CAVITY LOAD IMPEDANCE DIAGNOSTIC AT THE AUSTRALIAN SYNCHROTRON

Rohan Dowd, Adam Michalczyk, Karl Zingre, ASCo, Clayton, Victoria

Abstract

RF cavities are routinely detuned slightly from resonance to maintain Robinson stability of the beam as beam loading increases. Detuning the cavities results in a reduction of the overall energy efficiency of the RF and can waste many MW hours of energy per year. It is therefore desirable to only detune as much as required by the beam loading to maintain stability. A new system for monitoring the load impedance of the Storage Ring RF cavities has been developed at the Australian Synchrotron. The system utilises the Analogue devices AD8302 chip to monitor the load impedance of the Cavities and allow for more efficient detuning of the system. An overview and commissioning results of this system will be presented.

STORAGE RING OVERVIEW

The Australian Synchrotron is a 3rd generation light source facility located in Melbourne, Australia and has been operating since April 2007. The 3 GeV storage ring is 216 metres in circumference and can store a beam of up to 200 mA current. A design overview can be found in [1]. The storage ring RF system operates at a frequency of 500 MHz and consists of 4 HOM damped copper cavities, fed by 4 independent 150 kW klystrons. The cavities are grouped into pairs and positioned in adjacent straight sections of the storage ring. A full overview of the storage ring RF system and performance can be found in [2].

CAVITY REGULATION AND RF DISTRIBUTION

The Low level Electronics (LLE) contain phase and amplitude regulation loops to keep the fields in the cavities stable under the effects of beam loading and amplifier noise. There is also a tuning loop that controls movable plungers in the cavities to compensate the effects of thermal expansion and keep the cavities on resonance. This loops examines phase difference between the incoming RF and cavity RF and seeks to minimise any difference. An adjustable offset is including in these loop controllers to allow for deliberate detuning of the cavities to achieve Robinson stability. Due to lack of diagnostic information, the amount of detuning introduced onto the cavities has been applied in a simple “apply more detuning until the beam is stable” manner. While this detuning has been successful to date it is difficult to know if we have have too much detuning on one cavity and not enough on the other, or if all cavities have more than they need for beam stability.

The RF power distribution is shown in figure 1. The directional couplers near the roof penetrations are the closest to the cavities (directly below them) and give both the forward and reverse RF power signals. These signals are used in the normal LLE monitoring, but also have additional signal output splitters attached which are used for our cavity monitor system.

MONITOR SYSTEM DESIGN

In order to monitor the cavity load impedance, we need to combine information from the forward and reverse power signals to determine the complex reflection co-efficient of the cavities. The information required to determine this is the relative amplitude and phase difference between the two signals. Using a phase and amplitude detector we could then feed the DC analogue output signals from this into an ADC to be converted into process variables (PVs) in our EPICS database. The PVs are then analysed by a MATLAB gui in the control room and the cavity load impedance can be determined and plotted on a Smith chart. The overall design of the system is shown in figure 2.

One of our design goals for the phase and amplitude detector was for it to be inexpensive, compact and reliable. The Analogue Devices AD8302 integrated circuit seemed to be a natural choice [3]. It is a dedicated circuit for phase and amplitude measurements in the 0.3-2.7 GHz range, required minimum external components and was easy to implement in the design. The final design of the phase and amplitude measurements is shown in figure 5.

Due to the equipment rack layouts, the cable distance between the monitor units and the ADCs is several metres. Isolated outputs and higher gain were added to the boards for a better resolution and signal-noise ratio on these long transmission lines. The higher gain brings the outputs from 30 mV/dB and 10 mV/Deg to 150 mV/dB and 50 mV/Deg. The 24V power supplies were also chosen as isolated DC-DC converters to further reduce potential noise problems.

The first two 1 kHz low pass filters are anti-aliasing filters and also to reduce unnecessary signal bandwidth which is expected to be quasi-static. Last two filters are implemented to remove a 500 kHz ripple of $\pm$20 mV caused by modulation/demodulation in the isolation amplifier. This ripple could easily mask real signal changes. The system has provision for differential driving of ADCs (last two inverting buffers) to reduce common mode noise, however this is not currently used due to the input requirements of the ADC currently used. At present common mode noise does not seem to be a problem.

As this phase and amplitude detector was a prototype

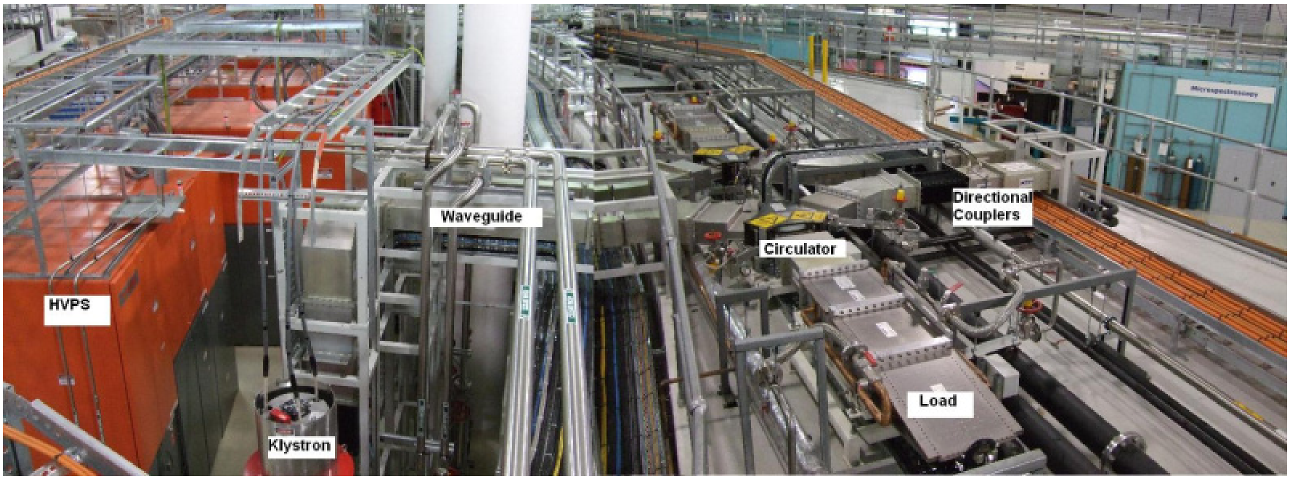

Figure 1: RF power distribution on Storage Ring tunnel roof for sector 7 RF.

design, we allowed for some possible alternate solutions when designing the PCB layout. As can be seen in figure 3 the PCB board is somewhat larger than needed as it allows for an alternate power supply in case of bad noise and use of the AD8302 evaluation board instead of the on board chip in case of exceptionally bad matching.

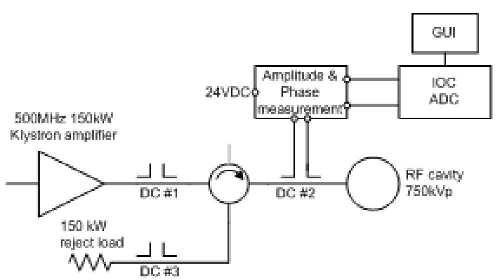

Figure 2: System layout.

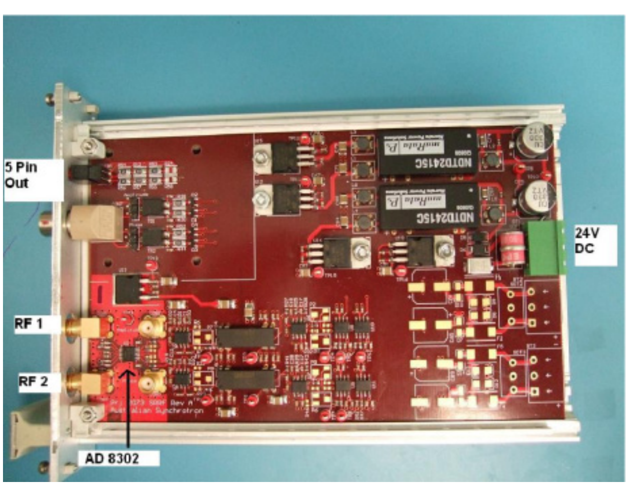

Figure 3: Final circuit board.

Figure 4: Units installed in RF rack.

PERFORMANCE

The typical Nonlinearity of the AD8302 is < 0.5 dB and < 1 degrees but the slope can vary and has to be calibrated. The performance is likely to be even better for our limited dynamic range of 20dB and 60 degrees. After assembly each RF detector board was tested to check the linearity and slope of its phase and amplitude response. This was done using a split 500 MHz RF signal with one cable passing through either a programmable delay line (for phase measurements) or a number of attenuators (for Amplitude measurement). The typical results of these measurements can be seen in figure 6 and figure 7.

The final arrangements of the units in the equipment racks is shown in figure 4. Attenuators at the inputs were added to adjust the input power levels to be more similar and for better matching.

Calibration of the units is done by first tuning the cavities to resonance (minimum power reflected) and then completely off resonance (full power reflection). This provides

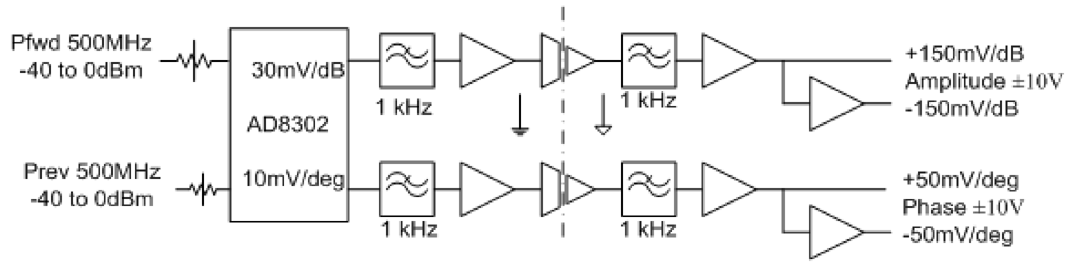

Figure 5: Monitor board design layout.

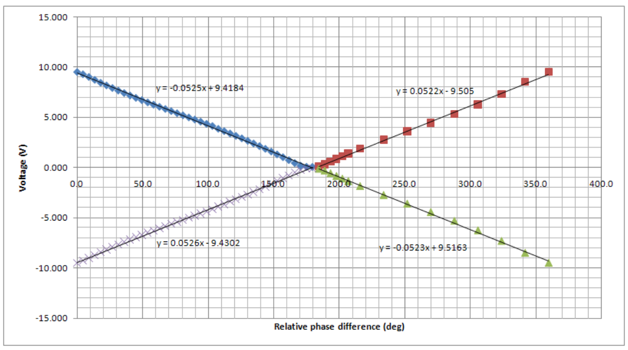

Figure 6: Phase response curve.

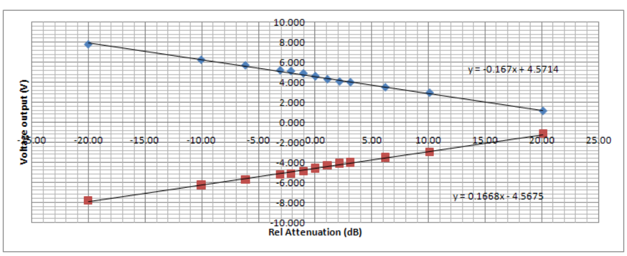

Figure 7: Relative Amplitude response curve.

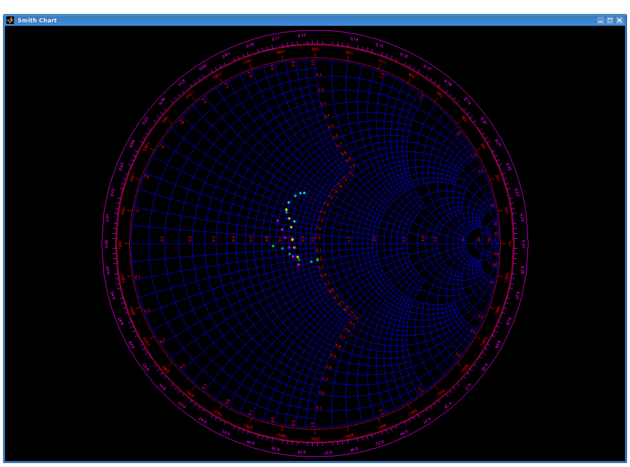

Figure 8: Smith chart display in the control room.

a reference point for both zero phase difference (on resonance) and zero amplitude difference (off resonance) Once calibration is complete the phase and amplitude measurements can be translated into a complex impedance via the equations:

$$\begin{aligned} Z &= \frac{1+\Gamma}{1-\Gamma} \\ \Gamma &= u + vi \\ u &= |\Gamma| sin\theta, v = |\Gamma| cos\theta \\ |\Gamma| &= \frac{1}{10^{R_l/20}} \end{aligned} \quad (1)$$

Where θ is the phase difference and R_l is the return loss, or relative amplitude. This impedance can then be plotted on a Smith chart to give a graphical representation of the current state of the cavities. A MATLAB GUI was written to do this and the result can be seen in figure 8. In this figure, the impedance of each cavity has been plotted during an injection from 0 to 200 mA. For most cavities, the impedance starts in the inductive side (due to the detuning) and as beam loading increases it moves towards the capacitive side. The different start locations indicated that indeed, the cavity detuning is not uniform and needs to be examined more closely. It was also a surprise that one cavity seems to start on the capacitive side. This will be investigated further.

CONCLUSION

A system for monitoring the cavity load impedance has been designed and commissioned at the Australian Synchrotron. Initial results have shown the expected cavity behaviour under beam loading and also indicate possible improvements that can be made to the detuning. Further studies of the cavity behaviour will now be conducted using this system.

REFERENCES

[1] J. Bolderman, D. Einfeld, Nucl. Intr. and Meth., A **521**, 2004, pg. 306

[2] R. Dowd et. al., Nucl. Instr. and Meth., A **592**, 2008, pg. 224-229

[3] Analogue Devices AD8302 data sheet, `http://www.analog.com`