Technical And Regulatory Aspects Of A Ka-Band Phased Array Antenna For Spacecraft Data Link Applications

2nd Ka-Band Utilization Conference
September 24-26, 1996
Florence, Italy

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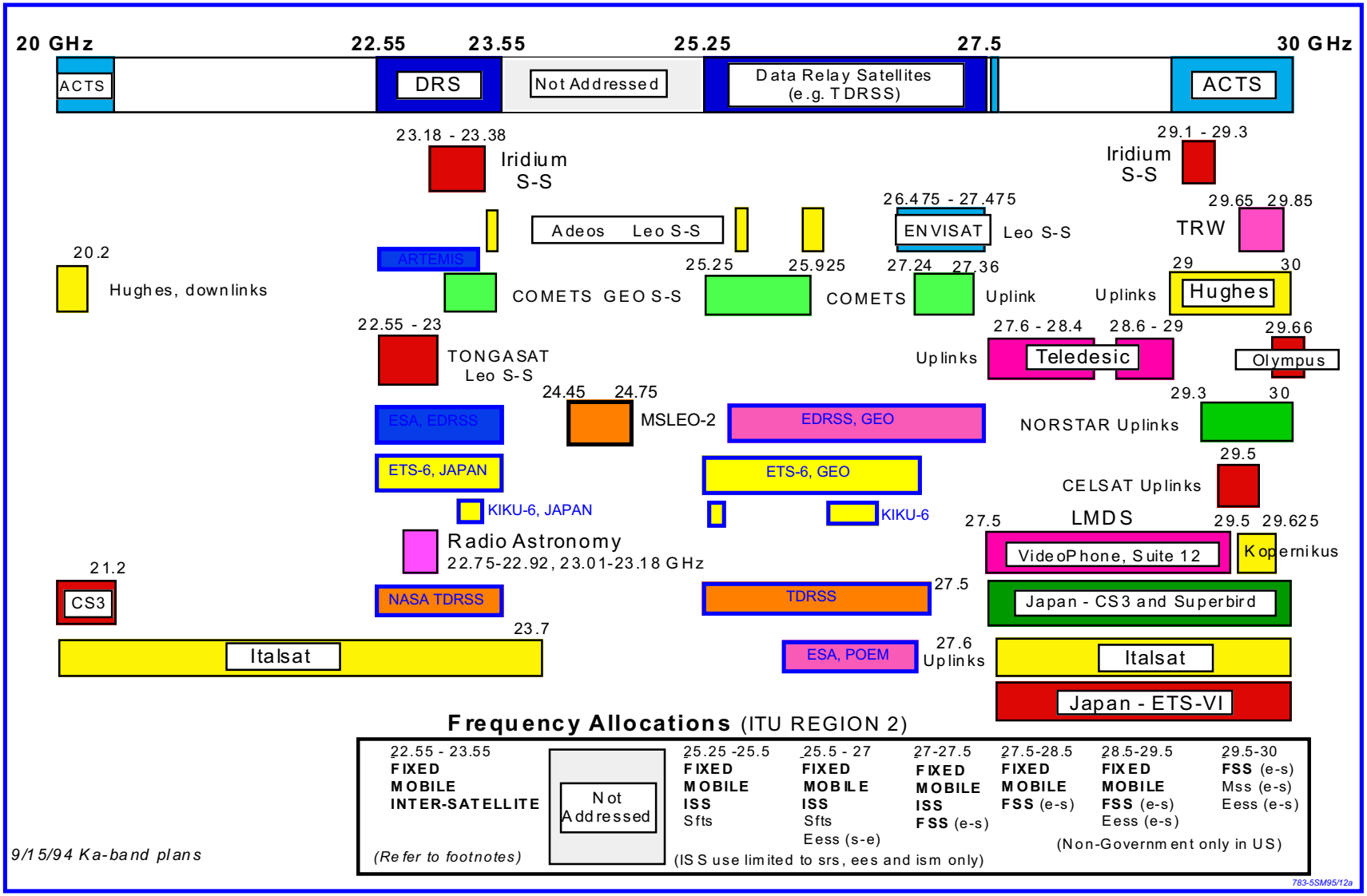
Paper Design

- *TDRSS H,I, & J Spectrum Allocations and Utilization*
- *TDRSS Related Hardware Activities*
- *Space to Earth Allocation in Ka-Band*
- *International Regulatory Activities*

Use of 20-30 GHz in 1995



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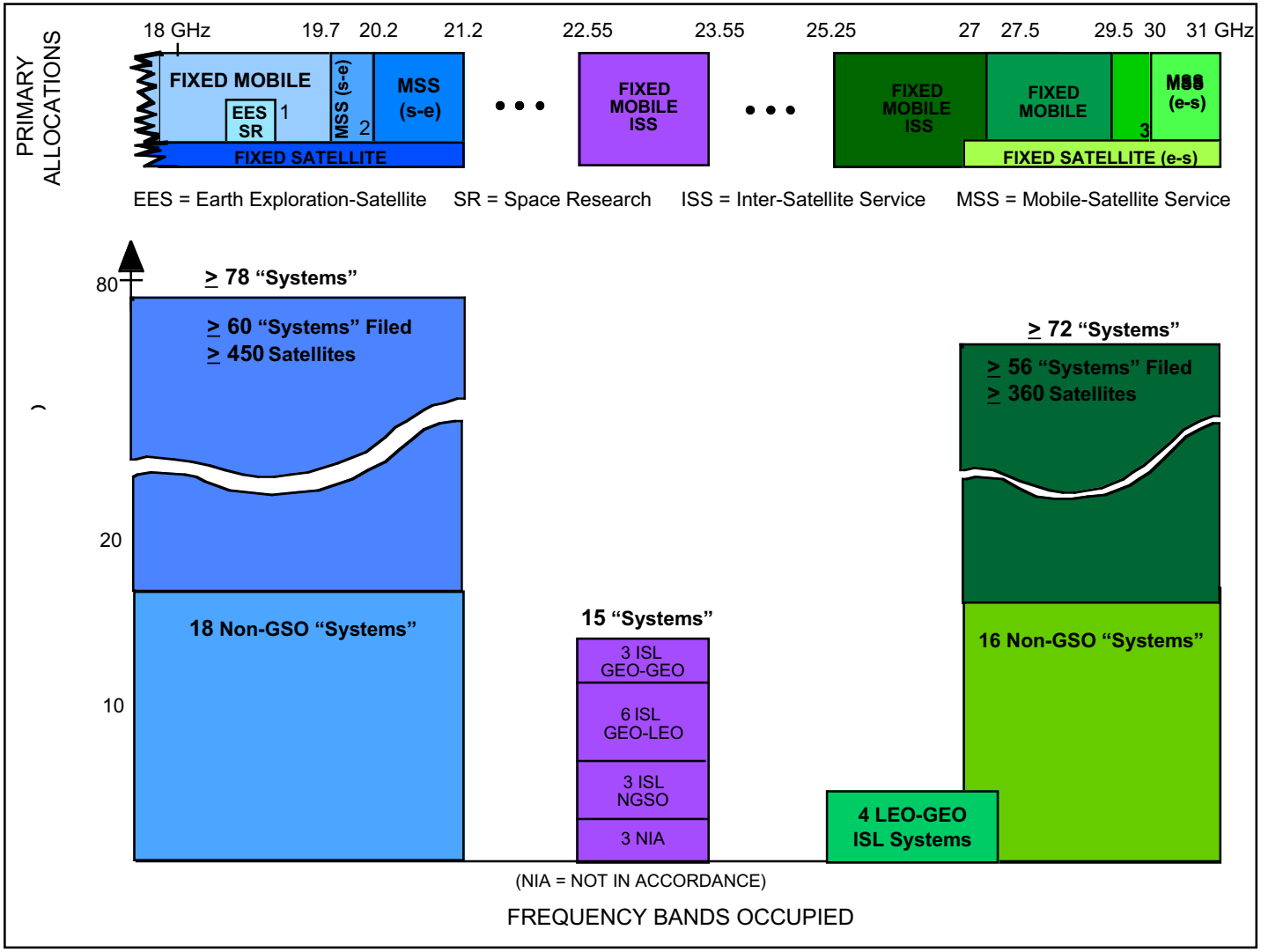
Space Systems Planned or Operating in the 20-30 GHz Band



NOTES:

1. [18.6-18.8 GHz]: EES and SR Primary In Region 2; Secondary in Regions 1 & 3
2. [19.7-20.1 GHz]: MSS Primary in Region 2; Secondary in Regions 1 & 3. [20.1-20.2 GHz]: MSS Primary
3. [29.5-29.9 GHz]: MSS Primary in Region 2; Secondary in Regions 1 & 3. [29.9-30 GHz]: MSS Primary

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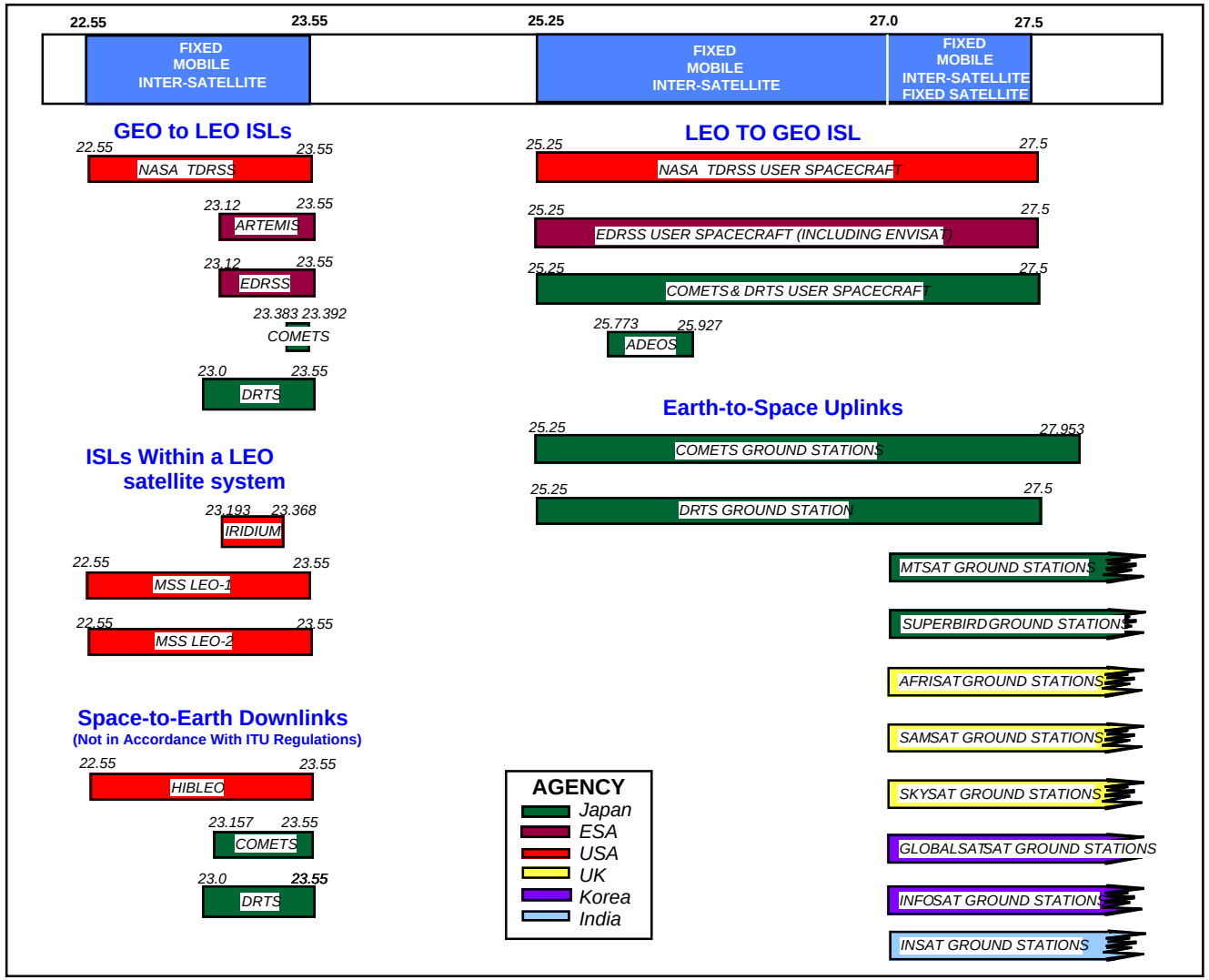
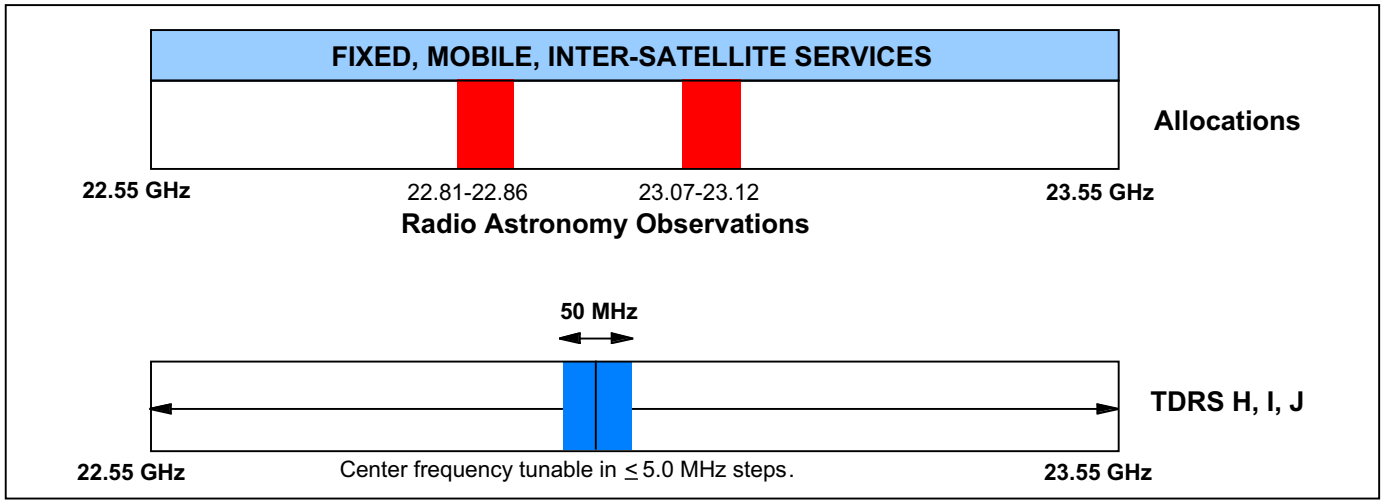
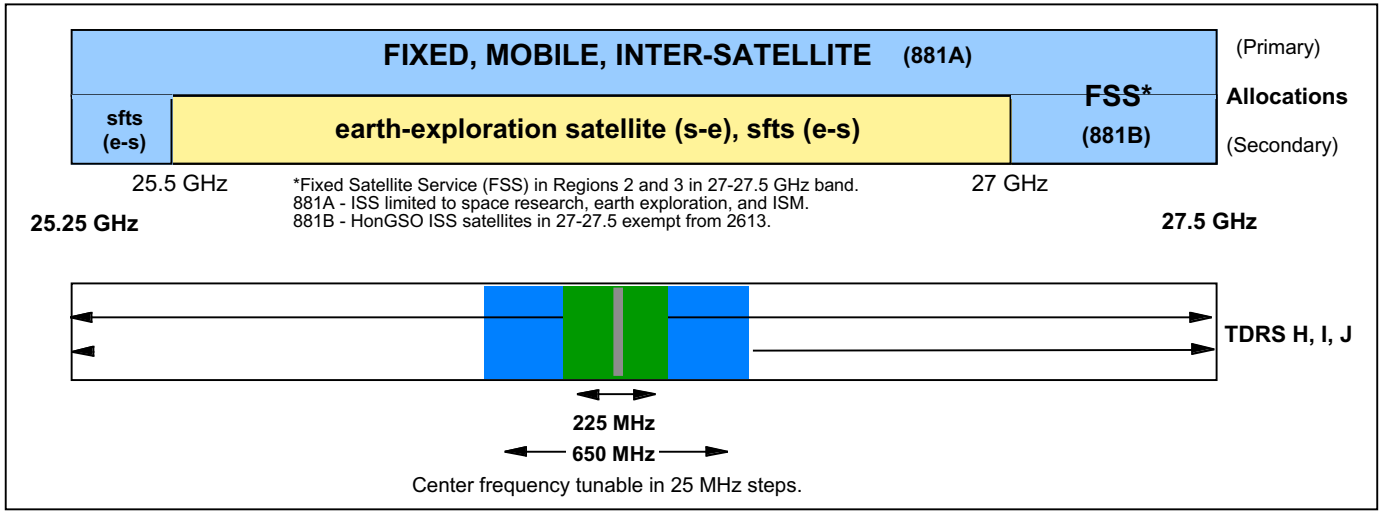
Satellite Systems Operating in TDRSS Bands



TDRSS H, I, & J Space-to-Space Frequency Plans



TDRS H, I, J Forward Service Space-to-Space Link Frequency Plan



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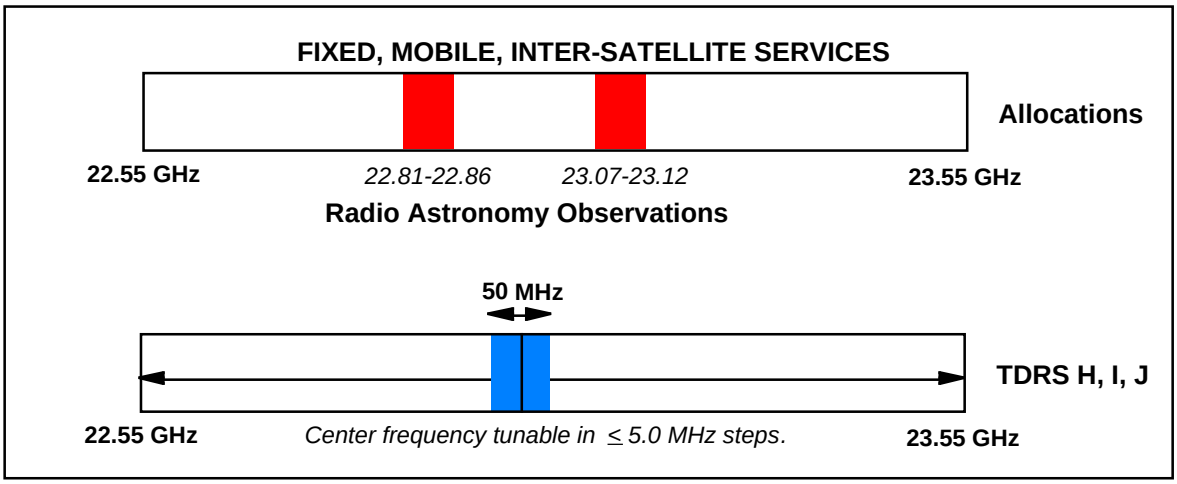
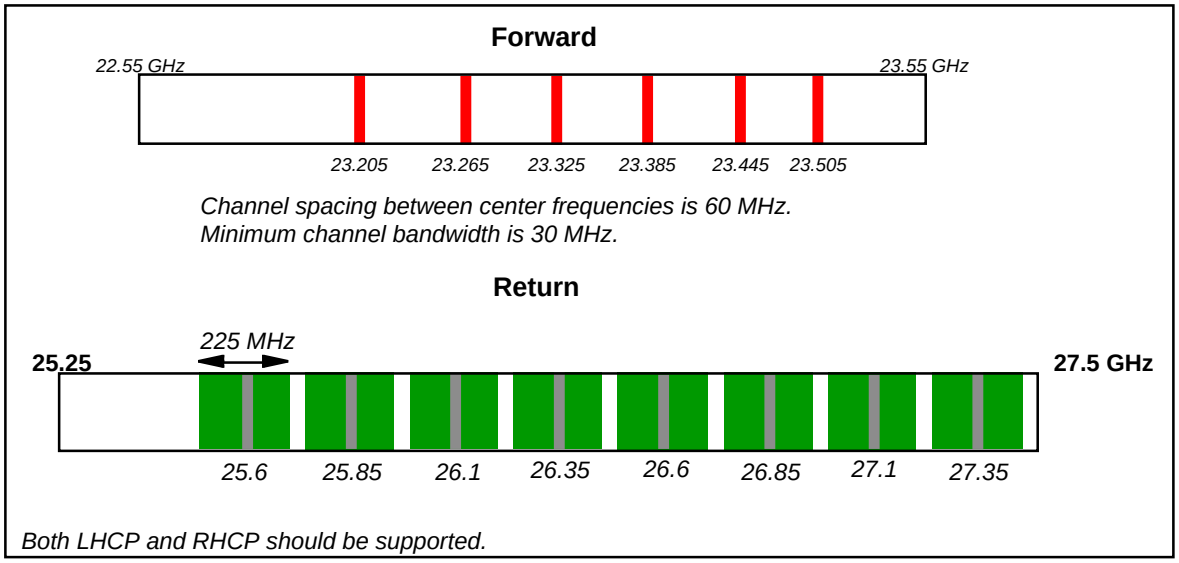
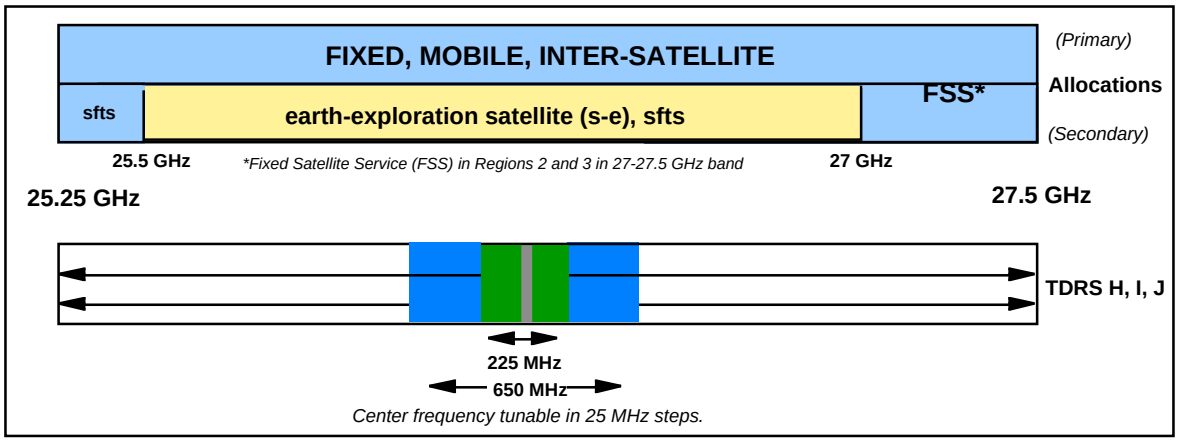
TDRSS H, I & J and SNIP Space-to-Space Frequency Plans



TDRS H, I, J Forward Service Space-to-Space Link Frequency Plan

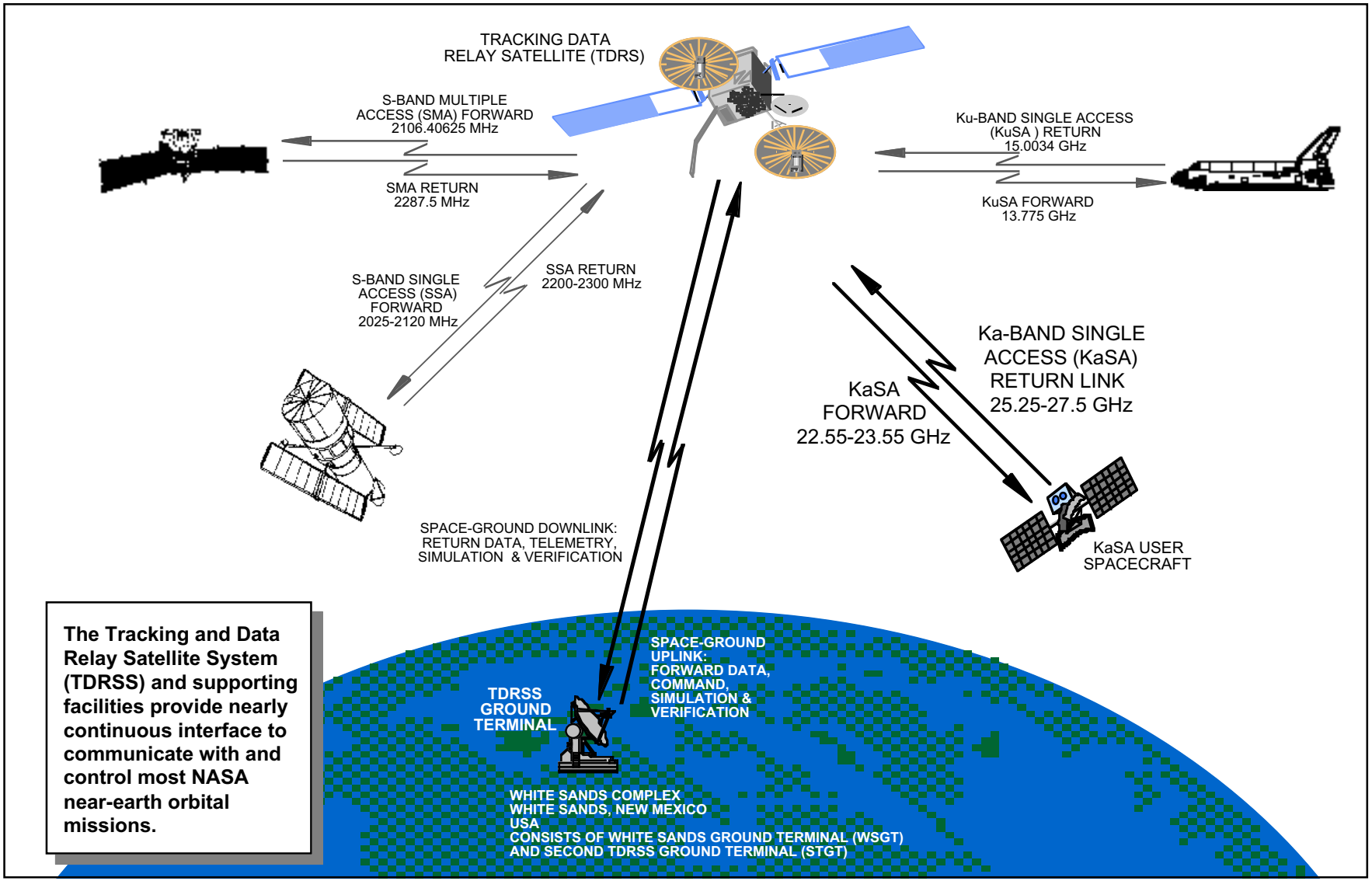


Space Network Interoperability Panel (SNIP) Recommended DRS Channelization



TDRS H, I, J Return Service Space-to-Space Link Frequency Plan

Tracking Data Relay Satellite Links



The Tracking and Data Relay Satellite System (TDRSS) and supporting facilities provide nearly continuous interface to communicate with and control most NASA near-earth orbital missions.

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854-8SM96/8

Frequency License Application

Service	Frequency (Ghz)	Maximum Data Rate
Space-to-Space Links:		
SMA Forward	2.1064	300 kbps
SSA Forward	2.025 - 2120	300 kbps
KuSA Forward	13.775	25 Mbps
KaSA Forward	22.55 - 23.55	25 Mbps
SSH Forward	2.025 - 2.120	72 kbps
KuSH Forward	13.775	216 kbps
SMA Return	2.2875	3 Mbps
SSA Return	2.200-2.300	6 Mbps
KuSA Return	15.0034	300 Mbps
KaSA Return	25.25 - 27.5	300/800 Mbps(1)
SSH Return	2.200 - 2.300	192 kbps
KuSH Return	15.0034	300 Mbps
Space to Earth Links:		
SMA Downlink	6 channels(2) in 13.4 - 13.625	3 Mbps
SSA 1 Downlink	13.6775	6 Mbps
SSA 2 Downlink	13.6975	6 Mbps
KuSA 1 Downlink	13.5284	300 Mbps
KuSA 2 Downlink	13.9284	300 Mbps
KaSA 1 Downlink	13.5284	300 Mbps
KaSA 2 Downlink	13.9284	300 Mbps
KaSA Downlink	13.725	800 Mbps(1)
SSH Downlink	13.6775 and 13.6975	192 kbps
KuSH Downlink	13.5284 and 13.9284	50 Mbps

Table 1

Frequency License Application (Cont.)

Service	Frequency (Ghz)	Maximum Data Rate
S-band TT&C Downlink[3]	2.211 or 2.2065	4 kbps
Ku-band TT&C Downlink[3]	13.7265 or 13.731	4 kbps
Auxiliary Functions		
Simulation/Verification		
KaSA Forward[4]	22.55-23.55	25 Mbps
KuSA Forward	13.775	25 Mbps
SSA Forward	2.025 - 2.120	300 kbps
KuSH Forward	13.775	50 Mbps
SSH Forward	2.025 - 2.120	192 kbps
SMA Forward	2106.4	10 kbps
Bilateration Ranging Transponder	2106.4	10 kbps
Ku-band Launch Area Relay	15.0034	300 Mbps
S-band Launch Area Relay	2.025 - 2.120	3 Mcps
Ku-band Launch Area Terminal	15.0034	3 Mcps
S-band Launch Area Terminal	2.200 - 2.300	3 Mcps
Ku-band RF SOC	13.775	300 kbps
S-band RF SOC	2.025 - 2.120	25 Mbps
Ku-band Compatability Test Van	13.775	25 Mbps
S-band Compatability Test Van	2.025 - 2.120	300 kbps

(1) TDRS H, I, J will have the capacity for 800 Mbps, but the ground terminals will require updating before this is achievable.

(2) TDRS H, I, J will be capable of transmitting 6 channels using redundant equipment

(3) TDRS H, I, J will be capable of transmitting on two telemetry frequencies. Frequencies will be selected by command. Ground terminals will be capable of operating at either frequency.

(4) TDRS H, I, J will be capable but ground terminals are not. telemetry test only.

Table 1

Frequency License Application (Cont.)

Service	Frequency (GHz)	Maximum Data Rate
Earth to Space Links		
SMA Uplink	14.8264 and 14.8164	300 kbps
SSA 1 Uplink	14.6795	300 kbps
SSA 2 Uplink	14.7195	300 kbps
KuSA 1 Uplink or KaSA 1 Uplink	14.625	25 Mbps
KuSA 2 Uplink or KaSA 2 Uplink	15.2	25 Mbps
SSH Uplink	14.6795 and 14.7195	72 kbps
KuSH Uplink	14.625 and 15.2	216 kbps
S-band TT&C Uplink (1)	2.03596 or 2.03182	2 kbps
Ku-band TT&C Uplink (1)	14.786 or 14.7816	2 kbps
Auxiliary Functions:		
Simulation/Verification		
KaSA Return (2)	25.25 - 27.5	800 Mbps
KuSA Return	15.0034	300 Mbps
SSA Return	2.200 - 2.300	6 Mbps
KuSH Return	15.0034	50 Mbps
SSH Return	2.200-2.300	192 kbps
SMA Return	2.2875	3 Mbps
Bilateration Ranging Transponder	2.2875	10 kbps
Ku-band Launch Area Relay	13.750-13.800	25 Mbps
S-band Launch Area Relay	2.025 - 2.120	11 Mcps
Ku-band Launch Area Terminal	15.0034	300 Mbps
S-band Launch Area Terminal	2.200 - 2.300	6 Mbps
Ku-band RF SOC	15.0034	300 Mbps
S-band RF SOC	2.200 - 2.300	6 Mbps
Ku-band Compatability Test Van	15.0034	300 Mbps
S-band Compatability Test Van	2.200 - 2.300	6 Mbps

(1) TDRS H, I, J will be capable of transmitting on two telemetry frequencies. Frequencies will be selected by command. Ground terminals will be capable of operating at either frequency.
(2) TDRS H, I, J will be capable but ground terminals are not. telemetry test only.

Table 1

TDRSS H, I & J Frequency Plan

Frequency	Function	Direction	
2025 - 2120 MHz	SSA Forward (SSH Forward Data)	TDRS-to-User	s-s
2031.822035.96 MHz	SGL Backup Uplink (TT&C) - S-Band	TGT-to-TDRS	e-s
2106.40625 MHz	SMA Forward	TDRS-to-User	s-s
2200 - 2300 MHz	SSA Return (SSH Return Data)	User-to-TDRS	s-s
2206.5/2211 MHz	SGL Backup Downlink (TT&C) - S-Band	TDRS-to-TGT	s-e
2287.5 MHz	SMA Return	User-to-TDRS	s-s
13.4 - 14.05 GHz	SGL Downlink (composite signal)	TDRS-to-TGT	s-e
13.405/13420 (1)	Multiple Access Down Data -1		
13.5284 GHz	Ku-Band Single Access-1 Down Data (Ka-Band Single Access-1 Down Data)		
13.6775 GHz	S-Band Single Access-1 Down Data (SSH Down Data)		
13.6975 GHz	S-Band Single Access-2 Down Data (SSH Down Data)		
13.731/13.7265 GHz(1)	Ku-Band TT & C (Telemetry)		
13.9284 GHz	Ku-Band Single Access-2 Down Data (Ka-Band Single Access-2 Down Data)		
13.725 GHz	Ka-Band Wideband Down Data		
13.4125/13.4275 GHz(1)	Multiple Access Down Data - 2		
13.435/13.4425 GHz(1)	Multiple Access Down Data - 3		
13.450/13.6075 GHz(1)	Multiple Access Down Data - 4		
13.615/13.4575 GHz(1)	Multiple Access Down Data - 5		

Table 2

TDRSS H, I & J Frequency Plan (Cont.)

Frequency	Function	Direction
13.622.5/13.600 GHz[1]	Multiple Access Down Data - 6	
13.775 GHz	KuSA Forward (KuSH Forward Data)	TDRS-to-User s-s
14.6 - 15.25 GHz	SGL Uplink (composite signal)	TGT-to-TDRS e-s
14.625 GHz	Ku-Band Single Access-1 Uplink Data	
14.6795 GHz	S-Band Single Access-1 Uplink Data (SSH Uplink Data)	
14.7195 GHz	S-Band Single Access-2 Uplink Data (SSH Uplink Data)	
14.786/14.782 GHz [1]	Ku-Band TT & C (Command)	
114.816/4.8264 GHz[1]	Multiple Access Uplink Data	
15.150 GHz	Pilot	
15.2 GHz	Ku-Band Single Access-2 Uplink Data	
14.625 GHz	Ka-Band Single Access Uplink Data - 1	
15.2 GHz	Ka-Band Single Access Uplink Data - 2	
15.0034 GHz	KuSA Return (KuSH Return Data)	User-to-TDRS s-s
22.55 - 23.55 GHz	KaSA Forward	TDRS-to-User s-s
25.25 - 27.5 GHZ	KaSA Return	User-to-TDRS s-s

[1] 1st entry is primary frequency selection/2nd entry is alternate selection for collocated spacecraft

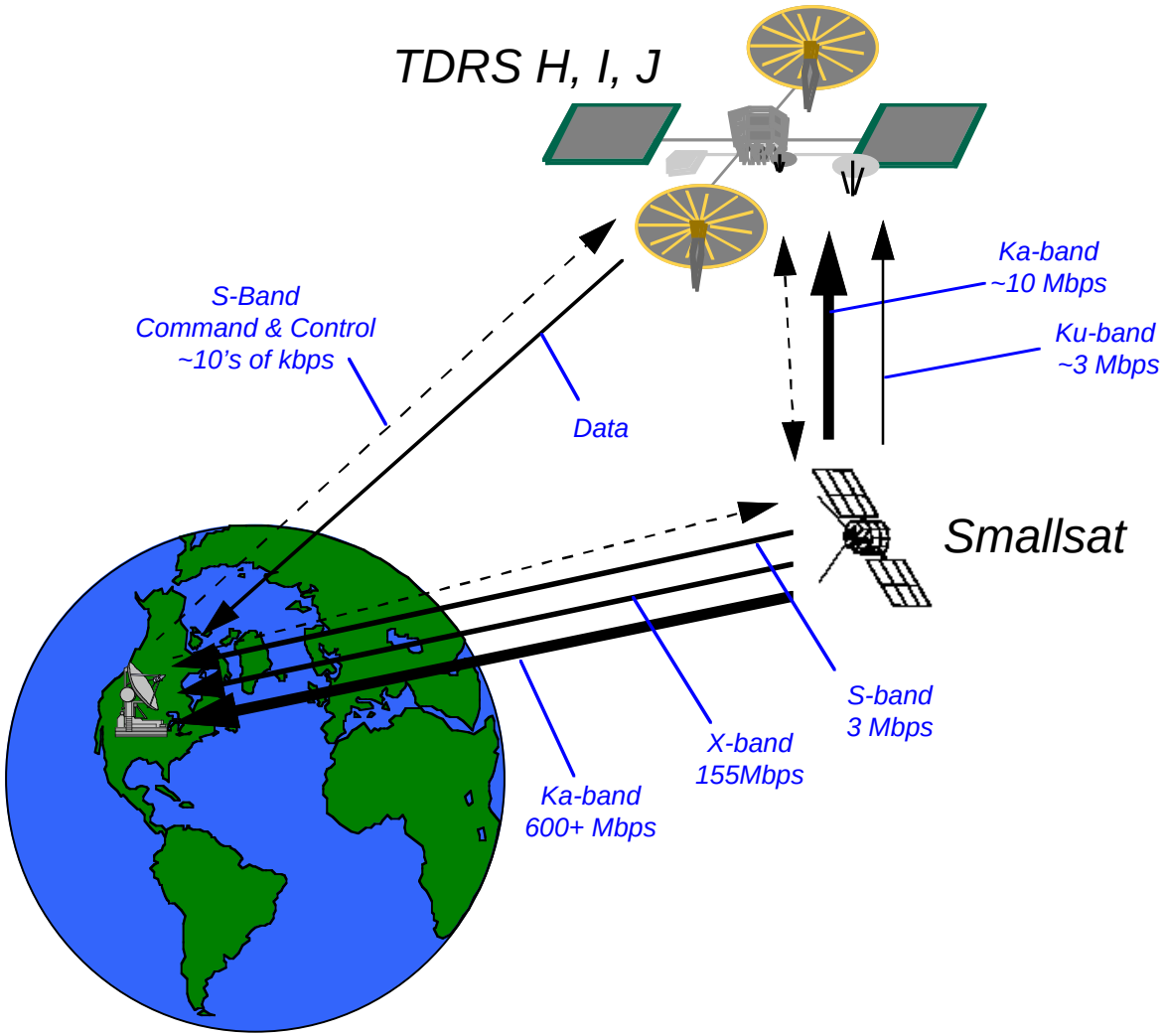
Table 2

TDRSS H, I & J Frequency Plan (Cont.)

Frequency Band	Function	Direction
2025 - 2120 MHz	S-Band Simulation and Verification and GSTDN Compatible TT&C (CTV, RFSOC, MIL Relay, TGT, GN)	TDRS-to-Earth station s-e
2106.40625 MHz	Bilateration Ranging Transponder System (BRTS)	TDRS-to-Earth station s-e
2200 - 2300 MHz	S-Band Simulation and Verification and GSTDN Compatible TT&C (CTV, RFSOC, MIL Relay, TGT, GN)	Earth station-to-TDRS e-s
2287.5 MHz	Bilateration Ranging Transponder (BRTS)	Earth station-to-TDRS e-s
13.775 GHz	Ku-Band Forward Simulation (CTV, RFSOC, MIL Relay, TGT)	TDRS-to-Earth station s-e
15.0034 GHz	Ku-Band Return Simulation (CTV, RFSOC, MIL Relay, TGT)	Earth station-to-TDRS e-s
22.55 - 23.55 GHz(1)	Ka-Band Forward Simulation (CTV, RFSOC, MIL Relay, TGT)	TDRS-to-Earth station s-e
25.25 - 27.5 GHz(1)	Ka-Band Return Simulation (CTV, RFSOC, MIL Relay, TGT)	Earth station-to-TDRS e-s
(1) Ground terminal operations at this frequency are TBR; will be used for testing		

Table 2

Smallsat Communications Options

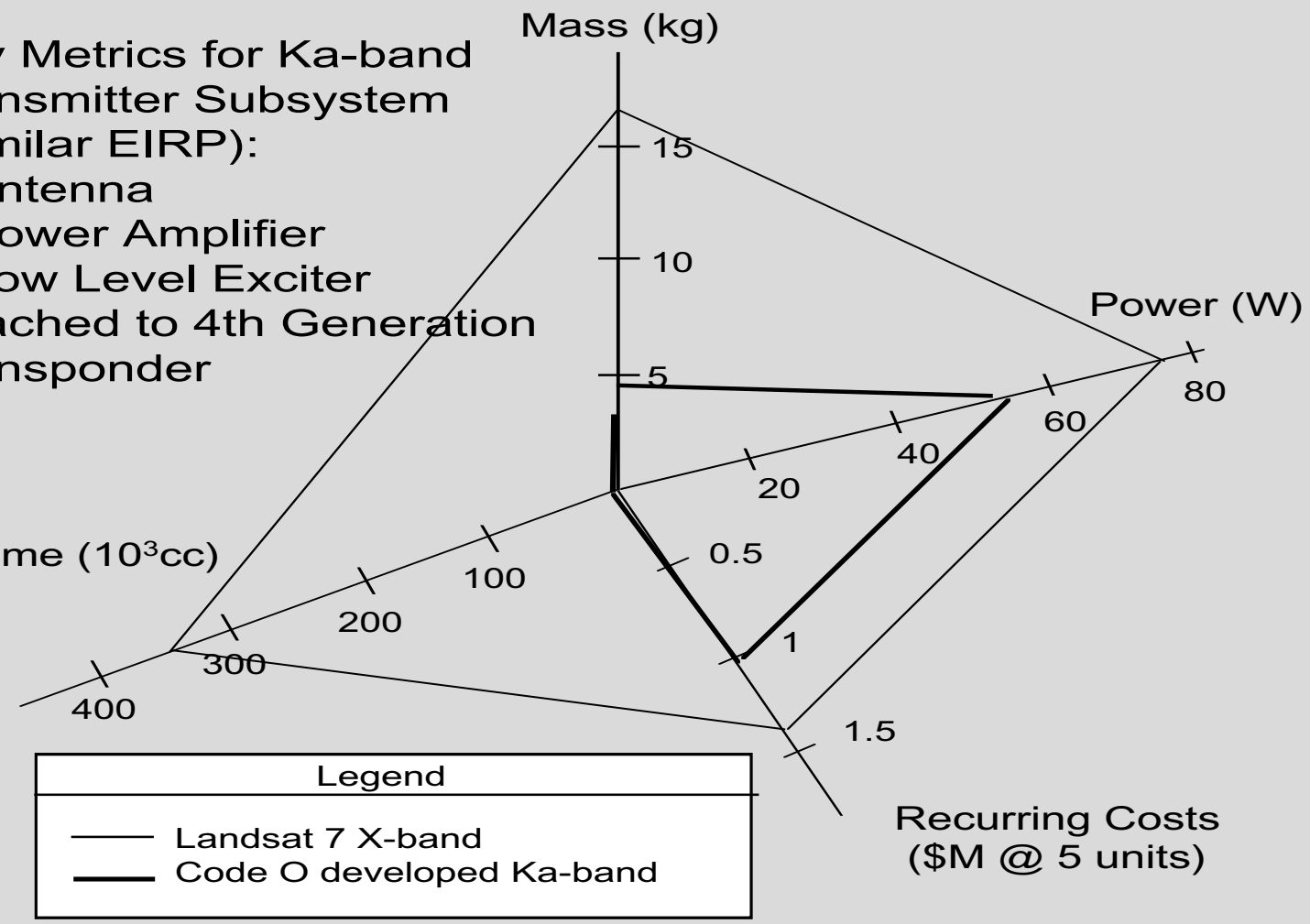


Expected Improvement of a High Data Rate Transmitter

Key Metrics for Ka-band Transmitter Subsystem (Similar EIRP):

- Antenna
- Power Amplifier
- Low Level Exciter

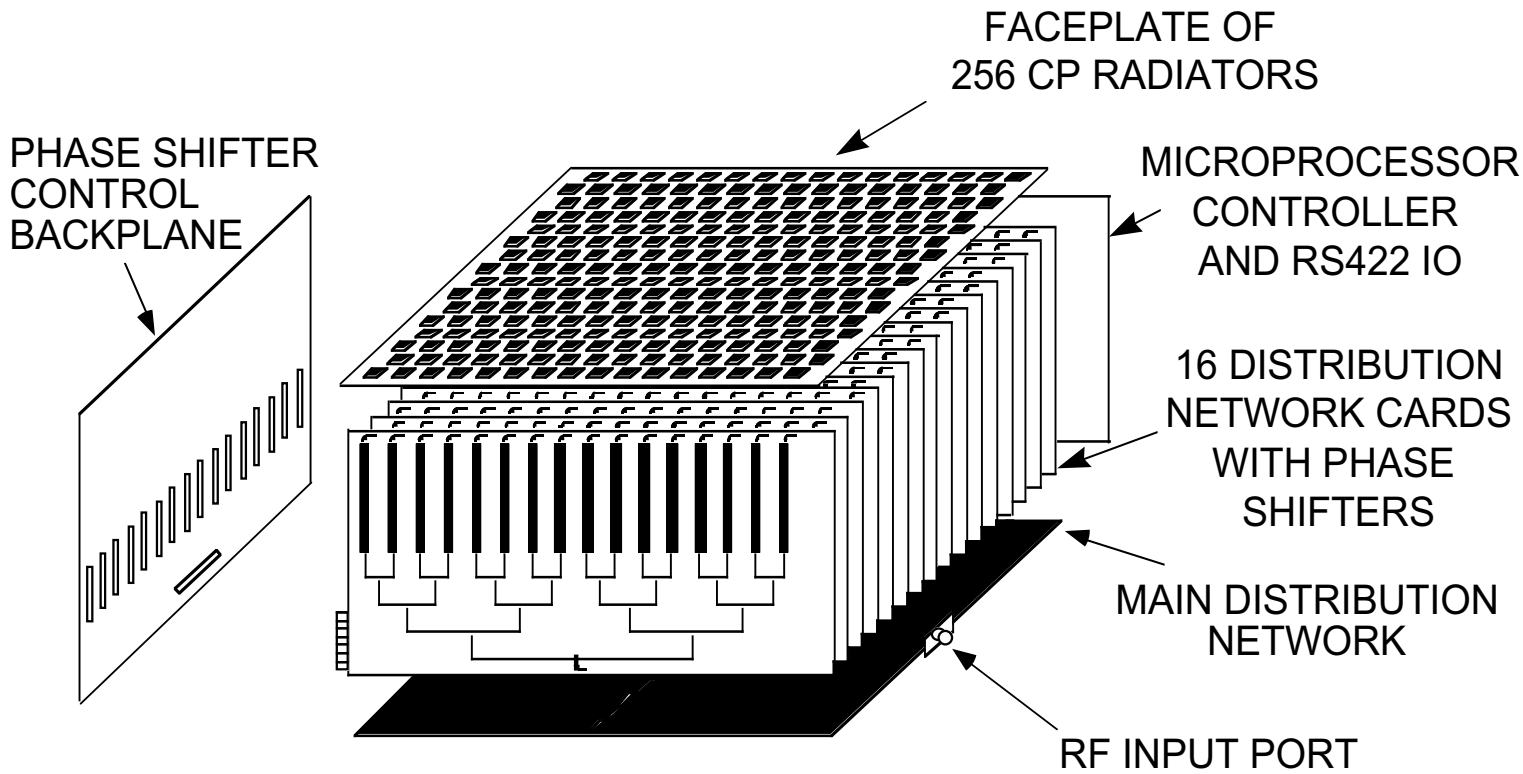
Attached to 4th Generation Transponder



Potential Phased Array Architecture

EXPLODED VIEW OF
FULLY POPULATED PHASED ARRAY ANTENNA

(housing and power supply not shown)



Basic Characteristics of the Phased Array Antenna

Maximum Envelope Dimension	30.5 cm
Transmit Frequency (via TDRSS)	25.25-27.5 GHz
Transmit Frequency (space to Earth)	25.50-27.0 GHz
Center Frequency Channel Spacing	25 MHz
Effective Isotropic Radiated Power	33dBW minimum
Supported Data Rates (via TDRSS)	up to 10 Mbps
Supported Data Rates (space-to-Earth)	up to 300 Mbps
Modulation Scheme	BPSK / QPSK
Angular Coverage, Off-Boresight	60 degrees minimum
Polarization	LHC
Axial Ratio	3 dB
Operating D. C. Power	approx. 45 Watts
D. C. Power Source	28V +/- 5V
Operating Temperature	-10°C to 55°C
Qualification Temperature	-20°C to 65°C
Lifetime	5 years minimum

Table 3

Current International Allocations 25.5 - 27.0 GHz

FIXED

INTER-SATELLITE 881A

MOBILE

Earth Exploration- Satellite (Space-to-Earth)

Standard Frequency and Time Signal-Satellite (Earth-to-Space)

881A limits the ISS to space research and Earth exploration-satellite service activities

26 GHz EES Consideration at WRC-97

A primary EES (Space-to-Earth) allocation is needed to initiate downlink service

- *PFD limits on EES satellite emissions will protect Fixed and Mobile receivers*
- *EES Earth stations must be coordinated with Fixed and Mobile transmitters*
- *No significant interference between EES and Inter-Satellite Service*

Representative Systems

System Example	A	B	C	D
Satellite Altitude (km)	*705*	*705*	*680*	*GSO*
Data Rate (MHz)	*1,000*	*40*	*1,000*	*15*
Satellite Transmitter Power (W)	*20*	*20*	*20*	*8*
Satellite Antenna Gain (dBi)	*28.0*	*25.0*	*39.1*	*41.8*
Earth station Antenna Gain (dBi)	*55.2*	*42.5*	*42.5*	*60.1*

Performance Characteristics of 26 GHz Downlink

Frequency Band (GHz)	26			
System Example	A	B	C	D
Type of Earth Station	Recorded data acquisition	Direct data read-out	Direct High-Speed data read-out	Direct data readout (GSO)
Typical minimum elevation angle(degrees)	5.0	5.0	5.0	5.0
Satellite antenna input power (dBW)	13.0	13.0	13.0	9.0
Satellite antenna gain (dBic)	28.0	25.0	39.1	41.8
Satellite EIRP (dBW)	41.0	38.0	52.1	50.8
Free space loss (dB)	189.0	189.0	188.8	213.0
Excess path loss (dB)	6.4	6.4	6.4	7.1
Earth station antenna gain (dBic)	55.2	42.5	42.5	60.1
Antenna pointing loss (dB)	0.5	0.5	0.5	0.1
Polarization mismatch loss (dB)	0.2	0.2	0.2	0.1
Modulator and demodulator losses (dB)	2.0	2.0	2.0	1.5
Receiver reference bandwidth (MHz)	1,340.0	53.6	1,340.0	10.1
Data rate (dB Hz)	90.0	76.0	90.0	71.8
Received energy per bit (dBW/Hz), Eb	-191.9	-193.6	-193.3	-182.6
Receiver system noise temperature (K)	715.9	715.9	552.7	715.4
Thermal noise power density (dBW/Hz)	-200.1	-200.1	-201.2	-200.1
Total internal noise power density (dBW/Hz), No	-200.1	-200.1	-201.2	-200.1
Eb/No	8.2	6.5	7.9	17.4
Link bit-error ratio	10^{-6}	10^{-6}	10^{-6}	10^{-7}
Satellite data handling error ratio	$5 \cdot 10^{-7}$	-	-	-
Overall received bit-error ratio	$1.5 \cdot 10^{-6}$	10^{-6}	10^{-6}	10^{-7}
Threshold Eb/No (or C/N) (dB)	3.9	3.9	3.9	10.5
Power margin (dB)	4.3	2.6	4.0	6.9

Table 4

Regulatory Considerations in the Design of 26 GHz Spaceborne Transmitters

- *Allocations*
  - *25.25 - 27.5 GHz band currently allocated to the Inter-Satellite Service (space-to-space) on a primary basis.*
  - *25.5 - 27.0 GHz band currently allocated to EES (space-to-Earth) on a secondary basis. WRC-97 expected to upgrade it to primary.*

Regulatory Considerations in the Design of 26 GHz Spaceborne Transmitters (Cont'd)

- *Power-flux density limits*
  - $\rho = -115$ dB(W/m^2 MHz) $0^o \leq \delta < 5^o$
  - $\rho = -115 + 0.5\,(\delta - 5)$ dB(W/m^2 MHz) $5^o \leq \delta < 25^o$
  - $\rho = -105$ dB(W/m^2 MHz) $25^o \leq \delta < 90^o$
- *Reference radiation pattern (As a design guide. Some adjustment needed to account for coma lobe at large scan angles.)*
  - $G(\phi) = G_m - 3\,(\phi/\phi_b)^2$ dBi $0 \leq \phi \leq 2.58\,\phi_b$
  - $G(\phi) = G_m - 20$ dBi $2.58\,\phi_b \leq \phi \leq 6.32\,\phi_b$

where ϕ_b = one-half the 3 dB beamwidth

Regulatory Considerations in the Design of 26 GHz Spaceborne Transmitters (Cont'd)

- *Spurious emissions*
  - *ITU-R Task Group 1/3 is studying the revision of Recommendation ITU-R SM.329-6 on Spurious Emissions in response to Recommendation 66 (WARC-92).*
  - *Spurious emissions could be limited to 60 dB or 70 dB below the carrier in most bands and more stringent limits in radioastronomy and passive sensor bands.*
  - *Results could be incorporated into the Radio Regulations in the 2002 time frame.*

Technical and Operational Characteristics of 26 GHz Fixed Service Systems to Facilitate Sharing with Data Relay Satellites (DRS)

- *Summary of ITU-R Joint Ad Hoc Working Party 7B-9D studies in support of a preliminary draft new recommendation.*
  - *Temporal characteristics of interference to DRSs*
  - *Protect orbital locations of DRSs*
  - *Use automatic transmit-power control*
  - *Account for atmospheric absorption on a case-by-case basis*
  - *Account for Fresnel zone blockage on a case-by-case basis*

List of Acronyms

BRTS	Bilateration Ranging Transponder System
Blvd	Boulevard
BRTS	Bilateration Ranging Transponder System
CMD	Command
CP	Circular Polarization
CTV	Compatibility Test Van
dBi	Decibels Isotrophic
DC	Direct Current
DG1	Data Group 1
DG2	Data Group 2
DRS	Data Relay Satellite
e-s	Earth to Space (Secondary)
E-to-S	Earth to Space (Primary)
Eb/No	Bit energy-to-noise density ratio
EES	Earth Exploration Satellite (Primary)
eess	Earth Exploration Satellite Service (Secondary)
EIRP	Equivalent Isotropically Radiated Power
EOS	Earth Observation Satellite
FSS	Fixed Satellite Service
FWD	Forward
Gen.	Generation
GHz	Gigahertz
GEO	Geosynchronous Earth Orbit
GN	Ground Network
Gov.	Government
GSFC	Goddard Space Flight Center
GSO	Geosynchronous Orbit
GSTDN	Ground Spaceflight Tracking and Data Network
ISM	Industrial, Scientific & Medical
ISS	Intersatellite Service
ITU-R	International Telecommunications Union-Radiocommunication Sector
KaSA	Ka-Band Single Access

List of Acronyms (Cont.)

kbps	Kilobits per second
KuSA	Ku-band Single Access
KuSH	Ku-Band Shuttle
LEO	Low Earth Orbit
LHCP	Left-Hand Circular Polarization
LO	Local Oscillator
Mbps	Megabits per second
Mchips/sec	Megachips per second
MD	Maryland
MIL Relay	Merritt Island Relay
MSS	Mobile Satellite Service
NA	Not Applicable
NASA	National Aeronautics and Space Administration
NTIA	National Telecommunications and Information Administration
NRZ	Nonreturn to Zero
PFD	Power Flux Density
PLEN-3	Plenary-3
PN	Pseudorandom Noise
Rd	Road
RF SOC	Radio Frequency (RF) Simulation Operation Center
RFI	Radio Frequency Interference
RHCP	Right-Hand Circular Polarization
RTN	Return
RX	Receive
s/c	Spacecraft
SA	Single Access
s-e	Space to Earth (Secondary)
S-to-E	Space to Earth (Primary)
SFTS	Standard Frequency and Time Standard
SG	Space to Ground
SGL	Space-Ground Link
SGLT	Space-Ground Link Terminal
SIM	Simulation
SMA	S-Band Multiple Access
SN	Space Network
SNIP	Space Network Interoperability Panel
SOC	Simulation Operations Center
SQPN	Staggered Quadriphase Pseudorandom Noise
SQPSK	Staggered Quadriphase Shift Keyed (or keying)
SSA	S-Band Single Access
SSH	S-Band Shuttle
SSL	Space-to-Space Link
STel	Stanford Telecommunications Inc.
STGT	Second TDRSS Ground Terminal
STS	Space Transportation System
STTCS	S-Band TT&C System
TBD	To be determined
TBR	To be required
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
TGT	TDRSS Ground Terminal
TT&C	Tracking, Telemetry and Command
TX	Transmitter
USA	United States of America
USAT	User Satellite
VA	Virginia
WARC-92	World Administrative Radio Conference-92
WP	Working Party
WPS	Wallops Island
WRC-97	World Radiocommunication Conference-97
WSC	White Sands Complex
WSGT	White Sands Ground Terminal
ZOE	Zone of Exclusion