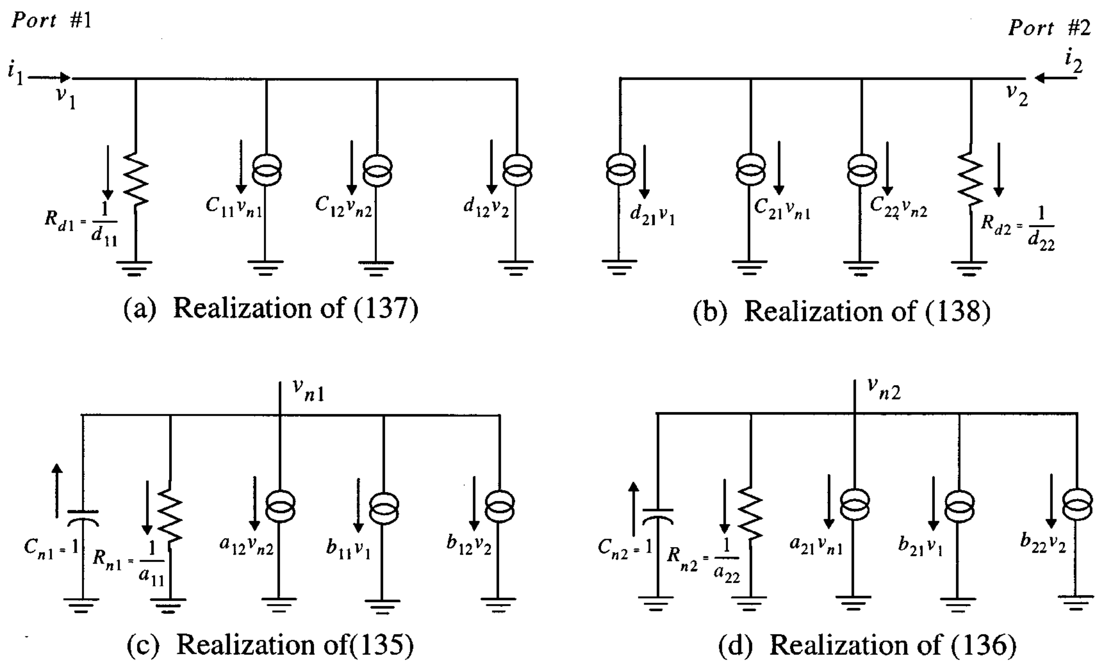

Fig. 25. Illustration of equivalent subcircuit generation from macromodels.

Unified Transient Simulation: Once a matrix-transfer function describing the multiport interconnect network is obtained, a time-domain realization in the form of state–space equations can be obtained as

$$\frac{d}{dt}[\boldsymbol{z}_\pi(t)] - [\boldsymbol{A}_\pi][\boldsymbol{z}_\pi(t)] - [\boldsymbol{B}_\pi][\boldsymbol{i}_\pi(t)] = \boldsymbol{0}$$
$$[\boldsymbol{v}_\pi(t)] - [\boldsymbol{C}_\pi][\boldsymbol{z}_\pi(t)] + [\boldsymbol{D}_\pi][\boldsymbol{i}_\pi(t)] = \boldsymbol{0} \quad (132)$$

where $\boldsymbol{i}_\pi$ and $\boldsymbol{v}_\pi$ are the vector of terminal currents and voltages of the linear subnetwork π [described by (56)]. The differential equations represented by the macromodel (132) can be combined with (55) using the relation $\boldsymbol{v}_\pi = (\boldsymbol{L}_\pi)^t \boldsymbol{v}_\phi$ as

$$\frac{d}{dt}\boldsymbol{z}_\pi(t) - \boldsymbol{A}_\pi \boldsymbol{z}_\pi(t) - \boldsymbol{B}_\pi \boldsymbol{i}_\pi(t) = \boldsymbol{0}$$
$$(\boldsymbol{L}_\pi)^t \boldsymbol{v}_\phi(t) - \boldsymbol{C}_\pi \boldsymbol{z}_\pi(t) - \boldsymbol{D}_\pi \boldsymbol{i}_\pi(t) = \boldsymbol{0}$$
$$\boldsymbol{C}_\phi \frac{d}{dt}\boldsymbol{v}_\phi(t) + \boldsymbol{G}_\phi \boldsymbol{v}_\phi(t) + \boldsymbol{L}_\pi \boldsymbol{i}_\pi(t) + \boldsymbol{F}(\boldsymbol{v}_\phi(t)) - \boldsymbol{b}_\phi(t) = \boldsymbol{0}. \quad (133)$$

Using standard nonlinear solvers or any of the general-purpose circuit simulators, the unified set of differential equations represented by (133) can be solved to yield transient solution for the entire nonlinear circuit containing interconnect subnetworks. For those simulators (such as HSPICE) that do not directly accept the differential equations as input, the macromodel represented by (133) can be converted to an equivalent subcircuit and is described in the next section.

Conversion of Macromodels to Equivalent Subcircuits: Conversion of differential equations to equivalent subcircuits can be accomplished in several ways. For the purpose of illustration, consider a simple case of two-port network with two states represented in the form of (132)

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix} = \begin{bmatrix}a_{11} & a_{12}\\ a_{21} & a_{22}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}b_{11} & b_{12}\\ b_{21} & b_{22}\end{bmatrix}\begin{bmatrix}v_1\\ v_2\end{bmatrix}$$
$$\begin{bmatrix}i_1\\ i_2\end{bmatrix} = \begin{bmatrix}c_{11} & c_{12}\\ c_{21} & c_{22}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} + \begin{bmatrix}d_{11} & d_{12}\\ d_{21} & d_{22}\end{bmatrix}\begin{bmatrix}v_1\\ v_2\end{bmatrix}. \quad (134)$$

Next, (134) can be rearranged as

$$\dot{x}_1 = a_{11}x_1 + a_{12}x_2 + b_{11}v_1 + b_{12}v_2 \quad (135)$$
$$\dot{x}_2 = a_{21}x_1 + a_{22}x_2 + b_{21}v_1 + b_{22}v_2 \quad (136)$$
$$i_1 = c_{11}x_1 + c_{12}x_2 + d_{11}v_1 + d_{12}v_2 \quad (137)$$
$$i_2 = c_{21}x_1 + c_{22}x_2 + d_{21}v_1 + d_{22}v_2. \quad (138)$$

In the above equations, the port voltages and currents are represented by v_1, v_2 and i_1, i_2, respectively. An equivalent network representing (135)–(138) can be constructed as shown in Fig. 25. Each state in the macromodel requires a separate node in the equivalent circuit and are represented by nodes n_1, n_2. The state variables x_1, x_2 can be represented by the capacitor voltages. These capacitors are denoted by C_{n1}, C_{n2} and the corresponding voltages by v_{n1}, v_{n2}. Next, the terms such as $a_{11}x_1$ in (135)–(138) can be represented by voltage controlled current sources. Equations (135) and (136) are fully represented by Fig. 25(c) and (d). Output equations represented by (137) and (138) are realized through equivalent circuits shown in Fig. 25(a) and (b). Generalization of the above discussion in the presence of more number of states or ports is straightforward.