CIRCUIT DESIGNER'S NOTEBOOK

ESR Loss Factors

The summation of all losses in a capacitor is called Equivalent Series Resistance, (ESR) and is typically expressed as milli-ohms. ESR losses are comprised of both dielectric loss (Rsd), and metal loss (Rsm).

ESR = Rsd+Rsm

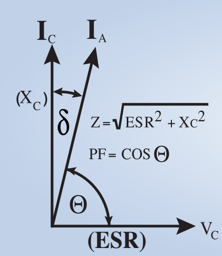
Dielectric loss (Rsd) is determined by the specific characteristics of the dielectric material. Each dielectric material has an associated loss factor called loss tangent. The loss tangent is numerically equal to the dissipation factor (DF) and is a measure of loss in the capacitor's dielectric at RF frequencies. The effect of this loss will cause the dielectric to heat. In extreme cases thermal breakdown may lead to catastrophic failure. The dissipation factor (DF) provides a good indication of the dielectric loss, and is typically measured at low frequencies e.g. 1MHz, where this loss factor is predominant.

Metal loss (Rsm) is determined by the specific conductive properties of all metallic materials in the capacitor's construction. This includes electrodes, terminations plus any other metals such as barrier layers etc. The effect of Rsm will also cause heating of the capacitor. In extreme cases thermal breakdown may lead to catastrophic failure. These losses encompass ohmic losses as well as 'skin effect' losses at frequencies typically above 30 MHz for most MLCs.

The following table illustrates the contribution of dielectric and metal losses for a 22pF ATC180R series capacitor. The losses are tabulated at various frequencies and are added together to yield ESR. Note that the dielectric losses are predominant at the lower frequencies and diminish at higher frequencies. The converse is also true for metal losses. Other capacitor values have the same pattern with different splits between Rsd and Rsm.

Frequency (MHz)	Capacitor (pF)	Rsd (m-ohm)	Rsm (m-ohm)	ESR (m-ohm)
1	180R220	145	7	152
3	180R220	48.2	7.8	56
30	180R220	4.82	9.18	14
300	180R220	0.48	28.51	29

Catalog ESR curves typically denote ESR values for frequencies at or above 30 MHz, where the losses are predominantly due to Rsm. At these frequencies the dielectric losses are virtually transparent and do not significantly influence the overall ESR.



ESR =	Q =	DF =	X_C =
$X_C \times DF$	$1/DF$	$1/Q$	$1/2\Pi \times F \times C$
X_C / Q	X_C / ESR	ESR / X_C	ESR / DF
$X_C \times \tan\delta$	$1/\tan\delta$	$\tan\delta$	$ESR \times Q$

Table 2: Relationship between ESR, Q, DF and Xc

Example:
Given a 100pF capacitor with an ESR of 18 milli-ohms (due to Rsm) @ 30 MHz, what is the ESR of this capacitor at 120 MHz?

Solution:
Take the square root of the ratio of the two frequencies

$\sqrt{120/30} = \sqrt{4} = 2$

Answer:
The ESR at 120 MHz is two times higher or 36 milli-ohms.

In most instances it is important to consider ESR and Q for designs at high frequencies and DF for designs at lower frequencies. The general rule is that DF is a factor that will help the design engineer evaluate Rsd losses at low frequencies, usually well below 10 MHz, while ESR and the associated Q value are virtually always associated with Rsm losses at higher radio frequencies i.e. above 30 MHz through microwaves.

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