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# THREE PHASE R.F. SYSTEMS FOR SUPERCONDUCTING CYCLOTRONS

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## Introduction

The initial design of the MSU K500 cyclotron r.f. system was reported on at the 1979 Cyclotron Conference.[1] In the course of bringing this system into operation some changes had to be made to that design, and these will be discussed.

## Dee stem moving short

After several evolutions we now have a successful moving short for the 6 dee stems. The stem current flowing on the 4 inch O.D. inner conductor is 2600 amps RMS, resulting in a linear current density of 206 amps per inch. The contact between the short carriage and the inner conductor is made by pushing on 12 foam rubber backed one inch arc lengths of a 1/4" diam door spring with a force of 110 lbs. The spring are made with silver-plated 20 mil BeCu wire. Thus each 20 mil contact carrys 4 amps and the contact force is 2 lbs/contact. The pneumatic piston force is released to move the shorts (RF off during movement) so that no galling takes place.

## Problems with 3$\phi$ operation

The r.f. system was operational 10/1/81 and after conditioning each dee separately to 100 KV, they were brought on simultaneously in the 3$\phi$ mode. The operating conditions agreed quite well with the calculations, and with our

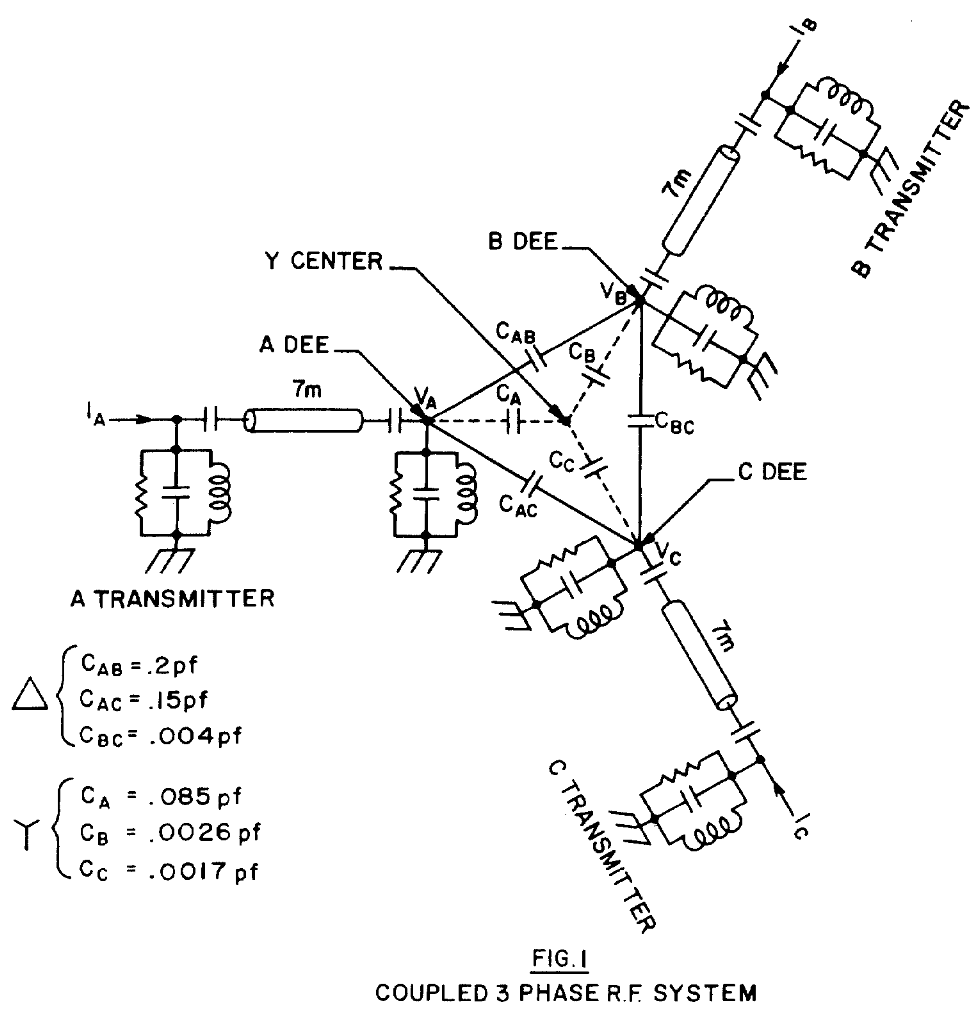


FIG. I

COUPLED 3 PHASE R.F. SYSTEM

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model studies. At this time neither the center plug nor the ion source were installed and the dee to dee capacities were small and symmetric.

When we installed these items we found that it was impossible to achieve 3φ operation with reasonable tuning adjustments. However, by trial and error, with no obvious criteria for adjustment we finally were able to accelerate a low energy deuterium beam that needed only 33kV on each dee.

It took some time to realize why there was such a large difference in 3φ operation with and without the ion source, but we finally realized that the ion source quite effectively shielded the B and C dees from each other. Fig. 1 shows the equivalent circuit and the measured values of the dee to dee capacities. We had developed a computer program[2] that could calculate everything about the coupled circuit, including the transmission lines and transmitters.

The technique used to make these calculations may be of interest to others. First, a Delta to Wye Transformation of the coupling capacitors is made. Then three sets of currents and voltages for all the nodes and branches are calculated; the first set for an input of $I_A$ only, the second set of $I_B$ only and the third for $I_C$ only. Then using the superposition theorem these three sets are vectorially added to achieve the final result.

For one dee at a time, and for 3φ operation with symmetric coupling, only two fast servos were necessary to keep everything in tune: the transmitter fine tuner which was adjusted to keep the grid drive and anode phases $180^{\circ}$ apart, and the dee fine tuner which was adjusted to keep the dee voltage and forward power in phase. It became obvious that for 3φ operation with unsymmetric dee to dee coupling something else was needed.

Computer studies with the actual coupling capacities verified that operating conditions were intolerable with only these two feedback elements. Using the computer in a feedback mode (iteration) we are able to show that if we at the same time absorb any reflected power, or adjust the dee tuning to minimize it, then 3φ operation with asymmetric coupling is possible.

## Neutralizing

It seemed more surefire and expeditions to neutralize the coupling capacity, as any loop that could symmetrize the dee capacities could as easily neutralize them. So now we neutralize, find that this is easy to do, and thus get independent operation of the three dees.

## Conclusion

More sophistication in control is necessary to get stable 3φ operation if the coupling capacities are unsymmetric. Studies show that if a circulator were used in the transmission lines to absorb any power going towards the transmitters, operation would be satisfactory even with asymmetric dee to dee coupling, but this is difficult over our 9 to 27 MHZ range. Since neutralizing is simple and easy we will use it and recommend its use to others.

## References


1. R.F. Systems, J. Riedel, IEEE Transactions on Nuclear Science, Vol. Ns-26, April 1979.

2. Program TRED 2, T. Miyanaga, MSU internal RF Note No. 74, May 29, 1981.