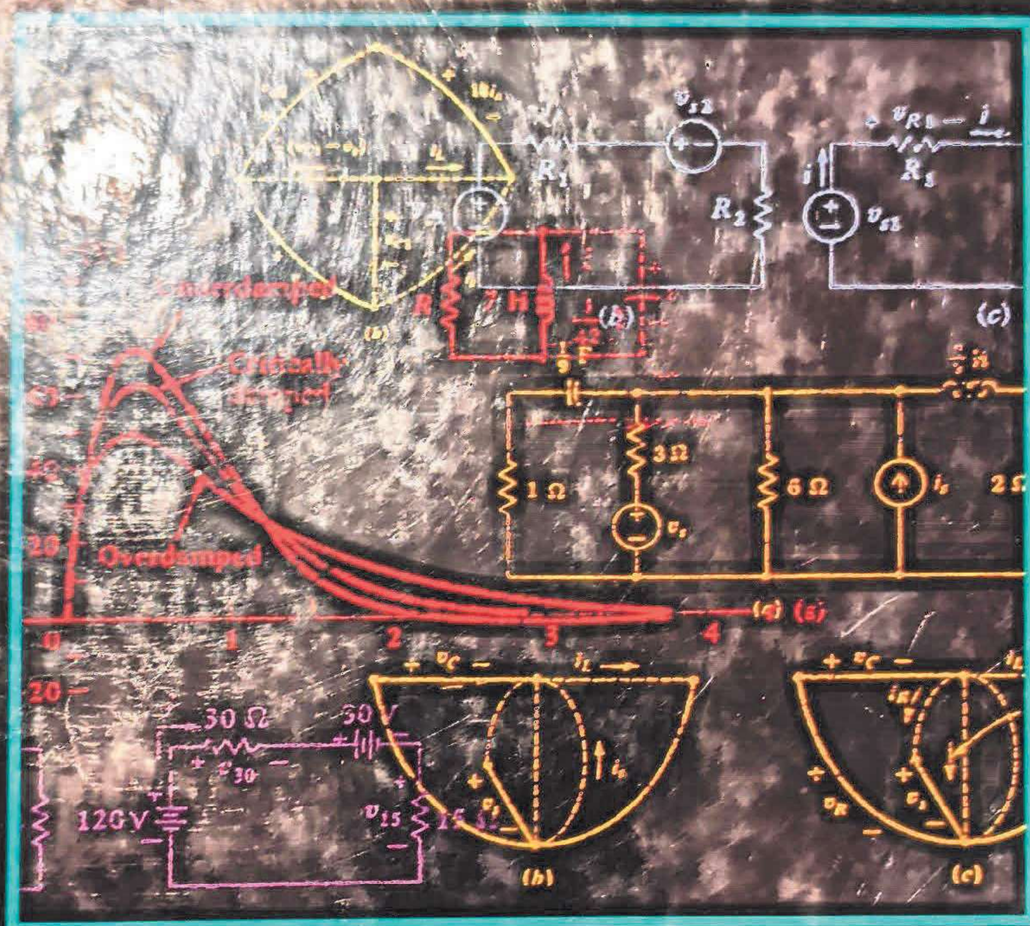
Engineering Circuit Analysis



FIFTH EDITION

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ENGINEERING CIRCUIT ANALYSIS

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3-5 Inductance and capacitance combinations

Now that we have added the inductor and capacitor to our list of passive circuit elements, we need to decide whether or not the methods we have developed for resistive circuit analysis are still valid. It will also be convenient to learn how to replace series and parallel combinations of either of these elements with simpler equivalents, just as we did with resistors in Chap. 1.

We look first at Kirchhoff's two laws, both of which are axiomatic. However, when we hypothesized these two laws, we did so with no restrictions as to the types of elements constituting the network. Both, therefore, remain valid.

Now we may extend the procedures we have derived for reducing various combinations of resistors into one equivalent resistor to the analogous cases of inductors and capacitors. We shall first consider an ideal voltage source applied to the series combination of N inductors, as shown in Fig. 3-12a. We desire a

Figure 3-12

(a) A circuit containing N inductors in series. (b) The desired equivalent circuit, in which $L_{eq} = L_1 + L_2 + \cdots + L_N$.

single equivalent inductor, with inductance L_{eq}, which may replace the series combination so that the source current $i(t)$ is unchanged. The equivalent circuit is sketched in Fig. 3-12b. For the original circuit,

$$\begin{aligned} v_s &= v_1 + v_2 + \cdots + v_N \\ &= L_1\frac{di}{dt} + L_2\frac{di}{dt} + \cdots + L_N\frac{di}{dt} \\ &= (L_1 + L_2 + \cdots + L_N)\frac{di}{dt} \end{aligned}$$

or, written more concisely,

$$v_s = \sum_{n=1}^{N} v_n = \sum_{n=1}^{N} L_n\frac{di}{dt} = \frac{di}{dt}\sum_{n=1}^{N} L_n$$

But for the equivalent circuit we have

$$v_s = L_{eq}\frac{di}{dt}$$

and thus the equivalent inductance is

$$L_{eq} = (L_1 + L_2 + \cdots + L_N)$$

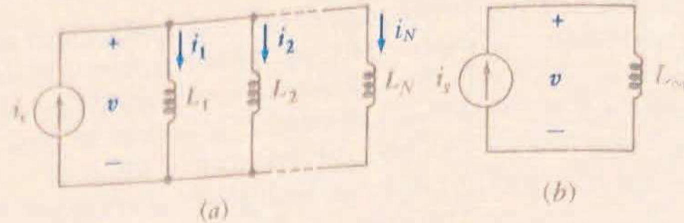
or

$$L_{eq} = \sum_{n=1}^{N} L_n$$

The inductor which is equivalent to several inductors connected in series is one whose inductance is the sum of the inductances in the original circuit. This is exactly the same result we obtained for resistors in series.

Figure 3-13

(*a*) The parallel combination of N inductors. (*b*) The equivalent circuit, where $L_{eq} = 1/[(1/L_1) + (1/L_2) + \cdots + (1/L_N)]$.



The combination of a number of parallel inductors is accomplished by writing the single nodal equation for the original circuit, shown in Fig. 3-13*a*,

$$i_s = \sum_{n=1}^{N} i_n = \sum_{n=1}^{N} \left[\frac{1}{L_n} \int_{t_0}^{t} v\,dt + i_n(t_0) \right]$$

$$= \left(\sum_{n=1}^{N} \frac{1}{L_n} \right) \int_{t_0}^{t} v\,dt + \sum_{n=1}^{N} i_n(t_0)$$

and comparing it with the result for the equivalent circuit of Fig. 3-13*b*,

$$i_s = \frac{1}{L_{eq}} \int_{t_0}^{t} v\,dt + i_s(t_0)$$

Since Kirchhoff's current law demands that $i_s(t_0)$ be equal to the sum of the branch currents at t_0, the two integral terms must also be equal; hence,

$$L_{eq} = \frac{1}{1/L_1 + 1/L_2 + \cdots + 1/L_N}$$

For the special case of two inductors in parallel,

$$L_{eq} = \frac{L_1 L_2}{L_1 + L_2}$$

and we note that inductors in parallel combine exactly as do resistors in parallel.

In order to find a capacitor which is equivalent to N capacitors in series, we use the circuit of Fig. 3-14*a* and its equivalent in Fig. 3-14*b* to write

$$v_s = \sum_{n=1}^{N} v_n = \sum_{n=1}^{N} \left[\frac{1}{C_n} \int_{t_0}^{t} i\,dt + v_n(t_0) \right]$$

$$= \left(\sum_{n=1}^{N} \frac{1}{C_n} \right) \int_{t_0}^{t} i\,dt + \sum_{n=1}^{N} v_n(t_0)$$

and

$$v_s = \frac{1}{C_{eq}} \int_{t_0}^{t} i\,dt + v_s(t_0)$$

Figure 3-14

(*a*) A circuit containing N capacitors in series. (*b*) The desired equivalent, $C_{eq} = 1/[(1/C_1) + (1/C_2) + \cdots + (1/C_N)]$.