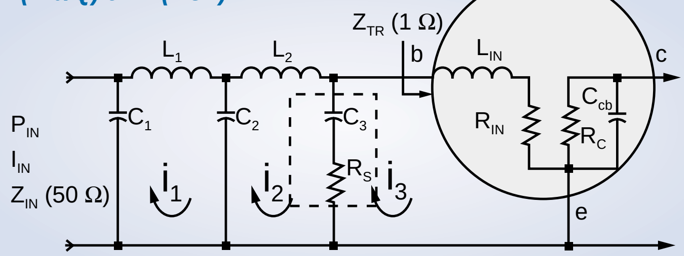
CIRCUIT DESIGNER'S NOTEBOOK

High Q Capacitors in Matching Applications

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

Capacitor Power Dissipation,
Pd = i^2 ***(Xc/Q) or*** i^2 ***(ESR).***



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. Lets 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 signal impedance from 50 ohms to 1 ohm. This will result in circulating current (i_3) to be more than seven times I_{IN}. See Fig 1.

Reasons for designing High Q capacitors into matching networks:

Output Capability – Low loss High Q capacitors in matching network applications will insure maximum effective gain and available output of the 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 LNA's used in satellite receiver applications require capacitors that exhibit high Q. Lossy passive components will add to 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 Fig1). In extreme cases, If C_3 is very lossy, it can get hot enough to melt solder due to high circulating currents. This can easily cause components to de-solder from the board as a result of excessive heat build up. Since C_3 is physically close to the active device, any additional heat generated by the capacitor will be reflected 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.

Example: Consider the following application:

Power Amplifier @ 150 MHZ

Output Power = 400 W.

System Impedance = 50 ohm.

$I = \sqrt{P/Z} = \sqrt{400/50} = 2.83$ A. rms.
Assume that an output coupling capacitor in a 400W amplifier has an ESR of 0.022 ohms. Under this condition power dissipation of the capacitor will be i^2 X ESR or $2.83^2 \times 0.022 = 176$ milliwatts. In this example we see that the power dissipated by the capacitor is directly related to the ESR, making Hi Q low ESR capacitors quintessential 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.

The following table shows typical power dissipation as a function of ESR at octavely related frequencies. The ATC 100B series, 220pF capacitor is compared to a typical 0805 NPO 220pF.

Frequency (MHz)	ESR (ohm) ATC 180R 220pF	Power Dissipation (W) ATC 100B 220pF	ESR (ohm) Typical 0805 NPO 220pF	Power Dissipation (W) Typical 0805 NPO 220pF
150	0.025	**0.200**	0.08	**0.640**
300	0.035	**0.280**	0.113	**0.904**
600	0.049	**0.392**	0.159	**1.272**
1200	0.069	**0.552**	0.224	**1.792**

Reliability – Excessive heat generated by lossy capacitors will affect the reliability of the active device as well as other components associated with or in close proximity to the heat source. Lossy capacitors in coupling, matching, bypass and blocking applications can easily lead to decreased MTBF of the entire circuit.

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