4.2.2 Surface Microstrip, Figure 4-3(a) The characteristic impedance, $Z_{0,surf}$, of a surface microstrip line is given below[1,2].

$$Z_{0,surf} = \frac{\eta_0}{2\sqrt{2}\pi\sqrt{\varepsilon_{r,eff}+1}} \ln\left\{1 + 4\frac{h}{w'}\left[4\left(\frac{14\varepsilon_{r,eff}+8}{11\varepsilon_{r,eff}}\right)\frac{h}{w'} + \sqrt{16\left(\frac{14\varepsilon_{r,eff}+8}{11\varepsilon_{r,eff}}\right)^2\left(\frac{h}{w'}\right)^2 + \frac{\varepsilon_{r,eff}+1}{2\varepsilon_{r,eff}}\pi^2}\right]\right\} \quad (4\text{-}4)$$

where η_0 is the wave impedance of free space, w' is the effective signal line width:

$$w' = w + \frac{t}{\pi}\ln\left\{\frac{4e}{\sqrt{\left(\frac{t}{h}\right)^2 + \left(\frac{t}{w\pi + 1.1t\pi}\right)^2}}\right\}\left(\frac{\varepsilon_{r,eff}+1}{2\varepsilon_{r,eff}}\right), \quad (4\text{-}5)$$

and

$$\varepsilon_{r,eff} = \begin{cases} \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left\{\sqrt{\frac{w}{w+12h}} + 0.04\left(1-\frac{w}{h}\right)^2\right\} & \frac{w}{h} < 1 \\ \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\sqrt{\frac{w}{w+12h}} & \frac{w}{h} \geq 1 \end{cases}. \quad (4\text{-}6)$$

W is the width of the signal line, *T* is the thickness of the signal line, *H* is the separation between the signal line and the reference plane, and ε_r is the relative permittivity of the substrate material. The accuracy of these equations is better than ±2 %[1,2]. For more accuracy, the effect of conductor thickness should be considered[3].

4.2.3 Embedded Microstrip, Figure 4-3(b). The effect of embedding the signal line in a single dielectric is to modify (4-4) using a modified $\varepsilon_{r,eff}$ [2]:

$$Z_{0,embedd} = Z_{0,surf}\frac{1}{\sqrt{e^{-2b/h} + \frac{\varepsilon_r}{\varepsilon_{r,eff}}\left(1-e^{-2b/h}\right)}}, \quad (4\text{-}7)$$

where *b*, see Figure 4-1(d), is:

$$b = h' - h. \quad (4\text{-}8)$$

4.2.4 Symmetric Stripline, Figure 4-3(c). As was the case for microstrip transmission line, the Z_0 of striplines is also dependent on the ratio of the condutor width and separation between the signal and ground planes. The equations for $Z_{0,SS}$ of a symmetric stripline are[2]:

$$Z_{0,SS} = \frac{\eta_0}{2\pi\sqrt{\varepsilon_r}} \ln\left\{1 + \frac{8h}{\pi w'}\left[\frac{16h}{\pi w'} + \sqrt{\left(\frac{16h}{\pi w'}\right)^2 + 6.27}\right]\right\}, \tag{4-9}$$

where

$$w' = w + \frac{t}{\pi}\ln\left\{\frac{e}{\sqrt{\left(\frac{t}{4h+t}\right)^2 + \left(\frac{\pi t}{4(w+1.1t)}\right)^m}}\right\}, \tag{4-10}$$

and

$$m = \frac{6h}{3h+t}. \tag{4-11}$$

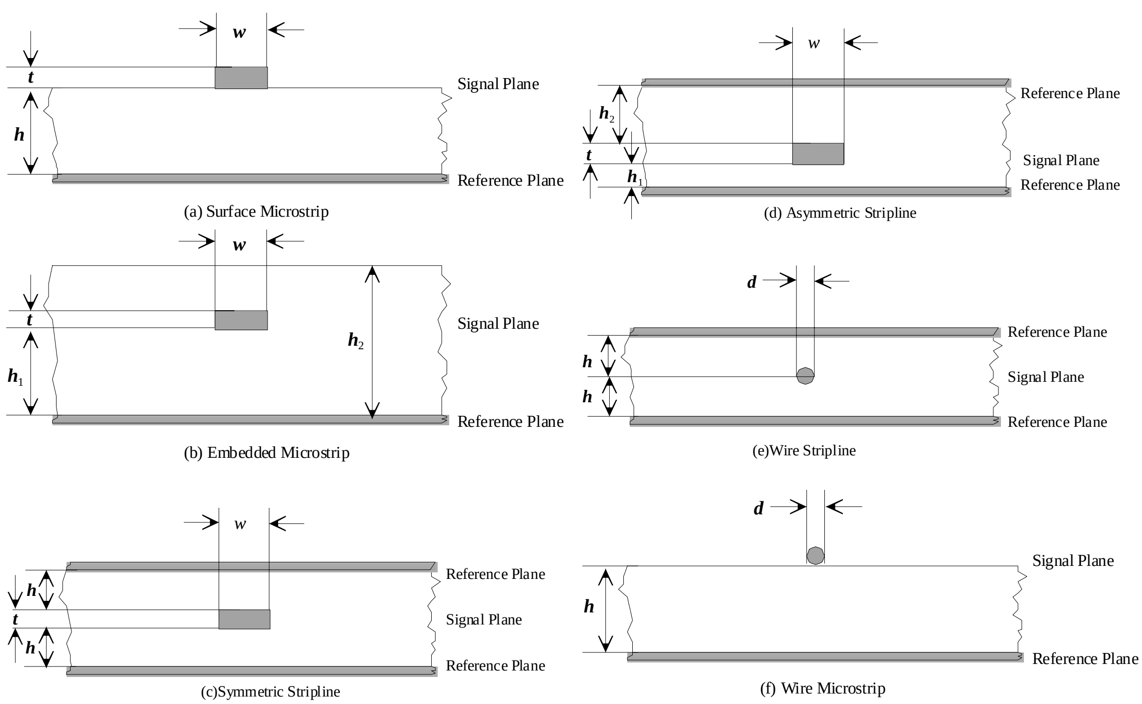

Figure 4-3. Typical unbalanced line configurations

4.2.5 Asymmetric Stripline, Figure 4-3(d). The $Z_{0,AS}$ for an asymmetric stripline is given by[2]:

$$Z_{0,AS} = \frac{1}{\varepsilon_r}\left[Z_{0,SS}(\varepsilon_r = 1, b = h_1 + h_2 + t) - \Delta Z_{0,air}\right], \tag{4-12}$$

where $Z_{0,SS}(\varepsilon_r=1, b=h_1+h_2+t)$ is the $Z_{0,SS}$ with air as the dielectric and total thickness, b, equal to h_1+h_2+t, $\Delta Z_{0,air}$ is:

$$\Delta Z_{0,air} = 0.0325\pi Z_{0,air}^2\left(0.5 - \frac{1}{2}\frac{2h_1+t}{h_1+h_2+t}\right)^{2.2}\left(\frac{t+w}{h_1+h_2+t}\right)^{2.9}, \tag{4-13}$$

where h_1 is the distance between the signal line and the lower reference plane, h_2 is the distance between the siganl line and the upper reference plane, and

$$Z_{0,air} = 2\left[\frac{Z_{0,SS}(\varepsilon_R = 1, b = h_1)Z_{0,SS}(\varepsilon_R = 1, b = h_2)}{Z_{0,SS}(\varepsilon_R = 1, b = h_1) + Z_{0,SS}(\varepsilon_R = 1, b = h_2)}\right], \tag{4-14}$$

where $Z_{0,SS}(\varepsilon_r=1, b=h_1)$ is the $Z_{0,SS}$ with air as the dielectric and total thickness, b, equal to h_1, and $Z_{0,SS}(\varepsilon_r=1, b= h_2)$ is the $Z_{0,SS}$ with air as the dielectric and total thickness, b, equal to h_2.

4.2.6 Wire Stripline, Figure 4-3(e). The Z_0 of a transmission line consisting of a circular signal conductor having a diameter d and centered between parallel ground planes separated by a distance h is[4]:

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{\varepsilon_r}}\ln\left(\frac{4h}{\pi d}\right). \tag{4-15}$$

This equation is accurate to within 1 % for $d \le h/2$[4].

4.2.7 Wire Microstrip, Figure 4-3(f).

$$Z_0 = \frac{\eta_0}{2\pi\sqrt{\varepsilon_{r,eff}}}\cosh^{-1}\left(\frac{2h}{d}\right) \tag{4-16}$$

where d is the wire diameter and h is the separation between the wire and the ground (reference) plane, and $\varepsilon_{r,eff}$ is given by (4-6). To compute $\varepsilon_{r,eff}$ using (4-6), d is obtained from [2]:

$$\frac{d}{w} = 0.5008 + 1.0235x - 1.023x^2 + 1.1564x^3 - 0.4749x^4, \tag{4-17}$$

where

$$x = \begin{cases} \dfrac{t}{w} & w \ge t \\ \dfrac{w}{t} & w < t \end{cases}. \tag{4-18}$$

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