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Back to Basics: Impedance Matching (Part 1)

Electronic Design
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The term “impedance matching” is rather straightforward. It’s simply defined as the process of making one impedance look like another. Frequently, it becomes necessary to match a load impedance to the source or internal impedance of a driving source.

A wide variety of components and circuits can be used for impedance matching. This series summarizes the most common impedance-matching techniques.

Rationale And Concept

The maximum power-transfer theorem says that to transfer the maximum amount of power from a source to a load, the load impedance should match the source impedance. In the basic circuit, a source may be dc or ac, and its internal resistance (R_i) or generator output impedance (Z_g) drives a load resistance (R_L) or impedance (Z_L) (Fig. 1):

$$R_L = R_i \text{ or } Z_L = Z_g$$

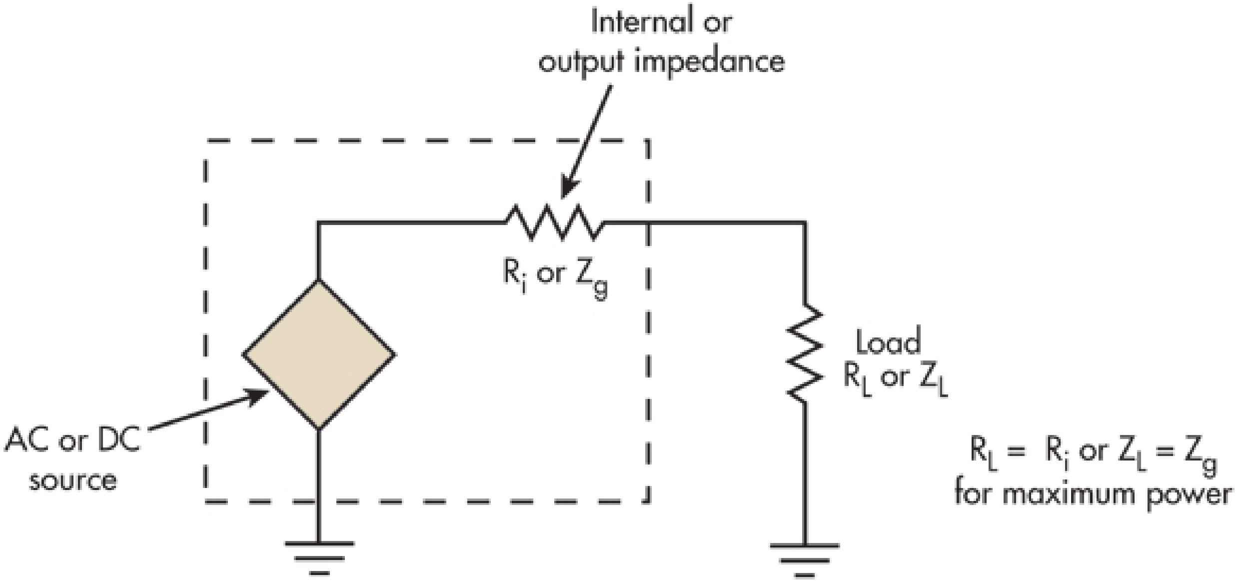

Fig 1. Maximum power is transferred from a source to a load when the load resistance equals the internal

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A plot of load power versus load resistance reveals that matching load and source impedances will achieve maximum power (Fig. 2).

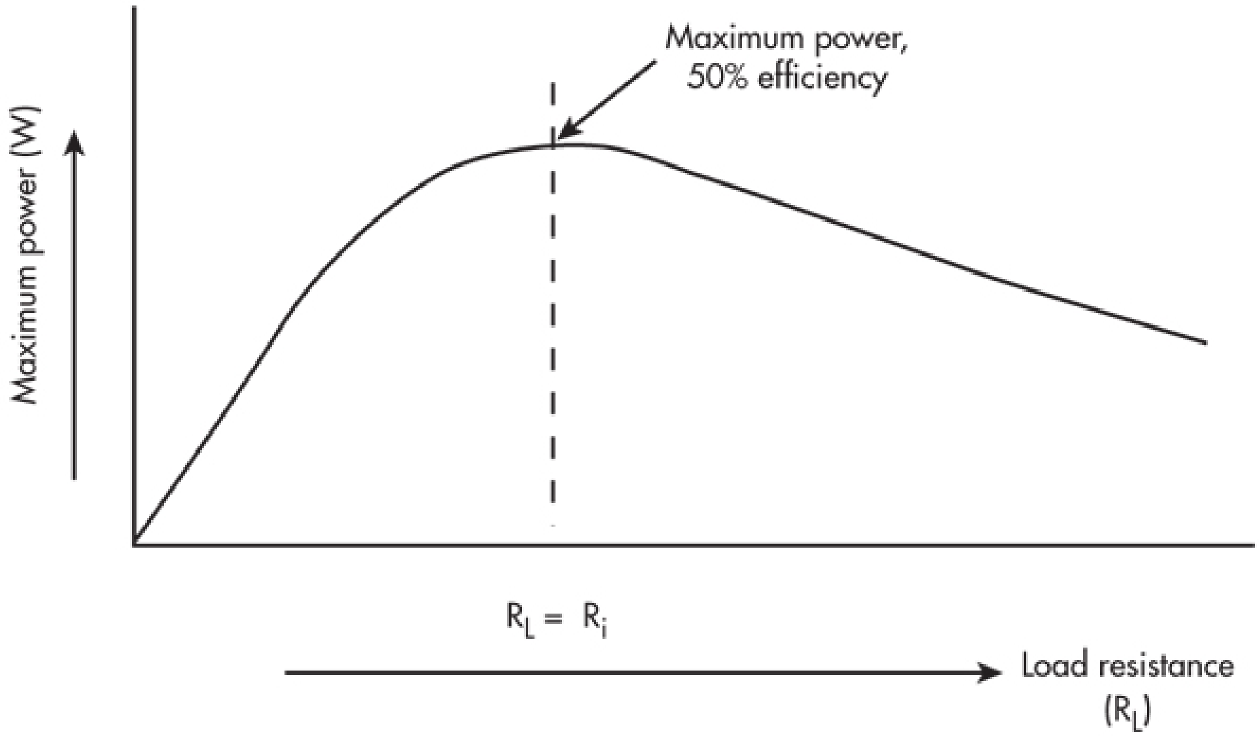


Fig 2. Varying the load resistance on a source shows that maximum power to the load is achieved by matching load and source impedances. At this time, efficiency is 50 %.

A key factor of this theorem is that when the load matches the source, the amount of power delivered to the load is the same as the power dissipated in the source. Therefore, transfer of maximum power is only 50% efficient.

The source must be able to dissipate this power. To deliver maximum power to the load, the generator has to develop twice the desired output power.

Applications

Delivery of maximum power from a source to a load occurs frequently in electronic design. One example is when the speaker in an audio system receives a signal from a power amplifier (Fig. 3). Maximum power is delivered when the speaker impedance matches the output impedance of the power amplifier. While this is theoretically correct, it turns out that the best arrangement is for the power amplifier impedance to be less mechanical response.

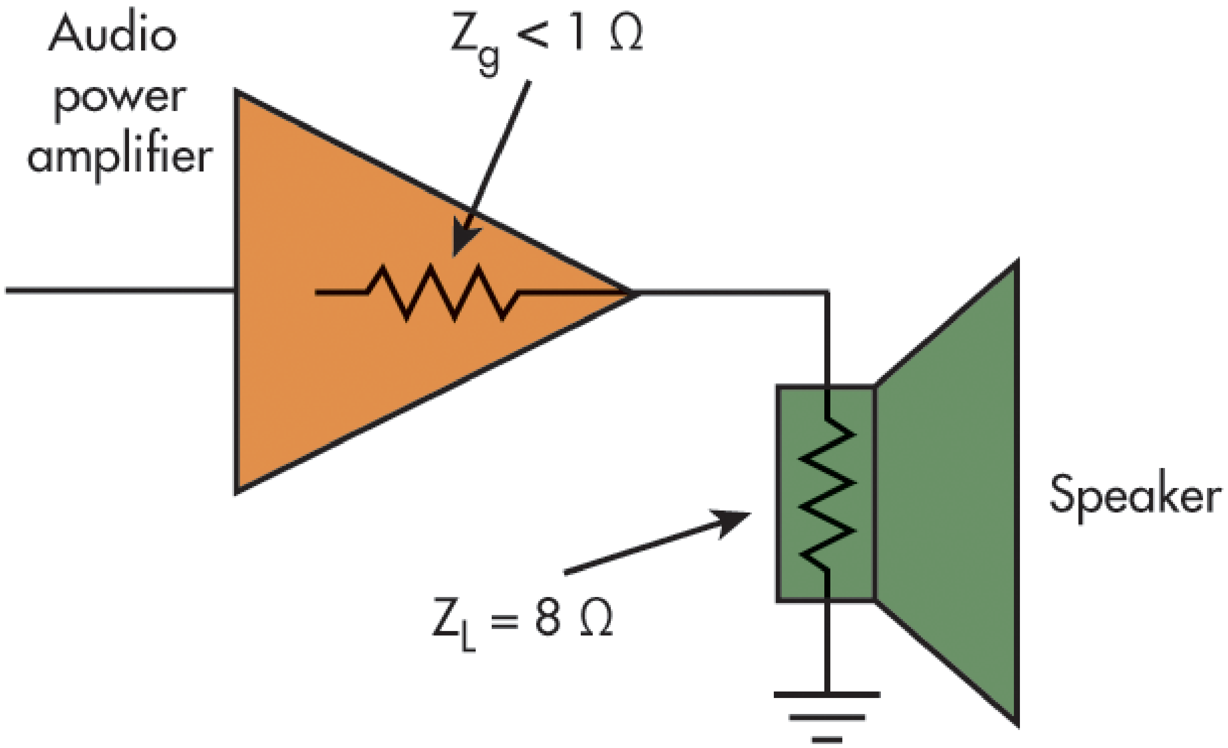
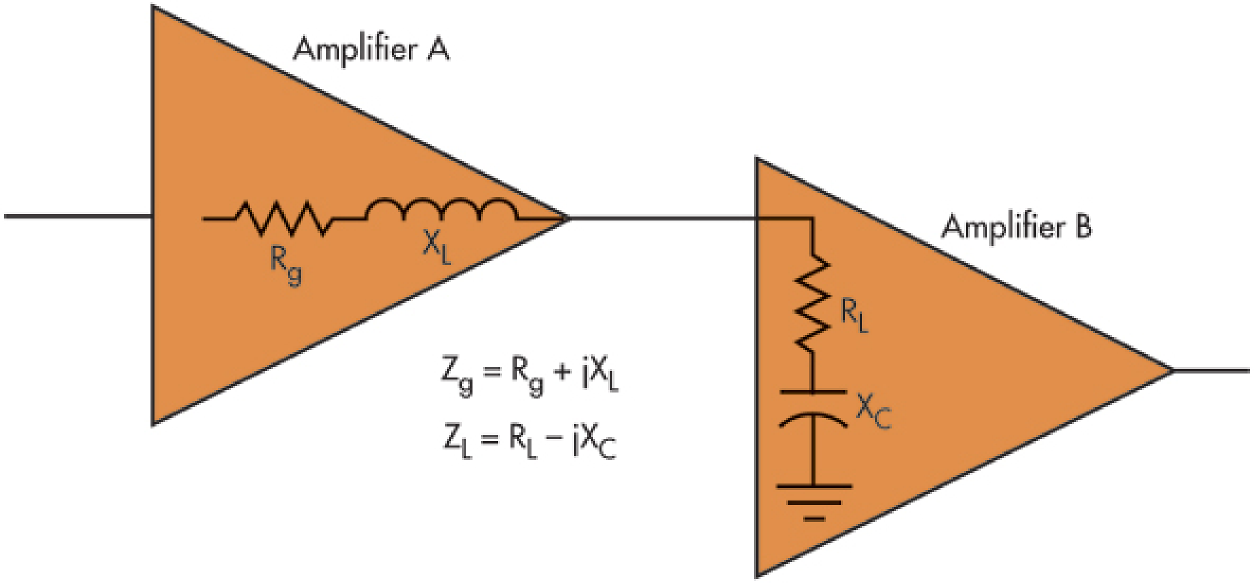


Fig 3. *Unmatchedimpedances provide the best amplifier and speaker performance.*

Another example involves power transfer from one stage to another in a transmitter (Fig. 4). The complex (R ± jX) input impedance of amplifier B should be matched to the complex output impedance of amplifier A. It's crucial that the reactive components cancel each other. One other example is the delivery of maximum power to an antenna (Fig. 5). Here, the antenna impedance matches the transmitter output impedance.



to stage. Most impedances include inductances and capacitances that must also be factored into the matching process.

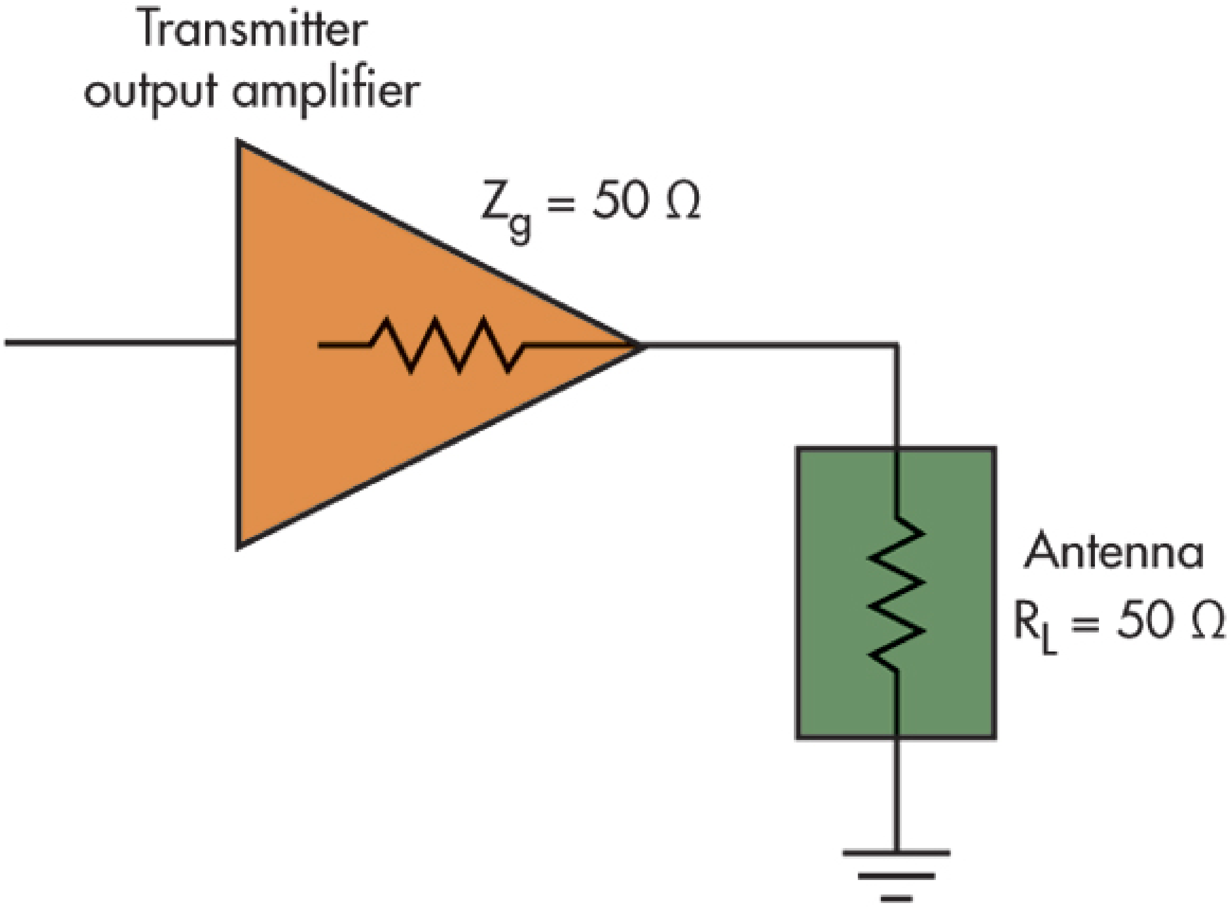


Fig 5. Antenna impedance must equal the transmitter output impedance to receive maximum power.

Transmission-Line Matching

This last example emphasizes another reason why impedance matching is essential. The transmitter output is usually connected to the antenna via a transmission line, which is typically coax cable. In other applications, the transmission line may be a twisted pair or some other medium.

A cable becomes a transmission line when it has a length greater than λ/8 at the operating frequency where:

$$\lambda = 300/f_{MHz}$$

For example, the wavelength of a 433-MHz frequency is:

$$\lambda = 300/f_{MHz} = 300/433 = 0.7 \text{ meters or } 27.5 \text{ inches}$$

A connecting cable is a transmission line if it's longer than 0.7/8 = 0.0875 meters or 3.44 inches. All transmission lines have a characteristic impedance (Z_O) that's a function of the line's inductance and capacitance:

$$Z \quad \sqrt{(L/C)}$$

To achieve maximum power transfer over a transmission line, the line impedance must also match the source and load impedances (Fig. 6). If the impedances aren't matched, maximum power will not be delivered. In addition, standing waves will develop along the line. This means the load doesn't absorb all of the power sent down the line.

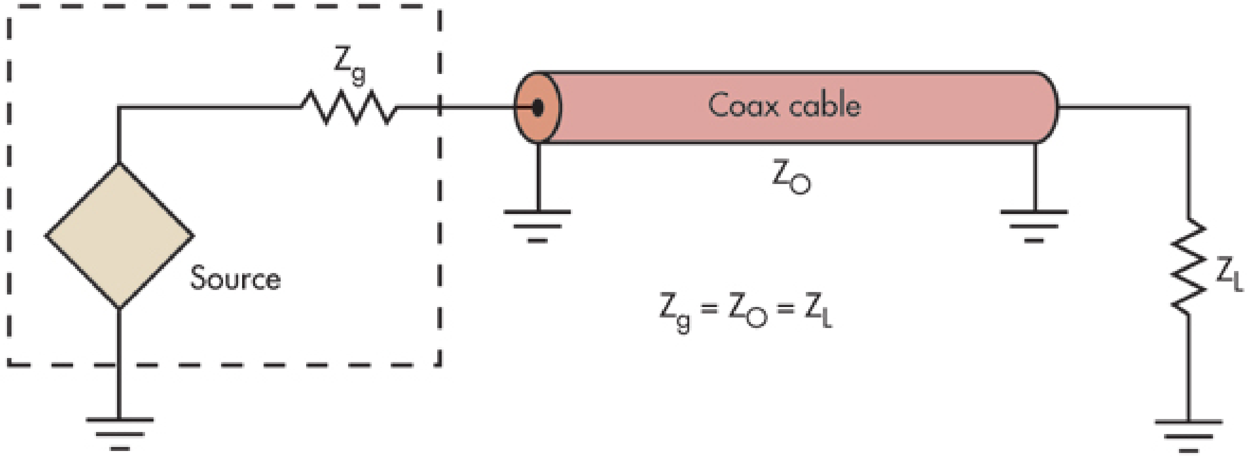


Fig 6. Transmission lines have a characteristic impedance (Z_O)that must match the load to ensure maximum power transfer and withstand loss to standing waves.

Consequently, some of that power is reflected back toward the source and is effectively lost. The reflected power could even damage the source. Standing waves are the distributed patterns of voltage and current along the line. Voltage and current are constant for a matched line, but vary considerably if impedances do not match.

The amount of power lost due to reflection is a function of the reflection coefficient (Γ) and the standing wave ratio (SWR). These are determined by the amount of mismatch between the source and load impedances.

The SWR is a function of the load (Z_L) and line (Z_O) impedances:

$$\text{SWR} = Z_L/Z_O \text{ (for } Z_L > Z_O\text{)}$$

$$\text{SWR} = Z_O/Z_L \text{ (for } Z_O > Z_L\text{)}$$

For a perfect match, SWR = 1. Assume $Z_L = 75\ \Omega$ and $Z_O = 50\ \Omega$:

$$\text{SWR} = Z_L/Z_O = 75/50 = 1.5$$

The reflection coefficient is another measure of the proper match:

$$\Gamma = (Z_L - Z_O)/(Z_L + Z_O)$$

For a perfect match, Γ will be 0. You can also compute Γ from the SWR value:

$$\Gamma = (\text{SWR} - 1)/(\text{SWR} + 1)$$

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