APPLICATION NOTE

RF Matching Network Characterization

In this application note we will focus on one critical component of a radio-frequency (RF) plasma processing equipment's power delivery system - the RF matching unit. The RF matching network used here consists of load and tune capacitors as well as an inductive coil. In the ideal world, the matching unit should not absorb any power. In practice, the coil has some resistance and there is power loss through ohmic heating. This reduces the matching network efficiency and may cause the coil to fail over time. High voltages across the capacitors (and high current flow through them) can also cause degradation over time. Continuous changes in the quality of the match components cause process drift and even worse, it can lead to a catastrophic failure event. Matching unit characterization is now a key requirement for fab managers and process engineers throughout the industry.

There are three key performance indicators for the matching network; the match impedance range, the match quality and the match efficiency including the internal resistance. The **Octiv Mono** VI probe and impedance meter is the ideal product for characterizing the matching network in terms of these three parameters.

Impedance Matching Range

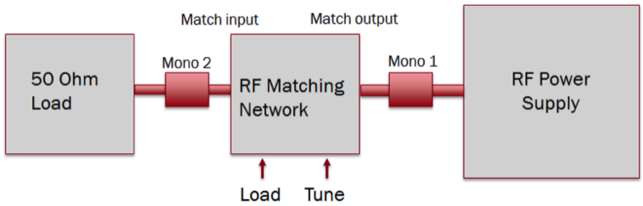

Figure 1: Schematic of the experimental setup used for RF matching network characterization using two Octiv Mono products.

The experimental setup used to characterize a typical RF matching unit is shown in figure 1. The RF generator is connected to the input of the first **Octiv Mono** unit using a short length of co-axial cable (transmission line). The output of the first Octiv Mono is connected to the output of the matching unit (this is opposite to normal use) with another short co-axial cable. The input and output of the second Octiv Mono unit are connected to the match unit input and 50 Ohm load respectively using two short lengths of co-axial cable.

The procedure for measuring the key matching unit parameters can be carried out as follows:

- Set the RF generator power level to 40 Watts
- Connect the Octiv units to the PC using the USB interface
- Select the 'time trend' mode of operation

- Manually move the load and tune capacitors through their full range (this process takes about 10 minutes)
- Export the data file to csv format for further analysis in excel (an example is provided with this report)

The result of such a characterization is shown in figure 2. The smith chart shows the full range of the matching network as measured by Octiv Mono 1.

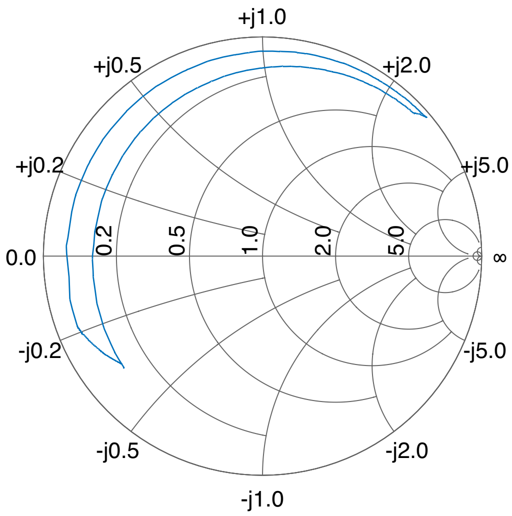

Figure 2: Smith chart detailing the full range of the RF matching network under test.

The matching network impedance range determines the range of plasma process impedances for which the RF power can be fully matched. The plasma impedance range is simply the complex conjugate of the matching network impedance range. The result of this analysis is shown in figure 3.

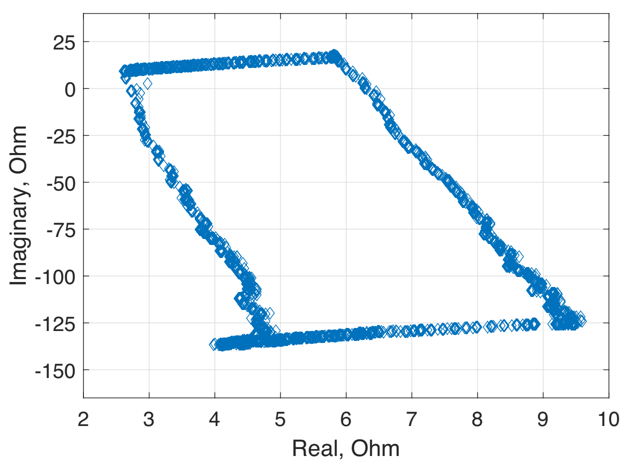

Figure 3: Matched plasma impedance range for the matching unit under test.

Quality Factor

The quality factor Q of the matching network is one of the most important quantities that can be measured. Octiv Mono 1 is used to measure this parameter directly. The quality factor is given by

$$Q = \sqrt{\frac{R_{SOURCE}}{R_{LOAD}} - 1}$$

Where R_{source} and R_{load} are the source and load resistance respectively. Figure 4 shows the Q factor measured for the matching network under test.

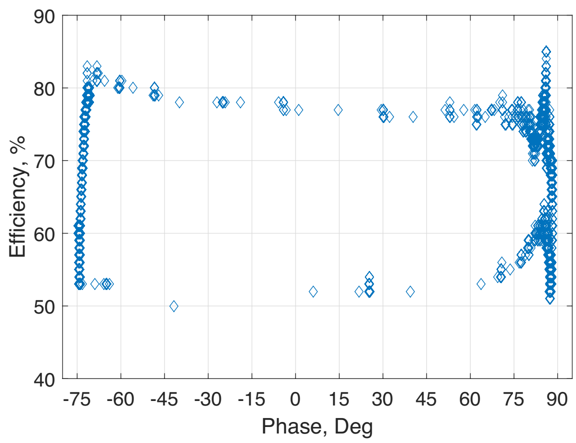

Figure 4: Matching network quality factor as a function of phase of the load impedance.

Matching Network Efficiency

The impedance of the matching network components would ideally consist of reactance only in order to have no power dissipation within the matching network. However, real components are lossy and so will dissipate some power. Inductors are typically one to two orders of magnitude more lossy than capacitors, and it is therefore usually assumed that all lost power is dissipated in the coil.

The power lost in the matching network can be measured in our experimental setup by comparing the power reported by the two Octiv Mono products. The difference between the power reported in Mono 2 and that reported in Mono 1 is the power absorbed in the matching network. This measurement is shown in figure 5. The powers reported by the two meters are quite different. This is often a shock to an engineer who views the matching network as ideal. The suspicion is cast on the meters. But the real reason is often the match efficiency and internal resistance.

The actual efficiency of the matching network is defined as

$$Efficiency = \frac{P_{out}}{P_{in}}$$

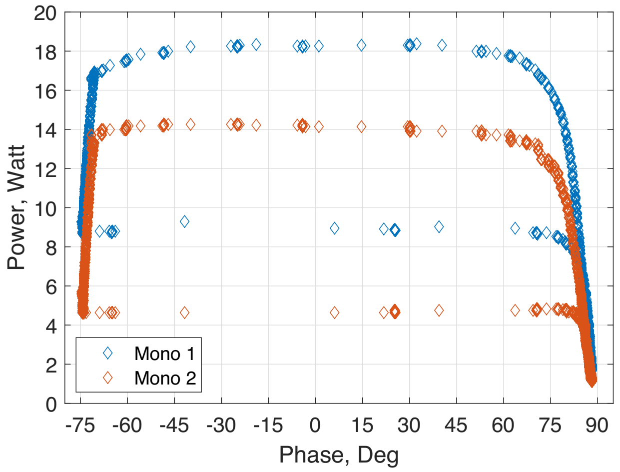

Figure 5: Power measured by Octiv Mono 1 and Octiv Mono 2 as a function of phase of the load side impedance.

Where P_{in} and P_{out} are the powers measured by Octiv Mono 1 and Octiv Mono 2 respectively. The result of this calculation is presented in figure 6. Interestingly, at certain match positions the efficiency can be as low as 50%.

Power Measurement Accuracy

The Octiv Mono power meters are designed to have 1% accuracy into a 50 Ohm load. As the phase of the load impedance advances towards 90° the accuracy of the power measurement decreases. High phase errors need to be avoided to ensure good accuracy of the power measurement. The accuracy versus phase angle of the load impedance is given in figure 7 for reference.

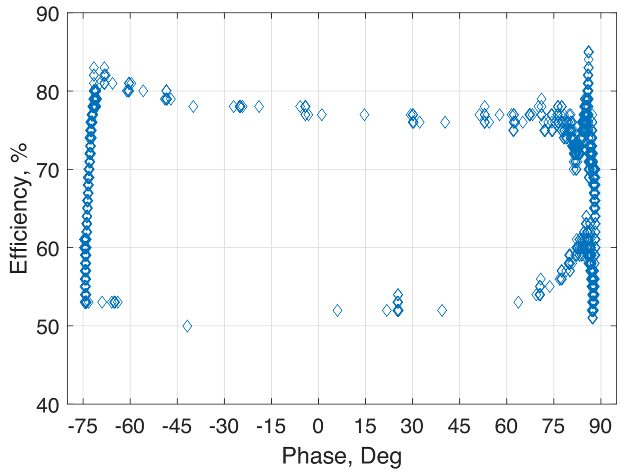

Figure 6: Matching network efficiency as a function of impedance phase of the load.

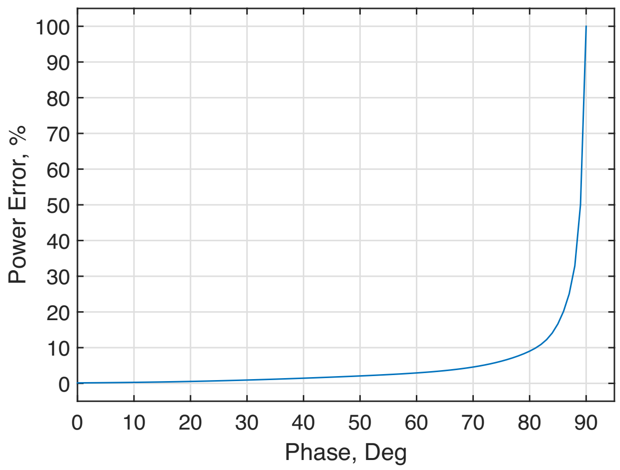

Figure 7: Accuracy of the Octiv Mono power measurement as a function of phase angle of the load impedance.

Internal Resistance

The efficiency of the matching network is determined by the internal resistance, mostly in the coil. The value can be determined from the measured efficiency and the absorbed power P_{abs}

$$R_i = \frac{P_{abs}}{Q}\sqrt{\frac{P_{in}}{50}}$$

Because the Octiv Mono accuracy decreases with increasing phase angle, the best values for Ri will be obtained at the lowest absolute phases. Figure 8 shows the calculated internal resistance as a function of load impedance phase angle. For the match unit under test the internal resistance is 0.7 Ohms.

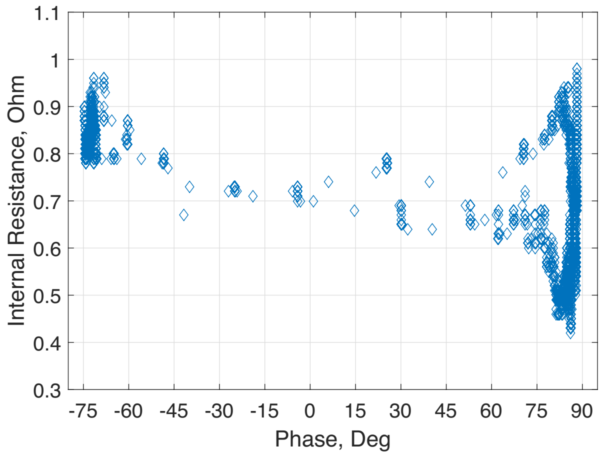

Figure 8: Internal resistance of the matching network as a function of phase angle of the load impedance.