RF BOOK

RF NOTE 79

December 28, 1981
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NEUTRALIZING

the three little dees

Symmetrizing the dee to dee capacities

Using the electrolytic tank we added copper pieces to the dee tips in such a manner as to increase the B to C and A to C capacities, so that the three capacities were equal to about 10%. Then the magnet cap was lifted, the ion source removed, and tips were added to the dees.

Unfortunately we had another oil spill, this time onto B dee. This was forevac pump oil. I will not go into the details of how this occurred. Suffice it to say that even though most of it was cleaned up, on pump down, the residual gas analyzer showed a signature different from the previously known signature of the hydraulic oil which was still there. Further, when the rf is on the oil peaks around mass 40 increase a factor of 10 while the water peak stays constant.

Anyhow, the dee capacities were now symmetrized, but only for rf test purposes, as these added tips would prevent acceleration of a beam. The purpose of the tests was to determine whether or not satisfactory rf operation would be possible if the dee capacities were symmetrized rather than neutralized.

R.F. Tests, Dec. 1 to 12, 1981.

First, we turned on in air using the 50 watt amplifiers to apply about 2 KV to the dees. Things looked very encouraging. Our only variable elements were the three dee fine tuners and the three input coupling capacitors. It was duck soup to adjust the input couplers to achieve ratios of forward to reverse transmission line power of 100 or more. Then the phase of the forward power with respect to the loop voltages could be adjusted to zero using the fine tuners and we thus got good three phase operation, with closed servo loops.

So we pulled a vacuum and turned on with the transmitters. All this was done at 17.654 MHz (where we had gotten our first beam that produced neutrons on Nov. 21, 1981). Operation was poor, though better than before we had symmetrized the dee capacities. One of the problems was that just as +120,0,-120 phase relations occurred with equal voltages the 6 interacting servo loops became unstable, so that two of them had to be opened. It was hoped that if the servo loops were speeded up and made more stable that 3ϕ operation with balanced dee capacities would be possible.

Meanwhile we also wanted to prove whether or not neutralization was possible. So we shut down to install a loop coupling between A or B dees, and at the same time run A at high power into the dummy load to work on improving the transmitter fine tuner loop response. In a later section I will present the details and calculations of these coupling loops.

The tests made with the one loop showed that it was too small, and, or the self inductance was too large. So we added a series capacitor to resonate out part of the self inductance and achieved neutralization at 17 and 9 Mhz. This was done with the 50 watt amplifiers with 100 volts on the dee, just below the multifactoring level. Meanwhile, work on "A" transmitter resulted in considerable improvement of the transmitter fine tuner servo.

By this time we had concluded that we either had to symmetrize the dee to dee capacities or neutralize them. However, there was an added consideration. To symmetrize the dee capacities would require loops between B and C dees, and these couplers would mechanically interfere with the mechanisms that permitted removal of the ion source and the center plug. Still, we thought we owed it to ourselves to investigate whether or not the improvement to the dee fine tuners would make it possible to achieve good 3ϕ operation with balanced dee to dee capacities.

We spent three days with the transmitters at high voltage (40 KV) trying to prove this. We failed. I am not convinced that with sophisticated enough servoes satisfactory 3ϕ operation with balanced or unbalanced dee to dee capacities could not be achieved. So we proved that either it was impossible or we were not smart enough.

In any case, we decided to go for broke for neutralizing. The best way to do this is to install fixed small loops between A & B and A & C with variable capacitors in series (always tuned so that we are below resonance). We have found a company (Comet, in Switzerland) who can supply these capacitors (for 3 K$ each), but the lead time to obtain these (about 4 months) and the considerable engineering effort entailed to execute this program led us to try a simpler solution.

Based on our measurements with the fixed loop plus series capacitors (all at low level) we conclude (God, I hope we are right in this conclusion) that with two such loops (upper and lower stems) we could neutralize from about 15 MHz to 30 MHz by suitably rotating them.

These four loops are now being fabricated in the machine shop and probably will be installed and everything ready for tests by 5PM, 12/18/81. We then propose to neutralize at 24.432 MHz and accelerate a Deuteron beam to 130 MeV. After this successful test (?) we will find out at what lower frequency we are incapable of neutralizing and then scratch our heads to help us decide what to do next.

I had intended to finish this rf note here, but now will continue.

Understanding the problem

Suddenly it became very clear as to what the problem was with unneutralized dee capacity operation--and with this understanding the solution immediately becomes obvious. For some time I had worried about what the dees saw looking backward through the coupler, the transmission line, the transmitter output coupler and finally the transmitter circuit and agreed with the dees that I didn't like what I saw. But the significance escaped me. Let me digress.

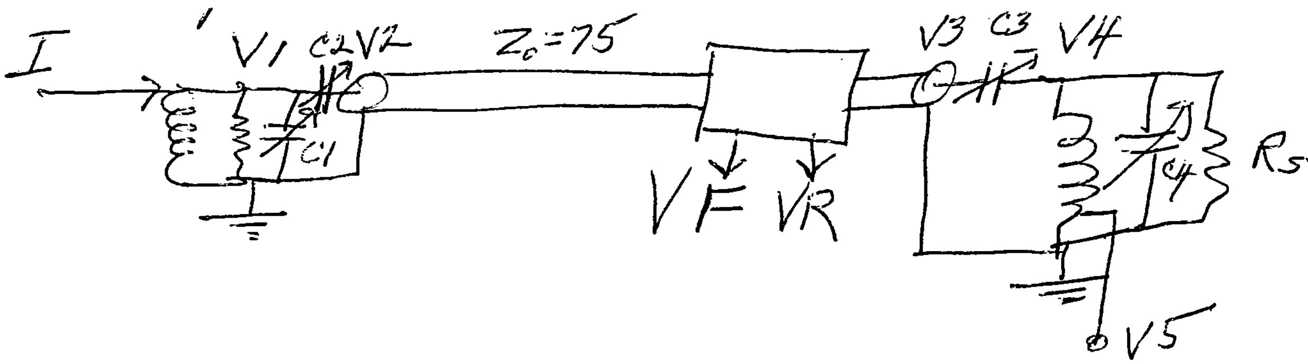
Over the years I have observed that when others (Lampf, Triumph, NSL) operating at a single frequency employed circulators between the transmitters and the load, circulators absorb all reflected power and only permit forward power to transmit the line. This is a good idea, but completely impractical over our 3 to 1 frequency range.

Now to the problem. In our computer program we use the superposition theorem to calculate the 3 dee system.

It is also appropriate to use this theorem in our thinking. Thus we turn on only transmitter A and compute the voltages and currents everywhere. We note that, depending on the frequency and line lengths we can get huge voltages at B and C transmitters. Then we shut A off and turn B on. Again, huge transmitter voltages. However, if the dee to dee coupling capacities are exactly equal, AND everything is tuned perfectly, AND dee voltages are symmetric (this means that each transmitter is delivering the correct power to drive its dee to the correct voltage) then on vectorially adding the three sets of voltages and currents everything comes out perfect and there is no reflected power in the lines. This means that the dee to dee capacities must be exactly symmetric. Our computer program verifies this. Even a 1% assymmetry is intolerable.

Since it is as easy to neutralize as to symmetrize, then we say that we MUST neutralize. Now that this is understood we are also able to show that even though neutralized, so that in effect we have three independent transmitter + transmission line + dee systems, the present criteria that we use for tuning is insufficient to guarantee correct results. In fact the present criteria and anode rf phase is 180° out of phase with the grid voltage, and the forward power signal is in phase with the monitor loop voltage, which does not result in a unique set of operating conditions. There are, in fact at least two sets of settings which satisfy the above criteria, one correct and the other resulting in a large reflected signal and a high anode voltage.

With the aid of the figure below I will explain this.



If we are tuned correctly, then V4/V1=7 and there is no reflected power ($V_R=0$). However if C4 is mistuned we will get a V_R. This signal rushes to C2 and sees an open circuit, is reflected back in phase and adds to V_F, the phase depending on the frequency and line length. Thus C4 tunes to make the new phase of V_F=phase of V5. And we are left with a large V_R and probably a large V1. There are probably an infinite set of stable conditions, all bad. Now I have finally defined why I am against weak coupling!

However there is an electronic solution to the problem. I need to make a computer study of all this, but it is obvious to me that we need to add a third tuning criterion. It is this: V_R must be zero. This can be accomplished by making an additional phase detector of the type such that $V6=k \sin\Delta\phi x|V_R|$, where $\Delta\phi$ is the phase difference of V_R and V4 compensated with appropriate line lengths. If V_R exists, the sign of $\Delta\phi$ should tell us whether C4 is too big or too small. V6 can then be added to the input of the dee fine tuner phase servo in such a way as to force the correct operating conditions to exist. V6 can be produced by using our 2MHz mixers to V_R and V5 and adding a ring modulator as a phase detector. T. Miyanaga can do all this easily with existing hardware, and when I return on Feb. 1 I presume it will all have been done and debugged.

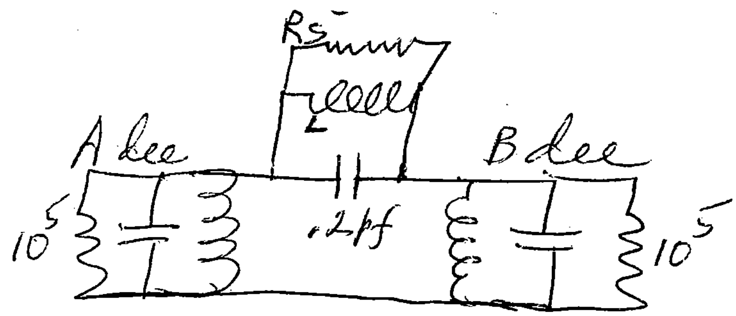
Neutralizing

On 12/18/81 we neutralized and within an hour got all three dees up to 40 KV at 24.423 MHz. It took only 6 more hours to get each dee independently up to 80 KV. We turned the magnetic field on and rebaked. Operation above 70 KV was difficult, partly because of problems with the final PS and anode sparks in B transmitter aggravated by the fact that the spark detector wasn't working properly.

Operation below the sparking level was beautiful! It was easy to get the correct phase relationships and balanced voltages. However our low level electronics was not working perfectly so that it was possible to have bad conditions as explained under "understanding etc."

Besides, we suspected something was wrong with the pullers due to the bent source. So we terminated hi level tests on 12/23/81, and investigated the frequency range over which our present loops could neutralize.

We could not neutralize at 9 MHz. We could neutralize at 12 MHz with a 20^{o} margin. I guess we could neutralize at 10 MHz. We cannot, of course, completly neutralize because of the finite Q of the neutralizing loops. The equivalent circuit of the neutralizers is shown below.



where L is a transformed coupler. Let us guess that the Q of the loops plus 15 inch transmission line is 500. The impedance of L and of the .2 pf dee to dee capacity at 27 MHz is $3x10^4$ Ω. So when A dee is excited to 100 KV we should expect B dee to have $10^5/Qx3x10^4=6x10^{-3}$V. Measurements with the Vector voltmeter show that we can easily get VA/VB 500. In any case, the neutralization capability is extremely good.

Merry Christmas.

12 PM
7/29/82

R.F. tests on the computer.

TRED3 calculates the performance of a dee-Klimotron varying the dee fine tuner for various settings of other parameters. It shows that if everything is perfect, everything is perfect, except that with a constant fundamental tube current, the maximum voltages occur at improper phase settings of the dee to V+ signal and anode to drive signals, always resulting in excessive anode volts.

If the input coupler is 2.5 times larger than it should be one can get a $\frac{V+}{V-}$ ratio rather large, and if at the same time one changes the anode FT for 180° Δφ between the anode & drive signals, and sets the dee FT for max $\frac{V+}{V-}$, using TRED4 to vary the anode FT, one notes that the anode voltage is very high and the line voltage also.

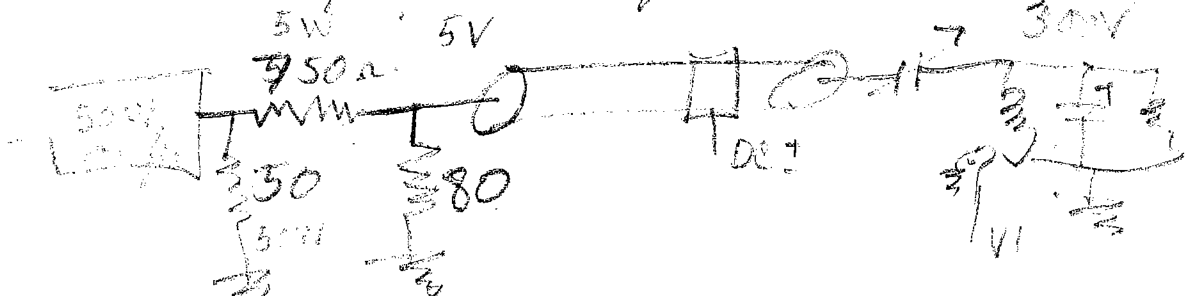
If the input coupler is 1/2 what it should be, ~~a large~~ again a large $\frac{V+}{V-}$ can be achieved by varying the dee FT, but if at the same time the anode FT is varied for ~~good~~ 180° Δφ from drive to anode everything is OK and the anode & line voltages are low.

~~For~~ the case where the dee coupler is 2.5 > than it should be, the dee to V+ phase is 11° retarded at max $\frac{V+}{V-}$ whereas at 1/2 it is only 2° advanced.
- I don't understand everything about this but I believe the calculations.

1.6×10^{-4}
$.16 \times 10^{-4}$
$.016 \times$
$.001$

Conclusions:

1. The phase detectors should be adjusted to give zero outputs for inputs that are 0° or 90° out of phase.
2. The cables from the V+ and loop signals should be carefully length adjusted so ~~that~~ the phase detector gives zero output when these are in phase.
3. In vacuo tests are difficult because the dee voltage must be less than 100 volts. For this reason, tests should be made in air, using the 50 watt amplifier as follows.



Check that phase of V1 − DC+ = 0 corresponds to max V1 for [illegible] and [illegible] MHz. If not, adjust cable lengths until it does. Also V− = 0 at $\Delta\phi = 0$.