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High Q Capacitors for Impedance Matching

Capacitor Q is almost always a primary design consideration in RF matching applications. The capacitor's power dissipation is inversely proportional to its Q factor and directly proportional to the equivalent series resistance (ESR).

An input matching network is essential for most RF amplifier designs in order to transform the relatively low impedance of the active gain device to the system impedance. The active device's input impedance is typically in the order of 0.5 to 2 ohms and is generally matched to a 50 ohm system impedance. If we assume that a transistor in a power amplifier has an input impedance of 1 ohm, this will require an impedance transformation of 50:1. Therefore, we must trade off voltage for current as the matching network transforms the impedance from 50 ohms to 1 ohm. This will result in circulating current I_3 that is more than seven times I_{in} (see Fig. 1).

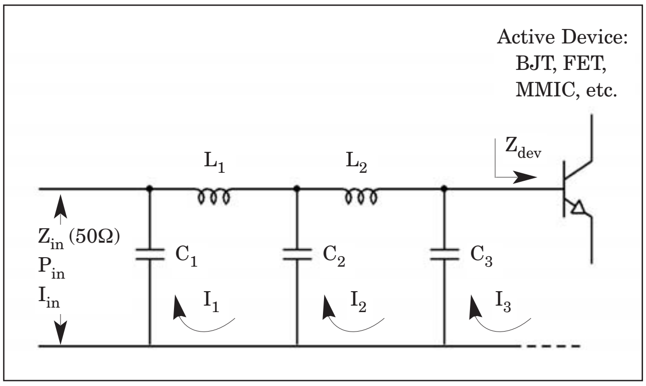

Figure 1 · Typical input matching circuit.

Reasons for Choosing High Q Capacitors

Output Capability—Low loss, high Q capacitors in matching network applications will insure maximum effective gain and available output of an amplifier. Losses due to component heating, especially in high RF power applications, are greatly alleviated with the use of high Q passive components.

Noise Figure—Small signal amplifiers such as LNAs used in satellite receiver applications require capacitors that exhibit high Q. Lossy passive components will add th thermal (kTB) noise and degrade the overall noise figure of the amplifier, thereby reducing the signal to noise ratio.

Likewise, MRI imaging coils also require extremely low loss capacitors. These applications utilize capacitors for tuning the coil in a resonant circuit, and must be transparent in that application. The signals being detected by MRI coils are sufficiently small that any loss contribution from low Q capacitors would generate increased thermal noise, making it difficult or impossible to process the signal.

Thermal Management—(Refer to Fig. 1) In extreme cases, if C_3 is very lossy, high circulating currents can cause it to get hot enough to melt solder. This can easily cause components to detach from the board as a result of excessive heat buildup. Since C_3 is physically close to the active device, any additional heat generated by the capacitor will be conducted into the transistor, thereby reducing reliability and possibly causing early device failure. Although it is desirable to mount matching capacitors physically close to the transistor's device plane for optimal RF performance, thermal management must be judiciously accounted for in these applications. Improper selection of capacitors in critical applications can easily lead to a myriad of circuit performance issues.

For example, consider the following application:

Power Amplifier @ 150 MHz
Output Power = 400 watts
System Impedance = 50 ohms

Thus: $I = \sqrt{P/Z} = \sqrt{400/50} = 2.83\ A_{rms}$

Assume that an output coupling capacitor in a 400W amplifier is a high Q device with an ESR of 0.022 ohms. Under this condition, the power dissipation of the capacitor will be $I^2 \times$ ESR, or $2.83^2 \times 0.022 = 176$ milliwatts. Power dissipation by the capacitor is directly related to the ESR, making high Q, low ESR capacitors essential for this application. Even small signal amplifiers that do not generate large currents will suffer in effective gain and overall noise figure if losses are not kept to a minimum.

High Q, low ESR capacitors such as the ATC 100B series (0805 size) have an ESR that is approximately one-third that of a typical general-purpose NPO 0805 capacitor.

Reliability—Excessive heat generated by loss capacitors will affect the reliability of the active device as well as other components in proximity to the heat source. Lossy capacitors in coupling, matching bypass and blocking applications can easily lead to reduced MTBF of the entire circuit.

This note is an edited version of "High Q Capacitors in Matching Applications," by Richard Fiore. This is one of several technical notes in the Circuit Designer's Notebook, *available from American Technical Ceramics (an AVX Company), www.atceramics.com*