R.F. BOOR

R.F. Note 78

November 23, 1981
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R.F. Triumphs and Failures

Contents (Concentrate on #9)

1. Vacuum requirements and multipactoring

To initially turn the rf on to each dee required a rapid rate of rise (2 kV/μρ) to break through multipactoring. After breaking through multipactoring and being "ON" it was early learned that the dee voltage had to be >20 kV, else a glow discharge would exist somewhere and the vacuum would go sour. Above about 4×10^{-5} is no man's land.

After running each dee at high voltage, operation became much easier, and now we find we can turn on much more slowly, and can run at as low as 5 kV on the dees. Further, there is no glow discharge anywhere because, at low voltage where very little heating obtains, the vacuum pressure is unaffected by the presence of rf.

2. One dee at a time operation

Tuning up and operating one dee at a time is a snap and within a few minutes of coming on at a new frequency it is possible to arrive at proper knob setting. These are: driver grid tuner, final grid tuner, final anode stem short, final anode fine tuner, transmitter output coupler, dee input coupler, dee stem short and dee fine tuners.

Phase servos can now be "closed" on driver grid, final grid, anode fine tuner and dee fine tuner and no further adjustments are needed as the voltage is raised and sparking occurs. The amplitude regulator can be "closed" and the performance is good except that the tuning loops have not yet had their open loop transfer functions optimized, so that there is a low level oscillation (about 1Hz) causing about $\pm 2^{\circ}$ dee phase modulation. Also there is a dead band in the grid servoes so they periodically (≈1 Min.) jump to a more correct value, causing a glitch in the dee voltage. When we have time we will correct these problems.

3. Modification of Transmitter Fine Tuner

Originally, the transmitter fine tuner had such a restricted range that we found it common for it to be at a position limit, and the dee stem short had to be "banged". So on 11/16/81 we exchanged the home-made tran. fine tuners for a duplicate of the output coupling capacitors, setting limits so that the capacity varied from 20 to 35 pf (≈7 turns). At the same time we threw out the propellers that had been cooling the couplers and now use house air and volume amplifiers (Bernoulli jets) to cool both condensers.

Operation with the new fine tuners is very much nicer, as it is now possible to achieve long operation without having to "bang" the stem shorts.

5. Transmitter Spark Gaps

Operating one dee at a time results in a maximum possible peak anode rf voltage less than the anode d.c. voltage, except transiently when we get a dee spark or suddenly remove drive. With 3 phase operation, however, mistuning of a dee or a transmitter can result in very high voltages appearing at the anode of one transmitter due to power being fed to it via dee to dee coupling from another transmitter. This has been verified with TRED2. Voltages of 50 kV have appeared, leading to tube sparks (crowbar) and, or sparks across the output coupler. This is intolerable, so we have installed spark gaps in each transmitter to protect them. These are 2" diameter opposing brass hemispheres with .25" gaps set to break down at 19kV d.c. These are mounted directly in front of our light sensors which turn off the rf drive in the event of the gaps firing. Thus everything is safe.

6. Three phase operational experience at 24, 9 and 18 MHz.

We first tried for a beam at 24 MHz where 78 kV dee voltage was required. It was difficult to tune things up for 3ϕ operation, but finally this was achieved. On trying to press on we found that the vacuum pressure would rise above 4 x 10^{-5} at voltages over 50kV. So we moved down to 9.28 MHz where only 32 kV was required. The procedure on moving to a new frequency is to first run one dee at a time (detuning the other two) and calibrating the voltage monitors using the X-ray spectrum technique. Again we found that tuning up for 3ϕ operation was difficult, usually requiring a few hours to get 3ϕ at the correct voltages. In each case this could only be done by having radically diverse anode currents, and by changing the phase of the grid drives by $\pm 60^{o}$.

Even so, we accelerated a beam out to the full radius, but believe it wasn't the right beam (C^{++}) as no neutrons appeared. So we moved to 17.7 MHz to accelerate D^{+} with 50 kV dee voltages.

After trying to tune up for 3ϕ operation it soon became apparent that this was impossible due to an intrinsic instability just as we approached 3ϕ in which the phase of one dee would instantly change by 90^{o}. Well, way back in RF Note , I gave reasons why there might be trouble between 18 and 22 MHz where the transmission line is nearly $\lambda/2$ long and being a little off tune presents a very high impedance to the transmitter. Remember that a fundamental rule of transmitters is that they are lazy and are always searching around for a means of achieving high voltage while doing the least work.

Fortunately we were prepared and we soon connected the 100 pf capacitors across the entrance to the transmission line that makes it look 3 ft. longer. After resetting the output couplers and the transmitter stem we came on and quickly achieved 3ϕ operations with the performance the same as at 9 & 24 MHz.

Although achievable, and stable, the tuning conditions are bad, and intolerable if we want to go to 100 kV.

7. Dee to dee coupling capacities:

Why was the 3 dee performance so different from our 3 dee high Q model experience and from the predictions of the TRED2 calculations? Mind, the 3 dee performance when we first turned on the 3 dees in September was satisfactory. The answer dawned on us: the difference between then and now is that then we came on with no center plug or ion source and now we have both. We made the experiment of removing the upper center plug, and indeed 3 dee operation was much improved.

It had never occured to me that the dee coupling capacities were nonsymmetric. On the hi Q model we investigated for a large range of coupling capacities, but always kept them symmetric. The same with TRED2. We immediately started calculating for disymmetric couplers and set up the electrolytic tank, built to measure electric fields in the center region, to measure the dee to dee capacities. The measured values are:

A to B = 2×10^{-13} F
A to C = 1.5×10^{-13} F
B to C = 4×10^{-15} F

a difference of 55 to 1 due to the plug shielding B from C.

It is possible to measure these ratios directly. This can be done by detuning one dee at a time and measuring the separation between the push push and the push pull modes. The ratio of the coupling capacities will be the same as the ratio of the ΔF's. We will do this when time permits.

8. TRED2 calculations for unsymmetric dee to dee coupling capacitors.

TRED2 had to be modified to calculate for disymmetric dee capacities, because the floating center of the transposed Y for Δ configuration was no longer zero for the perfectly tuned case and therefore a correct value for the equivalent L of the dee could not be straightforwardly calculated. So we did the same thing our dee phase servo does, and used an iderating routine to make L such that the phase across the input coupler was 90°. The program now takes a few hours to run. The results are discouraging, showing that 3 dee operation with balanced voltages is impossible with correct drive phases and tunes everywhere. It is a slow process to find out how to misdrive or mistune to get good 3 dee operation, assuming that that is even possible. It will take time before answers come from here.

9. On symmetrizing the dee capacities, or neutralizing them

The important parameter associated with the dee to dee capacities is the circulating energy flowing through them. This is

$E_{A-C} = (Va - Vc)^2\ WC/4$ for a half dee.

For 27 MHz this is

$E_{A-C} = (2 \times 10^5 \text{ Cos } 30^o)^2 \times 2\pi \times 2.7 \times 10^7/4 = 2.5 \times 10^5$ VA

a rather large number, for a whole dee. The circulating energy across this capacitor is 6 times the real power the tube can deliver which says that it can't be corrected for with real power. Ideally we would like to symmetrize these capacities at the center of the dees, but this is very very difficult without interferring with orbits or increasing gradients, if possible. Providing coupling across a hill severely reduces vertical aperture. So we limit ourselves to doing something about dee to dee coupling on the air side of the insulator, some 60 inches from the median plane.

There are three approaches that can be taken.

1. Capacity couple the dee stems to achieve symmetry. This would require couplers from A to B to C.
2. Inductively couple all stems to neutralize the dee to dee capacities, making the push push and push pull modes degenerate. Actually, this means three independent rf systems each of which can run at any phase or voltage, not knowing what the others are doing except when a glow discharge or spark occurs. The small beam current of $\approx 1\mu a$ does change the coupling, but insignificantly.
3. Using inductive coupling of opposite polarity to 2. above, one can increase the A to B & B to C equivalent capacitive coupling as in 1. above.

Since approaches 2 and 3 restrict the short travel, lopping about 2 MHz off the top of the frequency, we will first analyze 1.

<u>Capacity Coupling</u>

The voltage at the corona ring is 26 kV at 30 MHz and 90 kV at 10 MHz. Figure 1 is the equivalent circuit of the coupling scheme. C2 and L are lumped constants for the 15" long transmission line between B & C Bells.

Let the line be 4" OD coax of 66 Ω Zo. This is the Zo that holds the highest voltage for a given outer pipe. Thus

$$L = \frac{\ell Zo}{c} = 8 \times 10^{-8} \text{ H.}$$

$$C1 = C2 = \frac{\ell}{CZ02} = 9 \text{ pf and inner cond} = 1.33\text{" diam.}$$

It is straight forward, using longhand and a pocket calculator to calculate everything about Fig. 1. The significant calculation is to determine C1 such that $|V1|$ and $|V2|$ <2E4 and that the circulating energy in C2's and L is the desired value. C1 & C2 are adjusted to get the proper mode separation between B&C for the push push and push pull modes. Simple.

My guess (although later I will exactly calculate this)is that C1 must vary from 5 to 1 pf as F goes from 30 to 9 MHz. To achieve 5 pf a 3" high by 20" arc spaced .9 inches from the corona ring does the trick. This must be withdrawn some six inches to achieve

1 pf, but instead we can draw it back to a 2" spacing (where 100 kV can be held) and increase the C1's for the 9 MHz case.

Fig. 2 is a sketch showing how to modify the Bell to accomplish this.

The variation can be accomplished with a hydraulic piston follower buried in the inner conductor, which telescopes, using finger stock. The hydraulic fluid would be silicon oil fed with teflon hose.

Neutralizing (scheme 2)

Fig. 3 shows the loop scheme. Since the loop will have to be 2.2 times larger at 9 MHz than at 30 (because the stem current are down by that much) we will design for 9 MHz and simply rotate the loop for 30 MHz. The equivalent circuit is shown in Fig. 4. Lϕ is the loop self inductance and L is the lumped inductance of the 1" transmission line of Zo = 40 Ω. The voltage on the line is so low that the capacity of the line can be neglected.

$$L = \frac{\ell Z_o}{c} = 5 \times 10^{-8} \text{ H. and}$$

$$I = -j2\, V_o \cos 30^{\circ} / (W(2L_o + L))$$

the circulating energy is

$$\vec{V} \times \vec{I} = (2\, V_o \cos 30^{\circ})^2 / (W(2L_o + L))$$

assume $L_o = L/2 = 2.5 \times 10^{-8}$.

The required loop voltage comes from

$$\frac{(2\, V_o \cos 30^{\circ})^2}{2\, LW} = E$$

actual voltage = I Z
= 100 × ωL
= $10^2 \times 5 \times 10^{-8} \times 1.8 \times 10^8$
= 900
ωL = $6 \times 10^8 \times 10^{-7}$ = 6 Ω

When I have time I will present detailed calculations justifying the following design. The loop should be 4" long, 1" high and 2 inches wide and the end should be 1.75" from the stem and have 1/4" radiused edges. It will work fine, with the voltage on the line being about 1400 volts rms. The line will have about 100 amps in it so the 1/2" inner conductor must be water cooled.

10. Conclusions

It is time to go back to the Ozarks and gather in my winter wood, fish a little, play golf and dream. And eat din din on Thursday.

1.4×10^5 VA. × 2
= 3×10^5 VA.

$I_1 = 1.8 \times 10^5 \times$ ~~10~~/1.4 ~~1.8×10~~ $1.8 \times 10^8 \times 3 \times 10^{-13}$ = 10/1.4 amps. = 7

$IV = \frac{1.8 \times 10^5}{1.4} \times 10$ = ~~1.8×10^6~~ = 9×10^5

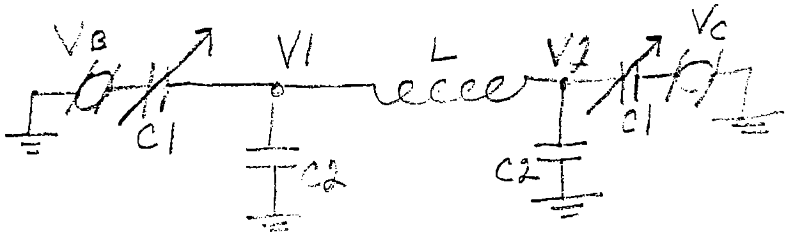


FIG 1

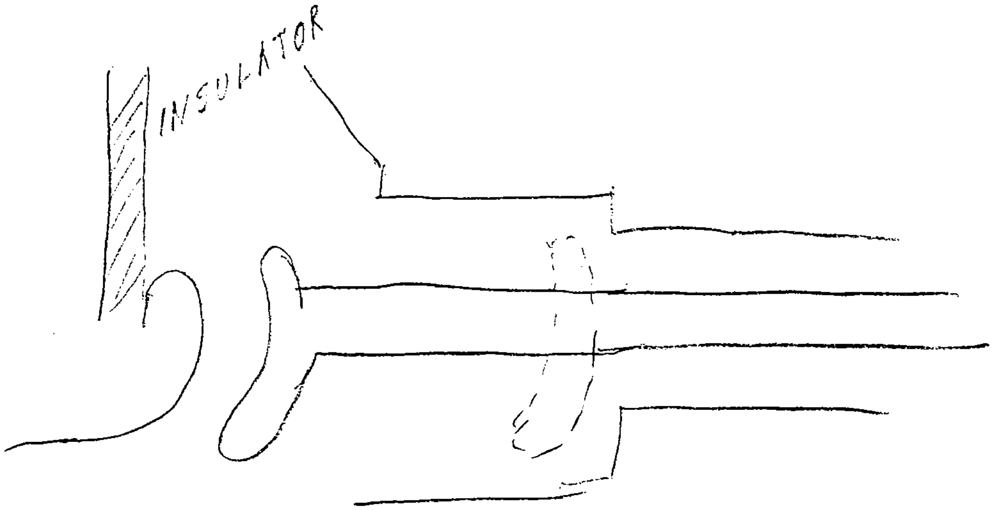
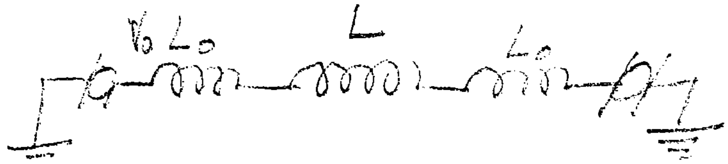


FIG 2



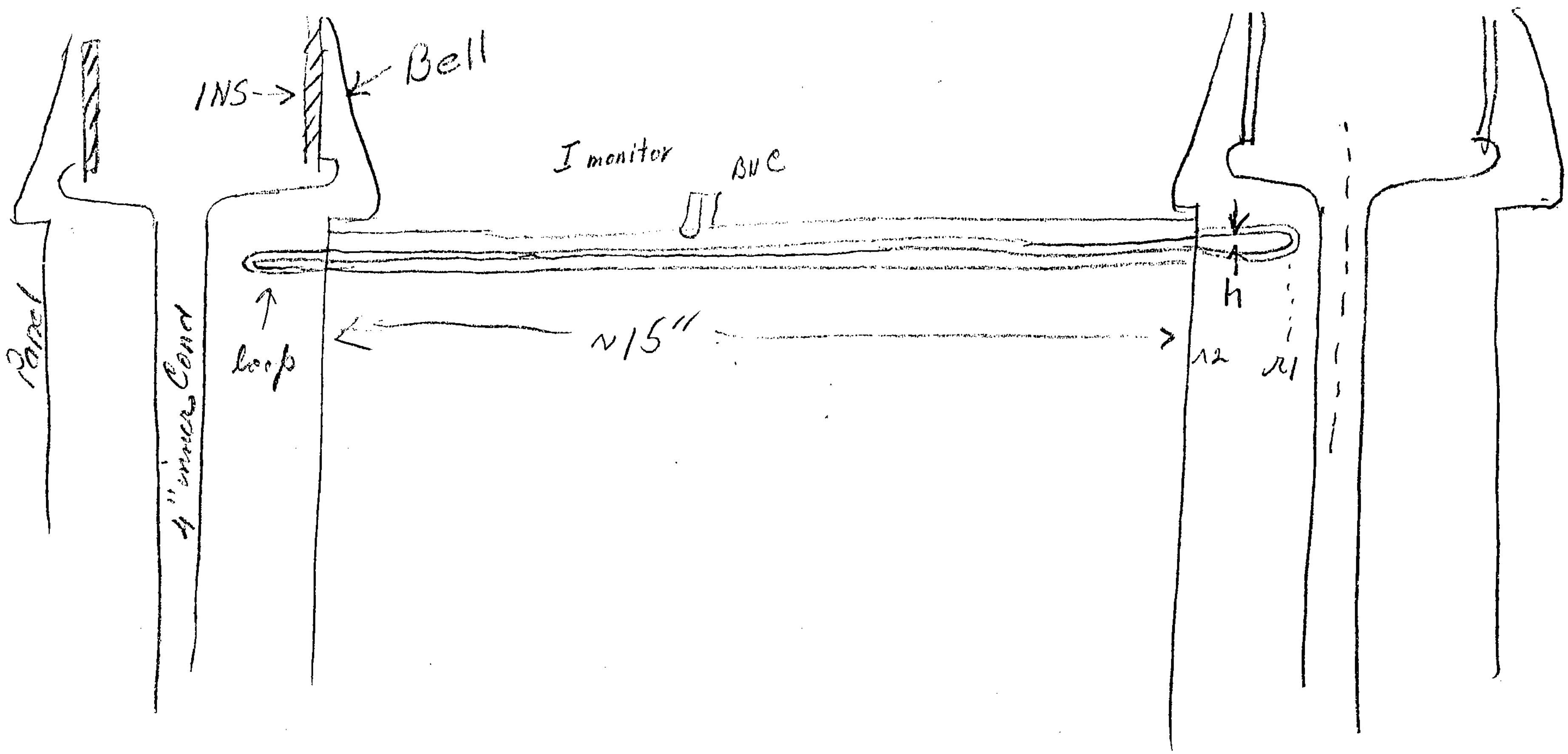


FIG 3