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Design, Development and Testing of a Prototype Hardware Module for Power and Phase Measurement of LHCD System

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ABSTRACT

In this paper we present the design of a hardware module for measurement of power and phase of the 64 channels of the LHCD (lower hybrid current drive) system at 3.7GHz. The power measurement module uses a single IC, LTC5508. The output (in volts) from the IC is then mapped to obtain the power value in dBm and the same is displayed on a computer. Raspberry Pi is used to display the results on a computer in the form of a GUI (graphical user interface). The phase module however incorporates ICs namely, AD8302 (for phase measurement).

Keywords: LHCD, Power measurement, Phase measurement

I. INTRODUCTION

In Steady state Superconducting Tokamak (SST-1) machine [1], the lower hybrid current drive (LHCD) system [2, 4] is employed to drive plasma current non-inductively for sustaining the plasma for CW operation. The system is based on four klystrons, each rated for 0.5 MW, CW RF power at 3.7GHz. The LHCD system is based on conventional grill antenna, which comprises of two rows, each having 32 waveguides, stacked adjacent to each other with a predefined periodicity to launch desired power spectrum having parallel refractive index centred at 2.25, when adjacent waveguides are phased relatively by 90^o. Here the term "parallel" implies parallel to ambient toroidal magnetic field of the SST1 machine. The grill antenna provides flexibility in changing the launched spectrum by changing the phase of the waves in each of the 64 input waveguides, using high power phase shifters connected to each of the 64 waveguides. Further each of these 64 waveguides have high power directional couplers to measure the forwarded and reflected power in each of these transmission line. From these measurements the coupling behaviour of the launched waves can be studied.

The current drive efficiency depends on plasma density, toroidal magnetic field and the coupling spectrum of launched LHW (lower hybrid wave) power. The power coupling becomes diverse due to phase differences at each waveguide.
Thus, it is quite important to measure the phase and power of the LHCD system.

II. POWER MEASUREMENT

The RF power measurement module is designed using LTC5508 [5]. The IC used is basically an RF power detector that operates in 300MHz to 7GHz range. The schematic for measuring power for 1 channel is shown in Fig.1. The input signal is fed through the SMA connector and voltage corresponding to the power appears at the output.

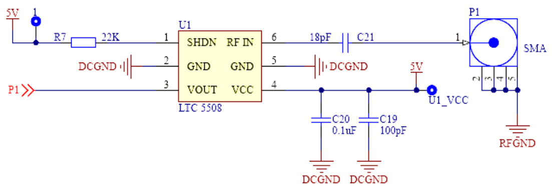

Figure 1. Schematic for power measurement for 1 channel

A. Hardware Testing

The RF power is measured at frequency 3.7GHz using IC LTC5508. The module is tested with input power from the signal generator from -30dBm to -20dBm with an increment of 5dBm and from -20dBm to +12dBm with an increment of 1dBm. The output signal from the PCB is fed to an analog-to-digital converter; MCP3008 is used as an ADC here. The digitally converted output is then fed to the GPIO of Raspberry Pi which is connected to a monitor display. The block diagram of test setup is depicted in Fig.2.

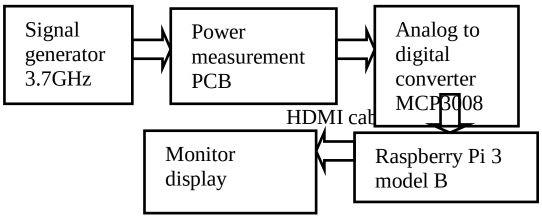

Figure 2. Block diagram for power measurement module

Figure 3 displays the actual test setup for power measurement module. A synthesized signal generator [SSG-4000HP] generates a 3.7 GHz signal which is fed to the power measurement hardware. The output voltage from the hardware is measured using a digital multimeter [MECO 171B+ TRMS] and the waveform is observed in a digital oscilloscope [GW INSTEK GDS-2202E].

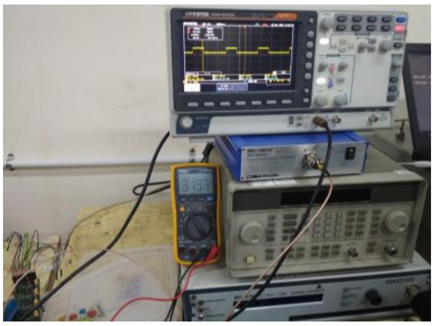

Figure 3. Test setup for power measurement module

B. Results

The output voltage of LTC5508 is in the range of 250 mV to 1030 mV. Fig. 4 shows the output voltage in mV for channel 1 for each input power level (dBm). The ideal characteristic of LTC5508 follows a semi-logarithmic curve. It can be observed from fig. 4 that the output voltage of channel 1 for power levels in the range -30 dBm to +12 dBm follows a similar semi-logarithmic curve. The maximum difference between two successive outputs is 60 mV which occurs at the highest power level +12 dBm (1030 mV at +12 dBm and 970 mV at +11 dBm) and the lowest successive difference is of 1 mV at -25 dBm (260 mV at -25 dBm and 259 mV at -30 dBm). Moreover, error percentage for detection of output voltage, to correctly map the power level, is depicted in the graph. Here, the error percentage is ±1 % and is shown in Fig. 4.

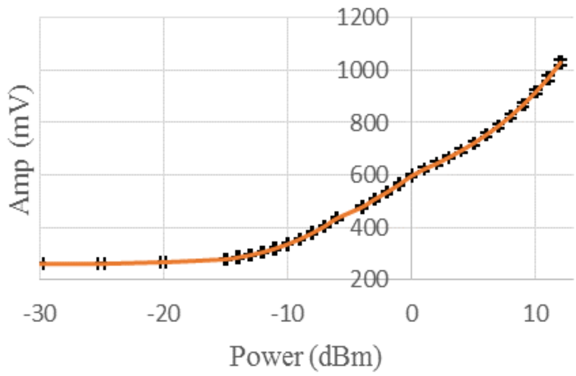

Figure 4. Output voltage of channel 1

The output from the hardware is given as input to the data acquisition system consisting of ADC, decoder and Raspberry Pi. The detected voltage levels from the IC are then mapped to corresponding power levels according to the datasheet of LTC5508. A graphical user interface is designed to display the mapped power output.

III. PHASE MEASUREMENT

The phase measurement module consists of a phase detector (AD8302 [6]). The block diagram of the module is represented in Figure 5.

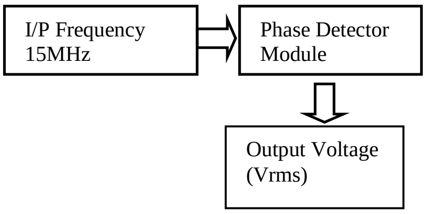

Figure 5. Block diagram of the phase measurement module

The schematic for the phase measurement module is shown in Fig. 6. From Fig. 6, it can be seen that two units of the phase detectors AD8302 are used. First unit provides the phase magnitude with respect to a reference signal and second unit provides some phase shift in the reference signal due to difference in path length resulting in phase difference between the channel signal and reference signal. The phase difference measurement is acquired by second unit.

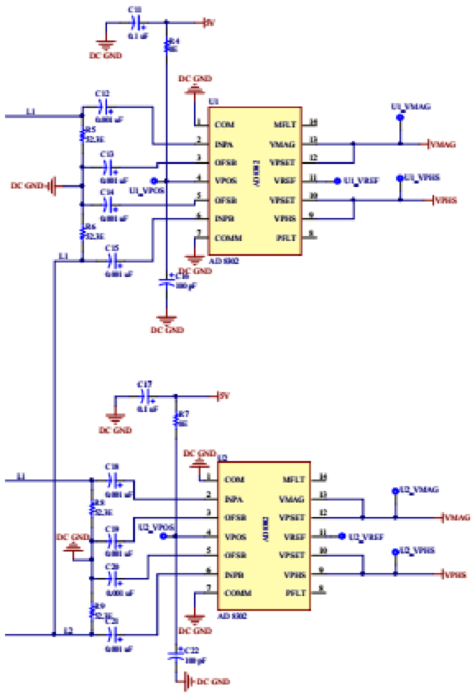

Figure 6. Schematic for the phase measurement

A. Hardware Testing

The test setup for measurement of phase module is similar to Fig. 5. The signal generator provides a signal of frequency 15 MHz. The signal is fed from the signal generator to the phase detector AD8302 to measure the phase difference, as observed from Fig. 6. The output voltage of the detector is measured and the phase is then mapped according to the datasheet of AD8302. Fig. 7 shows the actual test setup for phase measurement.

From Figure 7 it is observed that a signal generator having dual output channel with facility to change phase is used to generate signals of frequency 15 MHz. These signals are applied to the hardware module and the output is observed in a digital oscilloscope [Tektronix AFG3022C]. The oscilloscope displays the phase difference as a waveform.

B. Results

The hardware is tested by applying two signals with phase difference ranging from 0° to 360°. The power level of both the signals is set 0 dBm. The phase of channel 1 varies from 0° to 360° whereas the phase of channel 2 remains at constant 0°. Fig. 8 shows the results obtained. It can be seen that peak value of the graph i.e. 1.8 V is obtained at 250°.

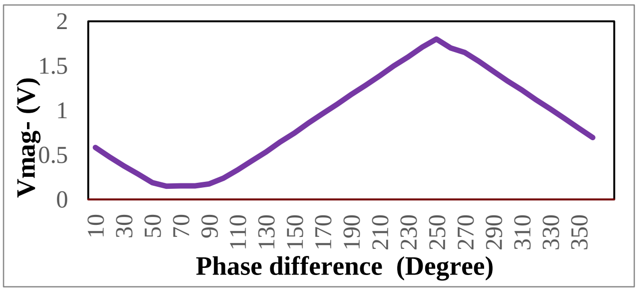

Figure 8. Output for phase measurement

The output voltage obtained from the second unit of AD8302 (after path delay) is compared to that obtained from the first unit of AD8302 (Fig. 8.). If the latter voltage output is greater than the former then the phase shift is said to be positive, otherwise the phase shift is negative.

The curve thus obtained, depicts a peak at 250° but the ideal curve for AD8302 peaks at 0°. The reason for this deviation is that the reference signal in this case (Fig. 6) had been given a phase shift by varying the path length. The path length of the signal from the down converter is different from the path length of the reference signal. Hence, the curve thus obtained illustrates the characteristic similar to that of the ideal curve.

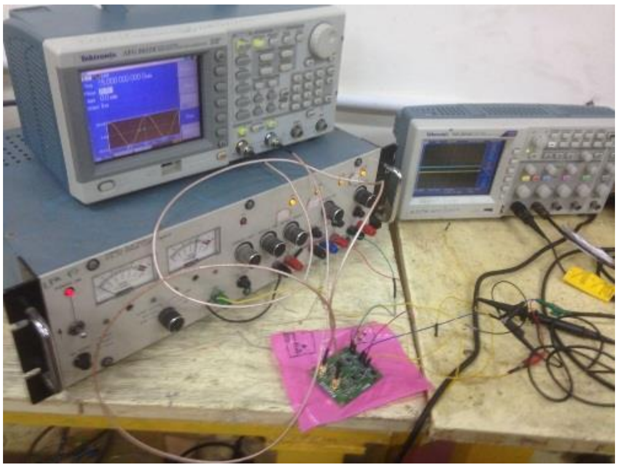

Figure 7. Testing of phase measurement module

IV. CONCLUSION

The designs of two hardware modules for measurement of power and phase of the LHCD system have been presented along with the test results. The output voltage from the power measurement module is mapped with respect to the characteristics provided in respective datasheets to obtain the power value in dBm. The phase module is tested by varying the phase of one signal and keeping that of the other signal as constant. It is found that the output voltages of both the modules conform to the ideal characteristics.

V. FUTURE WORK

1) An amplifier module with variable gain can be incorporated to amplify the DC outputs from the power measurement ICs in the range of 0-5V/0-10V. This amplification will help to test the power measurement module with existing LHCD system.

2) To optimize the speed of handling of power measurement data for CW operation, new dedicated hardware can be developed instead of Raspberry Pi which can provide 1 KHz of sampling rate for each channel.

3) For user interactive approach, GUI can be developed for visual representation of phase, forward as well as reverse power and can also perform data transfer in the background for distant monitoring.

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