Self-resonance in capacitors

Roger Harrison has been plotting again — this time it's self-resonant frequency versus lead length of ceramic capacitors!

THE LEADS AND CONSTRUCTION of all capacitors form an inductance which is effectively in series with the capacitance of the component. The combined effect forms a series resonant tuned circuit, the frequency of which (the self-resonant frequency) is mainly dependant on the length of the connecting leads, the construction of the capacitor and the way it is mounted.

The impedance of an ideal capacitor decreases with increasing frequency. But in a real capacitor the series inductance of the leads and construction causes the impedance of the capacitor to increase above the self-resonant frequency. Within a range of 0.7 to 1.4 times this frequency the impedance will be equal to, or better than, the reactance of the pure capacitance.

One can make use of this characteristic in bypass applications by using a capacitor of appropriate value and lead length so that its series resonant frequency is at, or close to, the frequency in use. Series resonant bypasses do a better job.

Alternatively, when selecting a bypass capacitor, always ensure that, for the value chosen, its series resonant frequency is above the highest frequency likely to be encountered in the circuit. This ensures that the impedance is always low over the frequency range of interest.

There are other ways in which the series resonance of a capacitor can be utilized. A pi-network, as is frequently used in the output stages of transmitters, is shown in Fig. 1. The output capacitor, C2, will have a value that depends on the frequency and the input/output impedances. The leads of this capacitor can be cut to length before installation so that the series resonant frequency of the capacitor falls on the second harmonic transmitter frequency. Thus it acts as a trap of very low impedance at this frequency.

If the second and third harmonics are to be suppressed, two capacitors may be connected in parallel (their added values to equal the value of C2), and resonated at the frequencies of the two harmonics. Other frequencies (such as spurious mixing products) may be suppressed in the same fashion provided each frequency is sufficiently separated.

In interstage coupling applications, the coupling capacitor may be resonated to the frequency used. Mounting a bypass capacitor flat against a groundplane (i.e. metal chassis or printed circuit board ground plane) increases its series resonant frequency by about 5%-10%. Adding 2 mm or 3 mm wide copper strips along the length of the wire leads of a capacitor can increase its series resonant frequency by 30%-40%.

The series resonant frequency of a capacitor may be measured by soldering

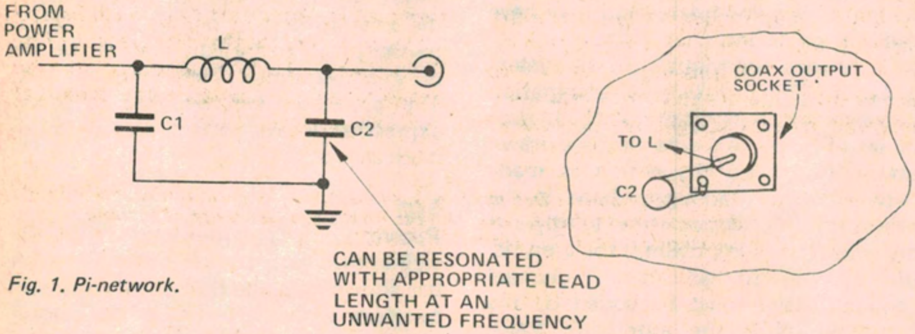

Fig. 1. Pi-network.

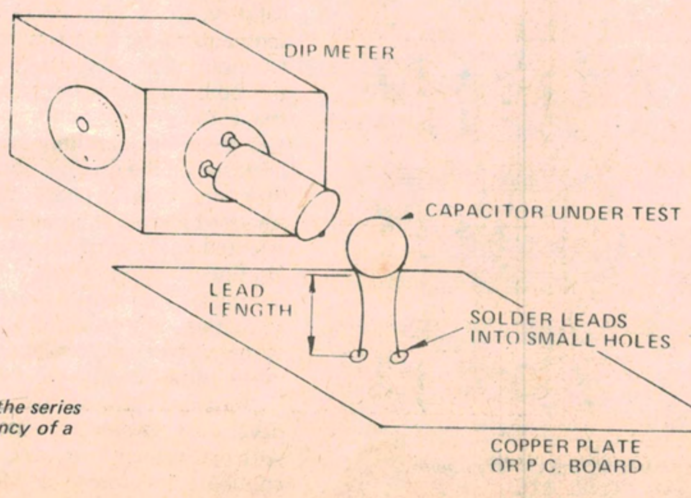

Fig. 2. Finding the series resonant frequency of a capacitor.

TABLE 1. SERIES RESONANT FREQUENCIES OF VARIOUS CAPACITOR STYLES

		Lead Lengths & Resonant Frequencies					
Value	**Style & Size**	**25 mm**	**20 mm**	**12 mm**	**5 mm**	**1 mm**	**Bandwidth**
100pF	Hi-K disc ceramic, 5mm dia	80 MHz	–	135 MHz	165 MHz	200 MHz	Broad
100pF	NPO disc ceramic, 20 mm dia	75 MHz	–	105 MHz	130 MHz	–	Narrow
100pF	NPO tubular ceramic, 20 x 3 mm	69 MHz	–	99 MHz	122 MHz	–	Narrow
100pF	Stacked mica	60 MHz	–	95 MHz	120 MHz	–	Narrow
470pF	Lo K disc ceramic, 5 mm dia.	–	–	65 MHz	80 MHz	140 MHz	Narrow
470pF	Hi-K disc ceramic, 7 mm dia.	40 MHz	–	60 MHz	–	–	Broad
680pF	Hi-K disc ceramic, 5 mm dia.	–	40 MHz	53 MHz	74 MHz	92 MHz	Narrow
1000pF	Hi-K disc ceramic, 5 mm dia.	34 MHz	37 MHz	45 MHz	58 MHz	84 MHz	Narrow
1000pF	Hi-K disc ceramic, 20 mm dia.	25 MHz	–	35 MHz	46 MHz	–	Sharp
1000pF	Plastic Film 'Greencap'	28 MHz	31 MHz	39 MHz	50 MHz	65 MHz	Sharp to Broad
4.7nF	Hi-K disc ceramic, 7 mm dia.	–	–	18 MHz	22 MHz	–	Broad
4.7nF	Hi-K disc ceramic, 'Red cap', 5 mm	18 MHz	21 MHz	25 MHz	33 MHz	–	Sharp to Broad
4.7nF	Plastic Film 'Greencap'	13 MHz	15 MHz	18 MHz	26 MHz	–	Sharp
.01μF	Hi-K tubular ceramic, 10 x 3 mm	8 MHz	–	11 MHz	14 MHz	–	Broad
.01μF	Hi-K disc ceramic, 10 mm dia.	–	–	13 MHz	15 MHz	–	Broad
.01μF	Hi-K disc ceramic 'Redcap', 5 mm	10.3 MHz	11.7 MHz	16 MHz	21 MHz	34 MHz	Sharp to Broad
.01μF	Plastic Film 'Greencap'	9.3 MHz	10.8 MHz	13.5 MHz	18 MHz	22 MHz	Sharp to Broad
1000pF	Resin-sealed Button Mica, 10 mm dia.	–	–	–	500 MHz	–	Broad
1000pF	Gold-sealed Button Mica, 10 mm dia.	–	–	–	800 MHz	–	Broad
1000pF	Solder-in Ceramic Feedthrough	–	–	–	400 MHz	–	Broad
1000pF	Screw-mount ceramic Feedthrough	–	–	–	250 MHz	–	Broad
.082μF	Resin-sealed Button Mica, 10 mm	–	–	–	100 MHz	–	Narrow

the leads to a relatively large copper plate or piece of p.c. board, as shown in Fig.2, and finding the resonance with a grid-dip meter (gate-dip meter, or base-dip meter for modern instruments).

Table 1 lists the series resonant frequencies of a variety of values, styles and sizes of capacitors. The lead lengths noted are the lengths of each lead (refer Fig.2), the disc ceramic is obviously a good choice for bypass applications into the middle VHF region. For applications to 60 MHz or so the common, plastic film 'greencap' is quite good along with various styles of ceramic capacitors. For stringent applications in the VHF-UHF region or for effective bypassing over wide bandwidths, the button mica capacitor or ceramic feedthroughs are necessary. Button ceramics exhibit similar characteristics. Note the high self-resonant frequency of the 0.082μF button mica.

The self-resonant frequency of disc ceramics is dependent largely on its diameter and lead length. The graph in Fig. 3 illustrates this for a variety of disc ceramics and a stacked mica capacitor for comparison.

Fig. 3. Self-resonant frequency versus lead length for various diameter ceramic disc capacitors (after J. Bork, 'A note on the self-resonance of ceramic capacitors; proc. I.R.E. (Aust) May 1957).

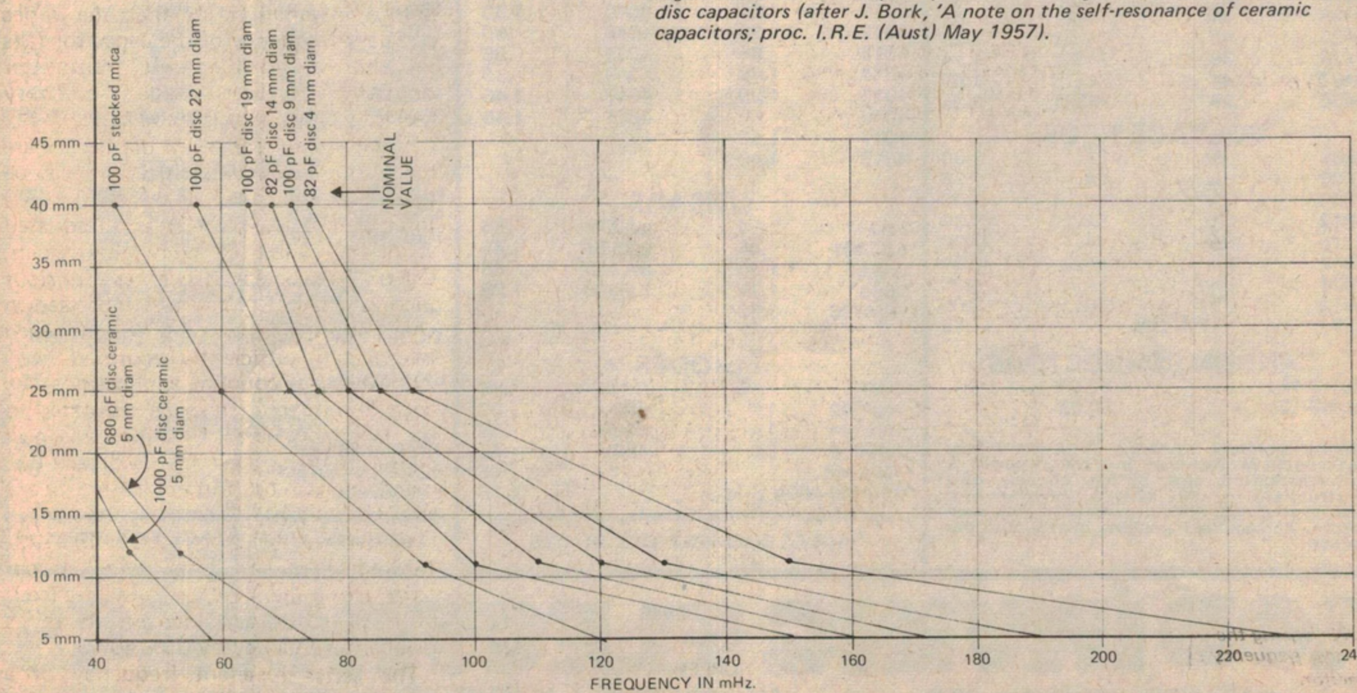

FIG 3