CHAPTER 31

Designing Practical Electronic Circuits

31.1   INTRODUCTION

In Chapters 23 and 24 we looked at the behaviour of basic components in electronics as well as simple systems that could be produced with them. In this chapter we will examine, in more detail, practical applications of electronics, especially using integrated circuit systems. We will look at circuit examples that you might like to try building as the basis of a hobby project. You might become interested enough to purchase and build one of the many hundreds of electronics constructor kits that are commercially available.

Most electronics today is based on combinations of integrated circuits, especially digital ICs, and these are quite easy to use. Always keep in mind the safety aspect of electricity and only deal with kits or projects that involve battery power supplies or use mains plug pack transformers, as described later in this chapter.

31.2   RLC RESONANCE AND TUNING CIRCUITS

Radio waves transmitted from sources such as AM and FM radio stations, television channels and CB or short wave transmitters all involve different frequency electromagnetic signals or voltages. In order to learn how to detect these signals with electronic circuits, we need to examine the AC behaviour of capacitor and inductor components.

Figure 31.1
Capacitors and AC voltage.

Recall the DC timing constant property of a charging capacitor in an RC circuit. Let's see what occurs when an AC voltage is placed across any capacitor, as in Figure 31.1. The capacitor will charge instantly, with the voltage across it at any time being equal to the

supply voltage. A sinusoidally varying AC voltage (sine wave) of frequency f will be given by the equation:

$$V = V_o \sin \omega t = V_o \sin (2\pi f)t$$

(where V_o is the voltage peak amplitude).

and this voltage will at any instant of time be equal to the voltage as defined by the capacitance, namely:

$$V = \frac{Q}{C} = V_o \sin (2\pi f)t$$

or

$$Q = V_o . C . \sin (2\pi f)t$$

but the current, I, flowing to the capacitor at any time will be given by:

$$I = \frac{dQ}{dt} \text{ (rate of change of charge with time)}$$

Hence, current flow in any capacitor connected to an AC voltage supply will be:

$$I = \frac{dQ}{dt} = \frac{d(V_o \, C \sin (2\pi f)t)}{dt}$$

$$I = V_o C \, 2\pi f \cos (2\pi f)t$$

$$I = I_o \cos (2\pi f)t \quad \text{where} \quad I_o = V_o \, 2\pi f C$$

(where I_o is the current peak amplitude).

Note that because the sine curve and a cosine curve are out of phase, the current peak, I_o, leads the voltage peak, V_o, by 90°. This is called a phase shift or **phase angle**. Also notice that the link between I_o and V_o for a capacitor can be written as:

$$V_o = I_o \, \frac{1}{2\pi f C} = I_o X_C$$

which is similar to Ohm's law and introduces a property of frequency-dependent resistance or **reactance** for a capacitor.

Figure 31.2
RC circuit and impedance.

- resistance vector (R)
- capacitive reactance vector (X_C)
- total impedance vector (Z)

$$X_C = \frac{1}{2\pi f c}$$

$$X = \sqrt{R^2 + X_C^2} \; ; \; \tan \phi = \frac{X_C}{R}$$

$$V_{AC} = I_{AC} Z$$

The **capacitive reactance**, $X_C = \dfrac{1}{2\pi f C}$, becomes a phasor quantity (similar to a vector quantity) with both magnitude in ohms and a phase angle in degrees. In the RC series circuit of Figure 31.2, the vectors are drawn representing pure resistance, R, in which current and voltage are in phase, and capacitive reactance, X_C, in which the current leads the voltage by 90°. The total AC resistance to the flow of alternating current (AC) from the supply is called the circuit **impedance**, Z, and is calculated by vector addition processes.

In a simple series RC circuit the total impedance:

$$Z = \sqrt{R^2 + X_C^2}$$

and the phase angle (ϕ) is given by:

$$\tan \phi = \frac{X_C}{R}$$

The impedance, Z, is measured in ohms. Ohm's law equivalent for this AC series RC circuit becomes:

$$V = I \cdot Z$$

Example
In the circuit of Figure 31.2, the AC voltage was 12 V RMS and the supply frequency is 50 Hz, the capacitor has a value of 0.33 µF and the resistance is 10 kΩ. Find:
    (a) the capacitive reactance X_C;
    (b) the total circuit impedance Z;
    (c) the AC circuit current (RMS);
    (d) the phase angle between voltage and current.

Solution
    (a) At $f = 50$ Hz:

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 0.33 \times 10^{-6}}$$
$$X_C = 9600 \ \Omega$$

    (b) Completing a vector diagram for impedance Z:

$$Z = \sqrt{(9600)^2 + (10\ 000)^2} = 13\ 900 \ \Omega$$

    (c) Hence, AC current, I_{RMS}, can be calculated using $V = IZ$.

$$12 = I_{RMS} \times 13\ 900$$
$$I_{RMS} = 0.86 \text{ mA}$$