Chapter 13 Introduction to Microwave Systems

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13.1 System aspects of antennas

- antenna characteristics

radiation pattern $$F(\theta,\phi) \equiv r^2 \left| \vec{E}(\theta,\phi) \times \vec{H}^*(\theta,\phi) \right| = r^2 S(\theta,\phi)$$

directivity $$D \equiv \frac{4\pi F_{\max}}{P_{rad}} = \frac{4\pi F_{\max}}{\iint F(\theta,\phi)\sin\theta d\theta d\phi} = \frac{4\pi A_e}{\lambda^2}$$

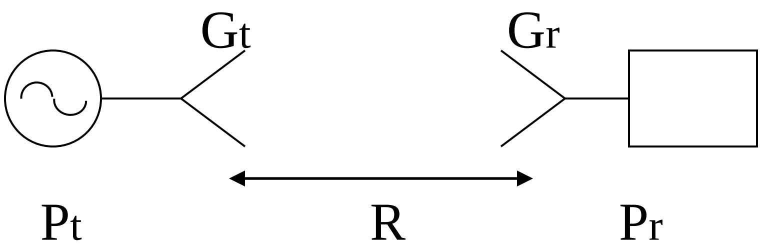
efficiency $$\eta \equiv \frac{P_{rad}}{P_{in}}$$ $$A_e \equiv \frac{P_l}{S}$$

gain $$G = \eta D$$

equivalent noise temperature $$T_e = \eta T_b + (1-\eta) T_p$$

13.2 Microwave communication systems

• Friis power transmission formula



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

Discussion

1. Ex.13.4 a DBS satellite @12GHz, P_t =120W, G_t =34dB → 2m dia. θ =1.7°, slant range 39000km, ground receiving terminal G_r =33.5dB → 0.5m dia. θ =6.2° T_A=50K, NF=1.1dB, BW=20MHz

(1)transmitter $EIRP = P_t G_t = 120 \times 2512 = 54.8 dBm$

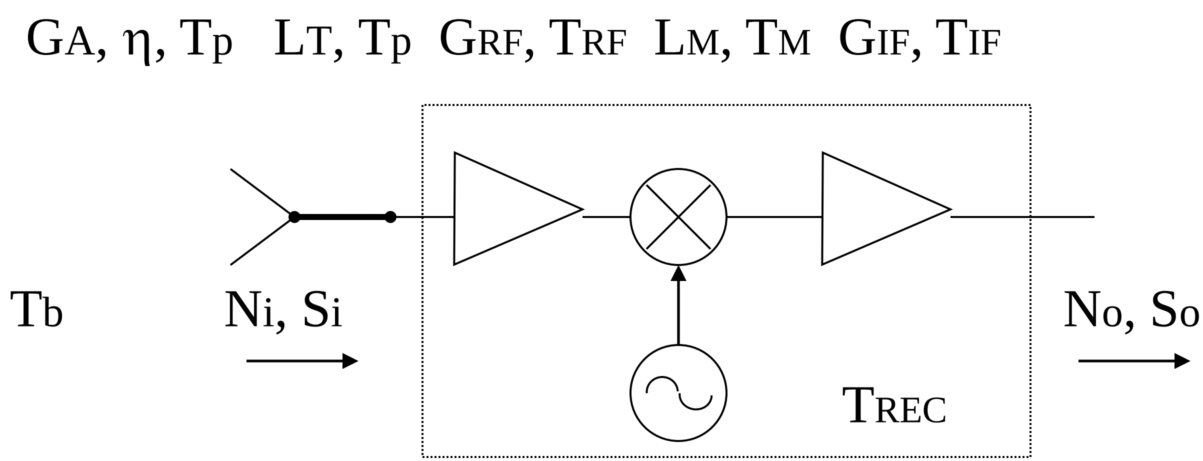
(2)$T_e = T_A + T_{LNB} = T_A + (F-1)T_o = 50 + (1.29-1) \times 290 = 134K$

receiver $\frac{G}{T} = \frac{2512}{134} = 12.2 dB/K$

(3)$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} = -117.9 dBW = -87.9 dBm$

(4)$CNR = \frac{P_r G_{LNB}}{k T_e B G_{LNB}} = 16.4 dB$

• noise analysis of a microwave receiver



equivalent noise temperature

(1) antenna

$$T_A = \eta T_b + (1-\eta) T_p, N_i = kT_A B$$

(2) cable

$$T_{TL} = (L_T - 1) T_p$$

(3) receiver

$$T_{REC} = T_{RF} + \frac{T_M}{G_{RF}} + \frac{T_{IF} L_M}{G_{RF}} \rightarrow T_{TL+REC} = T_{TL} + L_T T_{REC}$$

$\Rightarrow$

o/p signal power $S_o = \frac{S_i G_{RF} G_{IF}}{L_T L_M} = S_i G_{sys}$

o/p noise power

$$N_o = (N_i + kBT_{TL+REC})G_{sys}$$

$$= kB(T_A + T_{TL+REC})G_{sys}$$

$$= kB[\eta T_b + (1-\eta)T_p + (L_T - 1)T_p + L_T T_{REC}]G_{sys}$$

$$= kBT_{sys}G_{sys}$$

$$\frac{S_o}{N_o} = \frac{S_i}{kBT_{sys}}$$

Discussion

1. Ex13.5 a 4 GHz receiver with BW=1MHz, Si = -80dBm

$$\eta = 0.9, T_b = 200°k, T_p = 300°k \rightarrow T_A = 210°k$$

$$\rightarrow N_i = kBT_A = -115dBm \Rightarrow \frac{S_i}{N_i} = 35dB$$

$$L_T = 1.5dB = 1.41 \rightarrow T_{TL} = (L_T - 1)T_o = 123°k,$$

$$L_M = 6dB = 4, F_M = 7dB \rightarrow T_M = (F_M - 1)T_o = 1163°k,$$

$$F_{RF} = 3dB \rightarrow T_{RF} = (F_{RF} - 1)T_o = 289°k$$

$$F_{IF} = 1.1dB \rightarrow T_{IF} = (F_{IF} - 1)T_o = 84°k$$

$$G_{RF} = 20dB = 100, G_{IF} = 30dB = 1000$$

$$\rightarrow T_{REC} = T_{RF} + \frac{T_M}{G_{RF}} + \frac{T_{IF} L_M}{G_{RF}} = 304°k$$

$$\rightarrow T_{sys} = T_A + T_{TL} + L_T T_{REC} = 762°k$$

$$\Rightarrow \frac{S_o}{N_o} = \frac{S_i}{kBT_{sys}} = -80 + 110 = 30dB$$

13.3 Radar systems

• radar (radio detection and ranging) equation

$$P_r = \frac{P_t G}{4\pi R^2}\sigma\frac{1}{4\pi R^2}A_e = \frac{P_t G^2\lambda^2\sigma}{(4\pi)^3 R^4} \rightarrow R_{\max} = \sqrt[4]{\frac{P_t G^2\lambda^2\sigma}{(4\pi)^3 P_{\min}}}$$

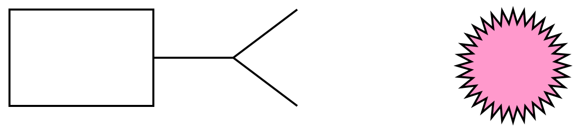
Discussion

1. Ex13.6 radar @10GHz, P_t=2kW, G=28dB, σ=12m^2, P_{min}=-90dBm
   $\rightarrow$ R_{max} = 8114km
2. pulse radar $\rightarrow$ detect target range and direction
3. Doppler radar $\rightarrow$ detect target radial velocity
4. radar cross section (p.665, Table 13.2)
   e.g. bird 0.01m^2, missile 0.5m^2, person 1m^2, fighter 3-8m^2,
   airplane 100m^2, truck 200m^2

5. SIR-C microwave image of Taipei area

13.4 Radiometry

• radiometer



T

$P = kT_B B = keTB$

T: physical temperature

T_B: brightness temperature

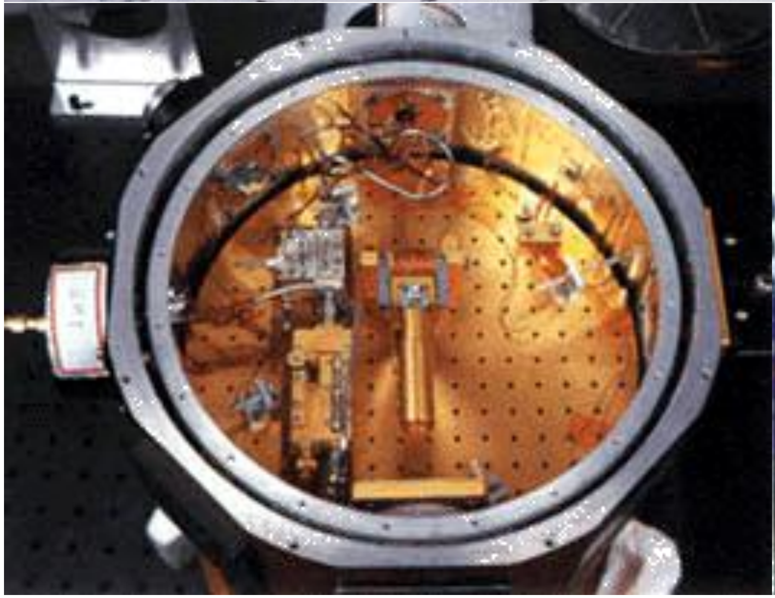
e: emmisivity

$0 \le e \le 1$

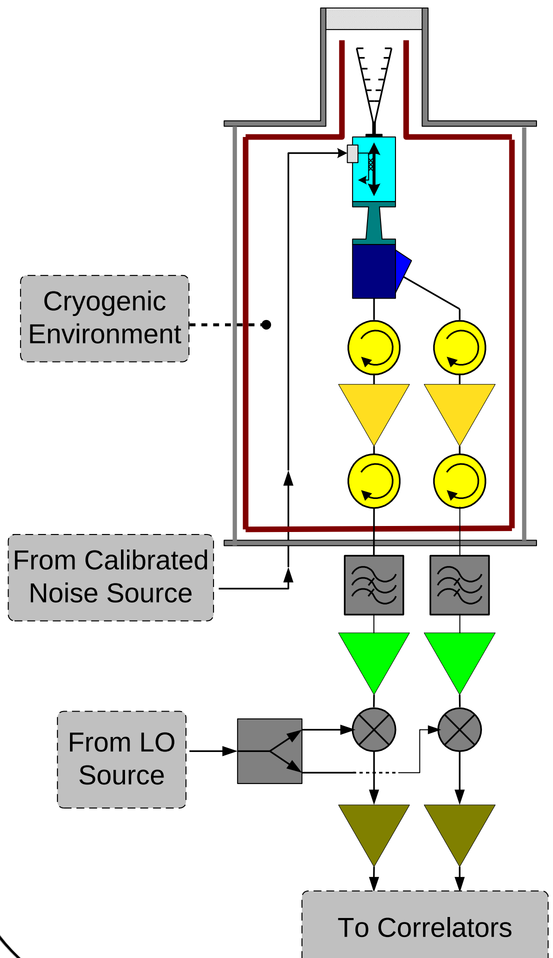
Discussion

1. radiometer measures the object noise power → T_B → object physical parameters (p.681)
   e.g. soil moisture, ocean surface wind speed, target image, mapping of galactic objects,…….
2. usually $T_B < T_R$ receiver temperature, $V_o = Gk(T_B + T_R)B$,
   T_R can be derived from the Y-factor calibration
3. measurement errors due to
   noise fluctuation → increase integration time
   receiver gain fluctuation → Dicke radiometer

4. SMA (sub-millimeter array) 200GHz-900GHz



5. AMiBA (Array for Microwave Background Anisotrophy)宇宙背景輻射陣列望遠鏡 85GHz-105GHz



Component Chain

Vacuum Window
↓
Corrugated Feed
↓
Noise Coupler
↓
Transition
↓
OMT
↓
Isolator
↓
RF Pre-Amplifier
↓
Isolator
↓
High-Pass Filter
↓
RF Post-Amplifier
↓
Sub-Harmonic Mixer
↓
IF Amplifiers

13.5 Microwave propagation

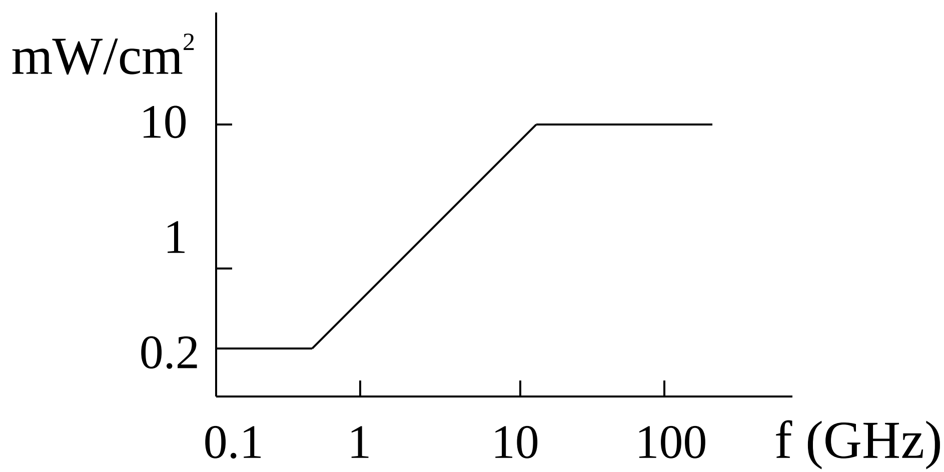
Discussion

1. "line of sight propagation", $1/R^2$, for microwaves
   → satellite communication
2. atmospheric attenuation effects (p.672, Fig.13.26)
   negligible for f<10GHz
   water vapor resonance @ 22.2GHz, 183.3GHz
   O_2 resonance @ 60GHz, 120GHz
   "microwave window" @ 35GHz, 94GHz, 135GHz
   → earth remote sensing
3. ground reflections
   → fading or scintillation problems for wireless communication in urban area
   → clutter problem for radar
4. plasma frequency ≅ 8MHz, total reflection from ionsphere
   for $f<f_p$ → short wave radio

13.6 Other applications and topics

Discussion

1. microwave oven @ 2.45GHz
   → conduction loss for large tanδ of material
2. energy tansfer → nonpilot airplane, solar power satellite station
3. micrwave exposure → thermal effects, IEEE Standard C95.1-1991
   Sun radiation 100mW/cm^2



4. Ex 13.7 6GHz microwave antenna 40 dB gain and 5W radiation
$\rightarrow$ power density at 20 m away

$$S = \frac{P_{in}G}{4\pi R^2} = 1mW/cm^2 < \text{standard}$$

ADS examples: Ch13_prj