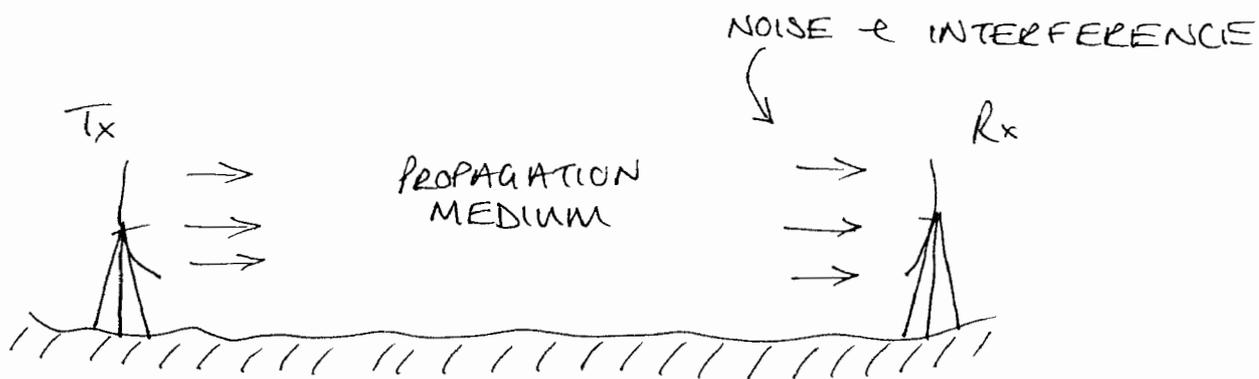


# REVIEW OF POWER & NOISE BUDGETS

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## ESSENTIAL ELEMENTS:

- \* ANTENNAS
- \* PROPAGATION MEDIUM - USUALLY EARTH'S ATMOSPHERE
- \* ENVIRONMENT - TERRAIN, VEGETATION, SEA ETC.
- \* INTERFERENCE & NOISE - NATURAL & MAN-MADE

## BASIC POWER BUDGET:

$$P_R = P_T G_T L G_R \quad [P_R = P_T + G_T + L + G_R \text{ (dBs)}]$$

WHERE:

- L - LOSS BETWEEN ANTENNAS.
- $G_T$  - TRANSMITTER ANT. GAIN.
- $G_R$  - RECEIVER ANT. GAIN.
- $P_T$  - TRANSMITTER POWER.
- $P_R$  - RECEIVER POWER.

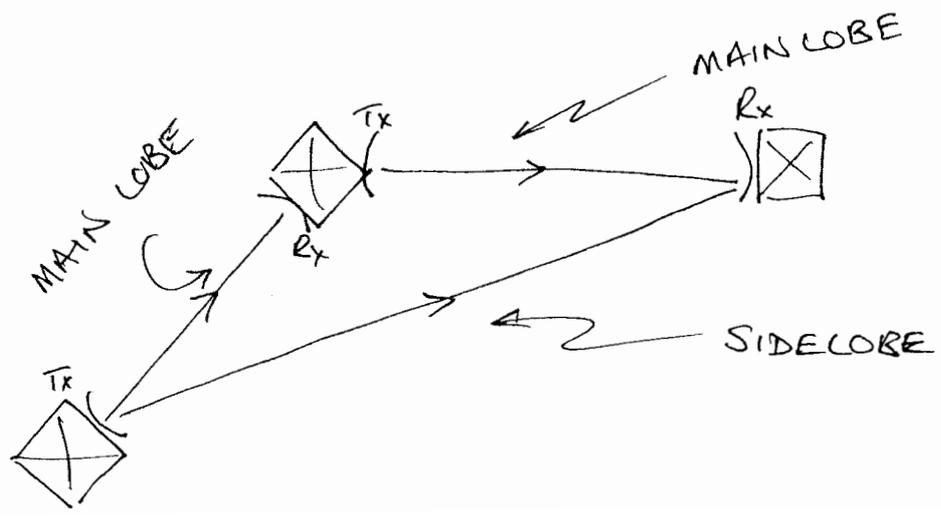
EFFECTIVE ISOTROPIC RADIATED POWER EIRP =  $P_T G_T$   
(SOMETIMES JUST ERP IS USED)

IN THIS CASE, 'L' INCLUDES :

- \* ABSORPTION LOSSES
  - \* SCATTERING LOSSES
  - \* "SPREADING" LOSS (FREE-SPACE-PATH-LOSS)
- } IN MEDIUM

THE "SPREADING" LOSS REPRESENTS SPREADING OF ENERGY IN THE MEDIUM AS OCCURS FOR ISOTROPIC ANTENNAS (I.E. ENERGY SPREADING WITH A SPHERICAL WAVEFRONT)

NOTE:  $G_T$  AND  $G_R$  THAT WE USE IN LINK BUDGETS IS NORMALLY THE MAXIMUM VALUE, BUT WE SHOULD ALSO BE INTERESTED IN THE BEAM PATTERN OR GAIN FUNCTION (AS A FUNCTION OF ANGLE) FROM THE POINT OF VIEW OF UNWANTED SIGNALS, E.G. MULTI-SECTION LINKS.



## FREE - SPACE PATH LOSS

AT A POINT AT A DISTANCE 'R' FROM AN ISOTROPIC TRANSMITTER THE POWER DENSITY IS GIVEN BY:

$$\frac{\text{POWER TRANSMITTED (W)}}{\text{SURFACE AREA OF SPHERE (m}^2\text{)}}$$

HENCE :  $\frac{P_T}{4\pi R^2} \text{ Wm}^{-2}$

NOW IF WE HAVE AN ISOTROPIC RECEIVING ANTENNA AT R, WITH AN EFFECTIVE ANTENNA APERTURE OF  $A_e$ , THE RECEIVED POWER IS:

$$P_R = \frac{P_T}{4\pi R^2} A_e \text{ (ISOTROPE)}$$

FOR AN ISO-TROPE  $A_e = \frac{\lambda^2}{4\pi}$

$$P_R = \frac{P_T}{4\pi R^2} \times \frac{\lambda^2}{4\pi} = P_T \left[ \frac{\lambda}{4\pi R} \right]^2$$

HENCE THE PATH LOSS IS:

$$\frac{P_T}{P_R} = \left[ \frac{4\pi R}{\lambda} \right]^2$$

HENCE THE FREE-SPACE-PATH-LOSS (FSPL) IS:

$$FSPL = 20 \log_{10} \left[ \frac{4\pi R}{\lambda} \right]$$

### EXAMPLES

#### 1. POINT-TO-POINT TERRESTRIAL LINK

$$P_T = 4W$$

3m PARABOLOIDAL ANTENNAS. (70% EFFICIENCY)

$$f = 4GHz.$$

SEPARATION DISTANCE = 40km.

FIND  $P_R$  (-49.7 dBW)

#### 2. SAT. TO EARTH BROADCAST LINK

$$P_T = 20W$$

1m SAT. ANTENNA (85% EFFICIENCY)

$$f = 12GHz.$$

ATMOSPHERIC LOSS = 2dB (VALUE EXCEEDED <0.1%)

SATELLITE RANGE = 39000 km.

RECEIVER ANTENNA (75% EFFICIENCY) 60cm.

FIND  $P_R$

3. LITTLE GREEN PERSON ON A PLANET NEAR  
ALPHA CENTAURI TRYING TO RECEIVE  
"FATHER TED"

$$P_T = 100 \text{ W}$$

$$f = 500 \text{ MHz}$$

$$G_T = 2.2 \text{ dB} \quad (\text{HALFWAVE DIPOLE})$$

ZERO ATMOSPHERIC LOSS

DISTANCE 4.2 LIGHT YEARS

$$(c = 3 \times 10^8 \text{ ms}^{-1})$$

GREEN PERSON RECEIVE ANTENNA: 30M

CALCULATE  $P_R$ .

4.

SUPPOSE WE WANTED LITTLE GREEN PERSONS TO RECEIVE "FATHER TED", HOW MUCH POWER WOULD WE NEED TO USE, GIVEN THAT WE HAD ACCESS TO THE ARECIBO MOUNTAIN SIDE DISH (305M IN DIAMETER)?

TO ANSWER THIS QUESTION WE NEED TO CONSIDER NOISE. WE HAVE TO CONSTRUCT A NOISE POWER BUDGET WHICH WILL RESULT IN A CALCULATION OF THE CARRIER-TO-NOISE RATIO CNR.

FOR ACCEPTABLE TV RECEPTION WITH PAL ANALOGUE TV WE NEED AT LEAST 35dB CNR OVER AN 8MHz BANDWIDTH.

## NOISE : A BRIEF REVIEW

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### THERMAL NOISE POWER :

$$N = kTB \quad (\text{WATTS})$$

- k - BOLTZMANN'S CONSTANT ( $1.38 \times 10^{-23}$  J/K)
- T - TEMPERATURE (K)
- B - BANDWIDTH. (Hz)

### NOISE FIGURE :

$$F = \frac{\text{INPUT SIGNAL-TO-NOISE}}{\text{OUTPUT SIGNAL-TO-NOISE}}$$

(IEEE DEFINITION IS MORE RIGOROUS)

FOR AN ANTENNA T IS REFERRED TO AS  $T_A$  - THE ANTENNA BRIGHTNESS TEMPERATURE.

### SOURCES OF NOISE :

- \* GALACTIC NOISE : DECREASES AS  $1/f$ .
- \* SOLAR NOISE : EMISSIONS FROM SUN
- \* COSMIC NOISE :  $\sim 3K$  LEFT OVER BIG-BANG.
- \* ATMOSPHERIC NOISE : GASEOUS ABSORPTION, RAIN, CLOUDS.

EXCESS TEMPERATURE FROM ATMOSPHERIC NOISE;

THE "RADIOMETER" EQUATION:

$$T_A = T_m \left(1 - \frac{1}{L}\right)$$

- $T_m$  - PHYSICAL TEMPERATURE OF THE MEDIUM
- $L$  - LOSS RATIO OBSERVED IN THE MEDIUM
- $L \gg 1$ .

SINCE THE PHYSICAL TEMPERATURES OF MOST OF THE ATMOSPHERIC ABSORBERS ARE 270 - 290K, AND SINCE AS  $L \rightarrow \infty$ ,  $T_A \rightarrow T_m$ , AS THE ABSORPTION INCREASES WITH FREQUENCY THE ASYMPTOTIC VALUE OF ANTENNA BRIGHTNESS TEMPERATURE IS  $\sim 290K$ .

SYSTEM NOISE TEMPERATURE

GIVEN A RECEIVING SYSTEM WITH A NOISE TEMPERATURE OF  $T_r$ , THE SYSTEM NOISE TEMPERATURE IS SIMPLY

$$T_s = T_A + T_r$$

THE OUTPUT NOISE POWER FROM A RECEIVER WITH GAIN  $g$  IS:  $N_{out} = g k T_s B$

[ IF WE HAVE NOISE FIGURE WE CAN CONVERT IT TO TEMPERATURE  $T_r = T_0 (F_r - 1)$   
 $T_0 = 290K$  - REFERENCE TEMPERATURE ]

# 1. POINT-TO-POINT TERRESTRIAL LINK

$$P_T = 4W$$

3m PARABOLOIDAL ANTENNAS (70% EFFICIENCY)

$$f = 4GHz.$$

SEPARATION DISTANCE = 40km.

$$P_T = 4W \Rightarrow P_T = 10 \log_{10} 4 = \underline{6 \text{ dBW.}}$$

$$\text{ANTENNA GAIN: } G = \eta \left[ \frac{\pi D}{\lambda} \right]^2 \quad [\text{FOR A CIRCULAR APERTURE PARAB.}]$$

$\eta$  - DETERMINED BY APERTURE ILLUMINATION AND APERTURE BLOCKAGE.

$$G_T = G_R = 0.7 \left[ \frac{\pi \cdot 3 \times 4 \times 10^9}{3 \times 10^8} \right]^2 = 11054$$

$$\Rightarrow G_T = G_R = \underline{40.4 \text{ dBi}}$$

$$\text{FSPL: } 20 \log_{10} \left[ \frac{4\pi R}{\lambda} \right]$$

$$\begin{aligned} \text{FSPL} &= 20 \log_{10} \left[ \frac{4 \times \pi \times 40 \times 10^3 \times 4 \times 10^9}{3 \times 10^8} \right] \\ &= \underline{136.5 \text{ dB.}} \end{aligned}$$

$$P_R = P_T + G_T + G_R - \text{FSPL}$$

$$= 6 + 40.4 + 40.4 - 136.5 = \underline{-49.7 \text{ dBW}}$$

5.

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LETS RETURN TO OUR SATELLITE DOWNLINK  
EXAMPLE:

$$P_T = 20W$$

1m, 85% SATELLITE ANTENNA.

$$f = 12GHz.$$

2dB ATMOSPHERIC LOSS (EXCEEDED < 0.1% OF TIME)

$$RANGE = 39,000 km.$$

ATMOSPHERIC TEMPERATURE = 285K

RECEIVER NOISE FIGURE = 1.8dB

LOSS RATIO = 1.58, NOISE BANDWIDTH 30MHz.

WHAT IS THE CARRIER-TO-NOISE RATIO?

### 3. LITTLE GREEN PERSON...

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$$P_T = 100W$$

$$f = 500MHz$$

$$G_T = 2.2dBi$$

ZERO ATMOSPHERIC LOSS

DISTANCE = 4.2 LIGHT YEARS

GREEN PERSON RECEIVER ANTENNA = 30m (100% EFFIC.)

$$P_T = 10 \log_{10} 100 = \underline{\underline{20 dBW}}$$

$$G_T = \underline{\underline{2.2 dBi}}$$

$$FSPL: \quad 365 \times 24 \times 60 \times 60 = 31536 \times 10^3 \text{ SECONDS PER YEAR}$$

$$\text{AT } c = 3 \times 10^8 \text{ ms}^{-1} \Rightarrow 9.4608 \times 10^{15} \text{ m PER YEAR}$$

$$1 \text{ LIGHT YEAR} = 9.4608 \times 10^{15} \text{ m.}$$

$$4.2 \text{ LIGHT YEARS} = 3.97 \times 10^{16} \text{ m.}$$

$$FSPL = 20 \log_{10} \left[ \frac{4 \times \pi \times 3.97 \times 10^{16} \times 500 \times 10^6}{3 \times 10^8} \right]$$

$$= \underline{\underline{358 dB}}$$

$$G_R = 10 \log_{10} \left[ 1.0 \left( \frac{\pi \times 30 \times 500 \times 10^6}{3 \times 10^8} \right)^2 \right] = \underline{\underline{43.9 dBi}}$$

$$P_R = 20 \text{ dBW} + 2.2 \text{ dBi} - 358 \text{ dB} + 43.9 \text{ dBi}$$
$$= -291.9 \text{ dBW}$$

5. FOR THE NOISE POWER BUDGET.

$$\begin{aligned} 10 \log_{10} (k_B) &= 10 \log_{10} (1.38 \times 10^{-23} \times 30 \times 10^6) \\ &= -153.8 \text{ dBW.} \end{aligned}$$

ANTENNA BRIGHTNESS TEMPERATURE:

$$\begin{aligned} T_A &= T_m (1 - 1/L) \\ &= 285 (1 - 1/1.58) \\ &= 105 \text{ K.} \end{aligned}$$

RECEIVER NOISE TEMPERATURE:

$$T_R = T_0 (F_R - 1)$$

$$F_R = 1.8 \text{ dB} \Rightarrow F_R = 1.5$$

$$\begin{aligned} T_R &= 290(1.5 - 1) \\ &= 145 \text{ K.} \end{aligned}$$

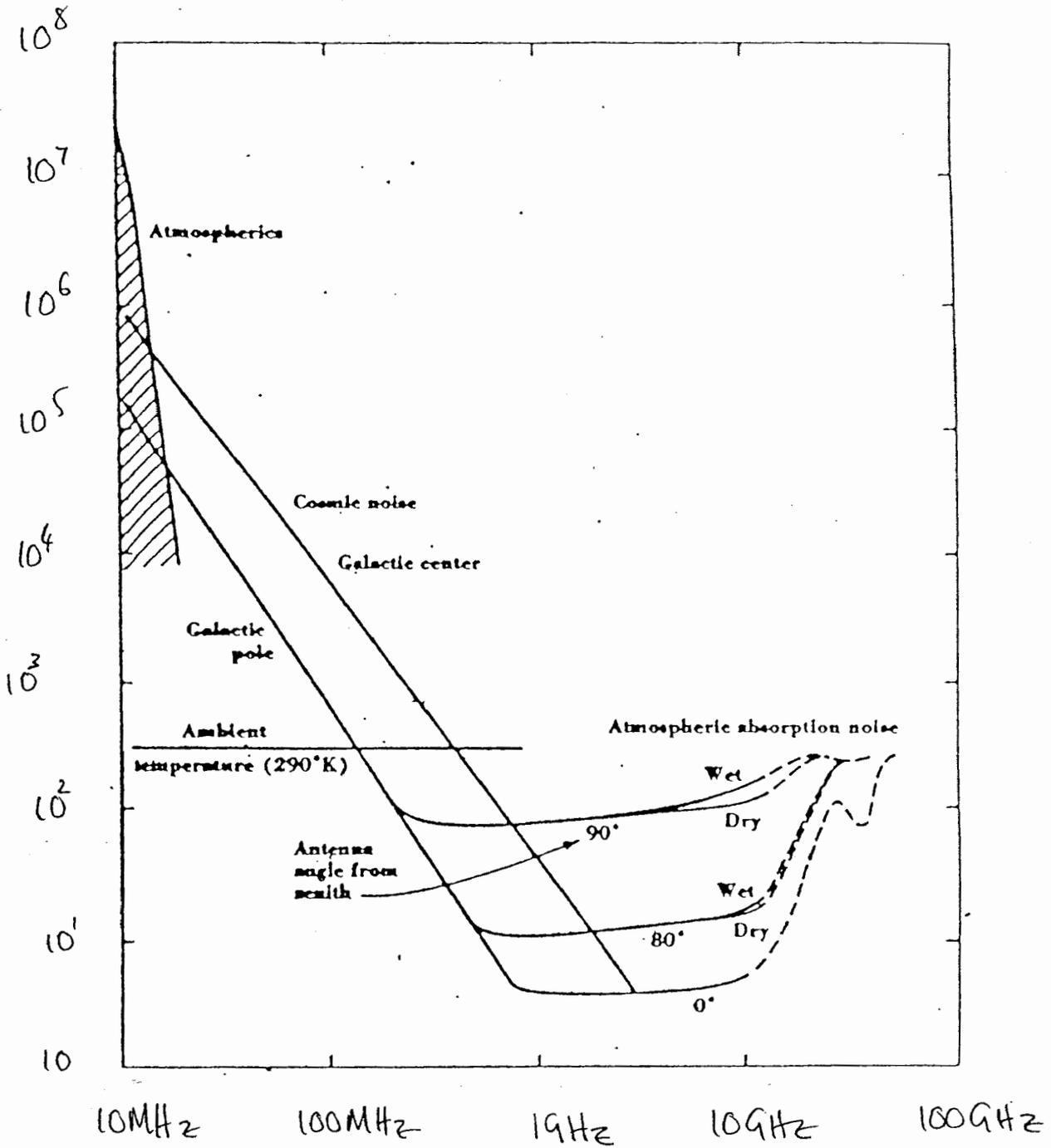
$$\text{SYSTEM TEMPERATURE} = T_R + T_A = 250 \text{ K}$$

$$\begin{aligned} \text{NOISE POWER} &= -153.8 + 10 \log_{10} (250) \\ &= -153.8 + 24.0 \\ &= -129.8 \text{ dBW.} \end{aligned}$$

HENCE THE CARRIER-TO-NOISE RATIO

$$= -117.2 + 129.8 = \underline{\underline{12.5 \text{ dB}}}$$

ANTENNA BRIGHTNESS TEMP (K)



FREQUENCY

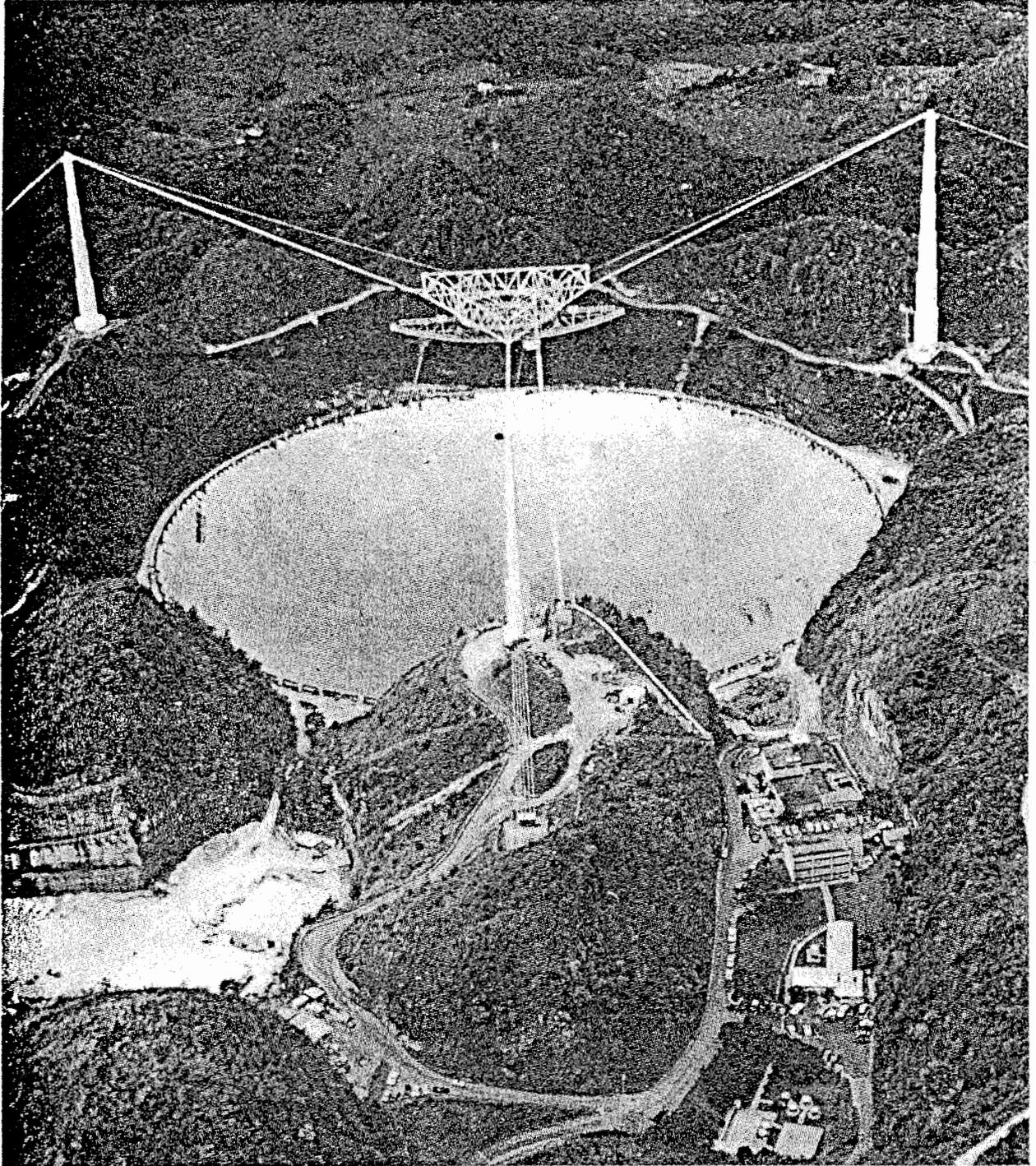


Figure 12-48 Air view of 305-m Arecibo dish. Feed structure is supported by cables from 3 towers. Beam steering by moving the line feed allows observations at angles up to  $20^\circ$  from the zenith. Away from the zenith, only part of the reflector can be used with resulting decrease in aperture efficiency. (Cornell University.)

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