PFC/RR-80-30

FINAL REPORT
LOWER HYBRID MDF PROJECT

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TABLE OF CONTENTS

General Introduction

One of the methods used to heat high density plasmas is the injection of microwave energy at the lower hybrid frequency. To this end, a system was designed and procured which is capable of delivering up to four (4) megawatts of RF power at a frequency of 4.6 GHz. This system will also provide a usable set of diagnostics, both of the system itself and the plasma interface.

The system is designed to utilize readily available or easily developed components and is constructed in a modular manner. Major subsystems are self-standing with simple interface, design and a high degree of subsystem flexibility.

The majority of this equipment was subcontracted to vendors for design and construction. The overall control, data acquisition and RF feed were designed in house. The installation and wiring tasks were integrated with the overall Alcator C experimental schedule so as to cause minimum interference with the experimental schedule. This mode of operation produced unavoidable delays in the equipment installation schedule, but maximized the experimental run time.

System Description

The system is configured in four groups, each capable of one (1) megawatt, as stand alone modules with a simple control and data collection module. Figure 1 shows the overall configuration. Input triggers are received from the Alcator control system to arm and enable the RF system. These triggers are then processed and distributed over the control system to each of the individual modules. Each of the RF modules can be set in pulse time delay, pulse width, pulse amplitude and will provide phase control of each of the four high power RF outputs. The modules are self-protecting.

The experimental data is collected on a digital data system which provides display and archive capability using a PDP 11/34 computer. The data system can also be used for off-line data reduction and analysis. Interface between the data system and the system control sets computer priority such that data is always taken during an experiment and allows off-line use of the system at rates higher than those normally used by the Alcator in order to facilitate processing of microwave windows and system maintenance.

Each of the RF modules provide four, phase adjustable, outputs to the grill. Figure 2 shows the grill arrangement and phase control. The grill is a 4 × 4 matrix of RF feeds. Each vertical column is set to be in phase by the mechanical lengths of the waveguide runs feeding them. Each element in the horizontal row is independently phase controllable. The phase control is provided by electronic phase shifters in the low power klystron input line. These phase shifters are four bit binary phase shifters which will change phase in under one (1) microsecond. If needed, this system can be upgraded so as to change phase electronically over the pulse by use of the phase controller output. By programming the phase controller different phase settings could be fixed over different portions of a single experiment.

A module supplies the RF power, phase, timing and amplitude control for the experiment. Figure 3 shows an RF module integrated with the data system. The exciter produces the frequency source required for system operation. There are three (3) outputs as follows:

4.600 GHz – high power output frequency

4.601 GHz – L. O. frequency for phase detector, and

1.0 MHz – phase reference signal.

The 4.6 GHz signal is amplified to the 25 watt level and split four ways to provide two reference signals and the main high power drive source. The RF drive is then passed through a PIN diode switch which provides a fast pulse shaping capability. This signal is again amplified and split to provide the drive for each of the four high power klystrons. Each of the four klystron drive lines has a mechanical phase shifter for alignment and an electronic phase shifter for phase programming. The 4.601 GHz signal is amplified and distributed to those locations in the system where phase measurements are to be made. The 1.0 MHz signal is amplified and distributed to the phase measurement circuits.

The high power amplifier consists of four 250 kilovolt klystrons operated cathode pulsed. The klystron output is passed through a harmonic filter to provide a match at the harmonics and remove the measurement error caused by harmonic power, followed by a circulator to provide a good match to the klyston. Klystron protection is provided with visual arc detectors and back power monitors.

The klystron beam voltage is provided from a single 65 kilovolt power supply and four modulators, one for each klystron. Each modulator is capable of supplying 55 kilovolts at 15 amperes with a regulation of ± 200 volts. The solenoid, Vac ion pump, filament power supplies and monitor functions are integrated into a self-consistent system to support klystron operation, with only a single input gate required to produce an output once the system is energized.

The machine interface provides the electrical and mechanical interface between Alcator and the lower hybrid experiment. The interface attaches to the machine port and supports the grill, provides mechanical motion and the A/D inputs for the data system. The high power RF inputs through DC blocks which provide ground isolation and is distributed to the grill through a set of power dividers. The vacuum window is a part of the grill. The grill and feed assembly is supported mechanically and movement is provided. A pair of directional couplers are used on each grill feed to provide both forward and reverse power and phase measurements. The analog signals are converted to digital ones which input the data system on command. A VSWR fault monitor is provided for each window.

The control is divided into two major subgroups: Module control and power system control. The module control receives an input trigger from the system control and produces delay, pulse width and fault function for proper module operation. Fault and pulse width information is displayed and operational controls are provided from one of two locations: control room and equipment. The power system control provides power up sequence, fault monitoring of the power system and receives a single gate signal which controls the modulator pulse width. The module control energizes the modulator and the RF separately to allow for rise time and setting of the modulator. The RF is applied, a fixed one millisecond, after the beginning of the modulator gate. Status information is available for input to the data system if required.

The data system is a PDP 11/34 based CAMAC system. The data system receives analog inputs from the system sensors, converts them to digital signals and stores the data in local mass memory. Upon receipt of a command from the computer, the data is transferred to a disk file and displayed on a terminal. As data is collected on the disk, files are transferred onto tape for permanent archive. Figure 4 is a graphic presentation of the data system. The system sensors input data which has been normalized to 10 volts full scale to the CAMAC system. The CAMAC system is set to take samples based on a master clock. This eliminates data skew and the ability to change sample rate under system control. The input data is converted to digital signals and stored in mass memory in the CAMAC crate. At the end of the experiment the data is transferred via fiber optic cable on a serial highway through the highway driver to the PDP 11/34. The PDP 11/34 then displays selected portions of the data and stores all the data on files. The PDP 11/34 uses RSX11-M operating system which supports Fortran and "C" compilers. The data is handled by a subroutine, which is written in "C" language and performs all the display and data handling functions.

Lower Hybrid Hardware – Present Status

The lower hybrid experimental hardware is designed to deliver microwave energy at 4.6 GHz and provide diagnostic data. The system uses 16 klystron amplifiers operating at 250 kW each to generate the power to be delivered to the plasma through 64 waveguides arranged in four 4 × 4 arrays. The delivered power is limited to 70% of the klystron power due to transmission losses.

At the present time all of the heavy power equipment has been received. The delivery of the final windowed waveguide arrays are still in the final development phase.

The following is a summary of the development status by major area:

1. Array development – Each array consists of 16 waveguides arranged in a 4 × 4 matrix, each with a vacuum window. Several options were available for the window design and several development contracts were let to ascertain the best approach. Varian was chosen as the vendor and supplied a sample "s" band, double, window which was used successfully in Alcator A. The development of the "c" band window has not proceeded as well. Due to the smaller size of the "c" band window, there has been considerable difficulty in the successful delivery of this window. The first 4 waveguide array (development model) has now been installed on Alcator C. The first 16 waveguide array failed the vacuum acceptance testing due to failure of the laser welding. A new fabrication procedure is being implemented which will use drawn waveguide techniques, thus avoiding laser welding altogether.

2. High power microwave components – Since the experiment operates at high peak power for times approaching the thermal time constants of the components and yet has a low average power, no commercial components could be found. Therefore, circulators and harmonic filters were successfully developed for use in the system and have been delivered to MIT.

3. High power klystrons – Varian was chosen as the vendor for the klystron development and has successfully delivered 17 klystrons and magnets. These klystrons are rated at 250 kW CW and have an oversize collector to compensate for the pulse heating during the experiment.

4. Modulator/power supply system – The power system is divided into four groups, each containing modulators and support supplies of four klystrons. One high voltage supply provides the prime beam voltage for each group. One power supply was acquired, surplus, from Lincoln Laboratory. Considerable modification was required to make the supply usable in the present application. The modulators and the remainder of the power system was purchased from Universal Voltronics. This equipment is installed and the system interconnection is in progress. The first power modulator/power supply group has been tested and used to power the first four klystrons. This gives the capability to begin experimentation at the one megawatt level.

5. RF source – The RF source provides phase controlled drive at the klystron input and the L. O. and reference frequencies for monitoring the experiment. The sources are in house.

6. Controls – The complexity of the system demands a reasonably complex control system. Klystron and window protection must be provided as well as interface capability to the Alcator control system and the PDP 11 based data system. The first of these control systems is presently being used to control the first group testing.

7. Data system – The data system needed for the experiment requires the capability to archive and display data. A PDP 11/34 was chosen as the control computer for the CAMAC system. The hardware for this system is in house and the computer software is presently usable, with 16 channels which is satisfactory for the first 4 waveguide experiment.

8. Receiver – Each waveguide feed is monitored for forward and reverse phase and amplitude. The outputs are then normalized to operate over the -5 to +5 volt scale of the CAMAC Analog to Digital converters. The receiver design is presently completed and the hardware has been tested. A proof of concept unit is completed which provides monitoring for the first four waveguide experiments, and proved to be successful when operated in the Alcator environment. The hardware for the 16 waveguide experiment still needs to be built. If the present design is used, a complete monitor system design is available.

9. Building modifications – The amount of heavy equipment needed for this experiment coupled with the lack of usable space in the facility has required some construction. Namely, the installation of transformer pads, prime power, protective walls. equipment platforms, suspension systems to hold equipment from the ceiling of the Alcator cell, the installation of conduit, pipe and cable trays. The modifications are complete with the exception of the Alcator cell modifications of the third and fourth systems.

In conclusion, all the major hardware has been ordered, and delivered to MIT, with the exception of the waveguide grills. The experimental power for the first megawatt experiment is available and the diagnostics for this first experiment are complete. The major task yet to be completed is the delivery of the final array. The window is still a difficult problem as was pointed out in the beginning of the project, but at present a viable design approach is being provided. In addition to a 2 × 4 back up approach is being developed.

Hardware Description – General

Due to the limited space available in the facility and the magnitude of the experimental hardware, the equipment needed to be spread throughout the facility. Figure 5 is an equipment layout by location. There are five major locations, by functions as follows:

1. Transformer pad – This outside location provides the high power 13.8 kV prime power input and facility for the large oil filled high voltage power supplies and transformers. This area is near the building and complies with all fire and safety requirements set by the building codes. The high voltage (65 kV DC) and low voltage AC leave the transformer pad via underground conduit and enter the building.

2. Power room – This indoor location at the building wall provides cable termination for all cables going to or from the transformer pad, 440 and 220 power distribution, and controls for the Lincoln Lab power supply.

3. Power area – This is a large area in the basement of the building which contains high energy handling equipment. The modulators and cooling pumps are housed in this area. The modulators are closed units containing a capacitor bank, crow bar, four modulators and the necessary controls to protect the hardware. A single DC input enters the modulator via cable tray and four modulated outputs (55 kVolts, 15 amperes, 0.5 sec pulse) leave the modulator via cable tray. Cooling lines are run with the cables for modulator and klystron cooling.

4. Cell – This is the main experimental area containing Alcator and the diagnostic hardware. To minimize floor area occupied by the lower hybrid experiment, the klystron assembly and support equipment were hung from the ceiling with only the machine interface electronics occupying floor space. The klystron assembly contains the klystrons, drive and fault electronics and water manifold for cooling. The high power microwave harmonic filter and circulator are mounted on the klystron assembly with waveguide runs to Alcator and the machine interface. The controls and RF source are contained in cabinets mounted on a balcony which surrounds the klystron assembly. The machine interface electronics are mounted on the floor next to Alcator. Data is passed by fiber optic cable to the data highway.

5. Control room – This contains the system timing, control and display equipment and is located above the cell. The equipment is mounted in cabinets on the floor of the control room. Data display and control for the experiment are available in this area.

6. Computer room – This contains the computer (PDP 11/34), tape transport and computer console. The room is climatically controlled to provide a proper environment for the computer equipment.

Controls

The size and complexity of the system forces the implementation of a complex control system. Figure 6 is a block diagram of the overall control system implemented with a single one megawatt RF module. Two pulses are received from the Alcator control system. The first (To - 5 sec) is used to set up the computer and data system such that all operating tasks in the computer are removed from core and the CAMAC equipment is initialized. The second (To - 2 milliseconds) is used to begin the video and RF pulse cycle and begin the data taking cycles. At the end of an experiment a signal is provided which begins the data display and archive cycles.

Video and RF cycle control is provided by either of two control locations (remote or module control), one located in the Alcator control room and the other at the equipment. These are identical units and provide for use with different trigger sources, give controlled delay, pulse width, limit duty cycle and provide fault control and monitor functions. Either of the two control locations can be made master with the other being a slave unit. A local/remote multiplex unit provides the logical switching necessary for this function.

The modulator and auxiliary power system are a self-consistent set of power sources with an integral control system designed to protect the klystron in the event of power source malfunction or tube arc. Control and monitor functions are provided at both locations.

The interface between the module control, the RF system and the modulator is by video pulse. A single video input is provided the modulator one (1) millisecond prior to the RF pulse and a single video gate is provided to the RF system. Both the modulator and RF video signals terminate at the same time. This sequence of video pulses allow slow rise and fall time of the modulator and provides a fast transition RF pulse through use of a PIN diode switch. This same switch is then used to remove RF in the event of a fault, or to control the energy delivered during high power processing of the windows and other portions of the microwave system.

Microwave System

The microwave system provides the RF source, low power microwave components and high power microwave components necessary to produce, amplify and transmit the microwave energy to the plasma.

The low level microwave system is shown in Figure 7. The RF source output at fo (4.60 GHz) is split two ways. One provides reference channels for experiments, the other provides RF drive of the high power source. The drive channel is controlled with a PIN diode switch which shapes the pulse and provides fast turn-off capability in the event of a fault. The pulsed output is amplified with a TWT amplifier to the 25 watt level, passed through a low pass filter to remove all harmonic power , and is split four ways to provide klystron drive. Each klystron drive line is passed through a mechanical phase shifter and an electronic phase shifter, couplers and circulators, and delivers approximately 1 watt of drive to the klystron input. The local oscillator (L. O.) output (4.601 MHz) is one (1) MHz offset from the RF output and used as the L. O. input for the receivers. The L. O. output is amplified with a TWT to the 25 watt level, passed through a low pass filter and distributed to the receiver inputs. A 1 MHz phase reference is provided and distributed as a logic signal for use as a phase reference for the phase detector. All RF source outputs are coherent.

There are two RF sources. One produces only fo, fo + 1 MHz and 1 MHz; the other produces additional L. O. outputs for use by experiments related to the lower hybrid experiment. The three output source is shown in Figure 8. The outputs are produced in a coherent manner, deriving from a single source. The basic source is a tunable crystal control oscillator at 100 MHz. The oscillator output is divided by 100 to produce a 1 MHz output and multiplied by 45 to produce a 4.5 GHz signal. The 4.5 GHz is mixed with the 100 MHz output and filtered to produce the 4.6 GHz output. The 100 MHz is mixed with the 1 MHz signal, filtered and mixed with the 4.5 GHz signal, and filtered to produce the 4.601 GHz L. O. output. In this manner all output signals are phase coherent. Figure 9 is a block diagram of the seven output RF sources. The basic source is a 100 MHz crystal controlled oscillator. The oscillator output is multiplied, divided and mixed to produce coherent outputs at 4.601 GHz, 101 MHz, 100 MHz, 60 MHz, 10 MHz and 1.0 MHz.

The klystron amplifier takes the input and produces a pulsed 250 kW output. The high power microwave system which follows the klystron is given in Figure 10. The klystron output is first passed through an optical arc detector and reverse power coupler to provide protection for the output window and cavity. The high power output is then passed through a resistive low pass filter to remove and terminate all harmonic power. This provides a match for the klystron at the harmonic and reduces errors in the experimental measurements caused by harmonic power coupling into the receiver inputs. The filtered high power output is then passed through a four port circulator to provide a match to the klystron irrespective of the load VSWR. In this manner the klystron output sees a match over all frequencies and VSWR's. The output is then monitored using directional couplers for both forward and reverse power.

The high power RF is fed to the experimental interface through a DC block and flexible waveguide. In a four waveguide experiment each klystron feeds only a single antenna and is monitored with a set of forward and reverse couplers for input to the receiver. In the sixteen (16) waveguide array, each klystron feed the four (4) vertical waveguides. The power is split in matched in-phase hybrid couplers ("Magic T") and each waveguide is monitored with a set of forward and reverse couplers. Each coupler is provided with a DC block to isolate the receiver input from Alcator ground.

Power Supply/Modulator

The power supply/modulator system supplies all the power and cooling required by the klystron. The outputs of the power supply/modulator system for each module are listed below (the total system has four modules):

Cathode pulse (4)	0–55 kV, 15 amperes, one half second pulse
Heater supply (4)	0–15 volts, 15 amperes
Solenoid supply (4)	0–90 volts, 40 amperes
Ion pump supply (4)	3.6 kV, 10 milliamperes

Cooling

Air	Cathode (4)	
Water	Modulator (4)	88 GPM, 55 PSI
	Solenoid (4)	
	Collector (4)	44 GPM, 100 PSI
	Body (4)	
	Purity system (1)	1 GPM

The power supply/modulator system receives only two inputs: 13.8 kV, 60 Hz and a 5 volt gate pulse.

The power supply/modulator system is shown in Figures 11 and 12. The input (13.8 kV, 60 Hz) power bus is distributed to the four power supplies and a stepdown transformer. There are two distinct types of HVPS (Fig. 11), the so called Lincoln Lab power supply (LLPS) and the fixed output supplies. The LLPS provides a continously adjustable, reversible power supply through use of an AC regulator in its front end. The regulation loop on this power supply fixes the output voltage to a preset level by regulation of the angle to which the AC regulator shaft is set. This regulation method was chosen as opposed to regulation of the DC output (capability supplied) to avoid the overshoot and movement of the regulator which would be caused by the pulse loadings of the power supply against its (regulation) characteristic impedance. The remaining power supplies are low impedance unregulated power supplies with tap changers on the secondary to provide fixed, set capability over a reasonable range.

The output of the high voltage power supply is connected through an underground cable to the modulator input. The modulator input (Fig. 12) connects to a 50 microfarad capacitor bank (which provides energy storage and transient suppression), crowbar, and fast interrupt (vacuum interrupt, Fig. 11) is provided to prevent component damage in the event of an arc. The crowbar is activated in the event of capacitor bank arc, or failure of the modulator to turn off in the event of a tube arc or overdissipation of the modulator tube.

The modulator output is regulated to a preset voltage with a maximum error of 200 volts. The voltage is set by setting the reference of the modulator regulation loop. The modulator functions as both a switch and a regulator. The output pulse width is set by the single gate input from the module control and in amplitude by the feedback loop reference. The output voltage and current are monitored to drive viewing and fault signals.

The cathode pulse output is supplied to the klystron through a high voltage cable. In the event of an arc this cable would ring producing destructive voltage transients. To prevent this damaging transient, cable terminations are provided at both ends of the cable in the form of 50 ohm resistors. To reduce the resistive losses an air wound choke is placed parallel to the modulator end termination. Spark gaps are also placed in the system to prevent overvoltage transients.

The heater supply floats at cathode potential and provides power to the filament and surge protection. Voltage and current monitoring as well as adjustment are provided in a control panel at ground potential.

The solenoid power supply is a current regulated unit, which provides the power for the tube solenoid. The current and voltage are interlocked to prevent the tube beam from being energized without the proper magnetic field.

The ion pump power supply provides voltage for the ion pump and provides monitoring of the tube vacuum. The power supply is interlocked to prevent tube operation in the event of poor vacuum in the tube.

The system is cooled both with air and with water. Each location which requires air cooling is provided with a fan and an air flow interlock. The heater power, for example, is removed in the event of the loss of tube cathode cooling air. The water system provides high purity water at the required flow rates throughout the system. Two separate flow paths are provided: one for the modulators and the other for the klystron and its associated loads. Each branch in the cooling system is interlocked to prevent overdissipation of any system component in the event of loss of cooling water.

Power supply/modulator status, faults, and control are provided at two separate external locations and at the modulator unit. The remote control panel is located in the Alcator control room and provides the minimum control required for operation, i.e., on, off, high voltage control, state monitoring, and high voltage monitoring. The local control panel is located in the experimental cell near the klystrons and provides a complete set of control and monitor functions. The internal control panel provided only enough control and monitor functions for convenient trouble shooting of the modulators.

The total power supply/modulator system provides a complete set of controls and monitoring functions to supply the klystron amplifiers with stable power. The power supply stability requirements were set to fix the phase stability at a level low enough such that no phase compensation loops were required to meet the experimental phase stability requirements. This stability has been more than met without the additional complication of phase correcting loops although the ability to add them later is built into the system.

Data Collection System

The data collection system is shown in Figure 13. The input signals come from a variety of inputs: Alcator, power supply/modulator, and the RF samples. It is the intention that the data collection system gather, display, and archive that data necessary for analysis of the experimental results at a later date. The implementation of this system will be shown later, involves the extensive use of CAMAC equipment and computer capability. The data system was sized to accommodate 256 data channels based on the measurement of forward and reflected phase and amplitude at each window, and some monitoring of the machine parameters and equipment operating parameters. This allows for the full instrumentation of the first three grills and a reduced capability of the fourth. This reduction in capability seemed reasonable since the last grill results should be predictable and diagnostic measurements could be combined to reduce the number of data channels required. However, the system could be expanded to handle more data channels by purchasing more CAMAC equipment.

In general all input samples are normalized to a 0–10 volt range and A/D converted for input to the computer with the computer controlling display and archive functions. The A/D converters and data transport are CAMAC devices with a PDP 11/34 as the controller. The use of this configuration was chosen because of the availability of hardware and software. Additional effort was required to develop specialized hardware to provide the receiver and to prevent data skew as well as the development of software to control the system.

Receiver

The receiver is designed to provide phase and amplitude measurements of the forward and reflected wave in the waveguides. Each waveguide is provided with a pair of couplers; one measuring the forward wave and the other the reverse wave. The couplers provide high directivity to reduce errors due to any cross coupling components. Figure 14 gives the general receiver configuration. The input from a coupler is split to provide an amplitude channel and a phase channel. The amplitude channel is detected with a zero bias barrier diode and amplified. The phase channel is mixed with the L. O. frequency to produce a 1 MHz IF signal. This IF signal is amplified and compared to a 1 MHz reference signal to produce a DC output signal which is directly proportional to phase module 2π.

The phase detector is shown in Figure 15. The 4.600 GHz input is brought in and mixed with a 4.601 GHz signal to produce a 1 MHz IF signal. The IF signal is then amplified in a phase compensated, nonlinear amplifier. The nonlinear amplifier provides high gain at low input levels and a decreasing gain at higher input levels. The output of nonlinear amplifiers is threshold detected at the zero crossings to provide a sharp rising trigger for the logic which follows. The error in this circuit is due to the rate of rise of the thresholded wave form. Therefore, the nonlinear amplifier characteristic was chosen to increase the gain (or rate of rise) with signal levels near zero and reduce the gain (clip) the wave form as the signal level increased. The logic which follows the amplification acts as a set-reset flip-flop. The output is integrated using a constant current source followed by a low pass filter. The wave form shown in Figure 15 is the operation of this curcuit. The input of the IF signal is compared to the 1 MHz reference signal to produce a duty cycle. The integration of this duty cycle (average) is then proportional to the difference phase. In the absence of an input signal the circuit produces a 50% duty cycle or 5 volts. Phase trim adjustments are provided in the 1 MHz reference line to a flow for calibration of the phase detector. Differential errors between phase measurement channels are 4° peak in the worst case.

The output of the receiver channels are converted to a digital signal and stored in a local mass memory. Figure 16 shows the A/D configuration. In the conventional CAMAC configuration each A/D unit is independently addressed creating a time skew between units equivalent to a command word cycle time. To avoid this time skew problem, a programmable clock is used and all samples are taken at the same time, driven by the clock pulse. In this configuration all A/D modules are armed prior to the experiment and the clock rate is set. The output of the clock is gated on during the experiment and data taken. At the end of the experiment the clock is gated off and an end of data signal is generated which resets the A/D module. The time synchronous data is then transferred from the memory over the data bus to the computer for display and archive.

Data System

The complete data system, with the computer hardware, is shown in Figure 17. The CAMAC crates are connected to the PDP 11/34 UNIBUS by a fiber optic data bus through a Jorway 411 highway driver. The UNIBUS then interconnects the computer hardware and peripherals. The PDP 11/34 has the maximum available memory (256 K bytes), two disks, a tape transport, floating point processor, and interface for a system console, teletype, display, and telephone modem. The computer capability provides the ability to collect, archive, and reduce data in a near stand alone manner. The limited memory of the computer is adequate for the experimental data and support software storage, but not for large scale computation. Since the major task of this computer is data acquisition, the priority levels of the RSX-11M operating systems are set to give the highest priority to the data acquisition task during and following an experiment and the priority is reset to user tasks after the data is archived. In this manner maximum use is made of the computer.

Software

The software presents a highly interactive data acquisition system designed to control hardware conforming to the IEEE standard modules instumentation and Digital Interface System (CAMAC). The system is capable of displaying data on graphic terminals. The data from the CAMAC equipment can be archived on disk and magnetic tape for later retrieval. The host computer is a PDP 11/34 with 256 K bytes of memory running on the RSX-11M operating system.

The support software to create the operating modes and provide the necessary functions are implemented under RSX-11M, a real time multi-tasking operating system. This means that the system is capable of processing data and manipulating devices in a real time environment. The operating system is "interrupt driven" which means that as a driver needs service or if the internal clock "ticks" the operating system is called to service the interrupt.

Figure 18 shows a functional diagram of the system software. The rectangular blocks represent software from available sources or modifications of available sources. The trapezoidal blocks represent programs or modules developed. In order to support the CAMAC family of devices, I/O support needed to be generated to allow access to these devices through RSX-11M.

An I/O operation under RSX-11M begins with the issue of a $QIO system call. The $QIO call is a directive to the RSX-11 operating system from a user program requesting some form of I/O service. An intital $QIO is issued to connect a particular device (allocate) to the calling task, another $QIO is issued for each READ or WRITE operation and finally a $QIO issued to deallocate the device. For file structured devices (such as disk and magtape) the $QIO directive goes directly to Executive Dispatcher. This is the part of RSX that actually controls the running of an available task. This section also decides which task is to stop or relinquish control to another task. The dispatcher also receives all system directives for the currently running task and routes them to the appropriate module of the RSX executive. In the case of QIO, this is handled by the QIO Executive Service Routine. This routine uses the QIO request packet (pushed on the tasks' stack) and forms additional data structures which it then passes on to the appropriate executive I/O subroutines. These routines actually call the selected I/O driver which performs the I/O operation by setting the appropriate information in the proper registers on the UNIBUS. The I/O driver is also responsible for handling interrupts from the device that it is driving. These interrupts are processed and, if significant, calls routines from the I/O subroutine area.

These routines do further processing and determine whether any task needs to be aware of the interrupt. If this is so, then the information is passed to the dispatcher which will use it to either wake up a sleeping task or to pend a task that is currently running. AST service (Fig. 18) is an optional service that can be envoked to aid in providing additonal information to a waiting task.

Some devices (such as disk, magtape) require more control of user options that can be conveniently handled by the fast executing I/O driver. These devices require substantial preprocessing above the interrupt level of operation. The ACP (Ancillary Control Process) is a way of providing for these additional needs. The ACP for a particular device acts as an additional interface between a user program and the operating system. The user communicates to the device through an ACP which takes the user command and generates additional commands to the I/O system to realize the wishes of the user.

Software Overview (CAMAC)

CAMAC I/O Driver

The purpose of the CAMAC I/O Driver is to provide fast response from RSX-11M to CAMAC interrupt request and to allow the user to easily specify any type of control or data function that they may require. The I/O driver is capable of transferring large amounts of CAMAC data quickly with little or no overhead yet also allows the user to perform all of the control functions that he may ever need to use. The driver is capable of supporting up to 256 data channels spanning a maximum of eight (8) crates per highway.

The driver is designed to the specifications and requirements of RSX-11M version 3.2 and configured to run optimally on a PDP 11/34 processor. Only the basic control features of CAMAC operation are handled in the Driver code. Operations requiring more sophistication are handled in the CAMAC Ancillary Control Process (ACP).

CAMAC ACP

The purpose of the CAMAC ACP process is to allow the user to perform more sophisticated commands to the CAMAC system. The ACP is responsible for formulating the data, constructing disk files and routine data from specified channels to allocated regions of memory. The ACP, since it runs as part of the executive, is also designed with speed of execution in mind.

QIO

The QIO is the only way that the user can communicate with the CAMAC system. Therefore, enough locations are available to contain all of the pertinent function codes and data. The QIO is 12 words in length, 6 of these words may be used to contain specific CAMAC information.

CAMAC Support Routines

The purpose of the CAMAC support routines is to make the user interface easier to use for a person programming on a high level language such as FORTRAN. The CAMAC support routines reside in a library object file. A user who wishes to use the set of routines will simply code them into his source program using the standard calling sequence. Routines are also provided to enable the user to easily retrieve data that has been placed on the disk or even support routines to restore desired data from a mounted magtape.

CO_2 Laser Scattering Detector System

The 4.6 GHz heterodyne receiver system to be used to investigate the interaction of driven lower hybrid waves driving the Alcator C lower hybrid heating experiment was fabricated by the AIL Division of the Eaton Corporation. The receiver consists of a Ge: Cu liquid helium cooled photomixer and matching network to permit efficient detection of scattered CO_2 laser radiation over a measured intermediate frequency bandwidth (3 dB points) of 4.5 GHz ± 300 MHz at a Noise Equivalent Power (NEP) of less than 8×10^{-19}W/Hz. Also included in this system are the necessary battery power supplies, radio frequency precomplifier, radio frequency local oscillator, mixer, and final intermediate frequency amplifier to convert a 4.6 GHz ± 200 MHz detector signal to a 0.2 - 400 MHz electrical signal to be transmitted by an optical link to the experiment equipment rack.

The Ge: Cu receiver system has passed its acceptance tests and will be installed in the next few weeks. The CO_2 laser scattering experiment (including the 150 W continuous CO_2 laser) is already in operation on the Alcator C machine.

Conclusion

The lower hybrid heating, experimental hardware has been designed and, with the exception of the grill assemblies, is in place at MIT. Of the four (4) modules, one is fully operational into a four waveguide grill. The second is in place with the majority of interconnections complete, and the remaining two are installed with no interconnections. The remaining assembly interconnections and checkout will be alone with in-house personnel over an extended period while the first one megawatt experiment proceeds. Initially, data will be collected using the four waveguide grill over the next six months while the first 16 waveguide grill is completed with higher power (1 MW) experiments to follow.

Acknowledgements

We wish to acknowledge the many important contributions made by various members of the Alcator C RF Heating Group during the completion of this project. Particularly important contributions were made by S. Barilovits, M. Carracino, J. Meyer, R. Parker, K. Rice, D. Reiser, J. Schuss, and G. White.

This project was supported by the U. S. Department of Energy.

Figures

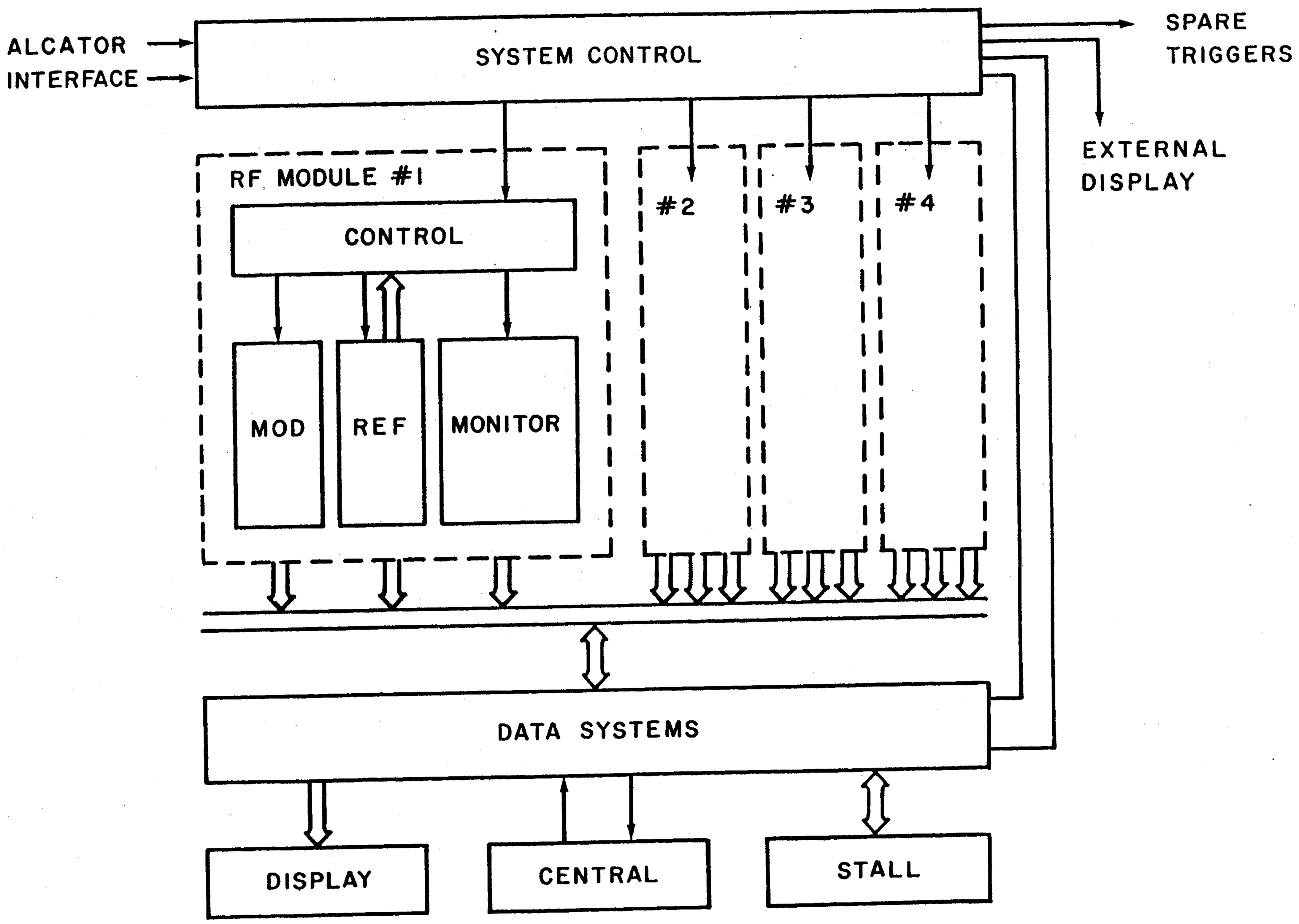


FIG I– SYSTEM CONFIGURATION

PFC-6043

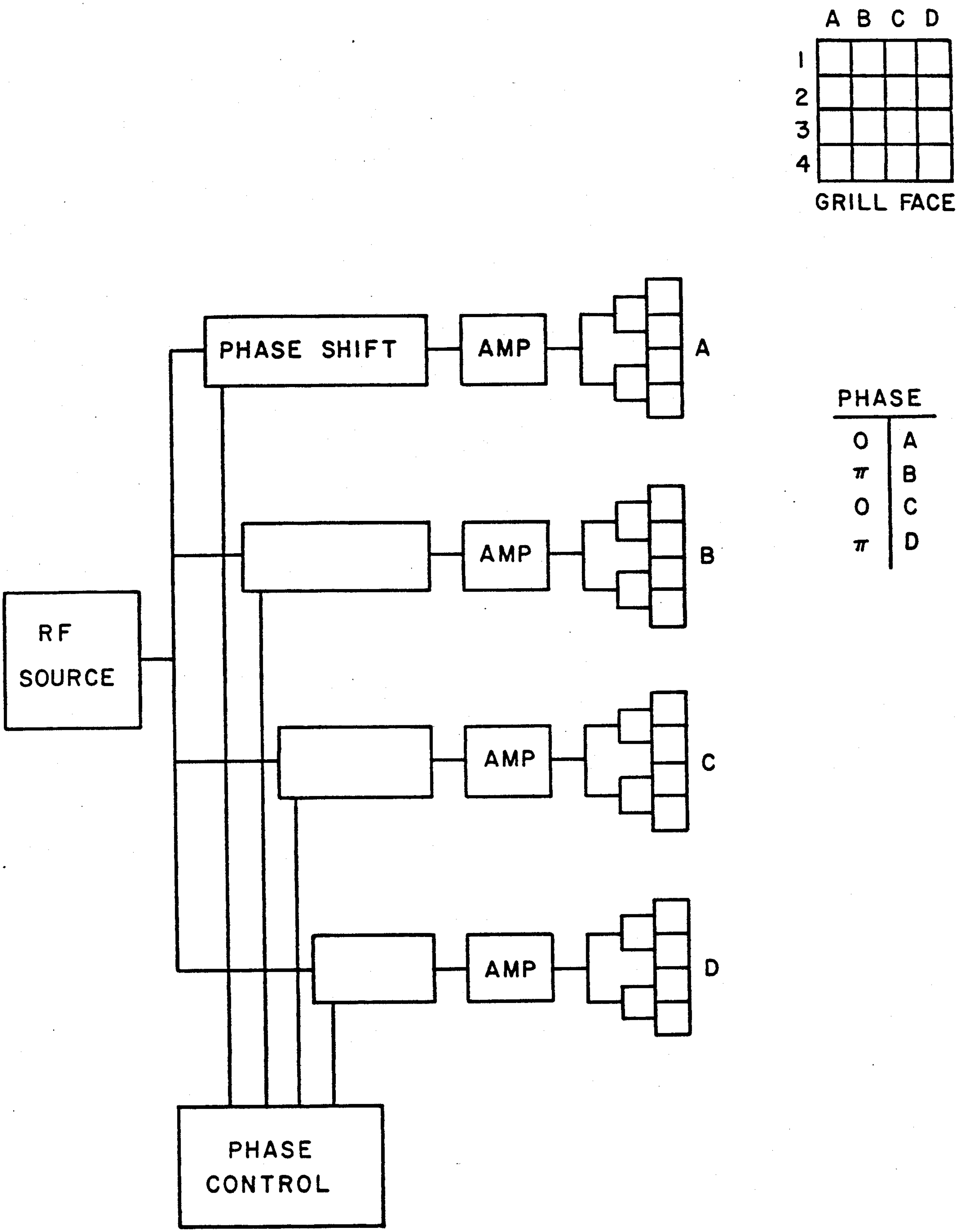

A B C D
1
2
3
4
GRILL FACE
PHASE
0 A
π B
0 C
π D
RF SOURCE
PHASE SHIFT
AMP
AMP
AMP
AMP
A
B
C
D
PHASE CONTROL

FIG 2 - RF FEED

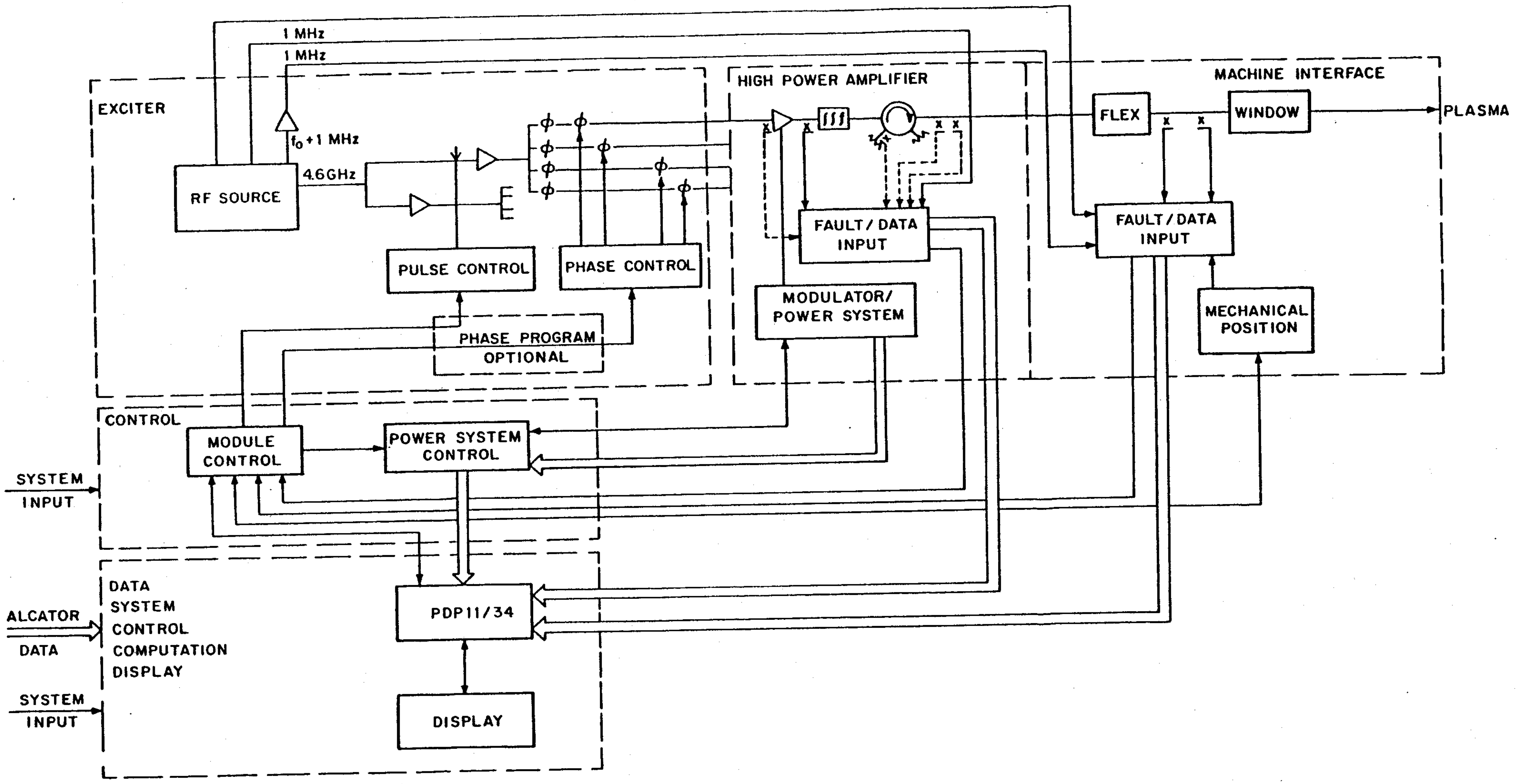


FIG 3 – SYSTEM BLOCK DIAGRAM

PFC–6045

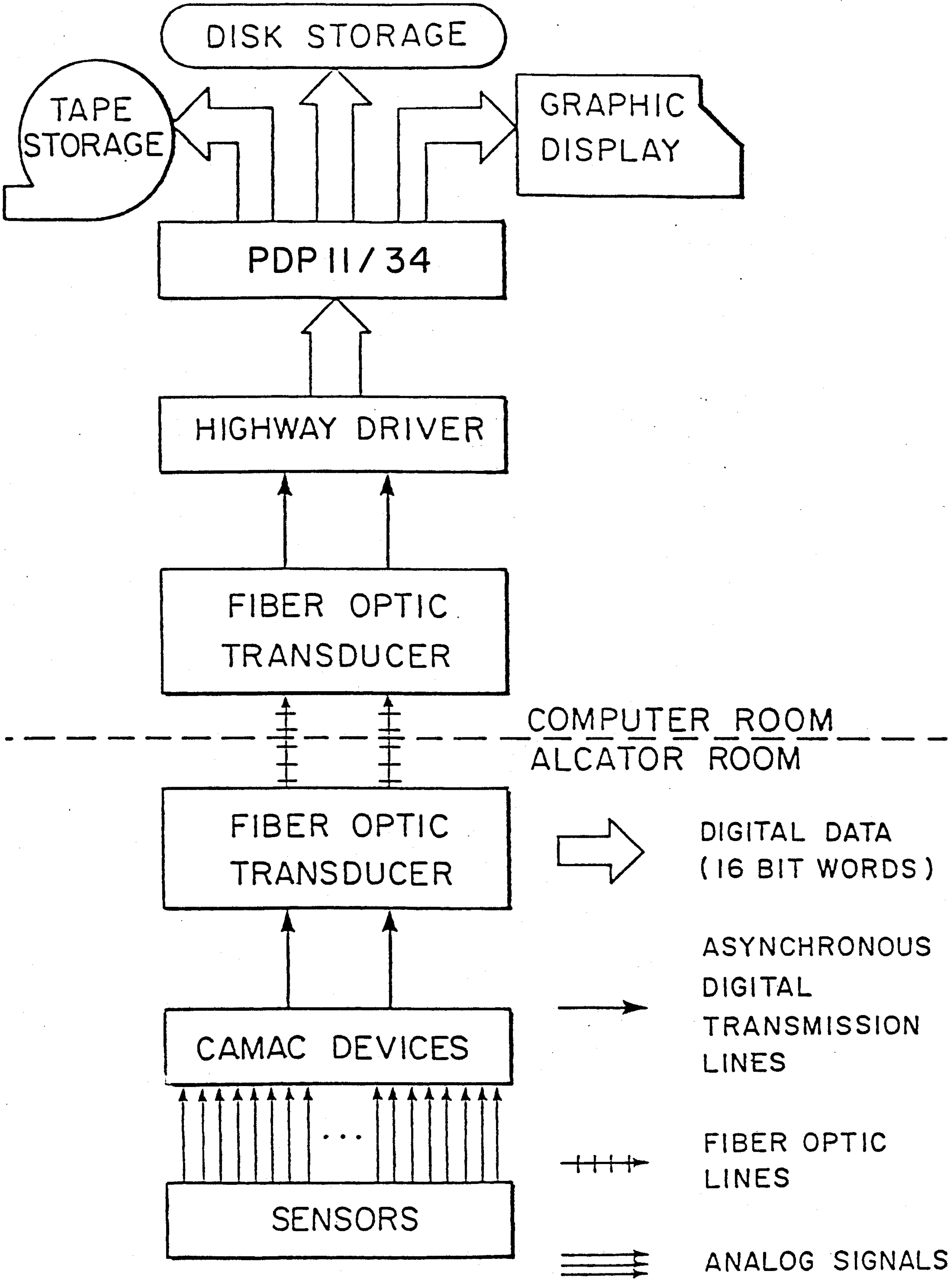


FIG 4 — DATA FLOW

PFC-6046

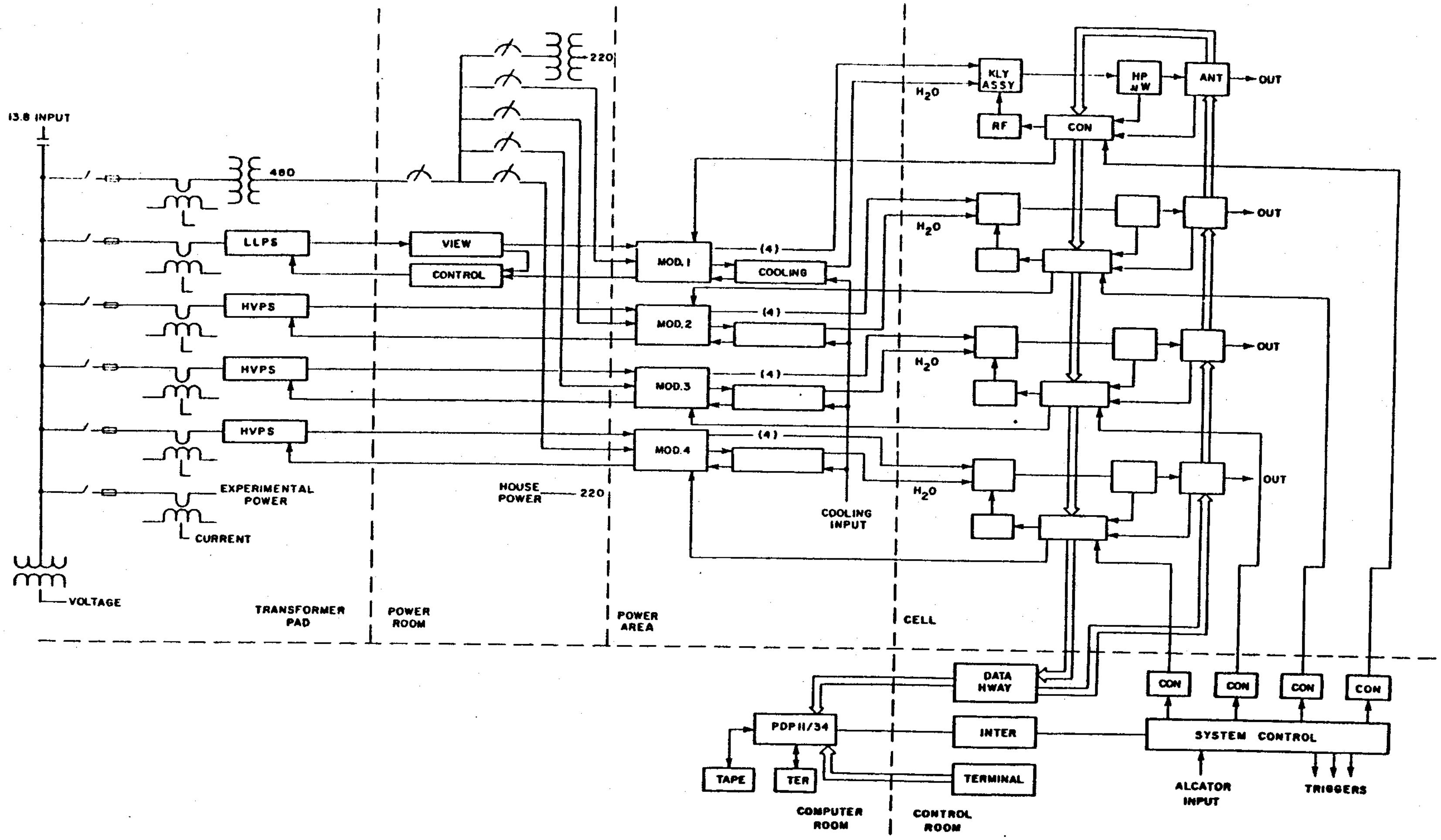


FIG 5 - HARDWARE CONFIGURATION

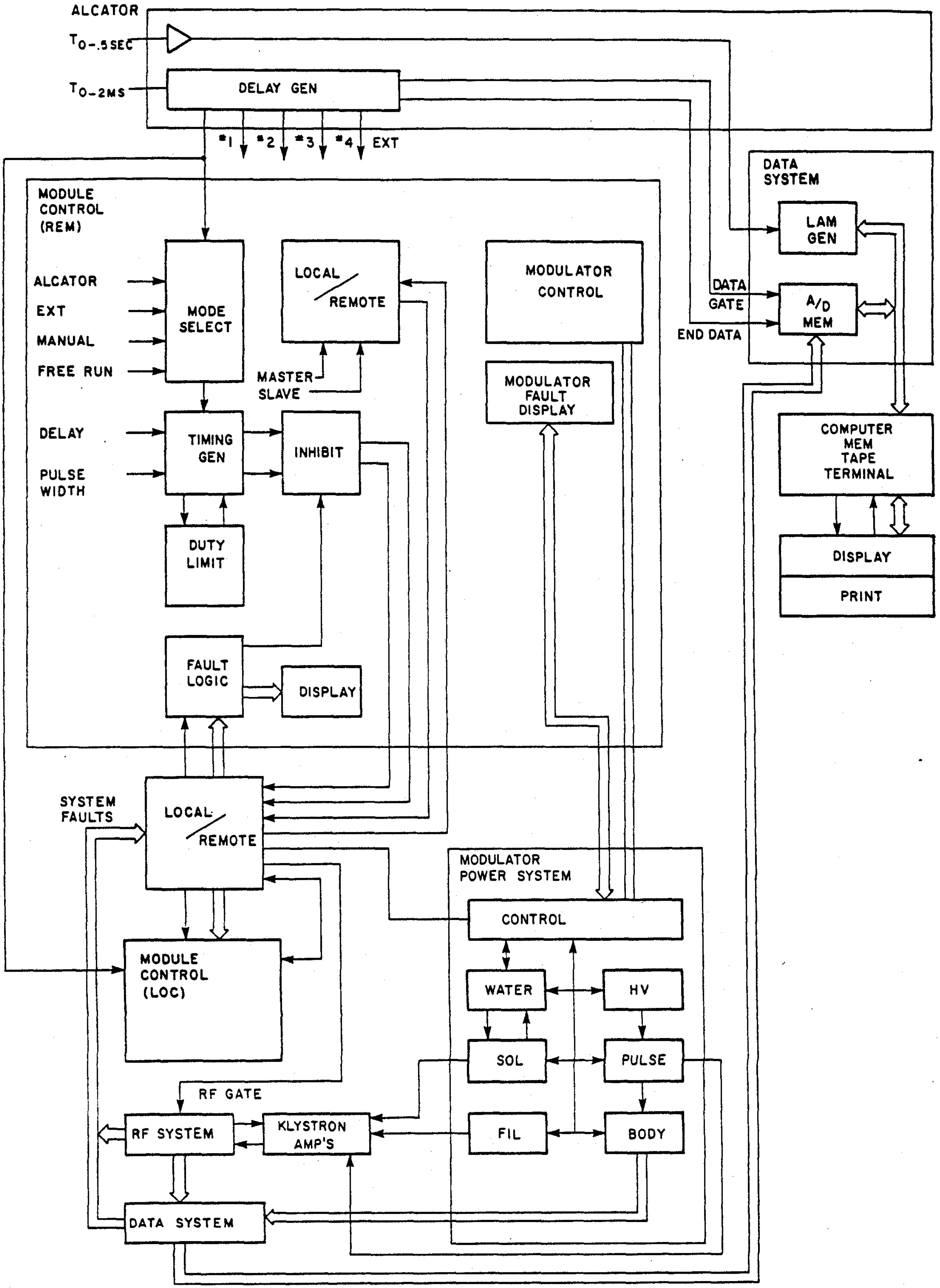


FIG 6-CONTROL SYSTEM

AFC-6048

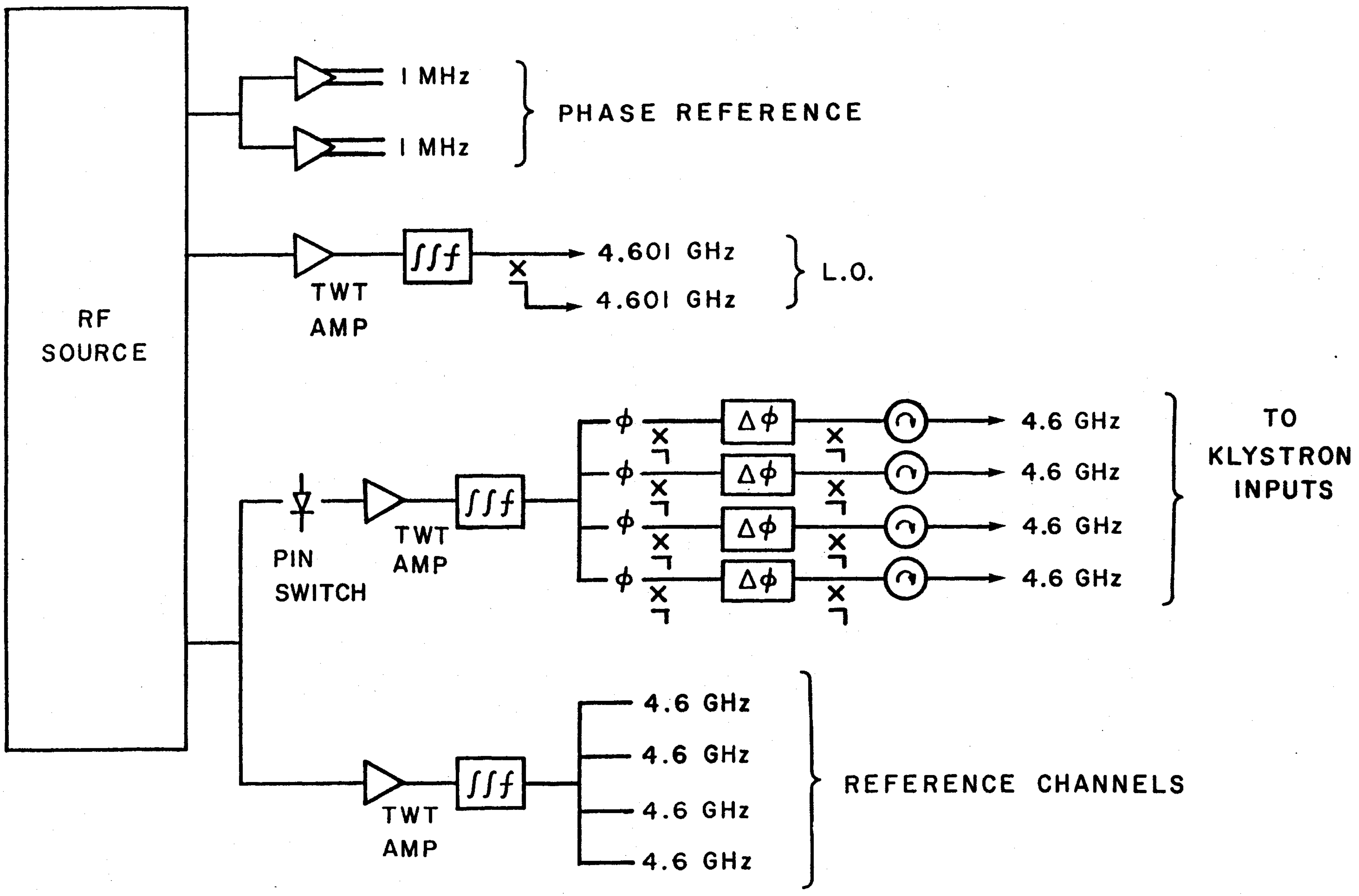


FIG 7 – LOW LEVEL MICROWAVE

PFC-6049

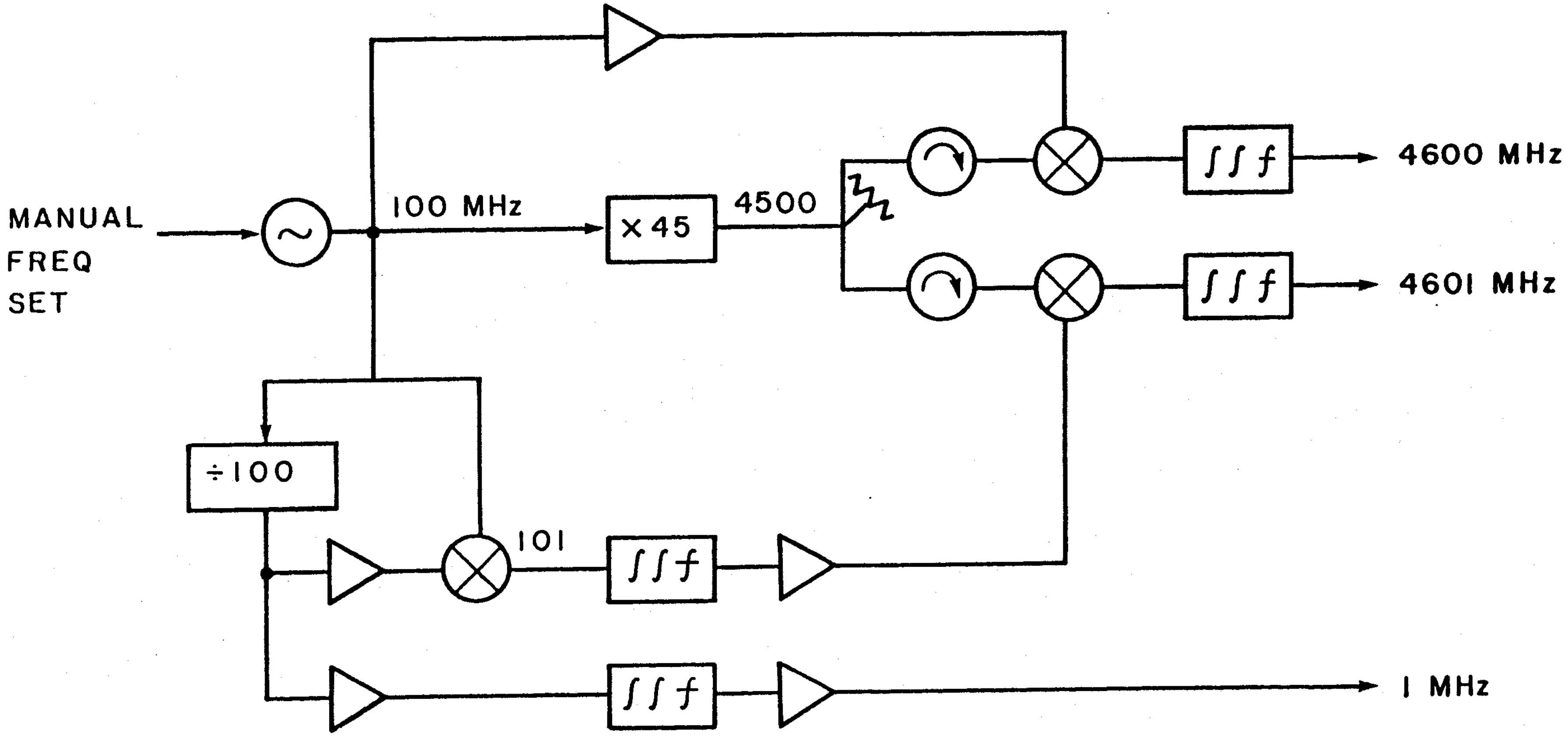


FIG 8 – RF SOURCE-3 OUTPUT

PFC-6050

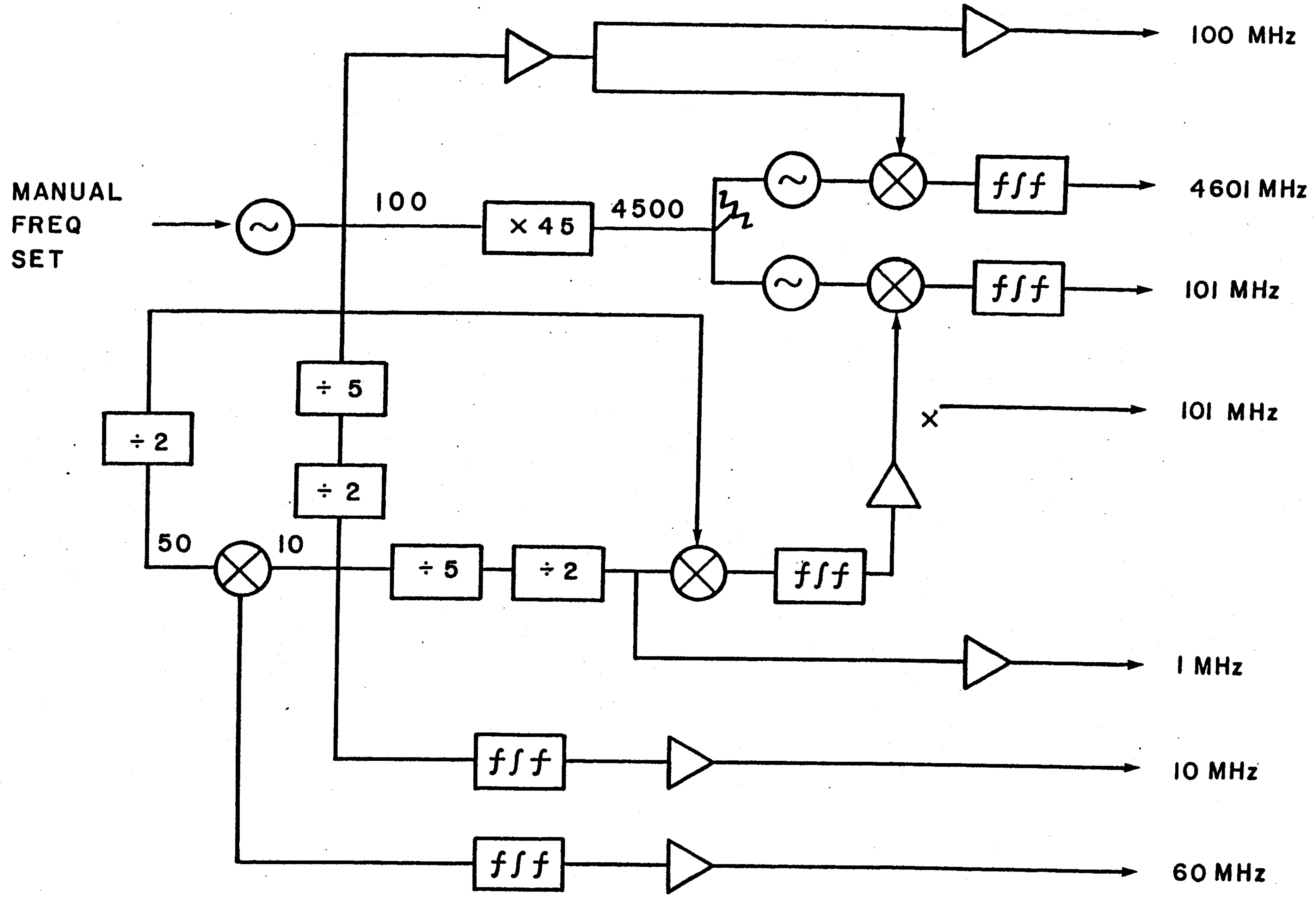
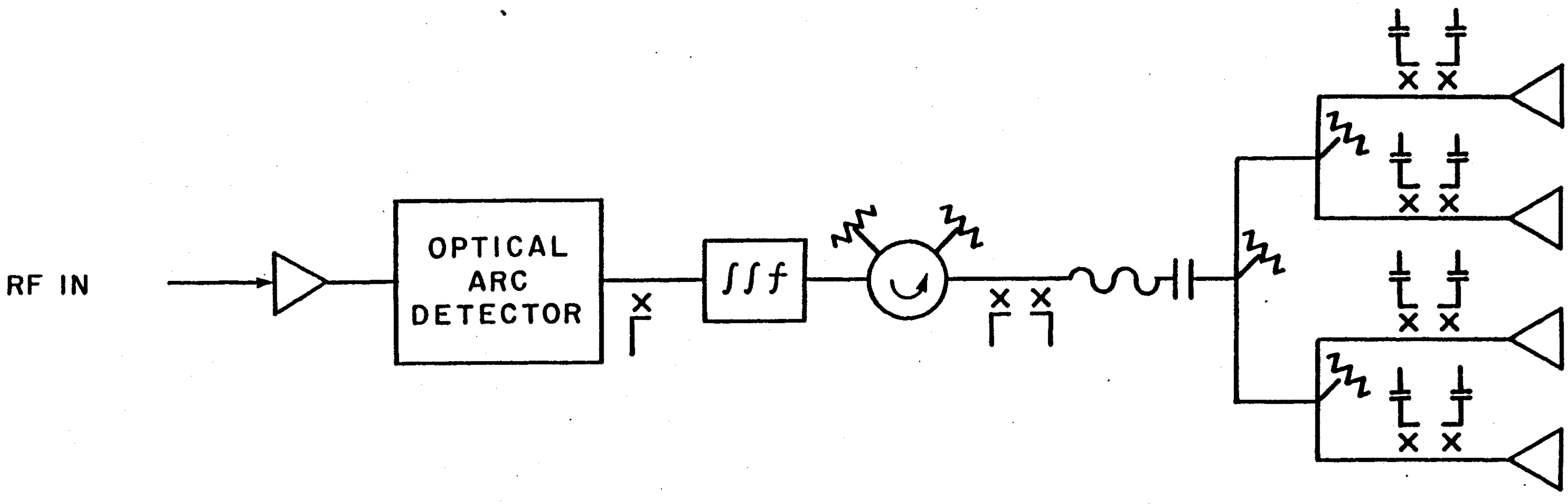
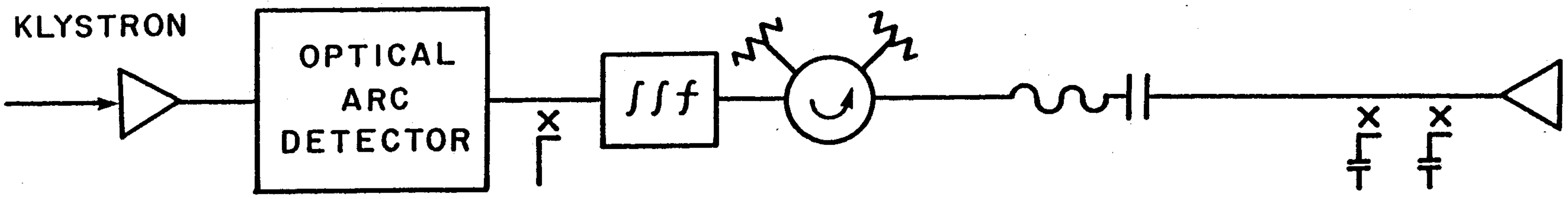


FIG 9–RF SOURCE - 7 OUTPUT

PFC-6051



SINGLE KLYSTRON OUTPUT – 16 WAVEGUIDE GRILL



SINGLE KLYSTRON OUTPUT – 4 WAVEGUIDE GRILL

FIG 10 – HIGH POWER MICROWAVE

PFC-6051

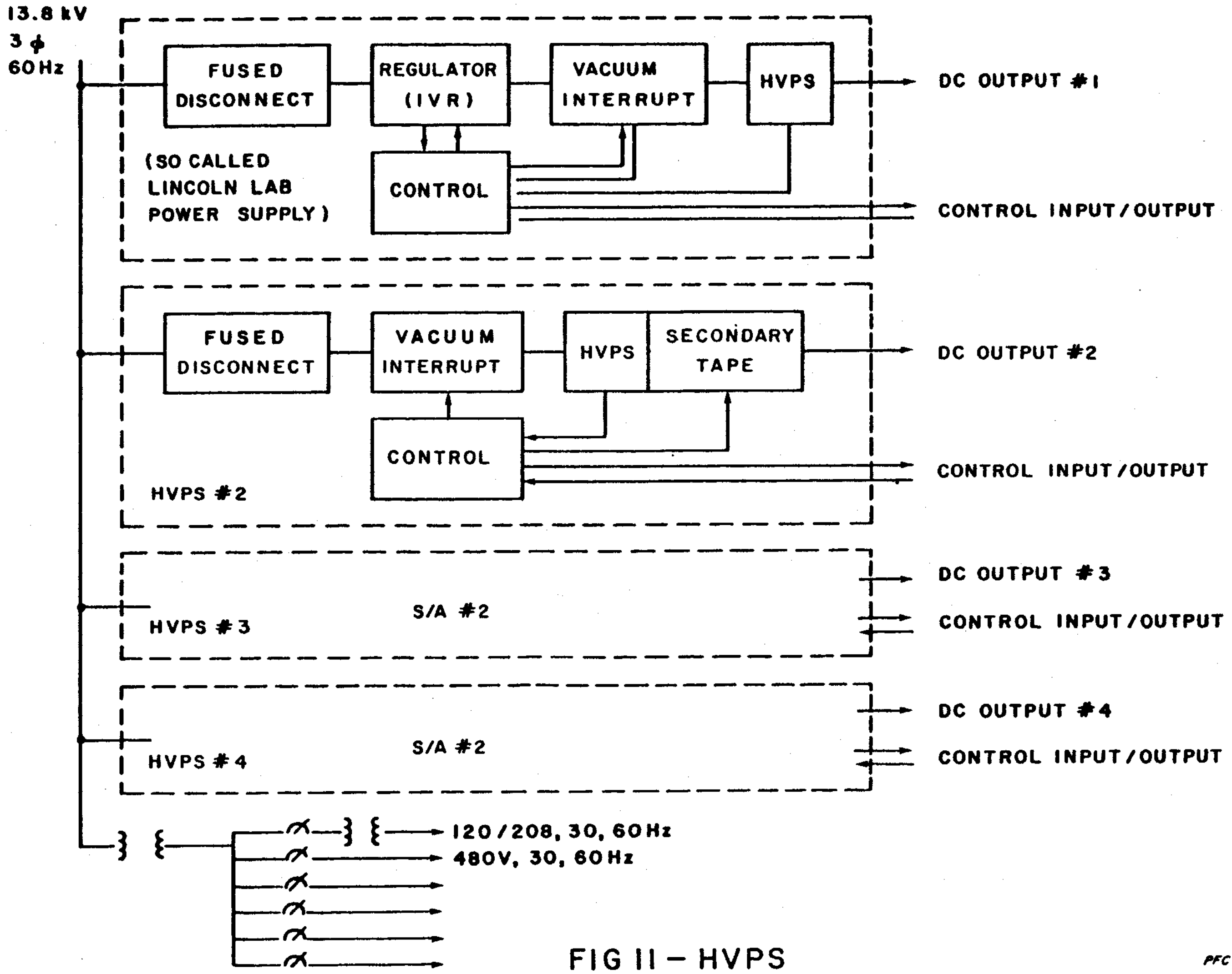


FIG 11 – HVPS

PFC-6053

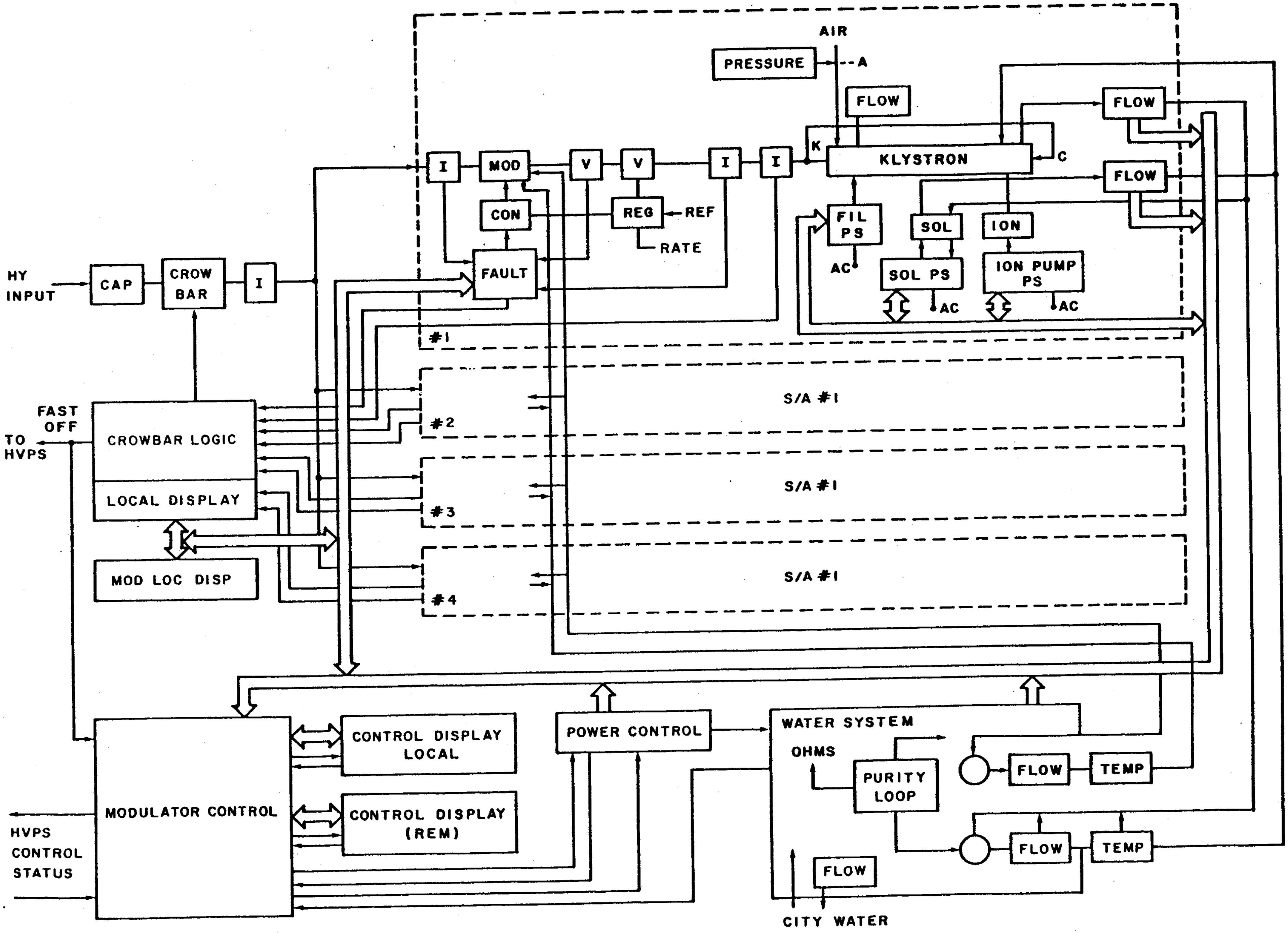


FIG 12 — MODULATOR/AUX POWER

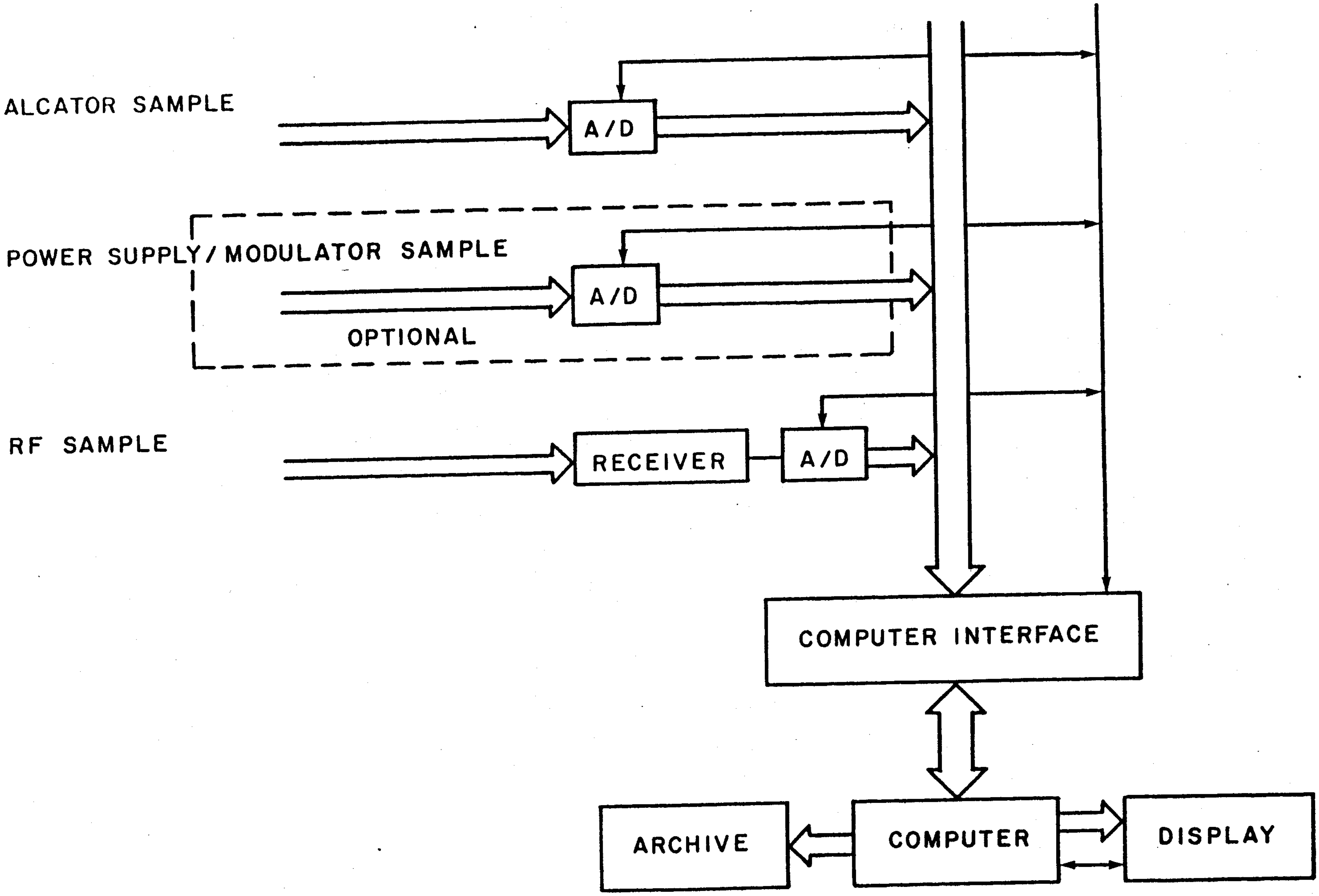


FIG 13 — DATA COLLECTION SYSTEM

PFC-6055

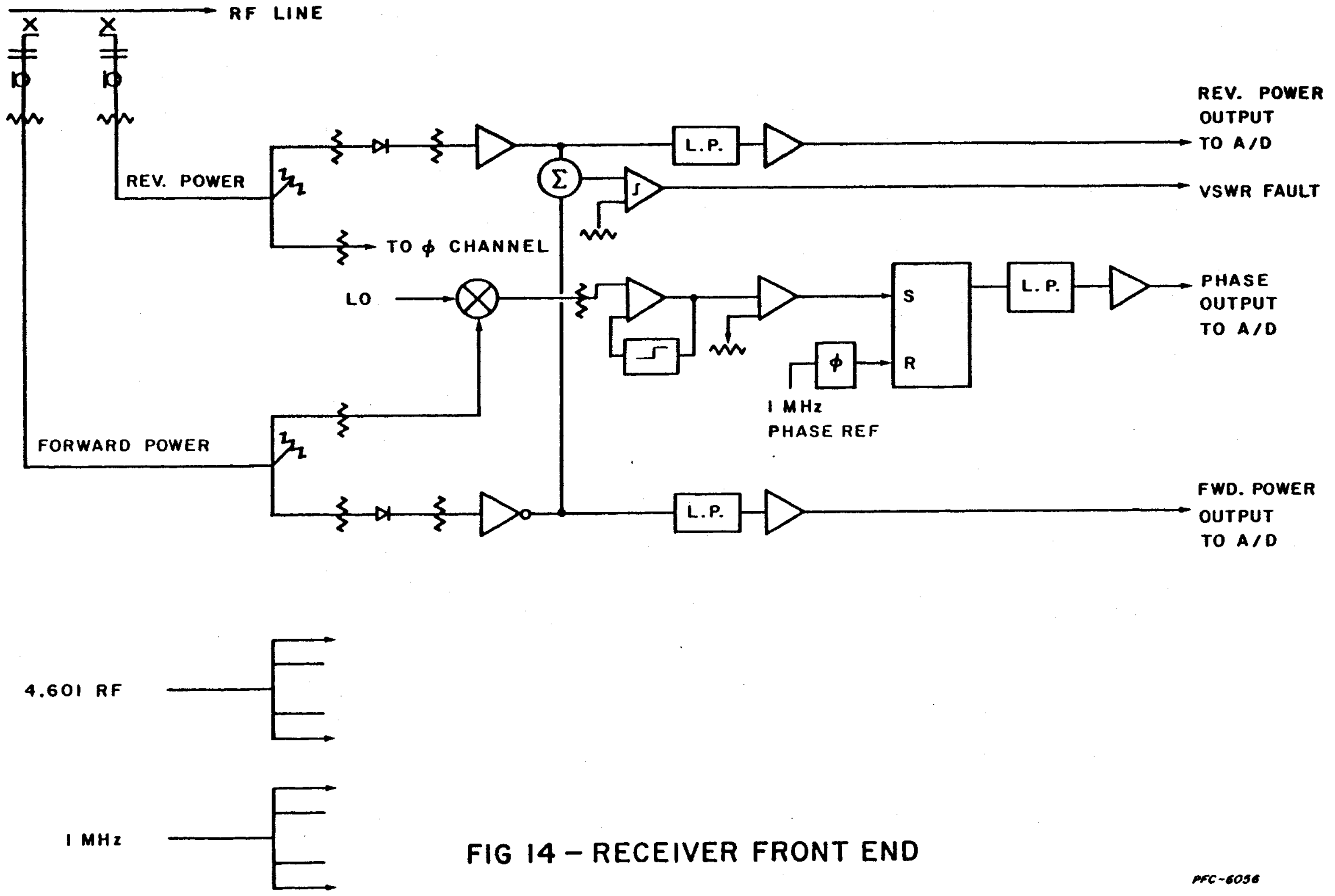


FIG 14 – RECEIVER FRONT END

PFC-6056

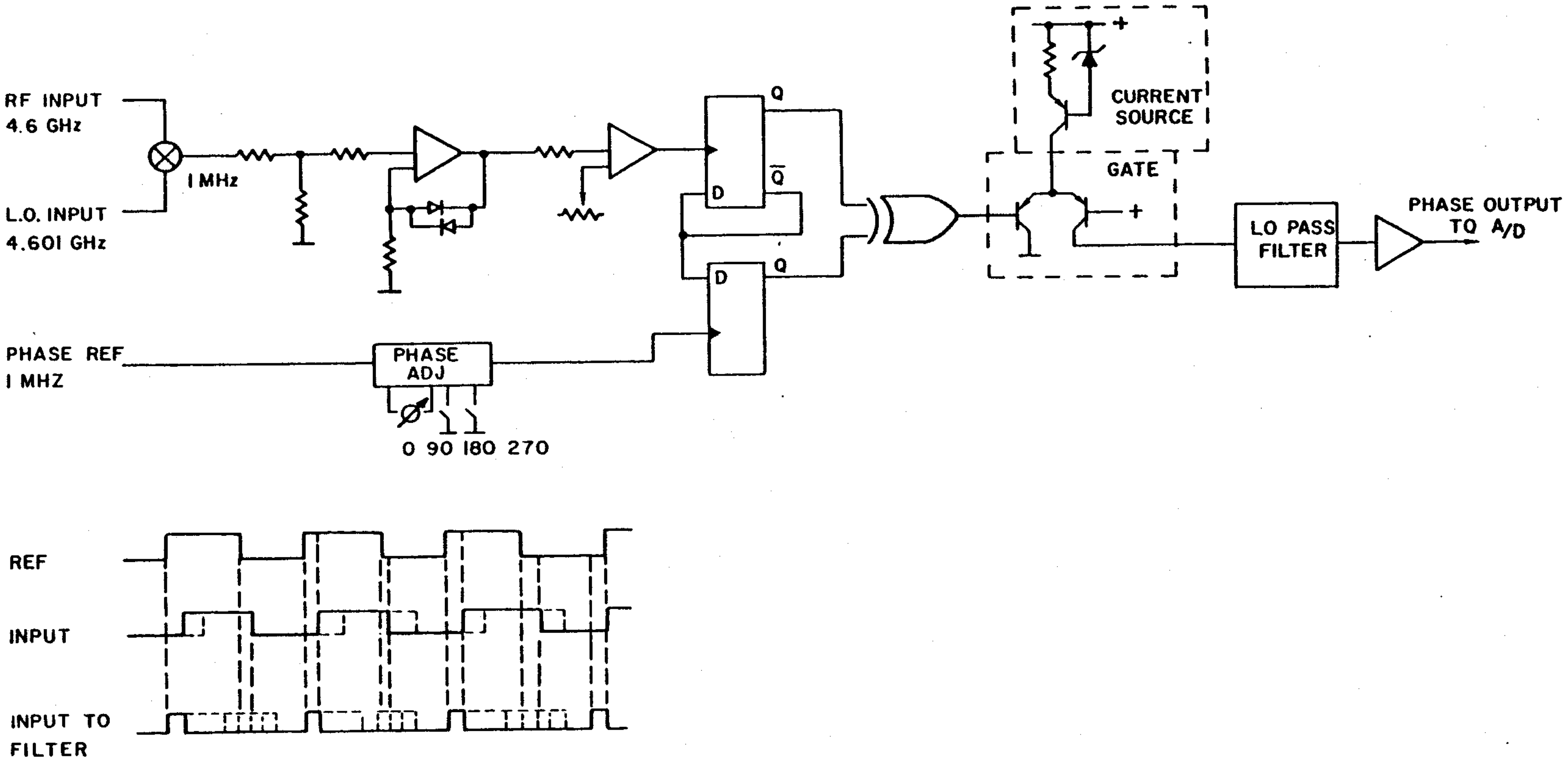


FIG 15 - PHASE DETECTOR

PFC-6057

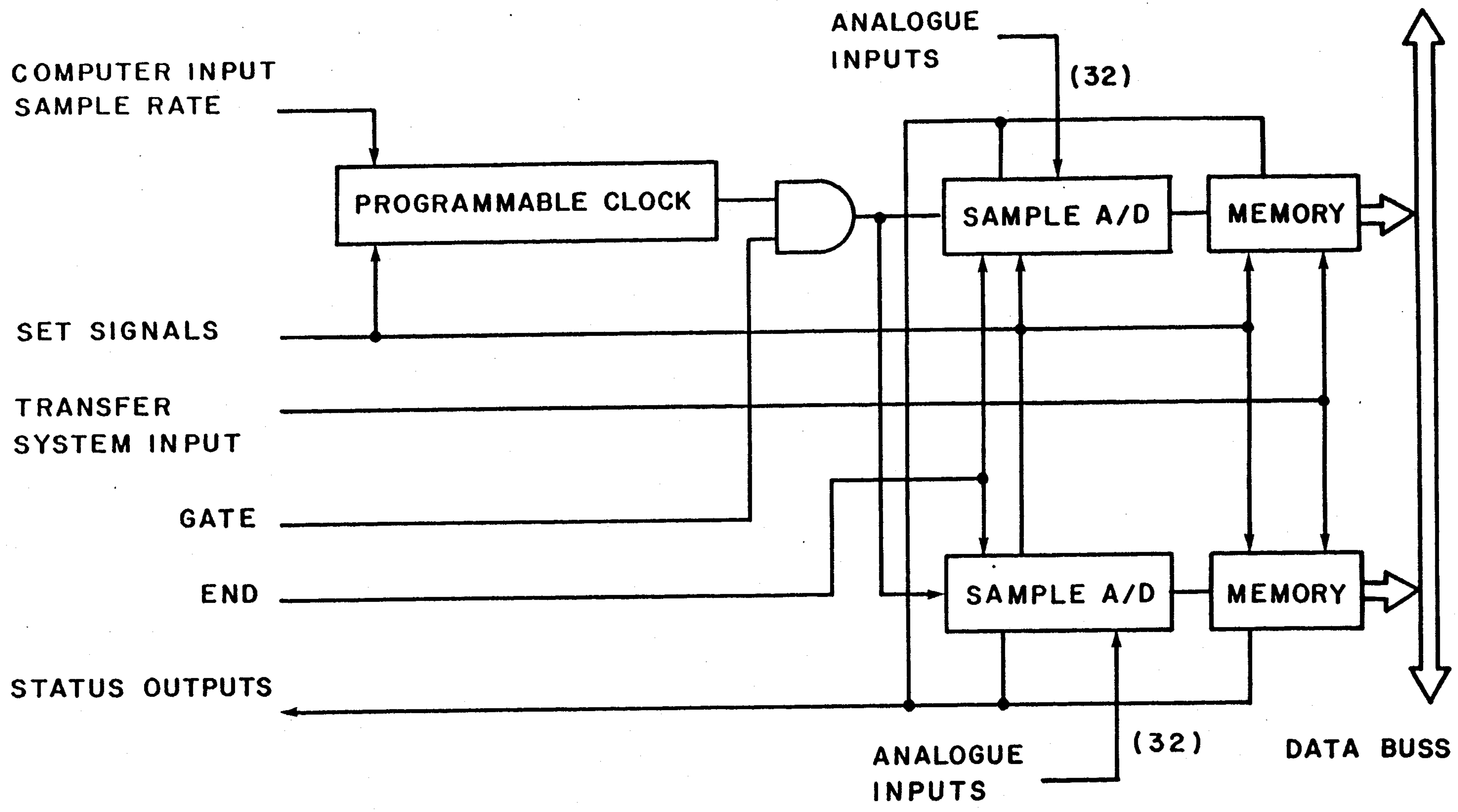


FIG 16 – RECEIVER DATA OUTPUT

PFC-6058

LOWER HYBRID HEATING EXPERIMENT DATA ACQUISITION SYSTEM

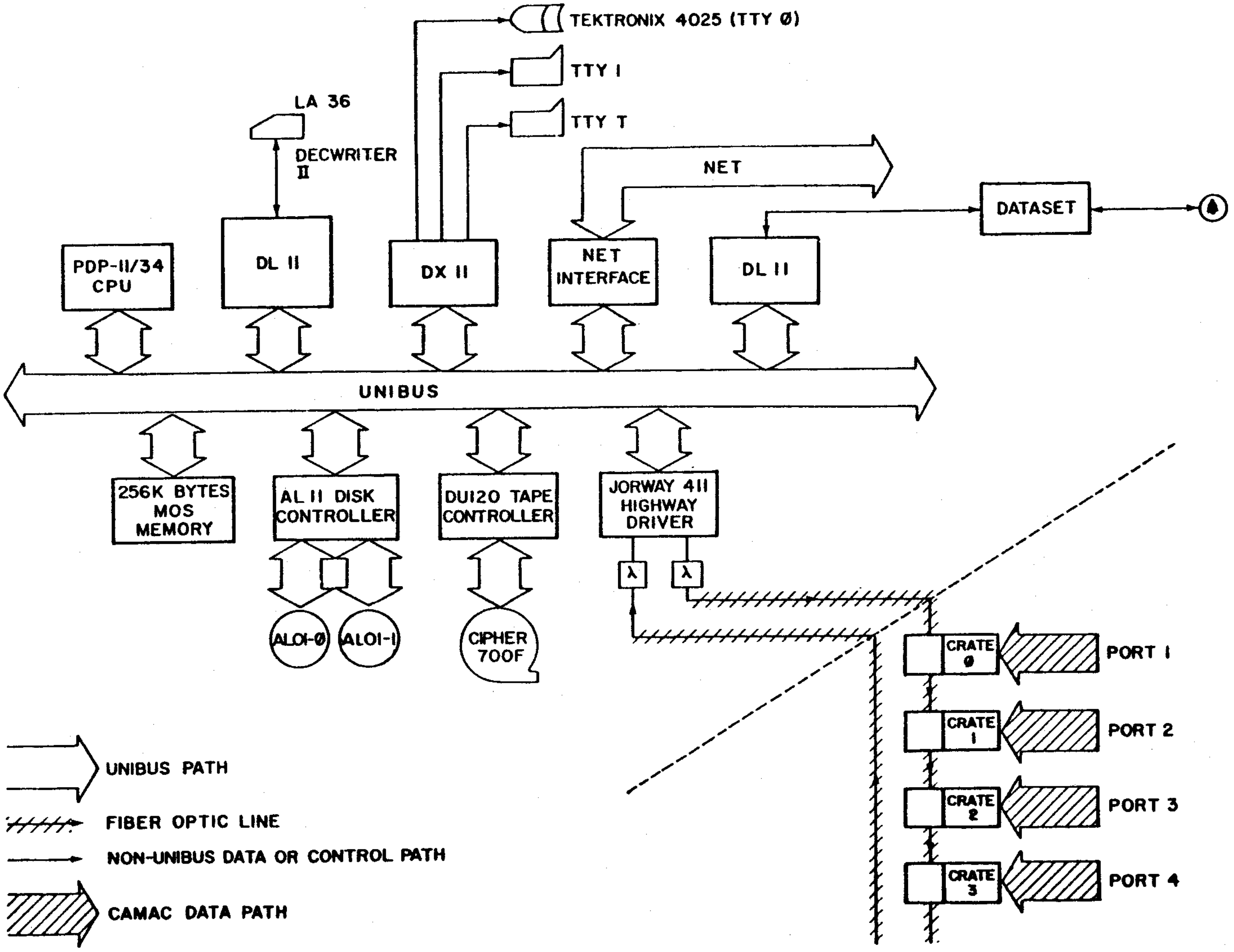


FIG 17 – DATA SYSTEM HARDWARE

PFC-6059

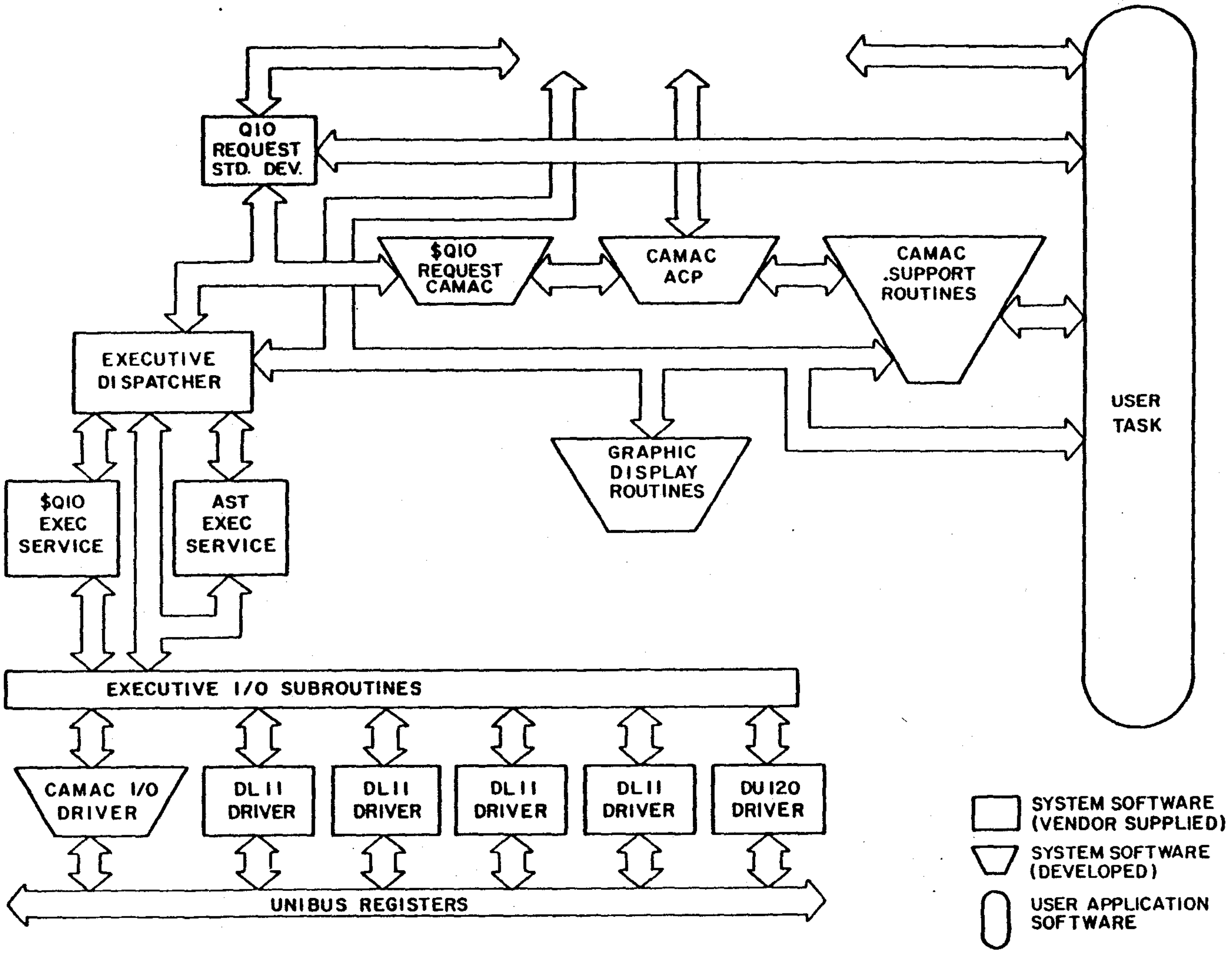


FIG 18 - SYSTEMS SOFTWARE

VKC-7849

Klystron Specification

(Peak Power, 250 kW)

(Frequency, 4.6 GHz)

SPECIFICATION

(April, 1979)

Description: VKC-7849 Klystron Amplifier, pulsed, 4.6 GHz, 10 MHz bandwidth, solenoid focused, liquid cooled, 250 kW nominal peak output.

Intended Use: The Klystron amplifiers are intended to be used in groups of four, operating at the same frequency with the outputs of all the amplifiers summed into a common element. To this end all tubes purchased under this specification must be of similar characteristics as well as within the allowable tolerances.

Physical Characteristics:

Dimensions: Tube Outline: per Varian outline drawing D139348.

Solenoid Outline: per Varian outline drawing D139090.

Mounting Position: Beam axis vertical, cathode down recommended.

Support: Mounting flange with 19-1/8 bolt circle to mate with solenoid VYW-7849.

Cooling: Air: Gun: 50 CFM free (Note 7)

Water: Body: 2 GPM or 100 PSI @ 37°C (max)

Collector: 20 GPM or 50 PSI @ 37°C (max)

Solenoid: 2 GPM or 100 PSI @ 37°C (max)

DC Connection: (Note 38) Flying leads - length per outline drawing

Coupling: Input: SMA plug coaxial connector

Output: Tapped, flat CPR-187 flange

Shock and Vibration: Operating: Normal laboratory environment, see Note 10

Non-Operating: Same

Shipping: In container: Shall be capable of withstanding shipment by common carrier without damage

Waveguide Pressurization: Dry air acceptable, dry N_2 preferred

Absolute Ratings Notes 1, 2, and 3

Parameter:	If(Surge)	tk	Ef	If	T(Air-Inlet)	Alt	MTBF	Pd	T(Water-Inlet)
Units:	A	Sec	Vdc	Adc	°C	ft	khrs	W	°C
Maximum:	20	---	15	15	+40	10,000	----	1.5	+40
Minimum:	---	300	---	---		----	5	---	0
								Note 5	Note 17

Parameter:	EFF	eby	ik	Pi(ave)	tp	Load	Insertion Loss	X-Radiation	Sol Voltage	Sol Current
Units	%	KV	a	Kwatts	Sec	VSWR	dB	MR/HR	Volts	Amps
Maximum:	---	50	15	5	0.5	2.0:1	---	2.5	90	36
Minimum:	35	10	---	---	---	---	70	---	---	---
		Note 6	Note 29			Note 6		At 12 inches Note 11		

Parameter:	Ion Pump Voltage	Ion Pump Power Supply Impedance	Capacitance C_E	Water Pressure	epx	Joules delivered to arc Per Arc	Shelf Life	Stray Magnitive Field K Gauss
Units:	KV	K ohms	μμf	PSIA	KV		Years	
Maximum:	3.6	---	150	200	7	12	3	.1
Minimum:	---	600	---		---	---		
			Note 4			Note 24	Note 35	Note 21

Temperature (Cooling Liquid):	Operating:	0 to 37°C (32°F to 98.6°F) Note 17
	Non-Operating:	0 to 27°C (32°F to 80.6°F)
Temperature (Ambient Air):	Operating:	0 to +52°C (32 to 125.6°F)
	Non-Operating:	-62 to +71°C (-80 to +160°F)
Humidity (Note 8,9,10):	Operating:	100% to 92°F including condensation, 5% at 125°F
	Non-Operating:	100% to 95°F including condensation, 5% at 125°F
Altitude:	Operating:	(Note 10): 10,000 Feet
	Non-Operating:	50, 000 Feet
Weight (Note 18):	280 Pounds Maximum, Tube (280 pounds maximum, solenoid)	
Stray Magnetic Field:	(Note 21): Stray external fields applied to the tube shall not exceed .1 KG in an undefined orientation; this field may or may not be present during tube operation and may change magnitude and orientation on a pulse to pulse basis. (This field is in no way controlled by the solenoid or any tube-related circuit).	

Test Condition I:

Parameter	E_f	Pulsewidth		VSWR	eb	t_k	Frequency
		Beam	RF				
Unit:	V	Sec	Sec	Source and Load	KV	Sec	GHz
Maximum:			CW	1.2:1	50	420	
Nominal:	Nameplate	CW	.5		Nameplate		Nameplate
Minimum:		10^{-6}	10^{-6}				
	Note 3			Note 23	Note 3		

Test Condition II:

Parameter	E_f	-		VSWR	eb	t_K	Frequency
Unit:	V				KV	Sec	GHz
Maximum:			CW	1.2:1	50	420	
Nominal:	Nameplate	CW	.5		Nameplate		Nameplate
Minimum:	Note 3	10^{-6}	10^{-6}	Note 23	Note 3		

Test Condition III: Note 18

GENERAL:

Ref	Test	Condition	Min	Max
3.6.2	Marking (Note 3)	Filament Amps, Filament Volts, Beam Volts, Beam Current, Frequency, Part Number, Serial Number, Solenoid Current, Date.	---	---
4.8.5	Holding Period (Notes 20, 25, 30, 32)	T_A = 27 ± 10°C, no Ion Pump Power Supply Connected.	48	---Hrs

Test I (Note 37) 100% Test

Method	Requirement	Notes	Test	Conditions	Sym	LIMIT Min	LIMIT Max	Units
		12,30			---			
1311	Heater Voltage				Ef		15	Volts
1301	Heater Current				If		15	Amp
4271	RF Bandwidth	13,3,22	1		BW	8		MHz
4306	Pulse Voltage	3	1		ek	---	50	KV
4250	Power Output	3,13	1		Po	250	---	K Watts
----	Dimensions	25	-	Per Varian Outline Drawing D139348				
----	Pulse Current		1		ik	---	15	Amp
4260	Noise Figure	3,26	1		NF	---	40	dB
4253	Gain, Saturated	3	1		G(sat)	55		dB
----	Pressure Drop	25						
	Collector			20 GPM Max			50	PSI
	Body			2 GPM Max			100	PSI
	Ion Pump	3,14,31	1	---	---	---	10	µAmp
	Stability	3,26,28	1	po = 250KW	---	---	1	---
	Input Watts	26,36	1	pi			715	kW

Test II 10% Sampling

Method	Requirement	Notes	Test	Conditions	Sym	Min	Max	Units
---	Additive Noise Intrapulse	3,16,26	1	po = 250KW	---	-77		dB
4257	Insertion Loss	26	---		---	70		dB
4243	Spurious Output	3,15	1	po = 250KW	---	-50	---	dB
4243	Harmonics	3,19	1		Pnf/Pf	-30	---	dB
---	Conversion Coefficient	13,3	1	Pd Varied po = 250KW $\Delta\Theta_o/\Delta Pd$	---	---	5	deg/dB
	Heater Voltage Power Sensitivity	13,2,26	1	po = 250KW $\Delta po/\Delta Ef$ Ef Varied	---	---	0.1	dB/Volt
---	Solenoid Phase	26	1	po = 250KW $\Delta\Theta_o/\Delta$ Is			5	deg/% I (Solen

Test III Note 18

Method	Requirement	Notes	Test	Conditions	Sym	Min	Max	Units
---	Beam Phase Sensitivity	18,26	1	po = 250KW $\Delta\Theta_o/\Delta Ek$ Ek varied	---	---	15	deg/%
	Heater Voltage Phase Sensitivity	18,26	1	po = 250KW $\Delta\Theta_o/\Delta Ef$ Ef Varied	---	---	0.1	deg/%

NOTES

Note 1 Tube shall operate with the VYW-7849 solenoid at the current trimmed from nameplate value for minimum body current.

Note 2 All voltages except the pump are referenced to the cathode.

Note 3 The beam and heater voltages for optimum performance are shown on the tube nameplate. The tube will be operated within ±5% of the nameplate values for beam and heater voltage. The tube shall be stable over the voltage range from 10 to 100% of nameplate.

Note 4 The summation of all stray capacitance which is pulsed to the cathode potential by a driving modulator.

Note 5 The tube will suffer no permanent damage with continuous operation at 3 dB overdrive.

Note 6 The tube will be stable with a 2.0:1 at any phase on the output and 1.2 on the input while the cathode voltage is between 10 kV and the maximum value.

Note 7 The tube shall meet all requirements with the cooling specified herein when operating under any combination of environmental conditions and maximum collector dissipation.

Note 8 DC connections shall be corona free with a static voltage applied which is equal to the normal operating voltage when the tube is subjected to an environment in which water is condensing on the insulating surfaces or the barometric pressure is equivalent to an elevation of 10,000 feet or both.

Note 9 The tube will operate with no arcing of the RF windows (Pressurized with dry air or N_2) when the tube is subjected to the environmental condition of Note 8.

Note 10 The tube must meet all electrical performance criteria under the operating environmental specifications.

Note 11 A radiation profile on one of the first tubes shall be provided by vendor to show compliance of the tube.

Note 12 Tests shall be performed at the nameplate frequency.

Note 13 Frequency of tubes ordered under this specification will be set by factory adjustment.

Note 14 Stray magnetic field may cause extraneous and/or erratic readings.

Note 15 The tube shall produce no spurious output greater than the value specified herein excluding AM or FM spectral lines and discrete harmonics directly related to the power supply frequency or modulation waveform, but including ion oscillations or other instabilities appearing as undesirable spectrum components.

Note 16 The tube noise performance shall be measured.

Note 17 Temperature to be stabilized ±10°C within this range.

Note 18 Varian to supply calculation or engineering evaluation.

Note 19 Harmonics to be measured using a directional coupler (calibrated at the second and third harmoniss for the TE_{10} mode), high and low pass filters and a bolometer.

Note 20 Following this test, the tube shall meet the requirements of Test I.

Note 21 The tube shall meet the requirements of Test I. 1 KG objective.

Note 22 Measured at points 1 db below the peak.

Note 23 The output match outside the operation range will not be controlled and the tube shall operate within the specified limits, into any match from short to open circuit at any phase and any frequency outside the tuning range.

Note 24 The energy delivered to an arc is that energy stored in the stray capacitance when charged to the maximum voltage plus that stored in the modulator capacitance charged to the same voltage when protected with a 10 µsec crowbar. The remaining energy is delivered through an impedance which will limit the current to the maximum peak current for a time not to exceed 70 milliseconds.

Note 25 Non-operating.

Note 26 These tests shall not be performed unless specifically required in the purchase order or contract and separately and specifically funded.

Note 27 Delete

Note 28 The stability test shall be run for a minimum of four hours, after a maximum of one hour of filament operation, immediately following the holding period. Stability shall be measured in terms of the number of arcs during the period of operation. An instability due to any causes, is counted if the RF energy is less than 70% of the normal level in the frequency range specified for a period of 2 microseconds.

Note 29 With RF drive whenever cathode voltage is applied.

Note 30 The tests of Test I shall be performed after holding period.

Note 31 The Ion Pump Current shall not exceed the specified limits when the tube is operating under the specified test condition.

Note 32 The Ion Pump shall not be energized between the beginning and the end of the holding period.

Note 33 Delete

Note 34 Delete

Note 35 Shelf Life shall be: Off-line storage, with the ion pump energized.

Note 36 The maximum input power to produce a minimum of 250 K Watts shall not exceed 715 K Watts (min eff = 35%) at maximum voltage and shall lie within the maximum voltage and current limits. All tubes of a given nameplate frequency shall meet the requirement with a maximum cathode voltage spread of ± 3500 volts.

Note 37 Each tube shall be supplied with the complete test results data resulting from Test I unless otherwise specified in the purchase order.

Note 38 All leads shall be capable of withstanding, without damage to connections, conductors or insulation; the following mechanical stresses: ten pulls of ten pounds each, applied up to forty-five degrees from the normal axis of the lead.

VYW-7849

Solenoid Specification
for
VKC-7849 Klystron

Specification

(April, 1979)

Description:

This specification describes the electromagnet (solenoid) to be used with a 250 kw klystron described in . The electromagnet will provide the required magnetic field for the klystron when operated within the specified range.

Mechanical: Varian outline drawing D 139090.

Electrical Connections: MS 3102A-18-11P

Weight: 280 pounds (Max)

Cooling: Water

Flow: 2 GPM or 100 PSI (Max)

Temp: 37°C Max

Air: Free Convection

Electrical:

Volts: 90 volts (Max)

Current: 36 Amperes (Max)

The solenoid shall operate with either electrical connection grounded and shall be protected from faults due to the input connection being broken while current is flowing.

Marking:

The connections shall be clearly marked. Nameplate or label shall indicate Vendor's name, Vendor's part number, serial number, date, and polarity.

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SPECIFICATIONS FOR
HIGH POWER CIRCULATOR

1.0 Scope

This specification covers the requirements for a high power circulator with a back power coupler for protection of a klystron amplifier tube.

2.0 Electrical Requirements:

This item shall meet the following requirements

2.1	Operating Frequencies:	4.600 ± 0.1 GHz
2.2	Insertion Loss:	0.3 db max.
2.3	Isolation:	20.0 db min.
2.4	VSWR Input Port:	(a) 1.2:1 on input port with a Load VSWR of 3.43:1 on output port. (b) 2.0:1 VSWR on input with a short on the output at any phase.
2.5	VSWR Output Port:	1.06:1 circulator output VSWR with 2:1 VSWR a input and 132 Kw applied to the output.
2.6	Power:	250 Kw nominal 350 Kw Peak max. 0.5 sec. pulse every 5 min.
2.7	Waveguide:	WR 187
2.8	Flanges:	CPR 187F
2.9	Terminations:	All required termination will be supplied by the contractor with a VSWR of 1.06:1 max. and must be demountable.

2.10 Back Power Coupler:	50.0 ± 1.0 db calibrated at operating frequencies. Values to be marked on coupler. The coupler output port shall be a type "N" female connector.

3.0 Mechanical Requirements:

3.1 Pressurization:	2 atmospheres of dry nitrogen or air without leaking.
3.2 Cooling:	Air cooling. (Note: liquid available if necessary, water.)
3.3 Drawing:	A mechanical outline drawing will be supplied by the contractor showing dimensions, and placement of markings. On drawing parts list the specifications of the terminations with vendor part number shall be called out.
3.4 Marking:	Clearly marked input, output termination rating, coupler and coupler calibrations.

4.0 Environmental:

4.1 Magnet Field:	This device will be required to operate in a stray magnetic field environment of 100 gauss.
4.2 Temperature and Humidity:	This device will be required to operate in an environment of 0°C to + 40°C and a humidity level of up to 90% with condensation.

5.0 Quality Assurance Provision

5.1 Acceptance Test:	Each item shall be tested for VSWR, insertion loss, and isolation. Test data will be furnished with each item.
5.2 General Warranty:	Contractor shall warrant that all items furnished shall be free from any defects in design, material and workmanship, and shall operate as specified for a period of 12 months from date of acceptance. Contractor shall with all possible speed correct or replace defective or non-conforming parts.

6.0 Notes

6.1 An outline drawing of this part shall be submitted to the Massachusetts Institute of Technology with quotation and after approval shall become part of this specification. After approval of this drawing all revisions will require approval by the Massachusetts Institute of Technology.

6.2 Due to the power requirement for this circulator we need a Thermal Analysis of how this will be accomplished with quotation.

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Cambridge, Massachusetts 02139

SPECIFICATION FOR

DUAL WAVEGUIDE SHUTTER SWITCH

1.0 SCOPE

This specification covers the requirement for a dual waveguide shutter switch in WR187 waveguide and mates with a dual CPR187F flange. Each waveguide shutter will be operational independent of the other.

2.0 ELECTRICAL REQUIREMENTS:

2.1	Operating frequencies	$4.6^{\pm 0.1}$ GHz
2.2	Insertion loss	0.2db maximum
2.3	Isolation	30.0db minimum
2.4	VSWR	1.15:1 maximum
2.5	RF Power	50 KW nominal 0.5 second pulse every 5 min.
2.6	Switching time	100.0 miliseconds maximum
2.7	Operating voltage	24-30 VDC
2.8	Pull-in voltage	18 VDC maximum
2.9	Drop-out voltage	0-12 VDC
2.10	Coil resistance	20 watts maximum
2.11	Coil temperature rise	65°C maximum
2.12	Actuation	Each waveguide shutter will be operatable.

3.0 MECHANICAL REQUIREMENTS:

3.1	Waveguide	WR187
3.2	Flanges	Mate with dual CPR187F
3.3	Pressurization	2 atmospheres of dry nitrogen or air without leaking.
3.4	Drawing	An outline drawing will be supplied by the contractor showing all dimensions.

4.0 ENVIRONMENTAL:

4.1	Magnet field	This device will be required to operate in a stray magnetic field environment of 400 gauss.
4.2	Temperature and humidity	This device will be required to operate in an environment of 0°C to +40°C and a humidity level of up to 90% with condensation.

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TWT AMPLIFIER SPECIFICATIONS

ELECTRICAL

Frequency	4.0 - 5.0 GHz minimum
Power Output	20 Watts minimum
Gain at Rated Power Output (20W)	38.0 db minimum
Duty	CW
Input Voltage	120 Vac ± 10%
Power Consumption	350 Watts maximum
Noise Figure	35 db maximum
Spurious Modulation (at saturation)	-35 db minimum
VSWR (input and output with circulators)	1.3:1 maximum

MECHANICAL

Connectors	N Type female

Each amplifier package will consist of the following as a minimum

1 - Traveling - wave tube
2 - Regulated power supply
3 - Complete air cooling system
4 - Isolator/circulator on RF input and output
5 - Beam current meter
6 - AC power on/off switch
7 - RF power on/off switch
8 - AC power on indicating light
9 - System ready indicating light
10 - RF power on indicating light

Each amplifier package will be rack mountable in a standard 19 inch rack with all RF connectors, switches, and monitors mounted on the front panel, the power connector shall be on the back panel.

The cooling system for the amplifier shall be self contained and provide all the cooling required by the amplifier when operated within the specified environment. The maximum exhaust air temperature shall not exceed 125°F with 115°F of input air.

The weight of each amplifier package shall not exceed 65 pounds.

A mechanical outline drawing of TWT amplifier package will be furnished with quotation.

OPERATING ENVIRONMENT

Temperature	40 - 95°F
Humidity	90%
Stray magnetic field	10 Gauss

PROTECTIVE FEATURES

The following protective features shall be privided as a minimum

1 - Automatic time delay
2 - Helix current overload
3 - Thermal overloads as required
4 - Short circuited and open circuited stability of RF input and RF output

WARRANTY

One full year regardless of the hours of operation.

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Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

SPECIFICATIONS FOR

SOLID STATE ELECTRO-OPTICAL ARC SENSOR

1.0 Scope

This specification covers the requirements for a Solid State Electro-Optical Arc Sensor that will detect visible arcs and respond to excessive reflected power in a high power microwave waveguide system.

2.0 Requirements

This device shall meet all of the requirements of the Varian VEC-8480 (spec. sheet attached) or the equivalent with the following additional requirements.

2.1 R.F. Requirements:

a) Frequencies	4.600 ± 0.1 GHz
b) Insertion Loss	0.15 db max.
c) VSWR	1.05:1 max.
d) Power	250 KW Nominal 350 Kw Peak max. 0.5 sec. pulse every 5 min.
e) R.F. Leakage	10.0 mw/sq. meter max. at a distance of 1 meter.

2.2 Mechanical Requirements:

a) Waveguide	WR 187 90° "E" plane bend
b) Flanges	CPR 187 F

2.3 Environmental:

a) Magnetic Field:	This device will be required to operate in a stray magnetic field environment of 100 gauss

b) Temperature and Humidity:	This device will be required to operate in an environment of 0°C to + 40°C and a humidity level of up to 90% with condensation. This device will be required to be drip proof.

2.4 Quality Assurance Provision

a) Acceptance Test:	Each unit will be tested for insertion loss, VSWR and DC requirements. Test data will be furnished with each item.
b) General Warranty:	Contractor shall warrant that all items supplied shall be free from any defects in design, materials and workmanship, and shall operate as specified for a period of 12 months from the date of acceptance. Contractor shall with all possible speed correct or replace defective or non-conforming parts.

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SPECIFICATIONS FOR

LOW PASS WAVEGUIDE HARMONIC REJECT FILTER

1.0 Scope

This specification covers the requirements for a low pass filter to reduce harmonic output of a klystron amplifier transmitter.

2.0 Electrical Requirements:

This item shall meet the following requirements

2.1 Operating Frequencies: 4.600 ± 0.1 GHz

2.2 Insertion Loss: 0.3 db max. over operating frequencies.

2.3 Harmonic Attenuation: 2nd harmonic 35 db min.
3rd harmonic 45 db min.
Reasonable attenuation up to the 5th harmonic

2.4 VSWR: 1.05 max. at 4.6 GHz
1.20 max. at 2nd harmonic
2.0 max at 3rd harmonic

2.5 Power: 250 Kw Peak Nominal 350 Kw Peak max.
.5 sec. pulse every 5 min.

2.6 Waveguide: WR 187

2.7 Flanges: CPR 187F

3.0 Mechanical Requirements:

3.1 Pressurization: 2 atmospheres of dry nitrogen or air without leaking.

3.2 Cooling: Air cooling. (Note: liquid available if necessary, water.)

3.3 Drawing: A mechanical outline drawing will be supplied by the contractor showing dimensions, placement of markings for Input port and Output port.

4.0 Environmental:

4.1 Magnet Field: This device will be required to operate in a stray magnetic field environment of 100 gauss.

4.2 Temperature and Humidity: This device will be required to operate in an environment of 0°C to + 40°C and a humidity level of up to 90%.

5.0 Quality Assurance Provision

5.1 Acceptance Test: Each item shall be tested for VSWR, insertion loss, harmonic attenuation. Test data will be furnished with each item.

5.2 General Warranty: Contractor shall warrant that all items furnished shall be free from any defects in design, materials and workmanship, and shall operate as specified for a period of 12 months from the date of acceptance. Contractor shall with all possible speed correct or replace defective or non-conforming parts.

6.0 Notes

6.1 An outline drawing of this part shall be submitted to the Massachusetts Institute of Technology with quotation and after approval shall become part of this specification. After approval of this drawing all revisions will require approval by the Massachusetts Institute of Technology.

6.2 Due to the power requirements for this filter we need a Thermal Analysis of how this will be accomplished with quotation.