Chapter 10 Microwave communications applications

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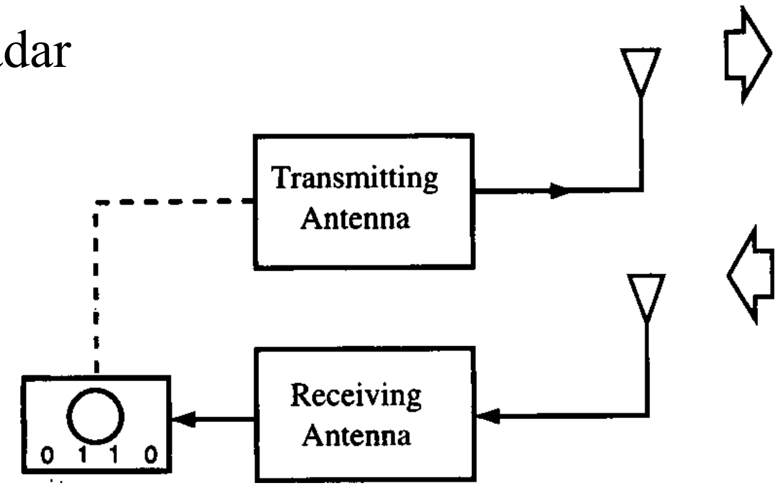
10.1 Introduction

1. Evolution of microwave applications
   World War II - radar
   1960 - satellite communication
   1980 - remote sensing satellite, DBS (direct broadcast satellite)
   1990 - PCN/PCS (personal communications network/personal communication services), GPS (global positioning system), VSAT (very small aperture terminals)
   2000 - Digital DBS, WLL (wireless local loop), GII (global information initiative)
2. Growth and expansion of microwave technology move from military and satellite applications into information and entertainment applications.

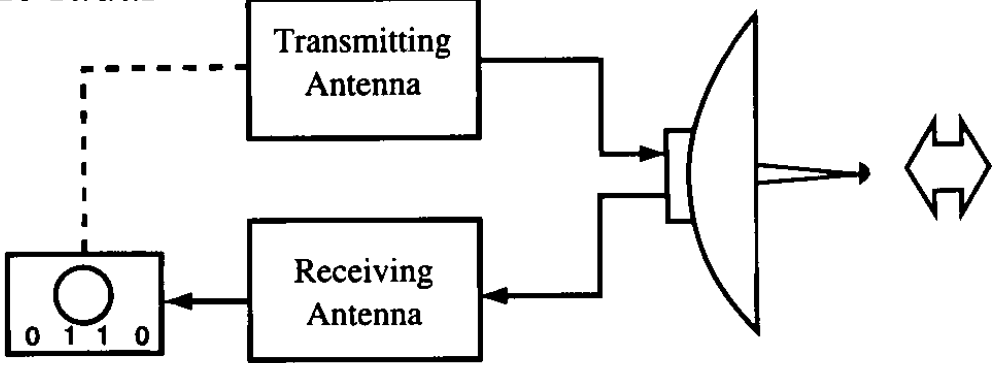
10.2 Radar (*ra*dio *d*etection *a*nd *r*anging)

1. Operating principle

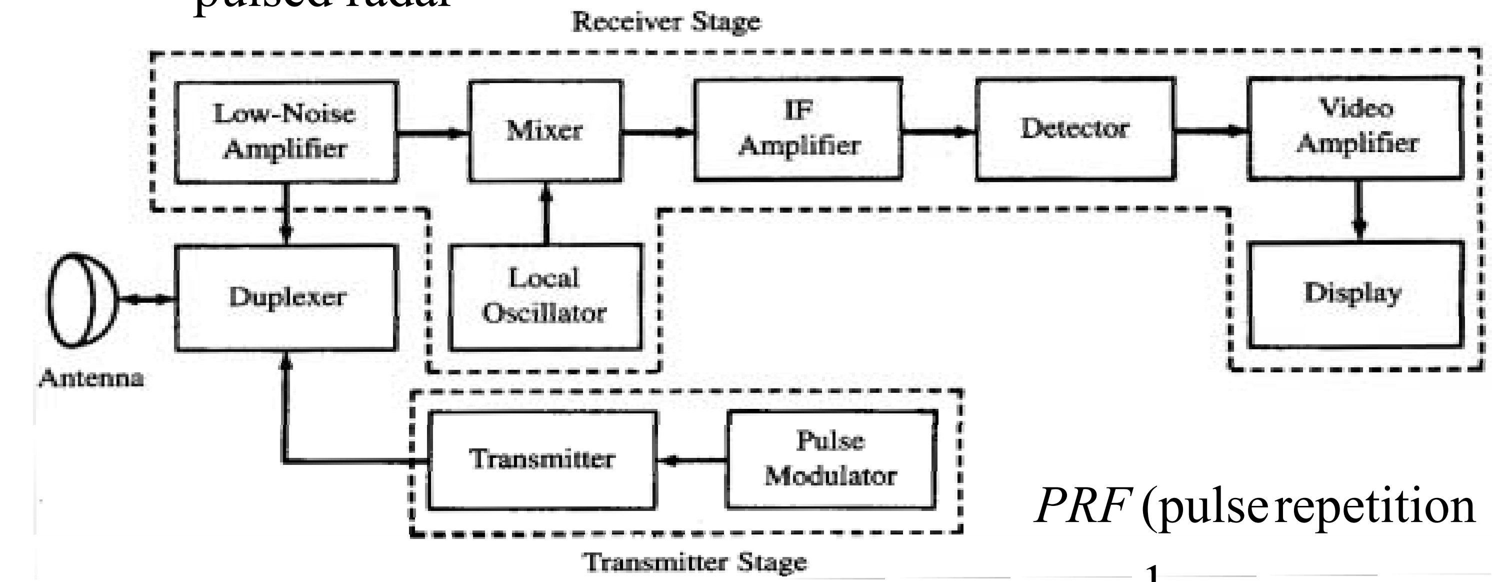
• bistatic radar

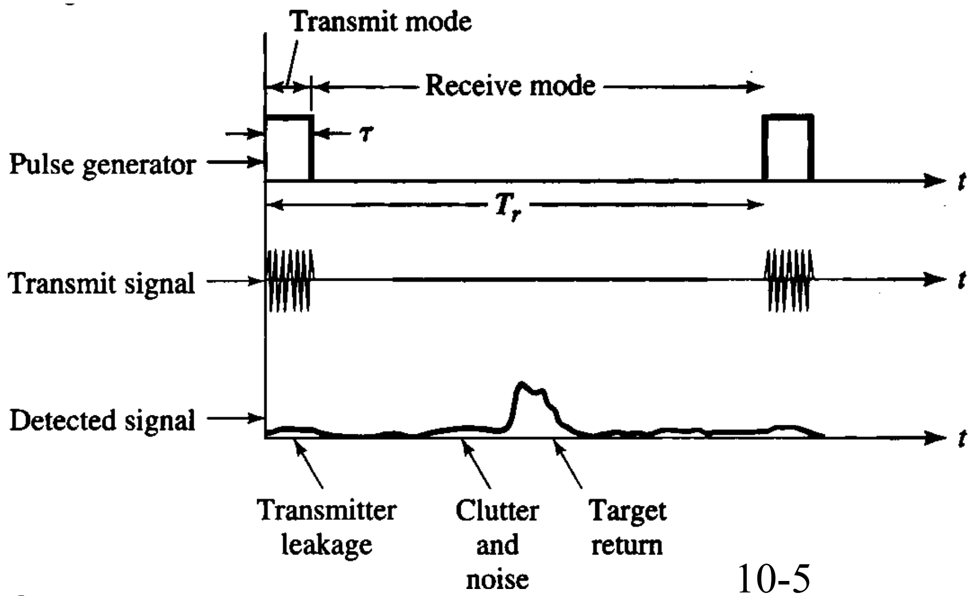


• monostatic radar



- pulsed radar





PRF (pulse repetition rate)

$$f_r = \frac{1}{T_r}$$

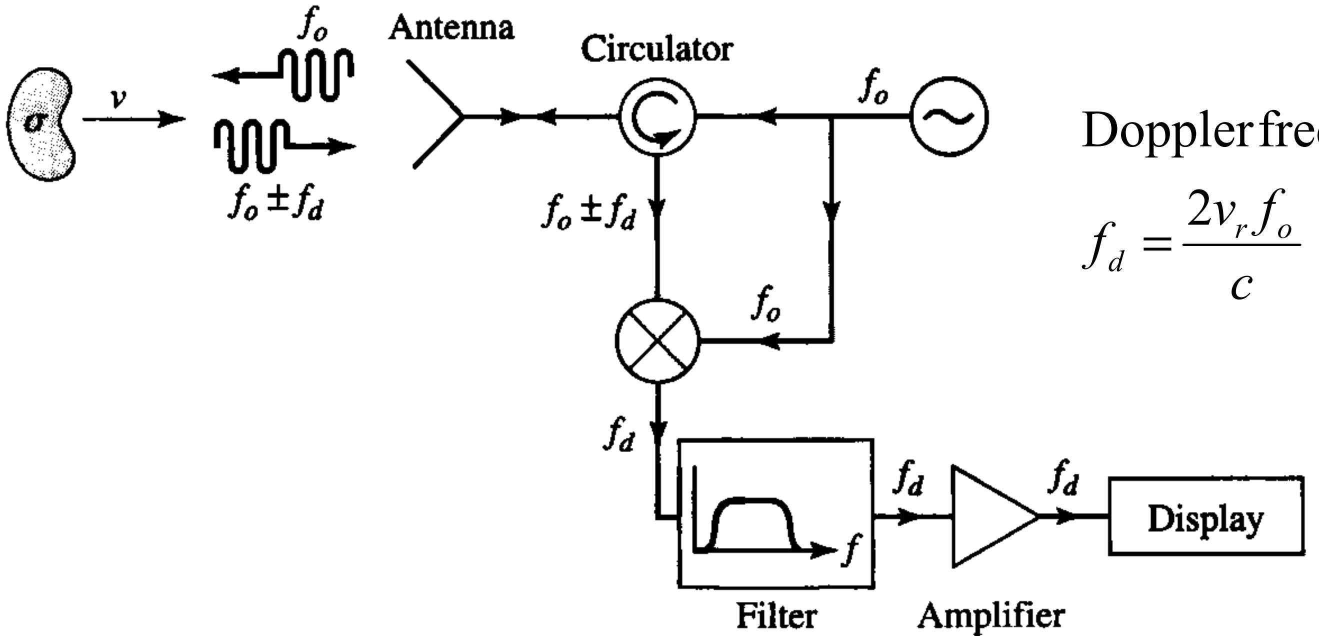
maximal unambiguous range

$$R < \frac{cT_r}{2}$$

range resolution

$$r > \frac{c\tau}{2}$$

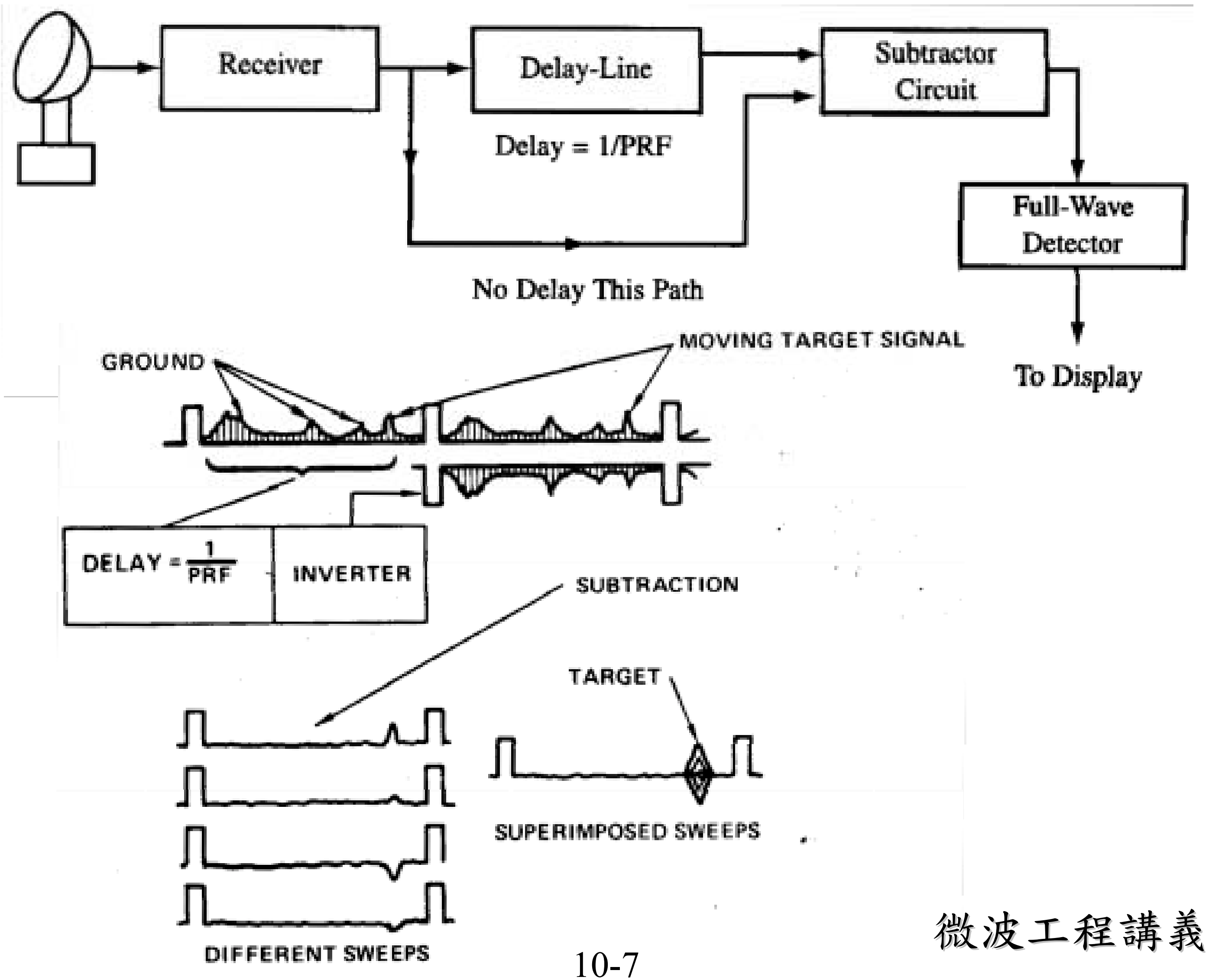
• Doppler radar



Doppler frequency

$$f_d = \frac{2v_r f_o}{c}$$

• MTI (moving target indicator) radar



2. Radar band

Band Designation	Nominal Frequency Range	Specific Radar Bands Based on ITU Assignments
L	1,000–2,000 MHz	1,215–1,400 MHz
S	2,000–4,000 MHz	2,300–2,500 MHz
C	4,000–8,000 MHz	5,250–5,925 MHz
X	8,000–12,500 MHz	8,500–10,680 MHz
Ku	12.50–18.00 GHz	13.40–14.00 GHz
		15.70–17.70 GHz
K	18.00–26.50 GHz	24.05–24.25 GHz
Ka	26.50–40.00 GHz	33.40–36.00 GHz

3. Radar equation

$$P_R = P_T G \frac{1}{4\pi R^2} \sigma \frac{1}{4\pi R^2} A_e = \frac{P_T G \sigma}{(4\pi R^2)^2} \frac{\lambda^2 G}{4\pi} = \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

$$\rightarrow \text{maximumrange}\, R_{\max} = \left[\frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 P_{\min}} \right]^{1/4}$$

RCS (radar cross section) $\sigma = \dfrac{P_s}{S_t}$

P_s : total power scattered by the target

S_t : power density incident on the target $= \dfrac{P_T G}{4\pi R^2}$

Object	RCS, m^2
Pickup truck	200
Automobile	100
Jumbo jet airliner	100
Large bomber or commercial jet	40
Cabin cruiser boat	10
Large fighter aircraft	6
Small fighter aircraft	2
Adult male	1
Conventional winged missile	0.5
Bird	0.01
Insect	0.00001

Ex. 10.1 A radar transmitter has 20kW at 10GHz. A target is at 18km away with radar cross section of 12.5m^2. The antenna gain is 20dBi. The received signal power is

$$P_R = \frac{P_T G^2 \lambda^2 \sigma}{(4\pi)^3 R^4} = \frac{20\times10^3 \times 100^2 \times 0.03^2 \times 12.5}{(4\pi)^3 \times (18\times10^3)^4} = 1.08\times10^{-14} W$$

$$\approx -110 dBm$$

$$P_n = kTB = -174 dBm / Hz @ 290^0 k$$

Ex. 10.2 The radar returned pulse delays 12us, then the target range is

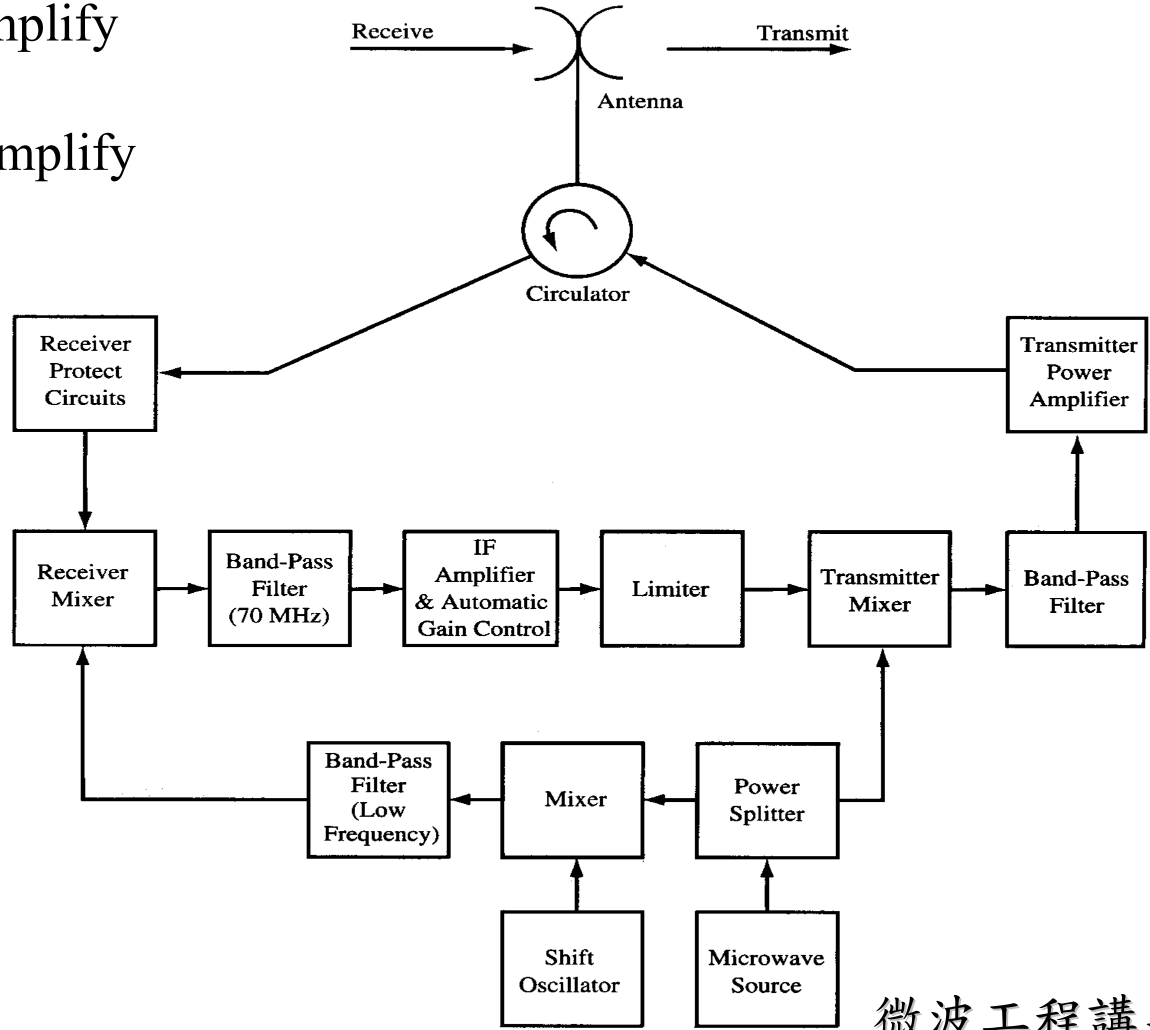
$$R = \frac{c\tau}{2} = \frac{3\times10^8 \times 12\times10^{-6}}{2} = 1800m$$

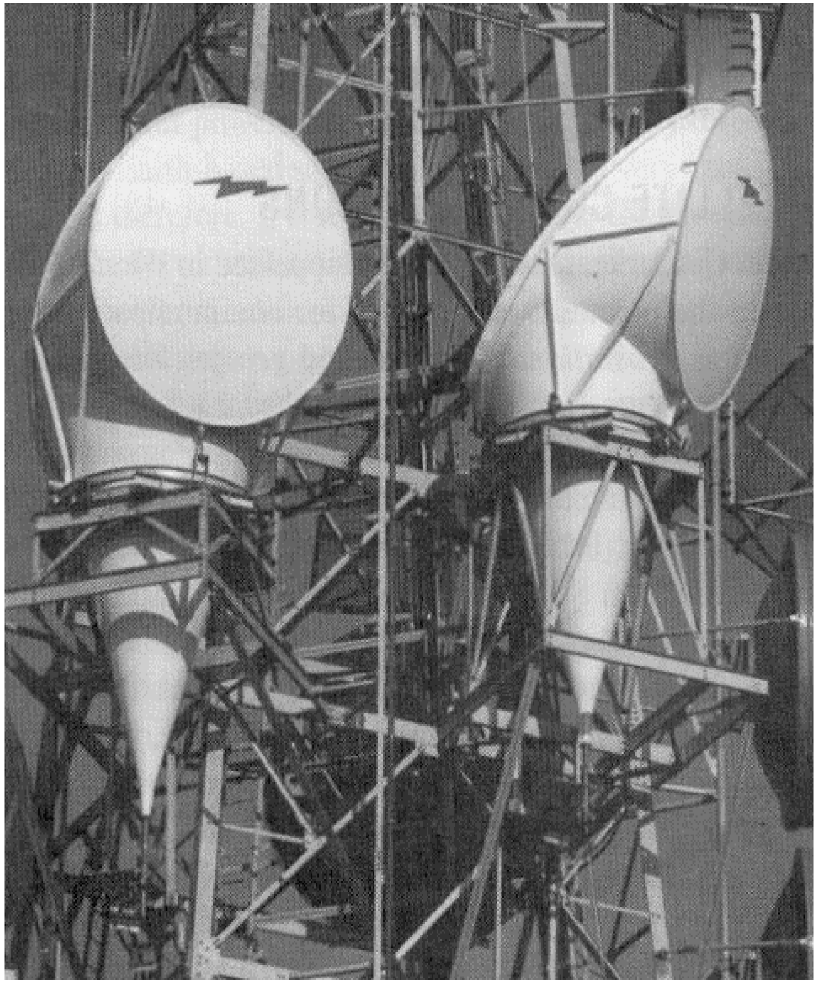
Ex. 10.3 Doppler shift of 10kHz is received for a 5GHz radar, then the target radial velocity is

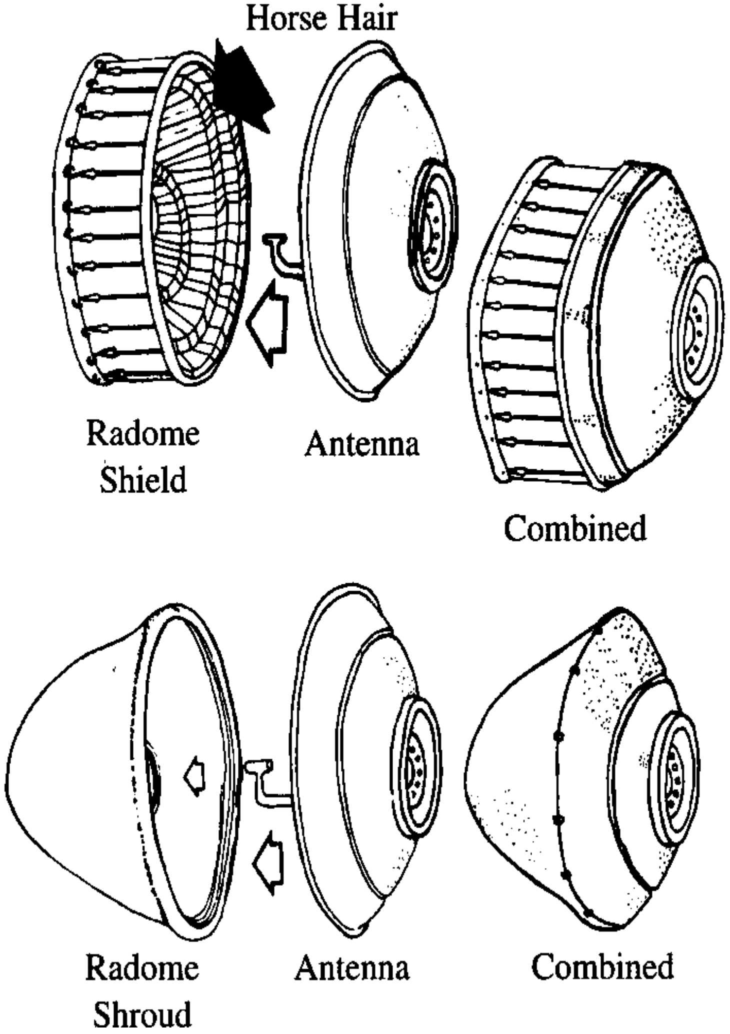
$$v = \frac{cf_d}{2f_0} = \frac{3\times10^8 \times 10\times10^3}{2\times5\times10^9} = 300m/\sec = 1080km/hr$$

10.3 Terrestrial communications

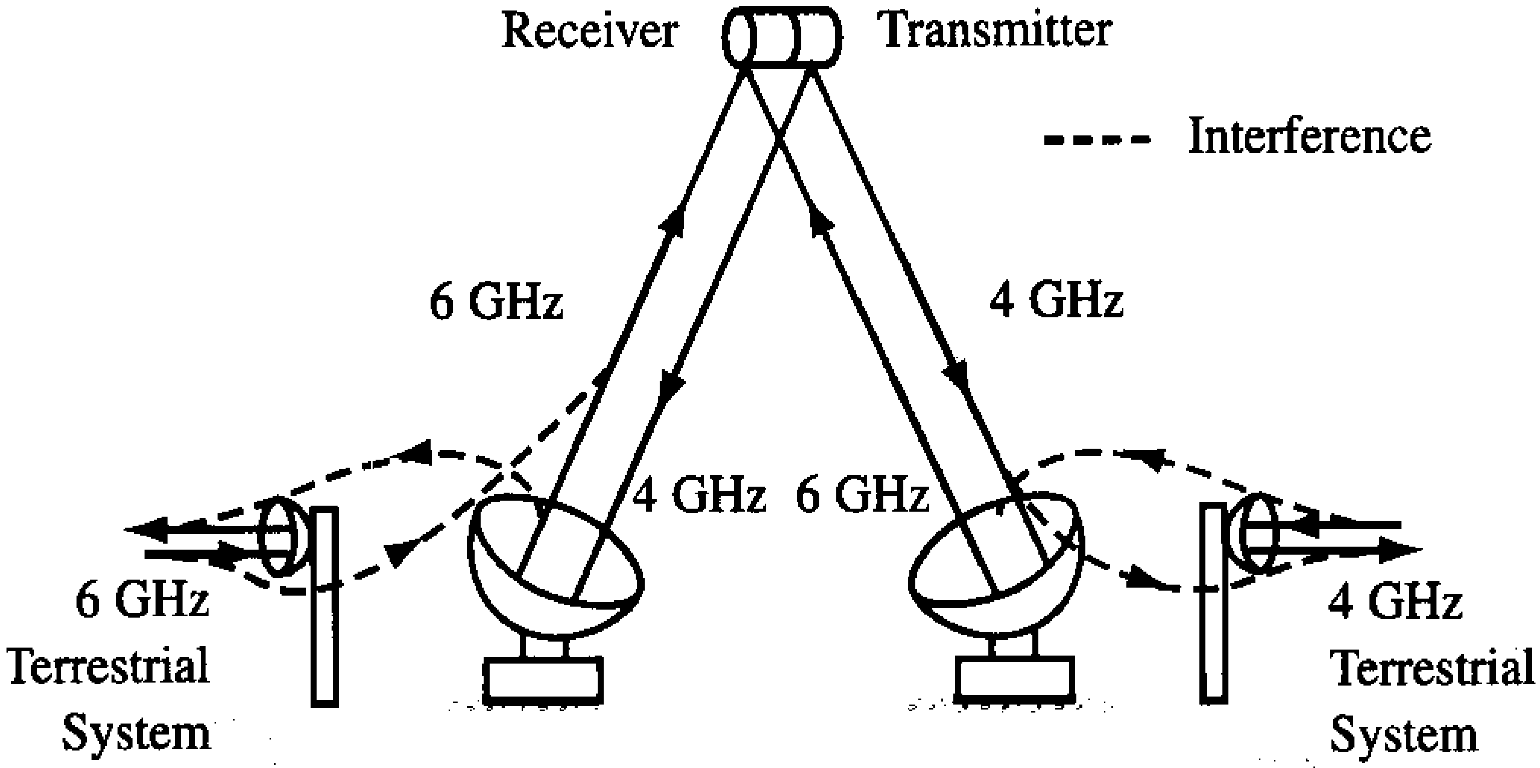
1. Line-of-sight microwave repeater tower: (LNA) → mix down → linear IF amplify
   → mix up
   → power amplify





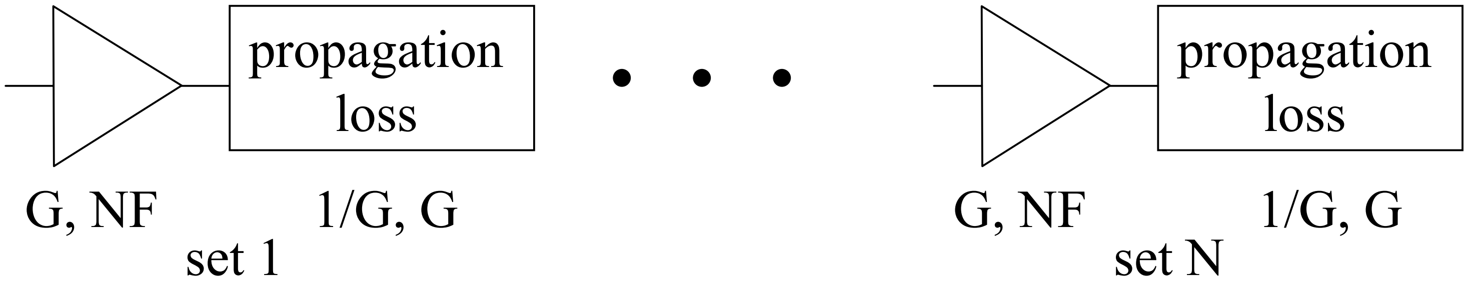

Horse Hair
Radome
Shield
Antenna
Combined
Radome
Shroud
Antenna
Combined

2. Possible interference between satellite an terrestrial links in C-band (4-6 GHz)



3. Repeater limitation

n sets of identical repeater arrangement



$$\text{unit set } NF_{unit} = NF + \frac{G-1}{G} = NF + 1 - \frac{1}{G}, G_{unit} = 1$$

$$\because NF_T = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \ldots + \frac{NF_N - 1}{G_1 \ldots G_{N-1}}$$

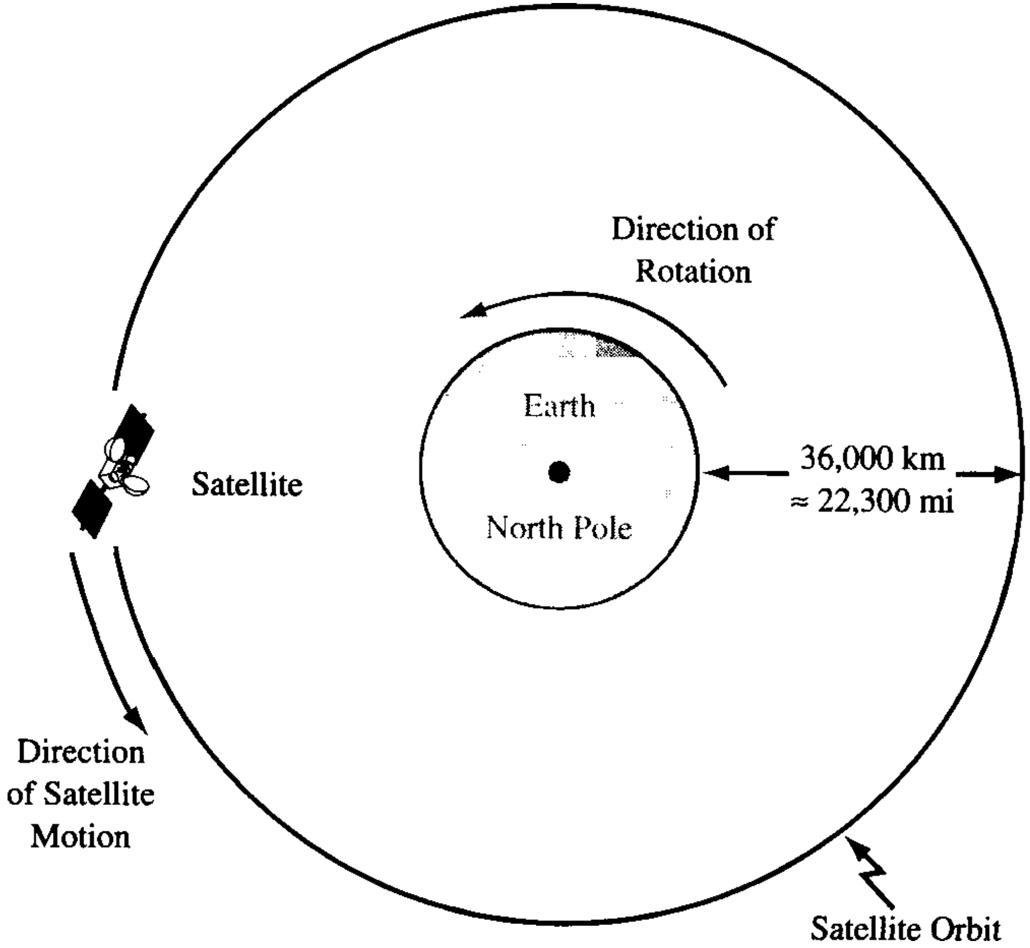
$$\Rightarrow NF_T = NF_{unit} + \frac{NF_{unit} - 1}{G_{unit}} + \frac{NF_{unit} - 1}{G_{unit}^2} + \ldots + \frac{NF_{unit} - 1}{G_{unit}^{N-1}}$$

$$= (NF + 1 - \frac{1}{G}) + (NF - \frac{1}{G}) + \ldots (NF - \frac{1}{G}) = 1 + N(NF - \frac{1}{G})$$

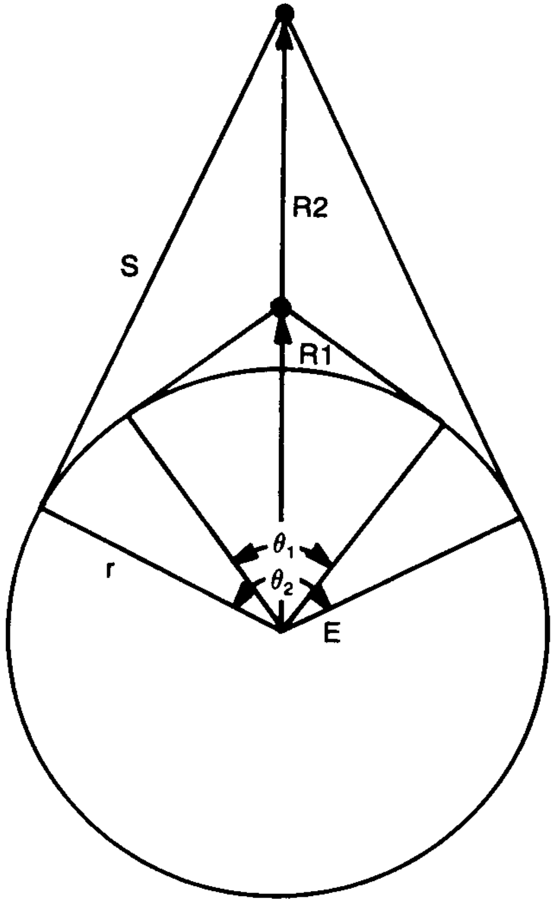
for large N and G $\rightarrow NF_T \approx N \times NF, NF_T(dB) = NF(dB) + N(dB)$

10.4 Satellite communications

1. GEO (geostationary earth orbit) satellite



2. Orbit



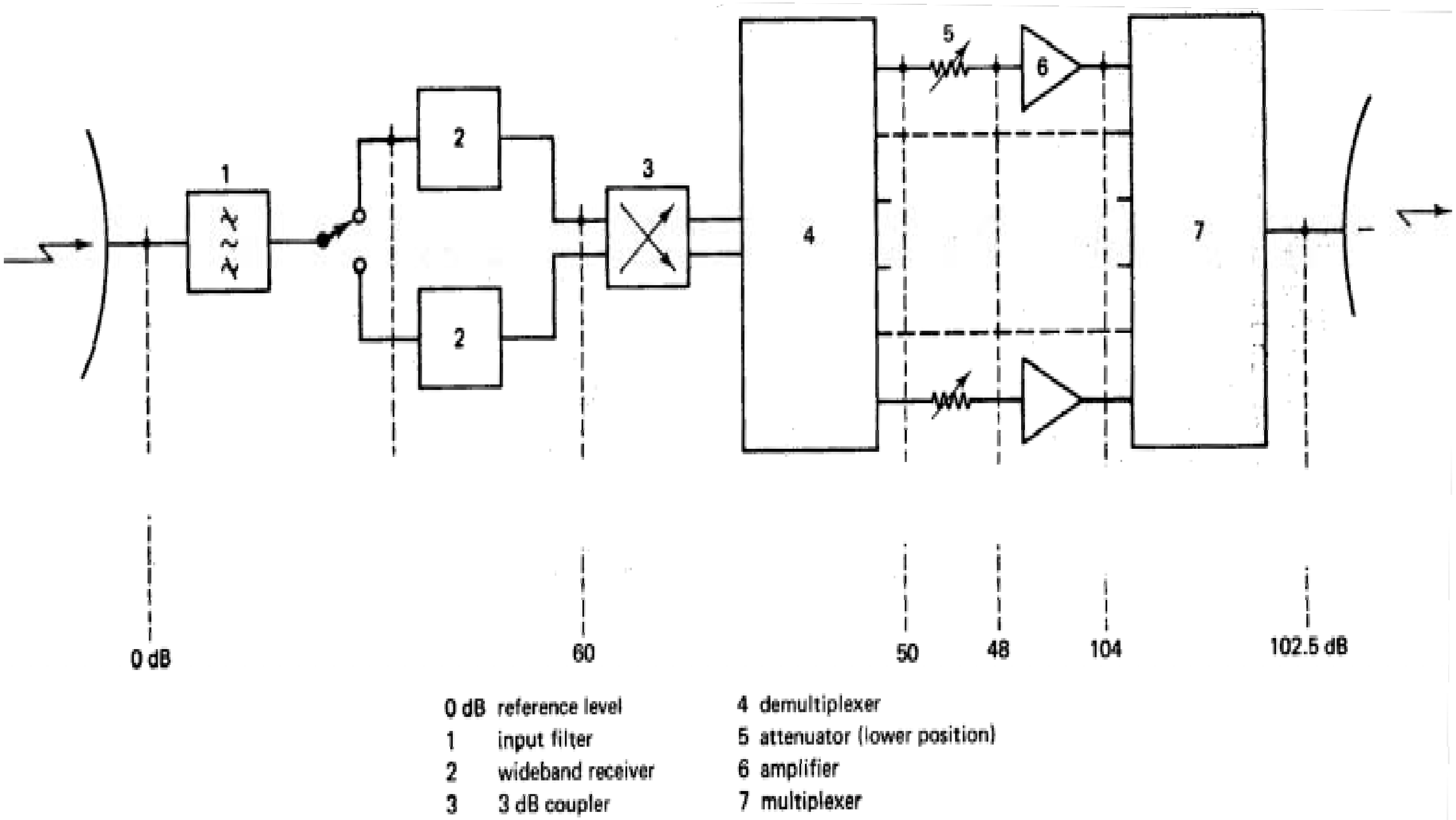
$$\theta_2 = 2 \times \cos^{-1}\left(\frac{r}{R2}\right)$$

r = radius of the earth, 6,378km

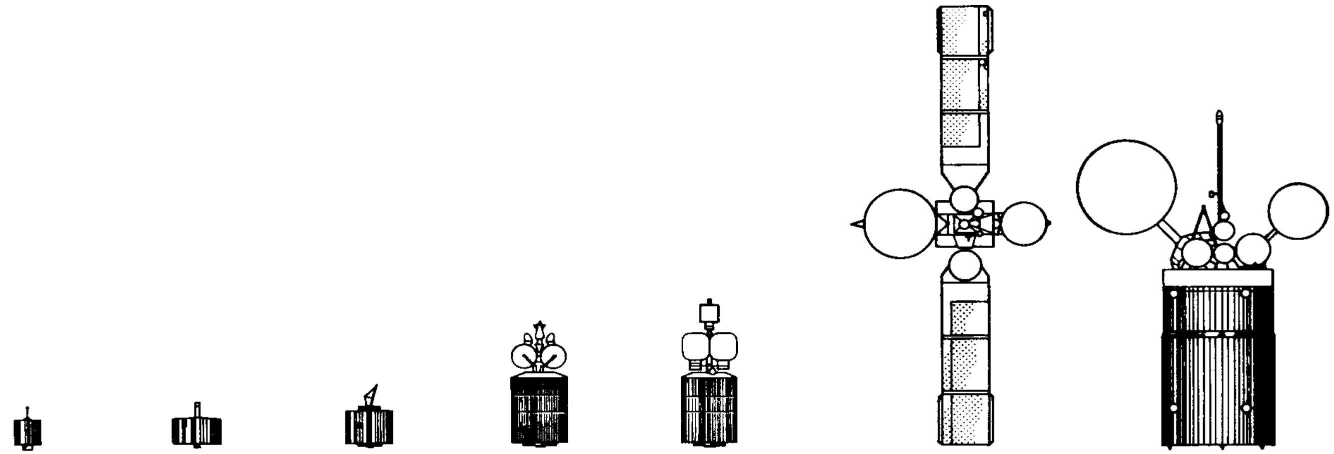
Orbit Altitude (km)	Orbital Period (Hours)	Theta (θ) (Degrees)
0	1.4	0
275	1.5	16.5
4,200	3.0	52.9
10,364	6.0	67.7
20,278	12.0	76.2
35,786	24.0	81.4

$$T = 2.7644 \times 10^{-6} r^{3/2} (hours)$$

3. Satellite transponder



4. INTELSAT (*In*ternational *Tel*ecommunications *Sat*ellite Organization)



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

5. Link calculation

$$\frac{C}{N}=\frac{1}{kTB}\frac{P_T G_T}{4\pi R^2}\frac{G_R\lambda^2}{4\pi}=\frac{P_T G_T G_R}{kTB}\left(\frac{\lambda}{4\pi R}\right)^2$$

$\left(\dfrac{\lambda}{4\pi R}\right)^2$: propagation loss, antenna gain $G=\left(\dfrac{\pi D}{\lambda}\right)^2$

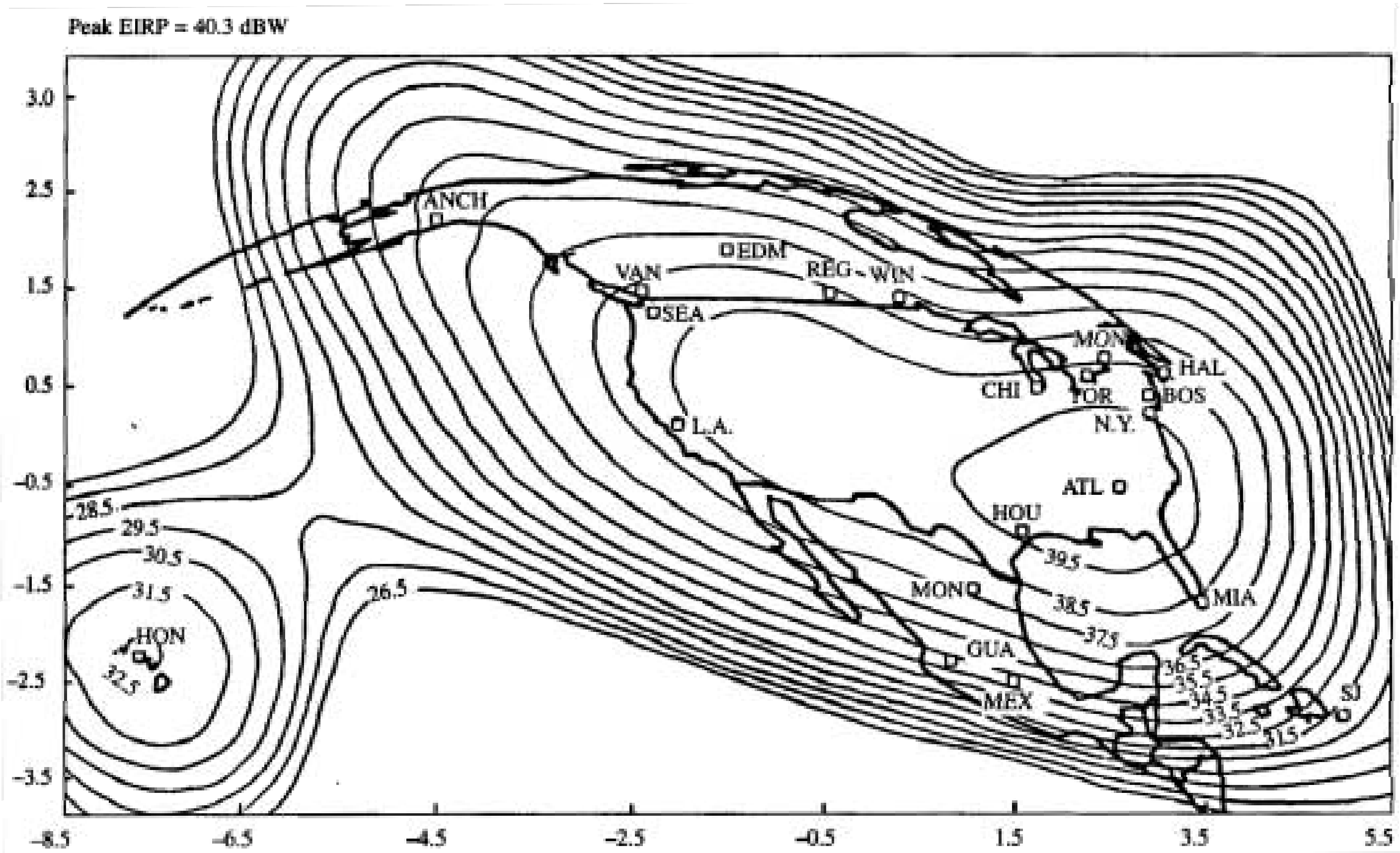
Ex.10.4

Data:	Ground transmitter frequency	6GHz
	transmitter power	300W
	antenna diameter	5m
	receiver noise temperature	800°k
	receiver bandwidth	40MHz
	Spacecraft transmitter frequency	4GHz
	transmitter power	200W
	antenna diameter	1m
	receiver noise temperature	1500°k
	receiver bandwidth	40MHz
	Satellite distance	42000km

up link		down link	
Ground :		Spacecraft :	
transmitter power	24.77dBW	transmitter power	23.01dBW
antenna gain	49.94dB	antenna gain	32.44dB
EIRP	72.71dBW	EIRP	55.45dBW
propagation loss	-200.47dB	propagation loss	-196.94dB
Spacecraft:		Ground:	
antenna gain	35.96dB	antenna gain	46.42dB
received signal	-91.8dBW	received signal	-95.07dBW
noise power density	-196.84dBW/Hz	noise power density	-199.57dBW/Hz
receiver BW	76.02dB	receiver BW	76.02dB
receiver noise power	-120.82dBW	receiver noise power	-123.55dBW
C/N	29.02dB	C/N	28.48dB

10.5 Domestic satellite bands (C and Ku)

1. C-band (4-6 GHz) with uplink at 6GHz and downlink at 4GHz for video services
2. Hughes Communication Galaxy V with footprint as



24 C-band transponders with 16W(24dBW) each, BW=36MHz
each channel has 4GHz guard band and uses opposite polarization

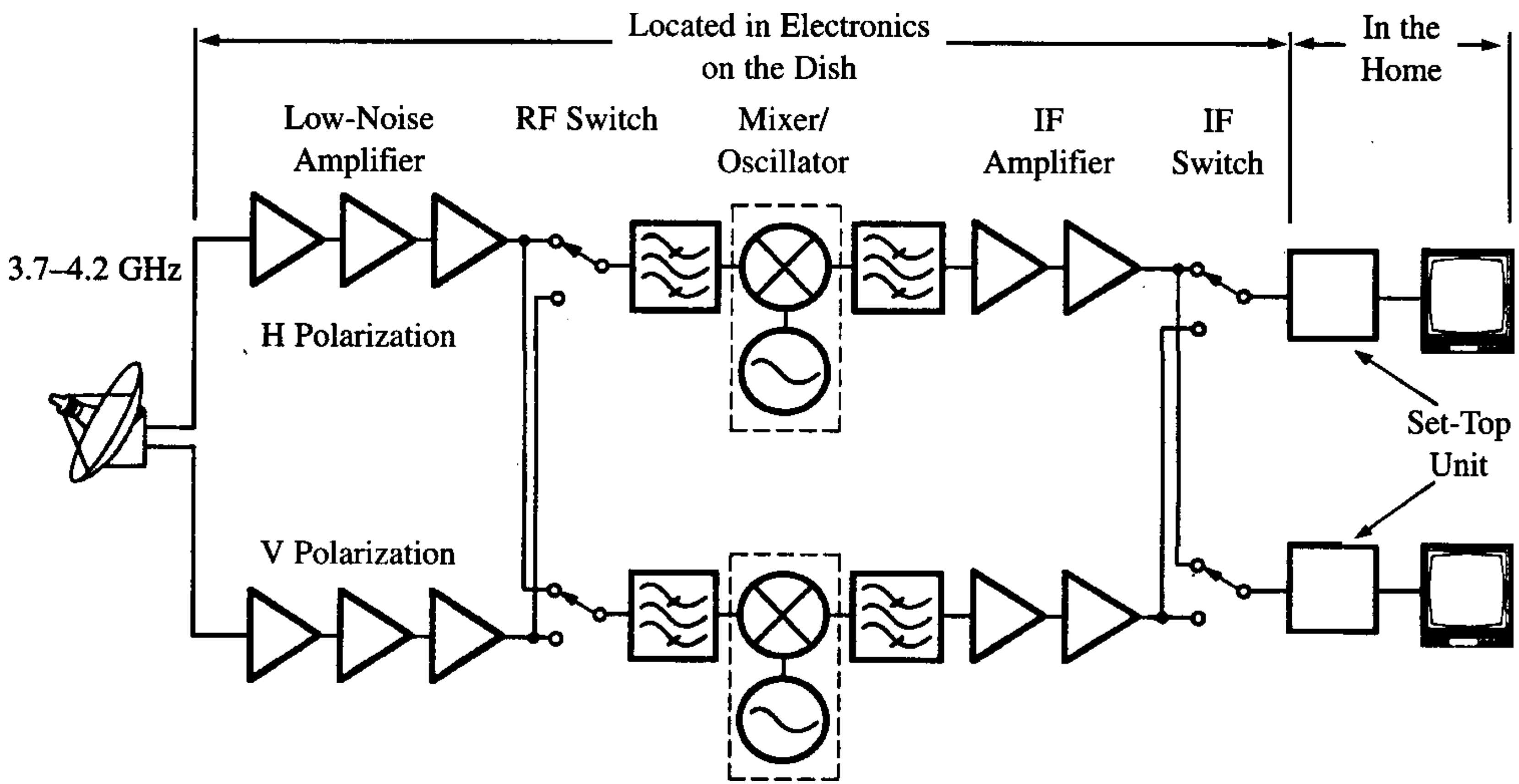
Channel	Center Frequency (MHz)	Channel	Center Frequency (MHz)	Channel	Center Frequency (MHz)
1	3720	9	3880	17	4040
2	3740	10	3900	18	4060
3	3760	11	3920	19	4080
4	3780	12	3940	20	4100
5	3800	13	3960	21	4120
6	3820	14	3980	22	4140
7	3840	15	4000	23	4160
8	3860	16	4020	24	4180

3. TVRO (television receive only)

Video Service	Location	Video Service	Location
Cinemax 1	G1-19	ESPN	G5-14
Cinemax 2	T2-21	Prime Ticket	F1-07
Disney East	G5-01	SportSouth	S3-19
HBO 1 East	G5-15	Nashville Network	G5-18
HBO 2 West	T2-14	ABC N.Y.	F2-04
Action PPV	F4-02	CBS Denver	F1-02
CNN	G5-05	FOX West	T3-23
CNBC	G5-13	NBC Denver	F1-14

G: Galaxy
T: Telstar
F: Satcom
S: SpaceNet

LNB (low-noise block)

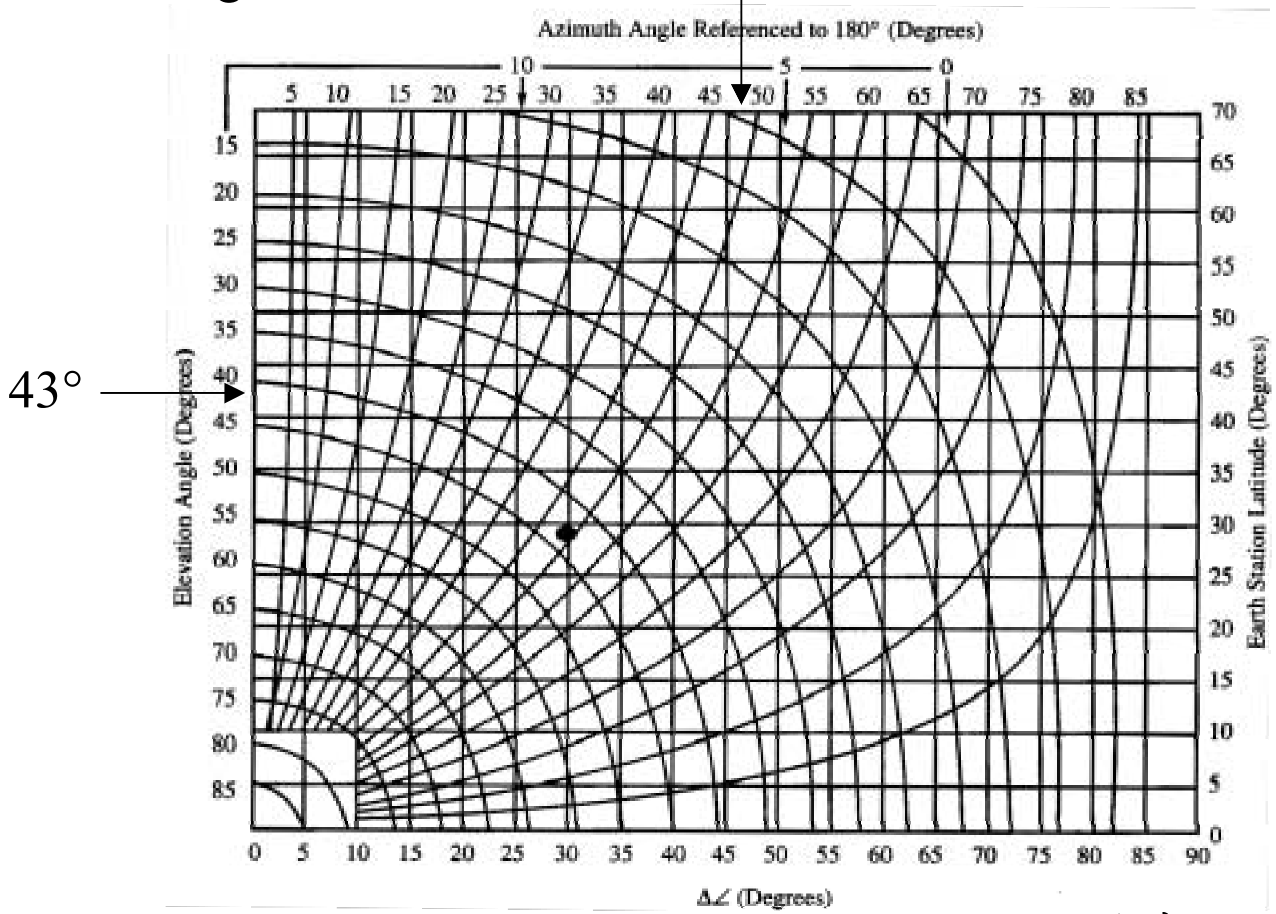


4. TVRO pointing angles

Houston (longitude 95.5°W, latitude 29.5°N), Galaxy (125°W)

ΔL=125-95.5=29.5°, 29.5°N → elevation angle 43°,

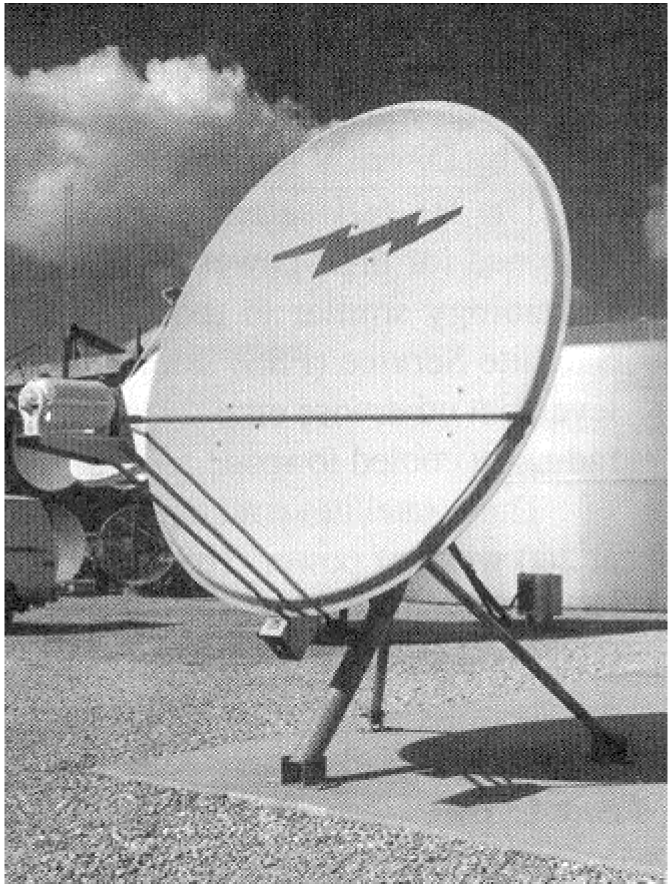
azimuth angle 49°W of south

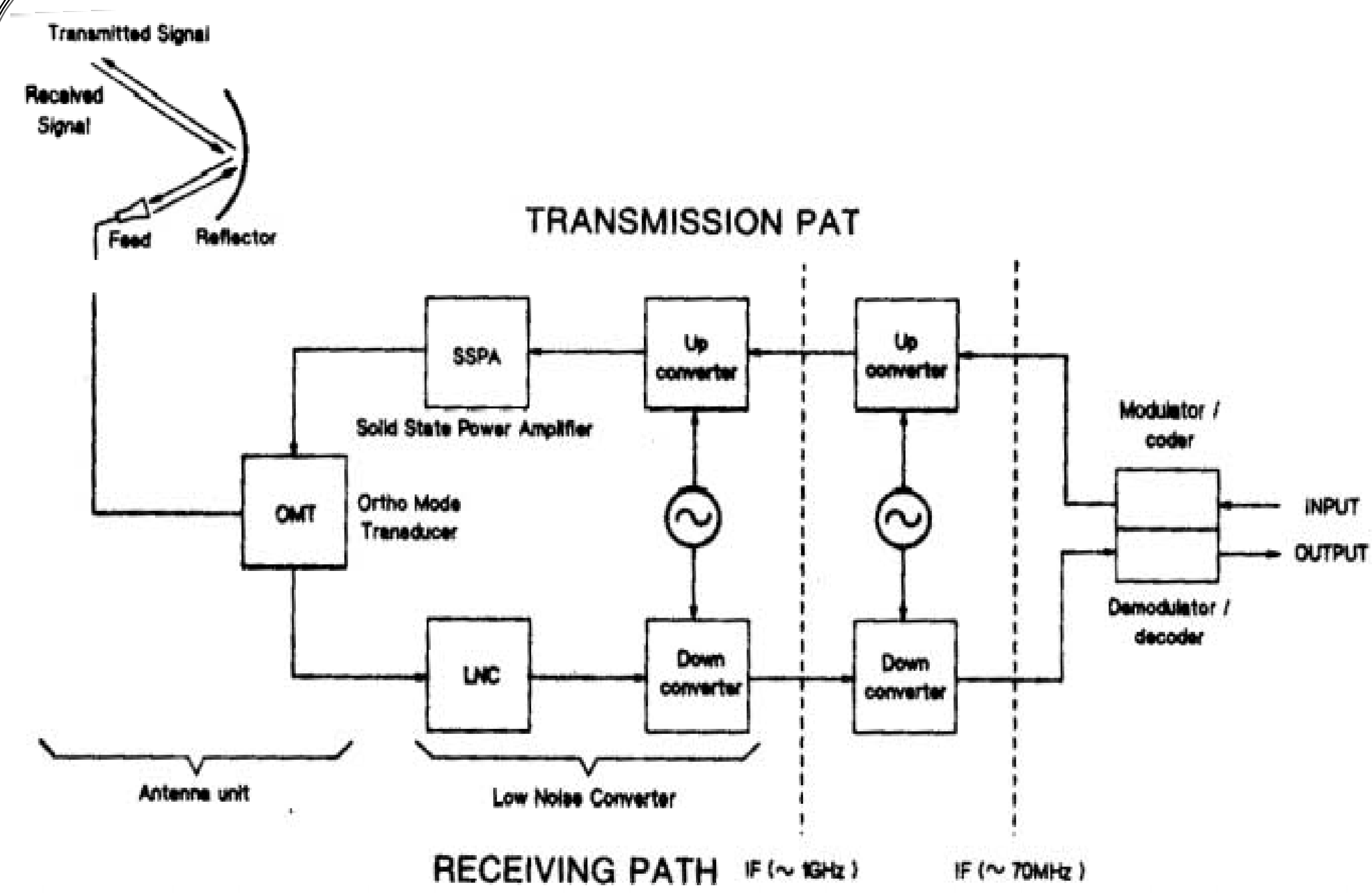


5. Ku band (12-14 GHz) with uplink 14GHz and downlink 12GHz through 32-band transponders for DBS, SNG (satellite news-gathering), two-way transfer of data and video using VSAT

Ku band may have smaller receiving antenna, but uses higher transmitting power and circular polarization to solve rain fade problem.

6. VSAT (very small aperture terminal)
has about 3-ft size antenna for two-way satellite communication in the applications of video conference and data exchange

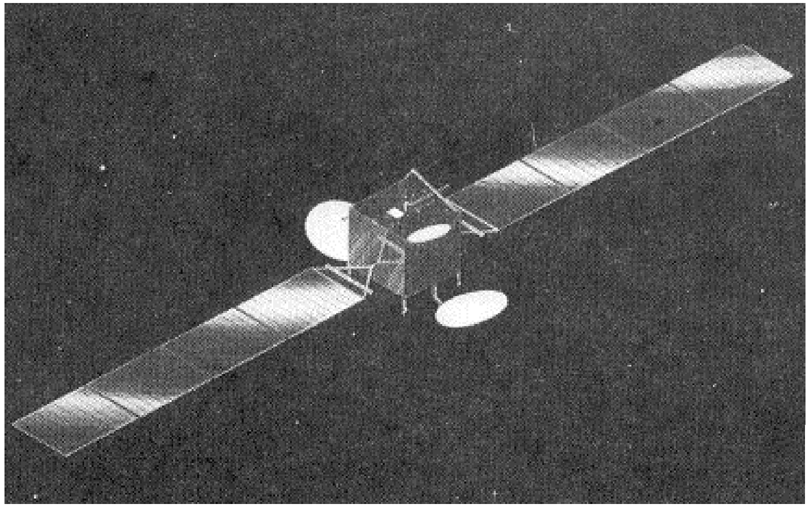



Transmitted Signal
Received Signal
Feed
Reflector
TRANSMISSION PAT
SSPA
Solid State Power Amplifier
Up converter
Up converter
Modulator / coder
OMT
Ortho Mode Transducer
INPUT
OUTPUT
Demodulator / decoder
LNC
Down converter
Down converter
Antenna unit
Low Noise Converter
RECEIVING PATH
IF (~ 1GHz)
IF (~ 70MHz)

微波工程講義

10.6 Direct broadcast satellites (DBS)

1. DBS-1 and DBS-2 uses DSS (digital satellite system) with MPEG-2 to provide laser-disc quality video and audio entertainment programs direct-to-home.
2. Hughes HS 601 satellite (DBS-1)

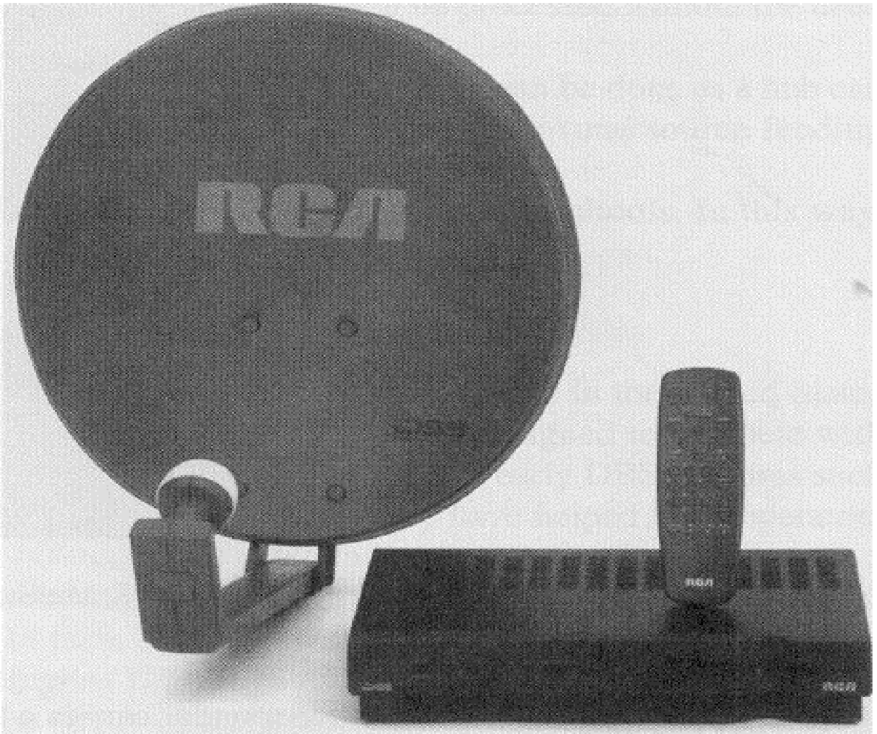


	Galaxy IV (4 kW)	DBS-1 (4 kW)
C-band Transponders:		
Active (Spare)	24 (6)	0 (0)
Ku* Transponders:		
Active (Spare)	24 (6)	16 (16)
Ku Transponder Power	50 w	120 w

*DBS band 500 MHz above the Galaxy band

	DBS-1	DBS-2
Launch	December 1993	August 1994
Satellite Ready	January 1994	August 1994
Polarization	LHCP	RHCP
Channels	2,4,6,....,32	1,3,5,....,31
Orbit Location	101.2°	100.8°

3. DBS-1, -2 characteristics
   (1) can provide HDTV transmission
   (2) Uplink 17.3-17.8 GHz and downlink 12.2-12.7GHz
   (3) QPSK modulation with RS (Reed-Solomon) and covolutional codes
   (4) use 18” dish receiver



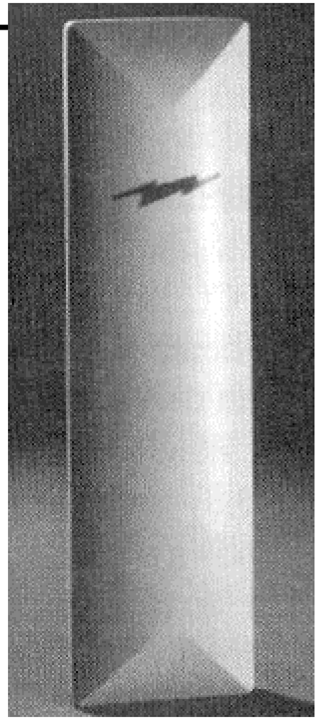
10.7 Wireless services and standards

1. Acronyms for wireless services

AMPS	Advanced Mobile Phone Service
B-CDMA	Broadband CDMA
CT-X	Cordless Telephone "X" (0,1,1+,2,3)
CDMA (IS95)	Code-Division Multiple Access
CDPD	Cellular Digital Packet Data
DECT	Digital European Cordless Telephone
DCS-1800	Digital Communications System 1800 (GSM at 1.8 GHz)
E-TACS	Extended TACS
E-TDMA	Extended TDMA
FDMA	Frequency-Division Multiple Access
GSM	Groupe Speciale Mobile (now Global System for Mobile Communications)
IMTS	Improved Mobile Telephone Service (precursor to AMPS)
ISM	Industrial, Scientific, Medical Bands
IS54	Interim Standard 54 (dual-mode TDMA/AMPS)
IS95	Interim Standard 95 (dual-mode CDMA/AMPS)
JDC	Japanese Digital Cellular
N-AMPS	Narrowband AMPS (more analog channels)
NMT	Nordic Mobile Telephone (analog cellular in Scandinavia)
PCN	Personal Communications Network
PCS	Personal Communications Services
PHP	Personal Handy Phone (PCS in Japan)
PSTN	Public Switched Telephone Network
PTT	Post, Telephone, Telegraph (telephone company in Europe)
TACS	Total Access Communication System (UK's analog cellular)
TDMA	Time-Division Multiple Access

2. Analog cellular telephone

Standard	AMPS	TACS	NMT
Mobile Frequency Range (MHz)	Rx: 869–894 Tx: 824–849	ETACS: Rx: 916–949 Tx: 871–904 NTACS: Rx: 860–870 Tx: 915–925	NMT–450: Rx: 463–468 Tx: 453–458 NMT–900: Rx: 935–960 Tx: 890–915
Multiple Access Method	FDMA	FDMA	FDMA
Duplex Method	FDD	FDD	FDD
Number of Channels	832	ETACS: 1000 NTACS: 400	NMT-450: 200 NMT-900: 1999
Channel Spacing	30 kHz	ETACS: 25 kHz NTACS:12.5 kHz	NMT-450: 25 kHz NMT-900:12.5 kHz
Modulation	FM	FM	FM



3. Digital cellular telephone

Standard	IS-54 North American Digital Cellular	IS-95 North American Digital Cellular	GSM Global System for Mobile Communications	PDC Personal Digital Cellular
Mobile Frequency Range (MHz)	Rx:869–894 Tx:824–849	Rx:869–894 Tx:824–849	Rx:935–960 Tx:890–915	Rx:810–826 Tx:940–956 Rx:1429–1453 Tx:1477–1501
Multiple Access Method	TDMA/FDM	CDMA/FDM	TDMA/FDM	TDMA/FDM
Duplex Method	FDD	FDD	FDD	FDD
Number of Channels	832 (3 users/channel)	20 (798 users/channel)	124 (8 users/channel)	1600 (3 users/channel)
Channel Spacing	30 kHz	1250 kHz	200 kHz	25 kHz
Modulation	$\pi/4$ DQPSK	BPSK/0QPSK	GMSK (0.3 Gaussian Filter)	$\pi/4$ DQPSK
Bit Rate	48.6 kb/s	1.2288 Mb/s	270.833 kb/s	42 kb/s

4. Analog cordless telephone

Standard	CT-0 Cordless Telephone 0	JCT Japanese Cordless Telephone	CT-1/CT-1+ Cordless Telephone
Mobile Frequency Range (MHz)	2/48 (U.K.) 26/41 (France) 30/39 (Australia) 31/40 (The Netherlands, Spain) 46/49 (China, Taiwan, S. Korea, USA) 48/74 (China)	254/380	CT-1: 915/960 CT-1+: 887-932
Multiple Access Method	FDMA	FDMA	FDMA
Duplex Method	FDD	FDD	FDD
Number of Channels	10, 12, 15, or 20	89	CT-1: 40 CT-1+: 80
Channel Spacing	40 kHz	12.5 kHz	25 kHz
Modulation	FM	FM	FM

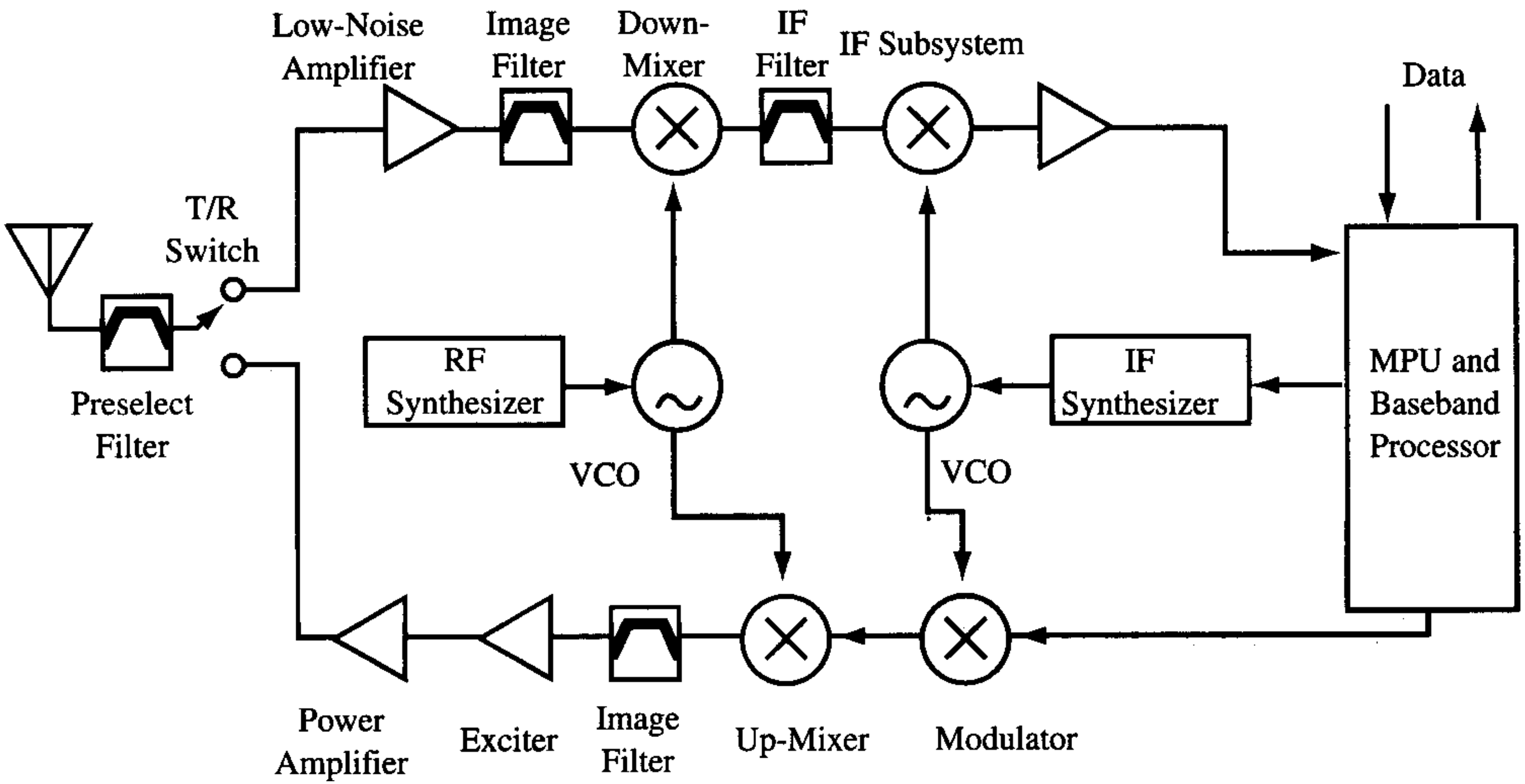
5. Digital cordless telephone

Standard	**CT-2/CT-2+ Cordless Telephone 2**	**DECT Digital European Cordless Telephone**	**PHP Personal Handy Phone**	**DCS-1800**
Mobile Frequency Range (MHz)	CT-2: 864-868 CT-2+: 930/931-940/941	1880-1990	1895-1907	Rx: 1805-1880 Tx: 1710-1785
Multiple Access Method	TDMA/FDM	TDMA/FDM	TDMA/FDM	TDMA/FDM
Duplex Method	TDD	TDD	TDD	FDD
Number of Channels	40	10 (12 users/channel)	300 (4 users/channel)	750 (16 users/channel)
Channel Spacing	100 kHz	1.728 MHz	300 kHz	200 kHz
Modulation	GFSK (0.5 Gaussian Filter)	GFSK (0.5 Gaussian Filter)	$\pi/4$ DQPSK	GSMK (0.3 Gaussian Filter)
Bit Rate	72 kb/s	1.152 Mb/s	384 kb/s	270.833 kb/s

6. Wireless LAN (local area network)

Criterion	*915 MHz*	*2.4 GHz*	*5.8 GHz*
Frequencies	902–928 MHz	2.40–2.4835 GHz	5.725–5.825 GHz
Bandwidth	26 MHz	83.5 MHz	125 MHz
FCC licensing	No (Part 15)	No (Part 15)	No (Part 15)
Availability	US/Canada	Worldwide	US/Canada
Development cost	Low (Si)	Low/medium (Si, GaAs)	High (GaAs)
Transmission range	Greatest (power-dependent)	95% of 915 MHz	80% of 915 MHz
Current status	Crowded	Light use	Almost no use
Outlook	High growth	Medium growth	Low growth
Interference sources (U.S.)	Primary users	Primary users	Primary users
	Many LANs	Few LANs	Very few LANs
	Many non-SS	Few non-SS	Very few non-SS
		Microwave ovens	
Additional interference sources (worldwide)	Cellular telephones		Some radar

6. Typical digital wireless personal communicator



7. Mobile satellite services

(1) Little LEOs (low-Earth-orbit satellite) for data transmission and messaging, e.g., Orbcomm, Starsys, and VITA.

(2) Big LEOs for voice and data communications, e.g.,

Iridium has 66 satellites constellation in 6 orbits at 747km

Globalstar has 48 satellites constellation in 6 orbits at 1390km

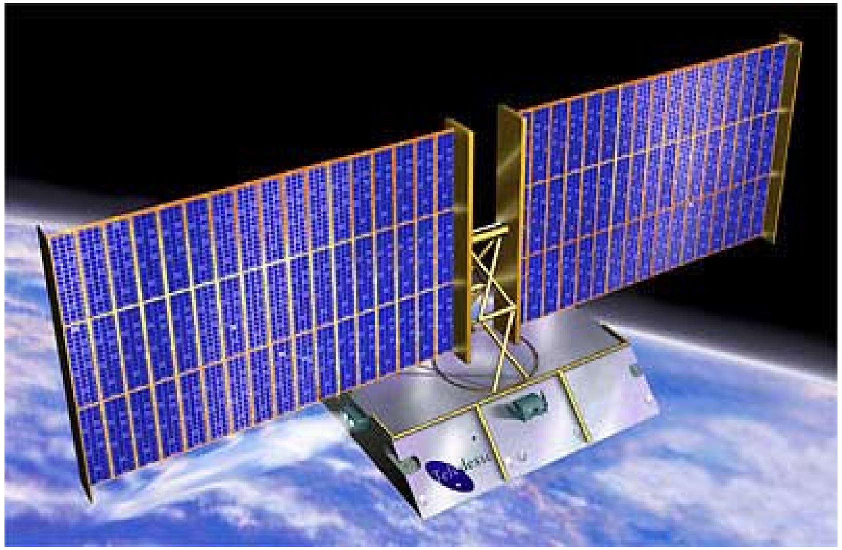
Odyssey has 12 satellites constellation in 3 orbits at 10350km

IMARSAT P has 10 satellites constellation in 2 orbits at 10350km

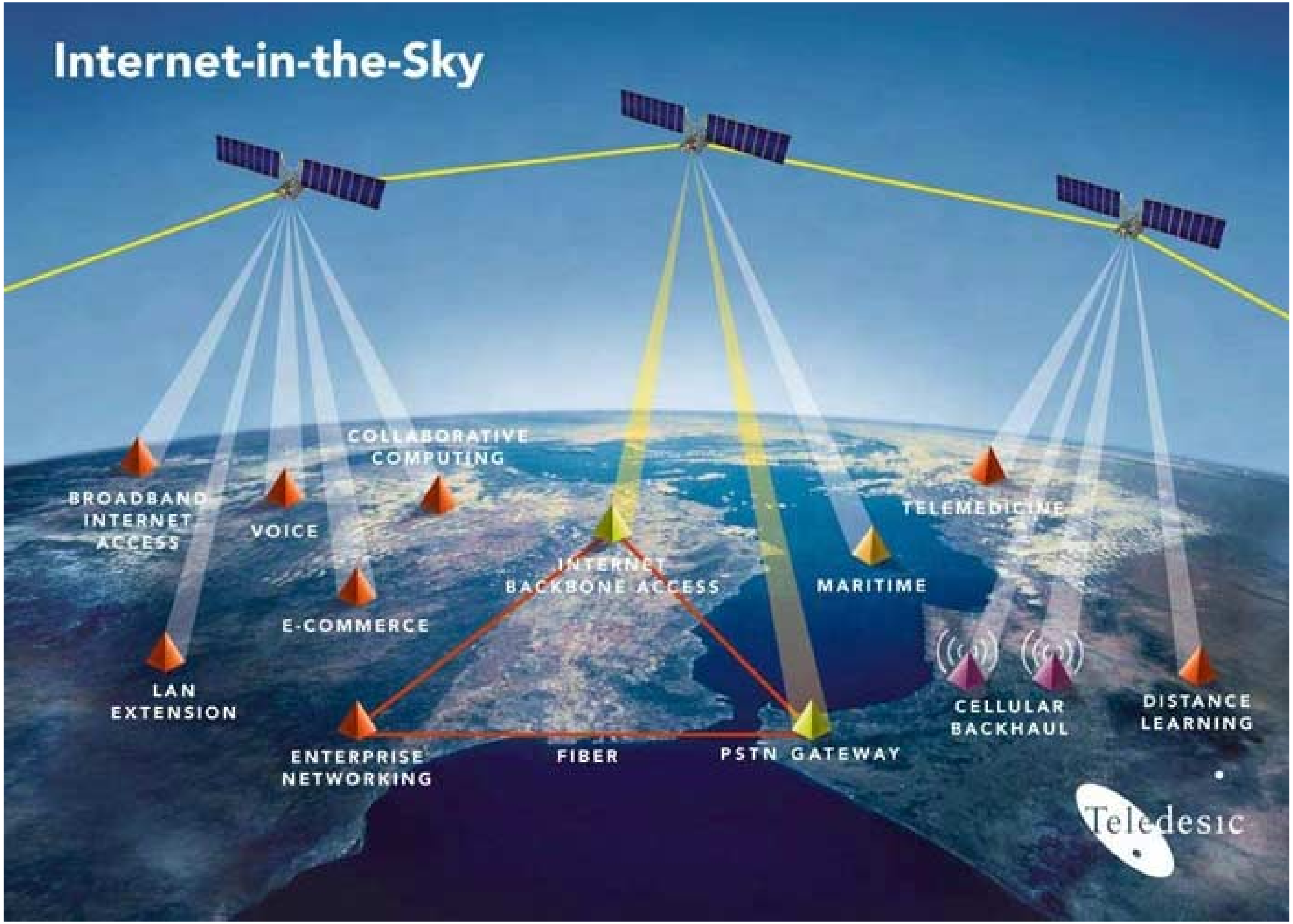
(3) Wideband data transmission, e.g.,

Teledeisc has 840 satellites constellation in 21 orbits at 700km

Spaceway has 8 satellites constellation in 1 orbit at 35000km

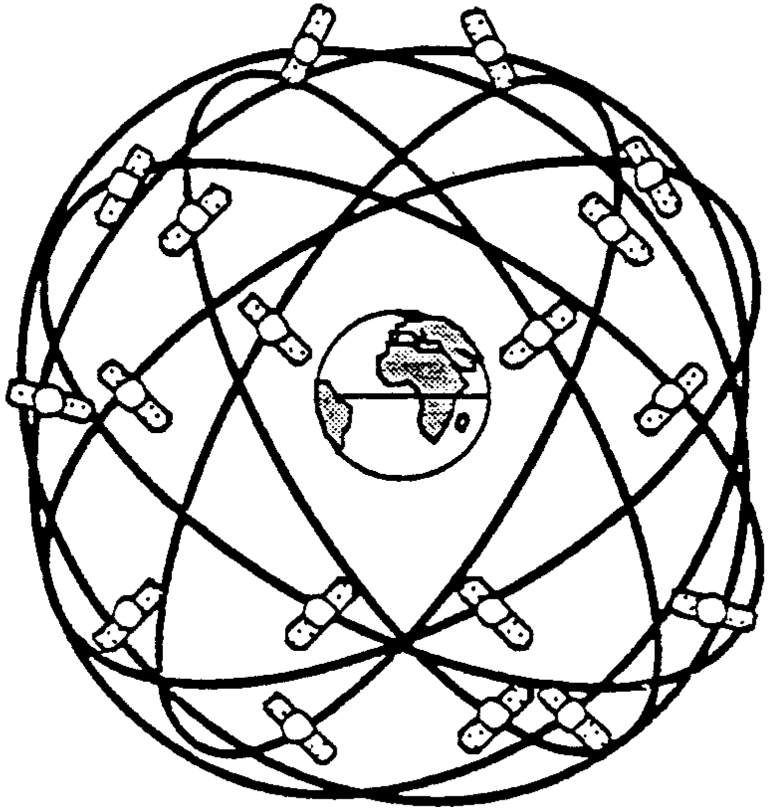


Teledesic satellite


Internet-in-the-Sky
COLLABORATIVE COMPUTING
BROADBAND INTERNET ACCESS
VOICE
TELEMEDICINE
INTERNET BACKBONE ACCESS
MARITIME
E-COMMERCE
LAN EXTENSION
CELLULAR BACKHAUL
DISTANCE LEARNING
ENTERPRISE NETWORKING
FIBER
PSTN GATEWAY
Teledesic

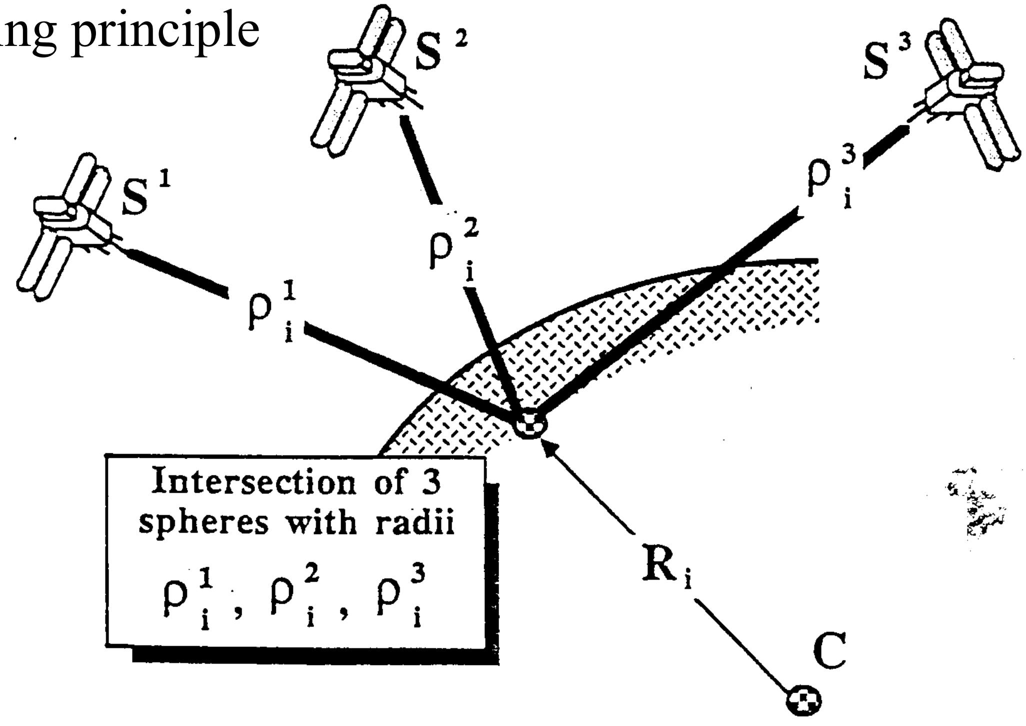
10.8 Global positioning system

1. GPS satellites



- carrier frequencies 1227.6 and 1575.42MHz
- **18 satellites, plus 3 active spares**
- **6 orbit planes**
- **12 hour period**
- **20,000 km height**
- **(almost) full coverage**
  (24 hours per day everywhere in the world)

2. Operating principle



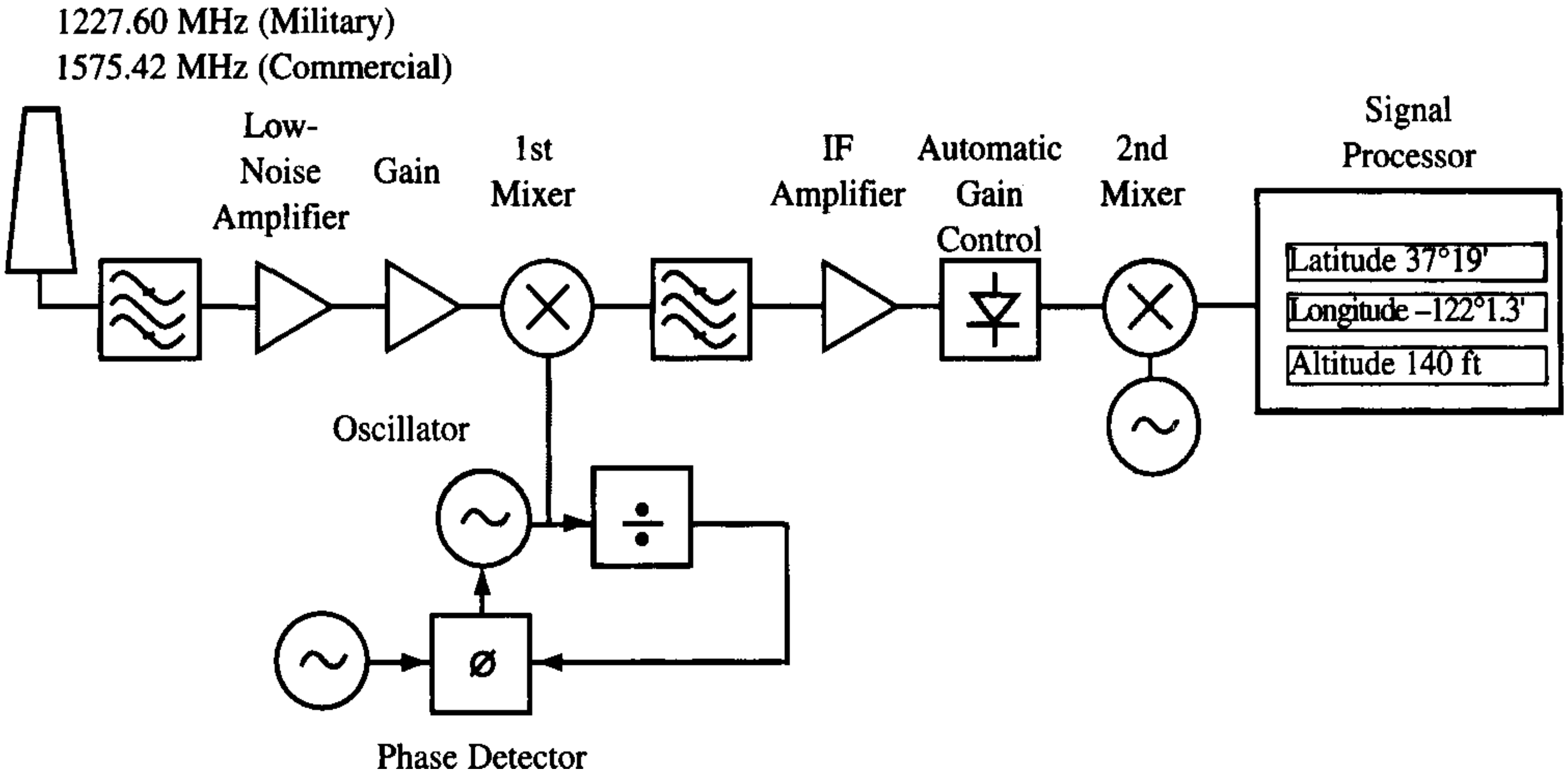
KNOWN: r^1, r^2, r^3

OBSERVED: $\rho_i^1, \rho_i^2, \rho_i^3$

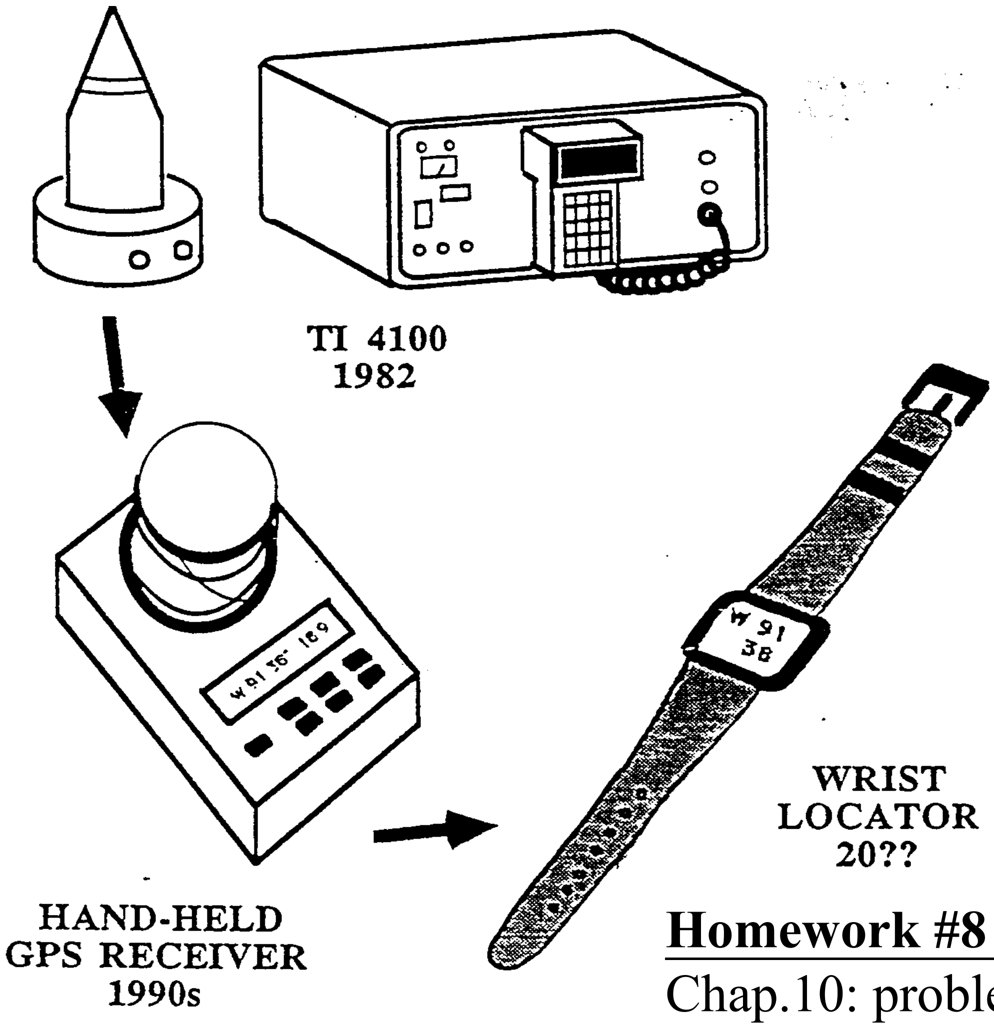
SOUGHT: R_i

$$\boxed{\left\| r^j - R_i \right\| = \rho_i^j \qquad j = 1,2,3}$$

3. GPS receiver



4. Future of GPS receiver



Homework #8 (due 2 weeks)
Chap.10: problems 1-7