Chapter 14 Introduction to Microwave Systems

14.1 System aspects of antennas
radiation pattern, directivity, efficiency, gain, temperature
14.2 Microwave communication systems
Friis formula, transmitter and receiver, receiver noise characteristics
14.3 Radar systems
radar equation
14.4 Radiometry
radiometer
14.5 Microwave propagation
atmospheric effects
14.6 Other applications and topics
microwave oven, energy transfer

14.1 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

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

efficiency $\eta \equiv \dfrac{P_{rad}}{P_{in}}$

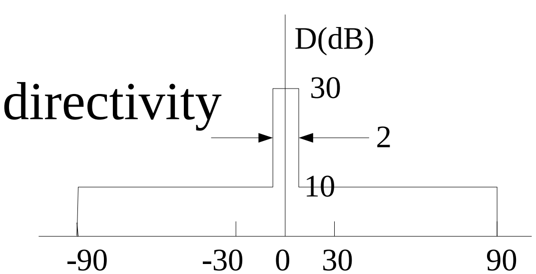
gain $G = \eta D$

equivalent noise temperature

$$T_A = \eta T_b + (1-\eta) T_p \qquad T_b = \frac{\iint T_B(\theta,\phi) D(\theta,\phi)\sin\theta d\theta d\phi}{\iint T_B(\theta,\phi)\sin\theta d\theta d\phi}$$

<u>Discussion</u>

1. Ex.14.3 Calculate TA with η=1 and an antenna directivity

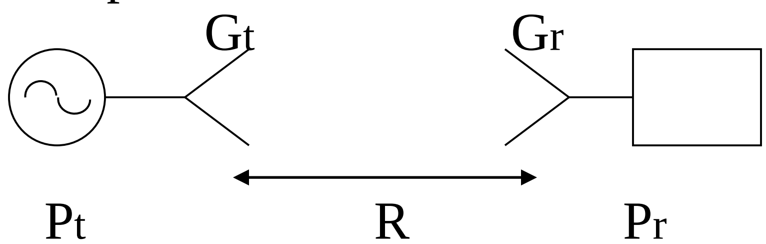


$$\textit{background}\ \text{noise temperature}\ T_B = \begin{cases} 10°K, |\theta| \le 30° \\ 100°K, 30° < |\theta| \le 90° \end{cases}$$

$$\rightarrow T_A = T_b = \frac{\int_0^{1°} 10\times1000 \sin\theta d\theta + \int_{1°}^{30°} 10\times10 \sin\theta d\theta + \int_{30°}^{90°} 100\times10\sin\theta d\theta}{\int_0^{1°} 1000\sin\theta d\theta + \int_{1°}^{90°} 10\sin\theta d\theta} = 86.4°K \approx \textit{sidelobe region}$$

14.2 Microwave communication systems

- Friis power transmission formula



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

<u>Discussion</u>

1. Ex.14.4 a DBS satellite @12.45GHz, P_t =120W, G_t =34dB → 2m dia. θ =1.7º, slant range 39000km, ground receiving terminal G_r =33.5dB → 18in dia. θ =6º, T_A=50K, NF=0.7dB, BW=20MHz

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

(2)$receiver\ T_e = T_A + T_{LNB} = T_A + (F-1)T_o = 50 + (1.179-1) \times 290 = 100.8K$

receiver $\frac{G}{T} = \frac{2239}{100.8} = 13.5 dB/K$

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

(4)$CNR = \frac{P_r G_{LNB}}{k T_e B G_{LNB}} = 17.7 dB > system\ link\ margin$

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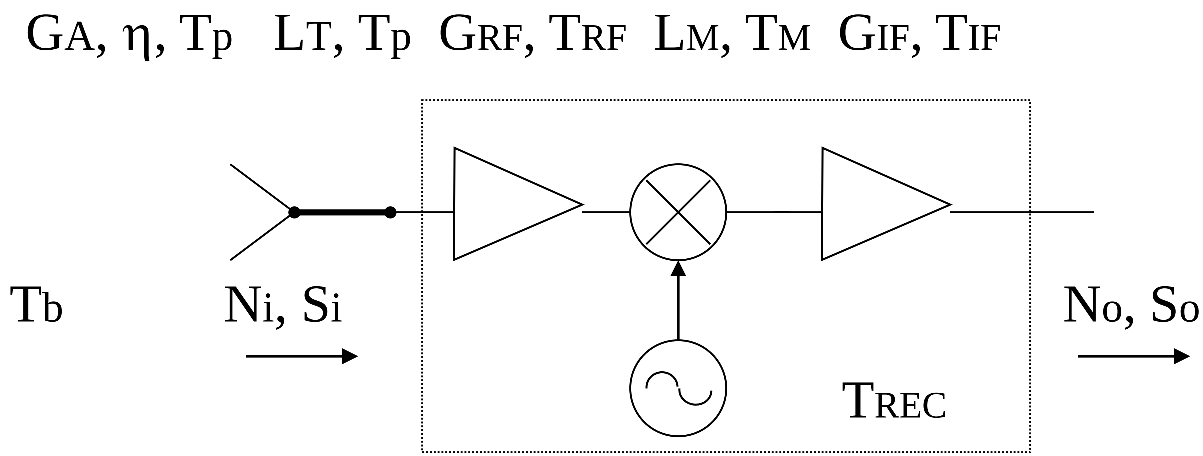
• noise analysis of a microwave receiver



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 $\quad S_o = \dfrac{S_i G_{RF} G_{IF}}{L_T L_M} = S_i G_{sys}$

o/p noise power

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

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

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

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

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

Discussion

1. Ex14.5 a 4 GHz receiver with BW=1MHz, Si = -80dBm

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

$$\rightarrow N_i = kT_AB = -115dBm \Rightarrow SNR_i = 35dB$$

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

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

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

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

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

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

$$\rightarrow T_{sys} = T_A + T_{TL} + L_T T_{REC} = 762°k \rightarrow kBT_{sys} = -110dBm$$

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

• noise analysis of a digital communication receiver

$$P_b : BER(\frac{E_b}{n_o} \equiv \frac{\text{bit energy}}{\text{noise power desity}})$$

$$\frac{E_b}{n_o} = \frac{ST_b}{n_o} = \frac{S}{n_o R_b} = \frac{S}{\frac{N}{B} R_b} = \frac{SB}{NR_b}, S : \text{signal power, } T_b = \frac{1}{R_b} : \text{bit period, } R_b\text{:bit rate}$$

Ex14.6 a LEO communication satellite f=16GHz,,P_t=80W, G_t=20dB, R=940km, a QPSK receiving handset G_r=1dB, T_{sys}=750K, L_{atm}=2dB BER=0.01, find $R_{b,min}$ for 10dB link margin

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} = 49 + 20 + 1 - 176 - 2 = -108dBm$$

$$S_{\min} = -108 - 10 = -118dBm = 1.58 \times 10^{-15} W$$

$$\text{QPSK } BER = 0.01 \rightarrow \frac{E_b}{n_o} = 5dB = 3.16 = \frac{S_{\min} B}{NR_{b,\max}}$$

$$\rightarrow R_{b,\max} = \frac{n_o}{E_b} \frac{S_{\min} B}{N} = \frac{n_o}{E_b} \frac{S_{\min} B}{kT_{sys} B} = \frac{n_o}{E_b} \frac{S_{\min}}{kT_{sys}} = \frac{1}{3.16} \frac{1.58 \times 10^{-15}}{1.38 \times 10^{-23} \times 750} = 48kbps$$

14.3 Radar systems

• radar (<u>ra</u>dio <u>d</u>etection <u>a</u>nd <u>r</u>anging) equation

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

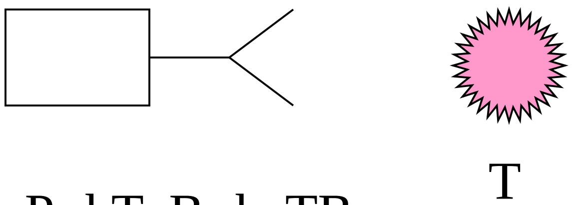
<u>Discussion</u>

1. Ex14.7 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.696, Table 14.3)
   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 (1994) microwave image of Taipei area

14.4 Radiometry

• radiometer



$P = kT_B B = keTB$

T: physical temperature

T_B: brightness temperature

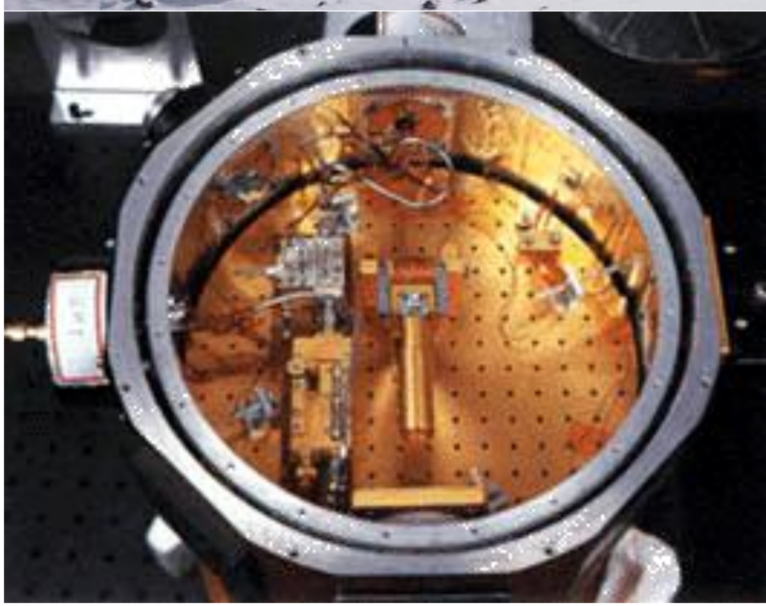
e: emmisivity

$0 \le e \le 1$

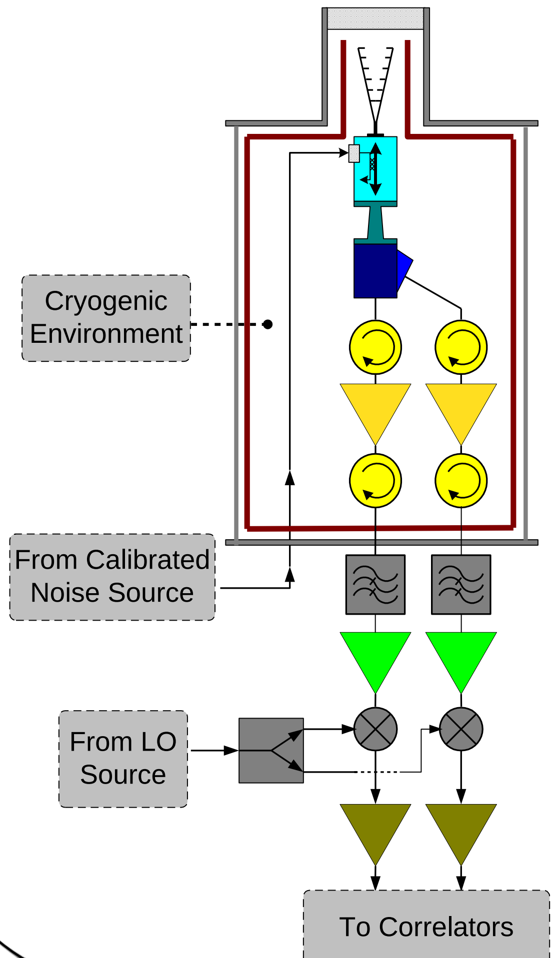
<u>Discussion</u>

1. radiometer measures the object noise power $\rightarrow T_B \rightarrow$ object physical parameters (p.699)
   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 $\rightarrow$ increase integration time
   receiver gain fluctuation $\rightarrow$ Dicke radiometer

4. SMA (sub-millimeter array) (1983, 1996~) 200GHz-900GHz



5. AMiBA (Array for Microwave Background Anisotrophy)宇宙背景輻射陣列望遠鏡(2001~) 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

14.5 Microwave propagation

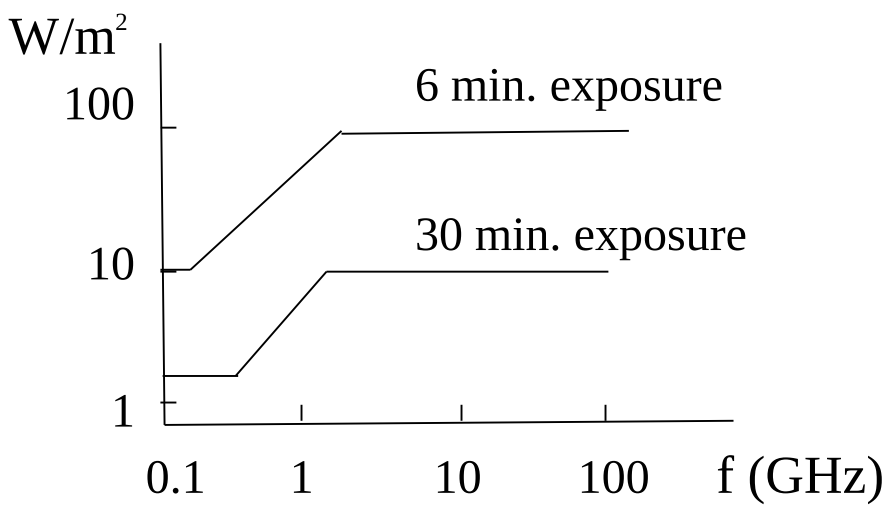
Discussion

1. "line of sight propagation", $1/R^2$, for microwaves
   → satellite communication
2. atmospheric attenuation effects (p.703, Fig.14.29)
   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

14.6 Other applications and topics

<u>Discussion</u>

1. microwave oven @ 2.45GHz
   → conduction loss for large tanδ of material
2. energy tansfer → nonpilot airplane, solar power satellite station, mobile phone, …
3. micrwave exposure → thermal effects, IEEE Standard C95.1-2005
   power density: $10W/m^2$~$1mW/cm^2$



4. Ex 14.8 a 18GHz microwave antenna 36dB gain and 10W radiation
→ power density at 20 m away

$$S = \frac{P_{in}G}{4\pi R^2} = \frac{10 \times 4000}{4\pi \times 20^2} = \begin{cases} 8W/m^2 \ @main\ lobe \\ 0.8W/m^2 \ @-10dB\ sidelobe \end{cases} < 10W/m^2$$

ADS examples: Ch14_prj