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RF POWER SYSTEMS FOR THE NATIONAL SYNCHROTRON LIGHT SOURCE

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Abstract

The booster synchrotron and the two storage rings at the NSLS are provided with rf power systems of 3 kW, 50 kW, and 500 kW nominal output power, all at 53 MHz. This power is supplied by grounded grid tetrode amplifiers designed for television broadcast service. These amplifiers and associated power supplies, control and interlock systems, rf controls, and computer interface are described.

Introduction

The NSLS is a dedicated facility for research with synchrotron radiation. The facility includes a 2.5 GeV electron storage ring, a 700 MeV storage ring and a 700 MeV booster synchrotron. Early in the design of the project an RF frequency of 53 MHz was chosen for the storage rings and booster. This relatively low frequency (for electron accelerators) has certain advantages for beam stability in the storage rings, and also is well within the range of efficient gridded tube power amplifiers.

The larger storage ring is called the X-ray ring because the characteristic energy of its synchrotron radiation is in the X-ray portion of the spectrum. A stored electron beam of .5 ampere at 2.5 GeV in this ring will radiate nearly 300 kW. This power and the cavity losses of 150 kW determine the required RF output of the source. The 700 MeV storage ring, or VUV ring, radiates 12 kW of synchrotron radiation in the vacuum ultra violet at a stored current of one ampere. Cavity losses bring the total power required to about 20 kW. In the booster synchrotron, beam loading is not significant, but cavity losses are between 1 and 2 kW.

These considerations and the desire that each amplifier be suitable as the driver for the next larger one lead to the choice of 3, 50, and 500 kW power capabilities. It turned out that the most economical approach to the 500 kW stage was a combination of four 125 kW amplifiers. These units are slightly modified versions of the 50 kW amplifiers, so the NSLS RF power systems are made up of a total of nine tetrode amplifiers of two types. This modular situation has simplified the design and construction of controls, power supplies and other support systems.

System Configuration

Figures 1, 2, and 3 are block diagrams of the three rf systems. The systems are identical in the lower level stages. Each storage ring has its own frequency synthesizer since the rings will operate simultaneously and may require slightly different frequencies. The booster must be phase locked to the storage ring it is filling, so its frequency source will be switched as needed. The accelerating cavities are described in another paper in these proceedings.[1]

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Amplifiers

The solid state amplifiers are commercial 100 watt units with 50 dB gain and 6 MHz bandwidth. They were supplied by Amplifier Research.

The tetrode amplifiers were made by RCA and are modifications of units designed for television translator and broadcast service. The amplifiers are grounded grid, grounded screen, and exhibit the advantages of this configuration: isolation between input and output, phase stability, freedom from oscillation, and low and constant input impedance. In addition, the beam power tetrodes utilized have good gain linearity characteristics, with about 16 dB of gain per stage.

The 3 kW amplifier is an RCA 8806 tube in a Y1378D cavity. The input tuned circuit is a resonant stripline and the output a coaxial cavity. These are mounted with the tube in an RF-tight enclosure which also serves to channel the cooling air past the anode. The amplifier mounts in a standard 24 inch wide relay rack along with its anode power supply and cooling blower.

An RCA A3016 tetrode is used in both the 50 kW and the 125 kW amplifiers. This is a water cooled tube with an anode dissipation rating of 100 kW. The cavities are numbered Y1377D and Y1386D respectively and they differ mainly in the size of the input and output connections and ratings of tuning and blocking capacitors. In these cavities, the tube is socketed in the open end of the input coaxial cavity. The enclosure serves as the outer conductor of the output cavity while the input cavity is the center conductor. The output connection is by direct tap to the center conductor. In Fig. 4 the interior of the 50 kW cavity can be seen. The adjustable tuning short for the output cavity is the "floor" of that cavity with the output tap above it. The tube is mounted with the cathode, grid, and screen connections plugged into the top of the input cavity and the anode connected to the blocker capacitor which covers the top of the cavity.

The 3 kW and 50 kW amplifiers have been operated routinely at the NSLS for tests of control systems, power supplies and accelerating cavities. the 125 kW amplifiers were all tested at full power at RCA before delivery, and one unit was run for a time at over 150 kW with no evidence of overheating or breakdown.

Transmission Line and Cavity Coupling

The drive splitters and output combiners for the 500 kW stage are shown schematically in Fig. 3. The hybrids are all of the 3 dB crossover type. The lengths of connecting coaxial line are such that the phase relationships are correct for proper combining of the amplifier outputs. There are no phase shifters or attenuators in this network, so accurate power combining depends on a reasonable match among the four final amplifiers. If it were necessary to operate with an unmatched (low gain) tube, a first order correction could be made with amplifier bias levels and tuning. The hybrids and connecting coax for the 500 kW stage were supplied by Dielectric Communications.

The impedance of the accelerating cavity changes with beam loading, so the match at the cavity input will vary with beam current. The coupling can be changed by rotating the feed loop (when not under vacuum) and has been adjusted to be matched at maximum beam current in the storage ring. The loop is over-coupled at smaller currents, giving a VSWR of up to 2, but less power is required with small beam. The amplifiers are designed to operate at full power into a VSWR of 2 and at reduced power into a VSWR of 3.

Hardware Management Controls

The hardware management system includes the control, monitoring and interlocking of the various electrode potentials and cooling services for the tetrode amplifiers.

The voltage and current signals are passed through operational amplifiers with gains adjusted so that each signal at normal operating level is about plus five volts. This signal goes to the computer for monitoring and readout, to a test point for local monitoring, and to a voltage comparator for registering over or under levels. The comparator outputs and other status signals are processed in TTL gates and latches to provide the overall logic. Amplifier status signals are sent to the computer and are indicated locally by LED's. Power supplies and cooling devices are controlled with solid state relays, conventional relays, and vacuum contactors.

The hardware management modules for the 3 and 50 kW amplifiers in the VUV system are illustrated in Fig. 5. The modules for all of the amplifiers are the same with the exception of the resistors which set the op amp gains and the time delays.

The anode and screen overcurrent circuits are redundant from the sensing resistors to the power supply control relays since substantial and expensive damage could occur were these interlocks to fail. Test circuits are provided for injecting overcurrent signals into each of these circuits.

Each hardware management circuit is built on eight 4-1/2 by 6-1/2 inch printed circuit cards which plug into the bins illustrated.

RF Controls

The RF control system receives signals from the amplifier output forward and reverse power directional couplers and from the accelerating cavity monitor loop. These are processed to provide control of cavity excitation, phase stabilization, cavity tuning control, and protection in the event of cavity breakdown or excessive mismatch.

An attenuator of the double balanced mixer type is used for level control and RF turn-off. Attenuator control current comes from an operational amplifier which compares the cavity monitor signal with the programmed level. The RF is turned off by shorting the attenuator control terminal to ground with a TTL gate. The RF can be pulsed by using this input, which is very helpful when conditioning the accelerating cavity to RF power.

Phase stabilization is with a varactor-type electronically controlled phase shifter. The phase error detector is a double balanced mixer.

An automatic tuning system is required for the storage ring accelerating cavities, since beam loading will cause substantial detuning. A double balanced mixer compares the phase at the cavity monitor with the phase of the cavity drive power. A phase difference causes the drive motor of the tuner plunger to restore resonance.

The phase detectors in both the automatic tuner and the phase stabilizer are connected so the correct phase gives a null output. Therefore, changes in signal amplitude will affect the feedback gain but will not change the null point.

The frequency synthesizers can be remotely controlled via parallel digital inputs allowing computer control should this prove desirable.

Computer Interface

It is evident from the preceding paragraphs that a decision was made not to put the control logic in the computer. This was not for fundamental reasons, but rather because of the time schedule and the relative inexperience of those on whom the software design work would have fallen. A control system was needed early on to exercise the equipment as it arrived and to aid development of the RF system as a whole. The probable long lead time required to develop software-based control logic overshadowed the advantage that such a system, once working, would be easy to duplicate.

The RF system, despite all its hardware, is designed to be run from a computer terminal. The hardware management module for each amplifier provides the computer with eight analog signals and twelve status bits. The commands to each amplifier are: Standby, Reset, and On. These are implemented by TTL levels.

The RF controls for each system provide five or more analog signals, and an equal number of status bits. The commands are: RF Drive On, and RF Amplitude.

There are no local meters at the RF power systems so checking will be done from a computer terminal, or by using a portable meter at the control module test points (as shown in Fig. 5).

Power Supplies

The anode power supplies were purchased as "power packs", that is, with transformer, rectifier, and filter, but without switchgear, controls, or enclosure. This afforded substantial economies and minimized problems of integrating the supplies into our control system.

The 12 kV, 8 amp supply for the 50 kW amplifier and the 18 kV, 12 amp supplies for each 125 kW amplifier are arranged similarly, with the three phase transformer located in one 24 inch rack, and the rectifier, filter, and vacuum contactor located in an adjacent rack. These power packs were supplied by American High Voltage Test Systems. The 5 kV, 2 amp supplies for the 3 kW amplifiers were provided by NWL Transformers.

Status

The 50 kW system for the VUV storage ring is in place in that ring and has powered the cavity to 10 kW which corresponds to the normal accelerating voltage with no beam loading. The system has also been run to full power into a dummy load, and higher power cavity excitation will be tested when the cooling system is installed.

The 3 kW booster system has been assembled and tested and is ready to install in location.

All components are on hand for the 500 kW X-ray system and assembly has started since this part of the building has recently become available.

Assembly of the control modules is essentially complete, but the software for the computer interface remains to be composed.

Acknowledgment

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Reference

1. K. Batchelor, J. Galayda, and R. Hawrylak, "Rf Cavity Designs for the NSLS", Proceedings, 1981 Particle Accelerator Conference.

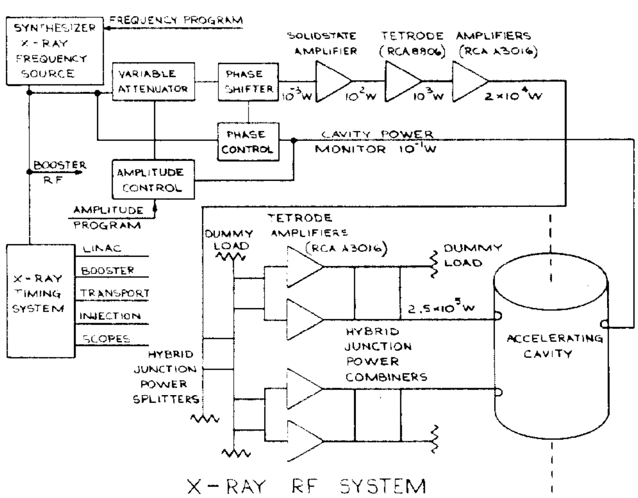


Figure 3.

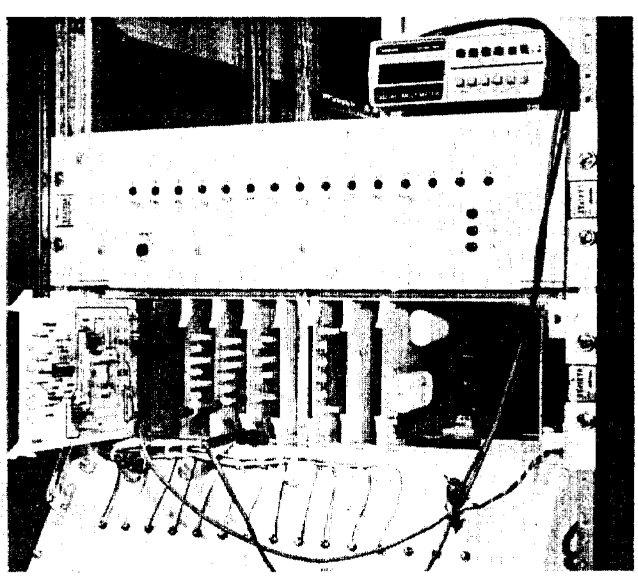


Figure 5. Hardware Management Modules.

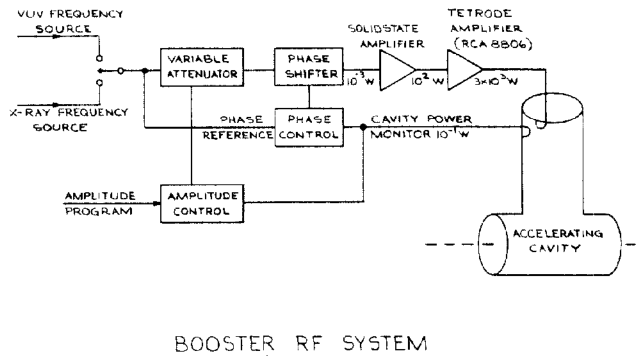
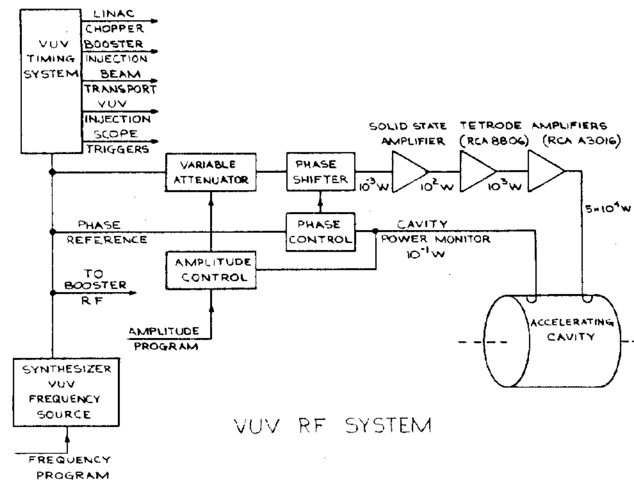


Figure 1.



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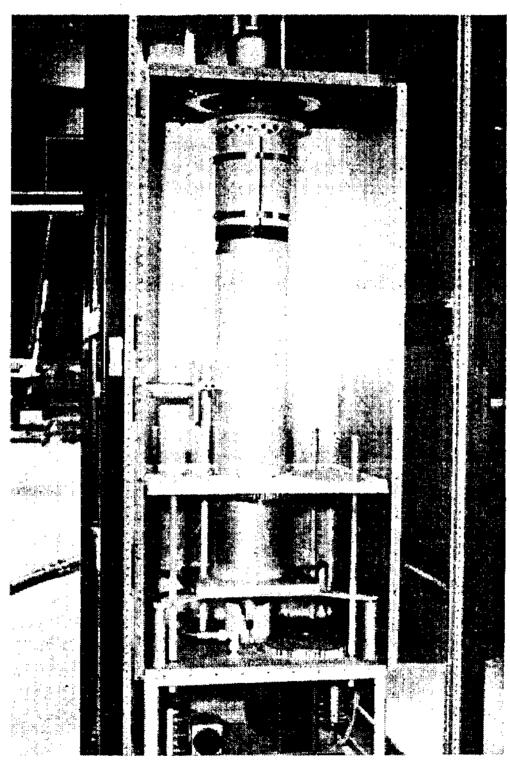

Figure 4. 50 kW Amplifier.