Клъстер АЕРО-КОСМИЧЕСКИ ТЕХНОЛОГИИ, ИЗСЛЕДВАНИЯ И ПРИЛОЖЕНИЯ
Cluster AERO-SPACE TECHNOLOGIES,RESEARCH AND APPLICATIONS

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Low Profile Tracking Ground-Station Antenna Arrays for Satellite Communications

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Outline

- High gain ground station antennas
- New ITU Frequency Bands Allocated for Small Satellites
- Antenna Arrays versus Reflectors at High Frequencies
- Low Profile Antenna Arrays
- Control and Tracking of Satellite Terminal Antennas
- “On-the-Move” Antenna Systems and Design Examples
- Conclusion and references

High Gain Ground Station Antennas

Using high-gain antennas and higher frequency bands are decisive in order to achieve high data rate communication with small satellite missions

Simplified link equation - carrier to noise spectral density

uplink $\frac{C}{N_0}\,[dB/Hz] = EIRP_{GS} + \left[\frac{G}{T}\right]_{sat} - LOSS + 228.6$

For small satellite $G \approx 5-7\ dB$

$T \approx 190\ K^0$ and $\frac{G}{T} \approx -15\ dB/K$

downlink $\frac{C}{N_0}\,[dB/Hz] = EIRP_{sat} + \left[\frac{G}{T}\right]_{GS} - LOSS + 228.6$

For small satellite $EIRP = 10 log P_{sat} G_{sat\ ant} \approx 10\ dBW$

$R_b = \left(\frac{C}{N_0}\right) - \left(\frac{E_b}{N_0}\right)$ Simplified data rate equation

$R_b = 10 \log r_b$ Data rate

$B = \frac{R_b}{\Gamma}$ Required radiochannel bandwidth

Spectrum efficiency

Tracking High Gain Antennas

- High gain antenna concentrates energy in the direction toward satellite forming a sharp beam
- In order to support required link reliability antenna needs to track the satellite
- The following communication scenarios are typical for high gain tracking antennas
  - Mobile antenna communicating with geostationary satellite
  - Fixed ground station antenna communicating with non geostationary satellite (LEO,MEO or HEO)
  - Mobile station communicating with non geostationary satellite

International Amateur Satellite Frequency Allocations

Range	Band	Letter	Allocation	Preferred sub band	User status	Notes
HF	40m		7.000 MHz-7.100 MHz		Primary	
	20m		14.000 MHz -14.250 MHz		Primary	
	17m		18.068 MHz-18.168 MHz		Primary	EARB
	15m	H	21.000 MHz-21.450 MHz		Primary	EARB
	12m		24.890 MHz-25.990 MHz		Primary	EARB
	10m	A	28.000 MHz-29.700 MHz	29.300 MHz-29.510 MHz	Primary	EARB
VHF	2m	V	144.000 MHz-146.000 MHz	145.800 MHz-146.000 MHz	Primary	
	70cm	U	435.000 MHz-438 MHz		NIB	
UHF	23cm	L	1.260 GHz-1.270 GHz		NIB	Only uplink allowed
	13cm	S	2.400 GHz-2.450 GHz	2.400 GHz-2.403 GHz	NIB	
	9cm	S2	3.400 GHz -3.410 GHz		NIB	Not available in ITU region 1

International Amateur Satellite Frequency Allocations -Cont.

Range	Band	Letter	Allocation	Preferred sub band	User status	Notes
SHF	5cm		5.650 GHz-5.670 GHz		NIB	Only uplink allowed
			5.830 GHz-5.850 GHz		Secondary	Only down link allowed
	3cm	X	10.450 GHz-10.500 GHz		Secondary	
	1.2cm	K	24.000 Ghz-24.050 GHz		Primary	
	6mm	R	47.000 GHz-47.200 GHz		Primary	EARB
	4mm		76.000 GHz-77.500 GHz		Secondary	
EHF			77.500 Ghz-78.000Ghz		Primary	
			78.000 GHz-81.000GHz		Secondary	
	2mm		134.000 GHz-136.000 GHz		Primary	EARB
			136.000 GHz-141.000 GHz		Secondary	
	1mm		241.000 GHz-248 GHz		Secondary	
			248.000 Ghz-250.000 GHz		Primary	EARB

NIB=Use is only allowed on a non-interference basis to other users; **EARB**=Entire Amateur Radio Band

REFLECTOR Versus ARRAY Antennas

Advantages and Disadvantages

In-motion Reflector Antenna

- Relatively large sweep volume
- Multiband operation easy to achieve
- Relatively low cost per dB Gain
- Mechanical beam pointing

In-motion Array Panel Antenna

- Small form factor, lower profile
- Shape and size can be tailored
- Efficient volume utilization
- Comparable performance even for highly asymmetrical shapes
- Different beam pointing options- mechanical, electronic or mixed

Low Profile Antennas

Design approaches

- **Low profile is highly desirable for reduction of visual signature**
- **Array technology provides options for beam steering, profile and performance optimization**
- ***Zenith panel* -** full electronic or mixed (electronic-mechanical) beam steering and very low profile
- ***Tilted panel*** - fully mechanical or mixed beam steering, performance optimization
- ***Multi-panel*** – mechanical steering, optimal performance for a given volume

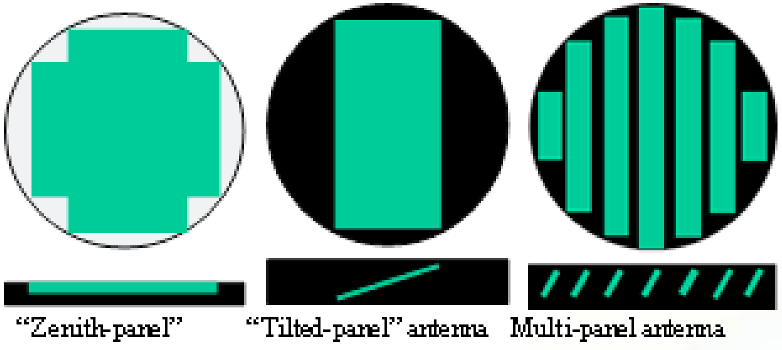
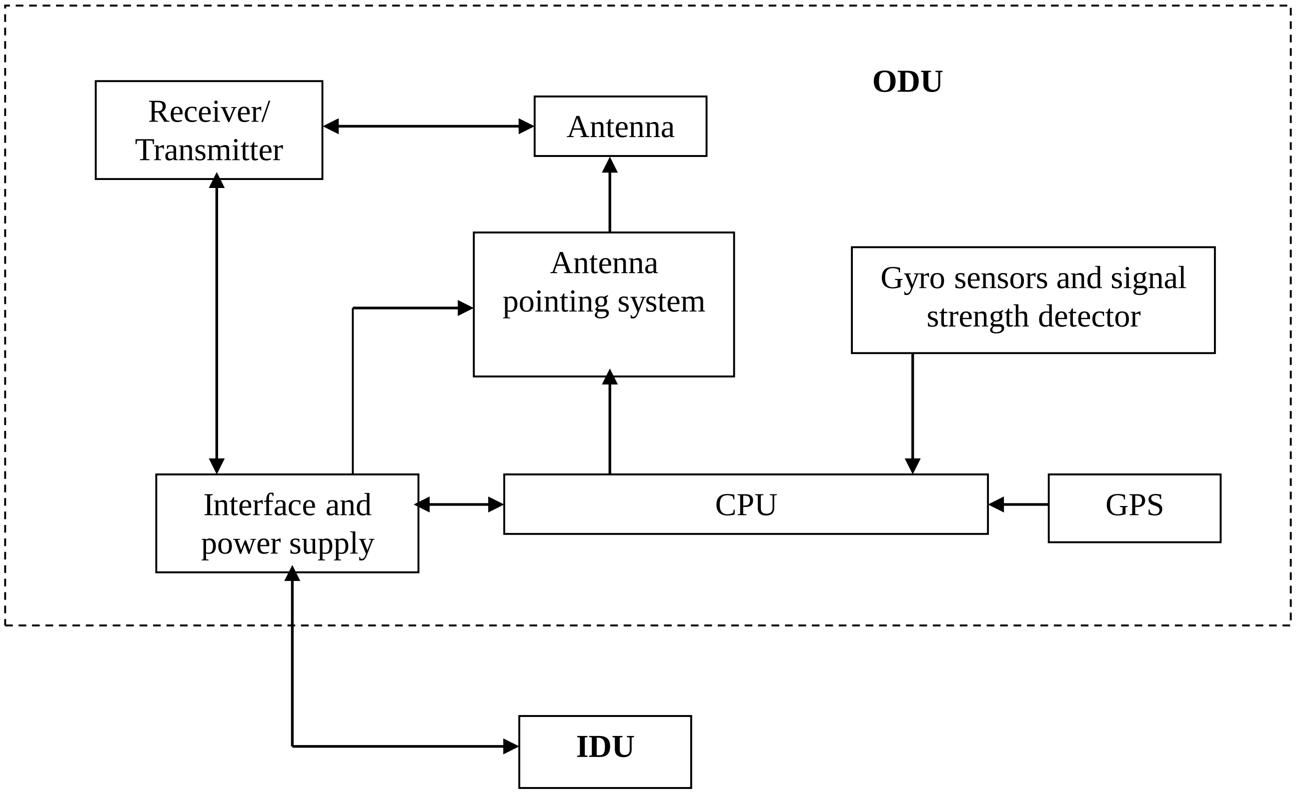


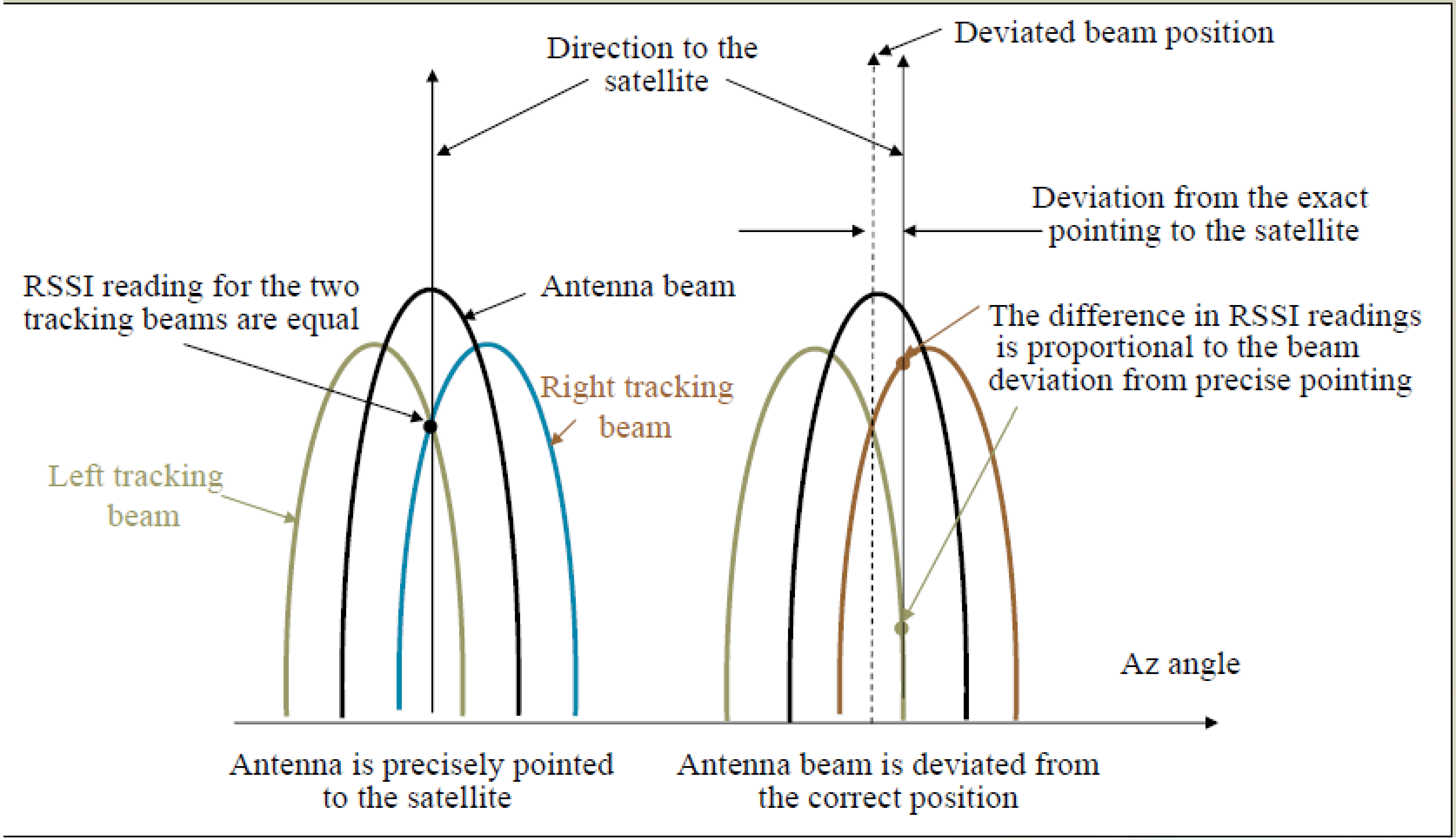
Fig. 1. Flat-panel antenna configurations

Control and Tracking of Satellite Terminal Antennas



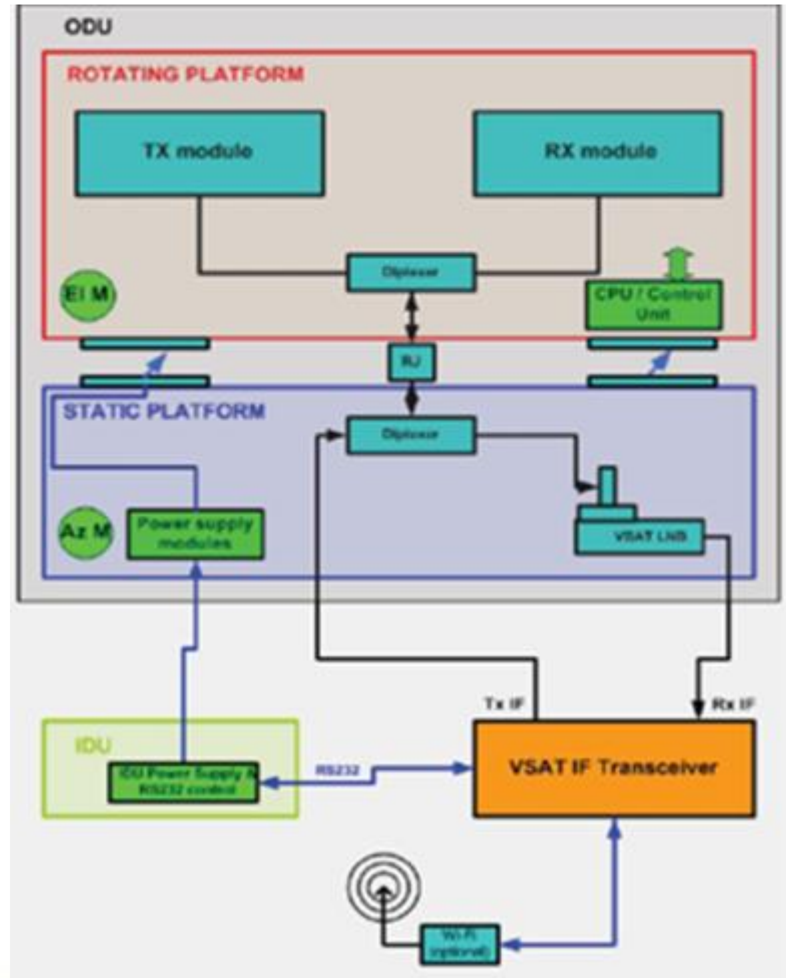
Tracking antenna block diagram

Close-loop tracking technique using “tracking beams”



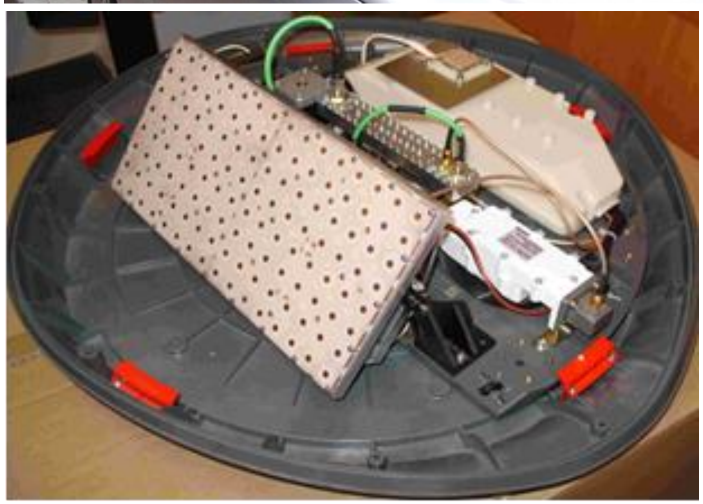
Design example- Multi-Panel SOTM – StealthRay 2000

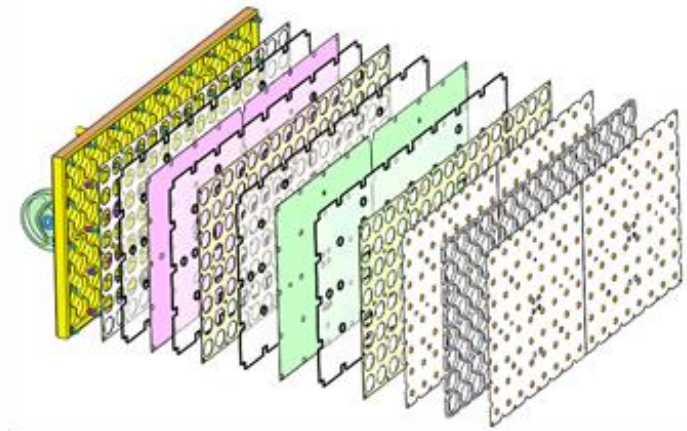
Low Profile SOTM Antenna for Commercial Applications

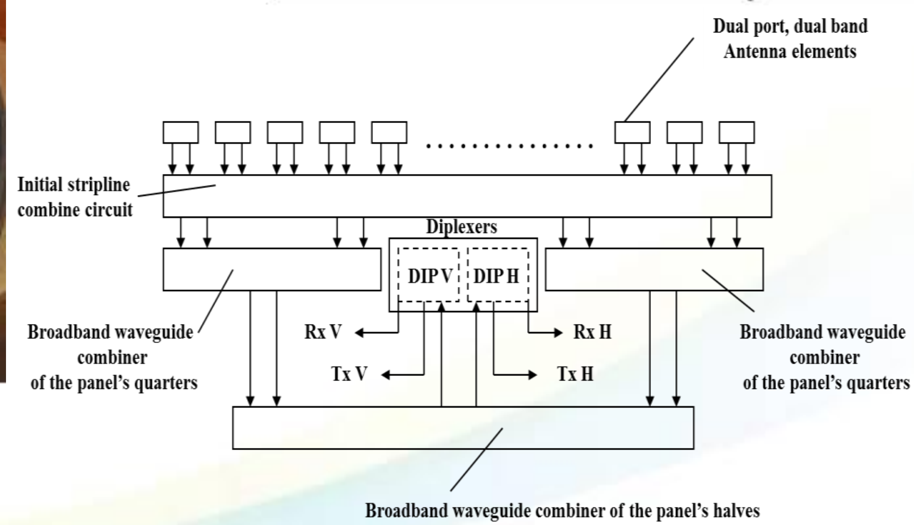


Design example – StealthRay 250

Small Footprint SOTM Antenna for Commercial Applications

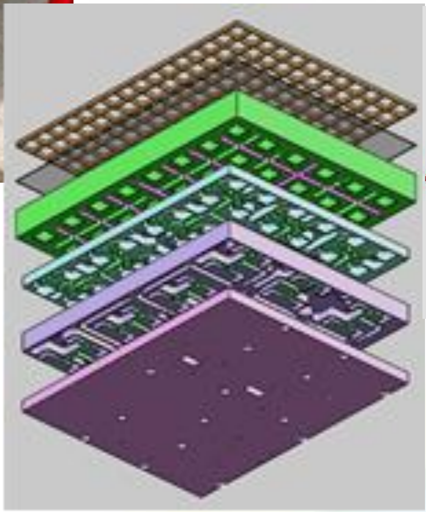


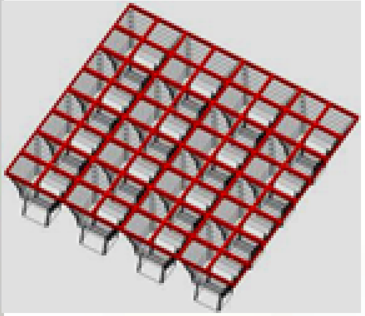




Design example -Tilted-Panel SOTM – EagleRay 7000

High-performance SOTM for Commercial Applications





Low Profile SOTM - Typical Applications

Commercial Application

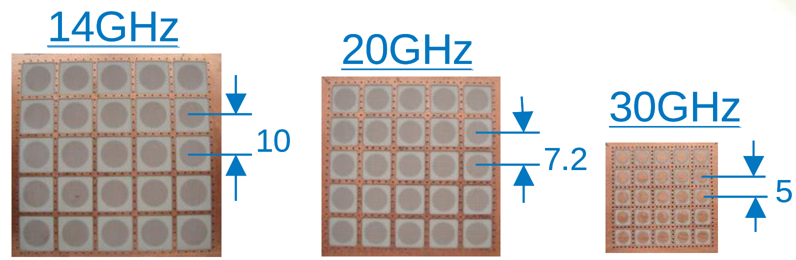
- Live satellite TV and Internet in cars, RVs and VIP vehicles
- Maritime satellite TV and Internet in yachts, cruise ships, ferries
- On-line fat pipe for custom content
- Telemedicine
- News gathering

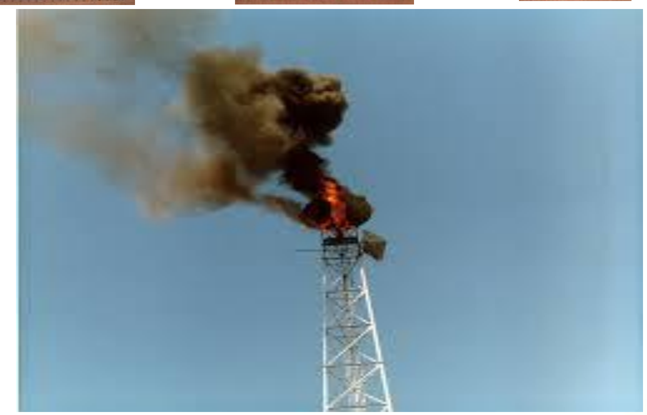
Defense and Security Applications

- Military C4I on-the move
- Homeland and national security applications
- UAV broadband communications
- Rescue services
- First responders backup communications
- Backhauling

Design example -Full Electronic Beam Steering Challenges

- Real estate – space between array elements dictated by frequency and FOV
- Power consumption and heat dissipation
- Antenna efficiency – planar array Gain degrades at low Elevation angles
- Complexity and cost – conventional FSS and BSS services require high gain large aperture antenna

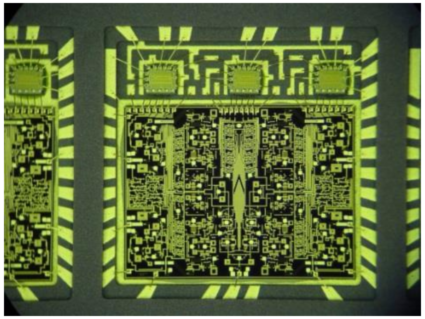




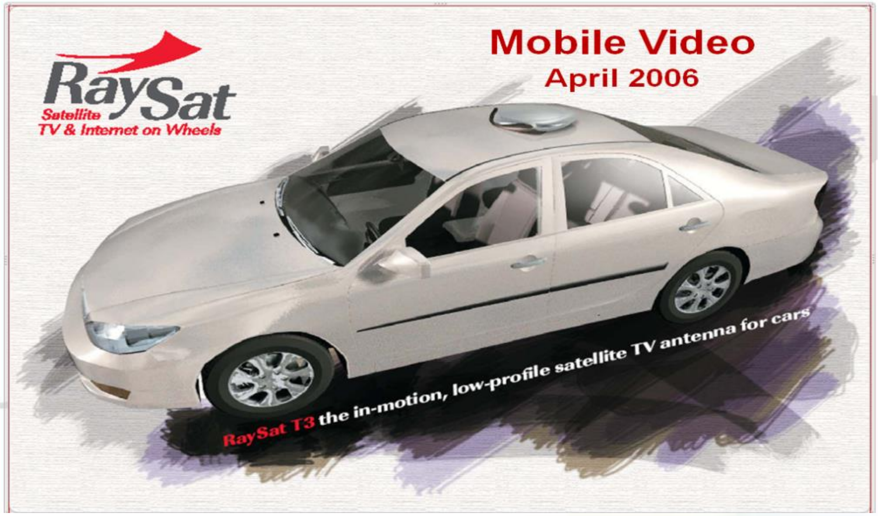
Full Electronic Control Tracking Antennas -design examples

First product was a Ku receive only antenna for passenger cars

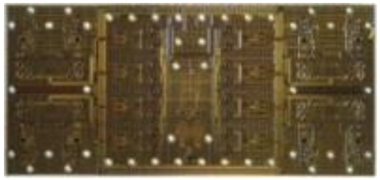
- **Antenna included 94 patches and was priced at $800 to consumer**
- **Based on highly integrated proprietary GaAs MMICS**



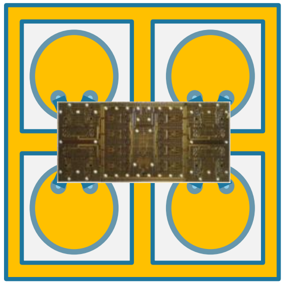
4 ports support two patches
22 mm^2 GaAs die in LTCC carrier matrix
>100K’s produced



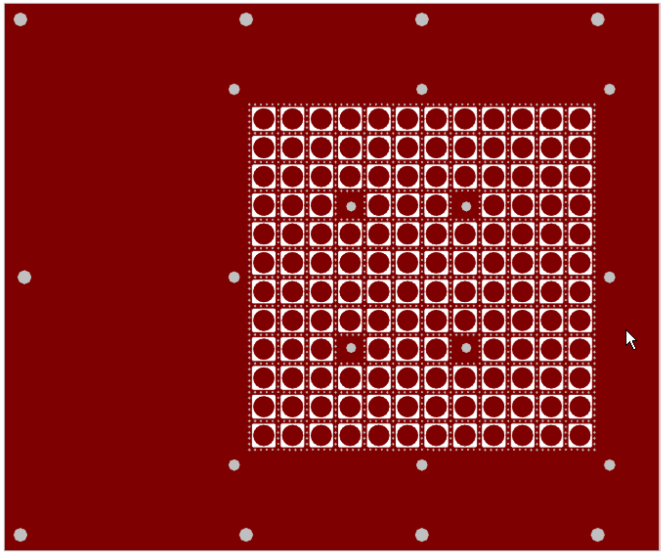
MMIC control approach…



- High density, mixed signal GaAs and SiGe chips
  - 4 or 8 RF channels, digital block, flip-chip



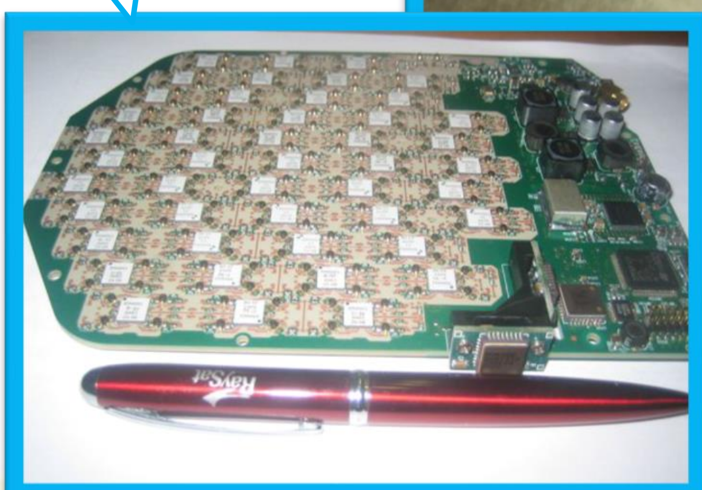
- Antenna unit cell
  - Chip drives 2 or 4 radiating elements
  - Planar design for low cost, high reliability and minimal signature



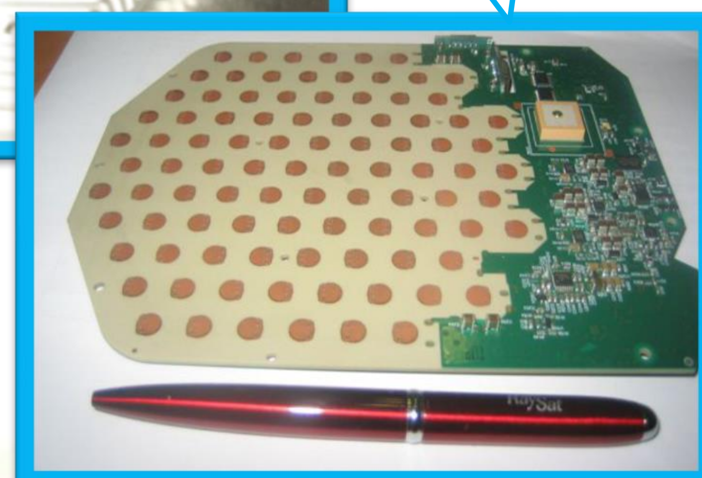
- Unit cell multiplied to create a complete antenna
  - Tracking circuitry, up/down converters
  - Scalable design - EIRP, G/T is proportional to array size

Receive-only PAA design example

Antenna Core
Bottom side



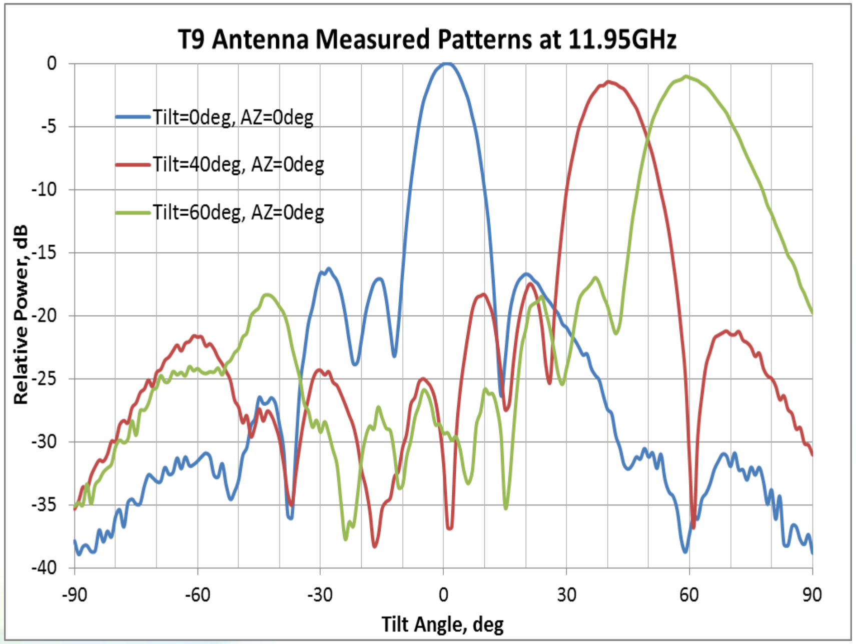
Antenna Core
Top side



Technical Specification

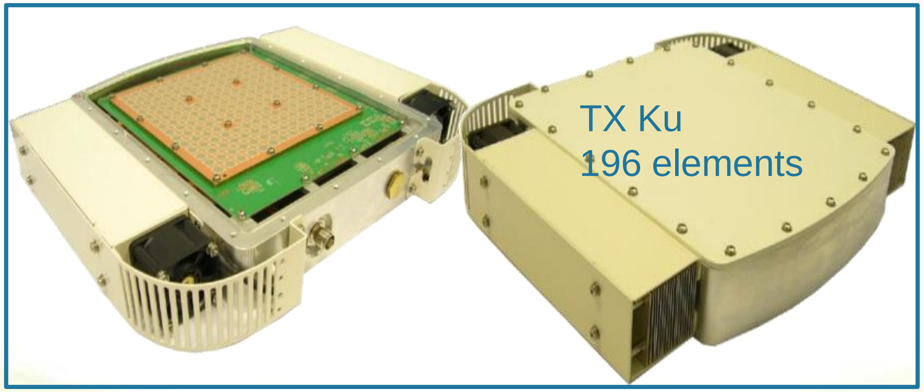
- **ODU dimensions:** 280x240x23 mm
- **ODU weight:** 1.2 kg
- **Frequency Band:** 11.7 - 12.75 GHz
- **Polarization**: Linear (auto control)
- **Cross Polarization:** >18 dB
- **Antenna G/T:** -4.5 dB/° K@30° EL
- **Tracking Rate:** >60º/second
- **Elevation Angle Range**: 30° - 90°
- **Azimuth Angle Range:** 360° continuous
- **Power supply:** 10-16V; 20W

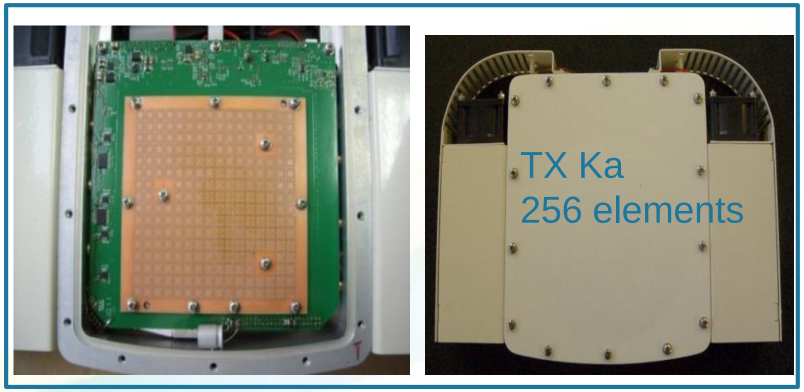
- **Antenna board includes**
  - 94 dual port patches
  - 47 RM4001 GaAs MMICs
  - 188 single-stage LNAs
  - Integrated GPS, CPU, LNB and power supply



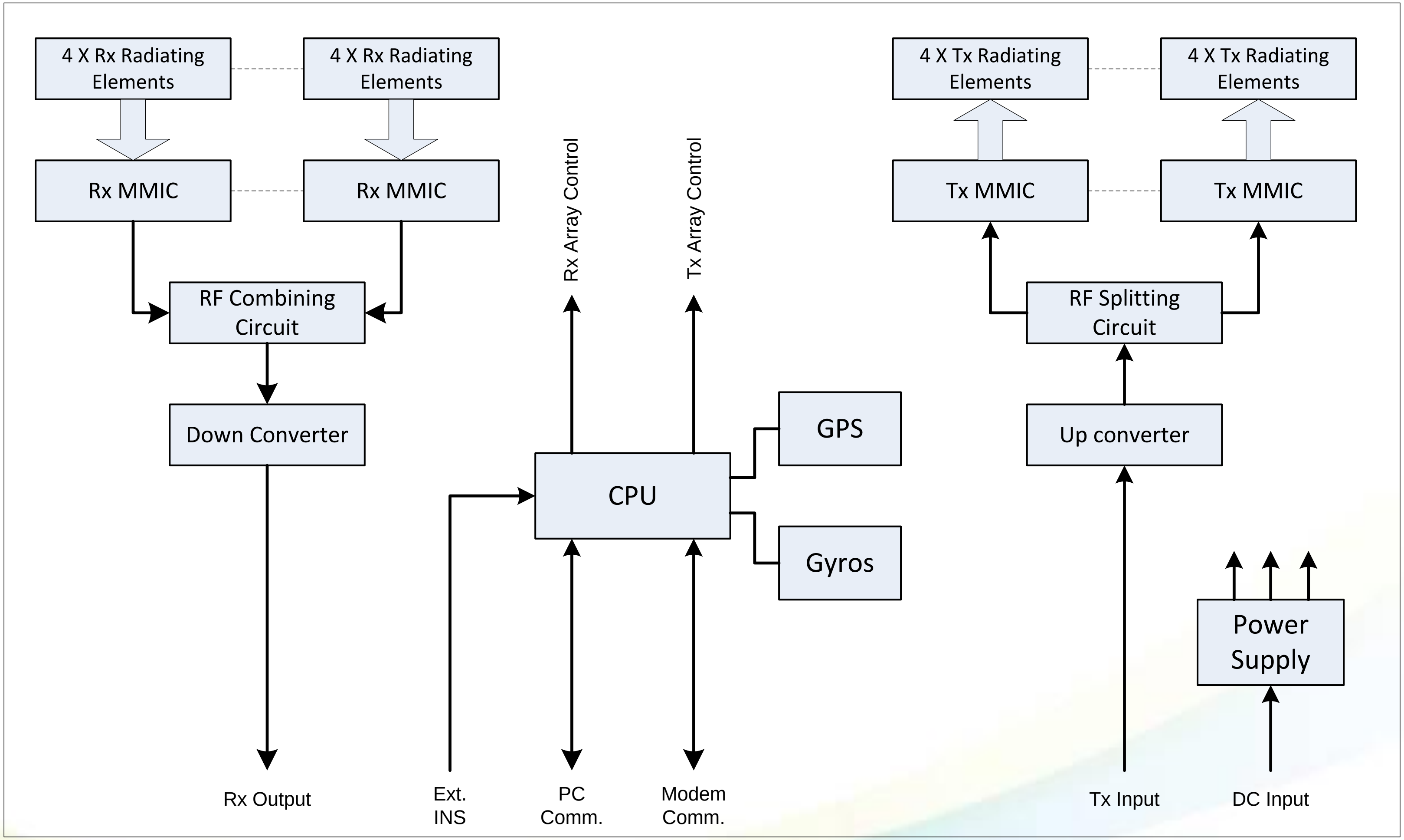
2-Way PAA design example

- Dual aperture (Tx, Rx) antenna architecture
  - Rx and Tx apertures may be at different size, according to mission requirements
- 8-channels SiGe MMIC
- Up / down frequency conversion built into antenna module
  - Directly interfaces with modem at standard L-band interface
- Using standard PCB and SMT assembly technology





PAA Simplified Block Diagram



2-Way PAA System Architecture

RX Antenna

TX Antenna

Modem + Antenna Controller
MLT/GLT 1000

Two-way Demo Installation

Mixed beam steering antenna design examples

- Lower cost and complexity alternative to full electronic beam steering antenna
- Allows for building “Full size” BSS antenna at “feasible” cost
- Receive only T2 antenna prototype build 2002 and successfully test on in-motion TV reception in Southwest USA
  - 2086 dual-port radiators
  - 780 discrete LNAs
  - 116 MMIC phase shifters
  - Terminal height: 6cm
  - Elevation Angle Range: 30° - 90°
  - G/T: >10dB/K (within FOV)

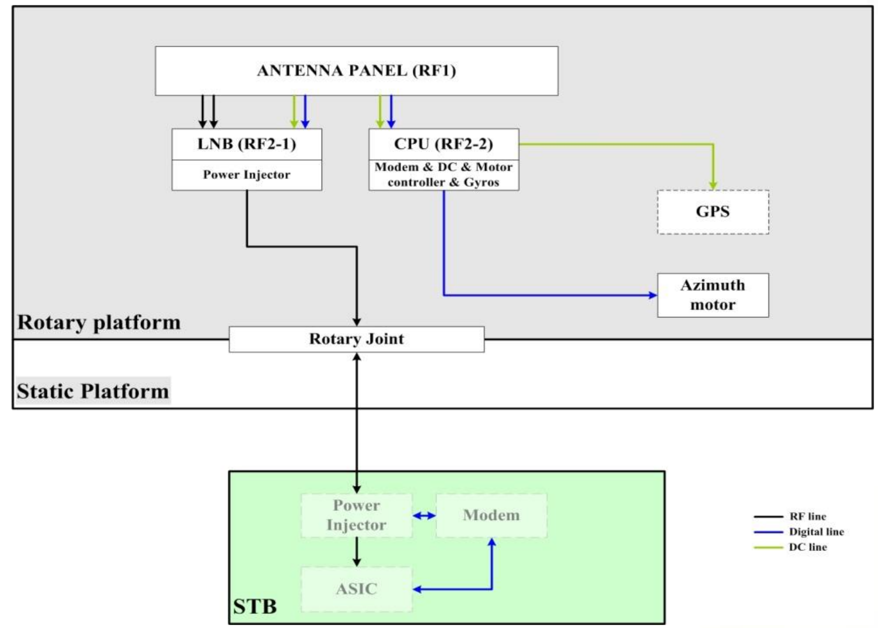
Low cost mixed steering antenna design example

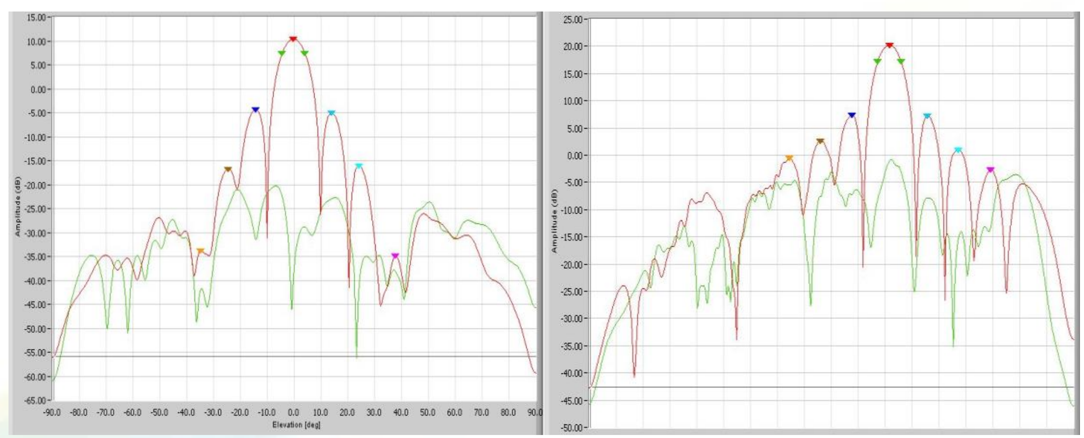
RaySat ANTENNA SYSTEMS
Satcom on-the-move

- T7 micro-antenna – receive only
- Developed for CruiseCast service in 2008
- Affordable cost for consumer market
- Dedicated "eco system"
  - Spread spectrum and signal coding
  - Interleaving protocol for buffering
- Mobile broad band service in USA
  - 22 channels of live TV
  - 20 channels of Satellite Radio
  - Data: mapping, traffic, weather, advert.

Technical Specification

- **Dimensions:** 286x264x110 mm
- **ODU weight:** 1.35 kg
- **Frequency Band:** 11.7- 12.75 GHz
- **Polarization**: Linear (auto control)
- **Cross Polarization:** >18 dB
- **Antenna G/T:** > -2.3 dB/°K
- **Tracking Rate:** 45º/second
- **Elevation Range**: +/-20° (from static tilt of 50°)
- **Azimuth Range:** 360° continuous
- **32 radiating elements**
- **4 MMICs RM4001**





Conclusions

- Using high gain tracking ground station antennas can improve significantly data rate communicating with small satellites
- Using recently allocated microwave frequency bands for amateur satellite communications broadband links with small satellite missions can be provided
- Broadband satellite communication technologies developed for mobile users can be successfully applied for high data rate links with small satellite missions

THANK YOU

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