Microelectronics Inc.

August 15, 2015

MLCC (Multi-Layer Ceramic Capacitor) Resonances and SPICE MLCC Models

The SPICE models shown below represent a MLCC (Multi-layer Ceramic Capacitor). The traces originate from vector network analyzer **(VNA)** measurements (except for **"Rs"**). The more complex model represents the capacitor more accurately, which is important for higher frequency applications since it includes the 1st **PRF** (parallel resonant frequency), which is part of a recurring series of PRFs. For the simpler model, which simulates only the **SRF**, the intrinsic capacitance is represented by **"Cs"**, and the parasitic inductance by **"Ls"** (which is obtained from **Table A** below). For the more complex model**, "Ls", "Cs", "Cp"**, and **"Rp"** are determined by the comparing the measured data to the model. For both models, the equivalent series resistance (ESR) is represented by **"Rs"**. All of the values have some degree of frequency dependence, some more, some less.

"Rs" will rise significantly as the frequency rises. Above 300MHz, when the skin effect of the electrode metal losses dominate the total ESR; if the ESR at a lower frequency is known, the following formula can be used to estimate the ESR at the higher frequencies: ESR_{HF}= ESR_{LF}(Sq. Rt.(HF/LF))
For example, if the ESR is measured as 0.06 ohms at 500MHz, the ESR at 1000 MHz can be calculated as follows: $ESR_{1000MHz}$= 0.06(Sq. Rt. (1000/500))= 0.06*Sq. Rt. (2)= 0.06*1.414= 0.084 ohms

A simple model of a capacitor is shown in **Figure A**. This model will simulate the **SRF** (series resonant frequency) of the part as well as the loss in the low-loss section of the part. **"Cs"** represents the intrinsic capacitance of the part measured at low frequency. Do note that the **"Rs"** in our model increases as frequency increases (see the preceding paragraph). Do also note that the **"Ls"** in our model will vary depending on the physical length and other dimensions of the part (see **Table A**). Above the **SRF**, the sign of the reactance reverses, and the MLCC becomes a DC blocking "inductor".

IMPORTANT: Do note that it is inaccurate to use the loss number obtained from the VNA measurement to determine the **"Rs"** value. That is because the inherent calibration of the VNA is on the same order as the number to be measured. Use the loss obtained from the resonant line technique to determine this parameter. Use the VNA to determine **"Ls"** and therefore the SRF and PRF frequencies.

The Agilent 8722D using the 85052B cal. kit claims a S21 mag. uncertainty of **0.03 dB** in the 0.5 – 2 GHz range at ~ 0dBm mag. and **0.08 dB** in the 2 – 8 GHz range. This information was extracted from the S21 uncertainty graph in the 8722D user's manual. The typical low-loss area of a MLCC will show a measurement of **0.01 ~ .1 dB**. In addition, TRL calibration is typically used for this kind of component measurement where the reference plane is where the fixture contacts the MLCC.

IMPORTANT: Over ~ 1 GHz, the SRF can vary ~-40% / +20% for a given part depending on its mounting style, that meaning series versus shunt and/or the dielectric constant of the PCB the part is mounted on.

In the following **example** regarding the SRF-only SPICE model of a MNR03 (EIA 0603) 10pF MLCC (see **Figures A and B**), use the following values:

Cs = 10pF
Rs = 0.09 ohm   (from the measurement using the resonant line technique)
Ls = 0.24 nH (**the SRF [and so the simulated Ls] can vary** ~ +20% / -40% depending on mounting config.)

For various sizes, un-mounted **"Ls"** values in the SRF-only SPICE model are as per **Table A**:

Table A

AFM P/N	MNR/ANR01	MNR/ANR02	MNR/ANR03	MNR/ANR05	MPR/ANR11	MPR/ANR12
EIA Size	0201	0402	0603	0805	0505	1111
Ls	0.13 nH	0.19 nH	0.24 nH	0.29 nH	0.28 nH	0.57 nH

For other capacitance / frequency values, the resistance of **"Rs"** can be taken off of the ESR graph in the AFM Microelectronics data sheet for the particular part in question.   This ESR ("Rs" in our model) is measured data taken using the industry standard resonant line method.

Figure A

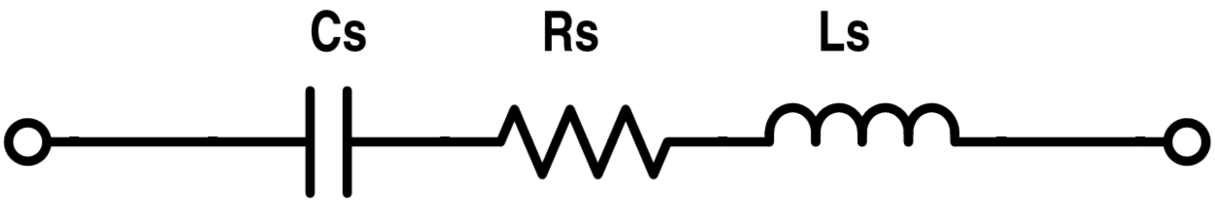
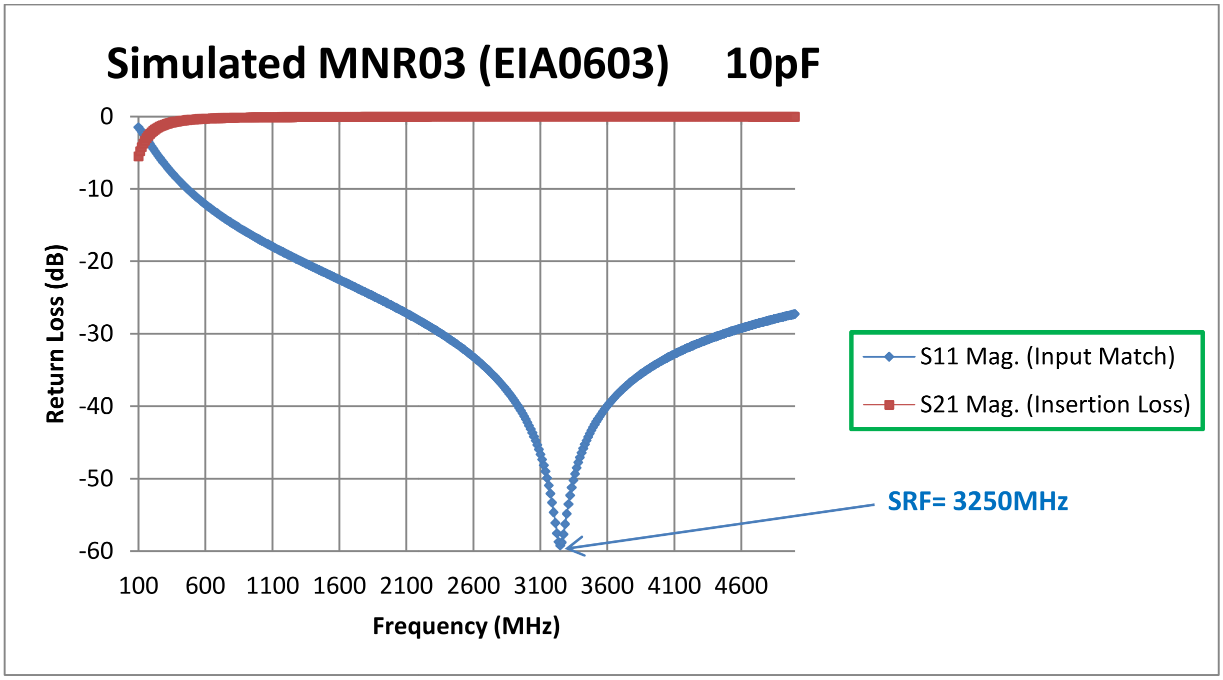


Figure B



The advantage of the following more complex model is that it can also simulate the 1st PRF (parallel resonant frequency) where there is an insertion loss dip. Significantly, not all of the parasitic element values can be directly taken from the graphical data. In our example regarding the SRF / PRF more complex SPICE model of a MNR03 (EIA 0603) 10 pF MLCC (see **Figures C and D**), use the following values:

Ls= 0.50 nH (**the SRF [and so the simulated Ls] can vary** ~ +20% / -40% depending on mounting config.)
Cs= 4.8 pF; Cp= 5.2 pF; Rp=78000 ohms
Rs= 0.09 ohms @ 900 MHz as measured using the resonant line technique.

Figure C

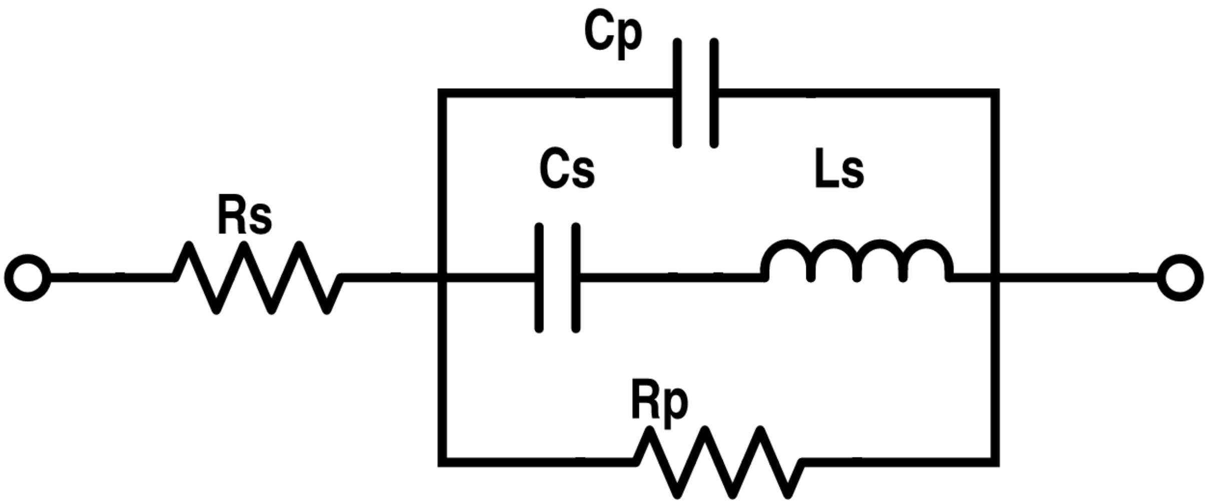
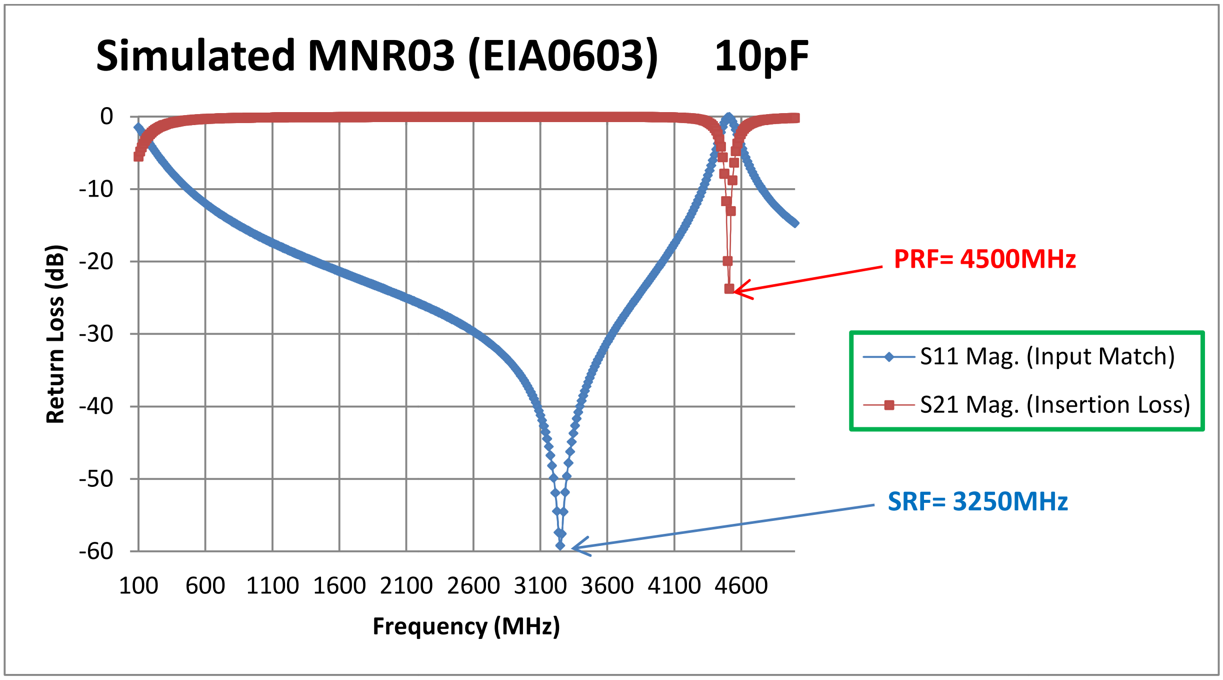


Figure D



AFM Microelectronics is a manufacturer of various kinds of MLCCs including high frequency, high-Q; high-temperature; and high current types.

For more information, or for quotes, samples, or the placing of orders, please contact AFM Microelectronics at:

775-800-7919 Sales & Technical Support; Edward Schoepke; Ed.Schoepke@afmmicroelectronics.com

Or

858-222-1199 AFM Microelectronics factory at:

9040 Carroll Way, Suite 3, San Diego, California 92121; www.AFMmicroelectronics.com