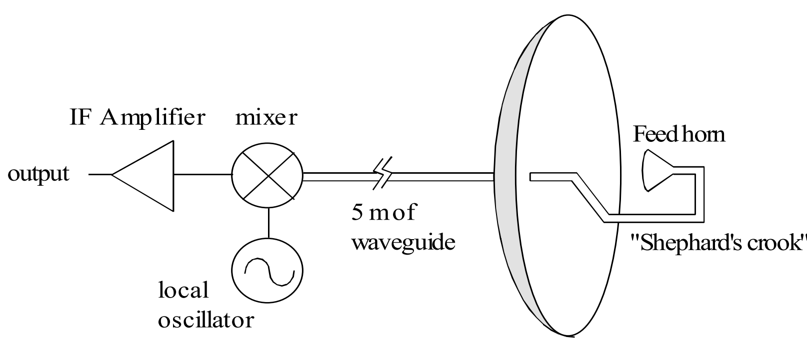
Reading: Balanis Chapters 2-4 & 8, plus Handouts

Homework #2 **Due: Wednesday, 23 April 2003**

1) Several years ago, the Voyager satellite transmitted some spectacular pictures back to Earth from a distance of about 4 light-hours. The main data link involved a frequency of 8.4 GHz, a 12 Watt transmitter, and an antenna whose beam was conically-shaped and fell to the half-power level at an angle of 0.5° off-axis (HPBW=1°).
   a) Find the gain of this antenna, and calculate the power density at the Earth.
   b) The Earth receiving station used parabolic dish antennas with diameters of 60 m. Assuming the effective area is about half the physical area, how much power is received?
   c) The effective noise temperature of the receiving system was about 30 K. What bandwidth of data transmission would this allow in order to maintain a signal-to-noise ratio of at least 10?
   d) A typical low-loss optical fiber transmission system can have an attenuation rate as low as 0.1 dB/km. Compare this loss with the transmission loss of the satellite link.

2) A microwave receiver system operating at a wavelength of λ_0=3 cm uses a paraboloidal antenna as shown below, with a directive gain of 30 dB. The 5 meters of waveguide connecting the antenna and receiver electronics has a total loss of 3 dB. The mixer has a conversion loss of 3 dB and a noise figure of 4 dB. The IF amplifier has a noise figure of 6 dB and a bandwidth of 1 MHz. The antenna noise temperature is 20 K. Assuming the receiver electronics and waveguide are at standard temperature of 290 K and the system is impedance-matched, find:
   a) The overall system noise temperature, and the incident power density required to give an output signal-to-noise ratio of 10 dB at the IF amplifier output.
   b) Repeat the calculation in (a) assuming that a low-noise microwave amplifier is inserted into the system just behind the feed horn. Assume a gain of 8 dB and a noise figure of 1 dB.



3) In this problem we treat the Sun as a giant thermodynamic antenna (blackbody radiator). The Sun has a mean radius of $r_{sun} = 6.96 \times 10^8$ m, a mass of $m_{sun} = 2 \times 10^{30}$ kg, and is 1.5×10^{11} m away from the Earth.
   a) Sensitive measurements using a radio antenna pointed at the sun indicate that the power spectral density (measured at the surface of the Earth) is approximately 10^{-21} Watts/m^2/Hz, at a frequency of 3 GHz. According to Planck's blackbody radiation law, a black body at temperature T will radiate a power per unit surface area of

$$P_{bb} = \frac{2\pi f^2}{c^2} \frac{hf}{e^{hf/kT} - 1} \quad \left[\frac{\mathrm{W}}{\mathrm{m}^2 \cdot \mathrm{Hz}}\right] \tag{1}$$

Using this theory, find the average surface temperature of the sun from the measurement (assume the sun is far enough away from Earth to behave as an isotropic point source). Note that $hf \ll kT$ at 3 GHz.

b) Using (1) **or** a good text on blackbody radiation, derive/find an expression for the total power radiated by a black body over all frequencies. This is the Stefan-Boltzmann radiation law. Use it to determine the total power radiated by the Sun, and the resulting total power density at the Earth's surface.

c) The Earth's radius is about 6400 km. What is the total power incident on the Earth from the Sun?

d) Assume that the Sun converts energy according to $E = mc^2$ at 0.01% efficiency. How long can the Sun continue to radiate at the present level?

4) The moon is approximately 3.8×10^5 km from the Earth, and has a diameter of approximately 3500 km. A radar with a wavelength of 10 cm and a symmetric conical beam of width $\Delta\theta$ transmits towards the moon and receives an echo. Assume the moon scatters 20% of the power incident upon it uniformly over a solid angle of 2π steradians (half a sphere). The rest of the power is absorbed. Find the ratio of received to transmitted power for radars for which:

a) The beam width is $\Delta\theta = 1°$

b) The beam width is $\Delta\theta = 0.1°$

5) In situations where the current distribution is known (or can be guessed) *a priori*, the *Induced EMF* method allows us to calculate the input impedance of an antenna. Using induced EMF theory, calculate the complex impedance of a center-fed dipole of radius $a/L = 0.01$. Generate a plot of the real and imaginary parts of the impedance over a frequency range wide enough to encompass the first few resonances. What are the resonant lengths of a dipole with this a/L ratio for the first two resonance? (specify your answer in terms of the free-space wavelength, λ_0.)