Diseño de circuitos de RF y microondas

TEMA 1

RF Circuit Design 2nd Ed.

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Chapter 1 *Components and Systems*

RF Circuit Design:

Theory and Applications

Reinhold Ludwig and Pavel Bretchko

Chapter 1 *Introduction*

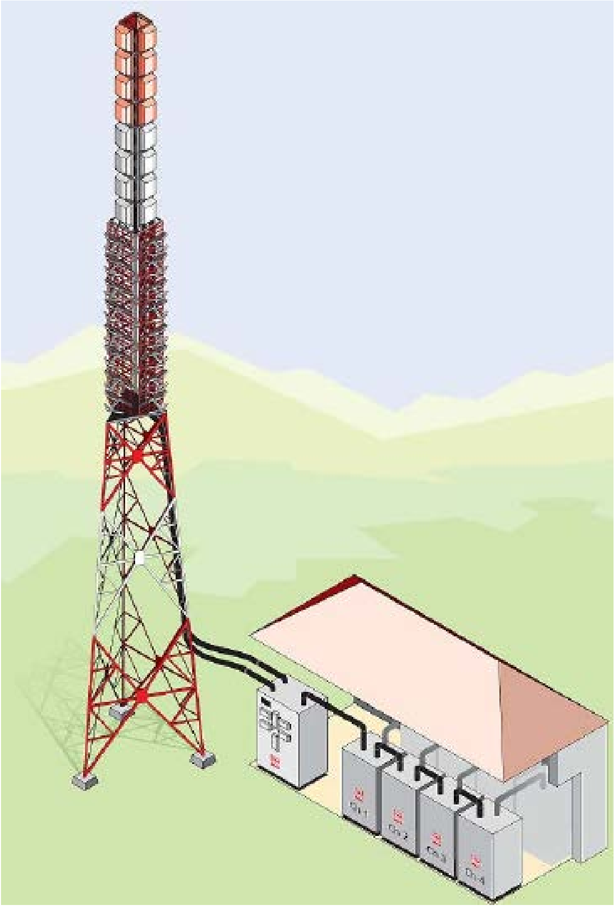
Practical RF Circuit Design for Modern Wireless Systems

Volume I: Passive Circuits and Systems

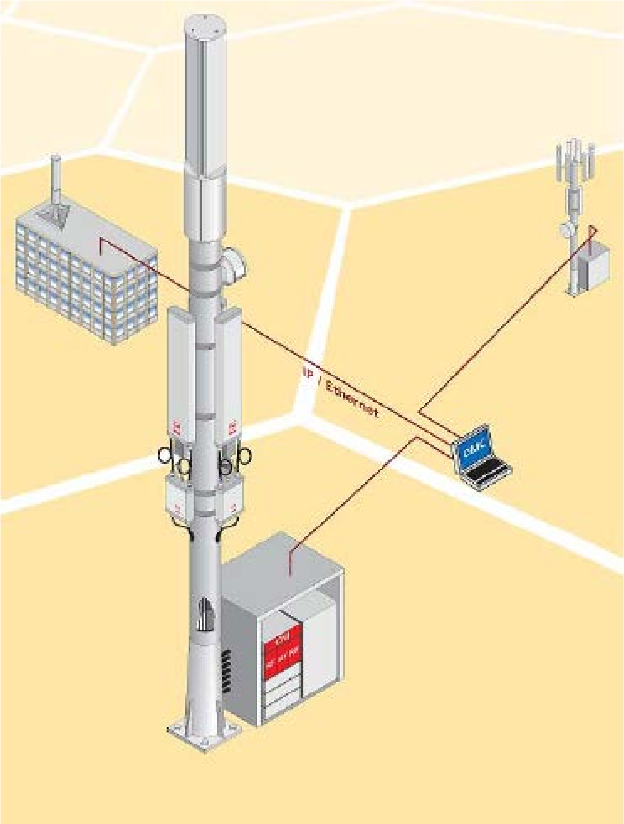
Les Besser and Rowan Gilmore

Chapter 7 *Passive component models*

Applications

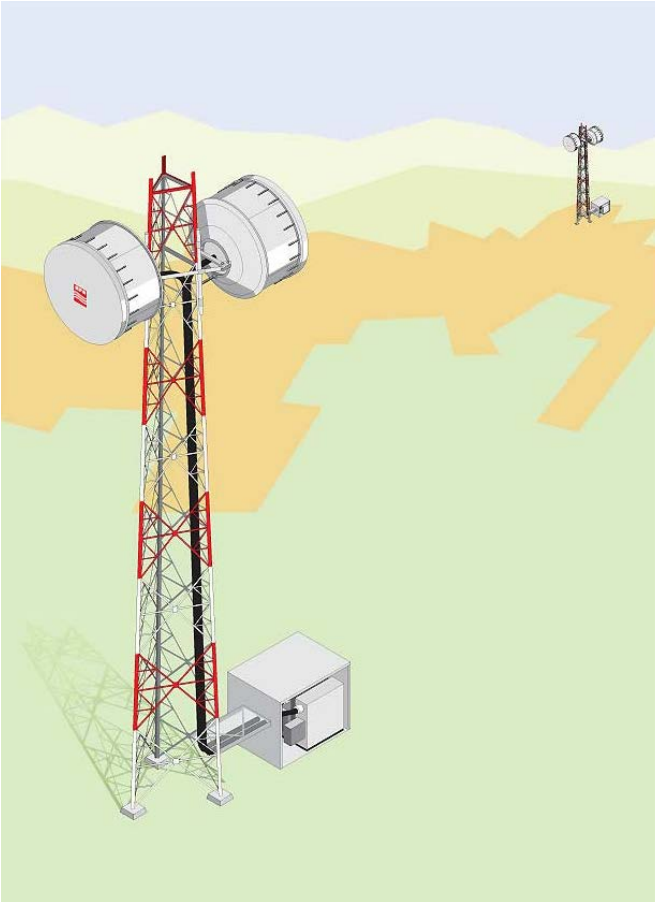


Broadcasting Systems
AM, FM, Digital TV Stations



Mobile Communications Base Stations
GSM, UMTS

Applications



Radiolink Communications

Satellite Communications
Navstar Global Positioning System (GPS) satellite

Applications

All these systems have in common that they consist of a hardware RF/microwave subsystem.

Types

- Active devices:

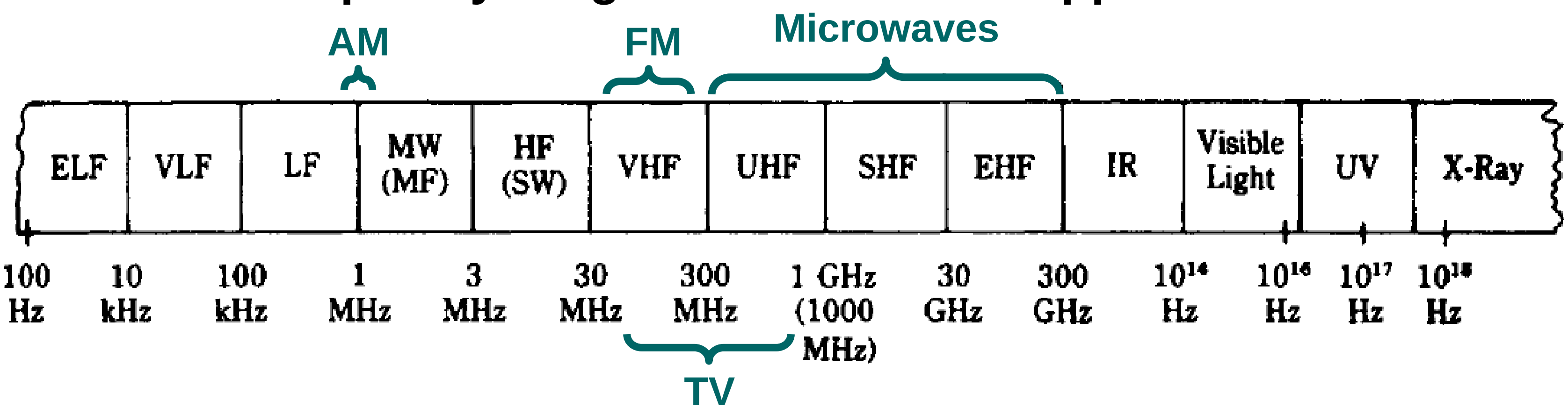
- power amplifiers,
- oscillators,
- frequency converters, ...

- Passive Devices: Typically the radiating elements (antennas) and power system consisting of:

- Filters,
- Multiplexers,
- Dividers / Combiners,
- Couplers, ...

Motivation

What is the frequency range of the previous applications?



Conventional analysis tools such as Kirchhoff type mesh voltage and current node laws strictly apply only to direct current (DC) and low frequency lumped components circuit consisting of resistors, capacitors and inductors.

The main objective of this course is to provide theoretical and practical design of analog circuits with operating frequencies in the range of radio frequencies (RF) and microwave.

Why is this course needed?

Conventional Circuit Theory does not always applies

Lumped component representation must be modified or completely replaced by another model

Motivation

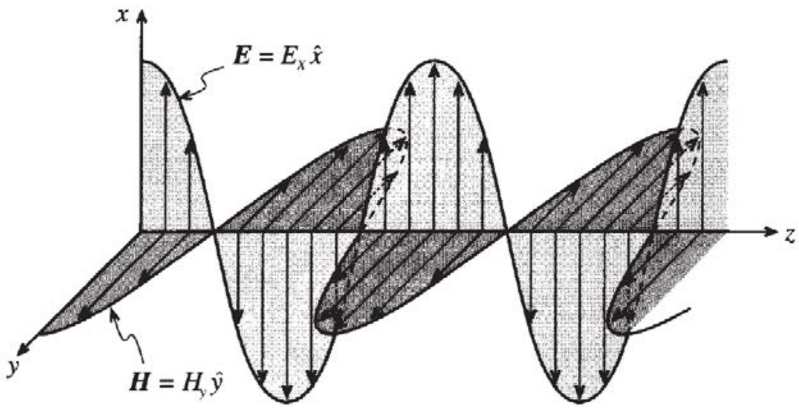
In order to understand the upper frequency limit, beyond which conventional circuit theory can no longer be applied to analize an electrical system we should recall the representation of an electromagnetic wave.

$$E_x = E_{0x}\cos(\omega t - \beta z)$$

$$H_y = H_{0y}\cos(\omega t - \beta z)$$

Plane electromagnetic wave propagating in free-space, in the z direction (+)

ω = angular frequency of the wave,
$\beta = 2\pi/\lambda$ = propagation constant,
λ = wavelength.



Field components are orthogonal to each other, and orthogonal to the direction of propagation (TEM)

$$v_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{\varepsilon\mu}}$$

phase velocity

$$\lambda = \frac{2\pi}{\beta} = \frac{2\pi v_p}{\omega} = \frac{v_p}{f}$$

Motivation

EXAMPLE

¿What is the wavelength of a plane electromagnetic wave propagating in free-space at frequencies of 30 MHz, 300 MHz y 3 GHz?

Solution

λ = 10 m @ f = 30 MHz
λ = 1 m @ f = 300 MHz
λ = 10 cm @ f = 3 GHz

As the frequency increases, the wavelength is reduced to dimensions that are comparable to the size of the circuit boards and even to the size of the components.

Frequency Band	Frequency	Wavelength
ELF (Extreme Low Frequency)	30–300 Hz	10,000–1000 km
VF (Voice Frequency)	300–3000 Hz	1000–100 km
VLF (Very Low Frequency)	3–30 kHz	100–10 km
LF (Low Frequency)	30–300 kHz	10–1 km
MF (Medium Frequency)	300–3000 kHz	1–0.1 km
HF (High Frequency)	3–30 MHz	100–10 m
VHF (Very High Frequency)	30–300 MHz	10–1 m
UHF (Ultrahigh Frequency)	300–3000 MHz	100–10 cm
SHF (Superhigh Frequency)	3–30 GHz	10–1 cm
EHF (Extreme High Frequency)	30–300 GHz	1–0.1 cm
Decimillimeter	300–3000 GHz	1–0.1 mm
P Band	0.23–1 GHz	130–30 cm
L Band	1–2 GHz	30–15 cm
S Band	2–4 GHz	15–7.5 cm
C Band	4–8 GHz	7.5–3.75 cm
X Band	8–12.5 GHz	3.75–2.4 cm
Ku Band	12.5–18 GHz	2.4–1.67 cm
K Band	18–26.5 GHz	1.67–1.13 cm
Ka Band	26.5–40 GHz	1.13–0.75 cm
Millimeter wave	40–300 GHz	7.5–1 mm
Submillimeter wave	300–3000 GHz	1–0.1 mm

IEEE frequency spectrum clasification

WIRE

Where is it found?

• Wirewound resistors, inductors, and axial- and radial-leaded capacitors all use a wire of some size and length either in their leads, or in the actual body of the component, or both.

• Wire is also used in many interconnect applications in the lower RF spectrum.

How does it behave at high frequencies?

The **behavior** of a wire in the RF spectrum depends to a large extent on the wire's **diameter** and **length**.

Passive Components Models

WIRE

Skin Effect

The alternating charge carrier flow establishes a magnetic field that induces an electric field (Faraday's law) whose associated current density opposes to the original current flow.

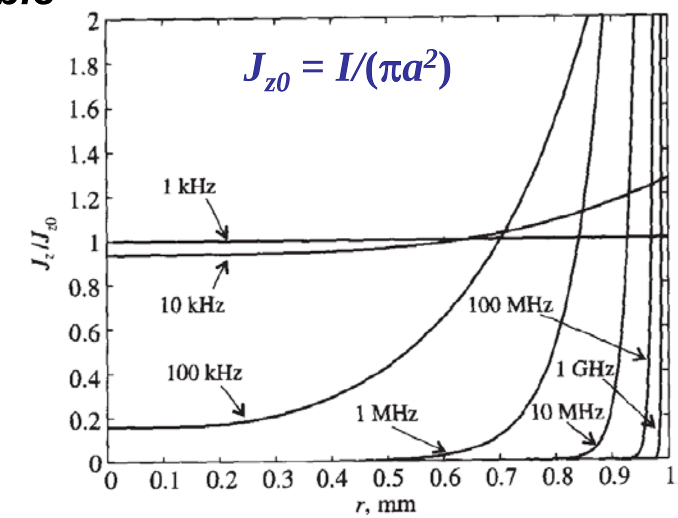
depends on the radial variable

$$\boxed{J_z = \frac{pI}{2\pi a}\frac{J_0(pr)}{J_1(pa)}}$$

alternating current density in a circular conductor

$p^2 = -j\omega\mu\sigma$,
ω = angular frequency of the current,

μ = magnetic permeability of the conductor,
σ = conductivity of the conductor,
J_i = Bessel functions of order i,
a = radius of the conductor,
r = radial variable (cylindrical coordinates).



normalized current density of circular conductor of radius a = 1mm

- At low frequencies → **uses entire cross-sectional area as a transport medium for charge carriers**

- As the frequency is increased, the magnetic field at the center of the conductor presents an impedance to the charge carriers → **current density decreases at the center of the conductor and increases around its perimeter**

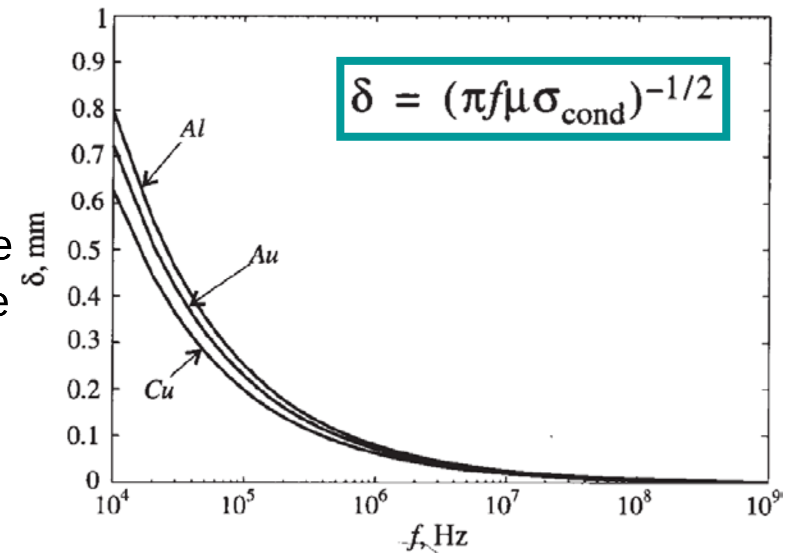
Passive Components Models

WIRE

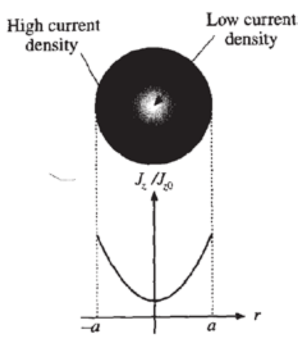
Skin Effect

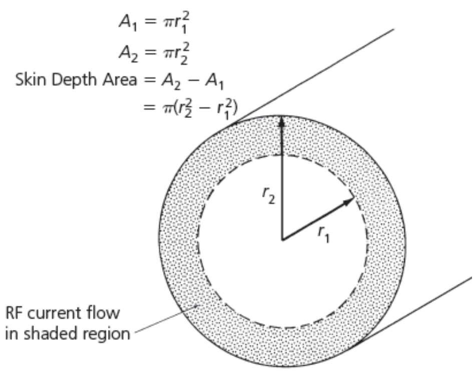
skin depth

The depth into the conductor at which the charge-carrier current density falls to 1/*e*, or 37% of its value along the surface (function of the **frequency** and the **permeability** and **conductivity** of the medium)



Effective decrease in the cross-sectional area of the conductor
(net increase in the ac resistance of the wire)





$$\boxed{R_{DC} = \frac{l}{\pi a^2 \sigma_{cond}}}$$

$$\delta \ll a$$

$$\boxed{R/R_{DC} \cong a/(2\delta)}$$

$$\boxed{(\omega L)/R_{DC} \cong a/(2\delta)}$$

EXAMPLE

For copper, the skin depth is approximately 0.85 cm at 60 Hz and 70 μm at 1 MHz
(63% of the RF current flowing in a copper wire will flow within a distance of 70 μm of the outer edge)

WIRE

Straight-Wire Inductors

In the medium surrounding a conductor carrying an alternating current there exists a magnetic field that is alternately expanding and contracting and, thus, producing a voltage on the wire which opposes any change in current flow (*self-inductance*).

$$L(nH) = K\,\ell\left(\ln\left(\frac{4\ell}{D}\right) - 0.75\right)$$

DC (low frequency) inductance of a circular conductor

K = 2,
l = the length of the wire in cm,
D = the diameter of the wire in cm.

EXAMPLE

Find the inductance of 5 cm of AWG No. 22 copper wire (*D* = 25.3 mils = 0.643 mm)

Solution

L = 2*5* [ln(4*5/0.0643− 0.75)] = 50 [nH]

Not so small after all

$$L = 2l\left[\log\frac{2l}{\rho} - 1\right]$$

inductance of a circular conductor when δ << a (large f) and the internal inductance of the conductor can be neglected

ρ = radius of the wire in cm.

$$L(\mathrm{nH}) = K\ell\left(\ln\left(\frac{2\ell}{W+T}\right)\right) + \frac{0.223(W+T)}{\ell} + 0.5$$

DC (low frequency) inductance of a flat ribbon conductor

W = width of the conductor in cm,
T = thickness of the conductor in cm.

Passive Components Models

RESISTORS

Resistance is the property of a material that determines the rate at which electrical energy is converted into thermal energy for a given electric current.

$$1\ \text{V} / 1\ \Omega = 1\ \text{C/s} = 1\ \text{A}$$

(1 volt across 1 ohm = 1 coulomb per second = 1 ampere)

$$P = EI = 1\ \text{V} \times 1\ \text{A} = 1\ \text{W}$$

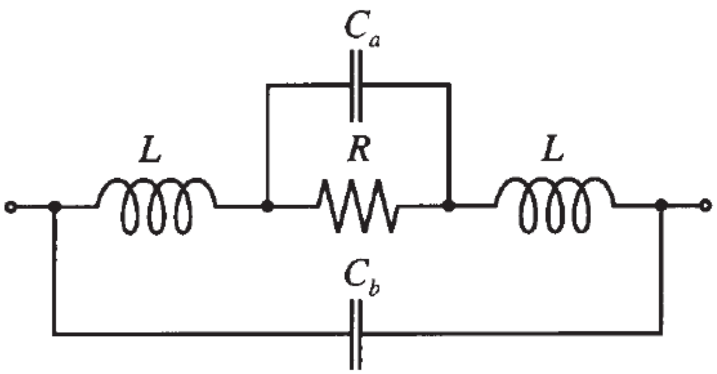
(corresponding thermal dissipation)

Where can we find them?

In transistor bias networks, pads, and signal combiners, etc..

How do they behave at high frequencies?

In some instances, such as in transistor biasing networks, the resistor will still perform its DC circuit function, but it may also disrupt the circuit's RF operating point.



R is the resistor value itself,

L is the lead inductance,

$C_{a,b}$ are parasitic capacitances that account for a charge sepparation (usually $C_b << C_a$).

Passive Components Models

RESISTORS

Carbon-composition resistors

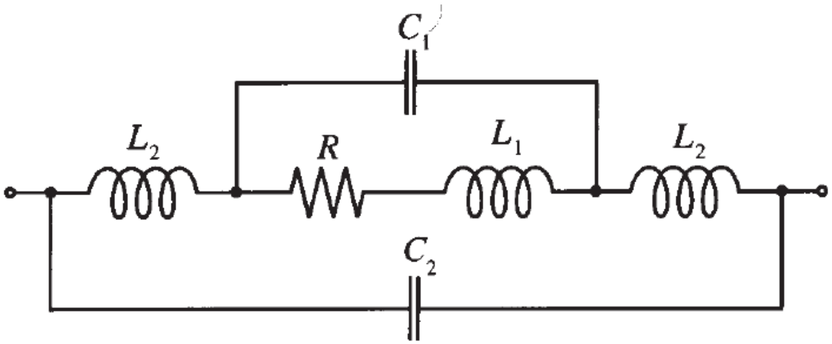
Have notoriously poor high-frequency performance.

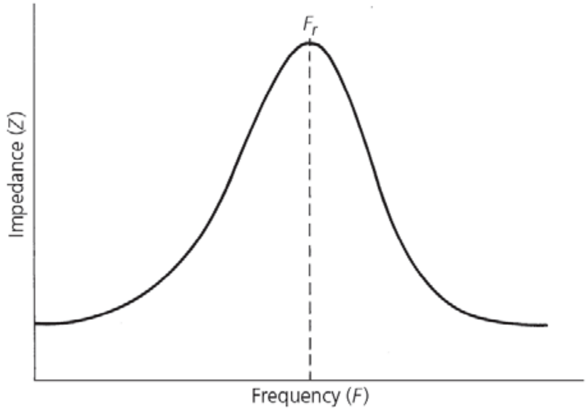
Consists of densely packed dielectric particulates or carbon granules.

Between each pair of carbon granules is a very small parasitic capacitor (these parasitics, in aggregate, are the major component of the device's equivalent circuit).

Wirewound resistors

- Inductor L_1, accounts for the inductance of the wound.
- Their impedances will first increase as the frequency increases (they look like inductors).
- At some frequency (*F*r), the inductance (L_1) will resonate with the shunt capacitance (C_1), producing an impedance peak.
- Further increase in frequency will cause the resistor's impedance to decrease.
- Again, usually $C_2 << C_1$



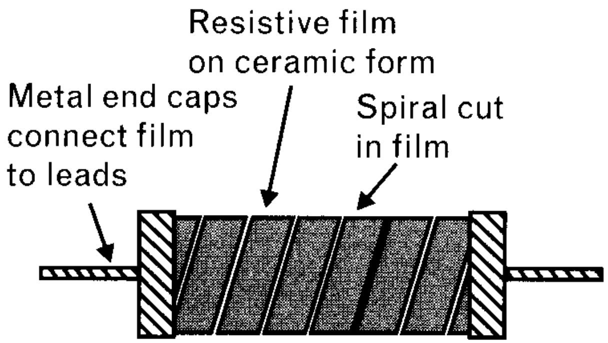


Passive Components Models

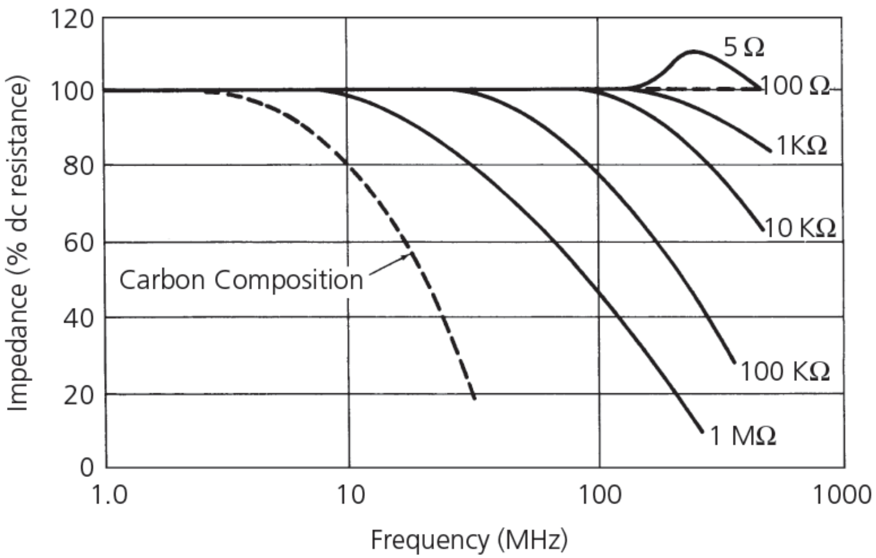
RESISTORS

Metal-film resistor

- Best characteristics over frequency.
- Same equivalent circuit as carbon-composition and wirewound resistor, but with lower values of the individual parasitic elements in the equivalent circuit.



Their impedance tend to decrease with frequency above about 10 MHz (due to the shunt capacitance). At very high frequencies, and with low-value resistors (under 50), lead inductance and skin effect may become noticeable. The lead inductance produces a resonance peak, as shown for the 5Ω resistance, and skin effect decreases the slope of the curve as it falls off with frequency.



Passive Components Models

RESISTORS

Metal-film resistor

EXAMPLE

The leads of a metal-film resistor are 1.27 cm (0.5”) long, and made up of AWG No. 14 wire (64.1 mils = 1.628 mm). The total stray shunt capacitance is 0.3 pF. If R = 10kΩ, what is its equivalent RF impedance at 200 MHz?

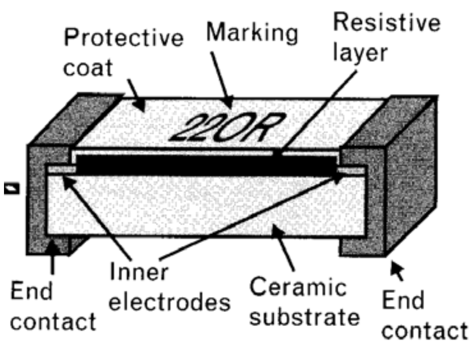
Solution

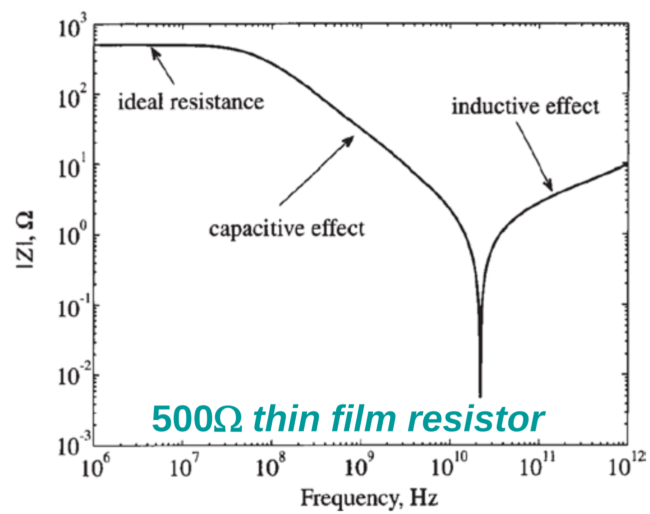
$L = 0.002*1.27*[2.3\log(4*1.27/0.1628-0.75)] = 8.7\text{ nH} \rightarrow X_L = \omega L = 2\pi*200\text{MHz}*8.7\text{nH} = 10.93\Omega$

$X_C = 1/\omega C = 1/(2\pi*200\text{MHz}*0.3\text{pF} = 2653\ \Omega \rightarrow Z_T = ?$

Thin-film chip resistors

- Eliminate or greatly reduce the stray reactances associated with resistors.
- Typically produced on alumina or beryllia substrates.
- Offer very little parasitic reactance at frequencies from DC to 2 GHz.





Passive Components Models

CAPACITORS

A capacitor is any device which consists of two conducting surfaces separated by an insulating material or dielectric. The dielectric is usually ceramic, air, paper, mica, plastic, film, glass, or oil.

The capacitance of a capacitor is that property which permits the storage of a charge when a potential difference exists between the conductors. Capacitance is measured in units of farads. A 1F capacitor's potential is raised by 1V when it receives a charge of 1C.

$$\boxed{C = \frac{Q}{V}}$$

C = capacitance in farads,
Q = charge in coulombs,
V = voltage in volts.

Where can we find them?
They are used extensively in RF applications, such as bypassing, interstage coupling, and in resonant circuits and filters.

CAPACITORS

Parallel-Plate Capacitor

$$\boxed{C = \frac{\varepsilon A}{d} = \varepsilon_0 \varepsilon_r \frac{A}{d}}$$

A = area of each metal plate,
d = the distance between the plates,
ε = permittivity of the dielectric material.

$\varepsilon_0 = 8.854 \times 10^{-12}$ F/m $\approx 10^{-9}/(36\pi)$ F/m
free-space permittivity

The ratio $\mathbf{k = \varepsilon / \varepsilon_0 = \varepsilon_r}$ is known as the dielectric constant of the material or relative permittivity. It provides a comparison of the given dielectric with vacuum (or air).

- Higher dielectric-constant materials will produce physically smaller capacitors, for a given value of capacitance.

- The influence of a dielectric on capacitor operation, over frequency and temperature, is often important.

Dielectric	K
Air	1
Polystrene	2.5
Paper	4
Mica	5
Ceramic (low K)	10
Ceramic (high K)	100 – 10,000

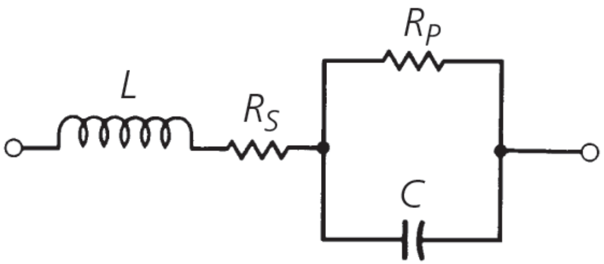
CAPACITORS

Real-World Capacitors

• The usage of a capacitor primarily depends upon the characteristics of its dielectric.

• The dielectric's characteristics determine the voltage levels and the temperature extremes at which the device may be used.

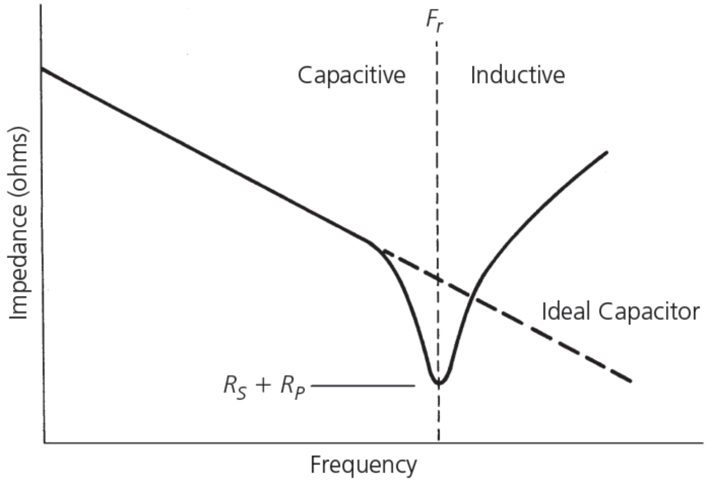
• Any losses or imperfections in the dielectric have an enormous effect on circuit operation.



Equivalent model

C equals the capacitance,
R_S represents the thermal-dissipation (loss) introduced by the leads,
R_P is the insulation resistance,
L is the inductance of the leads and plates.

As the frequency of operation increases, the lead inductance becomes important. At *Fr*, the inductance becomes series resonant with the capacitor, and above *Fr*, the capacitor acts like an inductor (large value capacitors tend to exhibit more internal inductance than small value capacitors).

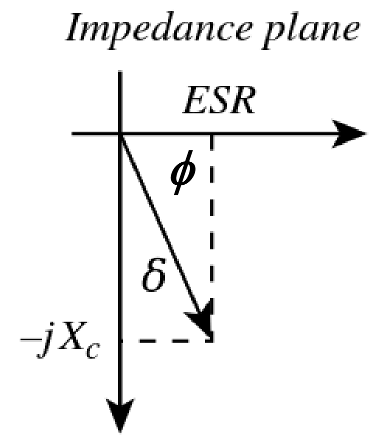


CAPACITORS

Real-World Capacitors

Power Factor — In a *perfect* capacitor, the alternating current will lead the applied voltage by 90°. This phase angle (ϕ) will be smaller in a real capacitor due to the total series resistance (*Rs* & *Rp*) that is shown in the equivalent circuit. Is a function of temperature, frequency, and the dielectric material.

$$\boxed{PF = \cos(\phi)}$$



$$\boxed{\delta = \pi/2 - \phi}$$

Insulation Resistance — Is a measure of the amount of DC current that flows through the dielectric of a capacitor with a voltage applied (no material is a perfect insulator $\rightarrow$ leakage current). This current path is represented by $R_P \sim 10^5 M\Omega$ or more.

Equivalent Series Resistance — Is the combined equivalent of R_S and R_P, and is the AC resistance of a capacitor.

$$\boxed{ESR = \frac{\tan(\delta)}{\omega C}}$$

Passive Components Models

CAPACITORS

Ceramic Capacitors for RF applications

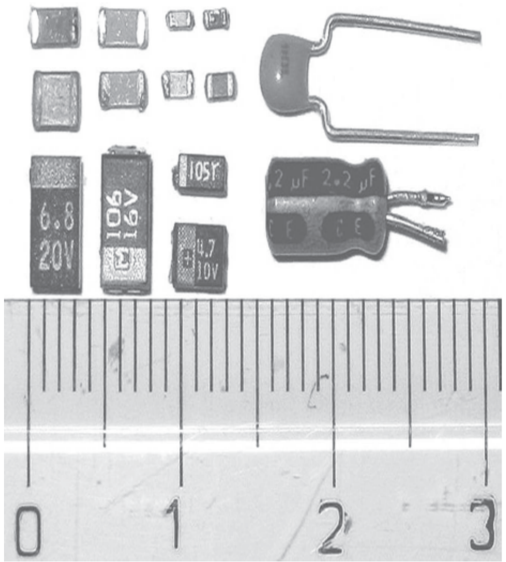
• Are typically high-Q (low ESR) devices with flat ribbon leads or with no leads at all

• The lead material is usually solid silver or silver plated (very low resistive losses)

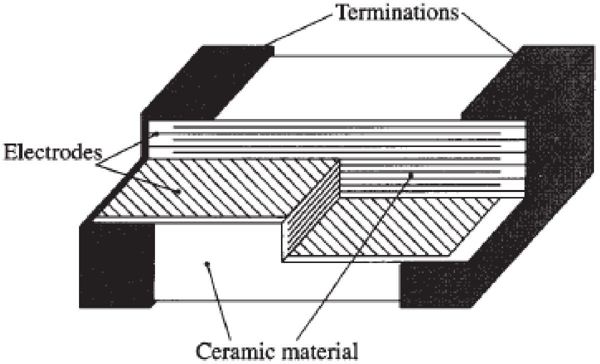
• At VHF frequencies and above exhibit very low lead inductance due to the flat ribbon leads

• More expensive and require special PCB areas for mounting

• The ones with no leads are called chip capacitors and are typically used above 500 MHz (lead inductance cannot be tolerated)



Chip and ceramic capacitors



Ceramic multilayer chip capacitors

Passive Components Models

CAPACITORS

Mica Capacitors

• Typically have a dielectric constant of about 6 (typically large size)

• Extremely good temperature characteristic

• Used extensively in resonant circuits and in filters where PCB area is of no concern

• Silvered mica capacitors have even better stability with very tight and reproducible tolerances of typically +20 ppm/°C over a range −60°C to +89°C

Metalized-Film Capacitors

• Broad category **encompassing most of other** capacitors which we have not yet been discussed (teflon, polystyrene, polycarbonate, and paper)

• Used in a number of applications, including filtering, bypassing, and coupling

• Most of the polycarbonate, polystyrene, and teflon styles are available in very tight (±2%) capacitance tolerances over their entire temperature range

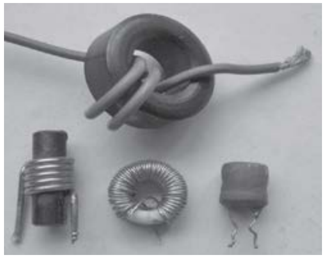
• Polystyrene, however, typically cannot be used over +85°C

• Typically larger than the equivalent-value ceramic types and are used in applications where space is not a constraint

Passive Components Models

INDUCTORS

They are basically a wire wound or coiled in such a manner as to increase the magnetic flux linkage between the turns of the coil. This increased flux linkage increases the wire's self-inductance.

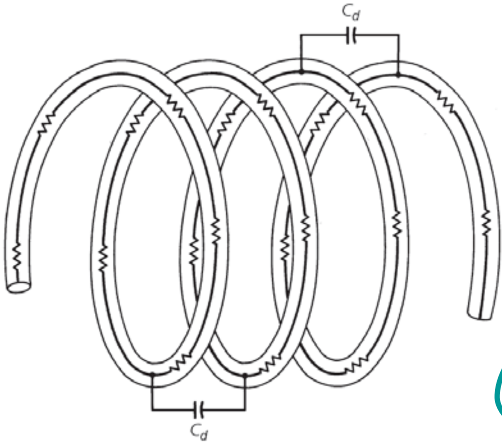


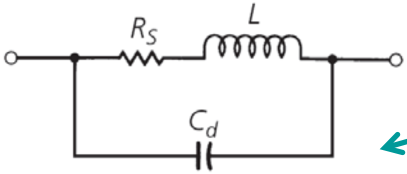
Where can we find them?

They are used extensively in RF design in resonant circuits, filters, phase shift and delay networks, and as RF chokes used to prevent, or at least reduce, the flow of RF energy along a certain path.

Real-World Inductors

Two conductors in close proximity but separated by a dielectric, with a voltage differential between the two, form a capacitor. Thus, if any wire resistance at all exists, a voltage drop (even though very minute) will occur between the windings, and small capacitors will be formed (**distributed capacitance, C_d**).





Equivalent model

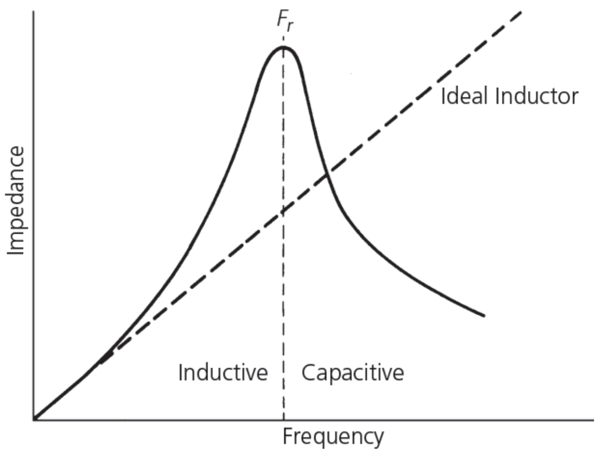
aggregate of the individual parasitic distributed capacitances

INDUCTORS

Real-World Inductors

Inductor impedance

- At low frequencies, is that of an ideal inductor.
- At medium frequencies, departs from the ideal curve and increases at a much faster rate until it peaks at the parallel resonant frequency (***Fr***).
- Above ***Fr***, begins to decrease with frequency and, thus, the inductor begins to look like a capacitor.



The series resistance of a coil keeps the impedance of the coil finite at resonance, and broaden the resonance peak of the impedance curve of the coil.

Quality factor

Is the ratio of an inductor's reactance to its series resistance and is often used as a measure of the quality of the inductor (**Q**). The larger the ratio, the better is the inductor.

$$Q = \frac{X}{R_s}$$

Passive Components Models

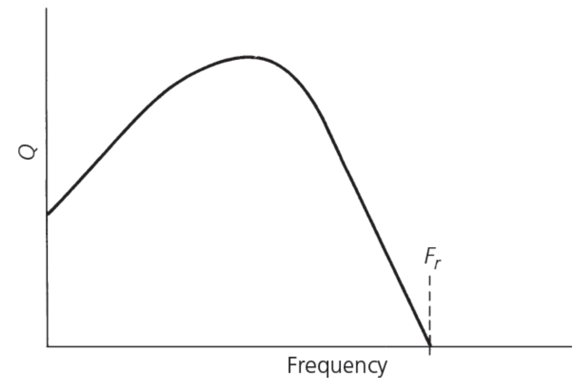
INDUCTORS

Real-World Inductors

Quality factor

• At low frequencies, is very good because the only resistance in the windings is the DC resistance of the wire.

• As the frequency increases, skin effect and winding capacitance begin to degrade it.



• At low frequencies, *Q* will increase directly with frequency (reactance is increasing and skin effect has not yet become noticeable).

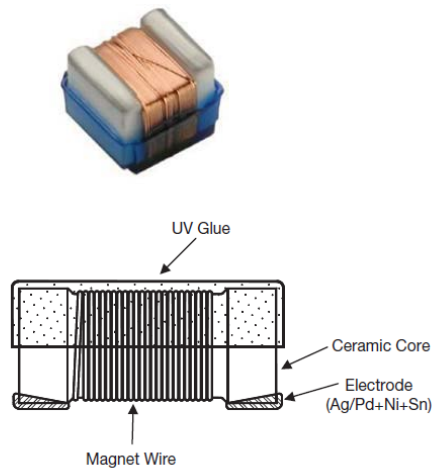
• Soon, skin effect does become a factor. The *Q* still rises, but at a lesser rate, and we get a gradually decreasing slope in the curve. The flat portion of the curve occurs as the series resistance and the reactance are changing at the same rate.

• Above this point, the shunt capacitance and skin effect of the windings combine to decrease the *Q* of the inductor to zero at ***Fr***.

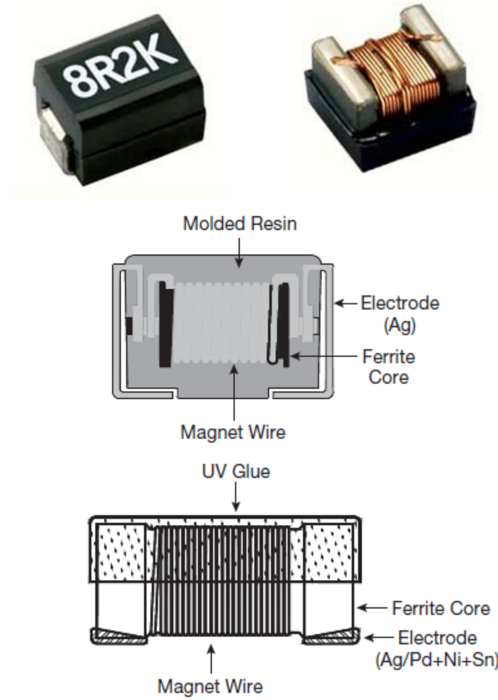
INDUCTORS

Real-World Inductors

Fixed-chip inductors
Feature a ceramic substrate with gold-plated solderable wrap-around bottom connections. They come in values from 0.01μH to 1.0 mH, with typical Qs that range from 40 to 60 at 200 MHz.



Wire Wound Chip Inductor (ceramic)



Wire Wound Chip Inductor (ferrite)

Increasing the *Q* of an inductor and extending its useful frequency range

1. Use a larger diameter wire (decreases the AC and DC resistance of the windings)

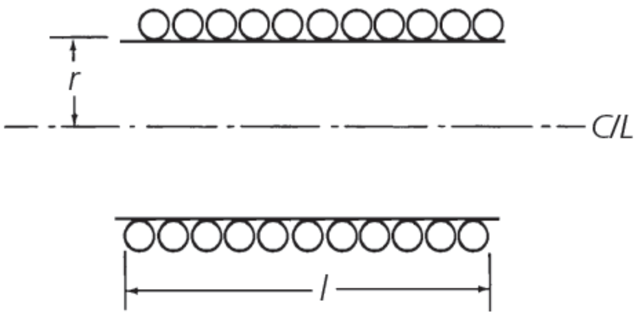
2. Spread the windings apart (decreases the interwinding capacitance)

3. Increase the permeability of the flux linkage path. This is most often done by winding the inductor around a magnetic-core material, such as iron or ferrite. A coil made in this manner will also consist of fewer turns for a given inductance.

Passive Components Models

INDUCTORS

Single-Layer Air-Core Inductor Design



$$\boxed{L = \frac{0.394 r^2 N^2}{9r + 10l}}$$

r = the coil radius in cm,
l = the coil length in cm,
L = the inductance in μH.

Coil length *l* must be greater than 0.67*r*.
This formula is accurate to within 1%.

EXAMPLE
Design a 100 nH air-core inductor on a 0.25” (0.635 cm) coil form.
Solution
For optimum *Q*, *l* = 2*r* $\rightarrow$ *r* =0.317 cm $\rightarrow$ *N* = $[29L/(0.394r)]^{1/2}$ = $[29*0.1/(0.394*0.317)]^{1/2}$ = 4.8 turns
The wire diameter cannot be larger than 0.635 cm/4.8 = 0.132 cm

Even though optimum *Q* is attained when *l* = 2*r*, this is sometimes not practical and, in many cases, the length is much greater than the diameter.

INDUCTORS

Single-Layer Air-Core Inductor Design

Dilemma

If we use the maximum wire diameter allowed we end up with a very tightly wound coil (increases the distributed capacitance between the turns and, thus, lowers the useful frequency range of the inductor by lowering its resonant frequency).

Solution

1. Use the next smaller diameter possible to wind the inductor while keeping the length value. This approach decreases the interwinding capacitance, but increases the resistance of the windings and lowers the *Q*.

2. Extend the length of the inductor (while retaining the maximum wire diameter allowed) just enough to leave a small air gap between the windings. This method will produce the same effect as the previous approach (reduces the *Q* but it decreases the interwinding capacitance considerably).

INDUCTORS

Magnetic-Core Materials

• In many RF applications, where large values of inductance are needed in small areas, air-core inductors cannot be used because of their size.

• A magnetic-core material with a much greater permeability (*μ*) than air, increases the coil's magnetic flux density by decreasing the "reluctance" path that links the windings.

Advantages

1. Smaller size due to the fewer number of turns needed for a given inductance.

2. Increased *Q*, since fewer turns means less wire resistance.

3. Variability, obtained by moving the magnetic core in and out of the windings.

Disadvantages

1. Each core introduce its own losses
→ could possibly decrease the Q (depends on the material and frequency of operation)

2. Permeability of all magnetic cores changes with frequency (usually decreases to a very small value at the upper end of their operating range).

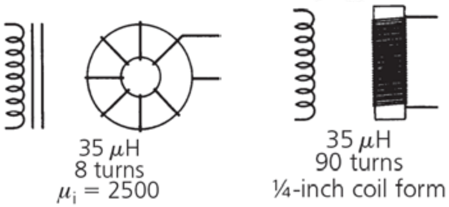
3. Higher permeability cores are more sensitive to temperature variation.

4. The permeability of magnetic cores changes with applied signal level.
Large excitation applied → core saturation may result

INDUCTORS

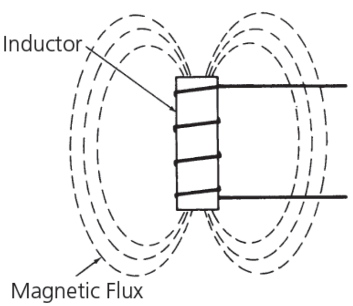
Magnetic-Core Materials (e.g. Toroids)

- Widely used to wind RF inductors and transformers
- Usually made of iron or ferrite
- Have various shapes, sizes and wide range of characteristics
- Can typically yield very high *Q*s
- They are self-shielding, compact, and easy to use



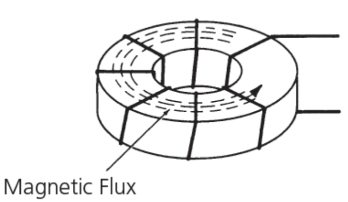
(A) *Toroid inductor* (B) *Air-core inductor*

In a typical air-core inductor, part of the magnetic-flux path is the air surrounding the inductor (tends to radiate).



(A) *Typical inductor*

A toroid, completely contains the magnetic flux within the material itself; thus, no radiation occurs (there is some radiation but it is minimized). This characteristic of toroids eliminates the need for bulky shields that reduce available space, and also reduce the *Q*.



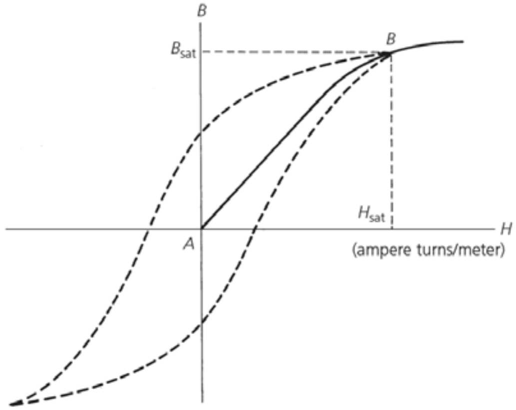
(B) *Toroidal inductor*

INDUCTORS

Magnetic-Core Materials (e.g. Toroids)

Core Characteristics

As the magnetic-field intensity (H) is increased (by increasing the applied voltage) from zero, the magnetic flux density (B) that links the turns of the inductor increases.



$$\mu = B/H \text{ [Weber/Ampere-turn]}$$

The permeability of a material is a measure of how well it transforms an electrical excitation into a magnetic flux.

- Initially the magnetization curve is linear (in this region is where the permeability is usually specified - initial permeability μ_i).
- As the electrical excitation increases, a point is reached at which the magnetic-flux intensity does not continue to increase at the same rate.
- Any further increase in excitation may cause ***saturation*** to occur. H_{sat} is the excitation point above which no further increase in magnetic-flux density occurs (Bsat). The incremental permeability above this point is the same as air.

→ ***the excitation should be kept small enough to maintain linear operation***

INDUCTORS

Magnetic-Core Materials (e.g. Toroids)

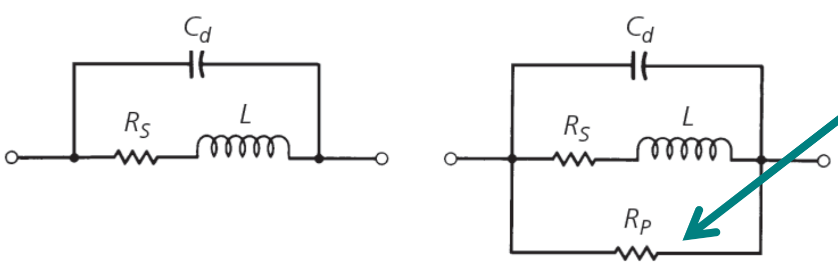
Core Characteristics

B_{sat} varies substantially from core to core, depending upon the size and shape of the material.

$$\boxed{B_{op} = \frac{E \times 10^8}{(4.44) f N A_e}}$$

must be less than B_{sat}

B_{op} = the magnetic-flux density in gauss,
E = the maximum rms voltage across the inductor in volts,
f = the frequency in hertz,
N = the number of turns,
A_e = the effective cross-sectional area of the core in cm^2.



(A) *Air core* (B) *Magnetic core*

Represents the losses which take place in the core itself
(varies, usually increases, with frequency)

Hysteresis represents the power lost in the core due to the realignment of the magnetic particles within the material with changes in excitation, and the **eddy currents** that flow in the core due to the voltages induced within.

INDUCTORS

Magnetic-Core Materials (e.g. Toroids)

Powdered Iron vs. Ferrite

• Powdered-iron cores can typically handle more RF power without saturation or damage than the same size ferrite core

• Unlike powdered iron, Ferrite, if driven with a large amount of RF power, tends to retain its magnetism permanently (ruins the core by changing its permeability)

High RF power levels → powdered iron core inductors

• In general, powdered-iron cores tend to yield higher-Q inductors, at higher frequencies, than an equivalent size ferrite core (the inherent core characteristics of powdered iron cores produce much less internal loss than ferrite cores)

Narrowband or tuned-circuit → powdered iron core inductors

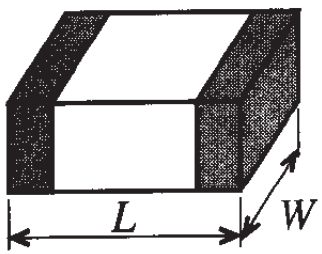
• For a given core size, ferrite cores have a much higher permeability. The higher permeability is needed at the lowend of the frequency range (for a given inductance, fewer windings would be needed).

VLF, or in broadband circuits (VLF through VHF) → ferrite core inductors

Save circuit board → ferrite core inductors

Passive Components Models

CHIP COMPONENT SIZE

Geometry	Size Code	Length L, mils	Width W, mils
	0402	40	20
	0603	60	30
	0805	80	50
	1206	120	60
	1218	120	180

Some standard chip component sizes

1 mil = 1”/1000 = 25.4 x 10^{-3} mm

Algunas marcas de componentes:

Vishay

AVX

Coilcraft (sólo inductores)

muRata

The End