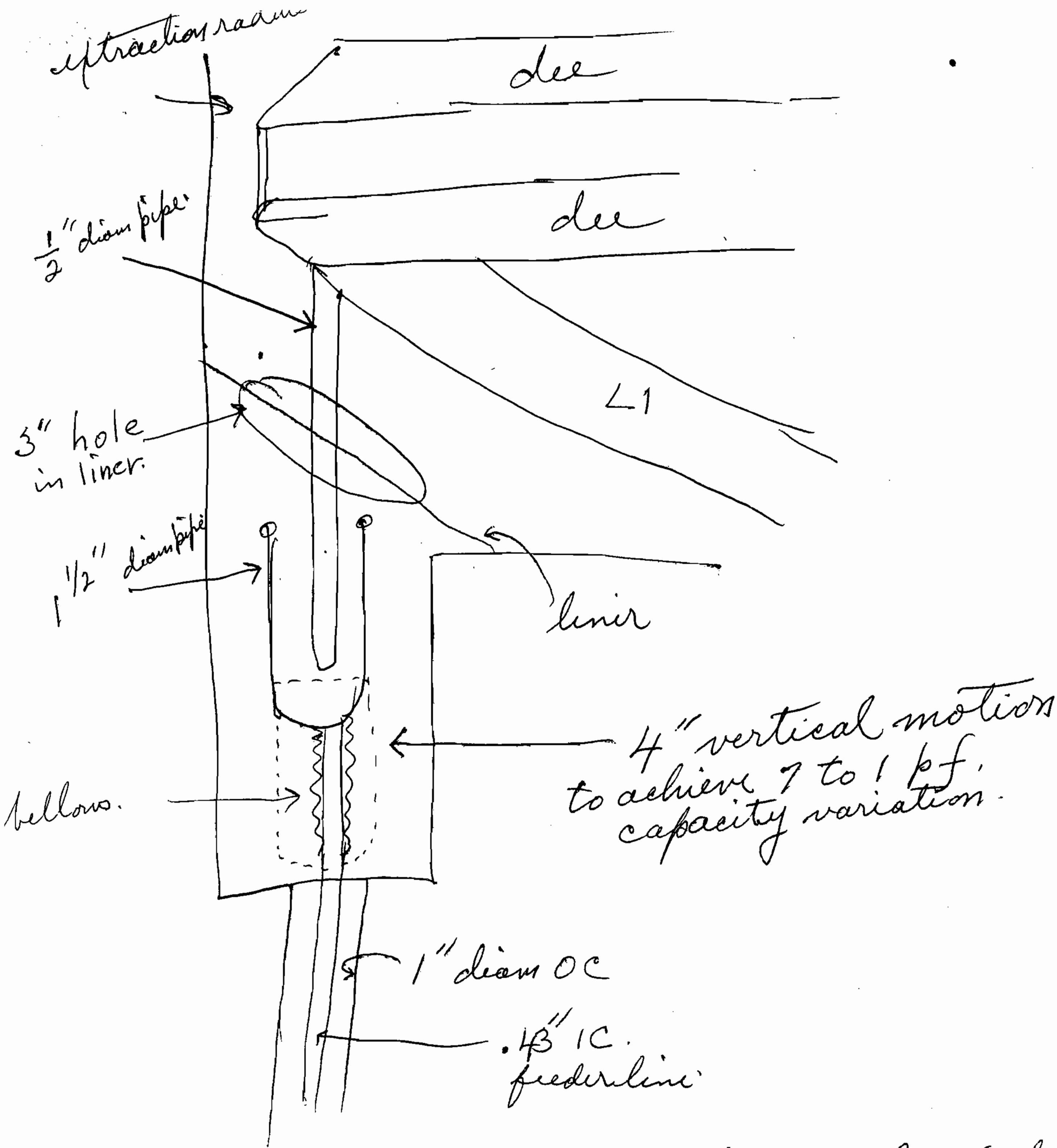
~~The~~ The method of accomplishing fine tuning is still that recommended in Note #1, namely, a hydraulicaly variable capacitor ~~from~~ ~~2~~ 1.5 ± 1 pf. ×6

Coarse Tuning

The moving short circuit design of R. Burleigh seems like a good approach. In that it will result in a area pressure of the order of 10,000 PSI it is believed to be superior for longevity considerations to ~~the~~ designs employing finger stock. However, probably someone should visit Chalk River and learn more of their testing results on moving finger stock contacts. Perhaps it really would not be necessary to build a vacuum model to test the ~~MSU~~ final MSU design! But then each person really wants to reinvent the wheel. In my opinion, a mechanical test in air of whatever design R.B. finally comes up with should be sufficient. However, it is a fun project to rf test it in vacuum and I would be happy to design and conduct the tests.

Capacative Coupler

The coupling capacitor (see RF note #2) should vary from 7 to 1.5 pf. (6 to 2 is the calculated requirements). The suggested method of accomplishing this is sketched on the next page.



this should be built into the model with a polystyrene rack & pinion + finger stock arrangement for varying the capacity. Thus, we can test the drive scheme on the model. Since the model has only 1 dee the minimum capacity will be 1/3, accomplished by suitable modification of the geometry.

1/2 Scale Model

Almost enough has already been said about the model. Here I would like to importune the designer to include provision for making the measurements. The HP vector voltmeter probes will be the measuring device and suitable holes with clasps and contact holes should be provided at 5 radial points (0, .5, 2, 2.5, 4) to measure the dee voltage. Also, ~~I~~ such provision should be made at the end of the feed line, and at the entrance to the stem. This latter is so that V6 can be measured to aid in determing an accurate computer model. Also it would be desireable to construct two adaptors to fit on the vector voltmeter probes to provide 100 to 1 attenuation and a maximum of .2 pf probe capacity. ~~I can design~~ I will send in a design for these.

Using the RX meter as a signal generator, the RX meter itself can measure the R and X looking into its 50 Ω cable output, thus permitting a simple and accurate measure of the power and the correctness of the setting of the coupling capacitor. The RX meter provides a 1 volt source at 50 Ω, and this should be capable of driving the dee at about 20 volts or more.