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R.F. Note #96

June 18, 1984
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1. <u>Problems with the K800 resonator</u>.

When we made the intial measurement of the top frequency achieved by the wood and copper model, we were elated to find that is was 28.13 MHz, in very good agreement with the computer model calculations. However, when we measured the frequency vs four other positions of the short, a discrepancy existed which is inexplicable. Fig. 1 shows the computer results and the measured results. Bah!

Then we added 10 pf capacitors at various locations on the median plane, liner to dee, and found thus that the equivalent capacity of the dee was about twice what the computer pgm said it should be. Bah! Fortunately, the discrepancy is in such a direction to indicate that the dee stems need not be as long as the computer pgm said they should be. Still, we are very unsatisfied.

If the frequency vs short position is so far wrong (13%) then the power requirements will be way off, and other bad consequences, unknown at present, will undoubtedly manifest themselves in the future. So it is necessary to resolve these discrepancies and explain them.

We will start by trying to improve our computer model. First, J. Vincent will go down to Texas A & M and learn how to use the pgm "superfish" to calculate what happens from the magnet valley to the short exactly. If this is not enough, we will acquire CAV3D from Munich and calculate everything exactly.

All this, however, will not affect proceeding with the mechanical design of the resonators; and this design should proceed forthwith.

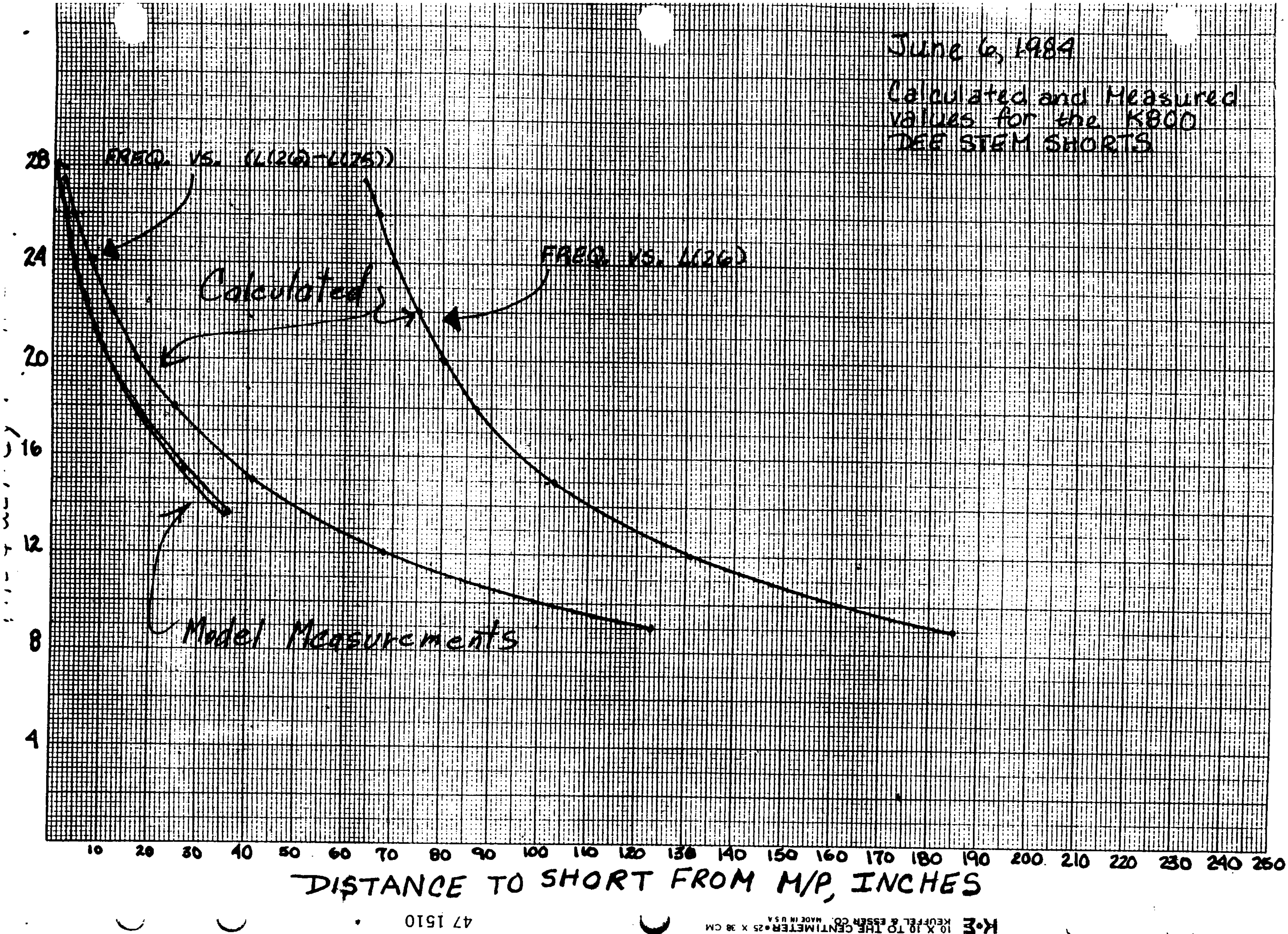

June 6, 1984
Calculated and Measured values for the K800 DEE STEM SHORTS
FREQ. VS. (L(26)-L(75))
FREQ. VS. L(26)
Calculated
Model Measurements
28
24
20
16
12
8
4
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
DISTANCE TO SHORT FROM M/P, INCHES
47 1510
K+E 10 X 10 TO THE CENTIMETER 25 X 38 CM KEUFFEL & ESSER CO. MADE IN U.S.A.

FIG 1

2. New ideas on neutralizing the K500 and K800 dee to dee capacities.

In RF note #78 I made the statement that detailed calculations of the neutralizing loops would be presented when I get time. Now is the time, in preparation for possibly modifying the K500 neutralizing scheme, and in any case, to design the K800 neutralizers.

The impitus to redesign the existing K500 scheme comes from the following considerations:

1. Sparking from stem to loops limit the max. dee voltage below 17 MHz to about 60KV. Smaller loops would be desireable.

2. The present loops can only neutralize down to about 12 MHz because they are too small.

3. In the K800, with the much larger magnetic field where the loops will be the present motor drives would not work. In fact they just barely work on the 500.

4. It would be desireable to have infinite resolution for control instead of the present bang, bang control.

5. The angular travel of 70° for the loops is insufficient, as we presently cannot neutralize above 25 MHz due to overneutralization.

At the location of the loops, the stems carry an rms current I (F) and have a voltage $kV\phi$, where the $V\phi$ is the dee voltage, Table 1 shows what these are for the top and bottom frequencies and, assuming 0.3 pf dee to dee capacities, what the circulating energy is that needs to be neutralized.

The loops have dimensions h (height), r 2, r 1 (outer and inner radius with respect to the center of the stem) and w (width).

Open circuited they will have a voltage $Vl=d\phi/dt$, where ϕ is the flux passing through the loop. The result of the arithmetic gives

$$V_{peak} = h\mu_o F I_o \ln \frac{r2}{r1} = \begin{matrix} 602 \text{ Vp at 9 MHz} \\ 3354\text{Vp at 27.5 MHz} \end{matrix}$$

An approximate formula for the self inductance of the loop is

$$L = \frac{Z_o\, h}{C} = \frac{337 \times (r2-r1)h}{3\text{ E8}} = 2.8 \times 10^{-7} \text{ H.}$$

The self inductance plus line inductance needed to achieve neutralization at 9 MHz for the K500 system is obtained from the equation $VI_o = 2.8 \times 10^5/2$ (we have top & bottom neutralizers) resulting in

$Ll = 2\, Vl^2/WE$ where Vl is the open loop voltage from one loop to the other and E is the IV from table 1. Putting in the numbers

$L = 2 \times 10^{-7}$ and as a result we can only neutralize down to 12 MHz.

TABLE I

Calculated results for various parameters relevant to neutralizing for 200 KV peak dee volts on both K500 and K800 dees.

	F MHz	V(corona ring)/Vϕ	I at loop rms	Tot.IV required	Tot.IV** available
K800	27.5	K .124	4.5×10^3	.866 MVλ	
	9	.866	2.2×10^3	.281	.25
K500	27.5	.13	5.2×10^3	.866	
	9	.885	2.8×10^3	.281	.2

** With the present K500 loops.

So we see that on the K500 we need larger loops to neutralize at 9MHz, and we need to rotate the loops by 82^{o} to neutralize at 27.5MHz. Actually, 70^{o} of rotation is adequare, if we start from 10^{o}, because the cosine of 10^{o} is only 2% different from the cosine of 0^{o}.

We aver that even with smaller loops it is possible to neutralize over the three to one frequency range by inserting a capacitor in series with the line connecting the two loops. In this case

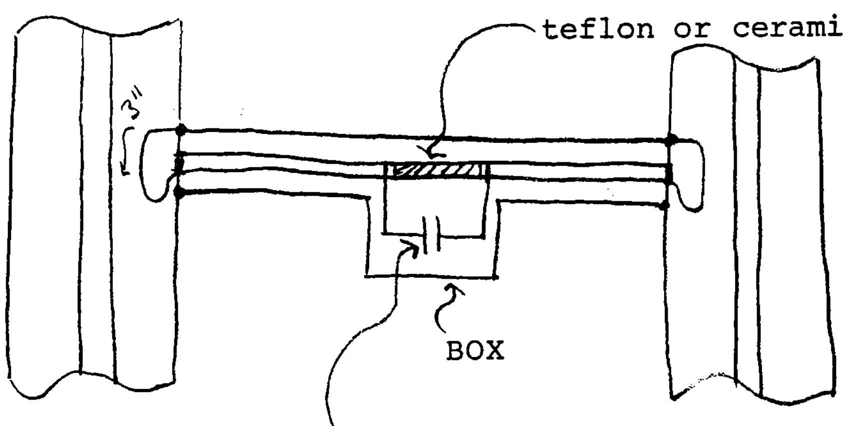
$$E = IV = (2V_L \text{ Cos } 30^{o})^2 \, / \, (WL - \frac{1}{WC})$$

where L is the sum of the line inductance plus the self inductance of the two loops and C is the series capacitor. Obviously if $WL = \frac{1}{WC}$ we can overneutralize! I don't want to go into the limitations on the above maximum E thus possibly achieved, but it is certainly limited by considerations of the effect of mutual inductances. However, for our case, I don't think that that is relevant.

Intuition and experience tells me that this will all work, but since some of the parameters are hazy I propose to make a test of the scheme on the K500 as follows:

Suggested Program.

Build equipment to make a test of this modified neutralizing scheme. The present loops are 3 inches deep radially. Make two loops the same except only 2.5 inches deep radially, thus giving a 2.5 inch gap to the stem. These loops need not be water cooled. Then we build a new method of coupling these experimental loops and replace the present neutralizers between A-C ir A-B with this setup. Fig. 2 below shows the scheme.



loops are variable over 90^{o}.

Then, in air we use 30 watts into the line to make 3KV on the dees and test the scheme. If we want more than 60KV below about 15 MHz, we must do this. We should be able to do all this using only 1/2 day of cyclotron time.

My calculations show that if the loop size is correct for neutralizing at 9 MHz, then it must be turned 80° to neutralize at 27.5 MHz. Since we can turn only 70°, the fact that we can't avoid overneutralizing above 25 MHz is explained. The fact that we can't neutralize now below 12 MHz isn't significant because the voltage pickup here varies as the Sin θ near 90° and 10° doesn't mean much.

I spent some time considering four alternate methods of neutralizing, namely,

1. Cap, coupling & λ/2 trombone.

2. Oppositely oriented fined loops & trombone.

3. Existing scheme, larger fixed loops, and variable length shorted line in the center.

4. Above proposed scheme with open line in center to replace capacitor. The loops would be fixed, as with either scheme 3 or 4 an infinite range of either capacity or inductance can be achieved.

I gave up on all of them because they would have to be at least 4 inch diameter lines and probably have to be cooled.

I think that some smart engineer could come up with a scheme that would result in neutralizing over our entire range with no variations. If I could get exact data into my computer, I'm sure I could do it - with a lot of time.

3. <u>Aydin power supply problems</u>.

Is a result of tests carried out on the Aydin power supply, the evidence resulted in a diagnosis that the rectifier transformer had one of its winding partially shorted. We drained the 1200 gallons of oil and were able to visually confirm this diagnosis. There were globs (pea sized) of copper sitting on top of various objects. We have shipped the rectifier cubicle back to Aydin in California and hope for a speedy return of it, however a wait of one month is optimistic.

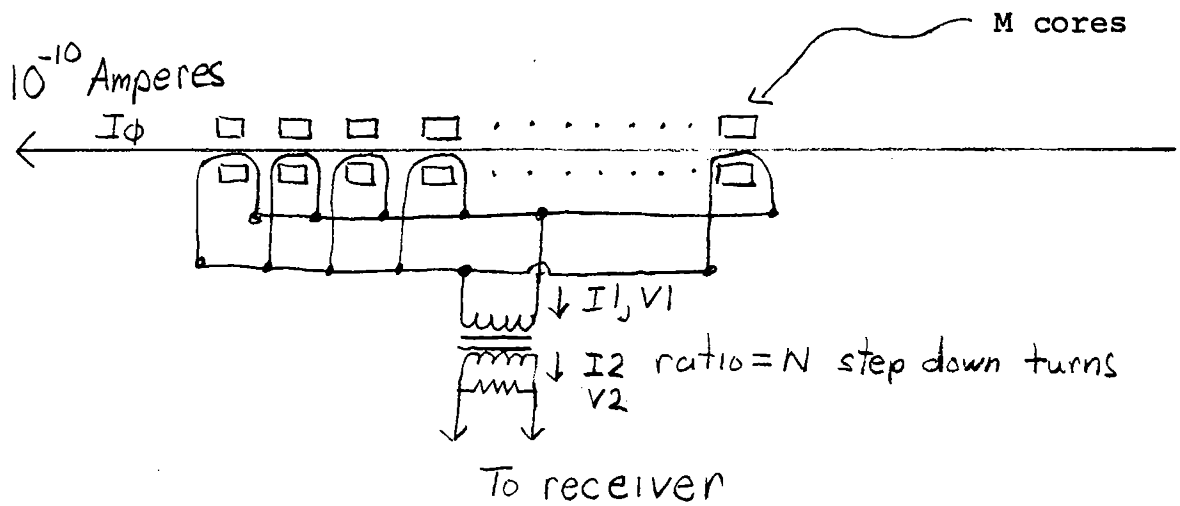
4. <u>Non intercepting beam current monitor</u>.

At the present time, perhaps it is not important to have a nonintercepling external beam current monitor available to the operators and capable of sensing 10^{-10} amps. But when we inject into the K800, it will probably be necessary. Therefore, I herein present a design for providing such a monitor.

Other people have such monitors. I have an incomprehensible note from IUCF, and one from Texas A & M. They were capable of measuring 2×10^{-8} amps. At Orsay a second harmonic true dc current monitor was developed which was good to 10^{-3} amps. I wasted six months with Zhing investigating the limits of second harmonic detectors and found it to be 10^{-6} amps, limited by Barkhausen noise.

Here is how I propose to produce a meter or chart recorder presentation of full scale 10^{-10} amps of beam current, not intercepting it! The way to monitor a beam is to extract energy from it by deaccelerating it. The beam of 10^{-10} amps has an energy pr about $10^8 \times 10^{-10} = .01$ Joules and if we wanted to extract all this energy we would allow it to enter a tuned cavity of $R_s = 10^8/10^{-10} = 10^{18}$ ohms. Even the best superconducting cavities do n't have such a high shunt impetance. But I have heard of 10^{12} ohm cavities, which means that, in principle we could develop 100 volts across it and extract 1 volt without disturbing the Q. However, this is impracticable.

Instead we propose to use transformers. Fig. 2 shows the scheme.



the cores would be Indiana General Q2 cores and $I1 = MI\phi$

$$I2 = NMI\phi$$

$$V2 = I2R = NMI\ R$$

let $N = 3$, $M = 10$, $I\phi = 10^{-10}$, $R = 300$

and $V2 = 10 \times 3 \times 10^{-10} \times 300 = 9 \times 10^{-7}$ or 1 μv.

We can buy a receiver for about $800 that can receive go MHz with a noise figure of .07 μv over a 200 Hz bandwidth. Thus, tuning to the second harmonic of our rf frequency (to avoid fundamental pickup) we should easily be able to have a good monitor of 10^{-10} amps of beam current. I visualize the cores as having r2 = 2 1/2", r1 = 1 1/2", W = 1/4". Thus the total stock is 1.5" long. I know how to make the 3 to 1 transformer using a very tiny core (1/4" OD). Shall we try it?