RADIO AMATEUR EXAM
GENERAL CLASS

By 4S7VJ

CHAPTER- 3

3.1 REACTANCE (X)

When a.c. voltage applied to a capacitor or an inductor the current (r.m.s.) is proportional to the voltage (r.m.s.). For d.c. circuits, resistance is the ratio between voltage and the current. There is a similar quantity called reactance for a.c. circuits. Unit is Ohm.

3.1.1 CAPACITIVE REACTANCE (X_C)

The reactance of a pure capacitor in an a.c. circuit is called capacitive reactance and it is inversely proportional with the capacitance and the frequency of ac. supply. The relationship between them is

$$X_C = 1/(2\pi fC)$$

X_C = Capacitive Reactance (Ohm - Ω)
f = Frequency (Hertz - Hz)
C = Capacitance (Farad - F)
π = 3.14 (mathematical constant, 22/7)

Although the unit of reactance is the Ohm, there is no power dissipation in reactance. The energy stored in the capacitor in one quarter of the cycle is simply returned to the circuit in the next. For the above formula if f in MHz and C in μF, then X_C will be in Ohms. It is more convenient.

Example:-
What is the capacitive reactance of a 500 pF capacitor at a frequency of 7060 kHz.

f = 7060 kHz = 7.060 MHz
C = 500 pF = 0.0005 μF
X_C = 1/(2 x 3.14 x 7.060 x 0.0005)
= **45.08 Ohm**

3.1.2 INDUCTIVE REACTANCE (X_L)

The reactance of a pure inductor (one with no resistance but practically all inductors have resistance) in an ac circuit is called inductive reactance, and it is directly proportional with the inductance and the frequency of the a.c. current through the inductor. The formula for it is:-

$$X_L = 2\pi fL$$

X_L = Inductive Reactance (Ω)
f = Frequency (Hz)
L = Inductance (H)
π = 3.14 (mathematical constant, 22/7)
(If L in μH and f in MHz then X_L is in Ohms)

Example:-
What is the reactance of a 20 μH inductor for 14200 kHz. If the resistance is negligible and current through the inductor is 10 μA, what is the voltage across the inductor.

f = 14200 kHz = 14.2 MHz
L = 20 μH
apply the formula
$X_L = 2\pi fL$
= 2 x 3.14 x 14.2 x 20
= **1784 Ohms**

apply the Ohm's law for the inductor
I = 10 μA = 1/100000 A
R = 1784 Ω
V = I x R
= (1/100000) x 1784 V
= (1/100000) x 1784 x 1000 mV
= **17.84 mV**

3.1.3 REACTANCES IN SERIES & PARALLEL

When reactances of the same kind **(with out combine capacitors and inductors)** connected in series or parallel the resultant is as same as resistances.

For series reactances:-

$$X = X_1 + X_2 + X_3$$

For parallel reactances:-

$$1/X = 1/X_1 + 1/X_2 + 1/X_3$$

3.2 PHASE & PHASE ANGLE

If a magnet rotates with a uniform speed near a coil (like a bicycle dynamo) the graph between the generated e.m.f. vs angle of rotation (Fig. 3.1) is a sine wave. One wavelength is represents 360 degrees or one complete turn. Any instance defined as the PHASE of the sine wave. The angle of rotation is called as the **phase angle.**

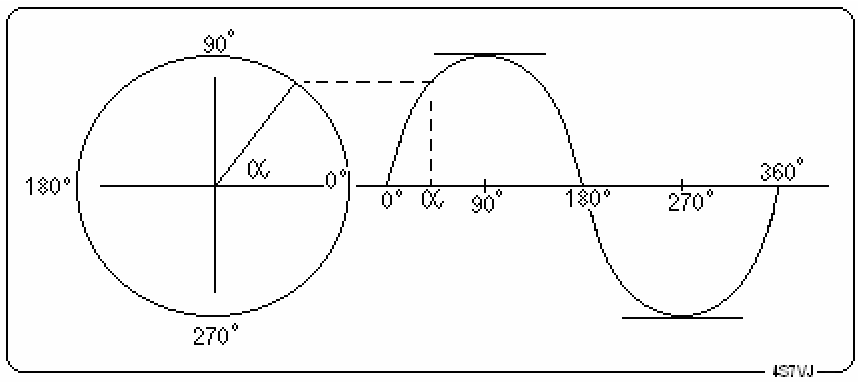

Fig. 3.1

3.2.1 PHASE DIFFERANCE FOR CAPACITOR

When a capacitor connected to an a.c. supply, while the voltage across the capacitor reaches maximum value, the current will be zero. If you draw both graphs in the same diagram we can realize the phase angle of the voltage is 90° and for the current is 180°, for the above instant. That means the current in the capacitor leads the applied voltage by 90°, or in other words the phase difference between the current and voltage is 90°.

3.2.2 PHASE DIFFERANCE FOR INDUCTANCE

When an inductor connected with an a.c. supply, the current is always lagging behind by 90° with the applied voltage, because of the induced back e.m.f.. For a resistance, no phase difference between the applied e.m.f. and the current. In other words the current is in-phase with the voltage for pure resistance.(non inductive resistor)

3.2.3 PHASE DIFFERANCE BETWEEN INDUCTANCE AND CAPACITANCE

If a pure inductor (L) and capacitor (C) connected in series with a.c. supply, the current through the L and C are completely out of phase, or phase difference is 180°. The equivalent reactance of this series combination is

$$X = X_L - X_C \quad \text{or} \quad X = X_C - X_L$$

3.3 IMPEDANCE (Z)

When a circuit contains both resistance and reactance (X_C or X_L or both) the combined effect of the two is called **IMPEDANCE** (Z). Impedance is thus a more general term than either resistance or reactance. The unit is "Ohm". The relationship between them is as follows:-

$$Z^2 = X^2 + R^2$$

or

$$Z = \sqrt{(R^2 + X^2)}$$

Eg:- Resistance of an inductor is 3 Ω and the reactance for a given a.c. supply is 4 Ω . What is the impedance for this moment?

apply

$Z^2 = R^2 + X^2$, $R = 3$, $X = 4$

There for $Z^2 = 3^2 + 4^2$

$= 9 + 16$

$= 25$

$Z = \sqrt{(25)} = 5\ \Omega$

3.3.1 OHM'S LAW FOR IMPEDANCE

Ohm's law can be applied to circuits containing impedance just as readily as to circuits having resistance or reactance only. The formula is

$$V = I Z$$

Where, Z = impedance

V = voltage across the impedance

I = Current through the inductor

Example:-

An inductor having a resistance of 50 Ω and a reactance of 120 Ω is connected to a 130 V a.c. supply. Find the current through the inductor and the power dissipation.

apply the formula

$$Z^2 = R^2 + X^2,\ R = 50\ \Omega,\ X = 120\ \Omega$$

therefore

$$Z^2 = 50^2 + 120^2 = 2500 + 14400 = 16900$$

$$Z = \sqrt{(16900)} = 130\ \Omega$$

for calculate the current, apply Ohm's law

$$\mathbf{V = I\ Z}$$

Therefore $I = V/Z$

Where V = 130 volts, Z = 130 Ω

then $I = 130/130$

$= \underline{\mathbf{1\ A}}$

Power is dissipating through the resistance(50 Ω) only.

therefore apply, $W = I^2 R$, I = 1A, R = 50 Ohms

$W = 1x1x50$

$= \underline{\mathbf{50\ Watts}}$

3.4 RESONANCE

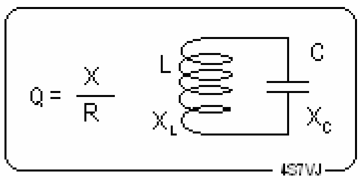

Fig. 3.2

3.4.1 SERIES RESONANCE CIRCUIT

Suppose a capacitor is connected in series with an inductor and a source of a.c.,(Fig. 3.2) the frequency of which can be varied over a wide range. At some low frequency, the capacitive reactance (X_C)will be much larger and the inductive reactance (X_L) will be smaller. The resistance of the circuit (R) is a constant, at any frequency (f). On the other hand, at high frequencies X_L is a higher value and X_C is a smaller value. At one particular frequency X_L and X_C will be equal
and the resultant inductance,

$$X = X_L - X_C = 0$$

Therefor the impedance is equal to the resistance. At this stage the current in the circuit will be maximum. This frequency is called **"RESONANCE FREQUENCY"** of the circuit.

3.4.1.1 RESONANCE FREQUENCY

The formula for the resonance frequency of tuned circuit is as follows:-

$$f = \frac{1}{2 \pi \sqrt{(LC)}}$$

where, f = resonance frequency (Hz)
L = inductance (H)
C = capacitance (F)
π = 22/7 = 3.14

Example:-

A 5µH inductor and 20 pF capacitor connected as a series resonance circuit. Calculate the resonance frequency.

apply the formula,

$$f = 1 / 2 \pi \sqrt{(LC)}$$

$L = 5\ \mu H = 5 / 10^6\ H$
$C = 20\ pF = 20 / 10^{12}\ F$
therefore $f = 1 / [2 \times 3.14 \times \sqrt{(5 \times 20 / 10^{18})}]$
$= 1 / [6.28 \times \sqrt{100} / \sqrt{(10^{18})}]$
$= 1 / [6.28 \times (10 / 10^9)]$
$= 0.1592 \times 10^8$
$= 15.92 \times 10^6$ Hz
= **15.92 MHz**

3.4.1.2 RESONANCE CURVE

If a plot is drawn of the current flowing in the series resonance circuit vs the frequency is varied, it would look like the curve in the diagram.(Fig. 3.3)

The shape of the resonance curve at frequencies near resonance is very sharp the sharpness of the curve is depend on the ratio of X/R of the circuit.

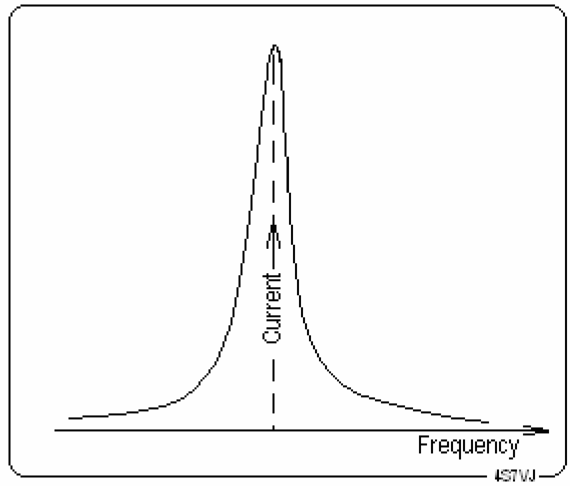

Fig. 3.3

3.4.1.3 Q-FACTOR (quality factor)for series resonance circuits

X/R ratio of a **series resonance circuit** is defined as the quality factor. (Q-FACTOR)

$$Q = X / R$$

Q = Quality factor
X = Reactance of either coil or capacitor
R = Resistance of the coil

There is no unit for the Q-factor because it is only a ratio. If the reactance of the series resonance circuit is of the same order of magnitude as the resistance, that means low Q circuit, the current is varying rather slowly as the frequency is moved in either direction away from the resonance. Such a curve is said to be broad. On the other hand if the reactance is considerably larger than the resistance, that means high Q circuit, the current is varying rapidly as the frequency moves away from the resonance and the circuit is said to be sharp. A sharp circuit will respond a great deal more readily to the resonant frequency than frequencies quite close to the resonance. Low-Q or broad circuit will respond almost equally for the band of frequencies centering around the resonant frequency.

3.4.1.3.1 Another formula for Q-factor

$X = 2\pi fL$ (for coil) or $X = 1/(2\pi fC)$, (for capacitor)

Therefore $Q = 2\pi fL/R$ or $Q = 1/(2\pi fCR)$

Normally we represent $2\pi f$ by Greek letter ω

Therefore $\omega = 2\pi f$, $Q = \omega L/R$ or $Q = 1/\omega CR$

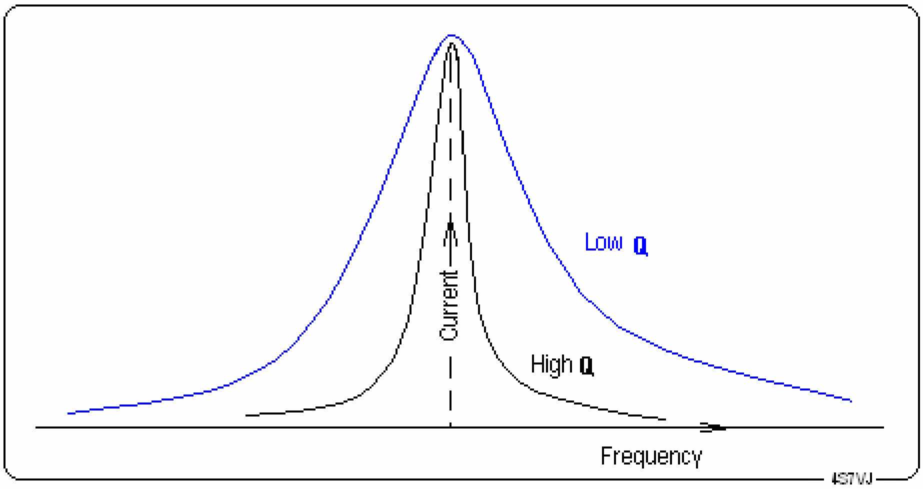

Fig. 3.4

3.4.1.4 **SELECTIVITY**

Selectivity is the ability to respond strongly at one desired frequency and discriminate against others. High-Q resonance circuits are essential to get more selectivity for receivers, especially for communication receivers. But the low-Q circuits are very useful for amplify a desired frequency band for the same receiver.

3.4.1.5 **VOLTAGE RISE AT RESONANCE**

When an a.c. voltage applied (induced signal voltage from the antenna for receivers) to L-C circuit, if it is resonance the voltage appears across either the inductor or capacitor is considerably higher than the applied voltage. The ratio of the reactive voltage to the applied voltage is also equal to the Q-factor. That means:-

the reactive voltage = Q x applied voltage

Example:-

For a series resonance circuit, inductive and capacitive reactance is 300 Ohms, the resistance is 2 Ohms. What is the Q-factor?

If the applied voltage is 10, What is the voltage across the capacitor or inductor?

Q-factor = X / R , X = 300 , R = 2
Therefore Q = 300/2
= **150**

applied voltage = 10 volts
voltage across capacitor or inductor = 150 x 10 = **1500 v**

3.4.2 PARALLEL RESONANCE CIRCUITS

When a variable frequency source of constant voltage applied to a parallel resonance circuit, there is a resonance effect similar to that in a series circuit. In this case the current drawn by the source is minimum at the maximum impedance of the circuit. Obviously that is the resonance frequency. At resonance frequency X_L and X_C are equal but the current through the inductor and capacitor is completely out of phase and they are canceling each other. Then the impedance is equal to the resistance of the coil.

At frequencies below resonance, the current through L is larger than that through C, because X_L is smaller than X_C. There is only partially cancellation of the two reactive currents, and therefore the line current is larger than the current taken by R alone. At frequencies above resonance the situation is reversed and more current flows through C than L, so the line current again increases. At resonance the current is totally depend on the resistance of the coil. **Finally we can say for the parallel resonance circuit shows maximum impedance at the resonance.**

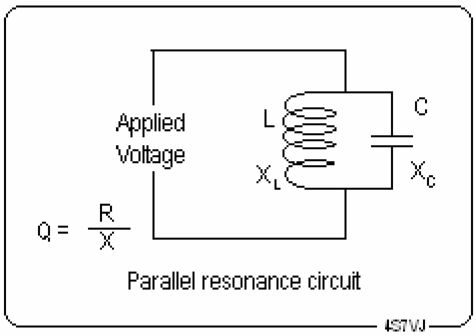

Fig. 3.5

3.4.2.1 Q-FACTOR FOR PARALLEL RESONANCE CIRCUITS

For parallel resonance circuits, quality-factor is the reciprocal of that of a series

$$\mathbf{Q = R / X}$$

X = 2πfL (for coil) or X = 1/(2πfC), (for capacitor)
Therefore **Q = R/2πfL** or **Q = 2πfCR**

Normally we represent 2πf by Greek letter ω
Therefore ω = 2πf, **Q = R/ωL** or **Q = ωCR**

3.4.3 APPLICATIONS OF RESONANCE CIRCUITS

3.4.3.1 SERIES RESONANCE CIRCUITS

These are very useful for various tuning stages of receivers and transmitters. For receivers high-Q series resonance circuits are useful for good selectivity. Low-Q circuits are useful for RF amplifier stage for amplify whole frequency band.

3.4.3.2 PARALLEL RESONANCE CIRCUITS

Parallel resonance circuits are useful for traps of multi band antenna systems. Normally these are low-Q circuits because those are acting like rejecter circuit for a particular frequency band.

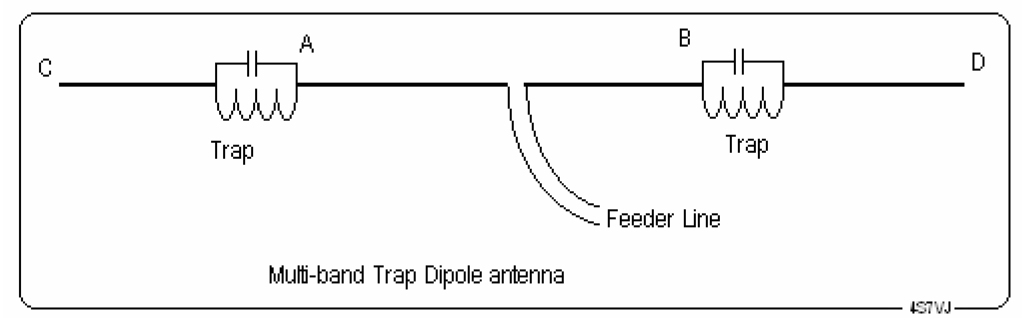

Fig. 3.6

Fig. 3.6 shows a multi band dipole antenna. For example if it is designed for 15m (21 – 21.450 MHz) and 20m (14 – 14.350) bands both traps (identical LC resonance circuits) must be tuned for 15m band. If any signal (TX or RX) reaches within 15m band both traps are resonating and acting as high impedance. Then the active part of the antenna is limited to "AB" portion; for 20m bad signals both traps having a very low (about 0.1 Ohm or less) impedance. Then whole "CD" portion is acting as the antenna.

3.5 TRANSFORMERS

Two coils having mutual inductance constitute a transformer. The coil connected to the source of energy is called primary coil and the other one is the secondary coil. A transformer can be used only with a.c., because for d.c., no voltage will be induced in the secondary coil since the magnetic field is not varying. The main purpose of the transformer is changing voltage according to the requirements. Step-up transformer will be increasing the voltage and step-down will be decreasing the voltage.

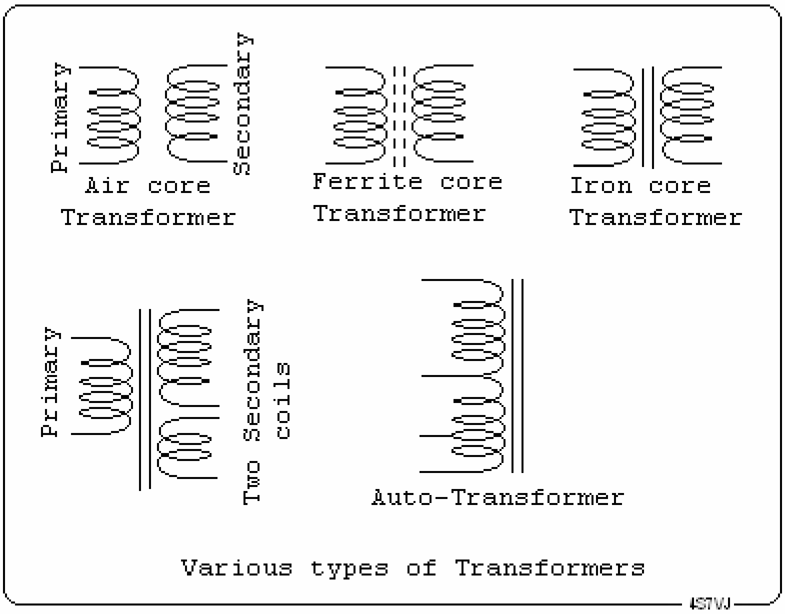

Fig. 3.7

3.5.1 VOLTAGE & TURNS RATIO

For a sine wave a.c. supply, the voltage is proportional to the number of turns. Therefore the ratio of the voltages of primary and secondary coils is equals to the ratio of number of turns.

$$V_s/V_p = N_s/N_p$$

Where,
V_p = primary applied voltage
V_s = secondary voltage
N_p = number of turns on primary
N_s = number of turns on secondary

3.5.2 EFFICIENCY & POWER

A transformer can only transfer power with different e.m.f. Hence, the power taken from the secondary cannot exceed that taken by the primary from the source. There is always some power loss in the resistance of the coils and the core material so practically the power output is slightly less than the power input.

efficiency = power output/power input, (less than 1)

OR

efficiency = 100 x (power output/power input) %

Normally efficiency is represented by a percentage.

3.5.3 CURRENT & TURNS RATIO

If we assumed that the efficiency = 100% then the current is inversely proportional to the number of turns.

$$I_s/I_p = N_p/N_s$$

Where, Is = secondary current
Ip = primary current
Ns = no. of turns on secondary
Np = no. of turns on primary

The actual current in the secondary winding is always slightly less than the theoretical value of secondary current.

Example:-

A transformer has a primary of 920 turns and applied voltage is 230 volts. There are two secondary coils. Voltages will be 1200 volts and 12 volts.

What is the voltage per turn and what will be the number of turns for both secondary coils.

voltage for 920 turns = 230
voltage per turn = 230/920
= **0.25 volts/turn**

1st method:-

for 1200 v. secondary:-

$N_s/N_p = V_s/V_p$

$V_p = 230$, $V_s = 1200$, $N_p = 920$

$N_s = N_p \times V_s / V_p$
$= 920 \times 1200 / 230$
$= 4 \times 1200$
= **4800 turns**

for 12 v. secondary:-

$V_p = 230$, $V_s = 12$, $N_p = 920$

$N_s = N_p \times V_s / V_p$
$= 920 \times 12 / 230$
$= 4 \times 12$
= **48 turns**

2nd method:-
Volts per turn = 0.25
Therefore turns per volt = 1/0.25 = 4
no. of turns for 1 volt = 4
no . of turns for 1200 v = 4 x 1200
= **4800 turns**

no . of turns for 12 v = 4 x 12
= **48 turns**

3.5.3.1 MAGNETIZING CURRENT

The current that flows in the primary when no power is taken from the secondary (secondary is open) is called the magnetizing current of the transformer. In the normal operations the magnetizing current should be very small in comparison with the primary load - current at the rated power output.

3.5.4 AUTOTRANSFORMER

The transformer principle can be utilized with only one winding instead of two; the principles just discussed apply equally well. A one-winding transformer is called an autotransformer (Fig. 3.7). The current the common section of the winding is the common difference between the line (primary) and the load (secondary) currents, since these currents are out of phase. Hence if the line and load currents are nearly equal the common section of the winding may be wound with comparatively small wire. The autotransformer is used chiefly for boosting or reducing the power line voltage by relatively small amounts. Continuously variable auto transformers are used for automatic a.c. voltage stabilizers.

3.6 THE DECIBEL

3.6.1 Comparison of Power Ratios

It is useful to appraise signal strength in terms of relative loudness as registered by the ear. For example, if a person estimates that a signal is twice as loud when the transmitter power is increased from 10 to 100 watts. He or she will also estimate that a 1000w signal is twice as loud as a 100w signal. The human ear has a logarithmic response. This fact is a basis for the use of the relative power unit called the decibel (dB). A decibel is one-tenth of a Bel. The number of decibels corresponding to a given power levels of P1 and P2 is given by,

dB = 10 Log(P2/P1)

It is convenient to memorize the decibel values for few of the common power ratios. A change of 1 dB in power level is just detectable as a change in loudness under ideal conditions. Double the power is 3 dB gain, 4 times is 6dB, 10 times is 10 dB, 100 times is 20dB, 1000 times is 30 dB, million times is 60 dB.
If P2 is smaller than P1, P2/P1<1 (decimal value)and there is no gain, it is a power loss or attenuation.
For example input power = 1mW and output is 0.01mW, then P2/P1 = 0.01/1 = 0.01, Log(0.01) = -2
Therefore power gain is -2dB. In another word power loss or attenuation is 2dB.

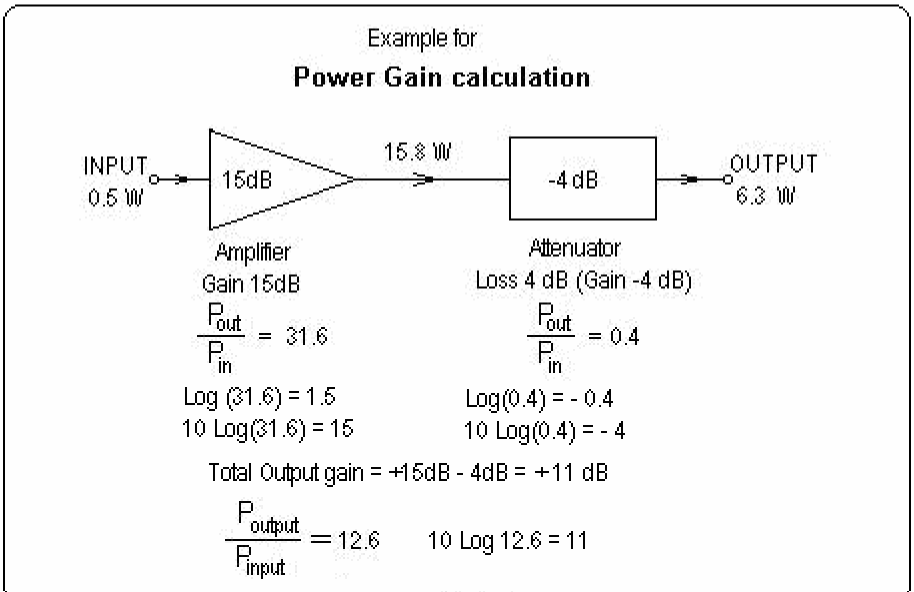

Fig 3.8

3.6.2 Comparison of Voltage and Current ratios

The decibel is based on power ratios. Voltage or current ratios can be used, but only when the impedance is the same (input and output) for both value voltage or current.

If the given power levels are P1, P2 and respective voltages are V1, V2 (for the same impedance of Z) then $P1/P2 = (V1/V2)^2$ because $P1=V1^2/Z$, $P2=V2^2/Z$
Then $dB = 10Log(P1/P2) = 10Log(V1/V2)^2 = 20Log(V1/V2)$

Therefore **dB = 20 Log(V2/V1)**

dB = 20 Log(I2/I1)

3.6.3 Absolute value for decibel

3.6.3.1 Absolute value for acoustic

The decibel is a relative unit. When using decibels to specify an absolute power, voltage or current level, the decibel value must be qualified by a reference level. For example, in a discussion of sound intensity, a reference level of 1 dB corresponds to an acoustical field strength of 10^{-16} W/cm², the normal human hearing threshold at 600 Hz and the threshold of pain occurs at 130 dB.

3.6.3.2 Absolute value for power gain (dBW and dBm)

In radio work power is often rendered in dBW, when the reference level taken as 1 watt and dBm for 1mW reference level.
Few examples with this notation:-

(i) 1kW is equivalent to 30dBW or 60dBm.
(ii) 500W is equivalent to 26.9dBW or 57dBm
(iii) 100W is equivalent to 20dBW or 50dBm
(iv) 1W is equivalent to 0dBW or 30dBm
(v) 100mW is equivalent to -10dBW or 20dBm
(vi) 50μW is equivalent to -43dBW or -13dBm

3.6.3.3 Absolute value for voltage gain (dBV and dBμV)

Voltages are some times given as decibel values with respect to 1 volt or 1 micro-volt.

Few examples:-

(i) 5V is equivalent to 14dBV or 134dBμV
(ii) 100mV is equivalent to -20dBV or 100dBμV
(iii) 1μV is equivalent to -120dBV or 0dBμV

3.7 <u>Power Factor</u>

I used the primary winding of a small power transformer as a choke coil and connected to AC mains supply in series with a capacitor of 2μF/300V (Fig 3.9) and these are the observations:
Resistance of the choke coil, R = 2140 Ohms
Inductance of the choke coil, L = 15 H (measured with DMM) and following readings were taken from clip-on ammeter and Digital Multimeter.
Applied voltage, V = 215 volts
Current through the circuit, I = 23.3mA = 0.0233 A
Voltage across the choke, V_L = 242 volts (greater than the applied voltage)
Voltage across the capacitor, V_C = 35 volts

Apparent power in the whole circuit = 215 x 0.0233
= 5 VA, (or 5watts)

Normally we use the unit as "VA" (Volt Ampere) instead of watts because this is an apparent power, not the actual power.

Actual power or the power loss in the inductor (choke coil), $I^2R = 0.0233^2 \times 2140 = 1.16$ Watts
The ratio of the power consumed to the apparent power is called the "Power Factor" of the circuit., and in this example the power factor would be 1.16/5 = 0.23 = 23%

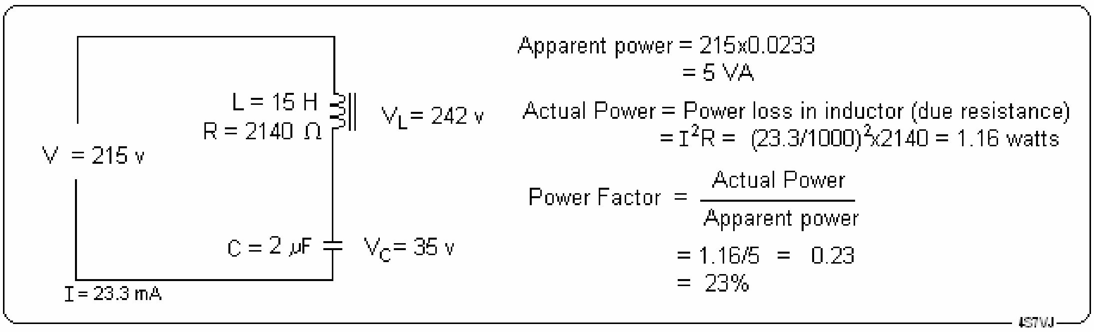

Fig. 3.9

3.7.1 Power Factor for Resister and Inductor

The power factor of a purely resistive circuit is 1 or 100%, while the power factor of a pure reactance is zero.

3.7.2 Cosφ

If the phase difference between the current and the voltage is φ then the power factor is equal to cosφ

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EXERCISE

3.1 What is the reactance of a capacitor having 1.5 μF for 50 Hz, 230 V ac-supply. What is the current flow.

(ans:- 2.1 kΩ, 0.1 A)

3.2 An inductor of 2 H. is connected to a 240 V 50 Hz supply What is the inductive reactance ? If the resistance is negligible, what is the current flow?

(ans:- 628 Ω, 382 mA)

3.3 An inductor having 4 μH is connected with a capacitor of 100 pF connected as a series resonance circuit. calculate the resonance frequency.

(ans:-7.96 MHz or 7960 kHz)

3.4 In a series resonance circuit, the inductor and capacitor each have a reactance of 200 Ohms at the resonant frequency. The resistance is 0.1 Ohms. What is the Q-factor of the circuit? If 10 mV applied to the circuit, What is the voltage across the capacitor or inductor at resonance?

(ans:- 2000, 20 Volts)

3.5 A transformer has a primary of 1100 turns and applied voltage is 220 volts. Centre tapped secondary voltages will be 12+12 V. What is the voltage per turn and what will be the number of turns for both secondary coils.

(ans:- 0.2 V/turn, 60+60 turns)

3.6 The secondary coil of a step-down transformer is 6V 2A and 50 turns. What is the number of turns and current consumption of the primary for 240 V ac supply?

(ans:- 2000 turns, 50mA)

3.7 If the input power of an amplifier is 10 watts, the power output will be 400 watts. What is the power gain ?

(ans:- 16 dB)

3.8 Power gain of a pre-amplifier is 50dB. It is coupled with a power amplifier having 20dB gain. What is the total power gain of the system?

If the input power is 1μW, what is the power output of the pre-amplifier and the final power output?

(ans:-70dB, 100mW, 10W)