

## HIGH FREQUENCY LOSS MODELING USING UNIVERSAL RELAXATION

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Universal relaxation with, values of  $n$  close to 1, has been observed in thin film barium strontium titanate (BST) from 1 mHz to 20 GHz [1]. Although it is not an intrinsic loss mechanism, it is generally dominant at frequencies below 100 GHz [2]. In addition to BST, we have also observed this behavior in strontium titanate and bismuth zinc niobate. Because of the simple form of the relationship between the real and imaginary parts of the dielectric susceptibility, we can use measured capacitance data that fits this model to calculate a corresponding  $Q$  for the capacitance. By fitting our capacitance data to equation 1 we obtain values for  $C_\infty$  and  $n$ . Equation 2 shows the expression we use to calculate  $Q$  directly from our measured capacitance data.

$$C = C_\infty + C_0 \left( \frac{f}{f_0} \right)^{1-n} \quad \text{where } 0 < n < 1 \quad (1)$$

$$Q = \left( \frac{C(f)}{C(f) - C_\infty} \right) \tan \left( \frac{n\pi}{2} \right) \quad (2)$$

Figure 1 shows the equivalent circuit for a parallel plate capacitor. The series components reflect electrode and electrode-film interface contributions to device measurements. The only resistances reflected our calculated  $Q$  values are those that appear in parallel with the capacitance. Figure 2 shows the results of our  $Q$  calculations for two devices from the same sample. The first device was measured at low frequencies using an impedance analyzer so that we could compare the measured and calculated  $Q$  results. The second device was measured at high frequencies using a network analyzer. The high frequency calculated  $Q$  values agree with the low frequency values, demonstrating the validity of this approach.

We can then use this calculated  $Q$  to evaluate the different contributions to the measured  $Q$ . Most notably, we can use the calculated  $Q$  as a way to estimate the frequency dependent resistance associated with the electrode-film interfaces. Figure 3 shows calculated  $Q$  values together with  $Q$  values obtained using resistance values from the network analyzer measurement. The corrected network analyzer  $Q$  refers to a data where part of the electrode resistance of accounted for by the measurement of a shorted device structure where the film has been completely etched away during processing. By comparing corrected network analyzer data with calculated  $Q$  values, we can obtain the frequency dependent series electrode resistance.

[1] J.D. Baniecki, R.B. Laibowitz, T.M. Shaw, P.R. Duncombe, D.A. Neumayer, D.E. Kotecki, H. Shen, and Q.Y. Ma, *Appl. Phys. Lett.*, **72**, 498-500 (1998).

[2] A.K. Tagantsev, V.O. Sherman, K.F. Astafiev, J. Venkatesh, and N. Setter, *J. Electroceramics* **11**, 5 (2003).

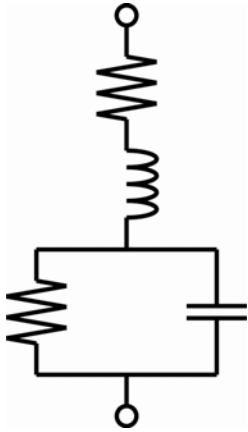


Figure 1. Equivalent circuit for a parallel plate capacitance. The series resistance and inductance are electrode contributions.

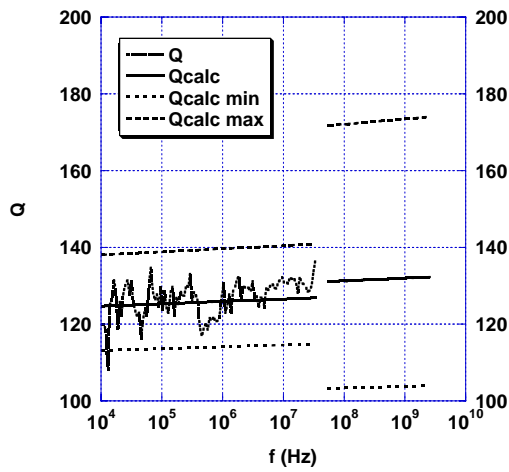


Figure 2. Comparison of calculated  $Q$  values ( $Q_{calc}$ ) with measured  $Q$  values ( $Q$ ) for a BST parallel plate capacitor.

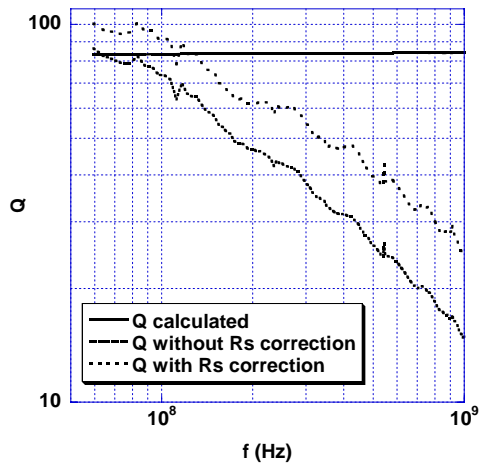


Figure 3. Comparison of calculated  $Q$  with  $Q$  values obtained from measured resistance both with and without a measured series resistance correction.