Microstrip Antennas cont.

(Chapter 14 in *Antenna Theory, Analysis and Design* (2nd Edition) by Balanis)

14.4 Quality Factor, Bandwidth, & Efficiency

- interrelated/interdependent "Figure of Merit" quantities
- trade-offs made when designing antenna

Quality Factor

- figure of merit for characterizing antenna losses
- loss mechanisms include- radiation/space wave (good), conduction/ohmic losses in ground plane and metallic patch (bad), dielectric (bad), and surface waves (bad)
- overall quality factor Q_t is defined in terms of the quality factors related to the loss mechanisms as

$$\frac{1}{Q_t} = \frac{1}{Q_{\text{rad}}} + \frac{1}{Q_c} + \frac{1}{Q_d} + \frac{1}{Q_{sw}}$$

  where Q_{rad}, Q_c, Q_d, and Q_{sw} are the quality factors due to the radiation, conduction/ohmic, dielectric, and surface wave losses, respectively.

- For thin substrates (i.e., $h << \lambda_0$), we can neglect losses due to surface waves ($Q_{sw} \rightarrow \infty$).
- Usually, assuming a thin, good quality circuit board, the dominant term is Q_{rad}.

- The other quality factors can be approximated as

$$Q_c = \frac{h}{\delta_s} = h\sqrt{\pi f \mu_c \sigma_c}$$

where δ_s, μ_c, and σ_c are the skin depth, permeability, and conductivity of the patch conductor (usually metal),

$$Q_d = \frac{1}{\tan\delta}$$

where $\tan\delta$ is the loss tangent of the substrate dielectric, and

$$Q_{\text{rad}} = \frac{2\omega\varepsilon_r}{h\,G_{t/l}} K$$

where $G_{t/l}$ is the total conductance per unit length of the radiating aperture/slot and

$$K = \frac{\iint\limits_{\text{slot area}} \left|\bar{E}\right|^2 dA}{\oint\limits_{\text{slot perimeter}} \left|\bar{E}\right|^2 dl}.$$

In the TM_{010}^{x} mode, $K = \frac{L}{4}$ and $G_{t/l} = \frac{G_{\text{rad}}}{W}$ where $G_{\text{rad}} = \frac{1}{R_{\text{rad}}}$.

Bandwidth

- the fractional bandwidth, appropriate for narrowband antennas, is given by

$$\frac{\Delta f}{f_0} = \frac{1}{Q_t}$$

- the percentage bandwidth is then

$$\frac{\Delta f}{f_0} \times 100\% = \frac{1}{Q_t} \times 100\%$$

- a modified form of the fractional bandwidth that takes into account impedance matching, as specified in terms of a VSWR specification, is given by

$$\frac{\Delta f}{f_0} = \frac{1}{Q_t} \frac{\text{VSWR} - 1}{\sqrt{\text{VSWR}}}$$

- The bandwidth of patches is directly proportional to the height of the substrate (i.e., BW increases as h/λ_0 increases). This is shown in Fig. 14.26 for two different substrates.

- Also, the bandwidth of patches is inversely proportional to the relative permittivity of the substrate (i.e., $\text{BW} \propto 1/\sqrt{\varepsilon_r}$). This is illustrated in Fig. 14.26 for ε_r = 2.2 and ε_r = 10 substrates. Note how the $\varepsilon_r = 10$ substrate has a significantly lower BW.

Radiation Efficiency

- The radiation efficiency is defined as the ratio of the power radiated to the power input to the antenna. For microstrip antennas, power can be lost to surface waves in addition to the conduction and dielectric losses noted in chapter 2.

- Therefore, e_{cdsw} is used instead of e_{cd}. For microstrip antennas, we can express the efficiency in terms of the previously defined quality factors as

$$e_{cdsw} = \frac{P_{\text{rad}}}{P_{\text{in}}} = \frac{1/Q_{\text{rad}}}{1/Q_t} = \frac{Q_t}{Q_{\text{rad}}}.$$

- The efficiency of patches is inversely proportional to the relative permittivity and height of substrates. This is shown in Fig. 14.26 for $\varepsilon_r = 2.2$ and $\varepsilon_r = 10$ substrates. Note how the $\varepsilon_r = 10$ substrate has a significantly lower efficiency.

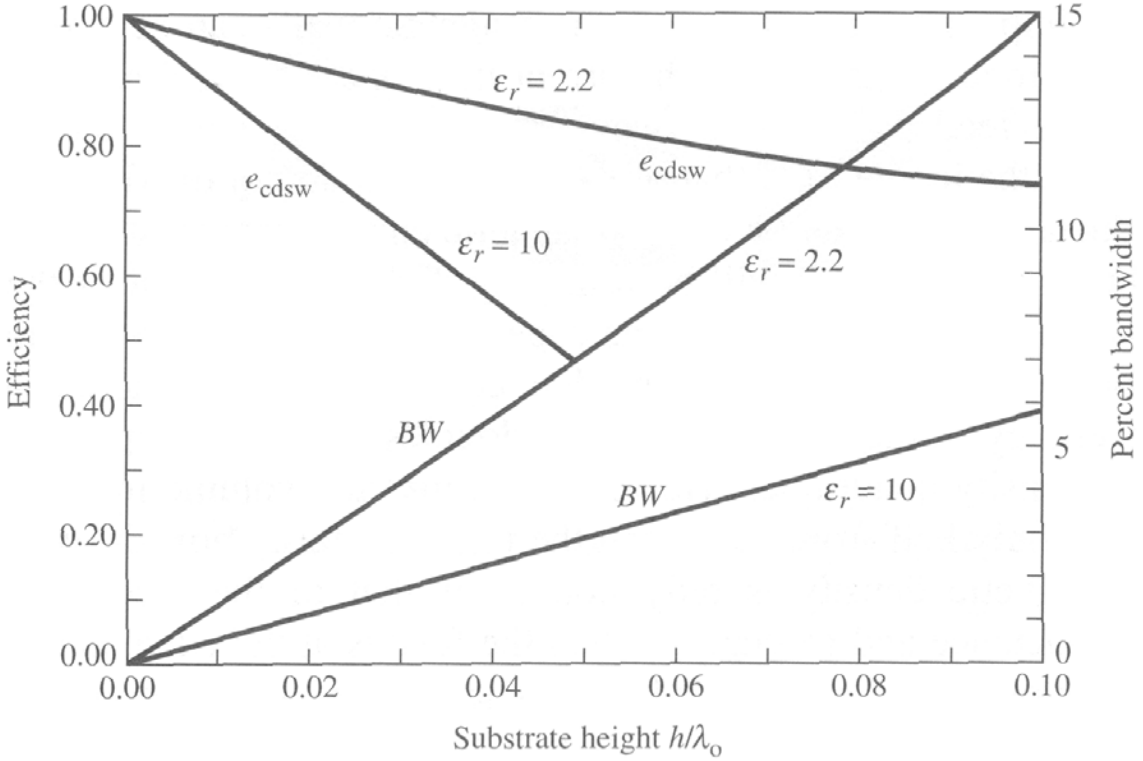

Figure 14.26 Efficiency and bandwidth versus substrate height at constant resonant frequency for rectangular microstrip patch for two different substrates … (From Balanis, *Antenna Theory, Analysis and Design* (*Second Edition*))

14.5 Input Impedance

- Best determined by experiment or full-wave modeling
- Figure 14.27 shows a typical variation in the resistance and reactance components of the input impedance.
- For thin substrates (i.e., $h \ll \lambda_0$), note that the feed reactance $|X_f|$ is much less the peak resistance.

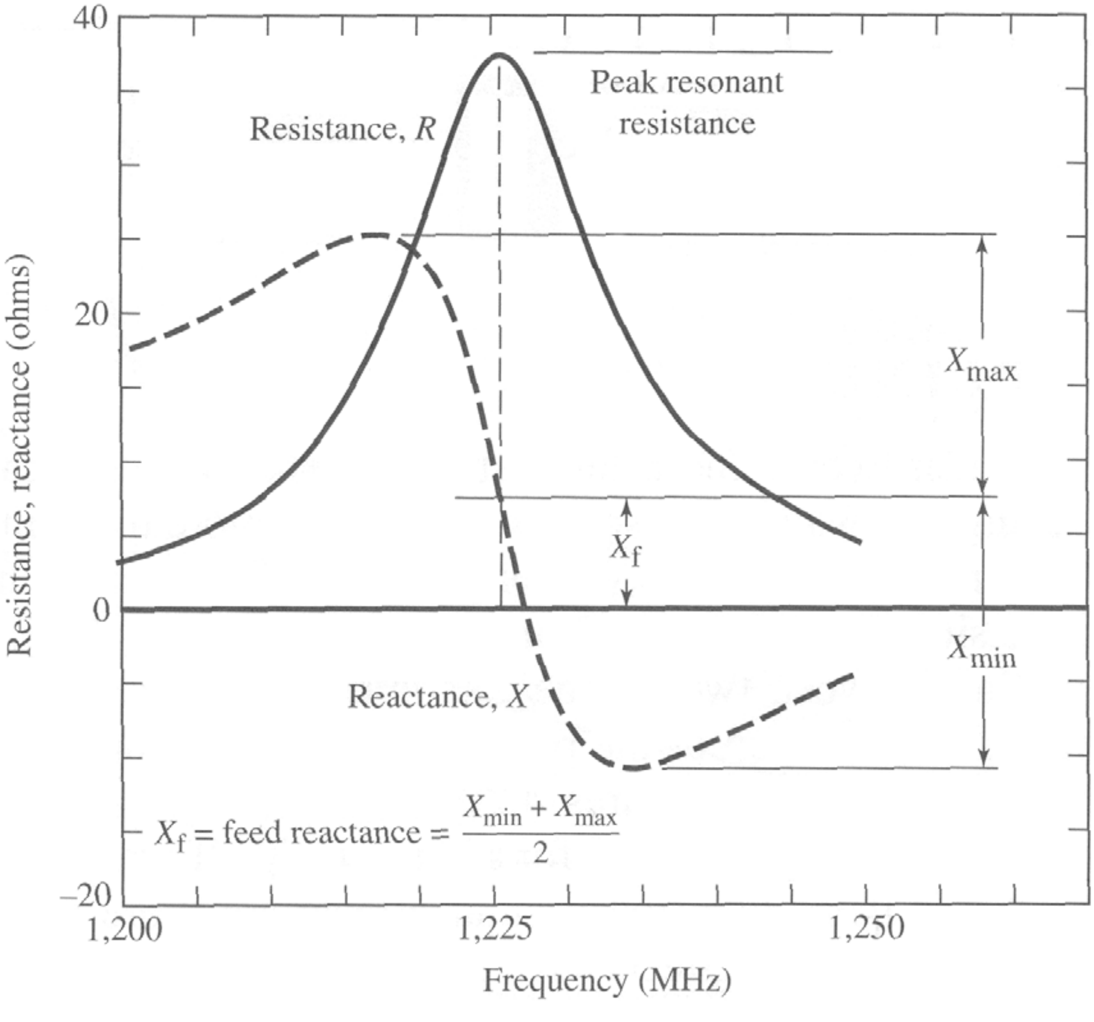

Figure 14.27 Typical variation of resistance and reactance of rectangular microstrip antenna versus frequency … (From Balanis, *Antenna Theory, Analysis and Design* (*Second Edition*))