EQUIPMENT NEEDED

RESISTORS
1–10 kΩ (1/4 W)
1–1.0 kΩ (1/4 W)

INSTRUMENTS
1–Oscilloscope
1–Function generator or audio oscillator

Inductor

1–100 mH

Capacitors

1–22 pF, 1–33 pF, 1–47 pF, 1–100 pF, 1–220 pF, 1–330 pF, 1–470 pF, 1–1000 pF

EQUIPMENT ISSUED

TABLE 16.1

ITEM	MANUFACTURER AND MODEL NO.	LABORATORY SERIAL NO.
Oscilloscope	TEKTRONIX TDS 3012B	
Function Generator or Audio oscillator	HP 33120A	

RESUME OF THEORY

The cosine of the angle between the voltage and current in a sinusoidal reactive circuit is referred to as the power factor. This angle is lagging (current lags the voltage) for an R-L circuit and leading (current leads the voltage) for R-C networks. Maximum power will occur when the power factor angle is equal to 0 degrees or a power factor equal to 1.0 where the cosine of the angle is called the power factor. Real or active power (P) in an ac circuit is equal to:

$$\boxed{P = IV \cos \cos \theta \text{ (in watts) where } \cos \theta = F_P} \tag{16.1}$$

Since most ac loads are resistive and inductive this will yield a F_P less than 1.0 or a phase angle not equal to 0°. This results in a reactive power (Q_L) for the inductor and is equal to:

$$\boxed{Q_L = IV \sin \theta \text{ (in VAR's–volts-amps reactive)}} \tag{16.2}$$

Real power (P) and reactive power (Q) are often combined into a power triangle to graphically show them along with the power factor angle and the apparent power (S) of the load. The apparent power is nothing more than the phasor sum of the real (P) and reactive (Q) power using the Pythagorean theorem.

$$\boxed{S = IV \text{ (in VA's, volt-ampres)}}$$

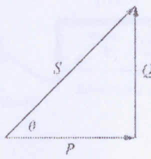
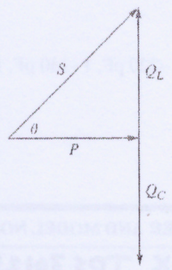


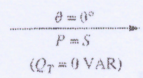
FIG. 16.1

For an ac induction motor the real power (P) determines the horsepower rating of the motor. However, the inductors in the motor provide the magnetic field which uses reactive power measured in VAR's. These VAR's add nothing to the horsepower of the motor. Since the electric power utility must supply these inductive VAR's this puts an extra burden on their generators. A capacitor added in parallel with the motor will add VAR's that are opposite the effect of inductive VAR's reducing or eliminating the VAR's in the network. Since the apparent power (S) will get smaller in magnitude, the current will decrease ($I = S/V$). Since less current is required a smaller diameter conductor (higher AWG#) can be used. Also, less VAR's are needed from the electric power utility. All of these advantages of F_p correction could add up to substantial financial savings. See Fig's 16.2 and 16.3



Power triangle with both inductance and capacitance

FIG. 16.2



Power triangle after corrections

FIG. 16.3

To compute the value of the capacitor to eliminate the inductive VAR's determine the amount of inductive VAR's using $Q_L = IV\sin\theta$. To eliminate the VAR's which means the power factor is equal to 1.0 let $Q_L = Q_C$. In this condition Q_T will be 0 and P will equal S with $\theta = 0°$.

To determine the value of the capacitor required to accomplish this use:

$$\boxed{Q_C = V^2/X_C \quad \text{or} \quad X_C = V^2/Q_C \text{ in ohms}} \tag{16.3}$$

and

$$\boxed{X_C = 1/(2\pi fC) \quad \text{or} \quad C = 1/(2\pi f X_C) \text{ in F}} \tag{16.4}$$

PROCEDURE

Part 1 Uncorrected F_p

(a) Construct the circuit shown in Fig. 16.4.

$R_{1\text{ measured}}$ = 10 KΩ

$R_{2\text{ measured}}$ = 1 KΩ

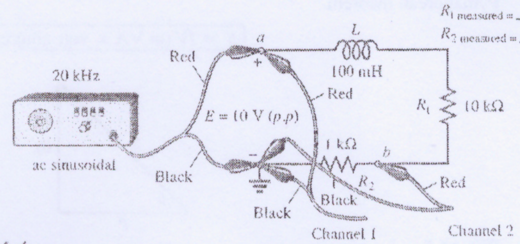


FIG. 16.4

(b) Connect the Oscilloscope Channel 1 to point "a" on the circuit and Channel 2 to point "b". Make sure you ground the oscilloscope as indicated.

(c) Set the function generator for an ac sinusoidal waveform with a frequency of 20 kHz and an amplitude of 10 volts peak-to-peak. Determine the rms value of the applied signal using the equation:

$$V(\text{rms}) = V(\text{pk-pk})/(2\sqrt{2}) \tag{16.5}$$

$$= 10\,V_{PK\cdot PK}/2\sqrt{2} = 3.54\,V$$

V_{rms} = 3.54 V

(d) Using the oscillsoscope measure the peak to peak voltage on Channel 2. This is the voltage across the 1.0 kΩ resistor. Convert this to V_{rms} and calculate the current in the circuit: $I = V_{rms}/1\text{ k}\Omega$.

$$V_{PK\text{-}PK_{CH\,2}} = 600\,mV, \quad V_{rms} = \frac{600\,mV}{2\sqrt{2}} = 212\,mV$$

$$I_{rms} = \frac{212\,mV}{1\,k\Omega} = 0.212\,mA$$

I_{rms} = 0.212 mA

(e) Notice the phase shift, θ of the two waveforms and that Channel 2 is to the right of Channel 1. This means that Channel 2 is "lagging" Channel 1. Measure this phase shift in degrees using the "Dual-Trace Method of Phase Measurement" as outlined in Experiment #8 or: $[\Delta t/\text{Period (T)}] \times 360° = \theta$.

$$\left[7\,\mu s/50\,\mu s \times 360°\right] = 50.4°$$

θ = 50.4°

(f) Fill in the "Uncorrected Data" Table 16.2 with the measured values and then compute P, S, Q_L and F_P.

TABLE 16.2 Uncorrected Data

V_{rms}	I_{rms}	Phase Shift, θ Degrees	F_P $\cos\theta$	$P = IV\cos\theta$ mW	$Q_L = IV\sin\theta$ mVARS	$S = IV$ mVA
3.54	.212 mA	50.4° LAG	0.64	0.478	0.578	0.75

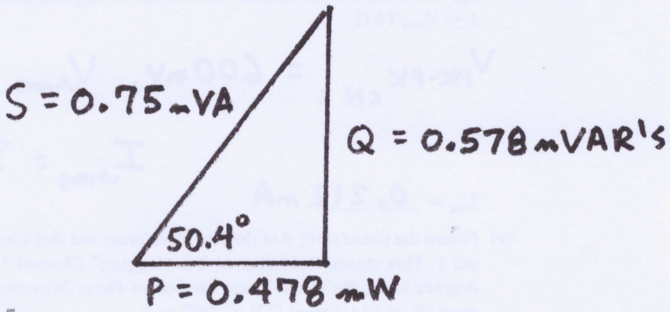
Calculations:

$P = (.212\,mA)(3.54\,v)\cos(50.4°) = 0.478\,mW$

$Q = (.212\,mA)(3.54\,v)\sin(50.4°) = 0.578\,mVAR's$

$S = (.212\,mA)(3.54\,v) = 0.75\,mVA$

(g) From the values in Table 16.2 Uncorrected Data, sketch the power triangle showing all of the values including θ.



Part 2 Corrected F_p

(a) Place a 100 pF capacitor between points "a" and "b" of the circuit. Measure the phase shift θ and indicate if it is lagging or leading.

(b) Measure the voltage on Channel 2 and then calculate the current using rms values. $V_{R_{rms}} = 177\,mV$

(c) Repeat steps (a) and (b) with the following capacitors: 220 pF, 330 pF, 470 pF and 1000 pF (only one capacitor at a time)

(a) through (c) Fill in Table 16.3 with the data from steps (a) through (d).

TABLE 16.3

Capacitor pF	Phase Shift θ	Leading/Lagging	Current mA
100	43.2°	LAGGING	0.177
220	30.6°	LAGGING	0.148
330	14.4°	LAGGING	0.13
470	7.2°	LEADING	0.13
1000	57.6°	LEADING	0.259
C_T	0°	—	0.127

$$I = \frac{177\,mV}{1000\,\Omega} = 0.177\,mA$$

(e) Make a plot of the current vs. the phase shift

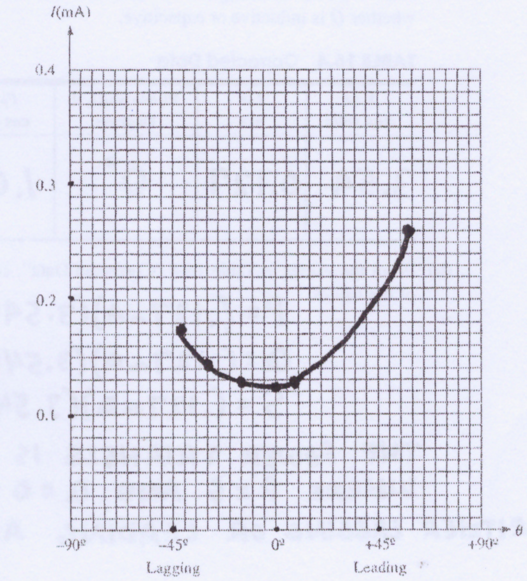


FIG. 16.5

(f) Calculate the capacitance required for unity power factor. This occurs when the inductive VARs equal the capacitive VARs.

$$X_C = V^2/Q_C \quad \text{and} \quad C = 1/(2\pi f X_C) \text{ in Farads} \qquad (16.6)$$

$$X_C = \frac{(3.54)^2}{.578\,\text{mVAR}} = 21{,}681\,\Omega, \quad C = \frac{1}{(2\pi)(20\,\text{kHz})(21{,}681)} = 367\,\text{pF}$$

C = 367 pF

(g) Place this capacitor (as close as possible using the available capacitors) between points "a" and "b". Be sure to remove all other capacitors.

(h) The phase shift should be close to 0 degrees. If it isn't try combining some of the other capacitors to achieve unity F_p ($\theta = 0°$). Remember that capacitors add when connected in parallel. *Record the resulting capacitance as C_T below.*

C_T = 367 pF

(i) Measure the voltage on channel 2 and then calculate the current using rms values. Enter the current in Tables 16.3 and 16.4 and on Fig. 16.5. Complete all entries in Table 16.3 and enter the voltage in Table 16.4.

$$V_{rms} = 127\,\text{mV}, \quad I_{rms} = \frac{127\,\text{mV}}{1000\,\Omega} = 0.127\,\text{mA}$$

(j) Fill in the "Corrected Data" in Table 16.4 using the capacitance C_T to produce a phase shift very close to 0 degrees. In Table 16.4 indicate whether F_P is lagging or leading and whether Q is inductive or capacitive.

TABLE 16.4 Corrected Data

V in rms volts	I in mA	Phase Shift, θ Degrees	F_P $\cos\theta$	P mW	Q mVARs	S mVA
3.54	0.127	0°	1.0	0.45	0	0.45

(k) From the values in Table 16.4 "Corrected Data", construct a power triangle showing all of the values.

$P = (.127\,mA)(3.54\,V)\cos 0^\circ = 0.45\,mW$

$Q = (.127\,mA)(3.54\,V)\sin 0^\circ = 0\,mVAR's$

$S = (.127\,mA)(3.54\,V) = 0.45\,mVA$

THE POWER TRIANGLE IS JUST A STRAIGHT LINE WHERE $P = S$ AND $Q = 0$ (SEE FIG. 16.3). F_P IS NEITHER LAGGING OR LEADING AND $Q = 0$.

EXERCISES

1. For the circuit of Fig. 16.4 calculate the power factor angle, θ, where $\theta = \tan^{-1}(X_L/R_T)$ ignoring R_l of the coil

$X_L = 2\pi f L = 2\pi(20\,kHz)(0.1\,H) = 12{,}566\,\Omega$

$$\theta = \tan^{-1}\left(\frac{12{,}566}{10k + 1k}\right) = 48.8^\circ$$

$\theta =$ 48.8° (EXPERIMENTAL $\theta = 50.4^\circ$)

2. Determine the impedance and the current in the circuit of Fig. 16.4. (Note: Since the series resistors of the circuit are large compared with the small inherent resistance of the inductor, this small resistance can be considered negligible or $R_l \ll R_T$).

$$Z_T = (1k + 10k) + j12{,}566 = 16{,}700\angle 48.8^\circ\,\Omega$$

$$I = \frac{3.54\,V}{16{,}700\angle 48.8^\circ} = 0.212\angle -48.8^\circ\,mA$$

$Z_T =$ 16.7 kΩ, $I =$ 0.212 mA