Capacitor Self-Resonance

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Objective

This Experiment will demonstrate some of the limitations of capacitors when used in Radio Frequency circuits.

After completing the experiment, the student should be able to

   a.   Measure the self-resonant frequency of a capacitor.
   b.   Measure the corresponding equivalent series resistance.
   c.   Avoid the problems associated with connecting capacitors in parallel.
   d.   Select suitable capacitors for various decoupling and coupling applications.

Equipment

- Spectrum Analyser with Tracking Generator up to 1 GHz.
- 50 ohm Microstrip Test Jig (See Appendix)
- 2 off Coax Cables, 50 ohm BNC to BNC, 0.5m long
- 10dB BNC Coaxial Attenuator (Pad)
- Various capacitors

Equipment Set-Up

Connect the equipment as shown in Fig. 1. Remove any capacitors from the Test Jig and check that the insertion loss is 10 dB over the entire frequency range of the spectrum analyser. Any small variation can be corrected by normalising the display. Always have at least 10dB on the input attenuator of the spectrum analyser.
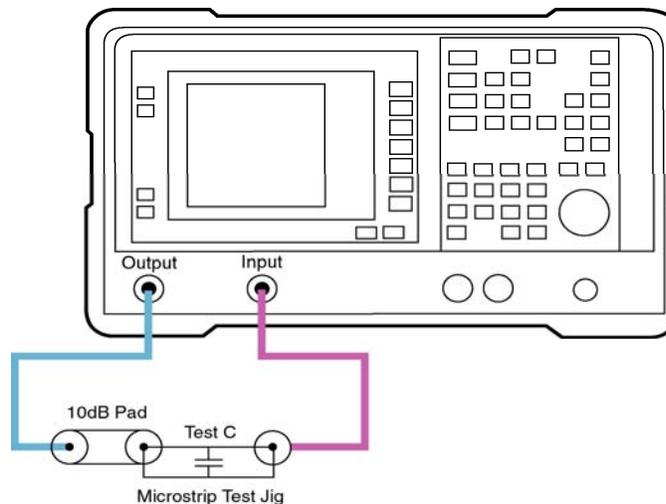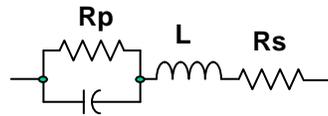

Fig. 1 Equipment Set-up

Theory

Fig. 2 Capacitor equivalent circuit

Figure 2 shows the equivalent circuit of a capacitor. R_p, the parallel leakage resistance is usually many Megohms and can be ignored at RF.

The inductance L is mainly due to the leads of the capacitor. The electrode structure has inductance but is usually only significant in leadless surface mounted types and large capacitors with spiral wound electrodes.

At the self-resonant frequency of the capacitor the impedance (|Z|) will be equal to the series loss resistance R_s.
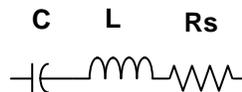

Fig. 2a. Equivalent circuit assuming Rp = infinity
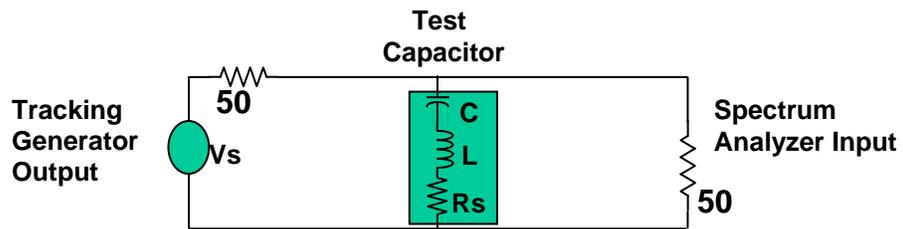

Fig. 3   Equivalent measurement circuit

From the equivalent circuit at resonance, Fig. 3, we can calculate the attenuation. Here we assume the system impedance is 50 ohms.

With the test capacitor (Z) disconnected, the input voltage to the spectrum analyser (Va) will be
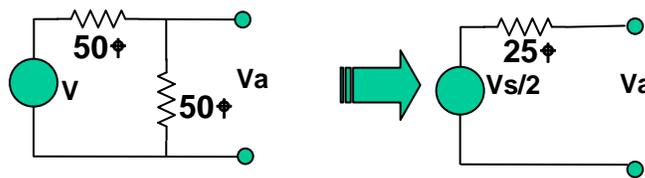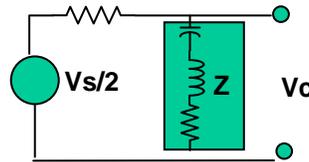
$$Va = \frac{Vs}{2}$$

Fig. 3a Thevenin Equivalent of source

With the test capacitor (Z) connected, the input voltage to the spectrum analyser (Vc) will be:

$$Vc = \frac{Vs}{2}\left\{\frac{Z}{25+Z}\right\}$$

At resonance the insertion loss (A) will be due to the equivalent series resistance (Rs)

$$A = \frac{Vc}{Va}$$

$$= \frac{Rs}{25+Rs}$$

$$\text{Therefore} \quad Rs = \frac{25 \cdot A}{1-A}$$

Or, if the insertion loss (Ad) is measured in dB then:

$$Rs = \frac{25 \cdot 10^{\left(\frac{Ad}{20}\right)}}{1-10^{\left(\frac{Ad}{20}\right)}}$$

Measurements

To make accurate measurements it is essential the output and input impedance of the tracking generator and spectrum analyser respectively are equal; this is usually 50 ohms. In addition, the characteristic impedances of all the cables, connectors and Test Jig must match this impedance.

A 10 dB Pad reduces any error due to the source mismatch. During the experiment, try making measurements with and without this pad to see if you can detect any change. Also, try putting the pad on the other port of the Test Jig to see if there is any change due to the input connection to the spectrum analyser. Note that you should have at least 10 dB selected on the input attenuator of the spectrum analyser to improve the input match.

Connect a 1 nF ceramic capacitor with 2-mm long leads (4 mm total) to the centre of the Test Jig. Measure the maximum insertion loss and corresponding self-resonant frequency. Tabulate your results as shown below calculating Rs, L and Q.

Continue measuring a range of different types of capacitors. Experiment with different lengths of lead on the same capacitor. Tabulate your results as before.

Reconnect a 1nF short lead capacitor to the centre of the Test Jig. Connect a 10nF capacitor in parallel with this. Note any changes in the insertion loss over the full 1 GHz sweep range.

Are there any frequencies where the insertion loss is less than that with a single capacitor? Replace the 10 nF with a 100pF short-leaded capacitor. Can you predict, from your previous measurements on single capacitors, where a minimum attenuation peak may occur? Experiment with a range of different capacitors noting their effect on insertion loss.

Does connecting the parallel capacitor at a different point on the microstrip line make any difference to your results?

Finally, connect a short wire link in place of the test capacitor. Is the attenuation now infinite? Can this measurement help you estimate the inductance of the capacitor leads?

Results

Capacitor Type	Dielectric	Value	Lead Length	Resonant Freq. MHz	Loss dB	Rs	L nH	Q
Ceramic Plate	K14000	1nF	2mm	94	37	0.36	2.9	4.7
Ceramic 1206 chip	X7R	1nF						
Polyester								
Polystyrene								
Various	Vary	10 pF to 1 F	Vary					

Student Questions

Estimate the inductance of the 2mm long leads of the 1 nF capacitor you first measured.

What type and value of capacitor would you choose to decouple the power supply of a 100 MHz small-signal high-gain amplifier?

It is sometimes an advantage to connect resistors* of, say, 10 to 100 ohm in series with the power supply between different stages of small signal RF circuitry. Can you think of two reasons why this should be?

* Often, low-Q ferrite bead inductors are used instead of resistors. These have a lower d.c. power loss in higher-power circuits.

Note to Tutors

The experiment can use any convenient transmission line as a Test Jig so long as:

1. It has the same characteristic impedance as the rest of the system

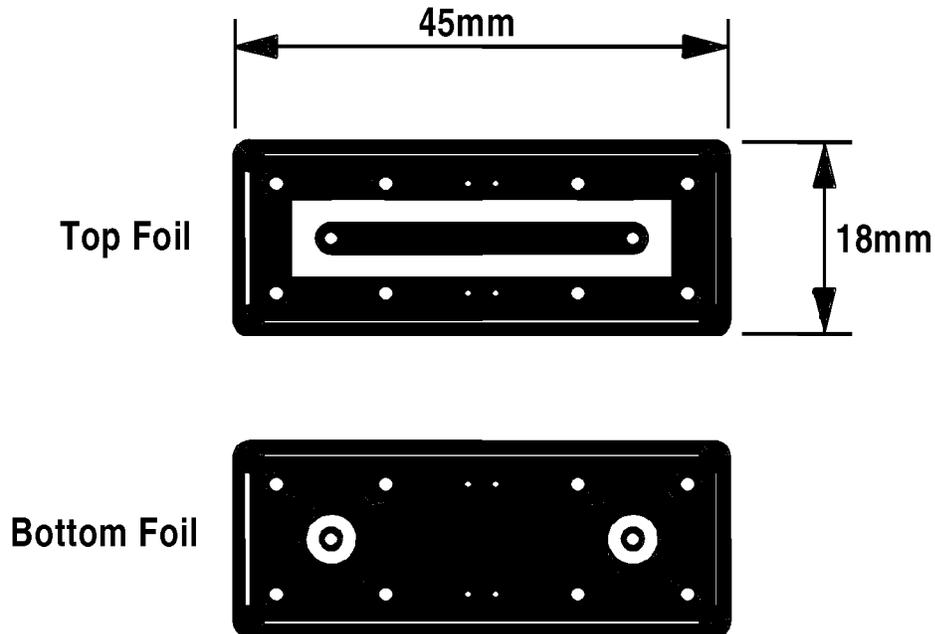2. Capacitors can easily be connected in parallel with it.

An informal arrangement could use a BNC Tee; however, it is difficult to measure short-leaded components with this arrangement.

A slot cut in semi-rigid cable has been used for small capacitors but is inconvenient for larger types.

For general-purpose use, a double-sided printed circuit board with 50-ohm BNC connectors is used. A 1.6 mm thick epoxy glass substrate (FR4 / GF) requires a track width of 3 mm for 50 ohms. The foil pattern of a suitable Test Jig is shown below.

Note the four small holes near the centre of the Jig connect the top and bottom ground planes. This makes the ground impedance low at the point where the test capacitor is connected.

Top Foil

45mm

18mm

Bottom Foil