WS11 – Digital Transformation SATCOM

Proliferated and Resilient Airborne and Ground Terminal Architectures

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(Some) SATCOM Terminal Market Examples

Commercial IFC

>1,500 Active Installs · >55 Million Operating Hours

High Power Microwave / EW

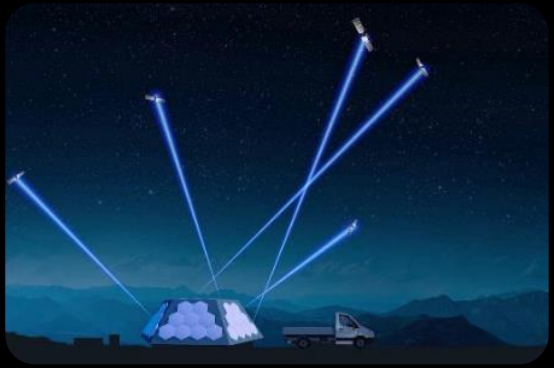
Counter-UAS · Counter-Advanced Threat

Airborne Satcom – Defense

E-4B · Army HADES · Others

Ground Mobile Satcom

Ku/Ka COTM · Mobile Gateway



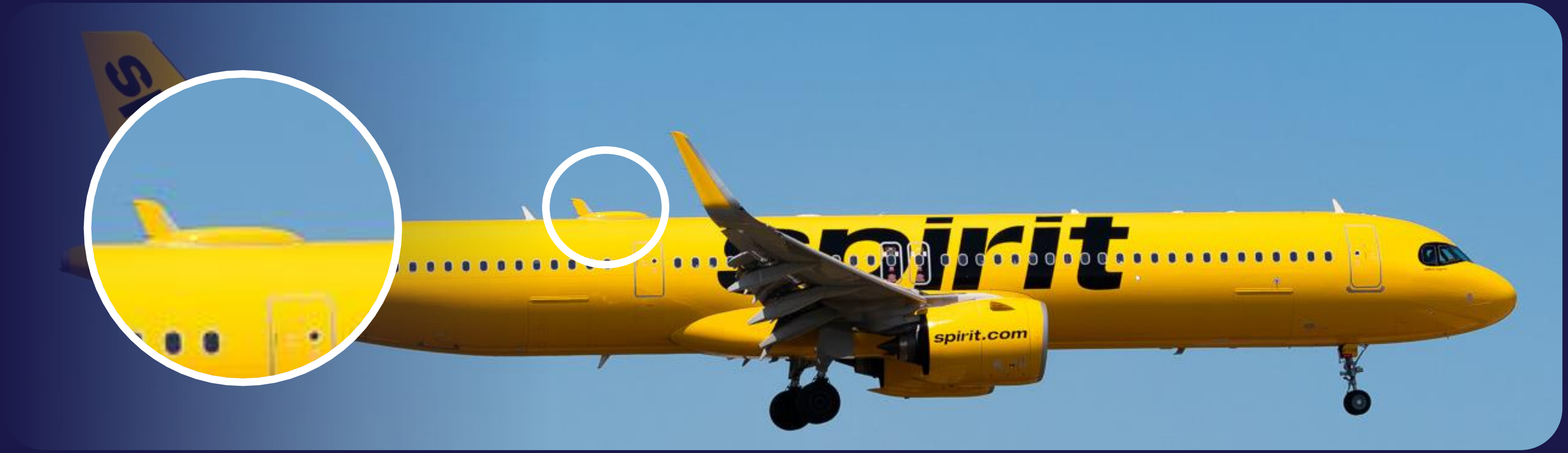
Gateway

LEO Gateway · COTQH · SIGINT

Satellite Payload

Intersatellite Links · High Throughput

(Some) Airborne SATCOM Terminal "Dual-Use" Examples



Serving the lowest cost commercial airline carriers to the most expensive US Air Force strategic aircraft

E-4B Advanced Airborne Command Post
In service since 2018

Sierra Nevada RAPCON-X

(Some) Government-Specific Key-Product Terminal Characteristics

Resilient in severe environments

- Natural protection against radiation, HEMP, scintillation, HPM, aircraft carrier EMI
- Meets EMI/EMC and EMP requirements
- All RF Components Fully-Recessed/Protected (WG fc > 14 GHz)

LPI, LPD, LO

- Antennas sidelobes are suppressed and can be confined to suppress radiation signatures and terrestrial interference
- Extremely Low RMS Sidelobe Emissions (< -55 dBc)
- Extremely Low On-Horizon Emissions (< -62 dBc)

All-Latitude Global Coverage

Survivable and operable in harsh environmental and shock conditions

- -55° C to 74° C operating temperature
- 20G, 11 msec sawtooth functional shock

Extended time-on-station (Low Drag)

- Low power and low drag (less fuel consumption)
- Unlimited on-the-Tarmac Operation

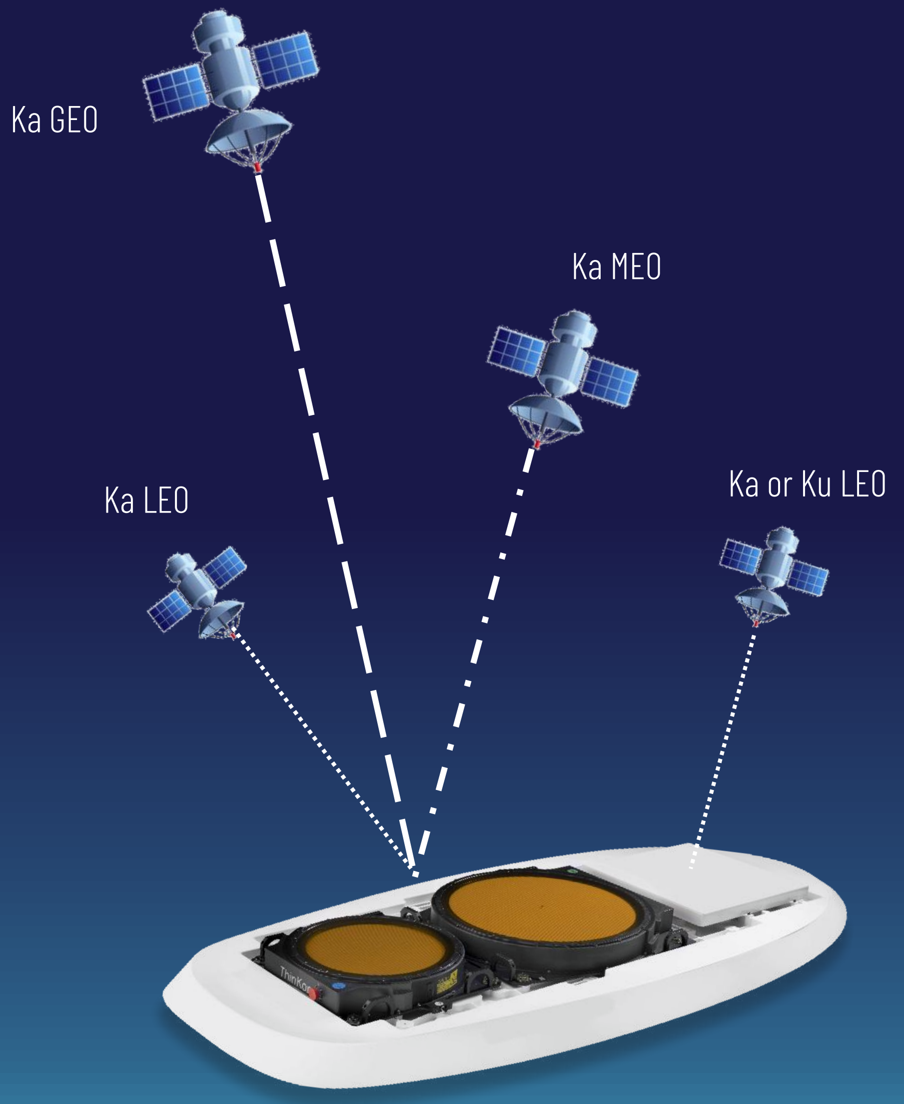
Meets All PTW Requirements

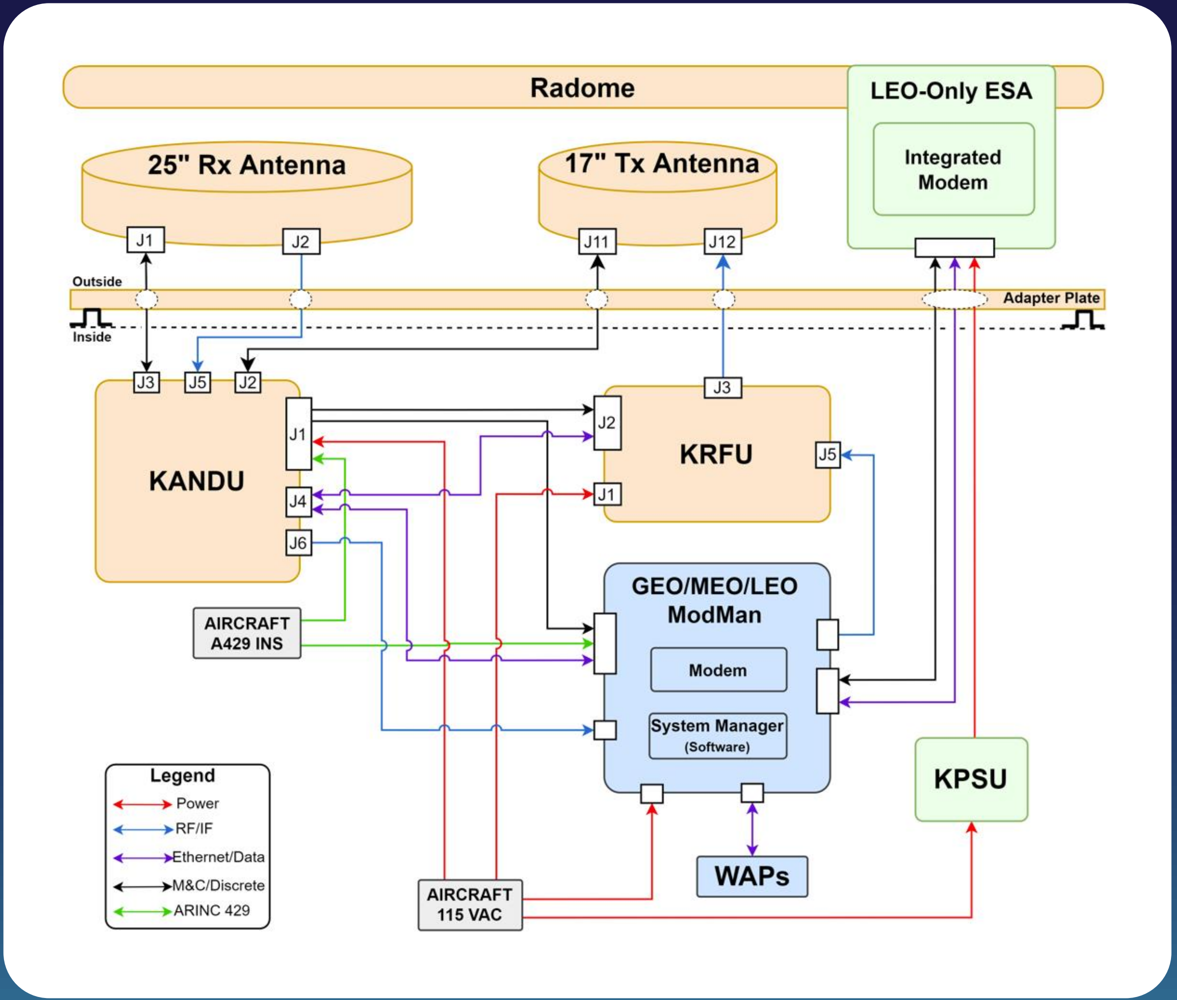
- Wide tunable and instantaneous bandwidth, analog scanning with a continuous data stream

Inherent anti-jam robustness

Requires Hosting of Diverse Flexible Waveforms is "Key"

Resiliency ➔ Multi-Provider, Multi-Orbit, Multi-Band Operation





Resiliency ➔ Multi-Provider, Multi-Orbit, Multi-Band Operation

...and Ka-band GEO Alone ➔ 100+ (Ka-Band) GEO Satellites with Diverse Waveform and Frequency/Channel Characteristics

Slot	Satellite (Inclination)	Coverage
-155.0	AEHF-3 (1.4 degs.)	Reconfigurable Phased Arrays (Hopped)
-135.2	WGS F6	10 Steerable 900Km/1.5 deg NCA Spots
-125.0	Galaxy 30	2 Steerable Spots
-121.0	Galaxy 23 (Echostar 9)	Fixed PHX + DEN Spots
-118.7	ANIK F3	1 Steerable Spot
-115.1	Viasat-1	108 Fixed Beams over CONUS
-111.2	Wildblue 1	36 Fixed Beams over CONUS
-111.1	ANIK F2	45 Fixed Beams over NA
-107.1	Echostar 17 (Jupiter 1)	60 Fixed Beams over CONUS
-105.0	AMC 15 (0.1 degs.)	12 Fixed Beams over CONUS
-102.7	DirecTV 12	48 Fixed Beams over CONUS
-102.7	DirecTV 12	Widebeam Coverage over CONUS
-102.8	DirecTV 10 (Spaceway 1)	48 Fixed Beams over CONUS
-102.8	DirecTV 10 (Spaceway 1)	Widebeam Coverage over CONUS
-99.2	DirecTV 14	48 Fixed Beams over CONUS
-99.2	DirecTV 14	Widebeam Coverage over CONUS
-99.2	DirecTV 11 (Spaceway 2)	Widebeam Coverage over CONUS
-97.1	Echostar 19 (Jupiter 2)	139 Fixed Beams over CONUS
-94.9	Spaceway 3	21+17 Fixed Beams over CONUS
-94.9	Spaceway 3	Widebeam Coverage over CONUS
-94.2	AEHF-2 (3.1 degs.)	Reconfigurable Phased Arrays (Hopped)
-84.0	Star One D1 (3/16)	18 Fixed Beams over Brazil
-74.8	SGDC 1	67 Fixed Beams over Brazil
-69.9	Viasat-2	20+72 Fixed Beams of NA+NAtlntc
-67.5	AEHF-4 (2.6 degs.)	Reconfigurable Phased Arrays (Hopped)
-67.0	SES-17	168 (500Km) Beams over SA+NA (400 Gbps)
-65.2	Eutelsat 65 West A	32 Fixed Beams over SA+CA
-63.0	Telstar 19V	50 Fixed Beams over SA+NA+NAtlntc
-61.0	Amazonas 3	18 Fixed Beams over SA+NA+NAtlntc
-55.0	Inmarsat 5-F2	72 Fixed 1200km/2 deg at Nadir Beams
-55.0	Inmarsat 5-F2	6 Steerable 900km/1.5 deg HCM/HCX Spots
-52.5	WGS F5	10 Steerable 900Km/1.5 deg NCA Spots
-33.5	Hylas 4 (0.1 degs.)	67 Fixed Beams over EUR+ME+AF
-24.8	Al ComSat 1	10 Fixed Beams over NAF
-20.1	Yahsat 3	58 Fixed Beams over SA+ME+AF
-12.0	WGS F9	10 Steerable 900Km/1.5 deg NCA Spots
-7.0	Nilesat 201	Widebeam Coverage over ME
-4.1	AMOS-3	Widebeam Coverage over ME
-0.7	THOR 7	30 Fixed Beams over EUR+ME+NAtlntc
3.1	Eutelsat 3B (0.1 degs.)	4 Fixed Widebeams over EUR+ME
4.1	AEHF-1 (4.3 degs)	Reconfigurable Phased Arrays (Hopped)
6.0	WGS F1	10 Steerable 900Km/1.5 deg NCA Spots
7.2	Eutelsat 7A Konnect	91 Fixed Beams over EUR+AF
7.0	Eutelsat 7B (0.1 degs.)	Widebeam Coverage over EUR
9.1	Eutelsat 9A (KA-SAT, 0.1 degs.)	81 Beams over EUR
11.0	Inmarsat GX5 (5F5)	72 Fixed Beams over EUR+ME
16.0	Eutelsat 16A (0.1 degs.)	Widebeam Coverage over EUR
20.0	Arabsat-5C (0.1 degs.)	10 Fixed Beams over Saudi Arabia
23.5	Astra 3B (0.1 degs.)	Widebeam Coverage over EUR
25.5	Es' Hail 1	Widebeam Coverage over MENA
26.0	BADR-5 (Arabsat 5)	Steerable Widebeam over Saudi Arabia
26.0	BADR-7 (Arabsat 6B)	24 Fixed Beams over ME+AF
28.2	ASTRA 2F (0.1 degs.)	Spot Coverage over France
28.5	ASTRA 2E (0.1 degs.)	Spot Coverage over WEUR
28.2	ASTRA 2G	Spot Coverage over France
30.5	Arabsat-5A (0.1 degs.)	Steerable Widebeam over Saudi Arabia
30.5	Arabsat-6A	5 Fixed Spotbeams over Central AF
31.5	ASTRA 5B (0.1 degs.)	2 Fixed Beams over N-EUR
31.0	Hylas 2 (0.1 degs.)	24 Fixed Beams over AF+ME+EUR
36.1	Express AMU 1	18 Fixed Beams over Russia
37.8	Athena-Fidus (Mil-Ka)	Mil-Ka
39.0	Hellas-Sat 3 (0.1 degs.)	Widebeam Coverage over EUR
42.5	Nigcomsat 1R	3 Fixed Beams over SAF,NG,EUR
42.0	Turksat 4A (0.1 degs.)	Widebeam Coverage over EUR
47.6	Yahsat 1B	61 Fixed Beams over ME+AF
49.0	Yamal 601	32 Fixed Beams over Russia
50.0	TurkSat 4B	12 Fixed Beams over E-EUR
54.5	AEHF-5 (4.6 degs.)	Reconfigurable Phased Arrays (Hopped)
55.1	GSAT 29	5 Fixed Beams + 1 Steerable over India
56.5	Inmarsat 5-F4	72 Fixed 1200km/2 deg at Nadir Beams
56.5	Inmarsat 5-F4	6 Steerable 900km/1.5 deg HCM/HCX Spots
57.5	WGS F2	10 Steerable 900Km/1.5 deg NCA Spots
60.3	WGS F10	10 Steerable 900Km/1.5 deg NCA Spots
62.6	Inmarsat 5-F1	72 Fixed 1200km/2 deg at Nadir Beams
62.6	Inmarsat 5-F1	6 Steerable 900km/1.5 deg HCM/HCX Spots
65.0	Amos-4 (EUR+Asia)	1 Steerable Beam over India, Pakistan
74.0	GSAT-11 (0.1 degs.)	4 Fixed Beams over India
74.9	ABS-2 (0.1 degs.)	Widebeam Coverage over MENA
88.4	WGS F4	10 Steerable 900Km/1.5 deg NCA Spotbeams
110.5	ChinaSat 16 (SJ-13)	26 Fixed Beams over China
137.8	AEHF-6 (6.2 degs.)	Reconfigurable Phased Arrays (Hopped)
140.0	Express-AM5	10 Fixed Beams over Asia
140.3	NBN-CO-1A (Sky Muster 1)	99 Fixed Beams over Australia
149.8	WGS F8	10 Steerable 900Km/1.5 deg NCA Spotbeams
150.0	JCSAT 1C (Kacific-1, JCSat 18)	56 Fixed Beams over Micronesia,AUS,NZ
172.0	Eutelsat 172B	1 Fixed Beam over Hawaii
175.0	WGS F7	10 Steerable 900Km/1.5 deg NCA Spotbeams
179.8	WGS F3 (0.1 degs.)	10 Steerable 900Km/1.5 deg NCA Spotbeams
179.6	Inmarsat 5-F3	72 Fixed 1200km/2 deg at Nadir Beams
179.6	Inmarsat 5-F3	6 Steerable 900km/1.5 deg HCM/HCX Spots

Challenge: Trying to "Cover them All" with Analog IF

17.3 – 21.3 GHz, 1000 MHz IF, 500 MHz Separation

Band Number	Min Freq. (MHz)	Max Freq. (MHz)	LO (MHz)	Min IF (MHz)	Max IF (MHz)	Per Band (MHz)
1	17300	18300	16350	950	1950	1000
2	17800	18800	16850	950	1950	1000
3	18300	19300	17350	950	1950	1000
4	18800	19800	17850	950	1950	1000
5	19300	20300	18350	950	1950	1000
6	19800	20800	18850	950	1950	1000
7	20300	21300	19350	950	1950	1000

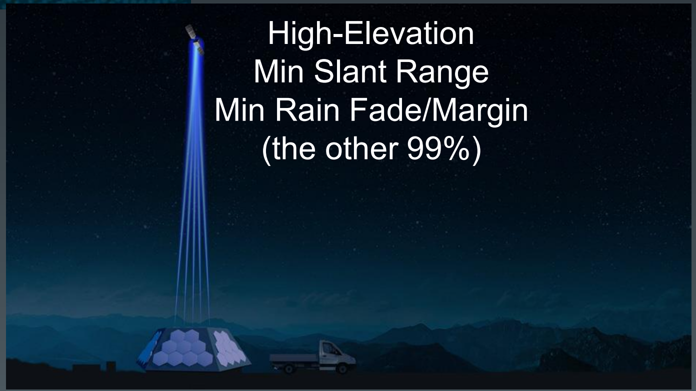
Hardware Challenge: Requires multiple PCB Designs and leads to degradation in LO leakage and image rejection, increase in current and significant price increases.

A Ground SATCOM Example: SW-Defined Multi-Beam Gateway (MPG)

A modular ground antenna system enabled by digitally combining independently controlled antennas into a compact, highly efficient array to enable operation on a wide array of GSO and NGSO networks

Increase Capabilities:
- Software-defined beamforming
- Simultaneously track multiple satellites
- Dynamically adapt to changing link demands
- Infinitely reconfigurable (1, 2, 4, 8 Beams)
- Modular, customizable and quickly scalable
- Superior acquisition and tracking
- Lower TCO

Decrease TCO:
- Rapid deployment
- Lighter weight with lower infrastructure costs
- Small footprint and efficient real estate usage
- Efficient spectrum utilization
- Network agnostic (DIFI)



Ideally-Suited for (15 dB+) Spatial Diversity Gain Exploitation (1x12m → 2 x 2m)

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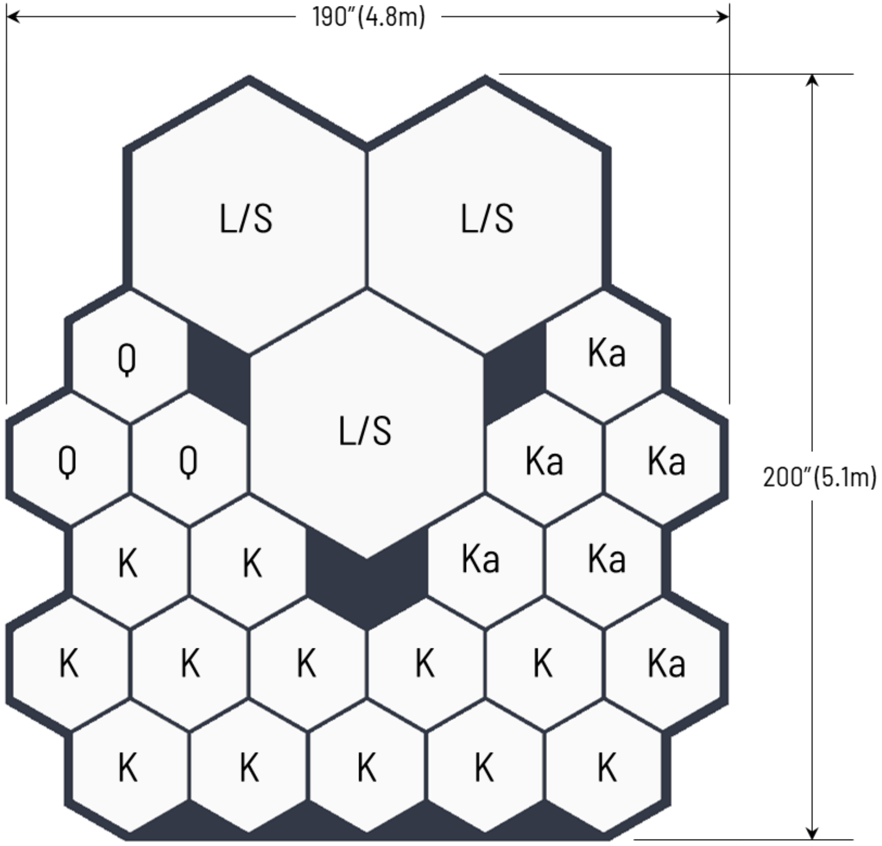
Enables Dynamic SW-Defined Multi-Beam Capability

- On-demand reconfigurability of beam count, beam position, polarization, performance (equivalent dish size)
- Independently controlled elements are coherently combined locally or in the cloud
- Utilize all available modules at any given time to track a single high value satellite or split the array as needed to track multiple satellite passes
- Instantaneous digital beamforming within a mesh network with high beam agility to dynamically adapt to changing demands in real time
- Multi-Band, Multi-Orbit, Multi-Constellation, Multi-Network (LEO, MEO, GEO, HEO)

Multi-Band and Multi-Beam Examples (L-, S-, K-, Ka-, and Q-bands)



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(Some) S/W-Defined Multi-Beam Use Cases

- Doesn't act as a large target for enemies
- If compromised, no ability to tell which direction antennas are pointed
- Low-profile & low-power
- Discrete installation
- Modular
- Scalable to meet mission data rate requirements
- Antennas operate with no visible movement
- Fixed or OTM applications

Shrouded

Container Embedded

Vehicle Embedded

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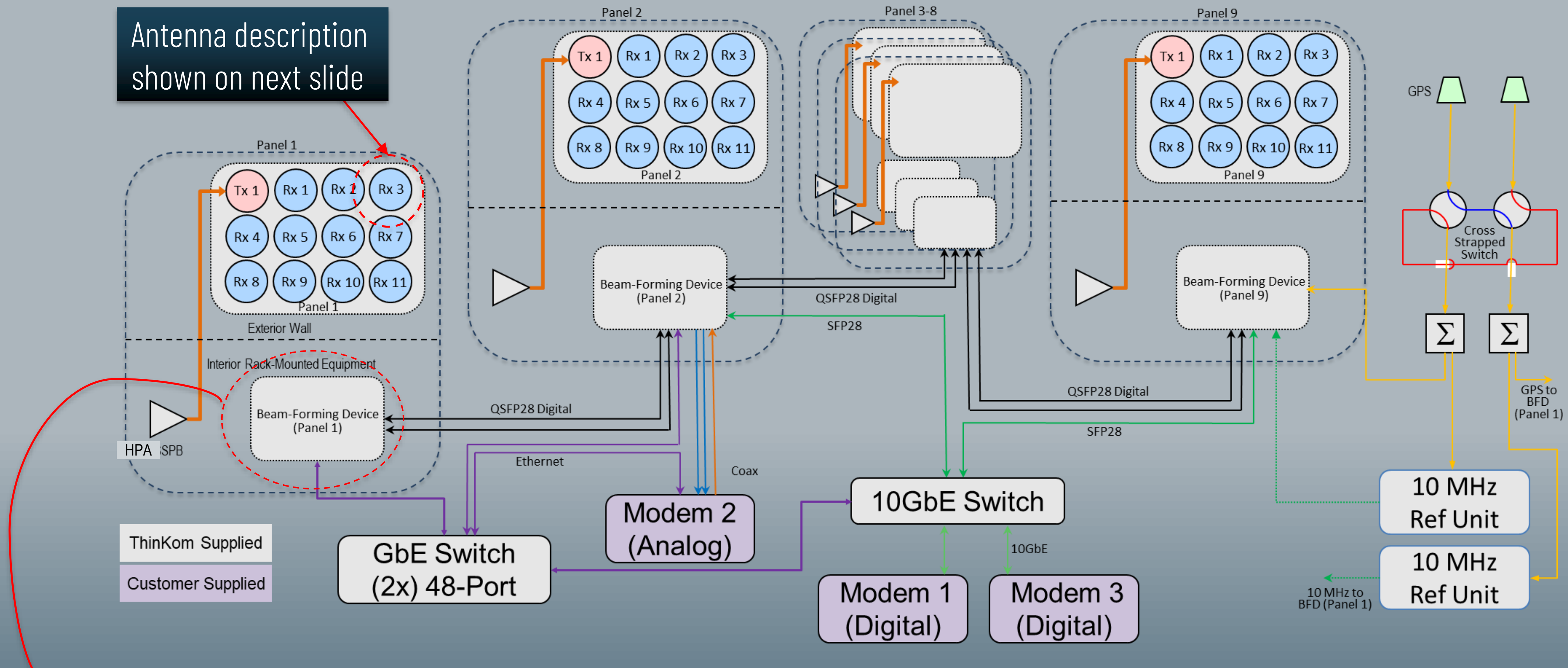
S/W-Defined Multi-Beam SATCOM – for Maritime

- Maintains low radar cross-section by mounting sub-flush to superstructure

- Distributed aperture avoids blockages while enabling link closure throughout roll and pitch motion in any sea state

MBG Block Diagram – Requiring Multiple Modems



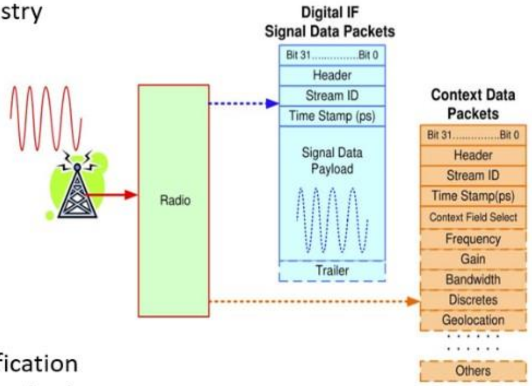
Beamforming Device (BFD)

- As the brains of the entire system, the BFD digitally combines the signals from multiple antenna modules (up to 16) to form any number of beams, including a single beam that scales with the combined active area of the antennas
- The BFD has the intelligence to maintain constant gain and phase-continuous signals during satellite handoffs. It also electronically manages sky scanning, fast acquisition, precision tracking and signal discrimination
- The BFD allows for complete modularity of antenna combining and can integrate with other BFDs creating a true mesh system with one interface
- The combined signals the BFD sends to the customer-supplied modem can be analog or digital, making it completely agnostic
- Antenna outputs can be coherently combined locally or in the cloud

If Resiliency Implies ➔ Multi-Modem, Multi-Beam, Multi-Band, Multi-Orbit, Multi-Constellation, Waveform-Diverse, SW-Defined SATCOM Terminal Capability – HOW??

Digital IF Interoperability (DIFI) Consortium

- Goal: Wide adoption of an interoperable Digital IF standard
  - Match the interoperability that is native to analog IFs (e.g. L-band)
  - Create an open, simple, interoperable digital IF standard, and encourage its adoption throughout the industry
  - Encourage adoption of the standard throughout the industry
- Purpose:
  - Define an interoperable standard based on VITA-49
  - Design standard for easy adoption
  - Publish as an open, referenceable standard
  - Provide a way to certify compliance
  - Market the standard through the satellite industry
- Structure: simple as possible
  - Leverage IEEE-ISTO to manage the Consortium and specification
  - Free spec, straightforward certification, membership a good value



DIFI Consortium Proprietary

ISTO | IEEE
INDUSTRY STANDARDS AND TECHNOLOGY ORGANIZATION

DIFI

IEEE-ISTO Std 4900-2021:
Digital IF Interoperability Standard

Version 1.2.1
Feb 7th, 2025

"Coming to the Rescue" – the DIFI Consortium is Defining, Standardizing (and Enabling) the Future for Multi-Provider, Multi-Orbit, Multi-Band, and Multi-Beam SATCOM Terminals!...

DIFI Can/Will Harmonize all of the "Multi's that Resilient SATCOM Demands

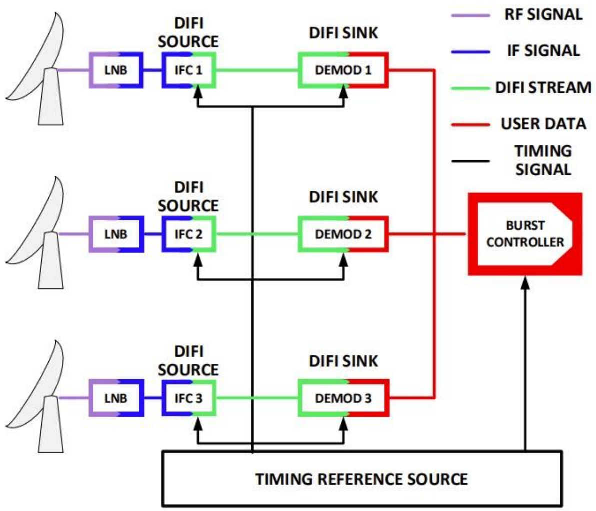


Figure 38. TDMA System Multi-source.

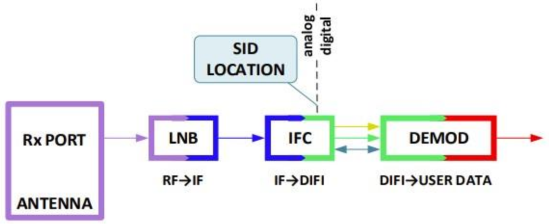


Figure 12. SID location – analog IF to DIFI

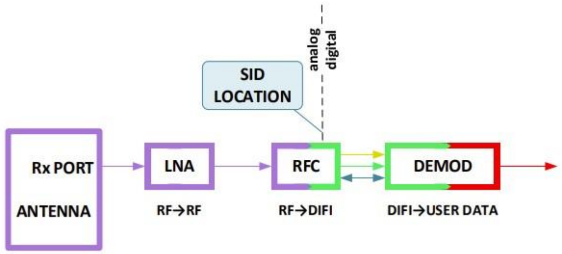
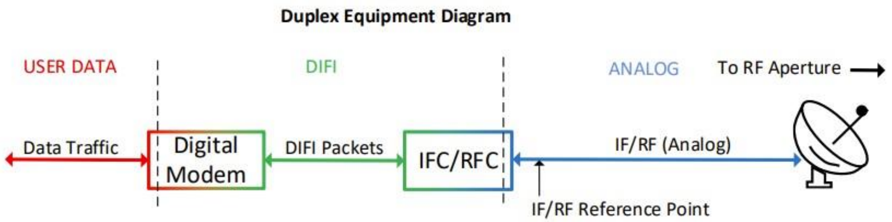


Figure 13. SID location – analog RF to DIFI



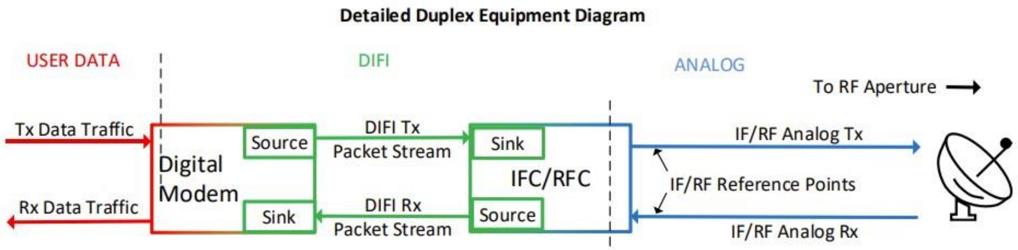


Figure 2. DIFI Standard Conventions

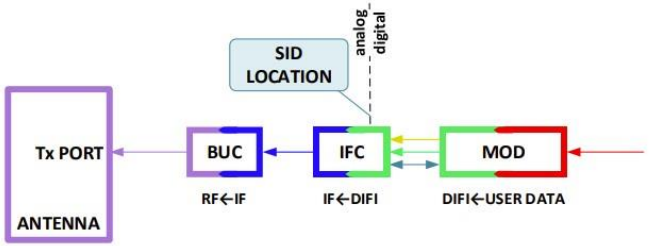
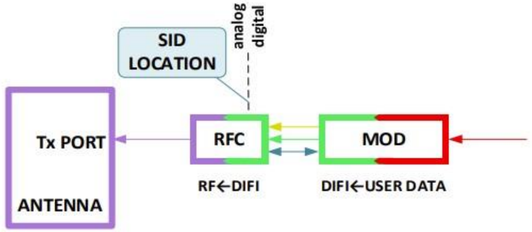


Figure 14. SID location –DIFI to analog IF



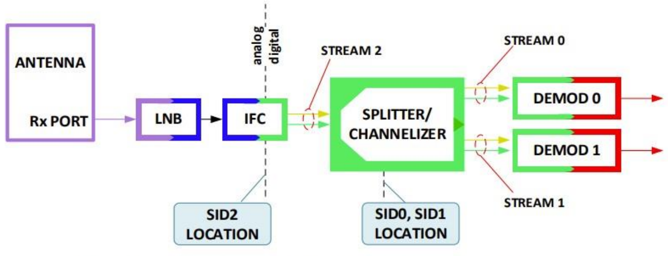


Figure 16. SID locations for category (iii) devices on the receive path.

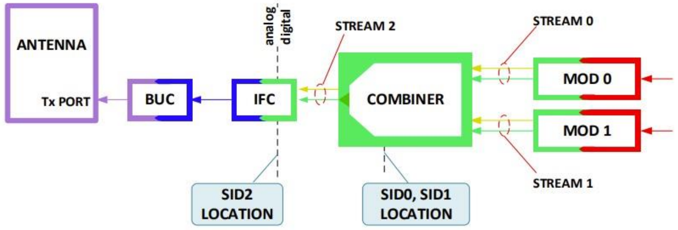


Figure 17. SID locations for category (iii) devices on the transmit path.

...AND including Specific Architectures for ESA (Phased Array) Antennas!

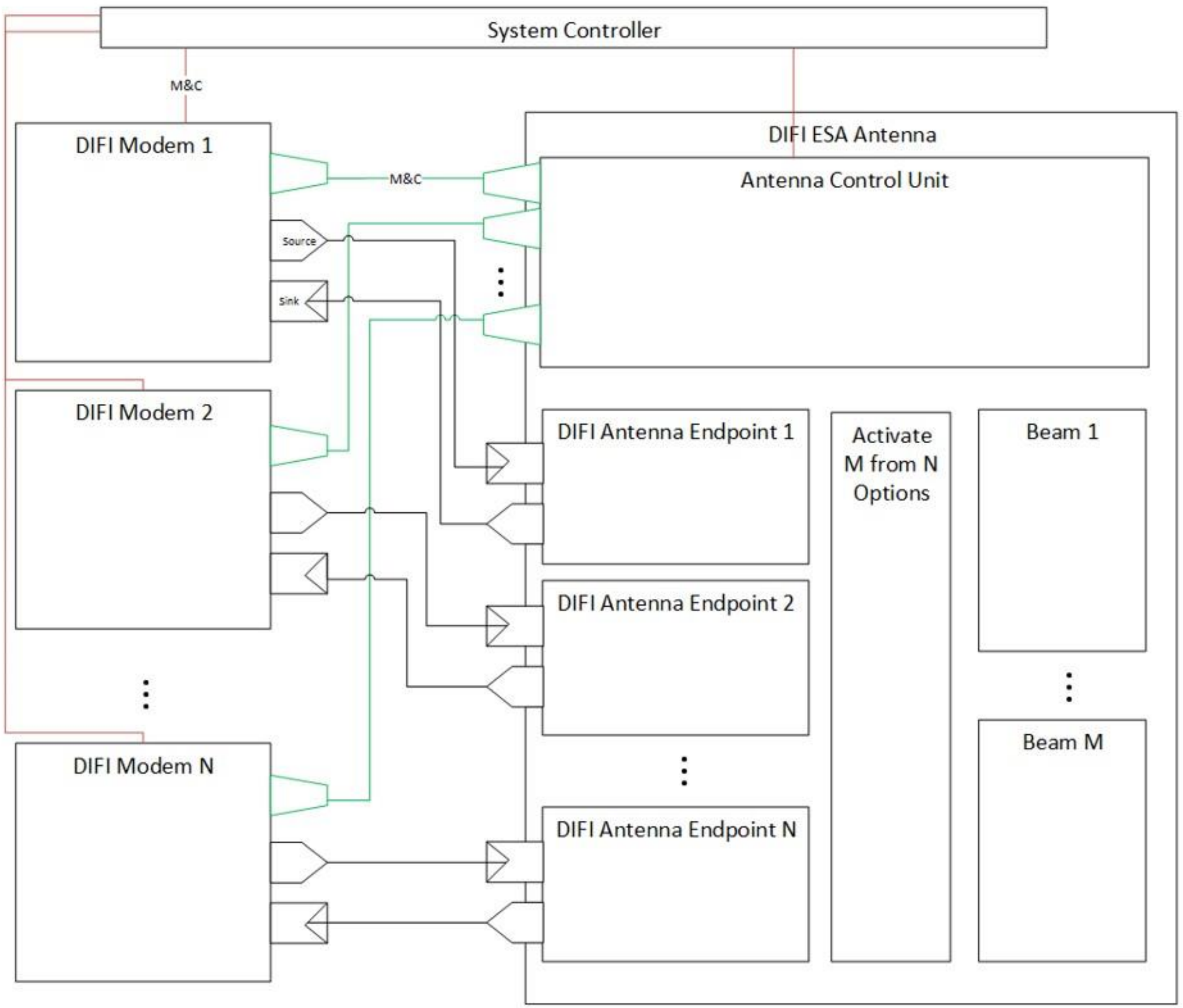
Requirements Definition for Management and Control Functionality of ESA in DIFI Deployments

ESA TWG

1 Executive Summary

This document describes the challenges and special characteristics of ESA antennas with respect to their interactions with a DIFI-aware modem in the form of requirements for configuration, control, management, and reporting. The features of DIFI as well as the unique behavioral properties of ESA do not require special handling of the waveform data stream, but do require additional information to be specified or transferred to ensure efficient and effective operation of the integrated terminal. The particular features of ESA antennas considered in this document for include multiple beams, fast beam switching during handovers, variable performance with scan or other operational state, and non-monolithic Rx and Tx RF chains.

Contents



Thank you!

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