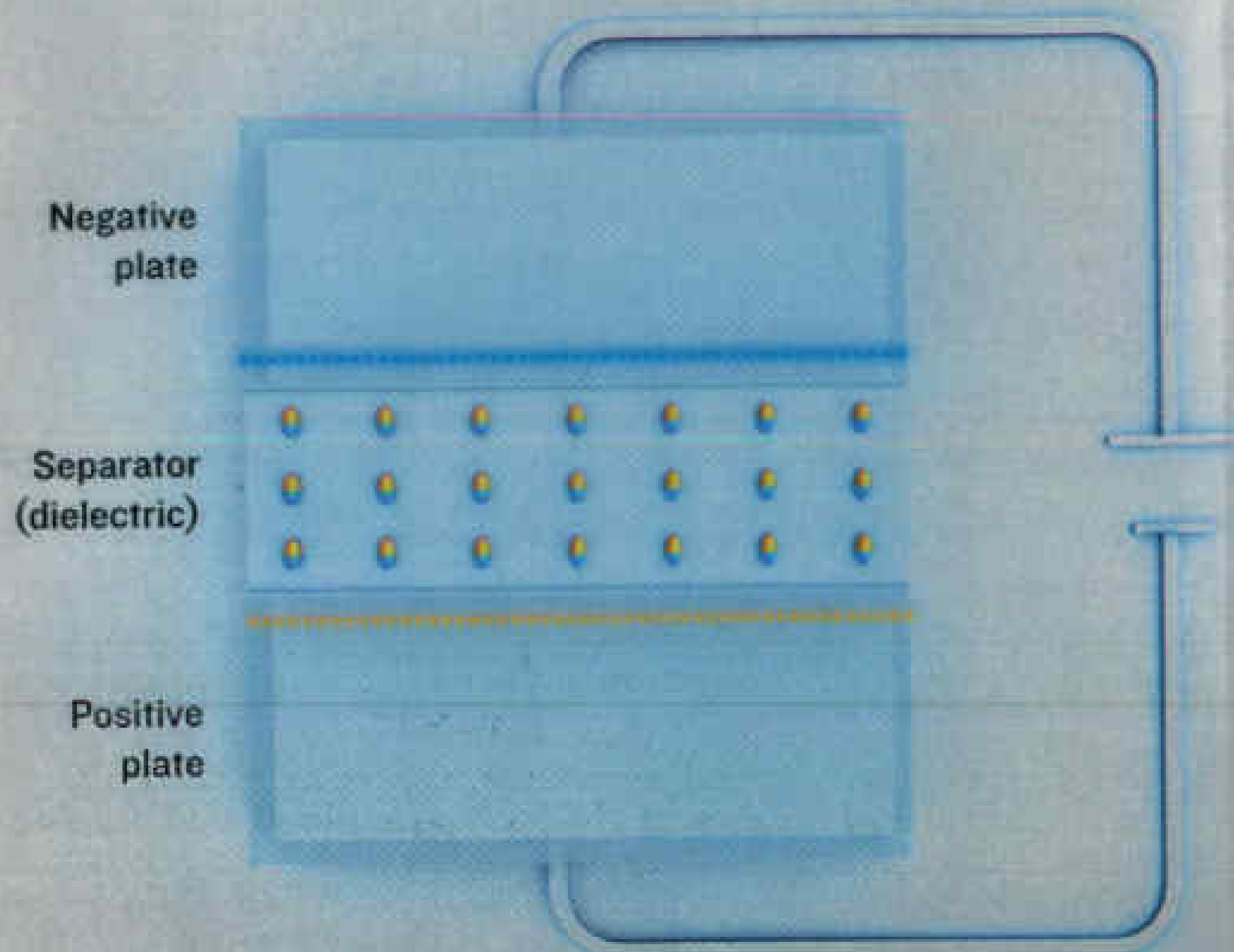
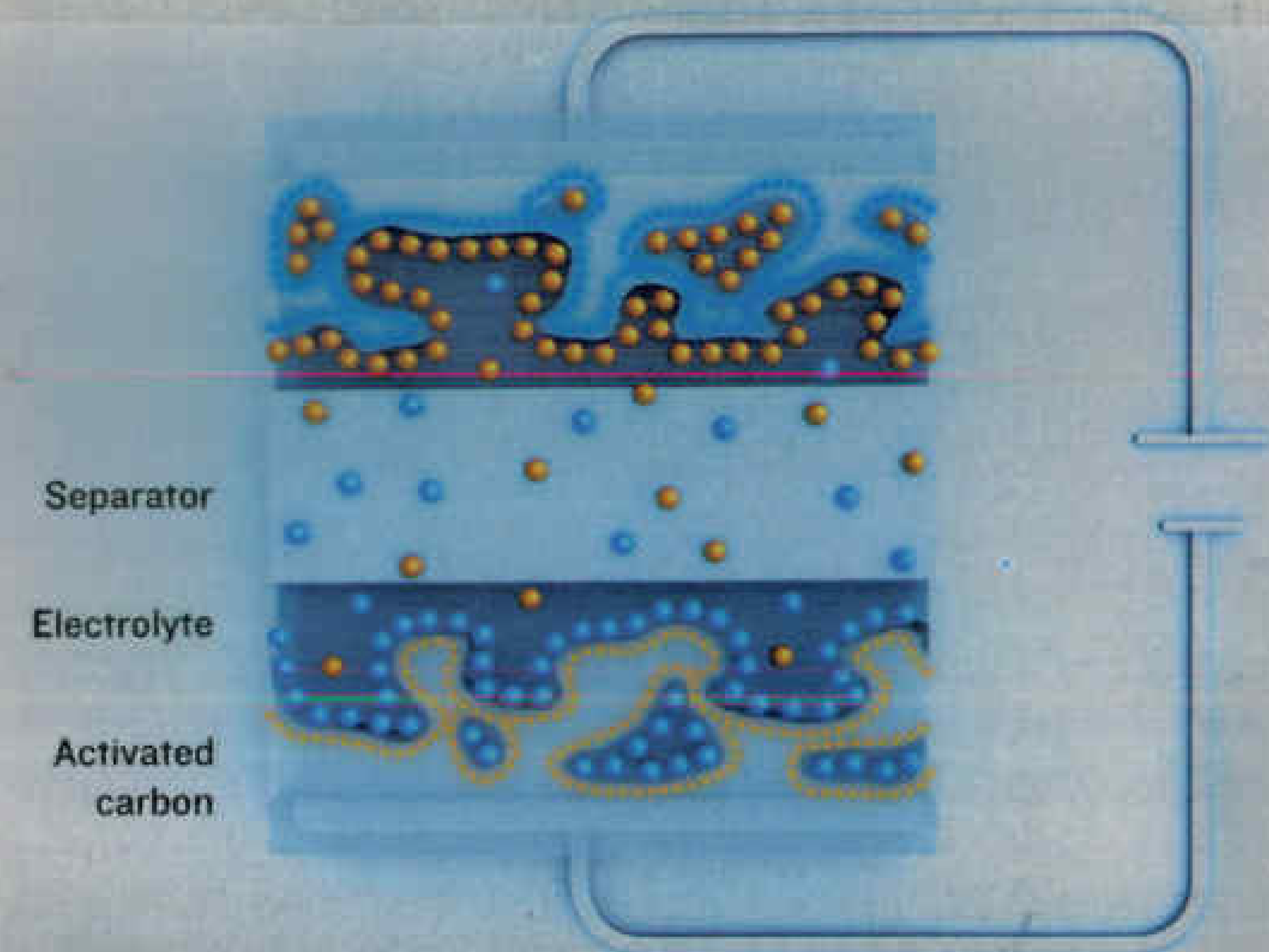
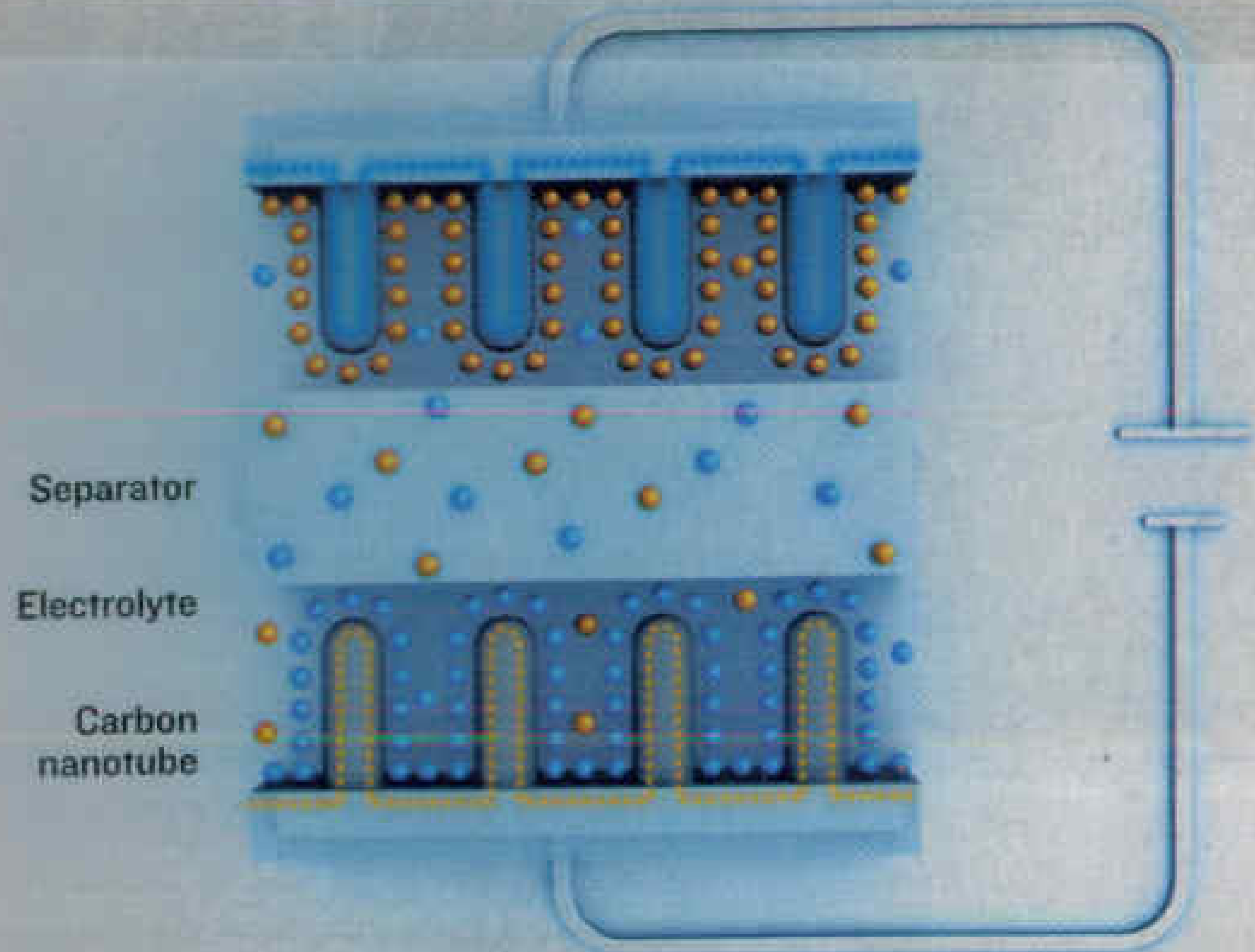
PILING ON THE FARADS



In a typical capacitor, electrons are removed from one plate and deposited on the other. Polarized molecules in the dielectric concentrate the electric field. One major factor determining capacitance is the surface area of the plates.



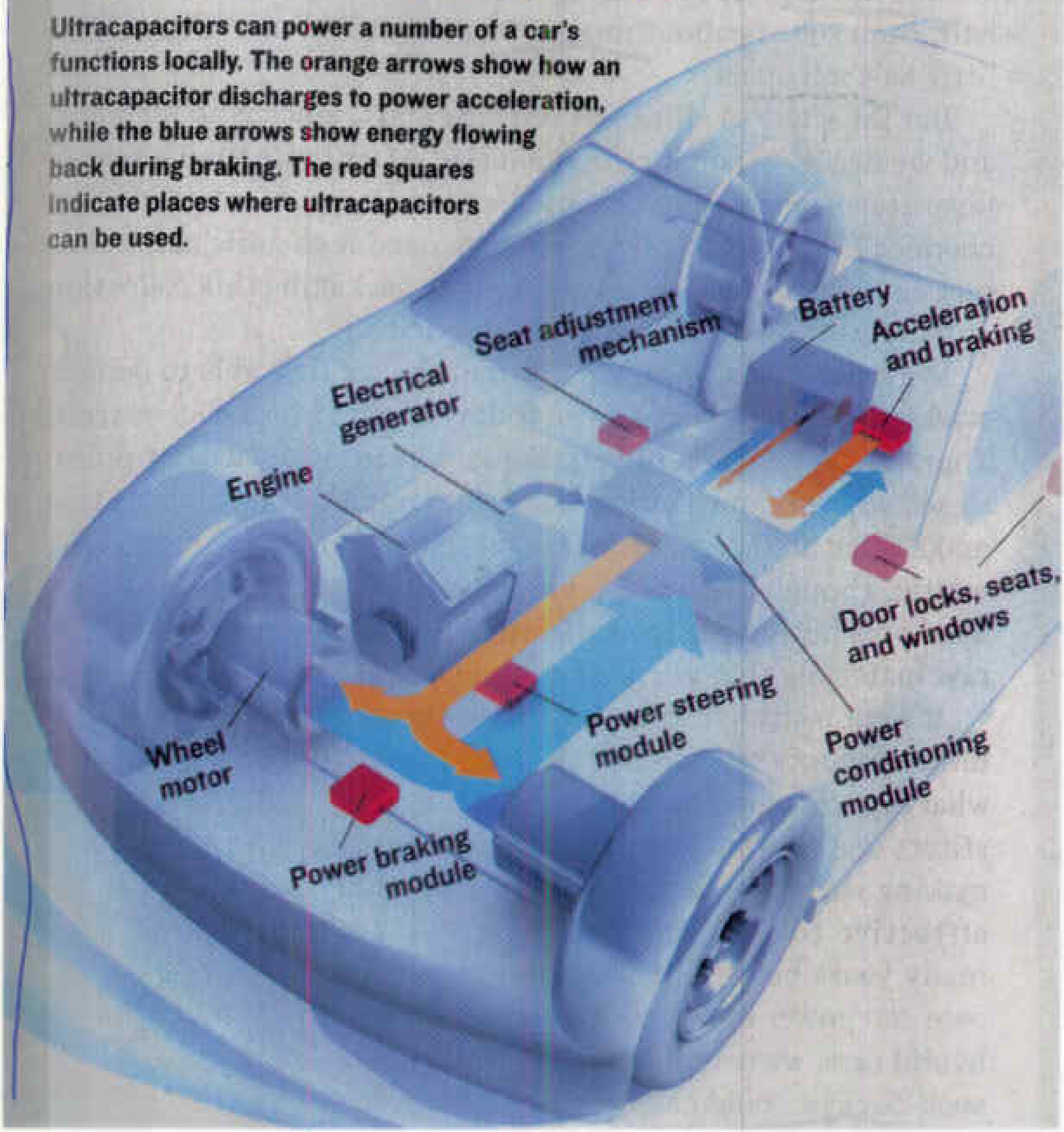
An ultracapacitor can store more charge than a capacitor can, because the activated carbon has a pocked interior, much like a sponge. This means that ions in the electrolyte can cling to more surface area.



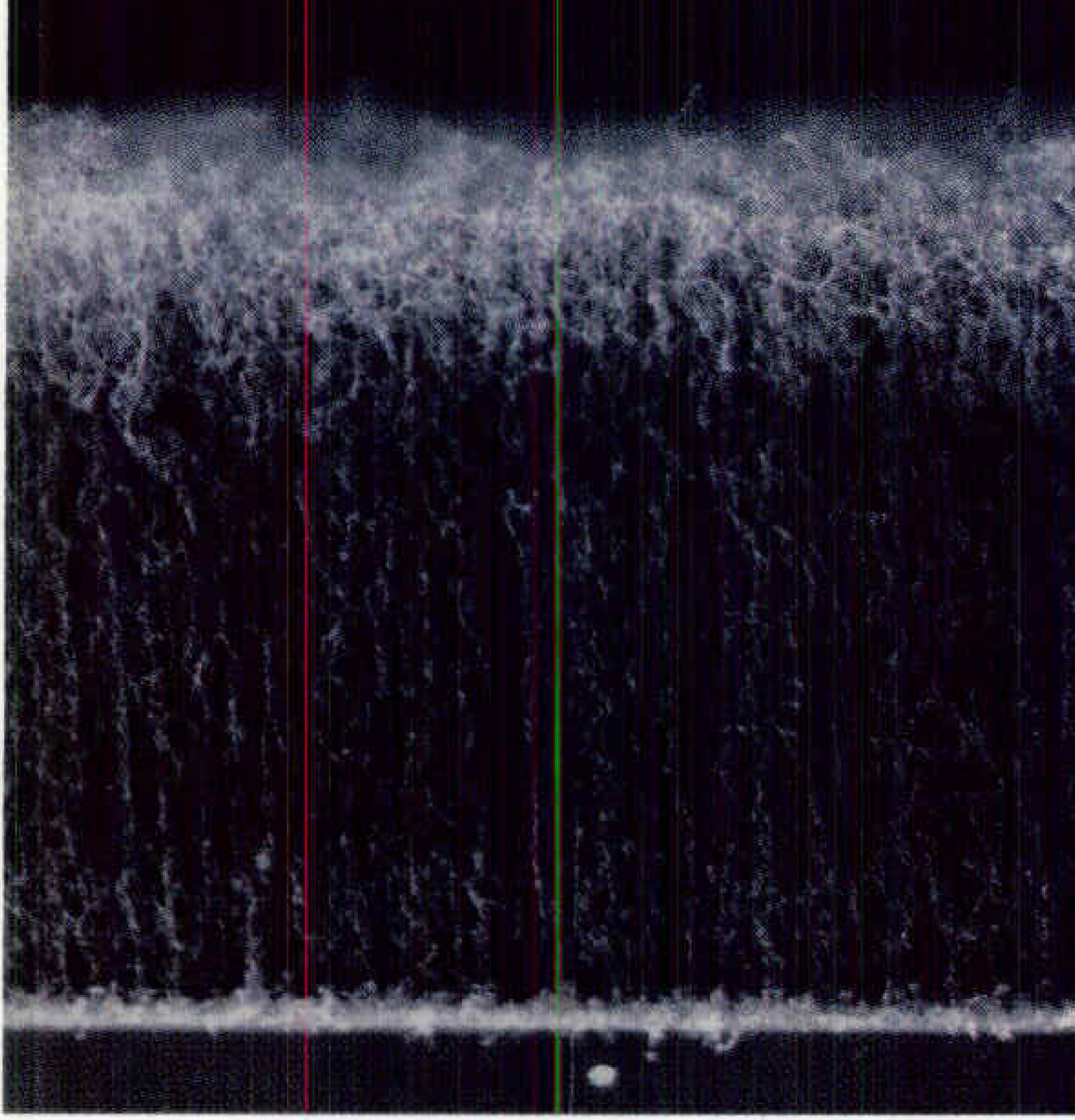
With finer dimensions and more uniform distribution, carbon nanotubes enable greater energy storage in ultracapacitors than activated carbon does.

HOW TO ULTRACAP A CAR

Ultracapacitors can power a number of a car's functions locally. The orange arrows show how an ultracapacitor discharges to power acceleration, while the blue arrows show energy flowing back during braking. The red squares indicate places where ultracapacitors can be used.



ELECTRIC SHAG: A cross section of an electrode made with carbon nanotubes.



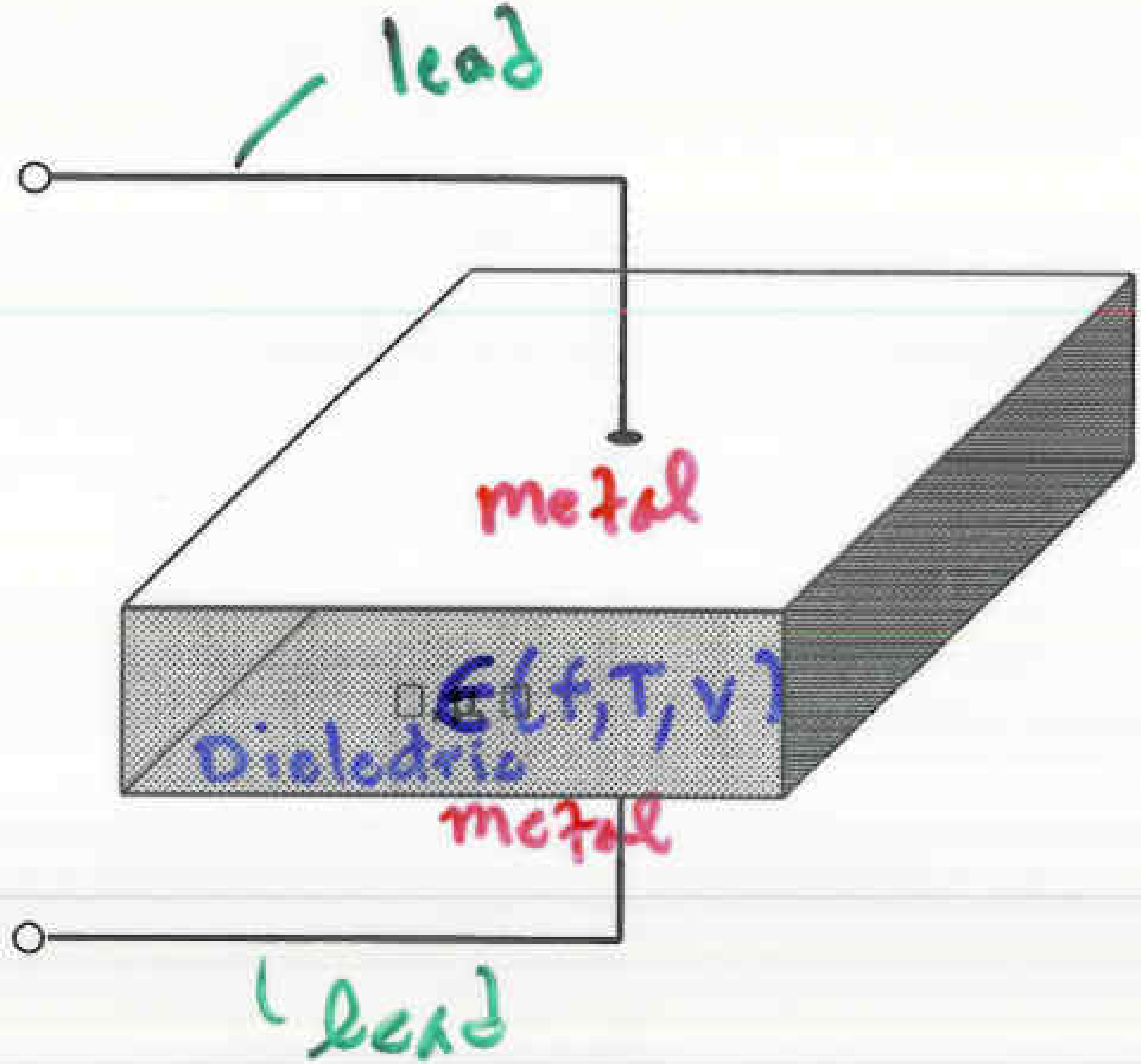
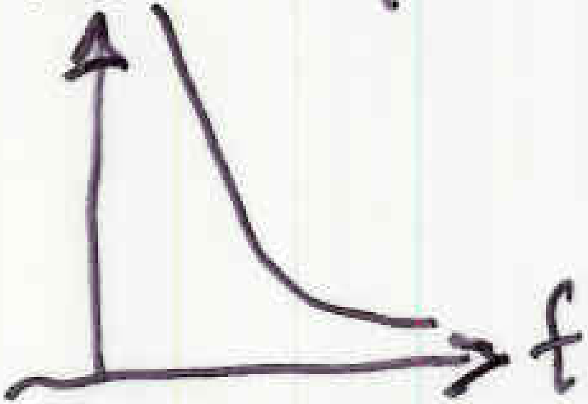


Figure 13. Generalized capacitor.

X_c Expect



What do you get?

ck-
ra-
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as
ap-
ace
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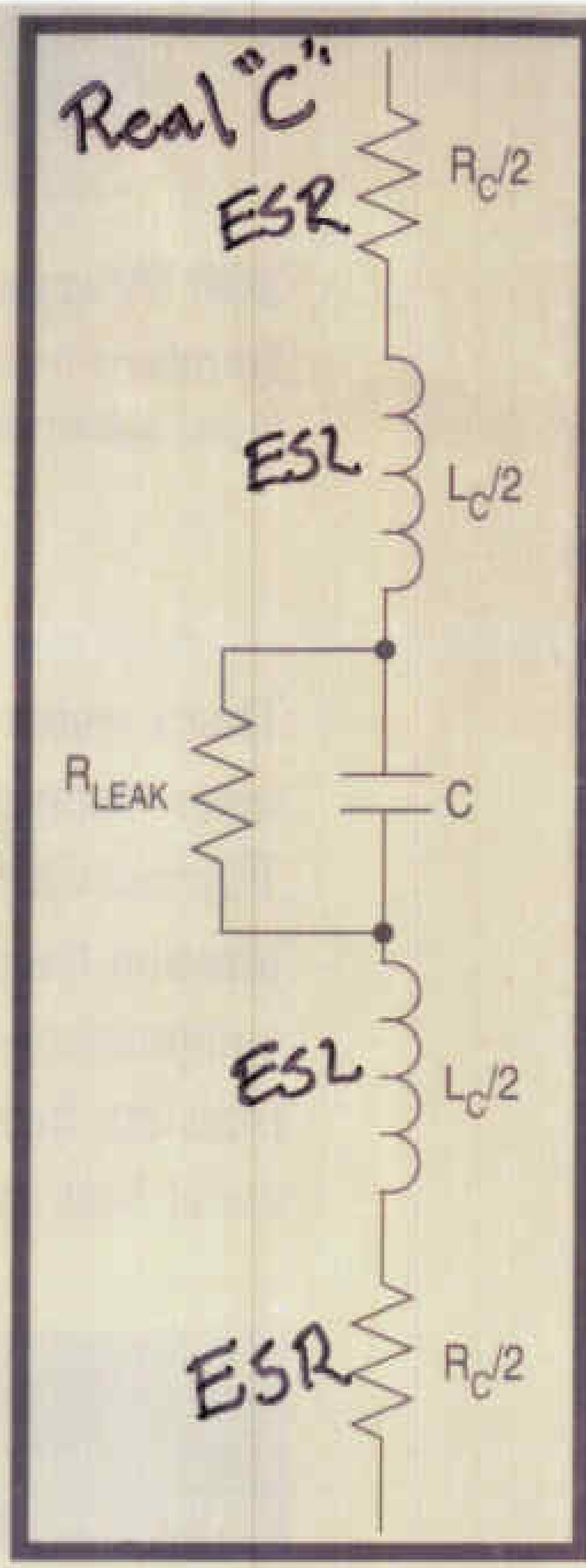


Fig. 2. *Actual capacitors have parasitic inductance and resistance.*

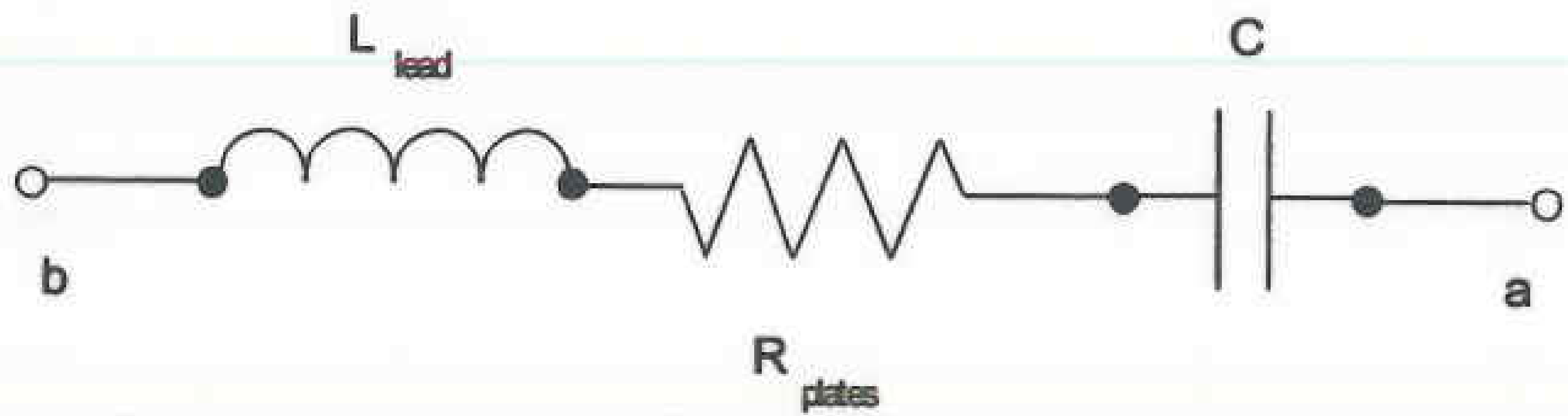
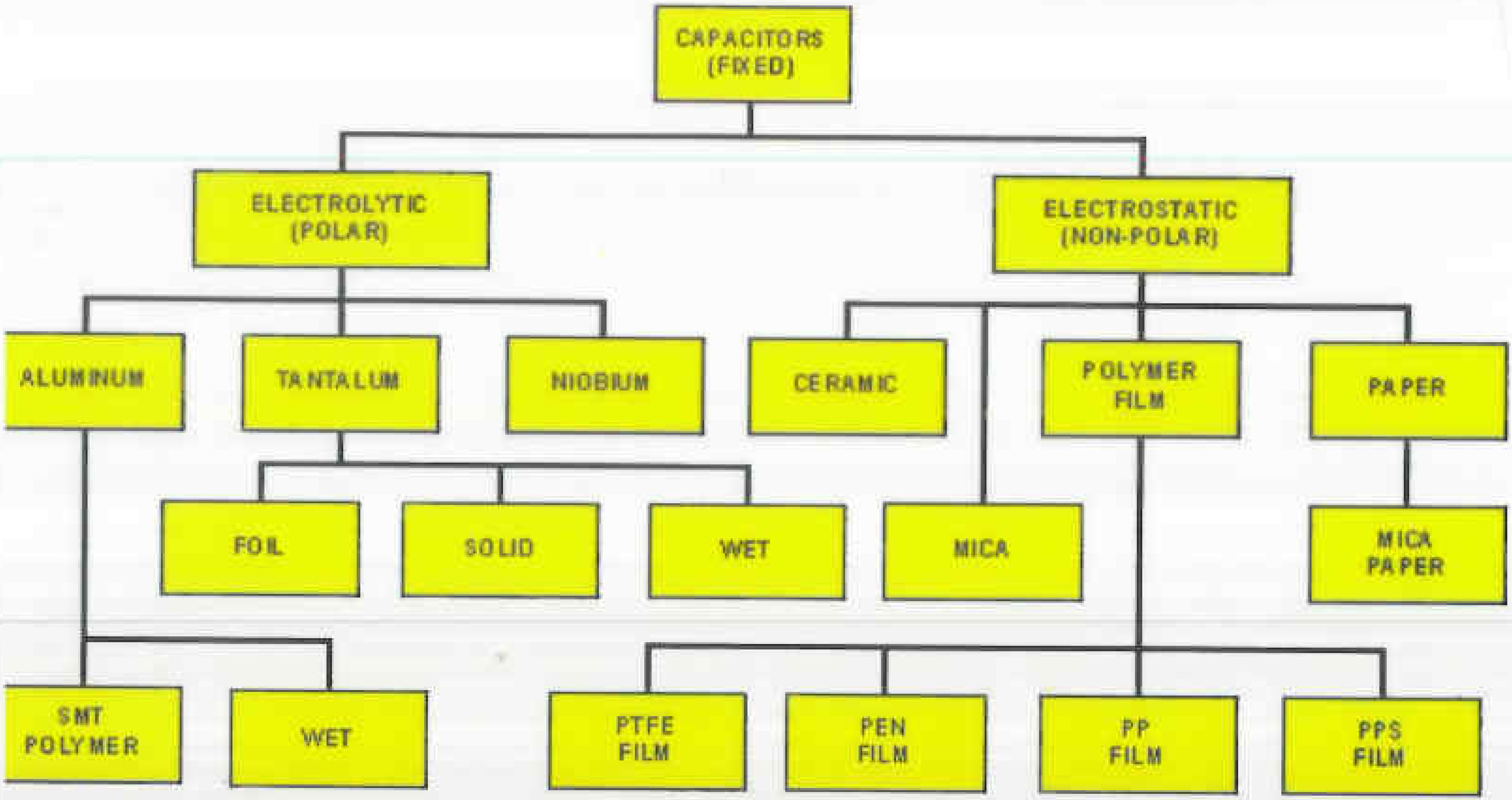


Figure 15. Simplified equivalent capacitor circuit.

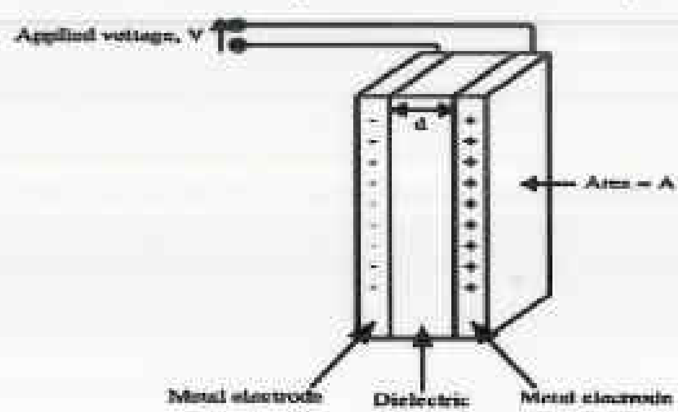
Capacitor Technologies



Vacuum Cap: High Q, high f, high voltage

Capacitor Fundamentals

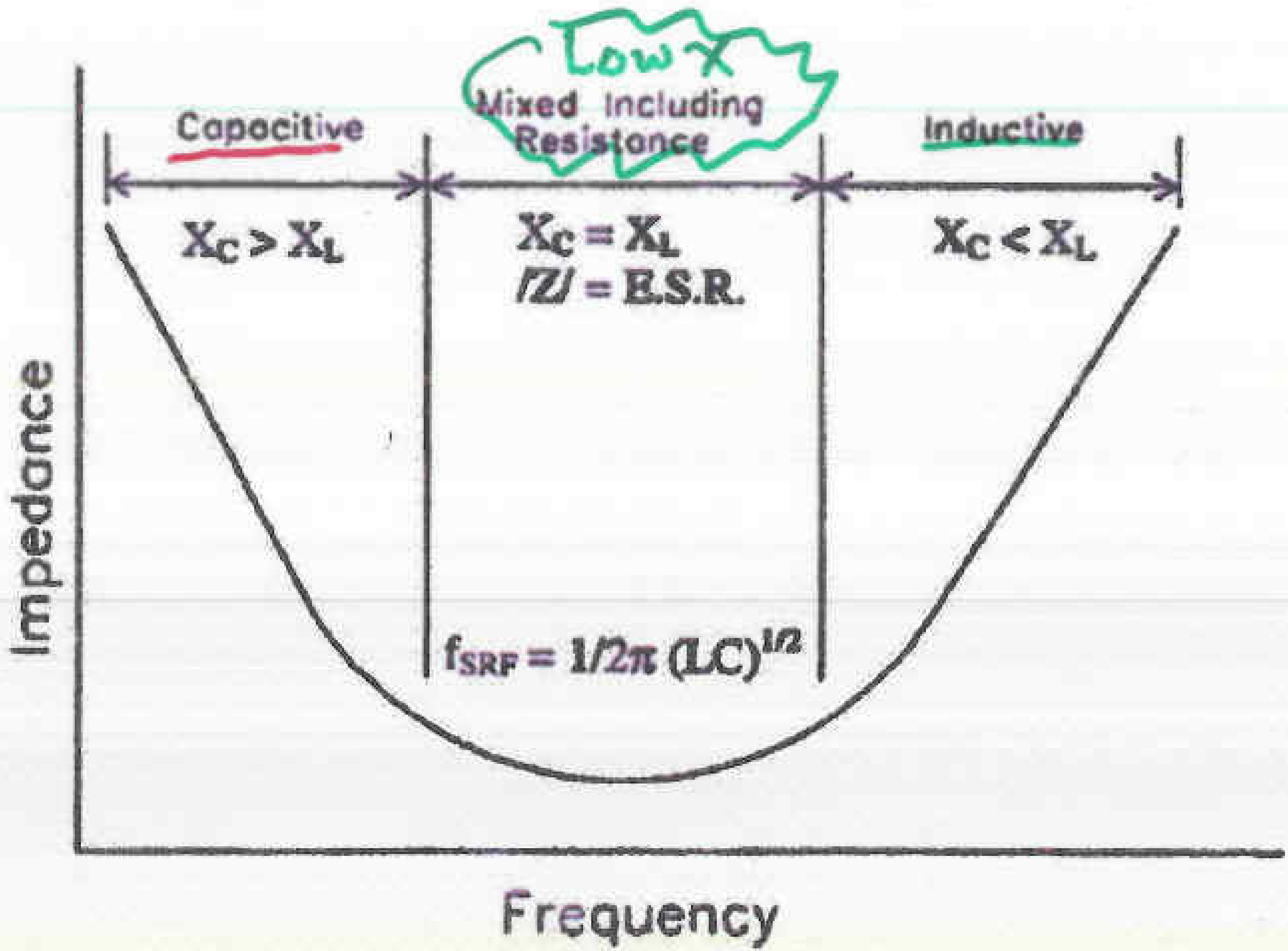
- In Conventional capacitors, capacitance is measured as the amount of charge divided by the voltage, and charge is proportional to area of the plates.
- Traditional capacitors require a large surface area plate to have more capacitance
- Ideally, to get a very large capacitance one wants a very large surface area with as little distance between the plates as possible



$C \approx ?$

- Following graph illustrates how characteristic of some capacitors vary ove frequency.

Impedance vs. Frequency



ESR
$R(f)$

Capacitance vs Frequency

The sheet resistance of the conductive plates of the capacitor and the wires that link these conductive plates to the terminals of the capacitors lead to a parasitic resistance that is called the ESR (Equivalent Series Resistance). The termination loop of the terminal wires also lead to a small and often negligible parasitic inductance called the ESL (Equivalent Series Inductance). Thus, the total impedance of a capacitor varies over the frequency at which it is used.

ESL small but
$L \frac{di}{dt} \uparrow$ as $f \uparrow$

nect small RF-bypass capacitors across

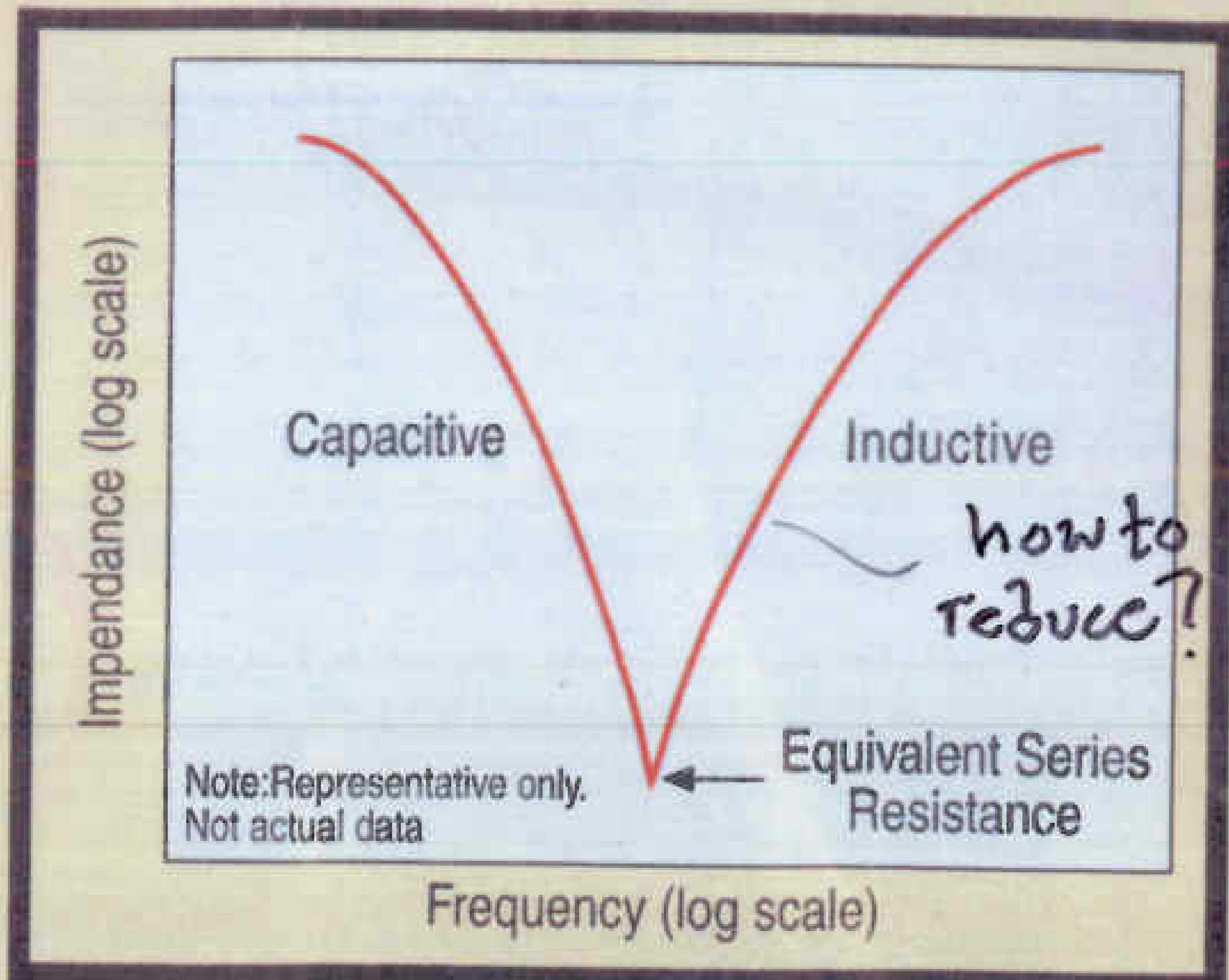


Fig. 3. *As frequency increases, the parasitic inductance of a capacitor becomes dominant.*

achieved in the last 10 years. With tantalum, the main ripple component comes from ESR.

$V_{in} = +5V$	$L = 8\mu H$ ($10\mu H$ nom)	$F = 650$ kHz
$V_{out} = +1.8V$	$t_{on} = 0.7\mu s$	$\Delta I_L = 0.24A$
$I_{out} = 600mA$	$t_{off} = 0.9\mu s$	$I_{peak} = 0.72A$

Nominal C	Minimum C	Dielectric	ΔV_c	ΔV_{esr}	ΔV_{esl}	ΔV_{out}
			$\Delta I_L/8Cf$	$ESR \cdot \Delta I_L$	$ESL \cdot \Delta I_L \cdot (1/t_{on}+1/t_{off})$	Graphic estimation
10µF	7µF	MK	6.5mV	2.6mV	0.4mV	≈ 8mV
22µF	16µF	MK	2.8mV	1.9mV	0.7mV	≈ 5mV
47µF	34µF	MK	1.4mV	1.4mV	0.7mV	≈ 3mV
33µF	27µF	TPA	1.7mV	17.7mV	3mV	≈ 20mV

Table 3. *Ripple characteristics of output capacitor in a step-down converter.*

Real $V_c(f)$

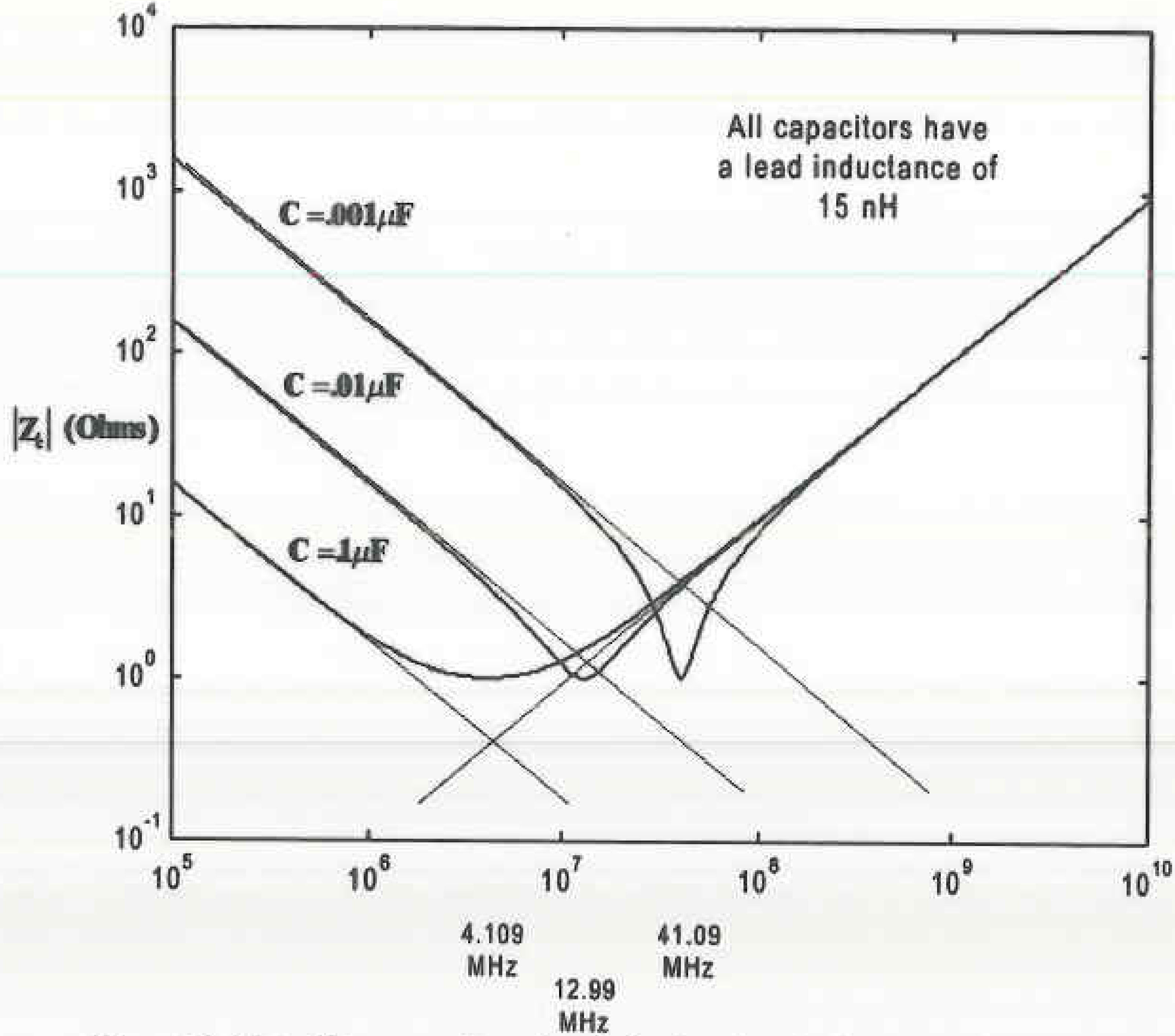


Figure 16: Plot of frequency dependent behavior of equivalent circuit for various capacitors.

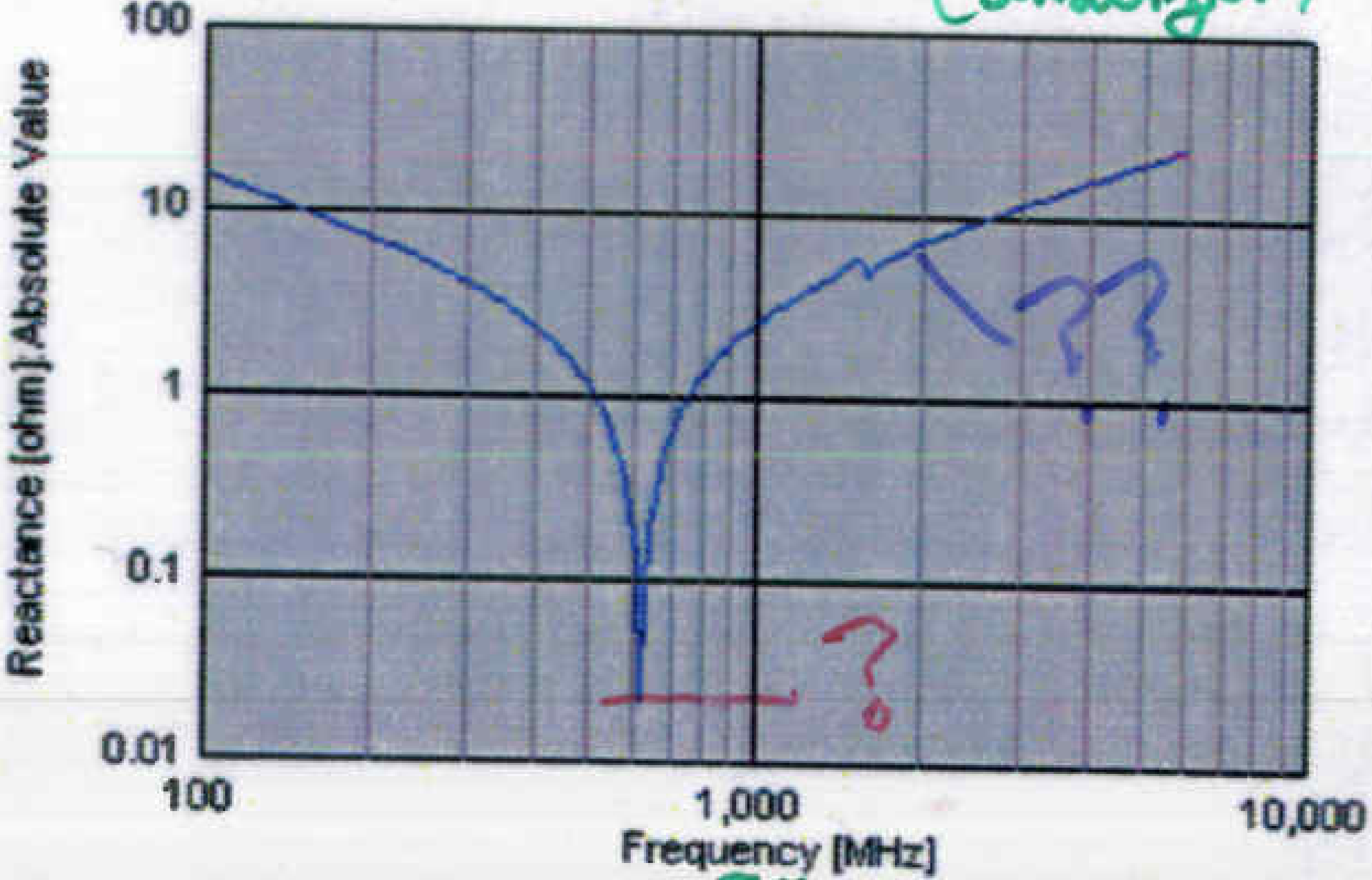
0H

- Most of the parasitic inductances that we are concerned with here are those associated with traces, bond-wires, lead terminations, etc. From an applications point of view, we need to be concerned about *PCB trace inductances* in particul --- for that is what we can minimize easily.

- But not all PCB trace inductances are "trouble-makers". For example, the traces in series with the inductor are "benign" --- because they can be looked at as jus being lumped together with the main inductor. A freewheeling path is available f them too --- the same as the freewheeling path of the main inductor.

- However, certain other trace inductances do not have any freewheeling path, ar will therefore "complain" --- in the form of voltage spikes across the board, as pe the basic equation V=LdI/dt. These traces are considered "high-frequency" or "critical traces" from the viewpoint of PCB layout, and their associated inductances are considered to be "uncoupled" or "leakage" inductances.

$Z_C(f)$ from a (network analizer)



(a)

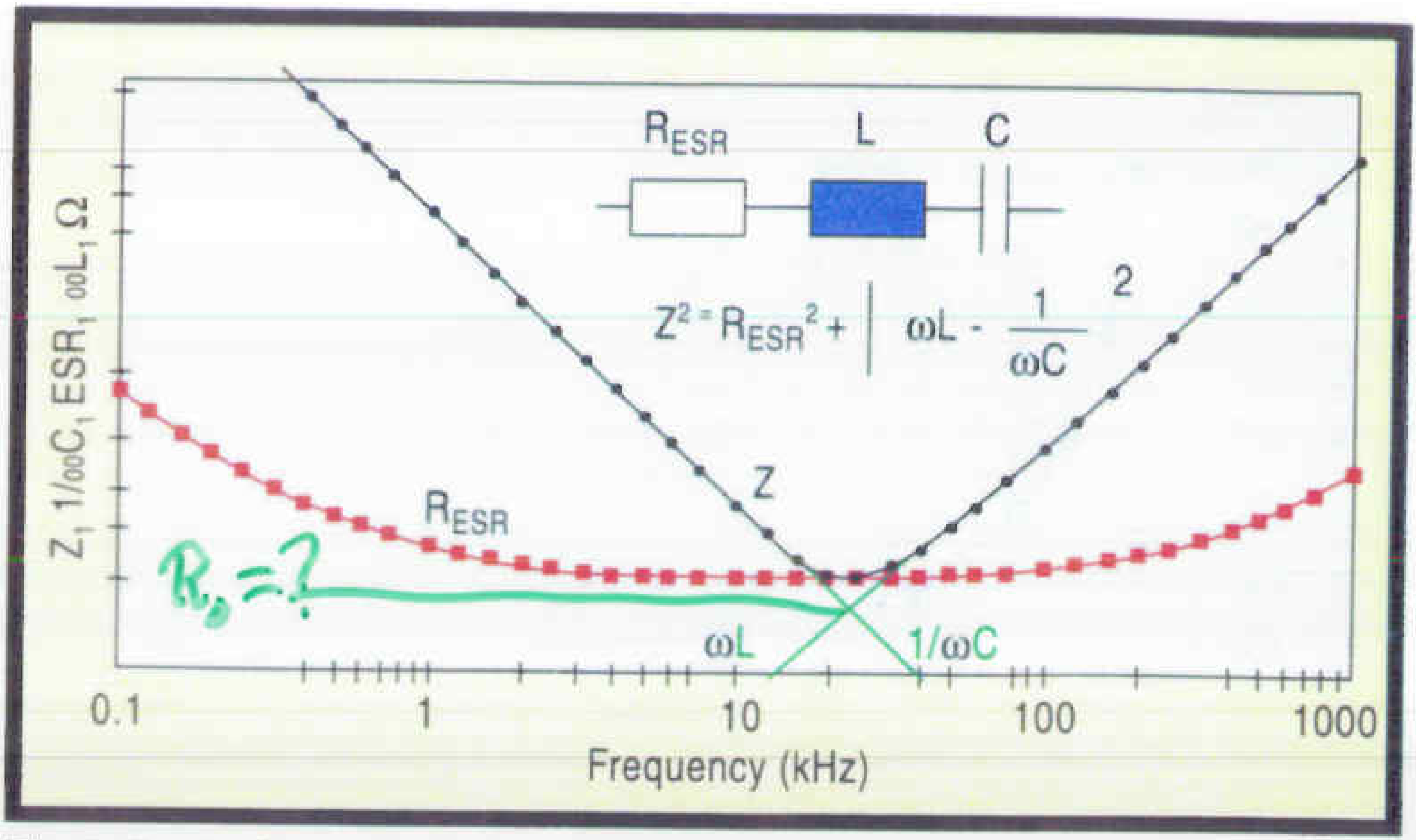


Fig. 5. *Equivalent circuit, impedance and frequency dependence of bulk capacitors.*

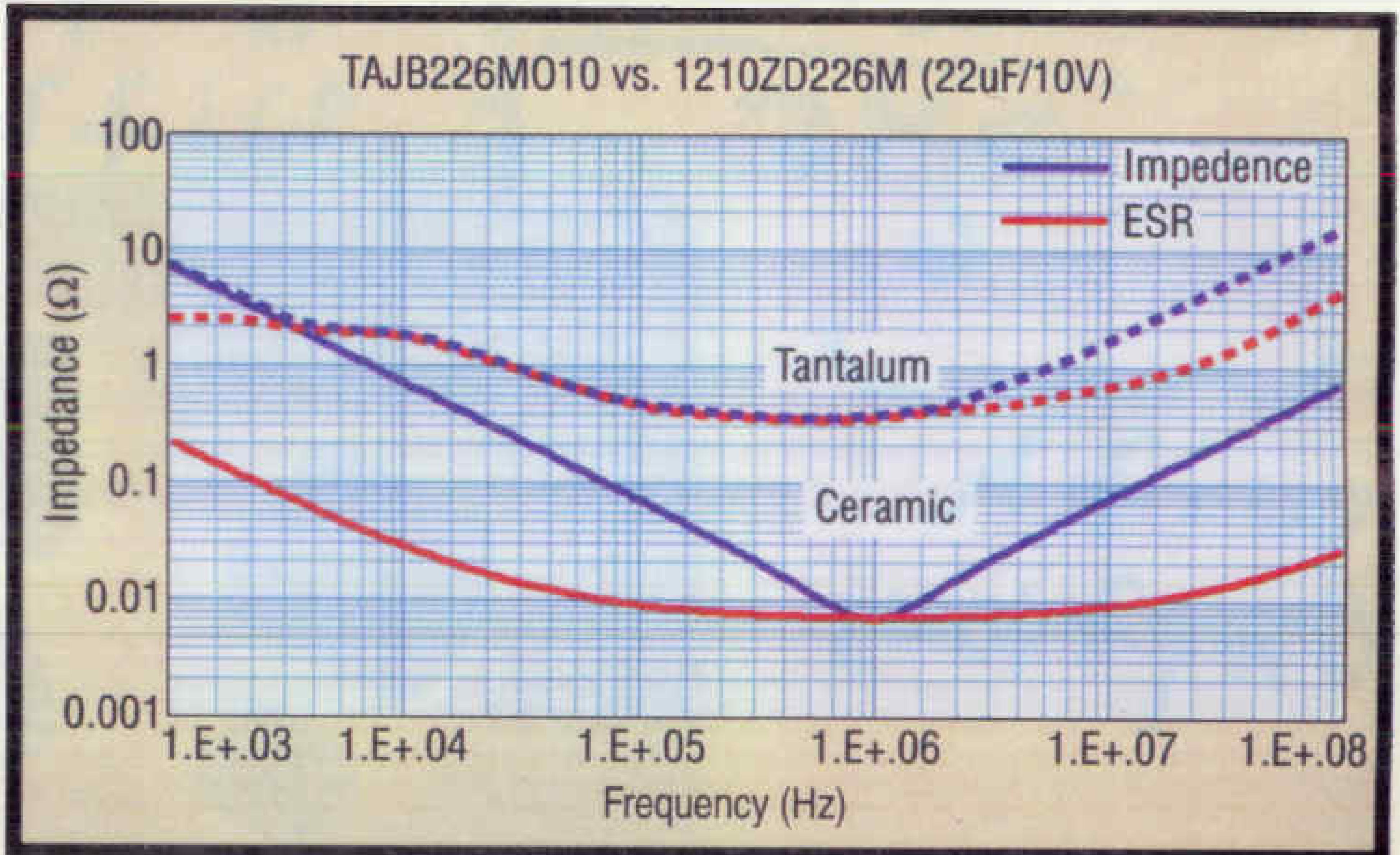
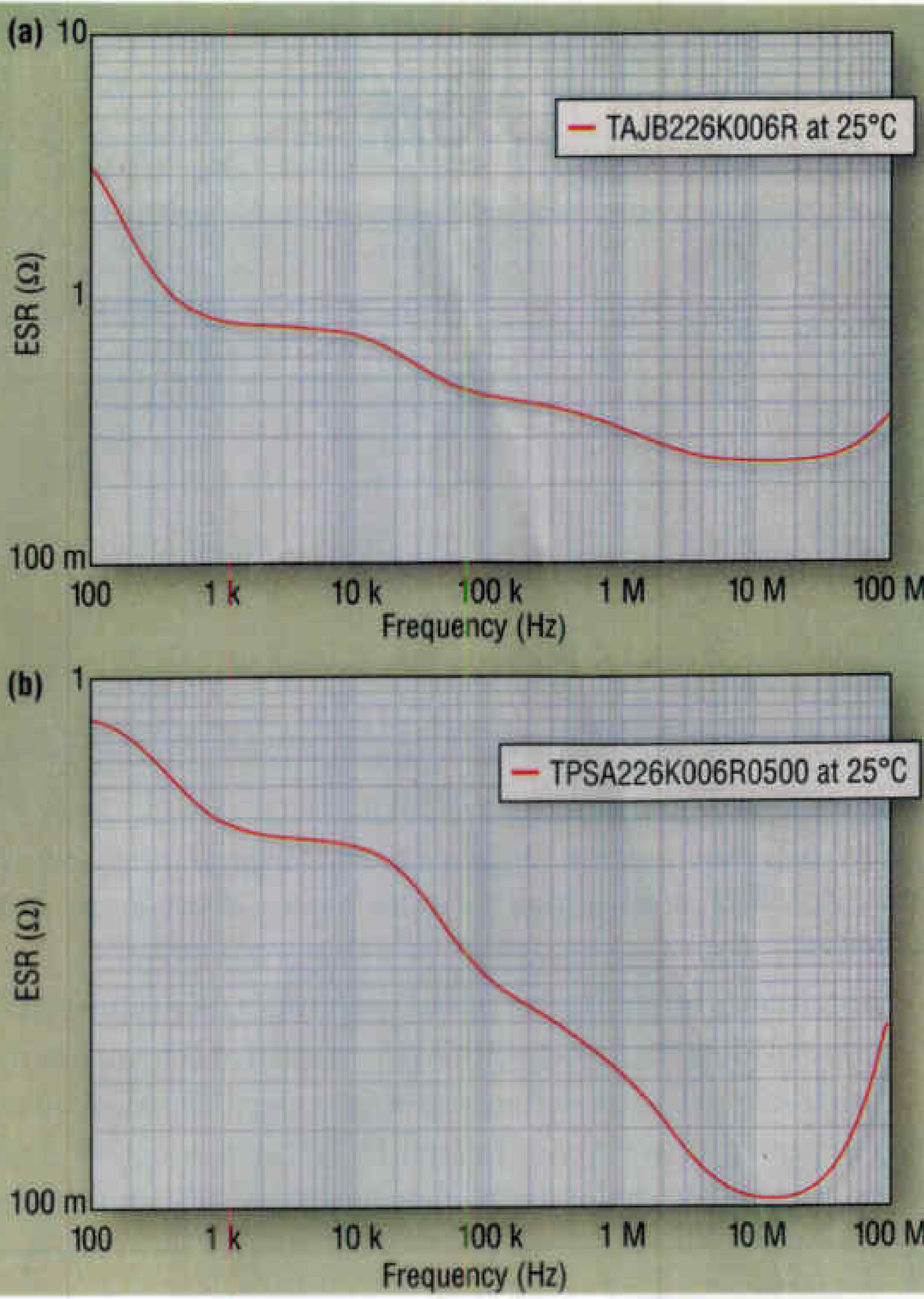


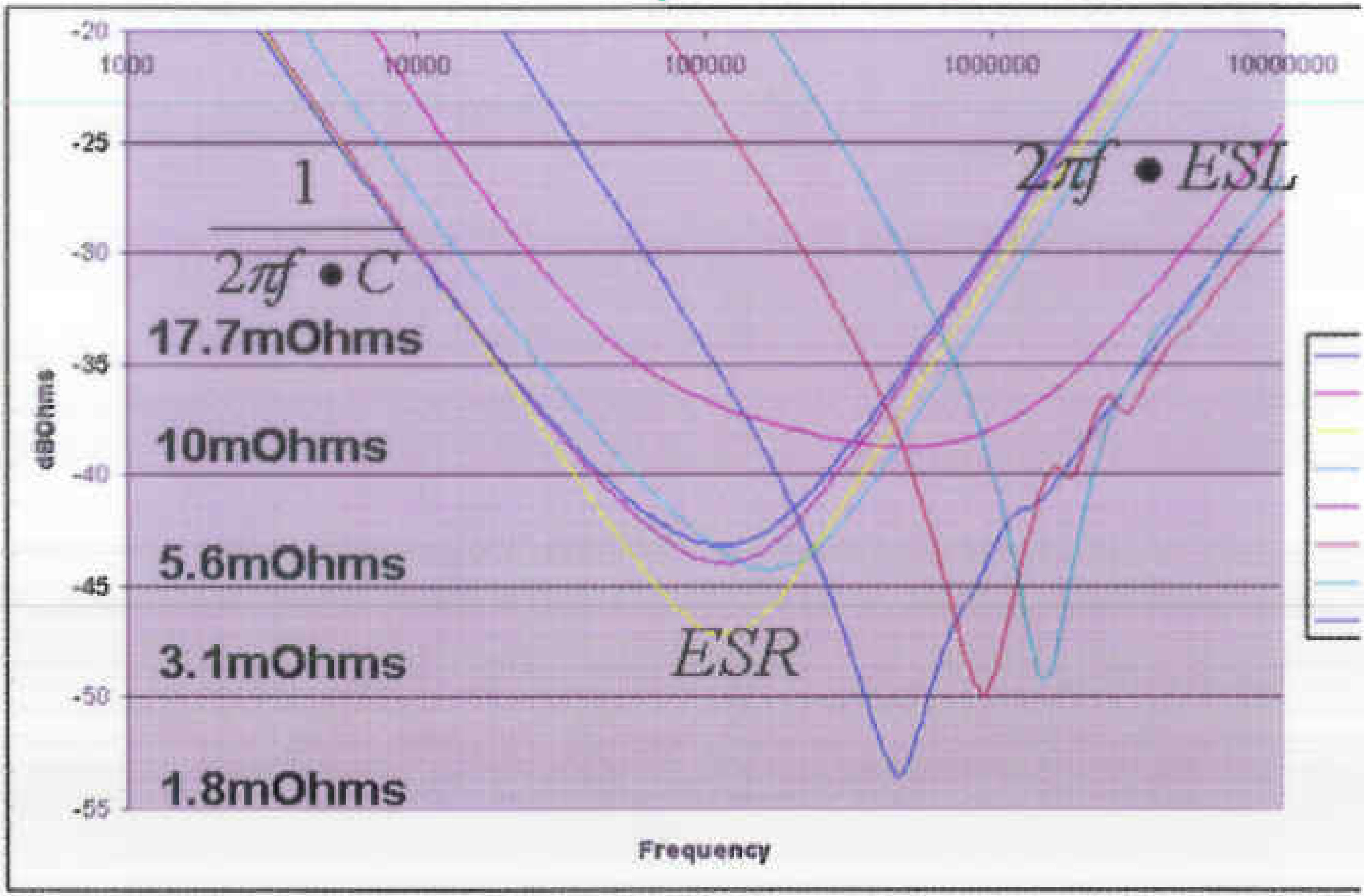
Fig. 1. *Impedance versus frequency*.

Technology	Capacitance Range (μF)	V_R Range (V)	ESR(min) (Ω)	Leakage nA × μF × V	Temperature Range (˚C)
Standard MnO_2	0.1 to 1000	4 to 50		10	-55 to +125
Low-ESR MnO_2	3.3 to 1000	4 to 50	0.1	10	-55 to +125
Standard 3f Multianode	330 to 1000	4 to 50	0.03	10	-55 to +125
Polymer	150 to 470	2.5 to 10	0.035	100	-55 to +105
Polymer Multianode	470 to 1000	2.5 to 6.3	0.01	100	-55 to +105

Capacitor characteristics.


(a)
10
1
100 m
ESR (Ω)
TAJB226K006R at 25°C
100
1 k
10 k
100 k
1 M
10 M
100 M
Frequency (Hz)
(b)
1
100 m
ESR (Ω)
TPSA226K006R0500 at 25°C
100
1 k
10 k
100 k
1 M
10 M
100 M
Frequency (Hz)

Various C all show
ESL, ESR, f_R



- Several factors affect the ESR:
  - Thickness and material of the electrodes
  - Area and aspect ratio of the electrodes
  - Number of layers and parallel termination that form the electrodes
  - Electrode surface flatness and metallization density
  - Distributed resistance of the dielectric
  - Frequency of operation

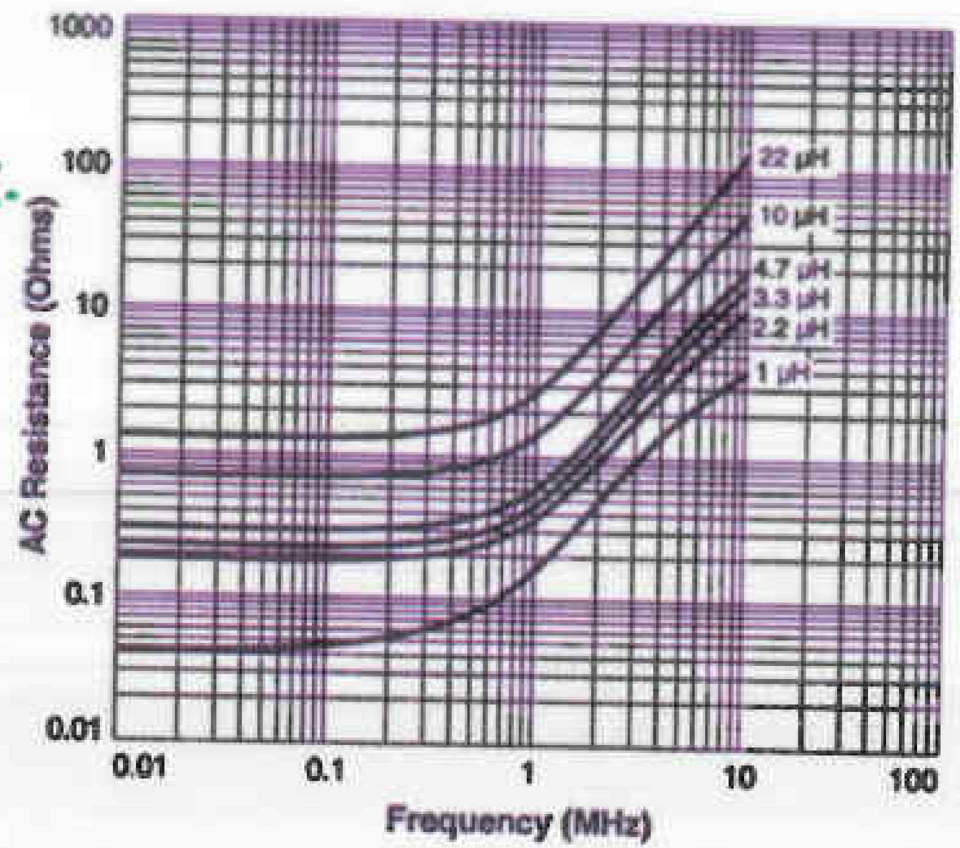
Below is a plot of ESR for various capacitors. Note that the ESR for ceramics can be as small as 1% of that of the Tantalum capacitors.

- Inherent to any conducting wire is an element of resistance. Also, the insulating material added around the wire, to prevent short circuit from one turn of the coil to another, acts as a dielectric that adds capacitance between the turns. So, each inductor comes with an inherent resistance and capacitance. In addition, at higher frequencies, current tends to flow closer to the conductor surface, an effect known as the skin effect. Thus, the total impedance offered by an inductor varies with voltage and frequency applied to it. An example inductor impedance vs frequency graph is shown below.

wire insulation → ϵ

needed to max. N^2

Typical AC Resistance vs Frequency



low f

rent is linear and equal to ΔIL/ton:

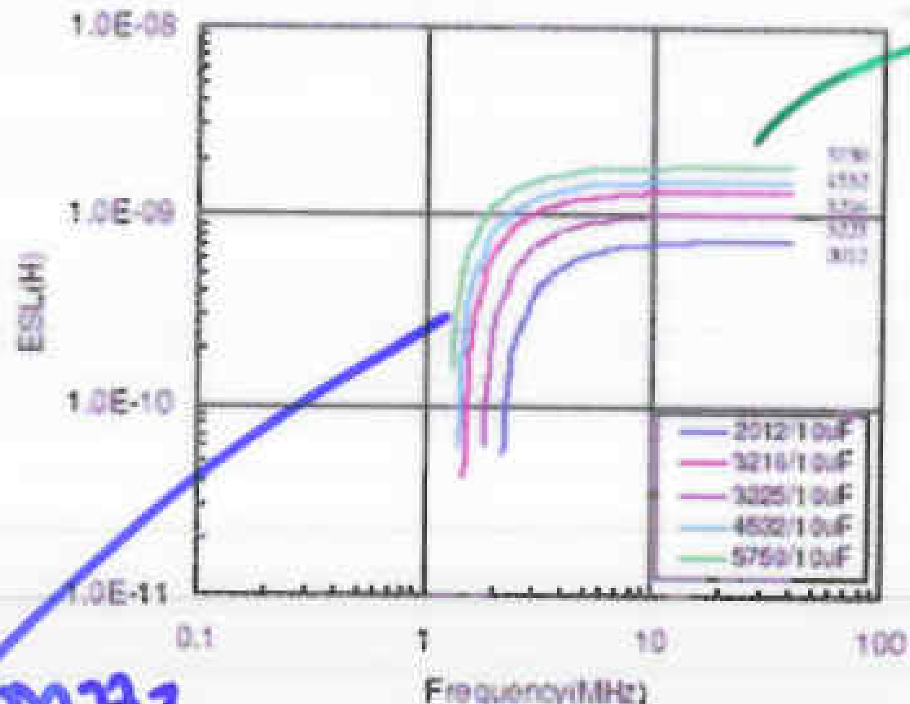
$$Vesl1\ (0 < t < ton) = ESL * \frac{\Delta I}{ton}$$

Vin = +5V	L = 8µH (10µH nom)	F = 650 kHz
Vout = +1.8V	ton = 0.9µs	ΔIL = 0.24A
Iout = 600mA	toff = 0.7µs	Ipeak = 0.72A

Nominal C	Minimum C	Dielectric	ΔVc	ΔVesr	ΔVesl	ΔVout
			Iout*toff/C	ESR *(Iout+ΔIL/2)	ESL *ΔIL/ton	Graphic estimation
10µF	7µF	MK	77mV	7.9mV	0.2mV	≈80mV
22µF	16µF	MK	33.8mV	5.8mV	0.4mV	≈36mV
47µF	34µF	MK	15.9mV	4.3mV	0.4mV	≈18mV
33µF	27µF	TPA	20mV	54mV	1.7mV	≈75mV

Table 5. *Ripple characteristics of input capacitor in a step-down converter.*

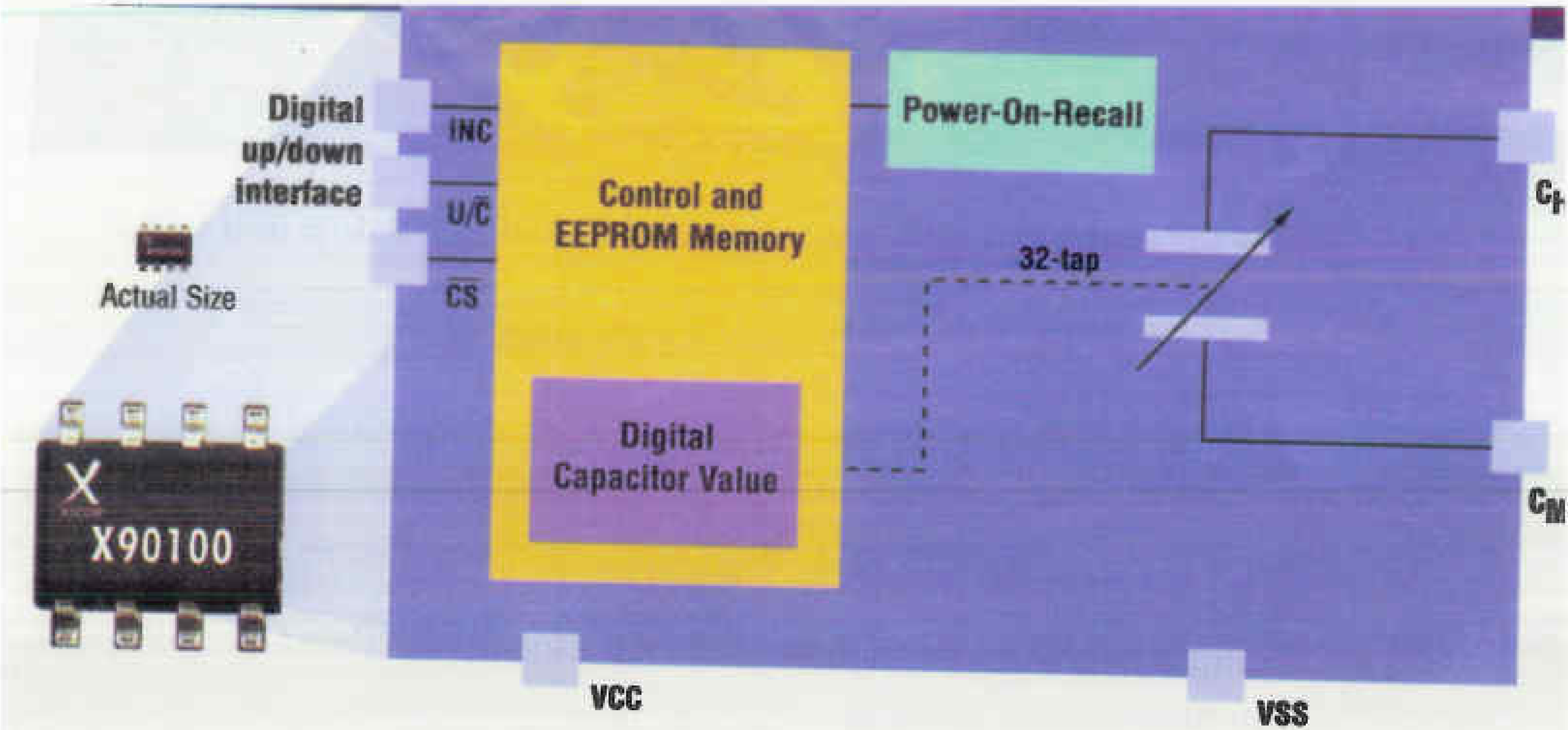
- Area and aspect ratio of the electrodes
- Number of layers and parallel termination that form the electrodes
- Cover layer thickness
- Case size



?

$1 \le f \le 3$ MHz
$ESL = f(f)$

$f > 3$ MHz
$ESL \neq f(f)$

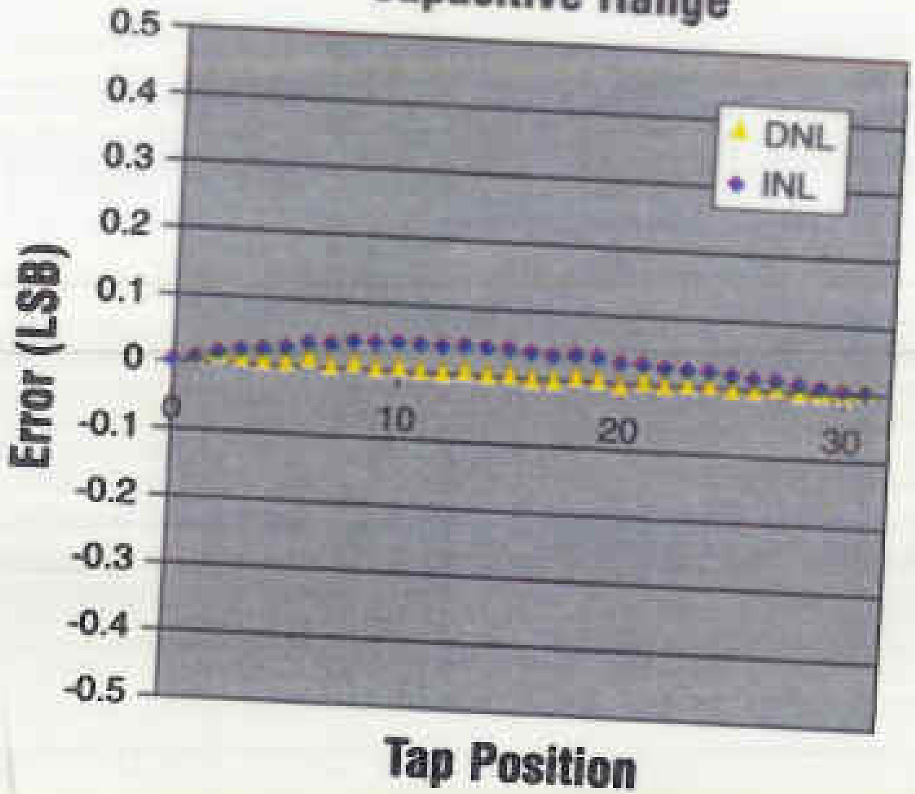


X90100 Replaces variable capacitors used to tune the frequency response of electronic systems up to 400MHz

Features

- 32-tap Digital capacitor
- Non-volatile EEPROM Storage of capacitor value with Power-On-Recall
- Fast setting time of 5µsec
- Excellent Linearity
- Simple Digital interface to program & store
- X90100M8I: $0.99 each in 10k units

Xicor X90100 Linearity Over Capacitive Range



Free Samples

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