To a second approximation:

$$V_{p(\text{out})} = 17\ \text{V} - 1.4\ \text{V} = 15.6\ \text{V}$$

Now, let's compare the theoretical values with the measured values. The sensitivity of channel 1 is 100 V/Div. Since the sine-wave input reads approximately 1.7 Div, its peak value is approximately 170 V. Channel 2 has a sensitivity of 5 V/Div. Since the half-wave output reads approximately 3.2 Div, its peak value is approximately 16 V. Both input and output readings are approximately the same as the theoretical values.

PRACTICE PROBLEM 4-5 As in Example 4-5, calculate the ideal and second approximation V_p(out) values using a 5:1 transformer turns ratio.

4-5 The Choke-Input Filter

At one time, the choke-input filter was widely used to filter the output of a rectifier. Although not used much anymore because of its cost, bulk, and weight, this type of filter has instructional value and helps make it easier to understand other filters.

Basic Idea

Look at Fig. 4-10*a*. This type of filter is called a **choke-input filter.** The ac source produces a current in the inductor, capacitor, and resistor. The ac current in each component depends on the inductive reactance, capacitive reactance, and the resistance. The inductor has a reactance given by:

$$X_L = 2\pi fL$$

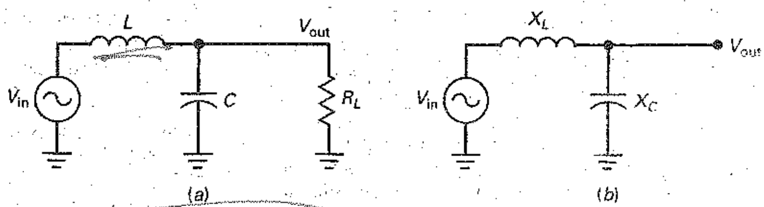
The capacitor has a reactance given by:

$$X_C = \frac{1}{2\pi fC}$$

As you learned in previous courses, the choke (or inductor) has the primary characteristic of opposing a change in current. Because of this, a choke-input filter ideally reduces the ac current in the load resistor to zero. To a second approximation, it reduces the ac load current to a very small value. Let us find out why.

The first requirement of a well-designed choke-input filter is to have X_C at the input frequency be much smaller than R_L. When this condition is satisfied, we can ignore the load resistance and use the equivalent circuit of Fig. 4-10*b*. The second requirement of a well-designed choke-input filter is to have X_L be much greater than X_C at the input frequency. When this condition is satisfied, the ac

Figure 4-10 (*a*) Choke-input filter; (*b*) ac equivalent circuit.



output voltage approaches zero. On the other hand, since the choke approximates a short circuit at 0 Hz and the capacitor approximates an open at 0 Hz, the dc current can be passed to the load resistance with minimum loss.

In Fig. 4-10*b*, the circuit acts like a reactive voltage divider. When X_L is much greater than X_C, almost all the ac voltage is dropped across the choke. In this case, the ac output voltage equals:

$$V_{\text{out}} \approx \frac{X_C}{X_L} V_{\text{in}} \tag{4-9}$$

For instance, if $X_L = 10\ \text{k}\Omega$, $X_C = 100\ \Omega$, and $V_{\text{in}} = 15$ V, the ac output voltage is:

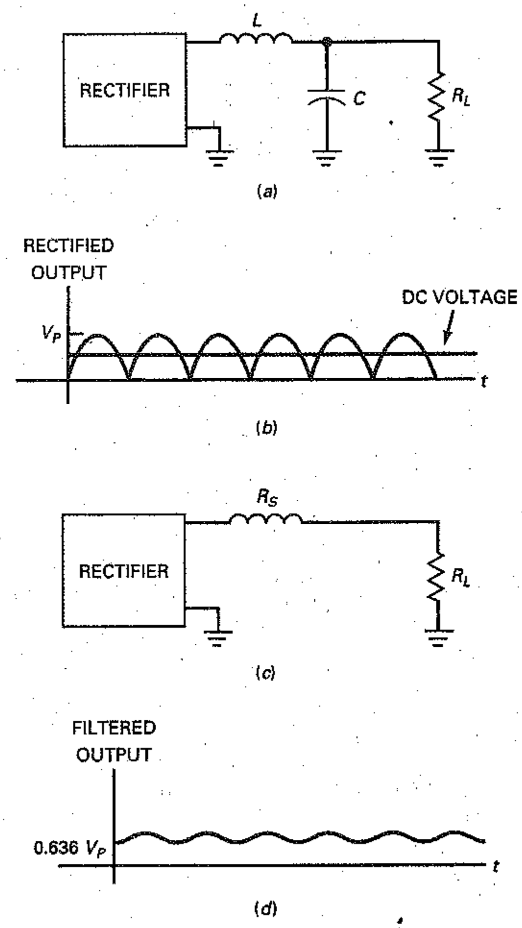
$$V_{\text{out}} \approx \frac{100\ \Omega}{10\ \text{k}\Omega}\, 15\ \text{V} = 0.15\ \text{V}$$

In this example, the choke-input filter reduces the ac voltage by a factor of 100.

Filtering the Output of a Rectifier

Figure 4-11*a* shows a choke-input filter between a rectifier and a load. The rectifier can be a half-wave, full-wave, or bridge type. What effect does the choke-

Figure 4-11 (*a*) Rectifier with choke-input filter; (*b*) rectifier output has dc and ac components; (*c*) dc equivalent circuit; (*d*) filter output is direct current with small ripple.



input filter have on the load voltage? The easiest way to solve this problem is to use the superposition theorem. Recall what this theorem says: If you have two or more sources, you can analyze the circuit for each source separately and then add the individual voltages to get the total voltage.

The rectifier output has two different components: a dc voltage (the average value) and an ac voltage (the fluctuating part), as shown in Fig. 4-11*b*. Each of these voltages acts like a separate source. As far as the ac voltage is concerned, X_L is much greater than X_C, and this results in very little ac voltage across the load resistor. Even though the ac component is not a pure sine wave, Eq. (4-9) is still a close approximation for the ac load voltage.

The circuit acts like Fig. 4-11*c* as far as dc voltage is concerned. At 0 Hz, the inductive reactance is zero and the capacitive reactance is infinite. Only the series resistance of the inductor windings remains. Making R_S much smaller than R_L causes most of the dc component to appear across the load resistor.

That's how a choke-input filter works: Almost all of the dc component is passed on to the load resistor, and almost all of the ac component is blocked. In this way, we get an almost perfect dc voltage, one that is almost constant, like the voltage out of a battery. Figure 4-11*d* shows the filtered output for a full-wave signal. The only deviation from a perfect dc voltage is the small ac load voltage shown in Fig. 4-11*d*. This small ac load voltage is called **ripple.** With an oscilloscope, we can measure its peak-to-peak value.

Main Disadvantage

A **power supply** is the circuit inside electronics equipment that converts the ac input voltage to an almost perfect dc output voltage. It includes a rectifier and a filter. The trend nowadays is toward low-voltage, high-current power supplies. Because line frequency is only 60 Hz, large inductances have to be used to get enough reactance for adequate filtering. But large inductors have large winding resistances, which create a serious design problem with large load currents. In other words, too much dc voltage is dropped across the choke resistance. Furthermore, bulky inductors are not suitable for modern semiconductor circuits, where the emphasis is on lightweight designs.

Switching Regulators

One important application does exist for the choke-input filter. A **switching regulator** is a special kind of power supply used in computers, monitors, and an increasing variety of equipment. The frequency used in a switching regulator is much higher than 60 Hz. Typically, the frequency being filtered is above 20 kHz. At this much higher frequency, we can use much smaller inductors to design efficient choke-input filters. We will discuss the details in a later chapter.

4-6 The Capacitor-Input Filter

The choke-input filter produces a dc output voltage equal to the average value of the rectified voltage. The **capacitor-input filter** produces a dc output voltage equal to the peak value of the rectified voltage. This type of filter is the most widely used in power supplies.

Basic Idea

Figure 4-12*a* shows an ac source, a diode, and a capacitor. The key to understanding a capacitor-input filter is understanding what this simple circuit does during the first quarter cycle.