Unit 3

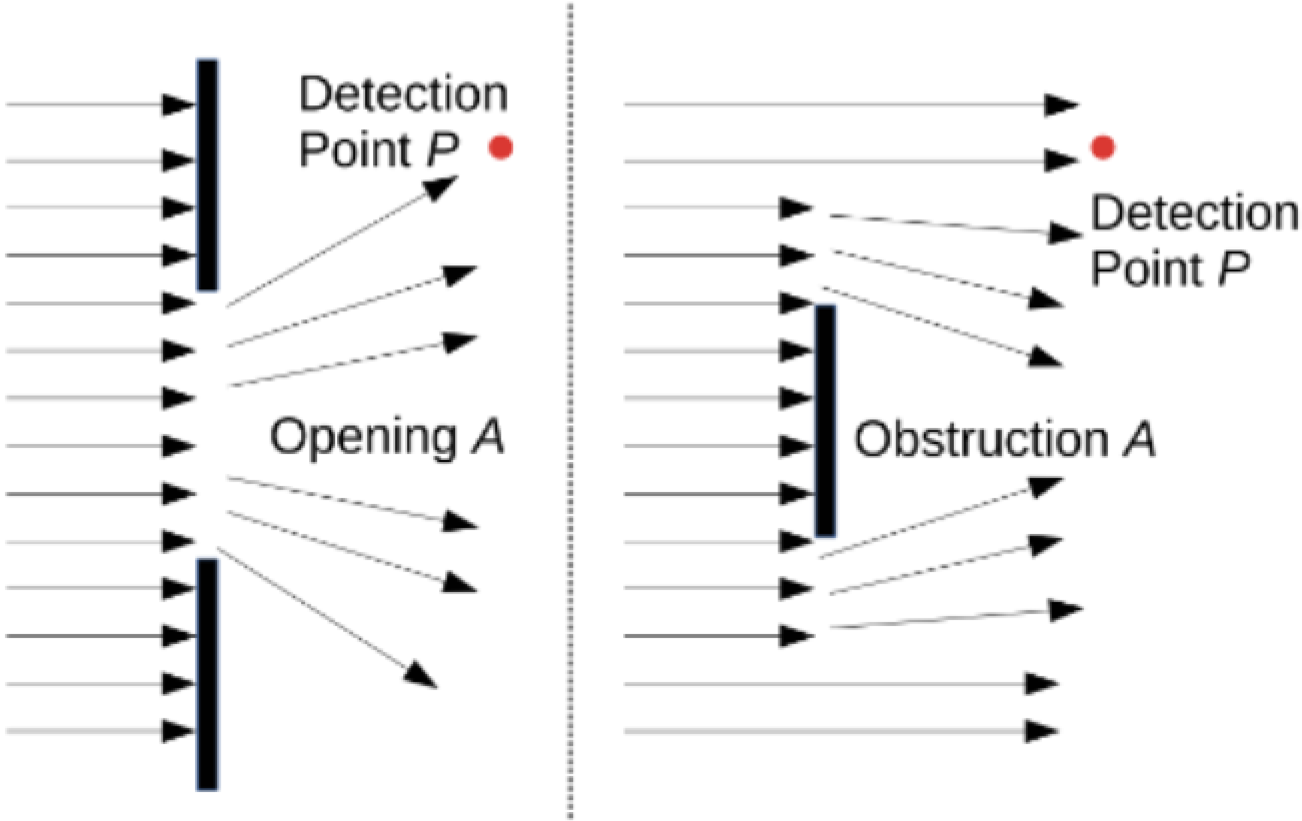
Aperture Arrays

Babinet's Principle

Babinet's Principle

- *Babinet's principle* in optics states that *when the field behind a screen with an opening is added to the field of a complementary structure, the sum is equal to the field when there is no screen*.
- In optics principle, it does not consider polarization but in antenna theory its primarily deals with absorbing screens. An extension of Babinets' principle, which includes polarization and the conducting screens, was introduced by Booker.
- Considering to Fig. 1(a), let us assume that an electric source **J** radiates into an unbounded medium (ε, μ) of intrinsic impedance $\eta = (\mu/\varepsilon)^{1/2}$ and produces at point P the fields $\mathbf{E}_0$, $\mathbf{H}_0$.
- The same fields can be obtained by combining the fields when the electric source radiates in a medium (ε, μ) with intrinsic impedance $\eta = (\mu/\varepsilon)^{1/2}$ in the presence of

Babinet's Principle – Optic's Approach



Babinet’s Principle

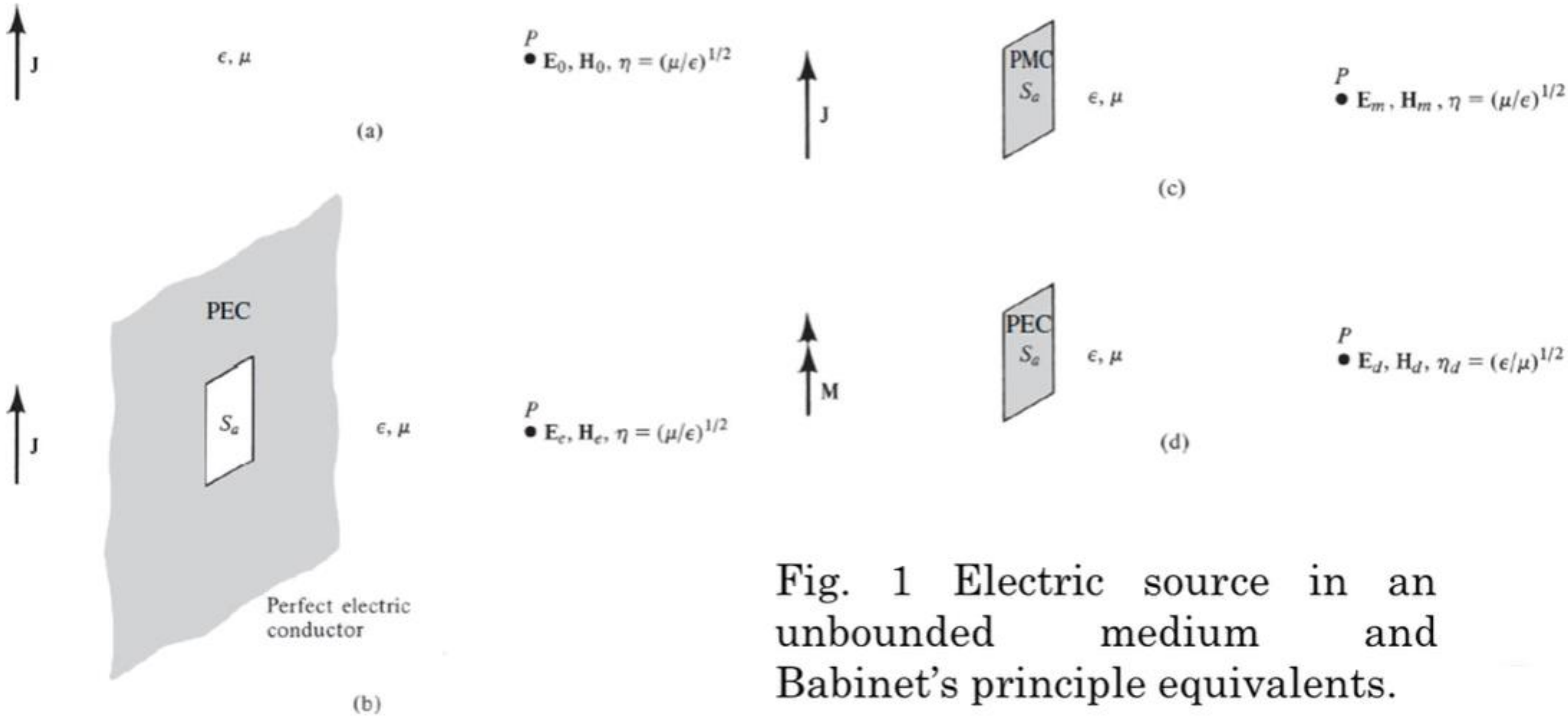


Fig. 1 Electric source in an unbounded medium and Babinet’s principle equivalents.

Reference : Constantine A. Balanis, “Antenna Theory Analysis and Design”, Third edition, John Wiley India Private Ltd., 2005.

Babinet's Principle

1. an infinite, planar, very thin, perfect electric conductor with an opening S_a, which produces at P the fields $\mathbf{E}_e$,$\mathbf{H}_e$ [Fig. 1(b)].
2. a flat, very thin, perfect magnetic conductor S_a, which produces at P the fields $\mathbf{E}_m$, $\mathbf{H}_m$ [Fig. 1(c)]

That is,

$$\begin{aligned} \mathbf{E}_0 &= \mathbf{E}_e + \mathbf{E}_m \\ \mathbf{H}_0 &= \mathbf{H}_e + \mathbf{H}_m \end{aligned} \qquad (1)$$

➢ The field produced by the source in Fig. 1(a) can also be obtained by combining the fields of

1. an electric source $\mathbf{J}$ radiating in a medium with intrinsic impedance $\eta = (\mu/\varepsilon)^{1/2}$ in the presence of an infinite, planar, very thin, perfect electric conductor S_a, which produces at P the fields $\mathbf{E}_e$, $\mathbf{H}_e$ [Fig. 1(b)].
2. a magnetic source $\mathbf{M}$ radiating in a medium with intrinsic impedance $\eta_d = (\varepsilon/\mu)^{1/2}$ in the presence of a flat, very thin, perfect electric conductor S_a, which produces at P the fields $\mathbf{E}_d$, $\mathbf{H}_d$ [Fig. 1(d)].

That is,

$$\begin{aligned} \mathbf{E}_0 &= \mathbf{E}_e + \mathbf{H}_d \\ \mathbf{H}_0 &= \mathbf{H}_e - \mathbf{E}_d \end{aligned} \qquad (2)$$

Babinet's Principle

- To obtain Fig. 1(d) from Fig. 1(c), $\mathbf{J}$ is replaced by $\mathbf{M}$, $\mathbf{E}_m$ by $\mathbf{H}_d$, $\mathbf{H}_m$ by $-\mathbf{E}_d$, ε by μ, and μ by ε. This is a form of duality.
- The electric screen with the opening in Fig. 1(b) and the electric conductor of Fig. 1 (d) are also dual. They are referred to as *complementary structures*, because *when combined they form a single solid screen with no overlaps*.

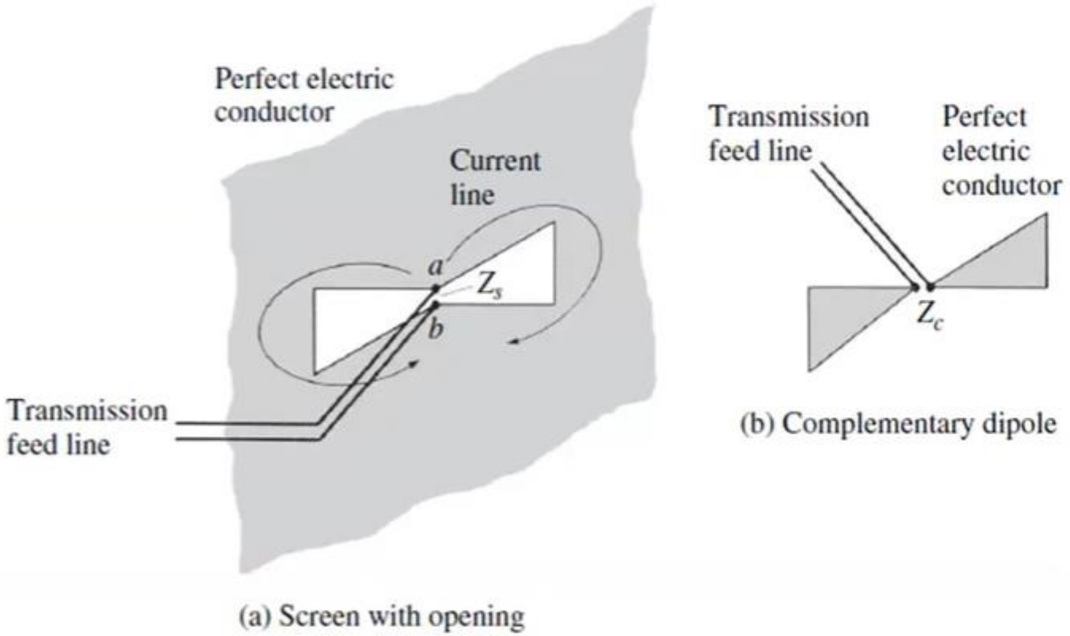


Fig. 2 Opening on a screen and its complementary dipole.

Babinet's Principle

- Using Booker's extension, by referring to Fig. 2, that if a screen and its complement are immersed in a medium with an intrinsic impedance η and have terminal impedances of Z_s and Z_c, respectively, the impedances are related by

$$Z_s Z_c = \frac{\eta^2}{4} \tag{3}$$

- To obtain the impedance Z_c, a gap must be introduced to represent the feed points.

- In addition, the far-zone fields radiated by the opening on the screen ($E_{\theta s}$, $E_{\phi s}$, $H_{\theta s}$, $H_{\phi s}$) are related to the far-zone fields of the complement ($E_{\theta c}$, $E_{\phi c}$, $H_{\theta c}$, $H_{\phi c}$) by

$$E_{\theta s} = H_{\theta c}, \quad E_{\phi s} = H_{\phi c}, \quad H_{\theta s} = -\frac{E_{\theta c}}{{\eta_0}^2}, \quad H_{\phi s} = -\frac{E_{\phi c}}{{\eta_0}^2} \tag{4}$$

- Unidirectional radiation can be obtained by placing a backing (box or cavity) behind the slot, forming a so-called *cavity-backed slot*.

Summary

Babinet's principle for complementary screens is that the sum of the wave transmitted through a screen plus the wave transmitted through the complementary screen, is the same as if no screen were present.

Test Your Understanding

Q. 1 A very thin half-wavelength slot is cut on an infinite, planar, very thin, perfectly conducting electric screen as shown in Fig. 3(a). Find its input impedance. Assume it is radiating into free-space.

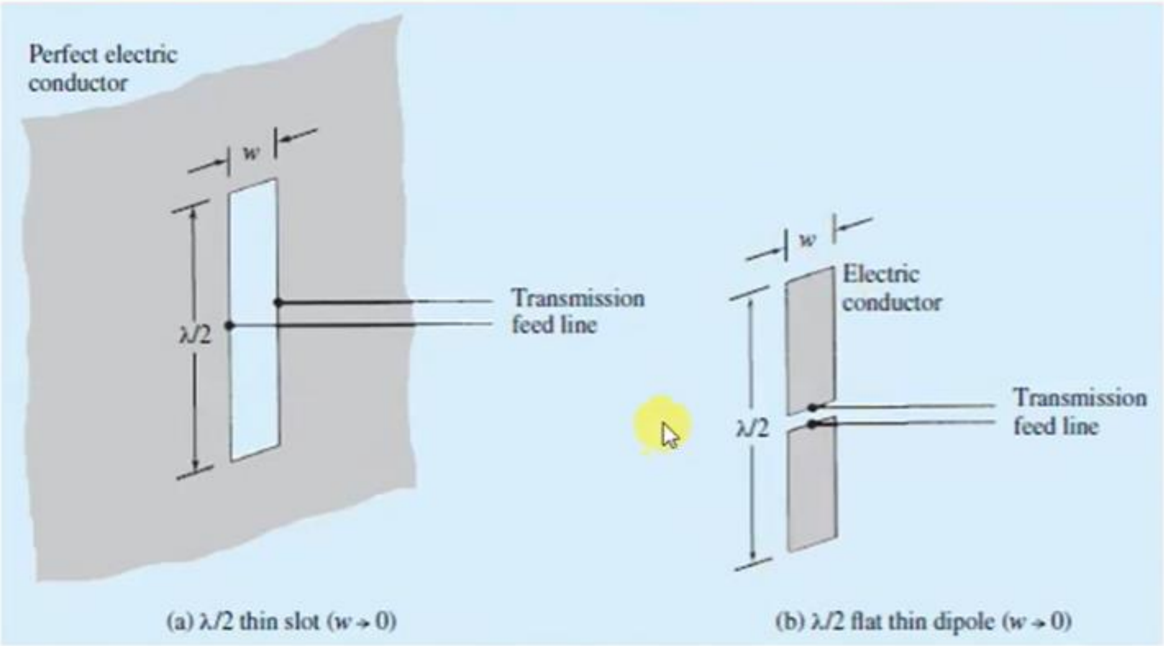


Fig. 3 Half-wavelength thin slot on an electric screen and its complement.

Test Your Understanding

Solution:-

From Babinet's principle and its extension we know that a very thin half-wavelength dipole, shown in Fig. 3(b), is the complementary structure to the slot. So, the terminal (input) impedance of the dipole is $Z_c = 73 + j42.5$. Thus, the terminal (input) impedance of the slot, using Eq. (3), is given by

$$Z_s = \frac{\eta_0^2}{4Z_c} \simeq \frac{(376.7)^2}{4(73 + j42.5)} \simeq \frac{35{,}475.72}{73 + j42.5}$$

$$Z_s \simeq 362.95 - j211.31$$

Reference

1. Constantine A. Balanis, “Antenna Theory Analysis and Design”, Third edition, John Wiley India Private Ltd., 2005.