RF SYSTEMS

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This last year has seen only minor updates and changes to the RF systems, as the Coupled Cyclotron Project continued to completion. The addition of the K1200 phase-shifted RF source from the K500 was the only new hardware added for coupled operation. Just recently, a High Intensity Beam Interlock system was also built and installed as a safety measure for coupled operation at high beam levels. Several upgrades to the RF system have also been done, including the elimination of vacuum tube regulated high voltage bias supplies, replaced by solid state devices.

During the period of shutdown, the RF systems did not accrue many hours, as expected. When some operations began around April, a few weak links in the system appeared. Three tube failures occurred, apparently unrelated. Several other failures occurred, including burnt fingers in the stems of the K1200, a burned transmission line connector (due to mis-assembly years ago), water leaks in the DA-2 multiple output power supplies, and some minor electronics failures where spares were on hand, mostly parts of the high-power RF systems. As operation time of the cyclotrons increases, there will probably be other failures of existing components that have aged. Our spares stock will hopefully make these occurrences a minor concern.

In late 2000, a tube rebuilder was identified thru the internet that has dealt with our high-power amplifier tubes, the Thompson (now Thales) TH555. These tubes sell new for around $40,000, but can now be rebuilt for about $8000. As we have had unsuccessful rebuilds in the past, we were skeptical of this vendor's capabilities, but the first tube they rebuilt has put in 1000 hours of RF service now with no problems. A second tube has been rebuilt and only recently put into service. As we expect to use about one tube every 6 months (26,000 hours/tube), this is an annual savings of around $64,000. A tube can be rebuilt several times unless it fails catastrophically, each time providing the same life as a new tube. Eventually, new tubes will have to be purchased, but we expect to have 4 spare tubes on hand by the end of the year without any new purchases. We visited the rebuilder facilities in New Orleans recently, and it looks like this vendor will be around for some time. It is a small family run business, with an amazing set of capabilities developed over the last 70 years.

One of the four spare tubes is a result of purchasing a second hand tube with no hours on it, though with 7 years of shelf life. The tube appears to be functional, and is being shipped to us for tests. This will be purchased for about 1/3 of new price.

Much has been learned about the characteristics of these tubes in the last year, thanks to the tube rebuilder and other sources. We have learned how to condition tubes in-house in several ways, and have improved operation of 2 tubes. One of these was written off as a failed tube several years ago, and is now back in the system and running full power in the K1200 cyclotron.

Another significant improvement in operation came with the development of a low power tune procedure. This allows an otherwise time consuming process of changing cyclotron frequencies to become a straightforward and quick procedure. Using a spectrum analyzer, weak RF leakage signals can be sensed in the cyclotron when it is off that can be used to set critical tuning parameters. This was a trial and error process previously since the RF could not be turned on without the tune being very close, yet the tuning could not be adjusted without the RF being on. With the low power pre-tuning procedure, the RF typically comes on at full power on the first try.

The following is a table summarizing the current status of the TH555 final tubes on hand.

Tube	Status	Total RF Hours
A11	K1200	50,706
A20	K1200	69,859
E4	K500	135
G1	K500	25,750
A16	Rebuilt, spare	1068*
10002	Spare	5677
10003	At Rebuilder	-
10101	Rebuilt, K1200	117*
10103	K500	5076
10116	Spare	2375

* Hours since rebuild

Current and Future Projects

Plans for the future include upgrading the solid state RF Driver amps, as the current models are no longer available and spares need to be purchased. Also we plan to upgrade the phase control system to a new in-house designed digital system capable of higher accuracy and stability. Some details on these two projects follow, as others may find these projects useful.

The RF drivers used in the cyclotrons are 50 Watt output amplifiers with around 40 dB of gain. They take the low level signals from the phase and amplitude control electronics and bring them up to a level for driving the amplifier tubes. To drive each dee, the 50 Watt signal drives a pair of 2000 watt tubes, which in turn drives the 250 KW tube. Normally this solid state amplifier is purchased as a rack mounted module, available from several vendors at a cost of between $4,000 and $8,000. A very similar amplifier is used in 2-way radio equipment in the amateur radio hobby. A complete transceiver in that market, with 100 Watt linear amplifier included, sells for around $600. We purchased one of these that had an easily separable RF amp module (about 50dB gain), and measured gain and purity against one of our existing linear amplifier modules. Results were very similar. The internal construction and components are almost identical. The main difference appears to be that one is hand made in America in small quantities, the other is made overseas in million quantities. If testing proves that these amplifiers perform well in our system, our plans are to adapt this sub-component of this commercial product to meet our needs. The minimal engineering effort required should provide savings at the quantity of 10 we would build or buy.

The phase control system of the NSCL cyclotron RF systems consists of simple analog mixers, quadrature dividers, and analog multiplier ICs. These provide a +-90 degree phase detection and +-180 degree phase shift. A different approach is to use high-speed logic and microcontroller processing to provide a digital phase measurement using zero-crossing timing. A prototype system has been built and verified which provides better than 12 bits of phase data over 360 degrees, at a 30 KHz sample rate with a 622 MHz timing clock, enough to maintain a 10 KHz loop bandwidth in a phase regulation system. With averaging, the accuracy can be extended further, although at reduced bandwidth. A second version of this prototype is starting which will incorporate improvements learned from the first prototype, and may be our final operating version used in the cyclotrons. This will eliminate several modules in our system that supply an offset frequency needed by the current phase detectors, as well as much instrumentation verifying phase settings, as the digital phase detectors read absolute phase.

A phase controlled signal source is being investigated that will use Direct Digital Synthesis to generate 6 separately phase controlled RF signals (and others for bunchers, etc.). Thus the digital phase can be set numerically (as opposed to using an analog signal) to control the phase relation of any part of the system, to an accuracy beyond what can be maintained by the other RF circuitry. Most of the circuitry inside this module will be in a Field Programmable Gate Array IC, which can be re-configured with software, allowing for a faster development time.