RF Note #47

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1. Events Before and After TEST 1

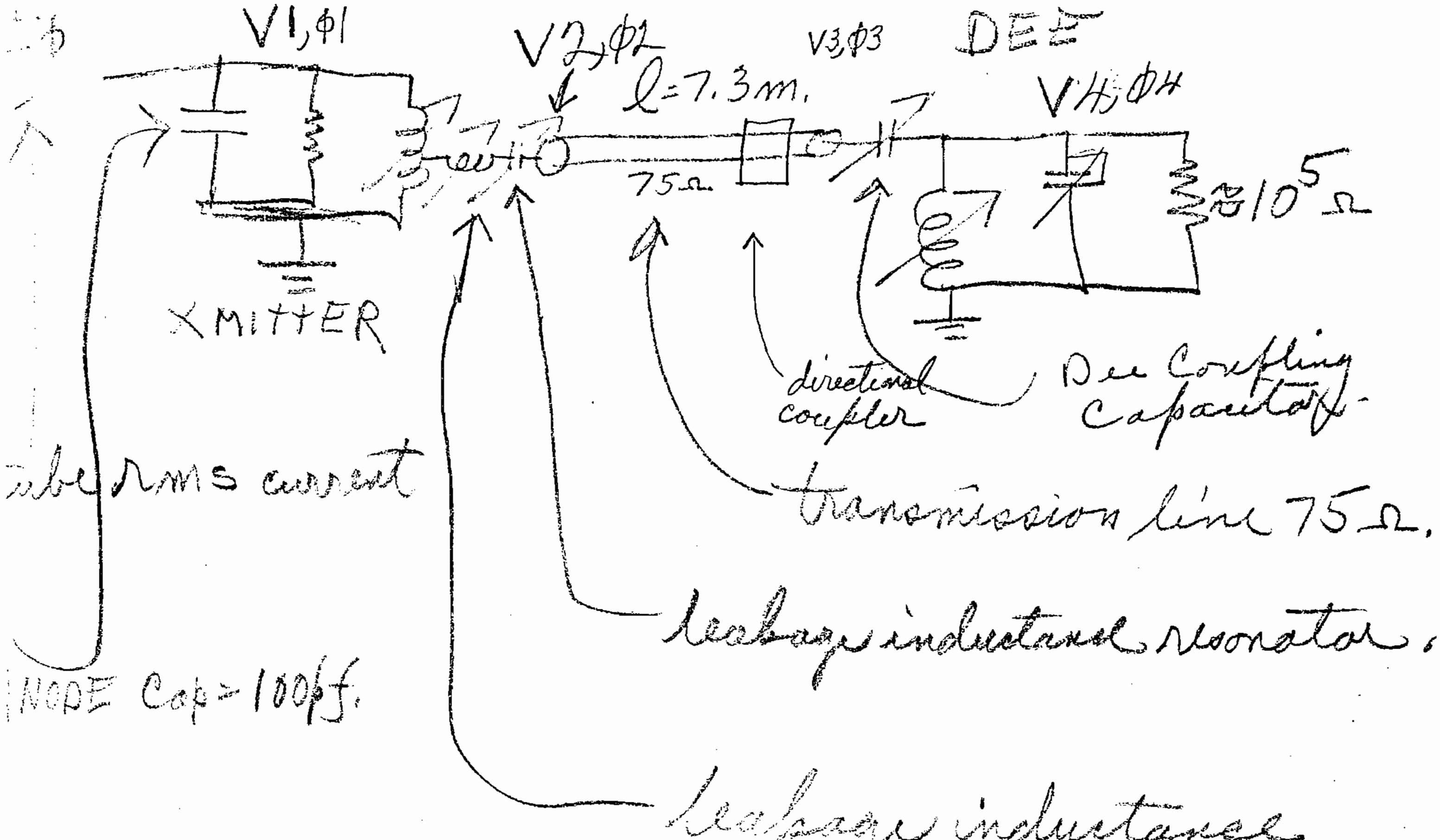
In the beginning there was the WORD. And the Word was MSUDS, an acronym standing for Michigan State University dee stem. RF note #17 delineates the results. With MSUDS all was well, and God was content, although someone said his fingers were crossed.

Then came TRED3. Only the Devil knows the origin of this acronym. TRED3, as documented in RF notes 38 and 46 showed that there was a possibility of trouble in heaven. Specifically it showed that when a frequency was chosen for which the line electrical length was π, there were three very close together modes, and it was difficult to distinguish the correct one from the undesirable one. TRED3 also showed that at frequencies reasonably removed from this "bad" frequency, although there were still three modes near the correct one they were nonmalignant, and could be ignored. Still, this was just a computer program and, hopefully, and probably, bore no relation to reality.

Then came TEST 1, when we endeavored to excite the dee + stem + transmission line + transmitter in air. This test was sort of a comedy of semi-hilarious errors: nevertheless a great deal was learned; enough to justify all the effort and provide commiseration for all our toubles, although at first TEST 1 belied some of the results of MSUDS, mainly in regard to "Q", eventually this was resolved, and, again God was content. Oh, that benign smile! But the remarkable thing was that, at 21 MHz, the results of TEST 1 completely vindicated the heretofore suspicious results of TRED3. Apparently God had said that in a weakly coupled system there was apt to be trouble, and He meant it! And He was right.

2. Heuristic explanation of the problem

Now let us try to understand the problem in a simple way. Below is a diagram showing the elements which TRED3 calculates.



$V3 = 10^5$ volts peak,

$V2 = V1/5$, $\phi 2 = \phi 1$

$I\phi \approx 10$ amps, $\phi 1 = 0$

$V5, \phi 5$ = forward directional coupler signal

$V6, \phi 6$ = reflected " " "

The transmission line when disconnected from the dee and transmitter resonantes in the $\lambda/2$ mode at 18.3 MHz, corresponding to a length of 8.197 meters or 26.9 ft. There is an anomoly here, as the measured length is more like 7.3 meters corresponding to a mode at 21 MHz. We will resolve this later.

Anyhow at frequencies near 20 MHz one would expect three modes which offer high and real impedances to the tube. Of course there is Fϕ, identified by there being 90° difference across the coupling capacitor. Then at a lower frequency the dee would be 180° out of phase with V3 and ϕ1 in phase with Iϕ. This is a transmission line mode, where the small but finite voltage across the dee coupler capacity pulls the frequency down. Then above Fϕ there is a frequency where the dee is naturally resonant with no coupler capacity and so is the transmission line. $\phi 4 = \phi 3$.

Later, we will say more about modes.

Voltage Calibration

During TEST 1 we calibrated the pick up loops using a spark gap facing the dee. Then we noted that the coupling capacitor sparked down at 24KV. Here is the math.

$$V = -\int_a^b E_r dr = \frac{q}{4\pi K_0}\left(\frac{1}{r}\right)_b^a = \frac{q}{4\pi K_0}\left(\frac{1}{a} - \frac{1}{b}\right)$$

where b & a are the radii of concentric spheres,

$$E_r = \frac{q}{4\pi K_0 r^2} \quad \text{and at a } V_a = \frac{q}{4\pi K_0 a^2}$$

$$\text{but } q = \frac{4\pi K_0 V}{\frac{1}{a} - \frac{1}{b}} \quad \text{so } E_a = \frac{V}{a^2\left(\frac{1}{a} - \frac{1}{b}\right)}$$

And the sparking voltage (V_s) is,

$$V_s = a^2\left(\frac{1}{a} - \frac{1}{b}\right)E_s$$

where E_s is the gradient in air where sparking will occur $= 33\text{KV/cm}$

Putting in the numbers for a = .5", b = 1.5" we find $V_s = 28\text{KV}$

so, since sparking occurred at 24KV we assume that the concentricity was misaligned by 75 mils! No doubt, Don Lawton will do better next time.

Turn On

It has become very obvious that the "turn on" generator is a very important part of the apparatus necessary to turn on, and equally obvious that its functions will have to be expanded. At present, the "turn on" gnerator has two switches, labelled "ON" -- "OFF" and "PULSE" -- "NORMAL", and two knobs labbelled "PULSE DUTY FACTOR" and "TURN ON RATE". The front panel output goes to the amplitude regulator and overrides the amplitude command. The amplitude regulator monitors the dee voltage, and - dV/dt. If -dV/dt exceeds a certain level it shuts off the "ON" signal which the, after one second returns to the "pulse" or "normal" mode. Then on 5/31/79 we added an "OR" circuit to this turn off mode derived from light pulses into 4 spark monitors distributed along the transmission line. This worked well, but must be augmented. Eventually, in order to avoid catastrophies, I visualize a 12 or 24 "OR" input to the turn on generator, with memory to show which OR input shut us off.

TEST 2

On 5/21/79 the vacuum was O.K. so we started thumping away at trying to break through multipactoring at 10 MHz. After thumping away for three hours we finally broke through and got about 50KV. Then the vacuum went sour due to the cryogenic pump becomming saturated. On 5/23/79 it was rehabilitated and at 14 MHz we thumped away again and soon broke through. Very quickly we observed sparking at the flange connecting the outer spinning surrounding the insulator to the bottom of the vacuum vessel. The solder connection had broken loose. This was resoldered by H.H. and on Thursday we tried again. Soon we achieved 65KV. Then on Friday we finally got to 100KV. Maybe 108KV. Something had been proved, but I'm not sure what. The fingers, on inspection, were undisturbed. There were a few insulator sparks, but the voltage there was only 75 KV. The heating of the hexagonal outer conductors and of the big spinning was excessive (70°C). So some improvements on cooling will be necessary.

On 5/30/79 we thumped away again at 10MHz, but with constant frequency and the capability of varying the fine tuner manually. No breakthrough. So after an hour we removed the latest improvement: a condenser that limited the turn on time to 20 μs. We immediately broke thru multipactoring and had 65KV, where P. Miller calibrated our dee voltage monitor with his X-ray equipment. The calibration is: one volt rms into the vector voltmeter = 80 KV. We had several air sparks at the insulator but few if any vacuum sparks. Then we went up to 100KV, where we had many vacuum sparks. The chart recorder showed that for several seconds we actually achieved 110KV. Then we started having sparking at the transmission line--dee coupler connection, and it was noon, so we quit, content. In the afternoon we tuned up to 22MHz and started thumping away. After 3 hours we hadn't broken thru multipactoring. Then we burned up various polystyrene insulators in the transmission line. The next morning everything was fixed and reassembled, this time with spark gaps and spark monitors at four places on the line, and the spark monitors fed the "OR" cirucit of the turn on module.

Well, due to lack of clear thinking on my part, and excessive haste to get on, we disconnected the spark monitors and the transmission line burned up again! Bah! My present theory (capable of being instantly modified) is that with the spark gaps set for 6KV, and with 5KV on the bias power supply, the first gap spark caused a continuous discharge across that gap from the bias supply, so that at every pulse the gap always broke down and, since it was only one inch away from the polystyrene, sparks eventually caught them on fire. We should have had a circuit to turn off the bias supply for one second. Oh well, live and learn.

Next time we will use teflon spacers, so that they won't burn; merly produce phosgene. A little whiff of phosgene will no doubt do us all good (phosgene was one of the lethal gasses used in the first World War). Enough of TEST 2. Although there were some exhilarating successes, let's hope TEST 3 goes better. One of the remarkable and satisfying results was the witnessing of remarkable stability in the C.W. performance with no feedback loops on amplitude or tuning. Only every few minutes did one have to tweak the fine tuner. Of course when someone walked on the platform everything went out of whack. We have here,a good human being detector. I don't think even a cat could walk on that platform without being noticed on our monitors!

On 1 June we thunked away again, but now with protection for line sparks. After two hours we broke through and calibrated the loop. So at 22 MHz, 2.1 volts rms = 62 K.V. We ran smoothly at 75KV.Then, while trying to go higher we burned up the fingers.

Final Power Supply

W. Johnson and I visited Transrex May 8, 1979. Final upshot of our visit was that Transrex would install a normal on off contactor in the supply ahead of the variac, and parallel it with another contactor that will have resistors in series with the current leads. Thus we can have step-start turn on and avoid voltage overshoot. Their output filter (20 MH, 18 µf) was calculated, and will be satisfactory. They were unable to find a commercial source of satisfactory current transductors, which they are committed to install. So we sent them the diagram of the standard PPA transductor, and a sample so that they could copy it.

Modes

Using TRED3, operating conditions within 1% of Fϕ were calculated for Fϕ varying from 8 to 32 MHz in 2 MHz steps for three lengths of the transmission line: 8.197 meters, 10.03 m and 11.86m. 8.197m is the present length, and inserting a trombone would permit variation from 10.03 to 11.86 meters. In addition to finding the normal modes, the operation at Fϕ was calculated for the dee Rs to be 100 ohms, corresponding to a short or a multipactoring regime.

Now for this latter condition there is a range of frequencies where very large line and tube voltagesexist for low drive currents. For the three lengths calculated, this region is [15 to 21MHz], [11 to 17 and 26 to 32] and for the longest length [10 to 15 and 22 to 27]. These regions occur near where the line is $\lambda/2$ or λ long. Note that with this trombone I can never find a good length for 11 to 15 and 26 MHz, and going longer doesn't help. Now these "BAD" regions are only BAD during sparking or multipactoring conditions, and by being more sophisticated in current control perhaps can be overcome. One certain way to overcome them is to switch in a 50 KW water load in parallel with the line at the transmitter, during the "bang on" time, and after achieving full voltage, switch it out.

For the normal situation, where we have broken through multipactoring, problem can best be appreciated by referring to Fig. 2, showing various things at 21 MHz. Curves like this can be drawn for any frequency. For the range 8 to 15 and 24 to 30 things aren't so bad; the modes are more separated, and present a low impedance to the tube.

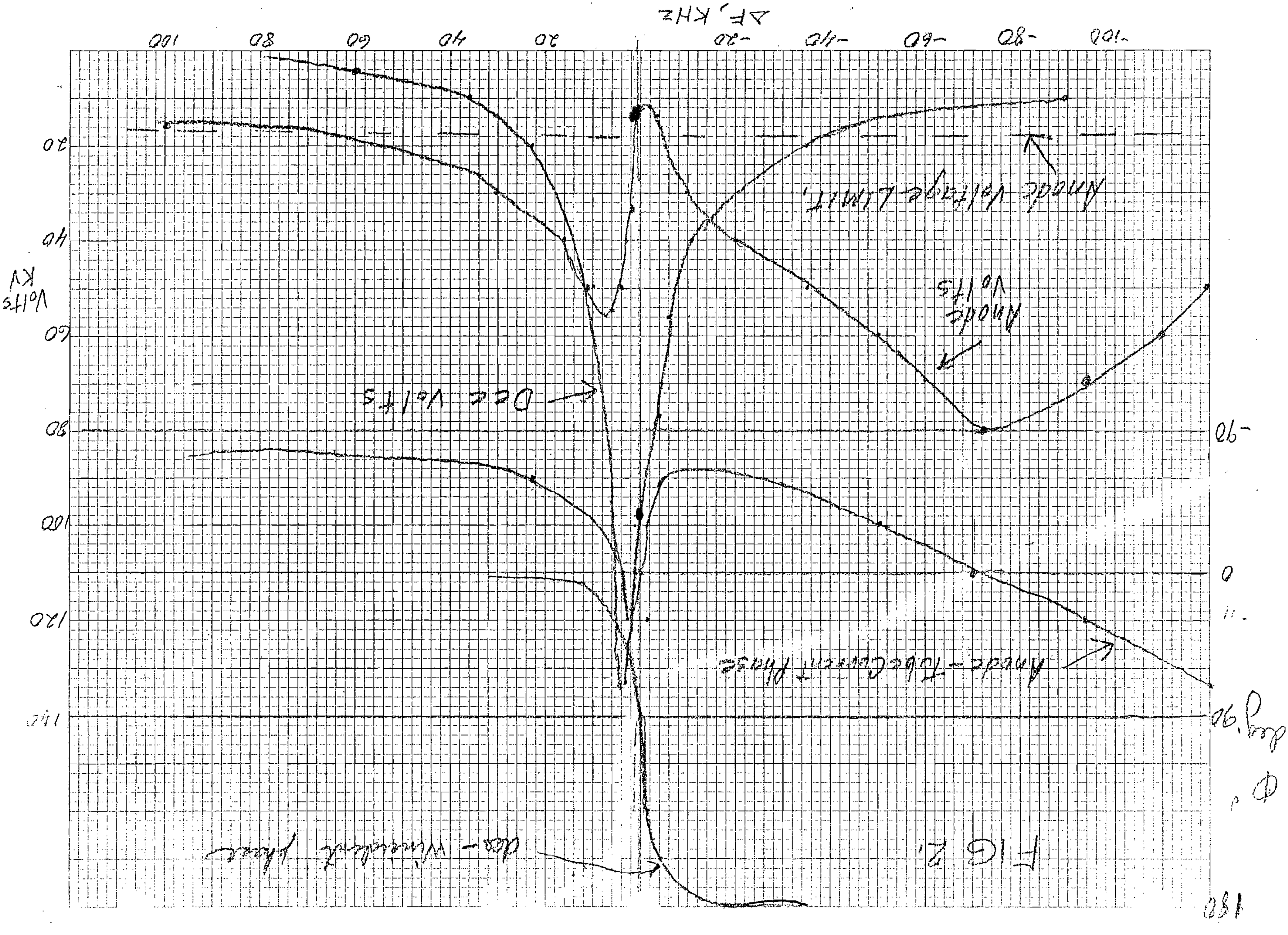


FIG 2'
ΔF, KHz
Volts
KV
Anode Voltage LIMIT,
Anode Volts
Osc Volts
Anode - Tube Current Phase
deg
Φ
20
40
60
80
100
120
140
0
-90

The main conclusion to be drawn from these curves is that the phase difference between the forward directional coupler signal and the stem loop pick-up signal is the only signal that tells us we are tuned. Furthermore, with the transmission line connected to the tube and dee as normal, it is impossible to find, by measurement, a correct setting for the dee coupling capacitor.

Fortunately, things are stable enough and repeatable enough so that, it is believed, we can pre set, for any frequency, the driver grid tuner, the final grid tuner, the transmitter stem, the output coupler, the dee stems and the dee coupler. Then when we turn on we need only tweek the fine tuner and the transmitter stem; all other adjustment remaining frozen.

We also looked at voltages in the transmission line for the case where we have a dee short, for a spark across the coupler, and for a spark at the bellows. At various frequencies the transmitter voltage and transmission line voltages will get too high: the line spark gaps will spark down or the screen will overcurrent.

JR/pcp