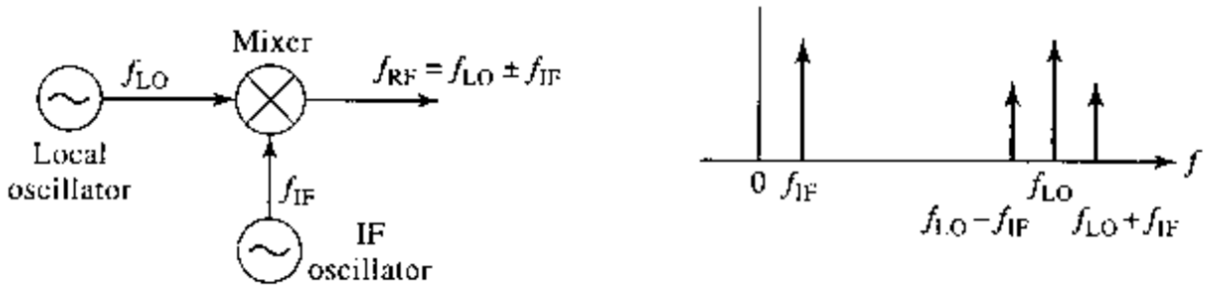
Mixers and wireless comm (pg671)

- Three-port device that uses a non-linear or time-varying (a shift in input is not correctly replicated in a shift in output) elements to achieve some type of frequency conversion

Frequency-up conversion



(a)

- A local oscillator (LO) signal (which has some higher frequency) is connected to one of the input ports. This can be represented as:

$$v_{LO}(t) = \cos 2\pi f_{LO} t. \tag{13.81}$$

- Now some lower frequency (closer to the baseband(which we can call intermediate frequency)) is applied at the second input
    - One of the signals would have the information that needs to be transmitted. HOW is info stored in devices???? Well a sinusoidal wave has properties such as phase, freq, and amplitude; one way we can store info is that we can quantize that signal into regions effectively creating a way to represent different info. For example lets say the letter A can be shown as R4, so an A can be seen a 0100 in binary

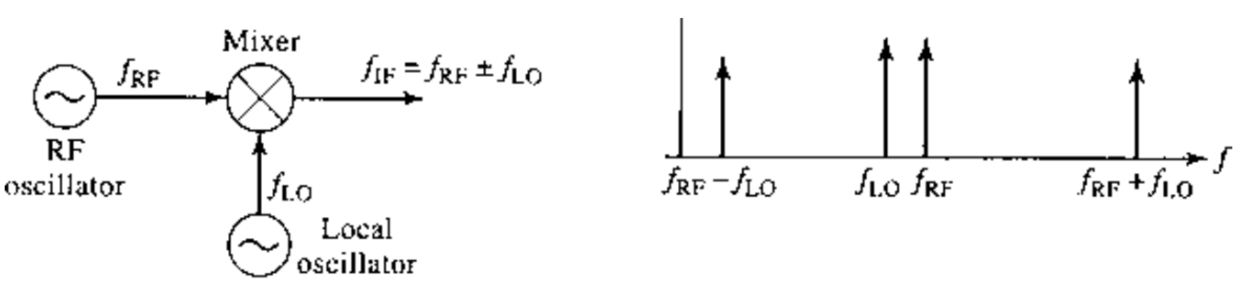
$$v_{IF}(t) = \cos 2\pi f_{IF} t. \tag{13.82}$$

- Noe the output:

$$\begin{aligned} v_{RF}(t) &= K v_{LO}(t) v_{IF}(t) = K \cos 2\pi f_{LO} t \cos 2\pi f_{IF} t \\ &= \frac{K}{2}[\cos 2\pi (f_{LO} - f_{IF})t + \cos 2\pi (f_{LO} + f_{IF})t], \end{aligned} \tag{13.83}$$

    - Here K is a constant accounting for the voltage conversion loss of the mixer

NOTE: Similar steps can be shown for frequency down conversions, see the diagram below:



Conversion loss:

- Mixer designs requires impedance matching at all ports (so each port would be matched with its own frequency)
- Now any undesired frequency would be dealt with by resistive loads (which could absorb these undesired frequencies) or reactive loads (which could block certain frequencies (capacitors))
- Now resistive loads increase loss and reactive loads can be freq sensitive, there are also general conversion losses
- Therefore conversion loss:

$$L_c = 10 \log \frac{\text{available RF input power}}{\text{available IF output power}} \geq 0 \text{ dB}. \tag{13.90}$$

Single-Ended Diode Mixer

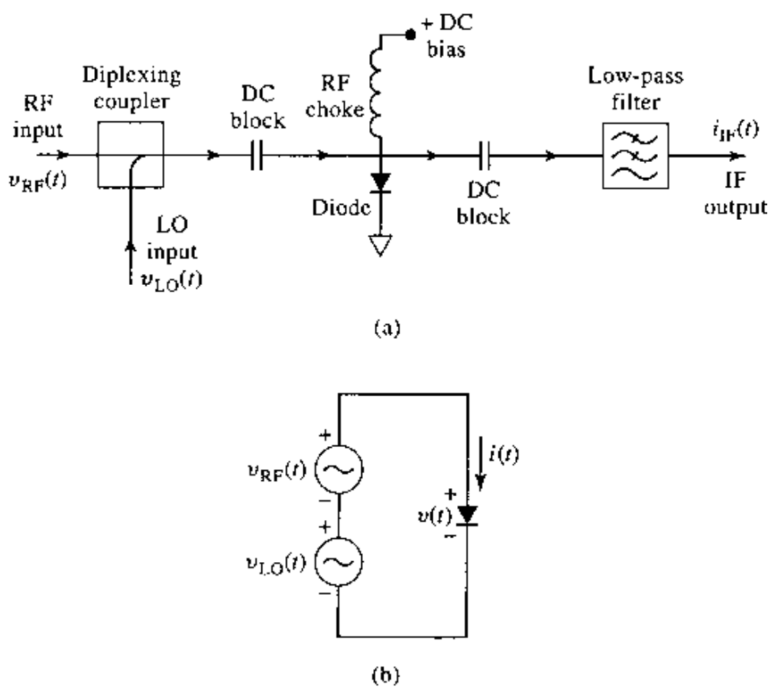


FIGURE 13.25 (a) Circuit for a single-ended diode mixer. (b) Idealized equivalent circuit.

- The RF and LO signals are combined in a diplexer (which essentially just superimposes the signal voltages)
- We use a DC biasing point to set the diode in its operational point
    - By proper biasing we can improve conversion efficiency and reduce loss
- Now we use DC blocks and RF chokes to assure the RF signals and DC bias are decoupled
- Then as your RF signal goes through the diode (which is some non linear device that creates different harmonics) that signal will then go through some filter for a desired frequency (setting the filter to create low pass and high pass filters)

filter. This leaves the IF output current as

$$i_{IF}(t) = \frac{G'_d}{2} V_{RF} V_{LO} \cos \omega_{IF} t, \tag{13.101}$$

where $\omega_{IF} = \omega_{RF} - \omega_{LO}$ is the IF frequency. The spectrum of the down-converting single-ended mixer is thus identical to that of the idealized mixer shown in Figure 13.24b.

System Aspects of Antennas

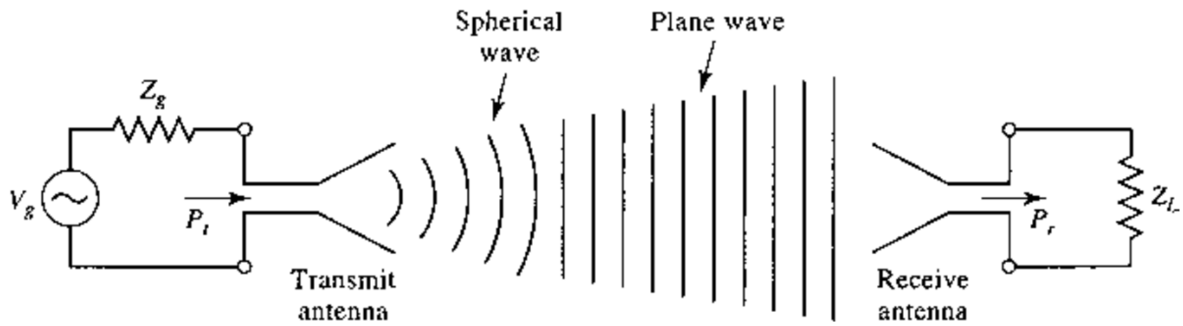
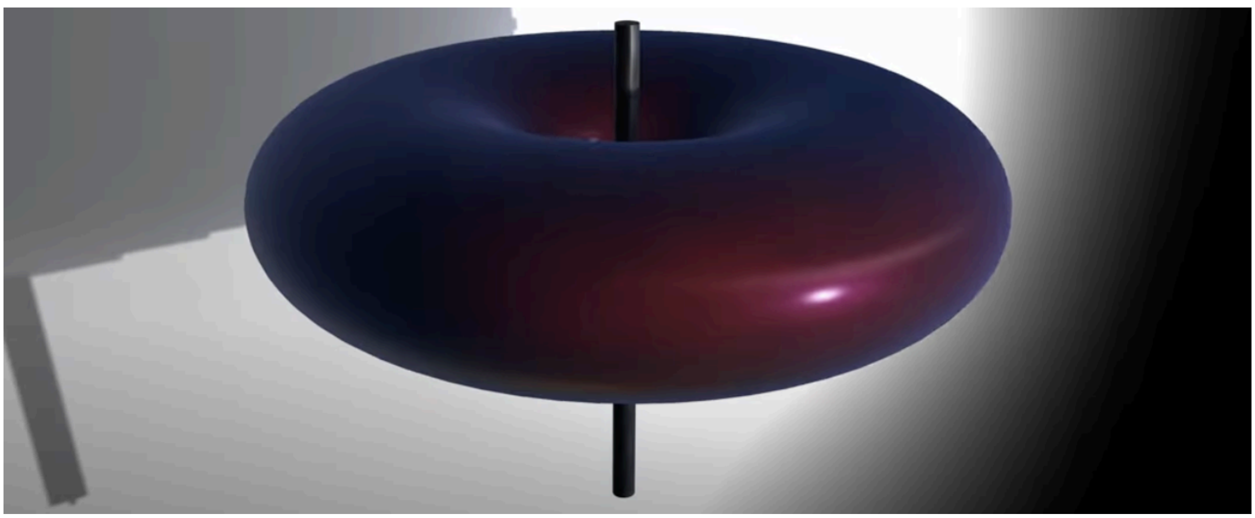


FIGURE 14.2 Basic operation of transmitting and receiving antennas.

- A transmitting antenna can be viewed as a device that converts a guided electromagnetic wave on a transmission line into a plane wave propagating in free space
    - One side appears as a electrical circuit element while other side provides an interface with a propagating plane wave
- Note, the antenna radiates a spherical wave that can be approximated as a plan wave at larger distances
- Wired Antennas:
    - Include diploes, monopoles, loops, sleeve dipoles
    - Have lower gain, WHY? a wired antenna spreads its energy out more widely, resulting in less power per unit area at a distance, leading to lower gain
    - Radiate their energy relatively in all directions



- Fields and power radiated by an antenna
    - Consider an antenna located at the center of a spherical coordinate system, the radiated electric field of an arbitrary antenna can be expressed as:

$$\bar{E}(r,\theta,\phi) = \left[\hat{\theta}F_\theta(\theta,\phi) + \hat{\phi}F_\phi(\theta,\phi)\right]\frac{e^{-jk_0 r}}{r} \text{ V/m}, \qquad (14.1)$$

    - Here Ko is free space propagation constant, and F is a pattern function
    - The interpretation is that this electric field propagates in the radial direction with phase variation of e^-jkor and amplitude variation of 1/r
    - Because this is Tranverse electromagnetic, the corresponding magnetic fields are:

$$H_\phi = \frac{E_\theta}{\eta_0}, \tag{14.2a}$$

$$H_\theta = \frac{-E_\phi}{\eta_0}, \tag{14.2b}$$

- Note: the time avg poynting vector (power) is:

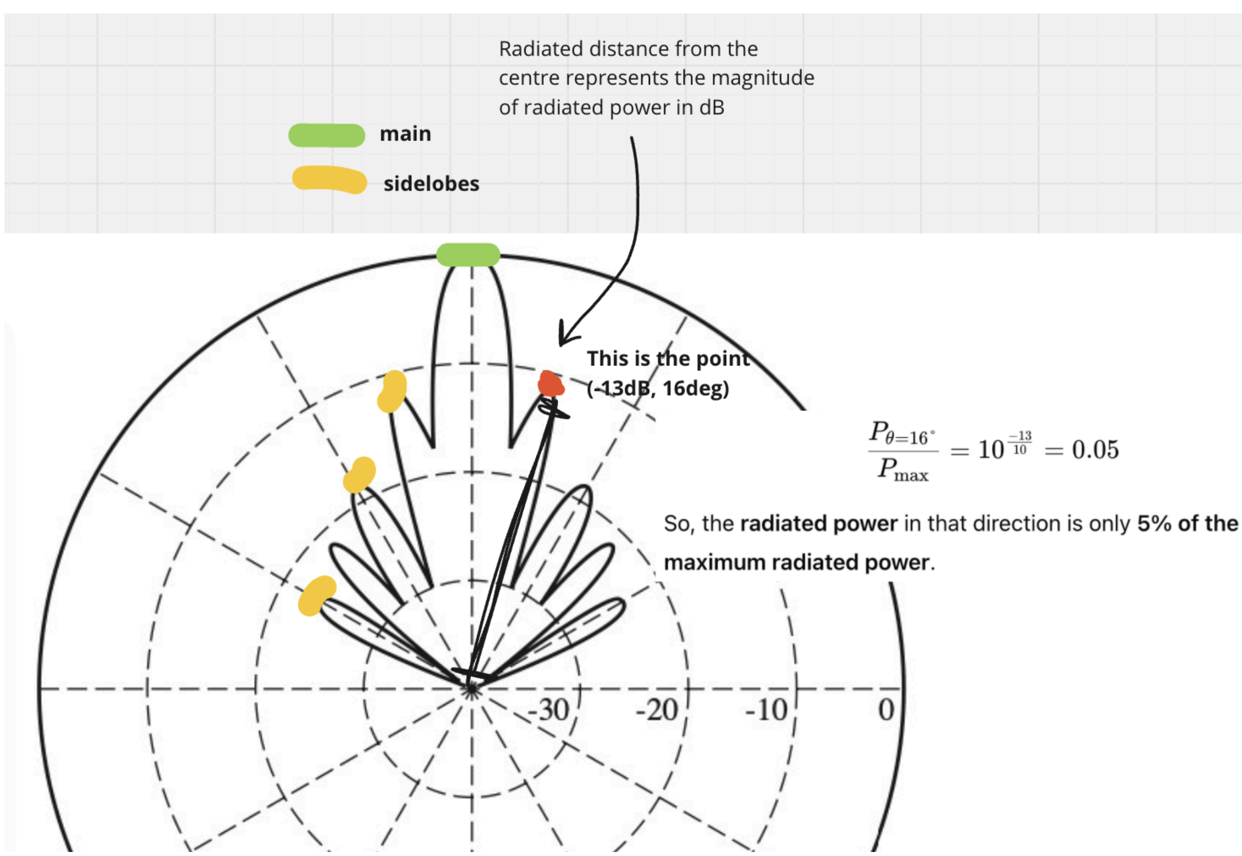
$$\bar{S}_{\text{avg}} = \frac{1}{2}\operatorname{Re}\{\bar{S}\} = \frac{1}{2}\operatorname{Re}\{\bar{E} \times \bar{H}^*\}\ \text{W/m}^2. \tag{14.4}$$

- Now 14.1 is approximated such that at large distances the near fields of an antenna are negligible, these large distances are when we can approximate the radial fields as planar/linear ones. Distance can be seen as:

$$R_{ff} = \frac{2D^2}{\lambda}\,\text{m}. \tag{14.5}$$

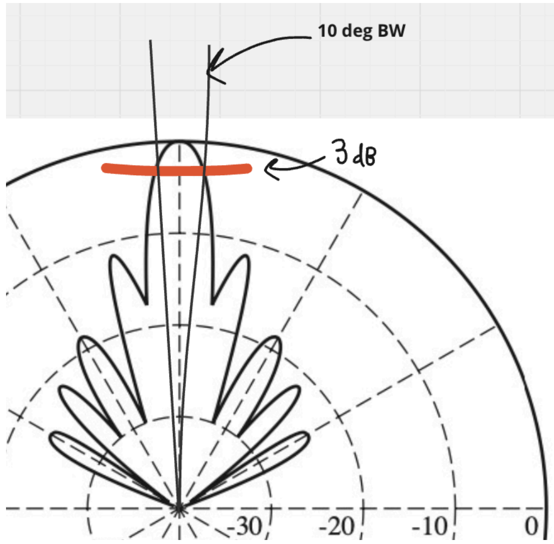
- Where D is a dimension of the antenna
- Note, we can find the total power radiated by the antenna by integrating the poynting vector over a unit sphere

Antenna Pattern Characteristics

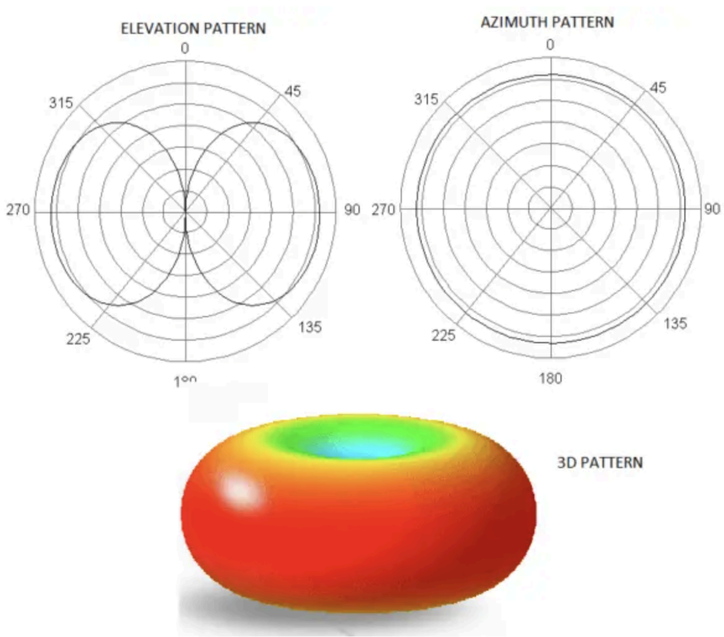


- Radiation pattern of an antenna is a plot of the magnitude of the far-zone field strength (electric field intensity at larger distances)

- We create radiation patterns from pattern functions (F_theta, or F_phi) versus theta (angle of elevation) or phi (azimuthal angle)
    - Understanding the patter function: the pattern function describes how the antennas radiated field (which is proportional to electric field, which is proportional to voltage) varies with direction



- A fundamental property of an antenna is to radiate in a given direction, therefore a broader main beam can transmit or receive at a wider angular region (opposite for narrow main beam)



- Antennas having a constant pattern in the azimuthal plane **(above pattern)** are called *omnidirectional*, and are useful for applications such as broadcasting **(so signals in all directions can be interpreted)** or for hand-held wireless devices, where it is desired to transmit or receive equally in all directions. Patterns that have relatively narrow main beams in both planes are known as *pencil beam* antennas, and are useful in applications such as radar and point-to-point radio links.

Another measure of the focusing ability of an antenna is the *directivity*, defined as the ratio of the maximum radiation intensity in the main beam to the average radiation intensity over all space:

$$D = \frac{U_{\max}}{U_{\text{avg}}} = \frac{4\pi U_{\max}}{P_{\text{rad}}} = \frac{4\pi U_{\max}}{\int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi} U(\theta,\phi)\sin\theta d\theta d\phi}, \tag{14.8}$$

~~where (14.7) has been used for the radiated power~~. Directivity is a dimensionless ratio of power, and is usually expressed in dB as $D(\text{dB}) = 10\log(D)$.

Wireless Communication (tranfer of information between two points without direct connection)

- Used in broadcast radio and television, cellular telephone and networking systems, direct broadcast satellite (DBS) television service, wireless local area networks (WLANs), paging systems, Global Posistioning Systems (GPS) service, and radio frequency identifications (RFID) systems
- Characterizing wireless systems according to nature of placement of users:
    - Point to point radio systems - single transmitter and single receiver is used (here we use high gain antennas (smaller more focused BW) to maximize received power and minimize interference with oth radios that may be operating with nearby systems
    - Point to multipoint systems - connect a central station to a large number of possible receivers (Example: AM and FM radio and broadcast television); here the central antenna uses a broad azimuthal beam to reach many listeners
    - Multipoint to multipoint - simultaneous connection between multiple users (Such systems generally do not connect two users directly, but instead rely on a grid of base stations to provide the desired interconnections between users. Cellular telephone systems and some types of WLANs are examples of this type of application.)
- Characterizing wireless systems in terms of directionality of communication:
    - Simplex - one direction (from transmitter to receiver)
    - Half Duplex - two directions, but not simultaneously
    - Full Duplex - two directional, simultaneously (some duplexing technology will be needed to avoid interference)
        - Explanation of duplexing systems (Example: FDD): https://www.youtube.com/watch?v=xtI1UppiNAA
- Friis Formula

$$P_r = \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t \text{ W.}$$

    - Gt - transmit antenna gain
    - Gr - receive antenna gain
    - Pt - transmit power
    - R - distance between transmit and receive antennas
    - In practice, the value given by the above should be interpreted by maximum possible received power
    - Ways to reduce power: impedance mismatch at either antenna, polarization mismatch between the antennas, propagation effects leading to attenuation or depolarization, and multipath effects that may cause partial cancellation of the received field.
    - Here the received power decreases as the separation between the transmitter and receiver increases (which is a result from the conservation of energy. HOW???? Conservation of energy states that the total energy in a system remains constant, therefore as radiated power radiates outward, the total power needs to be distributed equally, hence the power seen at the receiver lessens)

Factors affecting signal integrity (Pr)

- Mismatch at either antenna

1. Mismatch at Either Antenna

- **Effect on P_r**: Reduces received power due to signal reflection.
- **Why?** If the impedance of the antenna does not match the impedance of the transmission line or receiver (typically 50Ω for RF systems), part of the power is reflected back instead of being transferred efficiently.
- **Example**: If the Voltage Standing Wave Ratio (VSWR) is high, a significant portion of the transmitted power is lost due to reflection, reducing the power that reaches the receiver.

- Polarization mismatch between antennas
- Propagation effects leading to attenuation or depolarization

3. Propagation Effects Leading to Attenuation or Depolarization

- **Effect on P_r**: Causes signal weakening due to absorption, scattering, and refraction.
- **Why?** As electromagnetic waves travel, they experience **attenuation** (loss of energy) due to obstacles like buildings, trees, and atmospheric absorption (rain, fog, etc.). **Depolarization** can occur if the wave interacts with surfaces that scatter its electric field components, causing polarization changes that reduce reception efficiency.
- **Example**: In foggy or rainy conditions, microwave signals suffer attenuation due to water absorption, reducing P_r.

    - depolarization ????

- Multipath effects that cause partial cancellation of the received field

4. Multipath Effects that Cause Partial Cancellation of the Received Field

- **Effect on P_r**: Can cause fluctuations in received power due to constructive and destructive interference.
- **Why?** Multipath occurs when the transmitted signal takes multiple paths to the receiver due to reflections from buildings, the ground, or other objects. If these signals arrive **in phase**, they add up (constructive interference), increasing P_r. If they arrive **out of phase**, they cancel each other out (destructive interference), reducing P_r.
- **Example**: In urban environments, multipath fading can cause deep nulls (signal dropouts) where P_r becomes very low.

- Line losses

5. Line Losses

- **Effect on P_r**: Reduces power before it even reaches the receiver.
- **Why?** The transmission line (coaxial cable, waveguide, etc.) carrying the signal from the antenna to the receiver introduces resistance and dielectric losses, leading to power dissipation as heat.
- **Example**: A long coaxial cable with high attenuation (e.g., 3 dB loss per meter at high frequencies) can significantly reduce P_r, especially in satellite or high-frequency radar applications.