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Matching Networks for Power Amplifiers Operating into High VSWR Loads

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Here is a review of transmission line, LC and broadband transformer matching networks that enable operation into high VSWR loads, with notes on high power components and a PIN diode switching circuit

Last month [1], we examined methods for characterizing power amplifiers operating into high VSWR loads, as might be found in plasma or laser driver applications. This month, we follow up that article with notes on matching networks that can handle high power and tolerate the stresses of varying VSWR.

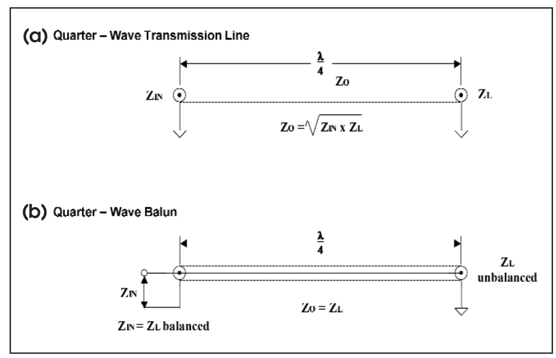

Figure 1 · (a) A quarter-wave transmission line transformer, and (b) a quarter-wave line used as a balun.

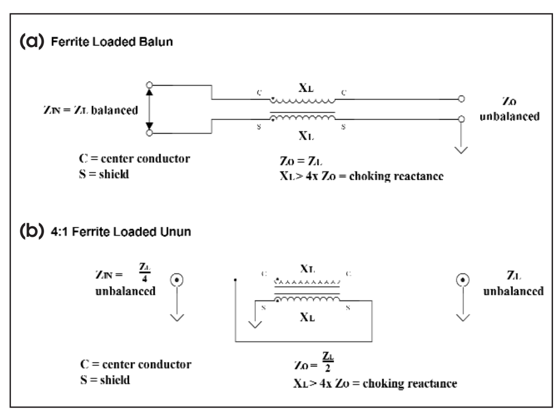

Figure 2 · (a) Ferrite-loaded transmission line used as a balun, and (b) a ferrite-loaded 4:1 transmission line transformer.

Matching Circuits and High Power Components

Matching circuits are an important part of the design of high-power RF amplifiers. A number of different types are discussed in the following sections along with components capable of withstanding the voltage and current stresses encountered.

• Transmission Line Matching

Figures 1 through 3 show a number of matching methods classified as transmission line transformers.

1. Figure 1(a) is a quarter-wave transformer whose characteristic impedance (Z_0) equals the square root of the product of $Z_{in} \times Z_L$.

2. Figure 1(b) is a quarter-wave transmission line used as a balanced to unbalanced transformer or balun.

3. Figure 2(a) is a transmission line used as a balun but loaded with ferrite cores to reduce the length. The choking reactance should be at least $4 \times Z_0$ in order to present a high impedance to common mode currents and thereby preserve the balanced to unbalanced properties.

4. Figure 2(b) is a ferrite loaded unbalanced to unbalanced 4:1 transformer known as an unun. Z_0 equals $Z_L/2$ and the choking reactance should be at least $4 \times Z_0$.

5. Figure 3(a) is a high-power transformer

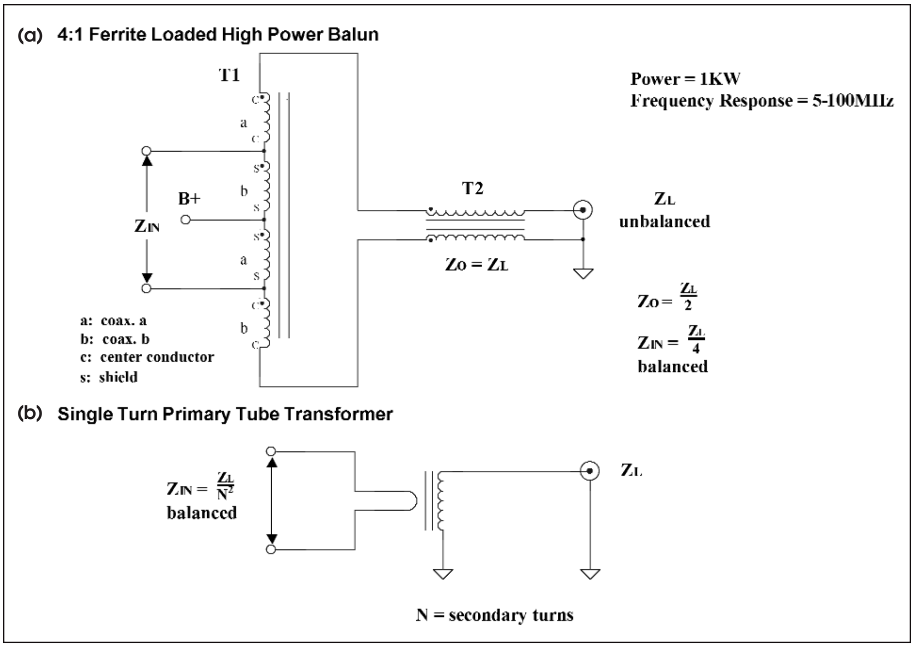

Figure 3 · (a) An improved high power 4:1 transformer with a separate balun, and (b) a conventional transformer with tightly-coupled windings.

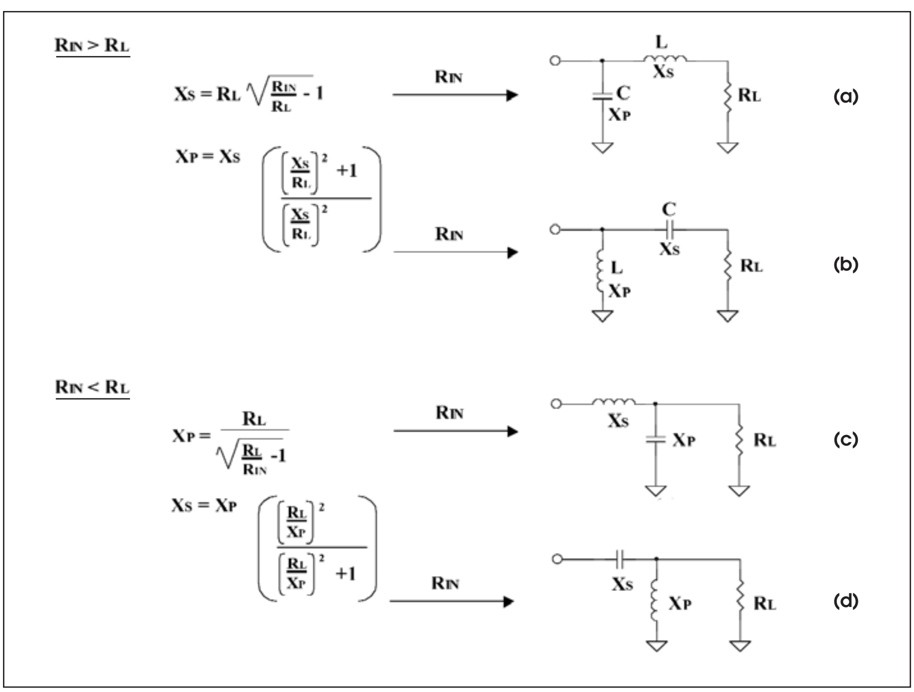

Figure 4 · LC Matching networks: (a) and (b) provide transformation to a load resistance lower than R_{in}, while (c) and (d) provide transformation to higher resistances.

using two coaxial cables wound on a common ferrite core that has a 4:1 impedance transformation. The cores are connected as shown. The power capability is 1 kW and its frequency response is 5-100 MHz. A separate balun is used to provide the balanced to unbalanced function. Z_0 of the two coaxial cables is $Z_L/2$.

6. Figure 3(b) is actually not of the transmission line class but is included for discussion. A single turn primary uses brass tubes that are loaded with ferrite toroids. A secondary is passed through the tubes and the impedance transformation varies as N^2 where N is the number of turns. This is a popular selection because of its simplicity, but is limited in bandwidth and power. The bandwidth can be extended if the secondary is made to be an unun as shown in Figure 2(b) using a semi-rigid coaxial cable. The outer conductor is insulated and placed inside of the brass tubes. The brass tubes and semi-rigid outer conductor then become a 1:1 transformer with close coupling and also provide the isolation requirements. This arrangement has been called a triaxial transformer and can extend the frequency response substantially.

• LC Matching Circuits

Figures 4 and 5 show various forms of LC matching circuits. The equations for calculating the matching components are included.

1. The circuits in Figure 4(a) and 4(b) transform R_L to a higher input R_{in} using either a series L and a shunt C, or series C and shunt L.

2. The circuits in Figure 4(c) and 4(d) transform R_L to a lower input R_{in} using either a shunt C and series L, or a shunt L and series C.

3. Figure 5(a) is a pi network that can match either a higher or lower input resistance. The pi can either be a high pass or low pass version. The low pass is a lumped constant version of a quarter wave transmission line. The inductance and capacitance values are equal to the square root of the product of $R_{in} \times R_L$.

4. Figure 5(b) is the design of a high power pi match with a 10:1 ratio between R_L and R_{in}. The component values, current and voltages have been calculated and the performance

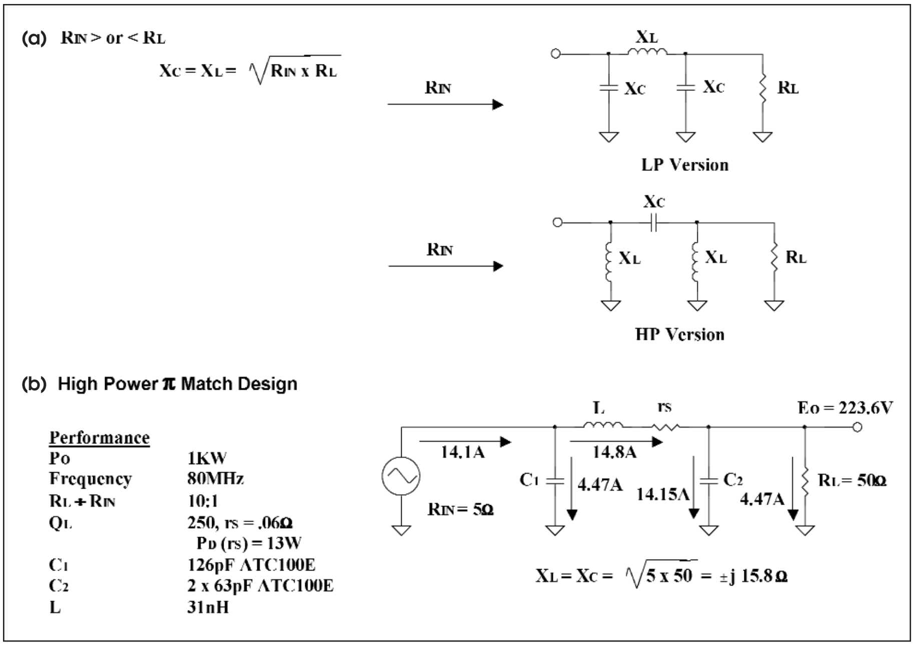

Figure 5 · High power pi network matching circuits. (a) shows the high-pass and low pass configurations; (b) is a high power pi network for a 10:1 transformation and 90-degree phase shift.

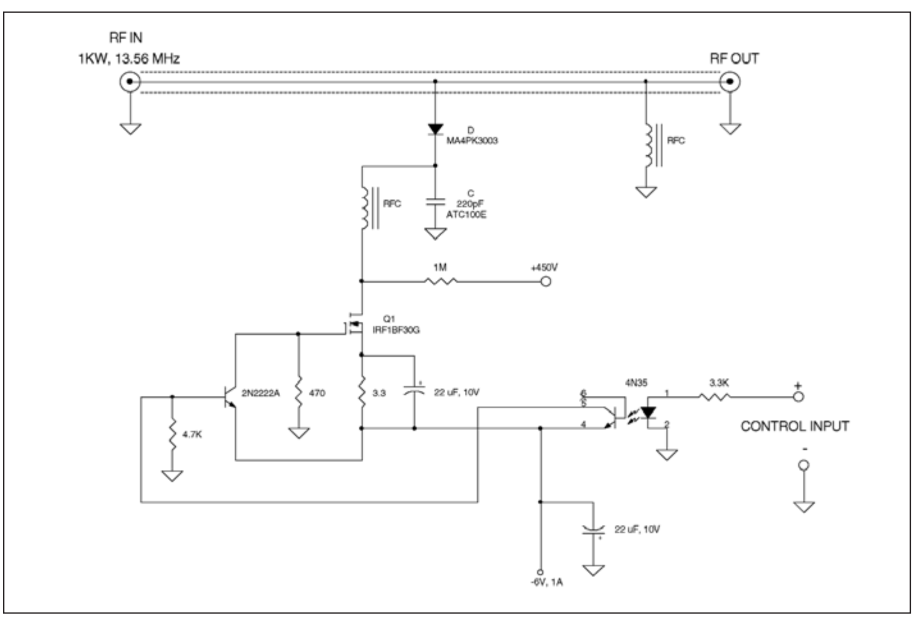

Figure 6 · A high power PIN diode switch circuit.

tabulated. The output voltage lags the input by 90 degrees and acts like a quarter wave transmission line transformer.

A High Power PIN Diode Switch

Figure 6 is the schematic diagram of a high power PIN diode switch used to switch a 220 pF ATC100E porcelain chip capacitor across a 50-ohm line for matching applications. The PIN diode is a MA4PK3003 that has a breakdown voltage of 3000 volts, a series resistance of 0.25 ohms, and a power dissipation of 50 watts. The 220 pF chip capacitor has a breakdown rating of 3600 volts and a current rating of 10 amps. A FET with a breakdown voltage of 900 volts is used to switch the pin diode on and off. A 450 volt DC voltage is used to back bias the diode in the off position. Switching speed is on the order of 10 µsec. An optoisolator connects the input to the switching circuit.

Summary

A previous article [1] demonstrated that high-efficiency amplifiers can be characterized for their ability to drive mismatched loads. Such characterization data is important for applications such as lasers, plasma chambers, ICP torches and others. Methods of testing and protection under mismatched conditions were also presented.

This article provides a summary of various matching circuits, including L networks, pi networks and transmission line transformers. The transformers include both line sections (e.g. quarter wave transformers) and ferrite-loaded broadband transformers.

High power components have also been discussed, including a PIN diode switch that can handle the high voltages and currents that can be present when matching to loads that are far from the nominal 50 ±j0 ohms of typical RF systems..

Reference

1. R. Brounley, “Mismatched Load Characterization for High-Power RF Amplifiers,” *High Frequency Electronics*, April 2004.

Author Information

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