Simulation of Coaxial Matching in RF Amplifier for Heavy Ion (up to Uranium) RFQ based LINAC to be used as a tool for Nuclear Physics Studies

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Introduction

An Alternate ECR based injector is being developed for the Superconducting LINAC booster at TIFR which would vastly enhance the capability of the LINAC as a research tool for nuclear physics studies [1]. As a part of this development, a prototype RFQ needs to be tested. This requires an RF source of 1 kW at 75 MHz. For this an RF amplifier was designed around pentode 5CX1500A [2]. A critical part in the design and during RF testing was matching the input and output impedance of the tube to the adjacent stages for achieving maximum power transfer. This was done using lumped component based matching networks. The capacitors used in output matching network were rated for high RF voltage and high power operation, but up to only 40 MHz. Hence during operation at 75 MHz, these capacitors were not exhibiting capacitive reactance and were dissipative in nature and so were becoming hot. Therefore, another scheme based on coaxial transmission lines (a distributed component) had to be designed for matching the tube output. This paper describes the design and simulation of a coaxial transmission line with stub which could replace the lumped output matching network of the amplifier in [2].

Transmission line with stub

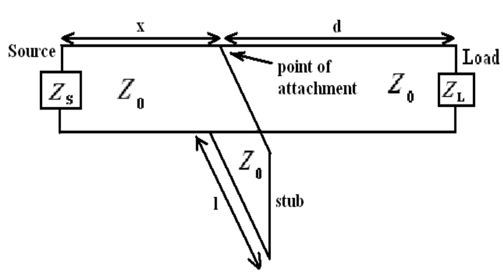

Fig. 1 Stub attached to a transmission line

The stub transmission line matching network consists of three sections as shown in Fig. 1. The characteristics of this matching network are dependent on the characteristic impedance (Z_0) of the three coaxial transmission line sections and their lengths: x, d, and l as shown in Fig. 1.

Output impedance calculation

The electrical equivalent of 5CX1500A tube output is a parallel combination of a capacitor C_{out}, corresponding to the inter-electrode capacitance across anode and cathode, and a resistance R_{out}, corresponding to the anode dissipation. The data sheet of 5CX1500A gives C_{out} = 16.5 pF. R_{out} is determined from the operating load line as in [3] to be 3.156 kΩ. Thus the equivalent impedance $Z_{out} = R_{out} \,//\, C_{out}$ = 5.23 – j 128.4 Ω. The matching network was designed to match this impedance to a 50 Ω load.

Output matching network design

Z_0 = 21.5 ohm [3] was taken considering airflow requirement and avoidance of voltage break-down. The stub was taken to be a shorted shunt type. Using RFSim99® a set of values for d, x and l were obtained to match the tube output to 50 Ω load.

This design was simulated using CST Microwave Studio (MWS) and Design Studio (DS). It turned out that length d is very short with respect to the wavelength and hence affects the smooth simulation of the model [4]. Hence a length of λ/2 (2 meters) was added to it since theoretically this length does not transform a purely resistive impedance.

The ratio of outer conductor diameter, b and the inner conductor diameter, a of the coaxial transmission line was determined to be

1.43 so as to obtain characteristic impedance close to 21.5 Ω.

This matching network was modeled using MWS and its S-parameters were extracted. This information was used to simulate the matching network in combination with the electrical equivalent of the tube output in DS. Fig. 2 shows the model developed in MWS inserted into a circuit developed in DS to observe the result of adding the matching network to the tube output.

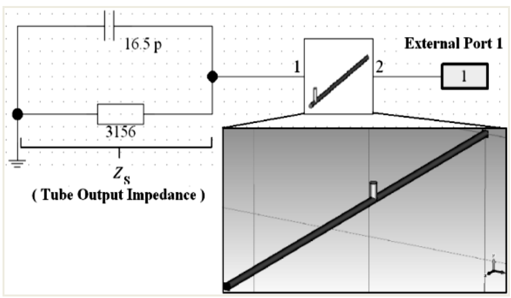

Fig. 2 Simulation of matching network in CST

Good matching was obtained by optimising the variables *d*, *x* and *l* for minimum (<-30 dB) reflection using 'Tune' and 'Optimize' tools along with manual tuning in CST DS. Table 1 shows the values of *x*, *d*, and *l* obtained using RFSim99, change made in *d* for MWS simulation, followed by the optimised values obtained in DS.

Table 1 Geometrical parameters of matching network

Length	RFSim99 result (mm)	Value in MWS (mm)	Optimised Value (mm)
x	815.6	815.6	846.92
l	79.2	79.2	55.17
d	16.4	2016.4	2103.34

The smith chart representation of the resultant impedance normalized to 50 ohm vs. frequency as observed at the external port 1 after optimizing in DS is shown in Fig. 3. Marker 1 shows the normalized impedance at 75 MHz which is approximately one. The absolute impedance obtained from the simulation is shown to be 49.9 – *j* 1.6 Ω. Fig. 4 shows the reflection loss ($S_{1,1}$) corresponding to this impedance to be -35.889 dB.

Conclusion

A practical implementation of this system would require a 1 m long coaxial transmission line and a 0.1 m long stub. If the inner conductor diameter is slightly larger than the tube anode diameter, say about 0.1 m, then to obtain the required ratio of *b/a*, the outer diameter should be about 0.143 m.

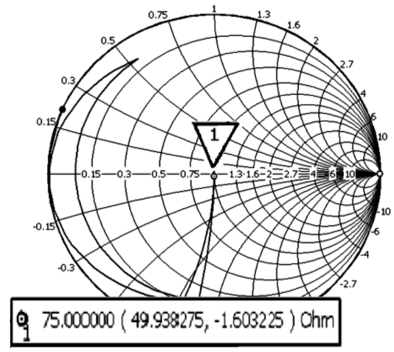

Fig. 3 Smith Chart: S1,1 vs Frequency

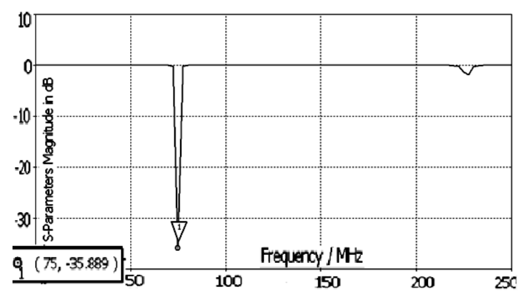

Fig. 4 $S_{1,1}$ vs. Frequency

References

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[4] CST Technical Staff, *Getting Started*. CST, 2009