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Automatic Impedance Matching System for RF Sputtering

A previously described[1] "L" type matching network used for rf sputtering is shown here as part of Fig. 1. The purpose of the network is to transform the complex impedance of a sputtering system to a purely resistive value of 50 Ω. This makes possible the use of a transmission line with a characteristic impedance of 50 Ω for the conveyance of rf power to the system. The rf power is conveniently monitored by a power meter in the transmission line. Since the power meter is capable of measuring both forward and reflected power, the voltage standing wave ratio (VSWR) on the transmission line can be computed. The VSWR will be unity when the matching network is adjusted so that the transmission line is terminated in its characteristic impedance. Practically, it is difficult to achieve a VSWR of unity (zero reflected power), so the network is adjusted to approach that optimum state as nearly as possible.

During operation of an rf sputtering system it can be observed that the reflected power tends to increase in value, due to changes in the impedance of the sputtering system that are caused by several factors. For example, surfaces in the system that are initially electrical conductors become insulated by the deposition of sputtered SiO_2, and this condition necessitates frequent adjustment of the matching network. The desirability of having the matching network automatically compensate for these changes is evident.

Since an impedance Z may be expressed as $Z = |Z| \angle \theta$, it is necessary only to measure the magnitude and phase angle of the impedance to determine it uniquely. Hence, to monitor the impedance, two conventional detectors,[2] a phase detector adjusted to 0° and a magnitude detector adjusted to 50 Ω, are placed in the transmission line.

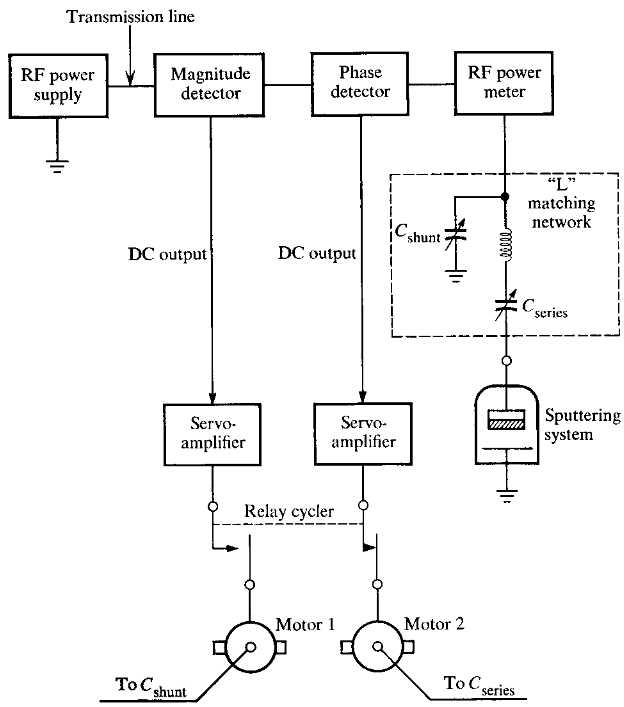

Figure 1 Block diagram of impedance matching system.

It should be made clear that the impedance being monitored is that of the matching network and sputtering system combined. The dc output signals of these detectors are used with servo-amplifiers to adjust the matching network. There are, however, three interrelated problems to be considered before the output signals can be used to adjust the matching network:

The first is that the adjustments of the shunt and series capacitances in the matching network are not independent; that is, they each affect both the phase and magnitude of the monitored impedance.

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The second is that any particular adjustment of one of the capacitors may produce opposite polarity signals from one of the detectors; for example, if the shunt capacitance is increased while the series capacitance is held constant, the magnitude detector may produce a positive output but, if the series capacitor is set to a new value, the same increase in shunt capacitance may lead to a negative output from the magnitude detector.

The third problem is that the impedance of the sputtering system, a glow discharge chamber, is dependent on the rf voltage supplied to it. This voltage is in turn a function of the matching network component values. Hence, matching the sputtering system to the transmission line becomes analogous to the "dog chasing its tail."

The following approach was used to surmount these problems. After starting with the sputtering system properly matched and operating, the capacitors in the matching network are adjusted to obtain representative combinations of capacitance that are near the "matched values." (The polarities of the detector outputs for various capacitor combinations are given in Table 1.) In an ideal case each detector output would follow one capacitor; that is, the output would be zero when the capacitor was at "match," positive (negative) for an increase in capacitance, and negative (positive) for a decrease in capacitance from the "match" value. This procedure would then be repeated for the other capacitor and detector. Thus it is apparent that under ideal conditions there would be no difficulty in using the detector outputs with servo-amplifiers to bring the system to a matched condition. Examination of the actual detector outputs in Table 1 indicates the choices that should be made: The shunt capacitor should be controlled by the magnitude detector output, with a positive output causing the shunt capacitance to increase; the series capacitor should be controlled by the phase detector output, with a positive output causing the series capacitance to decrease. Several possibly troublesome situations arising from the aforementioned choices are denoted by asterisks in Table 1. In the first situation, the series capacitance is decreased and the phase detector output is positive, decreasing series capacitance even further. This response, of course, tends to increase the mismatch. However, since the detector outputs are not independent, the output of the magnitude detector will change, causing the shunt capacitance to change, thereby further altering the detector outputs. There is thus a high probability that a "correct" detector output state will be reached and the system brought back to the matched condition. This process also occurs for the other conditions in Table 1. Hence, the first two problems have been satisfactorily dealt with. The third problem can be eliminated by allowing only one capacitor to be adjusted at a time. In this way the system will iteratively tune itself until it achieves a matched condition under which each detector output will be zero. A block diagram of the entire matching system is shown in Fig. 1.

Table 1 Relationship of detector output to capacitance changes.

Shunt capacitance	*Series capacitance*	*Output of magnitude detector*		*Output of phase detector*	
		Ideal	*Actual*	*Ideal*	*Actual*
0	0	0	(0)	0	(0)
0	+	0	(0)	+	(+)
0	−	0	(0)	−	(+)*
+	−	+	(−)	−	(−)
+	+	+	(+)*	+	(+)
+	0	+	(−)	0	(0)
−	0	−	(+)	0	(0)
−	+	−	(+)	+	(−)*
−	−	−	(+)	−	(−)

For capacitors: 0 indicates that capacitance is at the value necessary for a proper match.
+ indicates a fixed increase in capacitance from match values.
− indicates a fixed decrease in capacitance from match values.
For detectors: 0 indicates the output for the matched condition.
+, − indicate the polarity of the detector output voltage
*Incorrect adjustment; see text.

The automatic system is limited in that it cannot achieve a proper match when starting from a severely mismatched condition. However, this limitation is of little consequence since a normally operating sputtering system exhibits rather gradual impedance changes that are corrected well before the system becomes severely mismatched.

In addition to the convenience it affords, the automatic matching system has, by eliminating a troublesome variable, proved useful in the improvement of the overall rf sputtering process.

References

1. J. S. Logan, N. M. Mazza and P. D. Davidse, "Electrical Characterization of an RF Sputtering Gas Discharge," presented to the Fifteenth National Vacuum Symposium, Pittsburgh, October 30 to November 1, 1968.
2. V. True, "Automatic Antenna Matching System," *Electronics* **24**, 98 (1951).

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