LEDA RF DISTRIBUTION SYSTEM DESIGN AND COMPONENT TEST RESULTS*

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Abstract

The 350 MHz and 700 MHz RF distribution systems for the Low Energy Demonstration Accelerator (LEDA) have been designed and are currently being installed at Los Alamos National Laboratory. Since 350 MHz is a familiar frequency used at other accelerator facilities, most of the major high-power components were available. The 700 MHz, 1.0 MW, CW RF delivery system designed for LEDA is a new development. Therefore, high-power circulators, waterloads, phase shifters, switches, and harmonic filters had to be designed and built for this application. The final Accelerator Production of Tritium (APT) RF distribution systems design will be based on much of the same technology as the LEDA systems and will have many of the RF components tested for LEDA incorporated into the design. Low power and high-power tests performed on various components of these LEDA systems and their results are presented here.

1 WAVEGUIDE SYSTEMS

The first accelerating section of LEDA is the radio frequency quadrupole (RFQ). Three 350 MHz 1.3 MW CW klystrons can deliver RF power to the RFQ.[1] Each of the waveguide runs from the klystron contain several important components that will be described in the next section

The RFQ is followed by the Coupled Cavity Drift Tube Linac (CCDTL). This section of the accelerator is driven by a single 700 1.0 MW CW klystron.[2] Many of the components used in the 350 MHz system are also used in the 700 MHz systems. The 700 MHz RF systems will comprise most of the RF systems used on the APT accelerator. [3]

WR2300 full-hcight waveguide is used for delivering up to 1.2 MW of CW RF power at 350 MHz to the RFQ. In order to minimize the RF power passed through the vacuum windows to the RFQ the power is divided into equal parts. Hybrid couplers (3 dB) are used to split the power. After the power division, the waveguide size transitions to half-height and the power from one klystron is delivered to the RFQ through four waveguide feeds. Since the RFQ serves as the power combiner, the effective electrical length of the waveguide runs must be controlled. High-power phase shifters are introduced to the waveguide runs to set the phase at the proper value and to make adjustments when needed. A typical waveguide configuration from the klystron to the RFQ is shown in Figure 1.

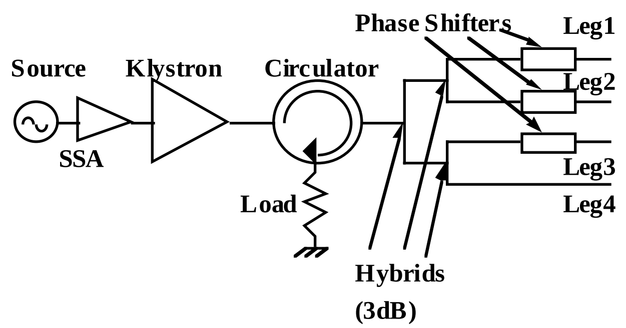

Figure 1: Schematic of LEDA RFQ RF power delivery system.

2 RF COMPONENTS

2.1 Circulators

Both the 350 and 700 MHz RF delivery systems use a high-power circulator to protect the klystron from excessive reflected power. The circulators used on LEDA are manufactured by Advanced Ferrite Technology (AFT). The circulators have a measured insertion loss of less than 0.05 dB at the center frequency. The isolation for the three ports of each circulator is greater than 30 dB.

2.2 Phase Shifters

Phase shifters supplied by Mega Industries are used to correct any phase differences introduced to the waveguide runs that lead to the accelerator. The phase shifters adjust the phase in the waveguide up to 45 °. The phase shifters move three posts in and out of a section of waveguide (0.0 to 2.5") to introduce the required phase shift. They are adjusted manually with a knob or electronically with a motor. A photograph of a 350 MHz WR2300 phase shifter is shown in Figure 2.

The WR2300 half-height phase shifters were tested on the test stand for 4 hours at 200 kW CW. The 45 ° of phase shift was demonstrated at this power level. A WR2300 full height phase shifter was tested on the up to 1.0 MW CW over the 45° range at 350 MHz for several hours. The external temperature near the base of one of

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the posts (with the posts fully inserted into the waveguide) reached a constant temperature of 154 °F at this power level. The posts were extracted with the power held constant and the temperature at that location reduced to 135 °F.

Figure 2: Photograph of 350 MHz WR2300 half-height Phase Shifter.

2.3 Waveguide Switches

A three port waveguide switch, also manufactured by Mega Industries, is used to isolate a klystron from the accelerating structure. The APT accelerator has installed redundancy on each copper structure and the waveguide switch is used to isolate a failed RF station from the cavity. A phase shifter and a shorting plate on the third port of the waveguide switch is used to present a short at the proper phase to the accelerating cavity iris to allow operation with one system removed.

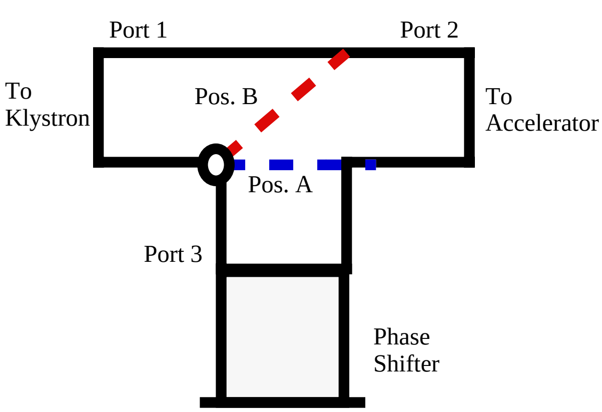

Figure 3: Schematic of a Waveguide Switch in its typical configuration.

As shown in Figure 3, with the waveguide switch in position A the power is directed to the accelerating structure. In position B a short circuit at the correct phase is presented to the coupling iris of the accelerator and any power from the klystron is reflected back to the circulator load.

2.4 Harmonic Filters

Harmonic filters are used between each klystron and circulator to de-Q any potential resonant circuits at the harmonic frequencies. The harmonic filter occupies a 46" section of waveguide. It has 6 antennas protruding into the narrow wall of the waveguide which are terminated in 200 W, 50 Ohm, air cooled loads. A photograph of a 350 MHz harmonic filter is shown in Figure 4.

Figure 4: Photograph of LEDA 350 MHz Harmonic Filter.

Since the fundamental frequency is carried in the TE_{10} mode with the electric fields orthogonal to the broad wall, the antennas are inserted through the narrow wall of the waveguide to couple out harmonic power in the TE_{11} and TM_{11} modes. [4] If the antenna is too thick, it can couple a significant amount of power at the fundamental frequency. An optimal length and thickness for the antennas were chosen.

The diameter of all antennas is 0.0787" (2 mm). The length of antennas for the harmonic filter for the 350 MHz system is 3.88" (9.85 cm) and 1.75" (4.44 cm) for the 700 MHz. The measured insertion loss for the harmonic filters are 0.04 dB and 0.01 dB for the 350 and 700 MHz filters, respectively. The measured antenna coupling value for either fundamental frequency is -60 to -70 dB. For the first through the third harmonic, the coupling value varied between -20 to -30 dB. Currently, several harmonic filters at 350 MHz are installed and have been in use for hundreds of hours without a failure. As much as 20 Watts of harmonic power have been measured on some antennas during operation of the klystrons at full power.

2.5 RF Loads

RF loads are used on the all high-power RF systems. Except for the test stand, 200 kW loads are placed on the return leg of the 3 dB hybrids and circulators. For testing

RF components, the test stands use RF loads that are capable of taking the full power out of the klystron.

The 350 MHz full power loads were developed by Titan Beta. They are used on the test stand for testing components up to 1.2 MW CW. To reduce the length of these water loads, they operate using a 70% water and 30% propylene glycol mixture. At this mixture, the VSWR for the loads according to factory low power testing is 1.05:1, however the best achieved under high power conditions is 1.07:1.

Similar loads are used for the test stand at 700 MHz. Premier Microwave (now Atlantic Microwave) provided the 1.0 MW CW RF water loads. Deionized water is used in these loads. The body of the load is stainless steel. The VSWR for these loads is also 1.05:1. This load has been operated at 1.1 MW for 24 hours of continuous operation for a klystron test.

Altronics Research supplies a coaxial mounted 50 Ohm film resistor rated at 200 kW. Five resistors of this type are used on each RF transmitter. It is based on a shell-and-tube design and is cooled with deionized water.

The resistor's transient rating is about 22 joules. It can accept 6 times the average rated power for 100 microseconds. Coolant flow results in a rated pressure drop of 50 psi at 20 gpm. All resistors are continuously monitored for flow and temperature. The flow rate is monitored using a Rosemount flowmeter coupled to a Oripac orifice plate. Omega RTD probes are used for all temperature measurements in the cooling systems. An Allen-Bradley system is used to monitor these sensors and software interlocks will recognize the effect of transients and the associated time constant of the piping system and instrumentation.

The robustness of this design has been an ongoing concern in relation to offnormal conditions expected during acceleration operation. At outlet temperatures above 90 °C, localized boiling has been observed to occur in the cooling channel, reducing the film's heat transfer coefficient and potentially creating conditions for failure. However, the rate of failure has yet to be determined. Preliminary acceptance tests of 21 resistors have accumulated nearly 100 hours of test stand time at rated power. Of the 21 loads, 18 passed the 4 hour full power test, 2 required rebuilding and passed the 4 hour test on the second attempt, and 1 was rebuilt twice before finally passing the 4 hour acceptance test.

2.6 Flexible Waveguide

Sections of flexible waveguide are located in every leg of every waveguide run to accommodate thermal expansion between fixed points. Ultraflexible pieces are used to connect critical components such as the klystron and RF windows [5] to the rest of the system.

Ultraflexible WR2300 half-height guide with a 90° E-plane bend incorporated into it is used as the last sections of waveguide that connects the RF windows to the RFQ. These sections allow for the expansion of the RFQ due to heating. The manufacturer of these flexible sections is Mega Industries. These sections have been tested and installed on the waveguide runs. The results of the mechanical testing is given in Table 1. The measured results for the compression and expansion displacement and the horizontal offset were not compliant with the original requirement. The results of all the mechanical tests were reevaluated and later determined to be sufficient.

	Measured	Expected
Çompression with 12.5 lbs force	0.109”	0.125” min.
Expansion with 12.5 lbs force	0.045”	0.125” min.
Vertical Tilt force to get 1° tilt	18 ft-lbs	25 ft-lbs max.
Horizontal Tilt force to get 1° tilt	14 ft-lbs	25 ft-lbs max.
Vertical Offset force to achieve 0.0625” offset	+7 lbs & -5 lbs	15.7 lbs max.
Horizontal Offset force to achieve 0.0625” offset	+18 lbs & -21.5 lbs	15.7 lbs max.
Clockwise Twist with 20 ft-lbs of torque	0.165”	0.10” min.
CounterClockwise Twist with 20 ft-lbs of torque	0.165”	0.10” min.

Table 1: Mechanical test results of the 90° E-bend flexible half-height WR2300 waveguide.

High-power electrical tests were performed on one WR2300 half-height flexible 90° E-bend. It was tested for 4 hours at 900 kW CW without failure.

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