Compact KU-Band T/R Module for Wide-Swath High-Resolution Radar Imaging of Cold Land Processes

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Agenda

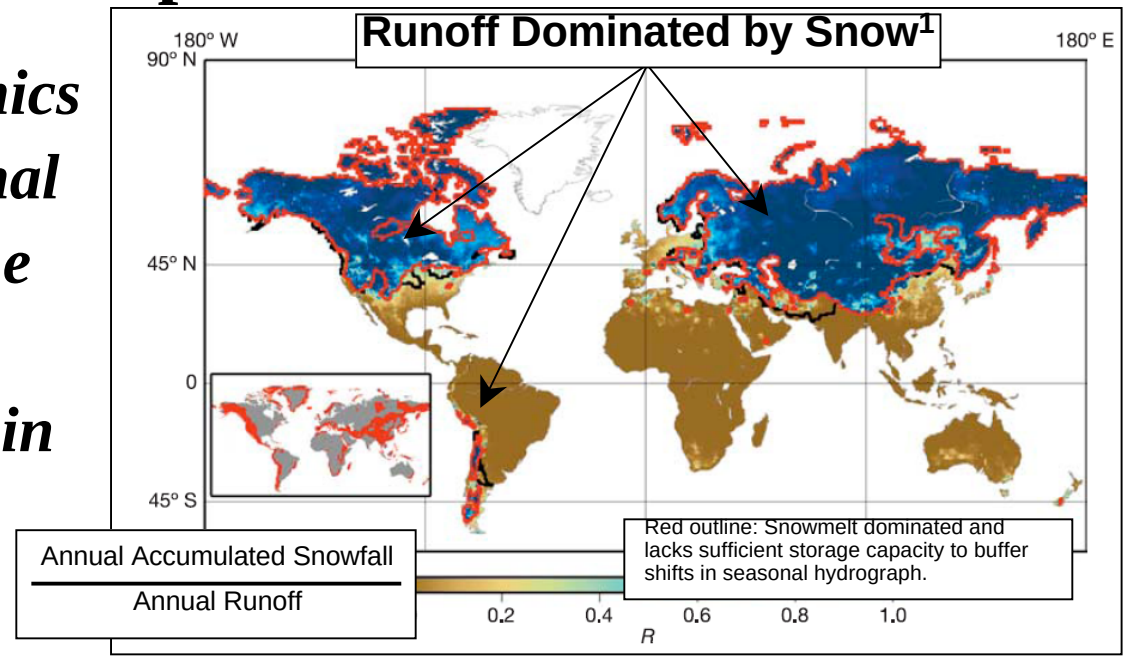
- Introduction
- Technical Development
  - Antenna Design
  - T/R Module Design
- Summary

Snowpack Provides Significant Water Supply

Runoff Dominated by Water from Snowmelt

- **Over much of the industrialized world (1/6 of world's population), 50-100% of runoff results from snowmelt[1], affecting about a quarter of the global gross domestic product.**

- ***Understanding the dynamics of water storage in seasonal snowpacks is critical to the effective management of water resources both within the U.S. and globally.[3]***



[1]Barnett et al, Nature (17), Nov 2005
[2]Anthes et al, p 4-39
[3]Anthes et al, p 4-38

Compact KU-Band T/R Module for Wide-Swath High-Resolution Radar Imaging of Cold Land Processes

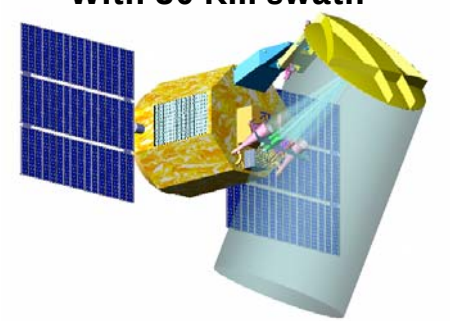
- **Objective: Develop compact Ku-band Transmit/Receive (T/R) modules to enable the electronic scanning of active phased array antenna beam for wide swath synthetic aperture radar (SAR) imaging of terrestrial snow cover**

Enables: Electronic scanning of wide swath Ku-band scanning SAR

How: Develop a dual-frequency (9.6 and 17.2 GHz), dual-polarized receive, high power (5W) T/R module

Current Technology Using Parabolic Reflector

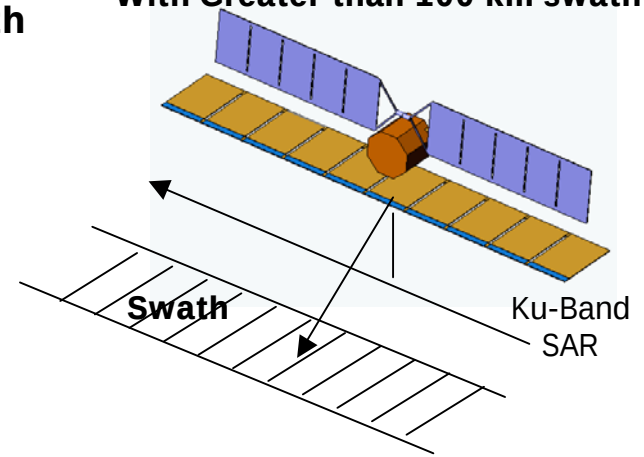
With 30 Km swath



- **Ku-band T/R Module Technology Enables 3-5 Times Increase in Swath Width**

Wide-Swath Phased Array Concept

With Greater than 100 km swath



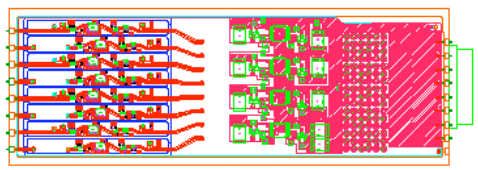
Key T/R Module Design Drivers

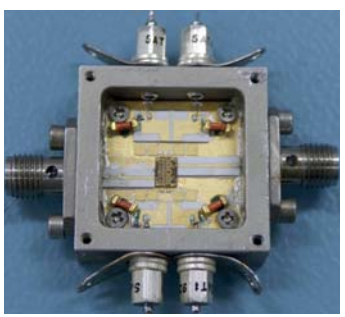
- Ku-band frequency design at 17.2 GHz
- Single polarization transmit and dual-polarization receiver
- High RF power output (>2W)
- Compact for integration with phase array
- Calibration stability (<0.2 dB)

Development Plan

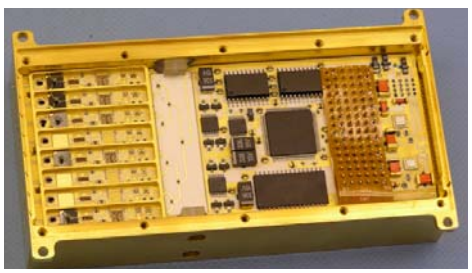
2006 (Phase 1) → 2007 (Phase 2) → 2008 (Phase 3)

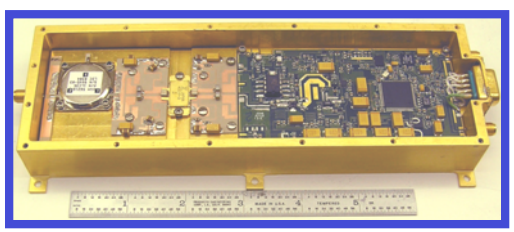
- SAR Requirement analysis
- Antenna configuration concept
- Detailed T/R design

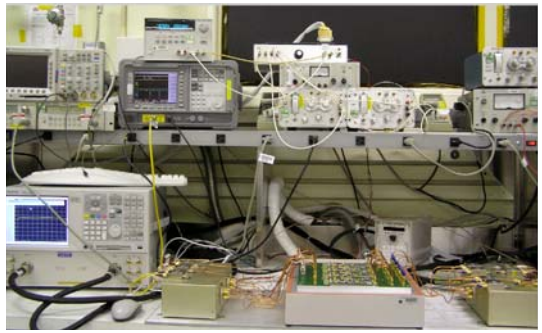


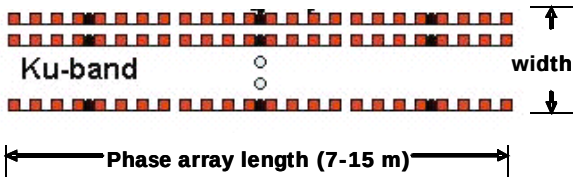


- T/R module subassembly and fabrication
- Antenna breadboard development







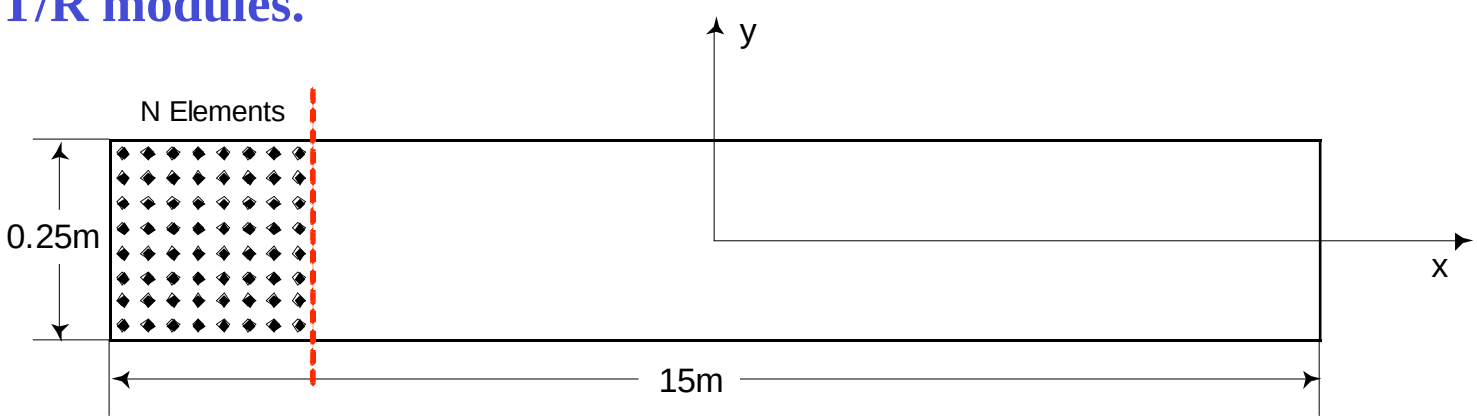


- T/R module assembly and test
- Antenna breadboard and T/R module I&T
- Spaceborne antenna performance

Compact Ku-band TR Module:
Development of a Dual Polarized Ku-band Microstrip Planar Array

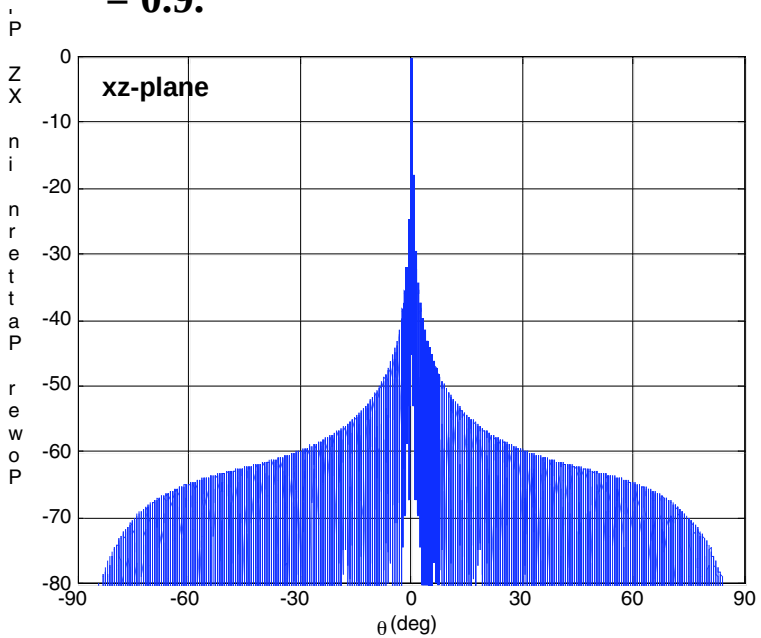
Desired Array Performance

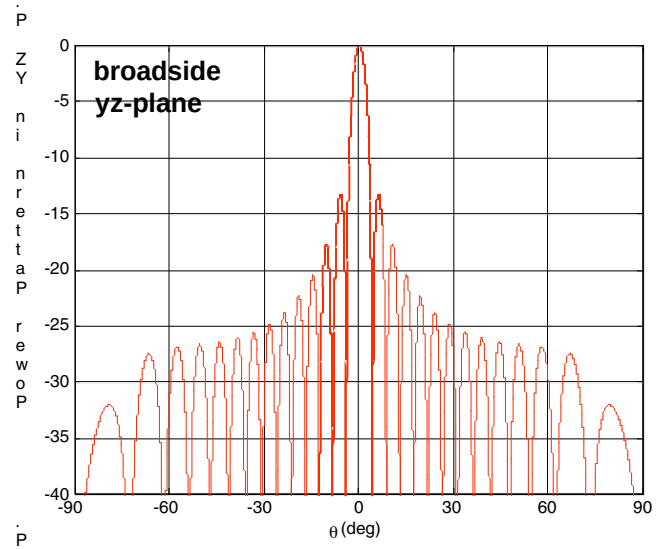
- An approximately 15m × 0.25m array operating at 13.4GHz.
- Horizontal and vertical polarizations.
- A broadside narrow beam with a desirable envelop in xz-plane.
- A steerable beam within ±6° in yz-plane without grating lobes. Sidelobe level less than -20dB at -40°.
- Output power ≈ 2kW or more, driven by T/R modules with a maximum output power of 5W/each. Each package contains four T/R modules.

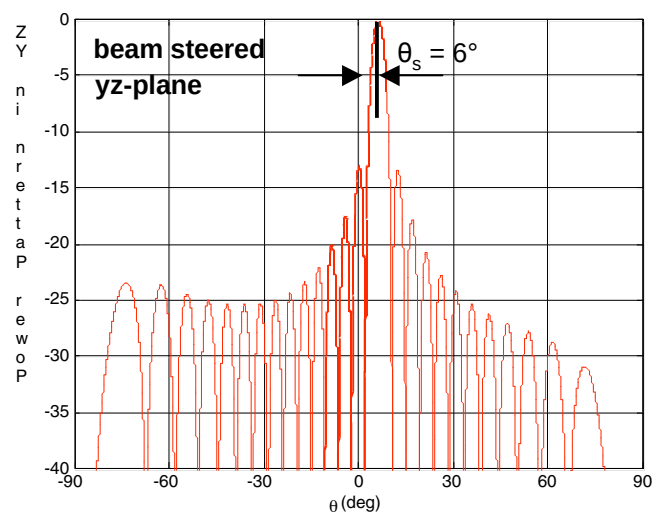


Desired Patterns of the Array

- $d_x = 0.70\lambda_0$ (15.7mm); $d_y = 0.85\lambda_0$ (19.0mm)
- $\cos^q(\theta)$ element pattern: $q_x = 1.3$, $q_y = 0.9$.

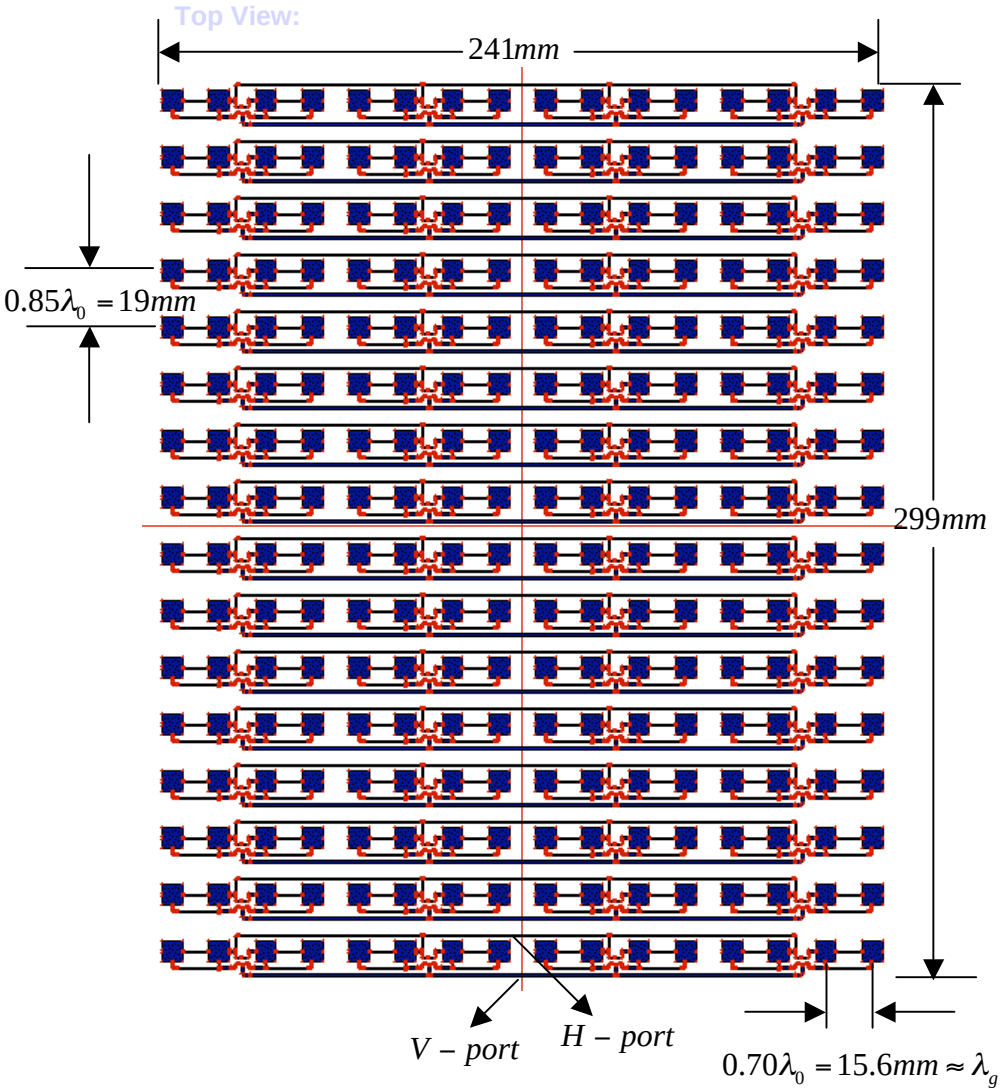






	SLL (broadside)	SLL (steered)	BW (broadside)	BW (steered)
xz-plane	-13.26dB	--	0.076°	--
yz-plane	-13.19dB	-13.10dB	3.74°	3.77°

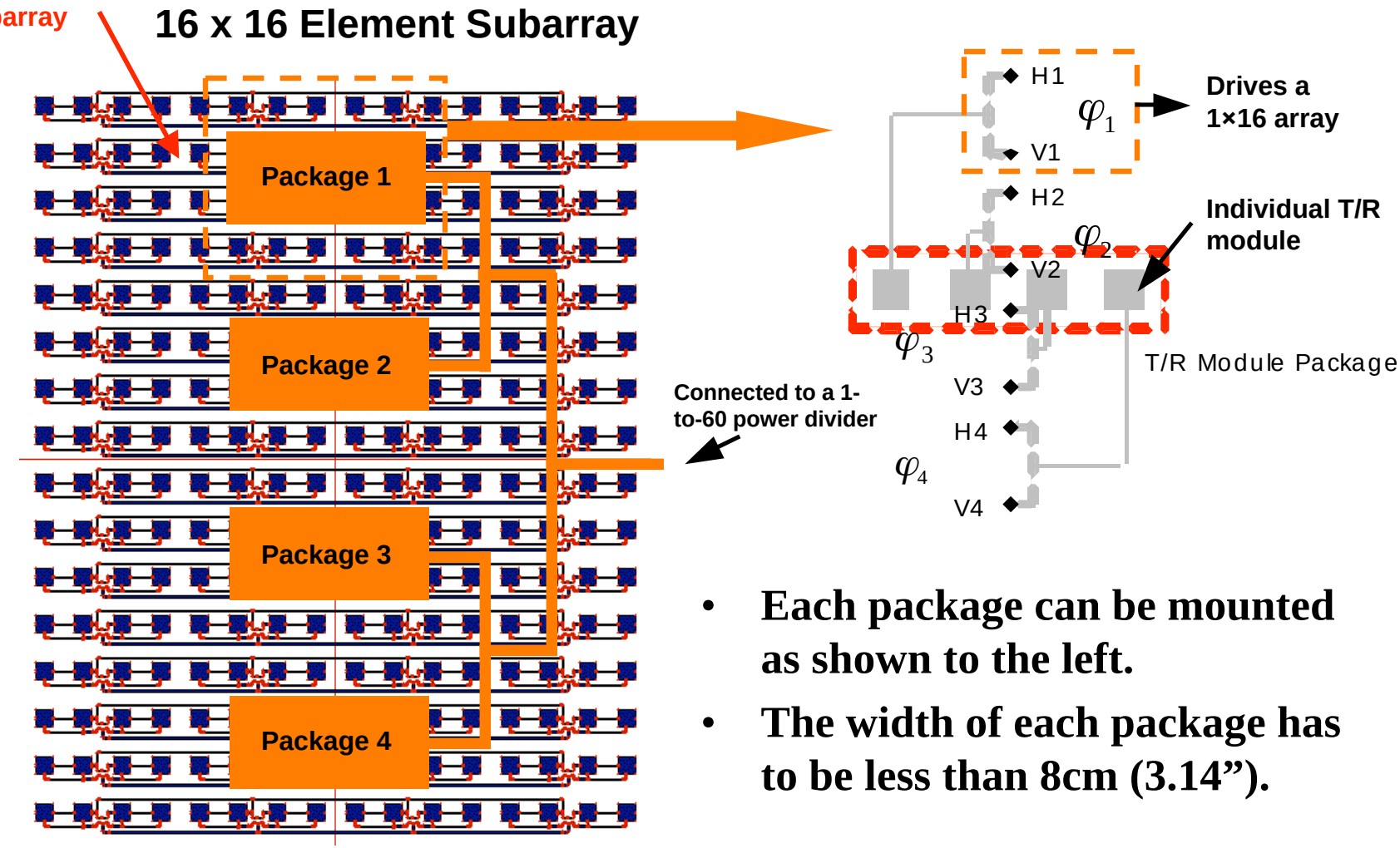
Configuration of A 16 × 16 Subarray



- **Parameters for the entire array**
  - **Total length: 0.25 × 60 = 15m**
  - **Total width: 0.32m (include the edges at top and bottom)**
  - **T/R Module packages: 4 × 60 = 240 (Each subarray is driven by 4 packages)**
  - **Directivity: about 50dB**
  - **Output power: 2W × 960 = 2kW**
  - **Return loss: < -20dB for each port**
  - **Isolation between two ports: >15dB**
  - **Sidelobe level: About -13dB in both planes.**

T/R Module Connections

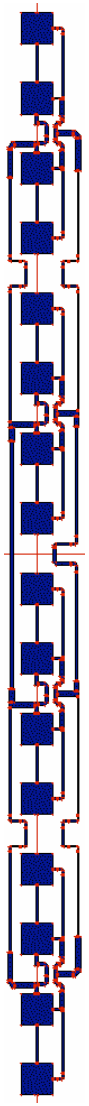
Research is focused on designing this 64 element subarray



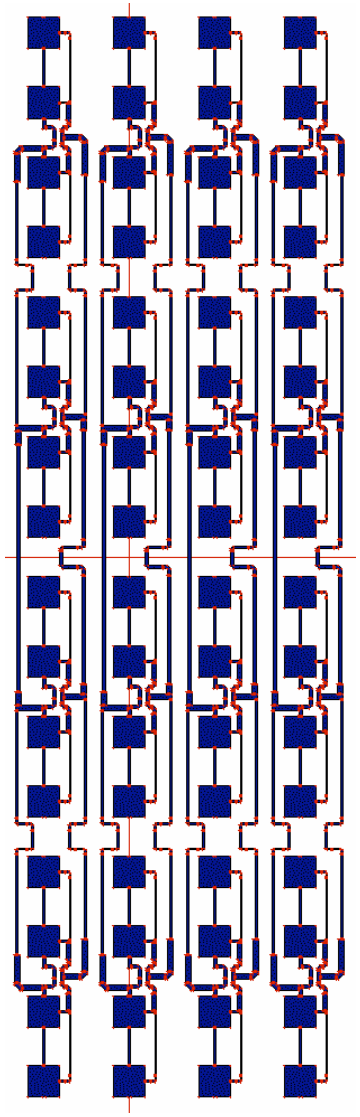
- Each package can be mounted as shown to the left.
- The width of each package has to be less than 8cm (3.14”).

From 1 x 16 to 4 x 16 Element Arrays

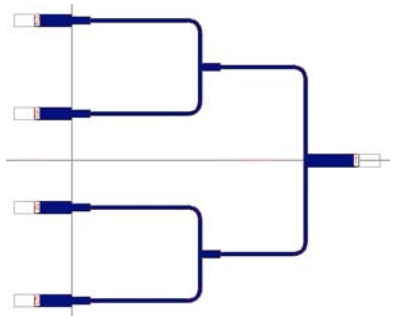
1×16 Array (Prototype 3)



4×16 Array

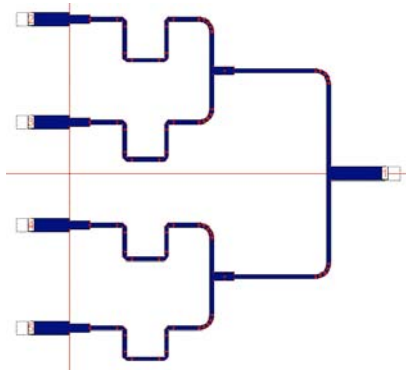


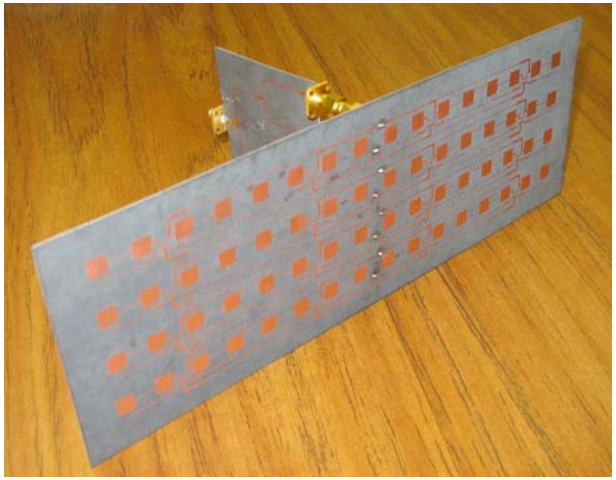
1-to-4 Power divider (Broadside)



OR

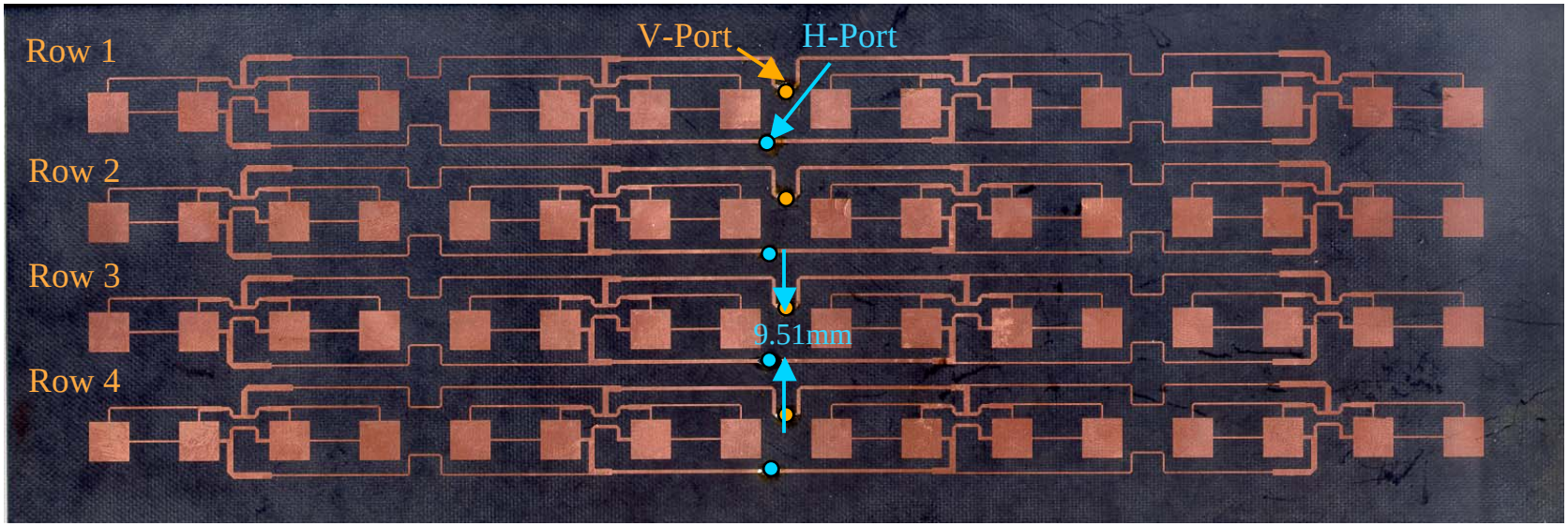
1-to-4 Power divider (Beam-Steered)

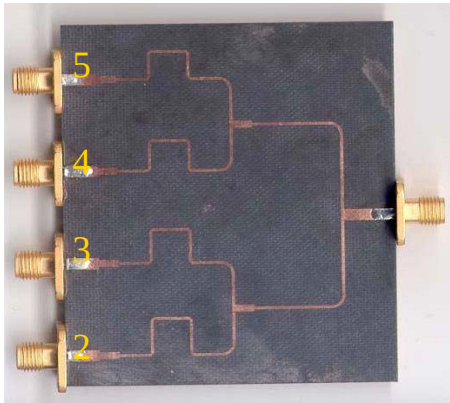




•For temporary measurement purposes without the T/R module, 1-to-4 power dividers were designed and presented in our mid-year report.

Modified 4×16 Array with Central Bending in V-Port Feeding Network



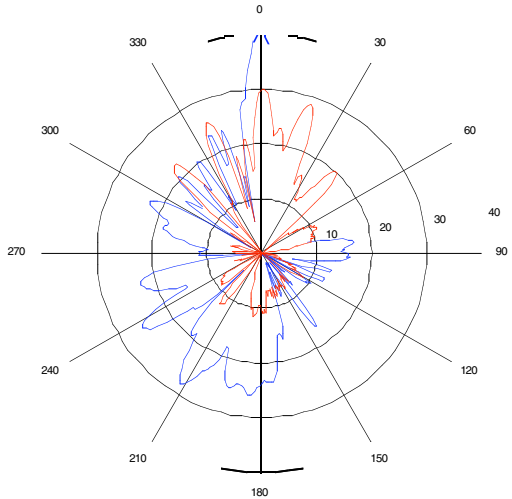


•4×16 array is designed and prototyped by bending the central part of V-port feeding network. The spacing between V- and H-ports of two adjacent rows is increased to 9.51mm.

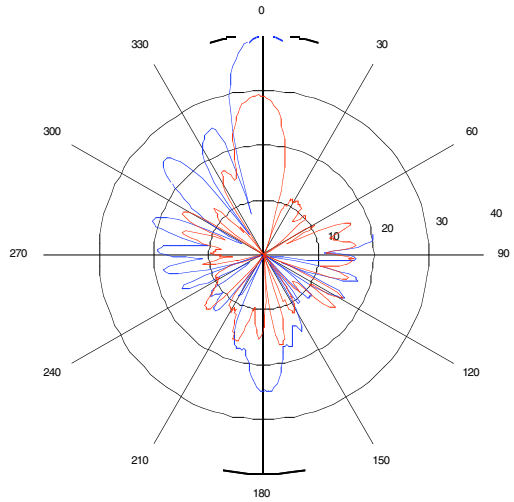
•1-to-4 power dividers are designed and fabricated (for both broadside and steered beams) to feed the 4×16 array.

Far-Field Measurements (Broadside Beam)

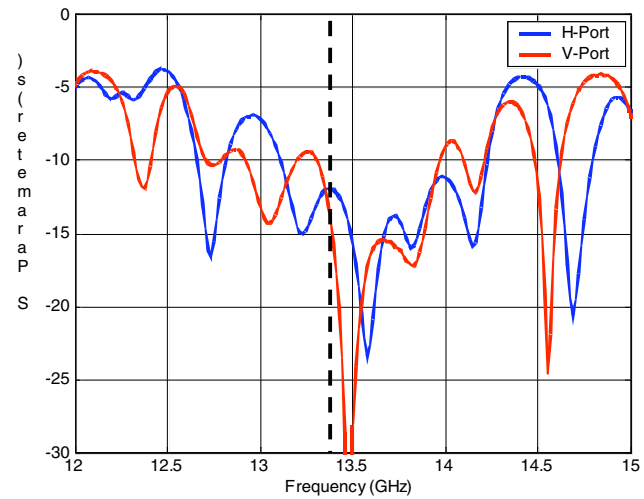
H-Port, xz-plane



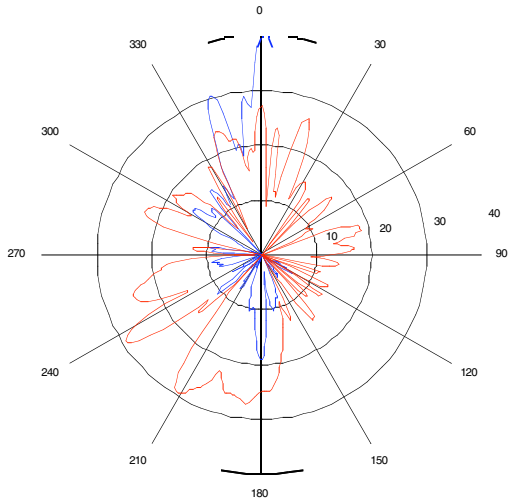
H-Port, yz-plane



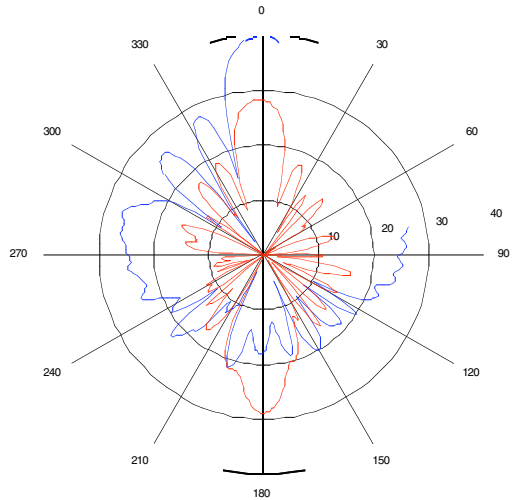
Measured S-Parameters from the Power Divider



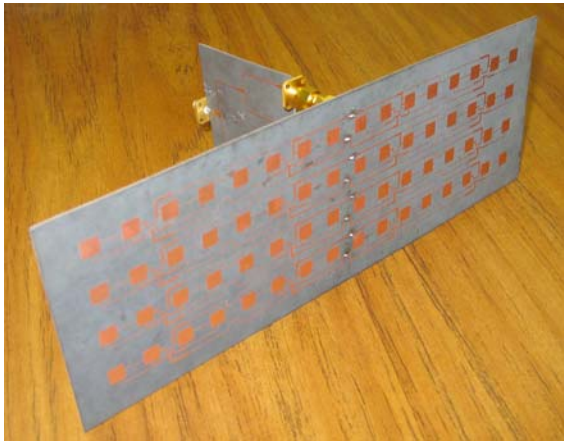
V-Port, xz-plane



V-Port, yz-plane

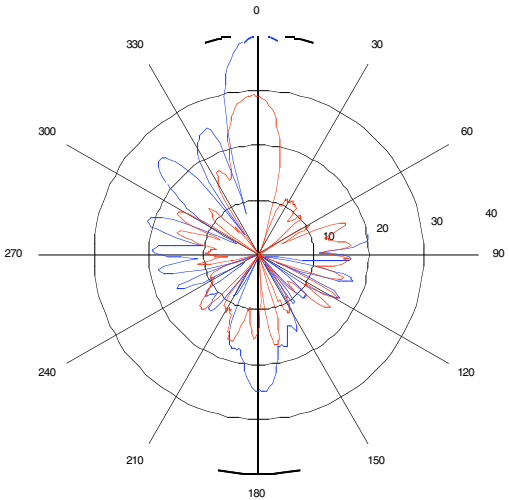


Fabricated Array Prototype (with Power Divider)

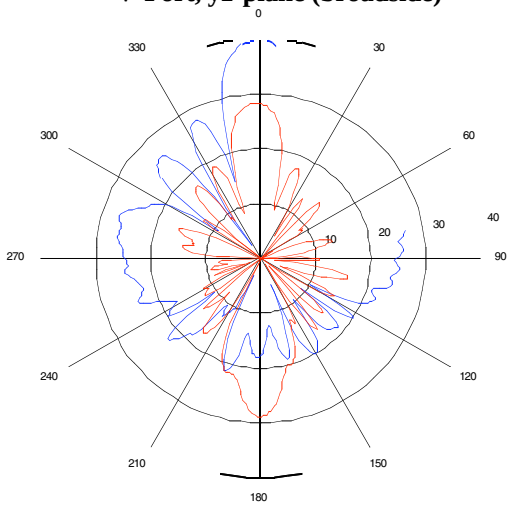


Far-Field Measurements (Beam Steered)

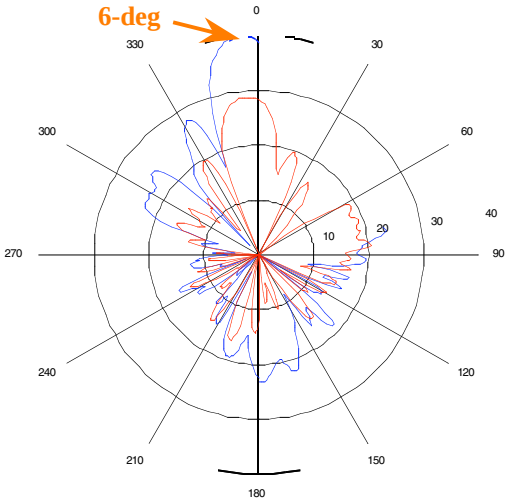
H-Port, yz-plane (broadside)



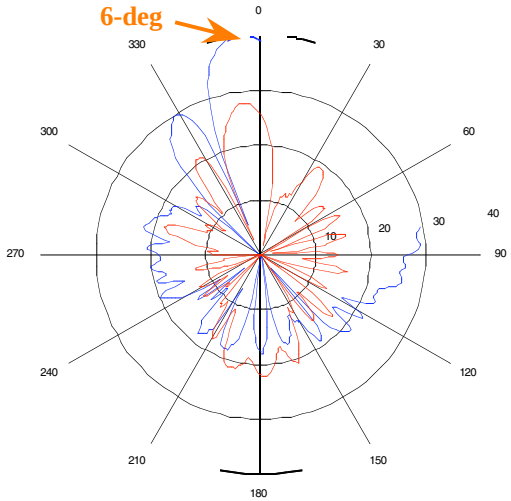
V-Port, yz-plane (broadside)

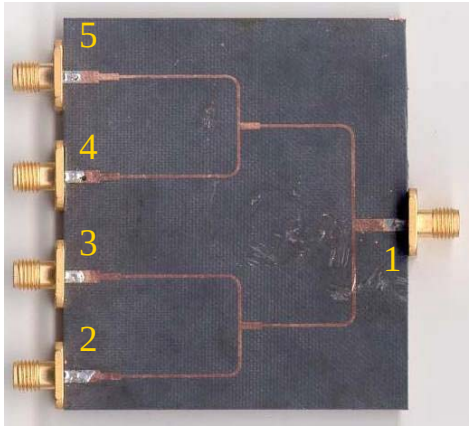


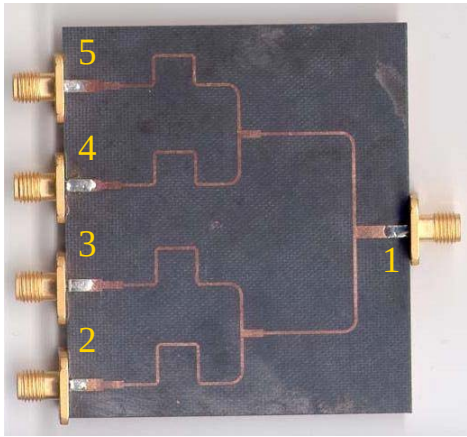
H-Port, yz-plane (steered)



V-Port, yz-plane (steered)

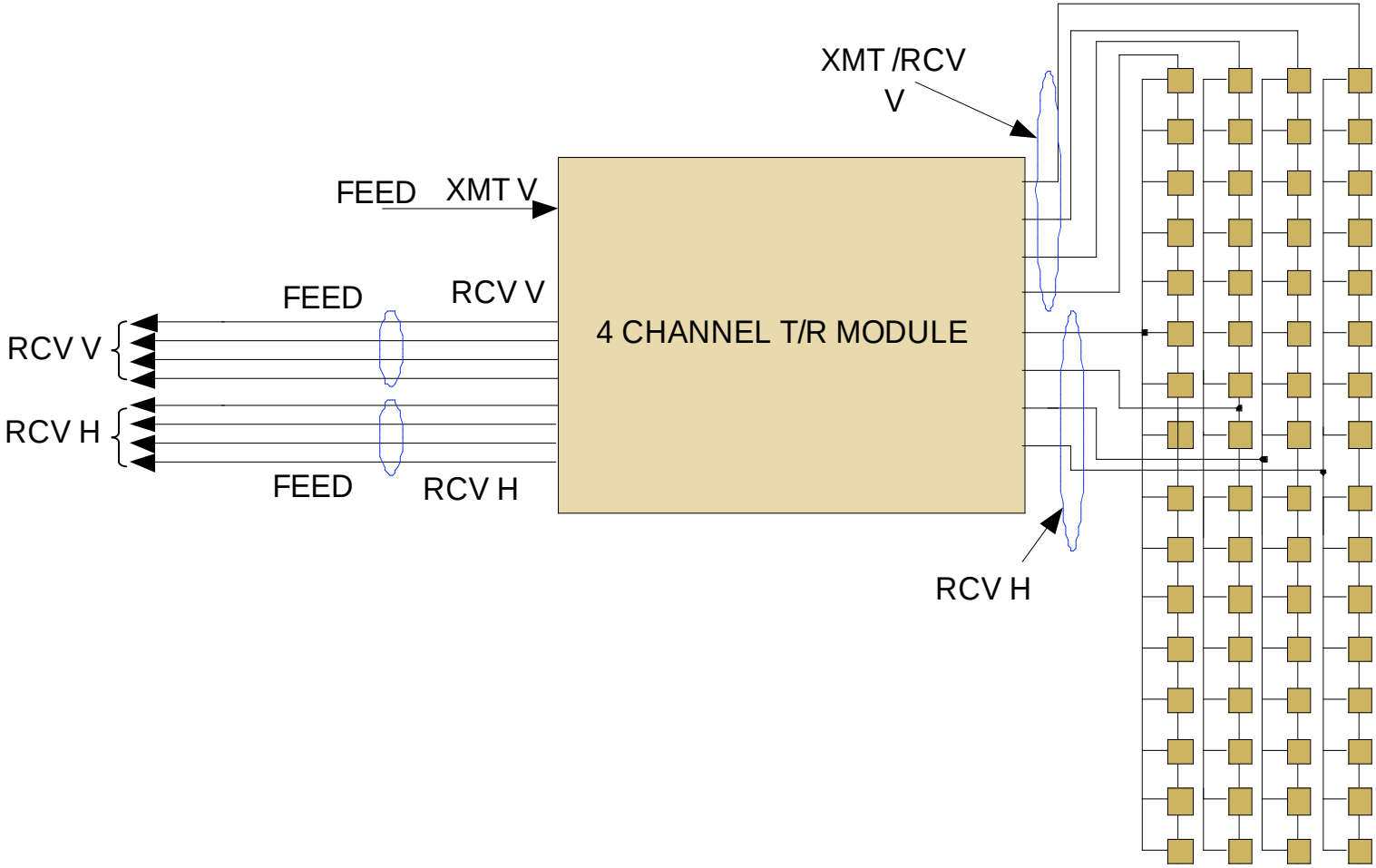






Compact Ku-band T/R Module:
T/R Module Design

Ku Band T/R Module RF In/Out Distribution



T/R Module Transmit Mode Specifications

Transmit frequencies	13-17 GHz
Transmit bandwidth	20 MHz
Transmit peak power	37 dBm (5 W)
Transmit power stability	<0.1 dB
Module input power	0 dBm
Module input power VSWR	<1.3:1
Transmit efficiency	>20%
Spurious signals	-40 dBc
PRF	8-10 KHz
Amplitude droop	<0.5 dB over 20 usec
Maximum duty cycle	10%
Pulse width	10-20 us
Power flatness over 20 MHz	<0.2 dB
Digital phase shifter	5 Bits
Phase shift accuracy	< 5deg rms
Phase switching time	< 1 us
Operating Temperature Range	-40 deg C to 70 deg C

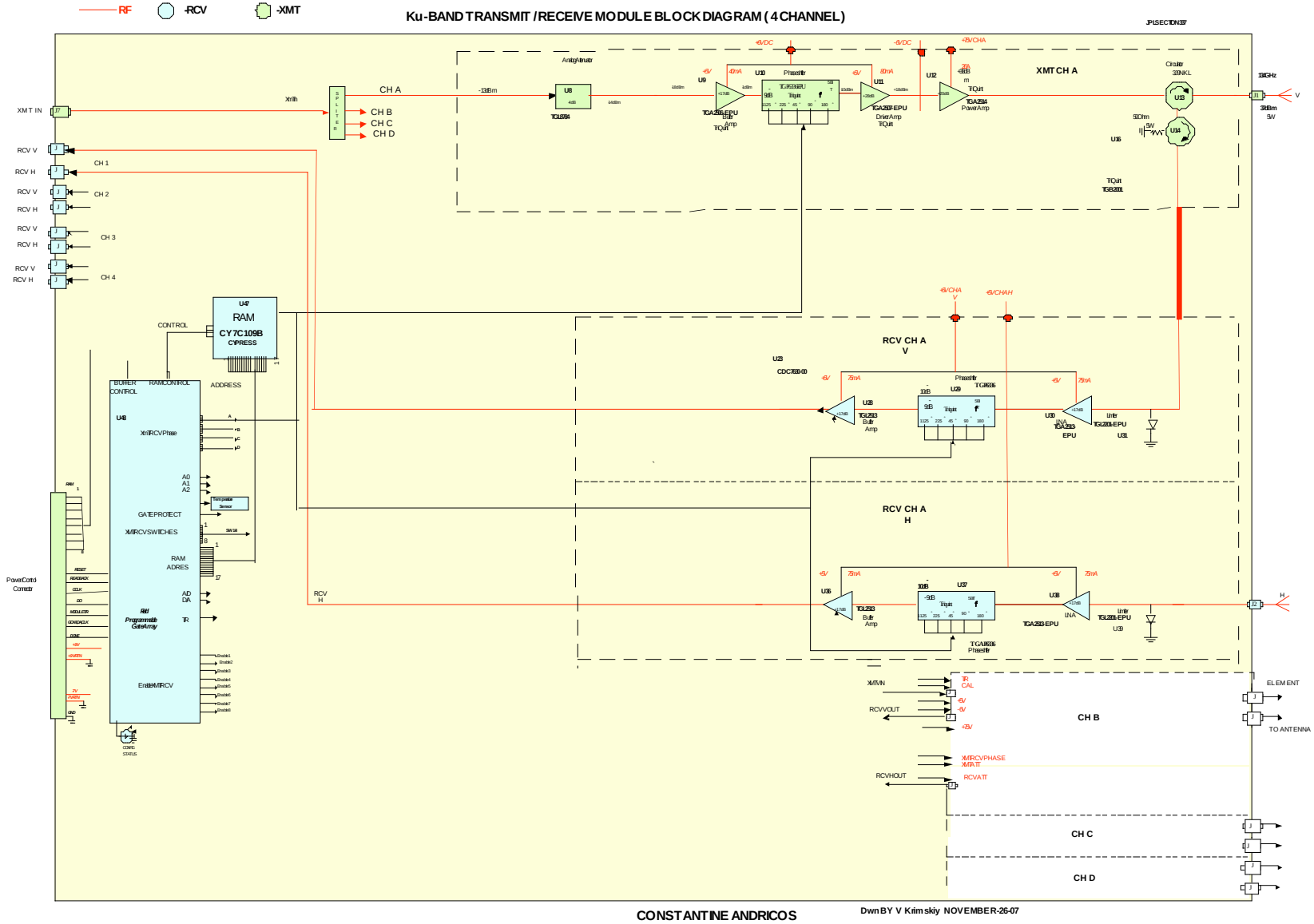
T/R Module Receive Mode Specifications

Receiver	Two parallel receive channels for each transmit channel (Vertical and horizontal polarization)
Frequencies	13-17 GHz with 20 MHz bandwidth
Gain	20 dB
Gain stability	<0.1 dB
Gain flatness over 20 MHz	<0.2 dB
Noise Figure	<2.5 dB
P in 1 dB compression	-30 dBm
Input/Output VSWR	<1.3:1
Analog attenuator range	> 15 dB
Digital phase shifter	5 bits
Phase shifter accuracy	< 5deg rms
Phase switching time	< 1 us
Isolation between channels	40 dB
Operating temperature range	-40 deg C to 70 deg C

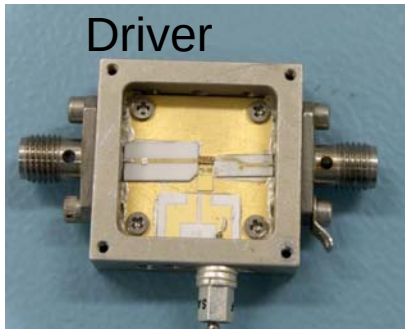
Module Self Calibration Goals

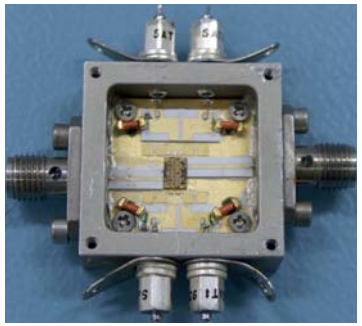
- Maintain the T/R module receive gain within 0.1 dB over All phase and attenuation settings
  - Temp (-40 deg C to + 70 deg C), power supply variations (+/- 10 %), Aging (3 db)
- Maintain the T/R module Transmit Power output within 0.1 dB over
  - All phase settings, Temp (-40 deg C to + 70 deg C), Power supply variations (+/- 10 %), Aging (2 dB)

BLOCK DIAGRAM OF T/R MODULE

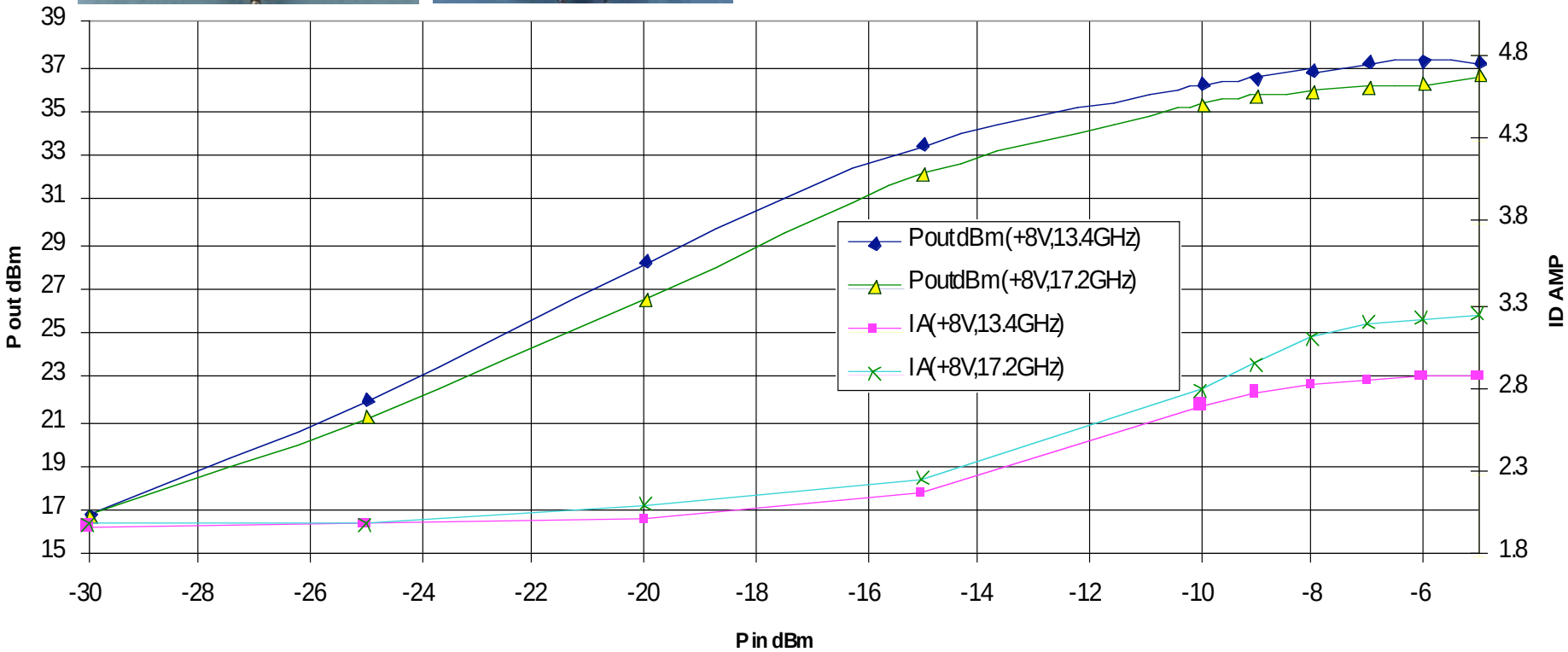


BENCH TEST OF TRANSMIT AMPLIFIER CHAIN
Pout VS Pin

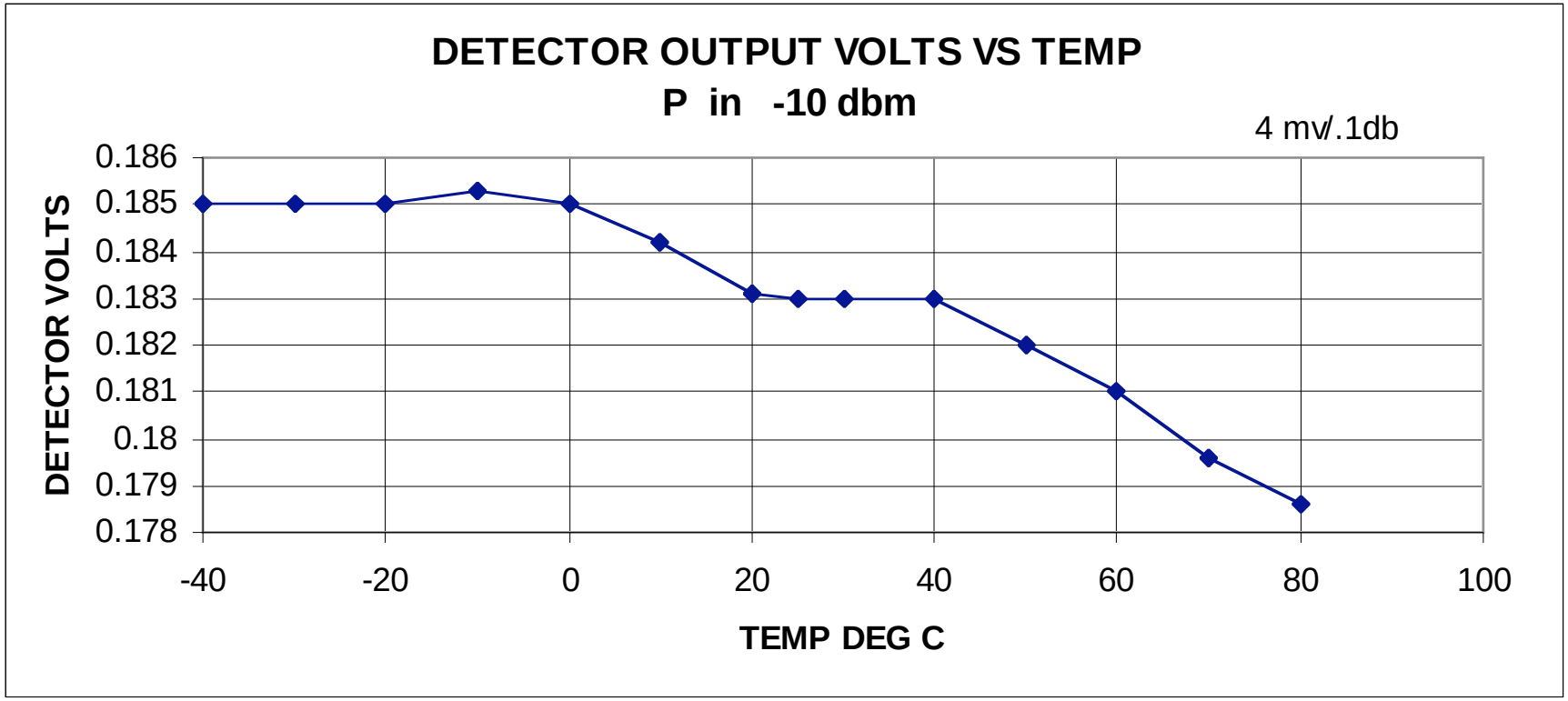




- Transmit power ~ 5 W at 17.2 GHz



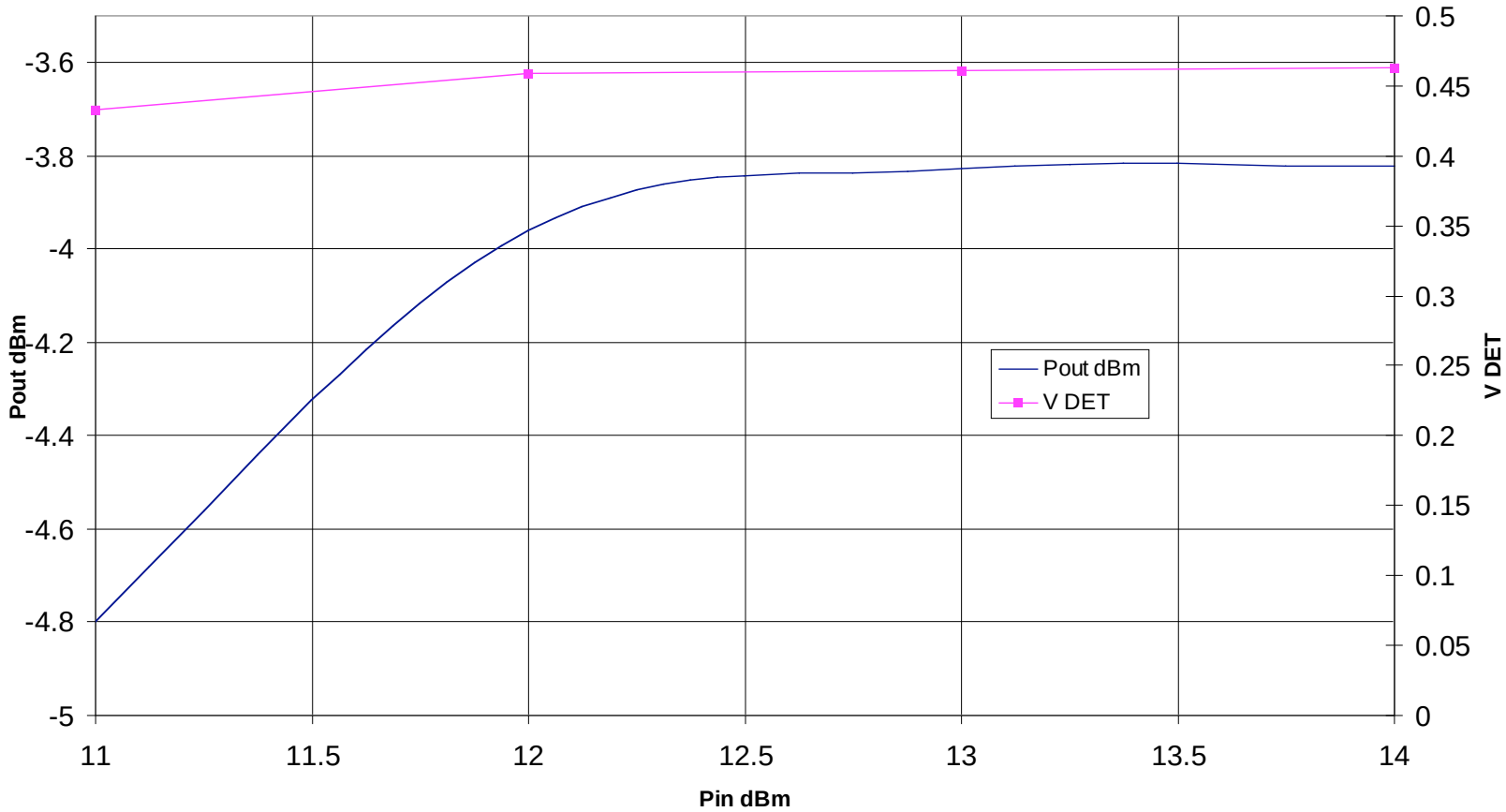
Component Testing
POWER DETECTOR CHARACTERISTICS OVER TEMPERATURE



- The gain detector output for constant input changes by less than 6mV from -40 to 70 deg C.
- The detector output is for the feedback gain control of transmit amplifier and LNA to <0.1 dB.

Breadboard Test of Receiver Closed Loop Receive Power Output vs Power input

TEST KU BAND RCV CLOUSED LOOP



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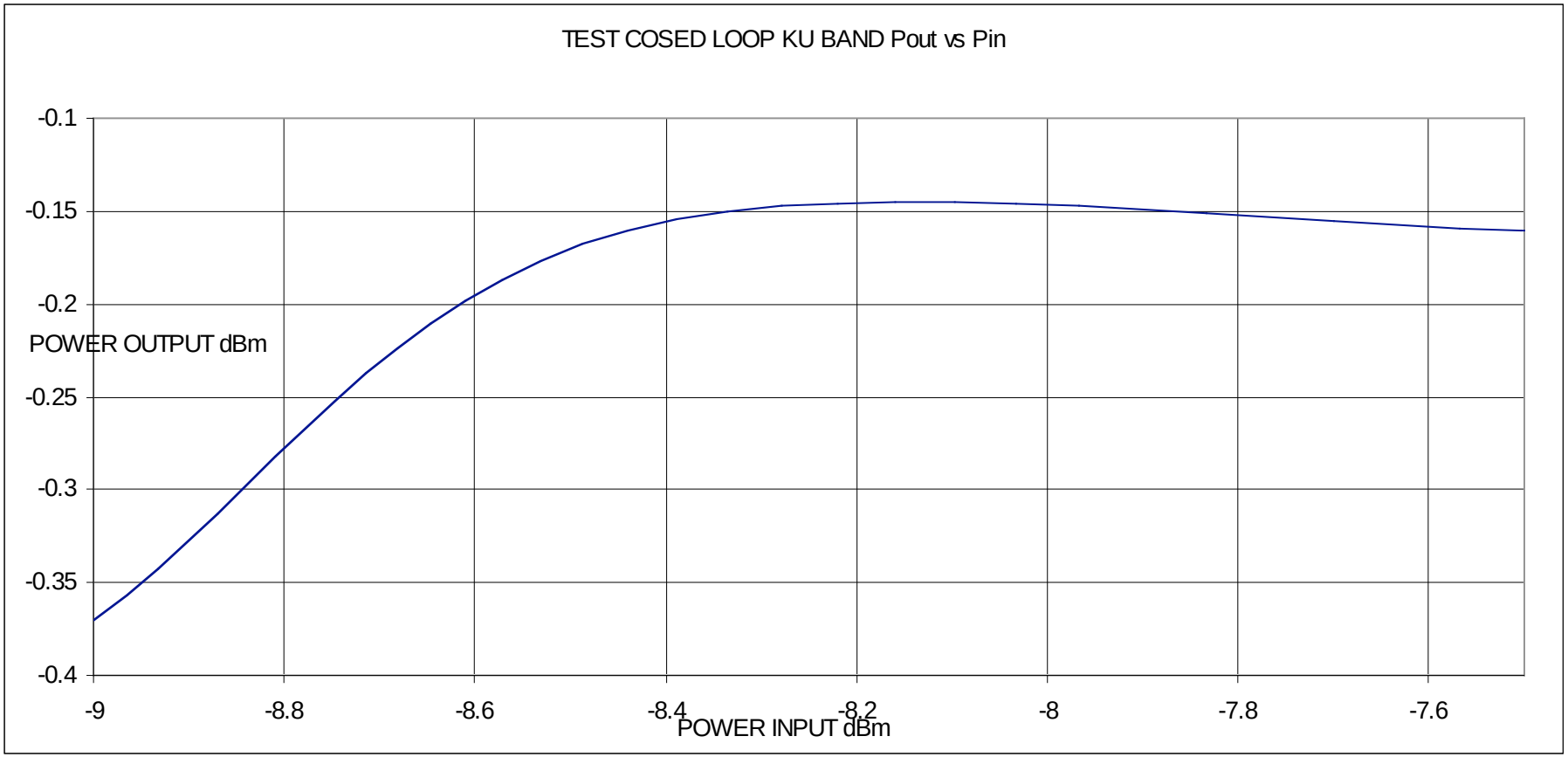
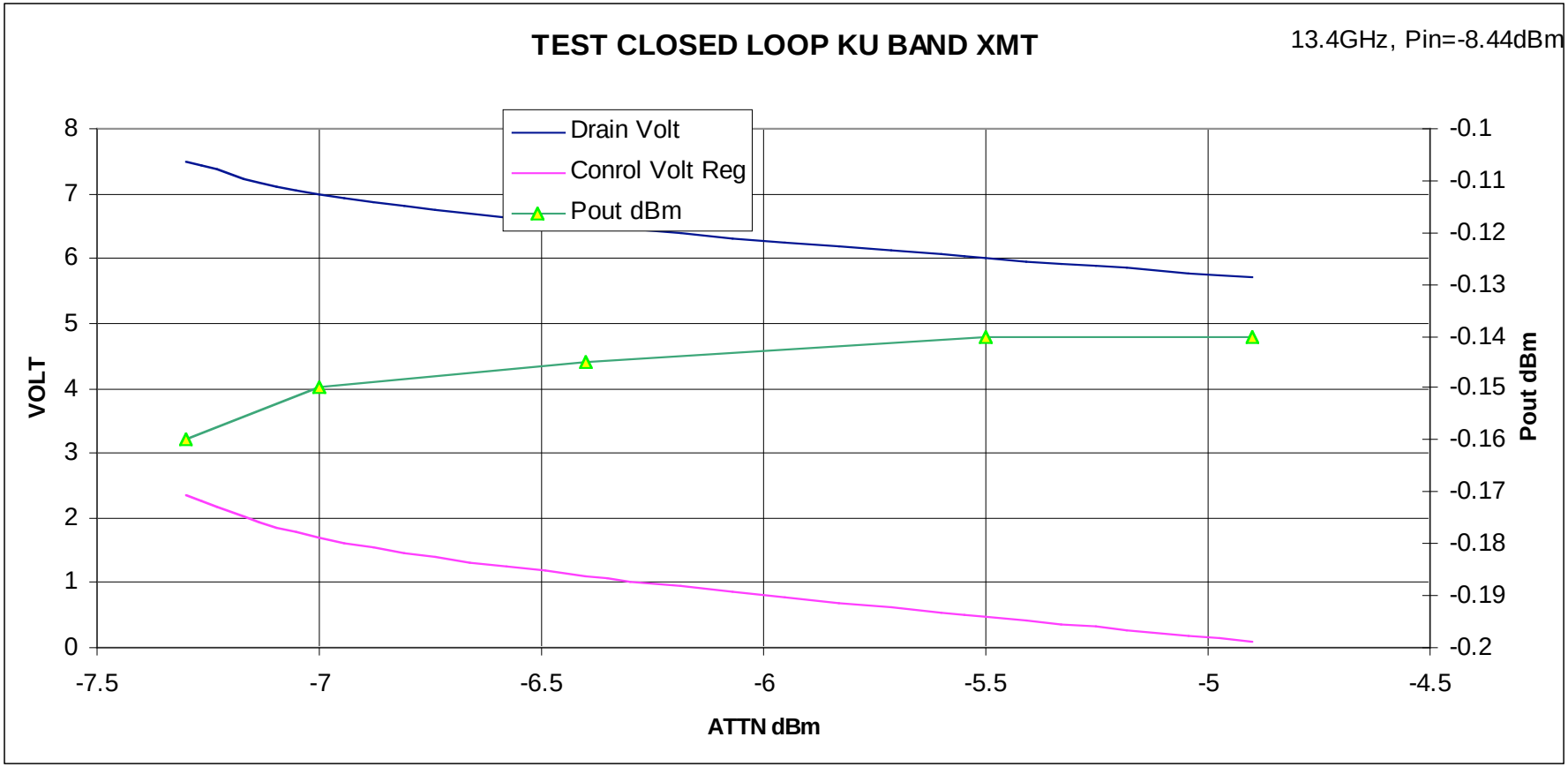
- This curve shows that the feedback loop holds the output constant (<0.1 dB) with varying input changes by 2 dB.

Breadboard Test of Transmit Closed Loop Transmit Power output vs Power input



- This shows the transmit loop functioning to hold the relative power output constant as the input power to the transmit chain varies by 1 dB.

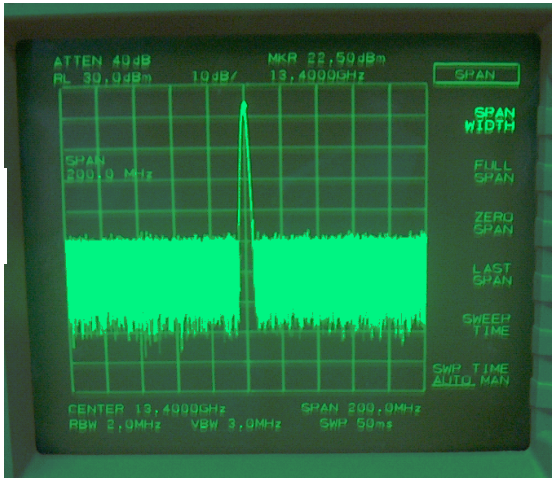
Breadboard Test of Transmit Closed Loop Transmit Power Output vs Gain Change



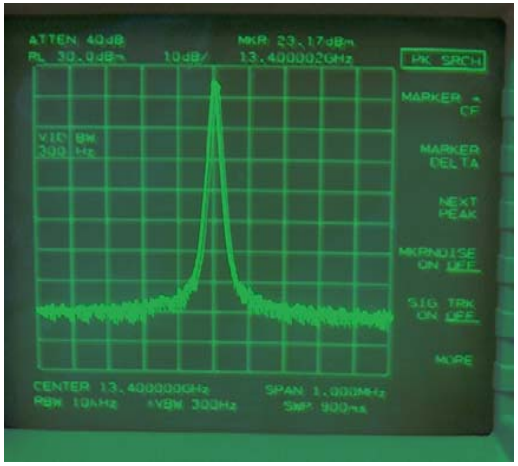
- This shows the transmit loop functioning to hold the relative power output constant (<0.05 dB) as the attenuator gain varies by 2 dB.

Breadboard Test of Transmit Signal
POWER SPECTRUM AT 5 WATTS OUTPUT

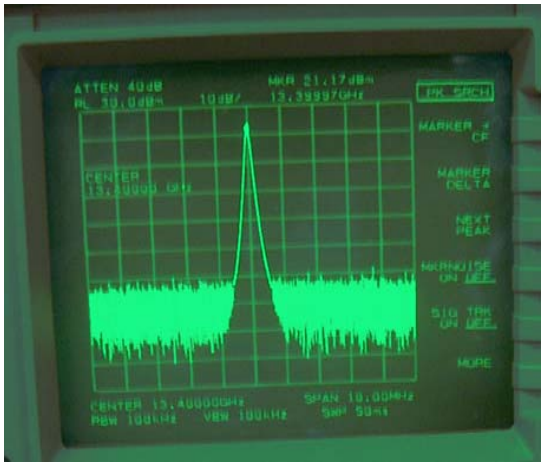
200 MHz Scan



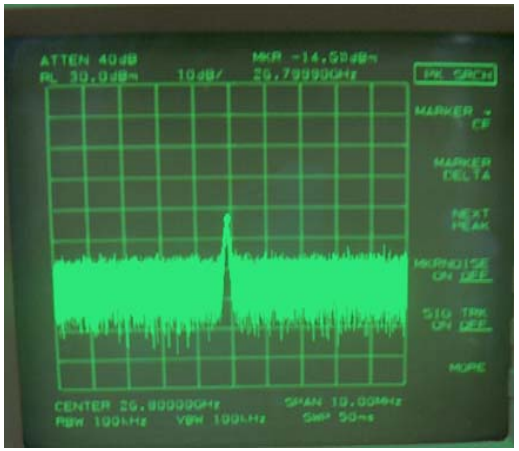
1 MHz Scan



10 MHz Scan



2nd Harmonic

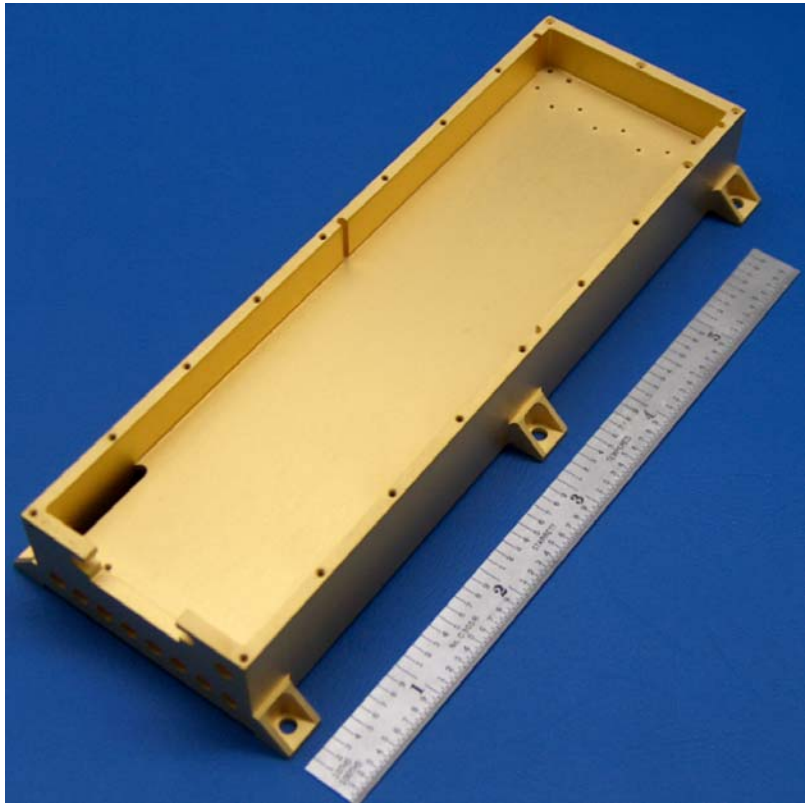


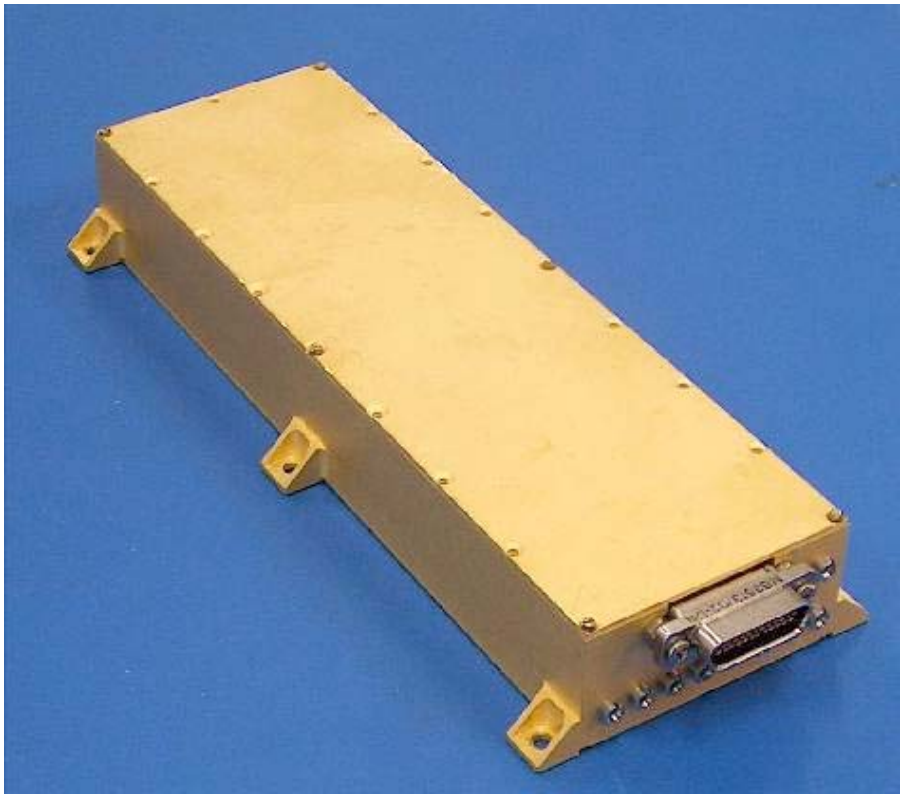
2nd Harmonic

- No spurious signals are seen in the spectrum output of the transmit chain looking at close in, 1 Mhz and far out spectrum sweeps, 200 Mhz.
- The 2nd harmonic is down about 35 dB

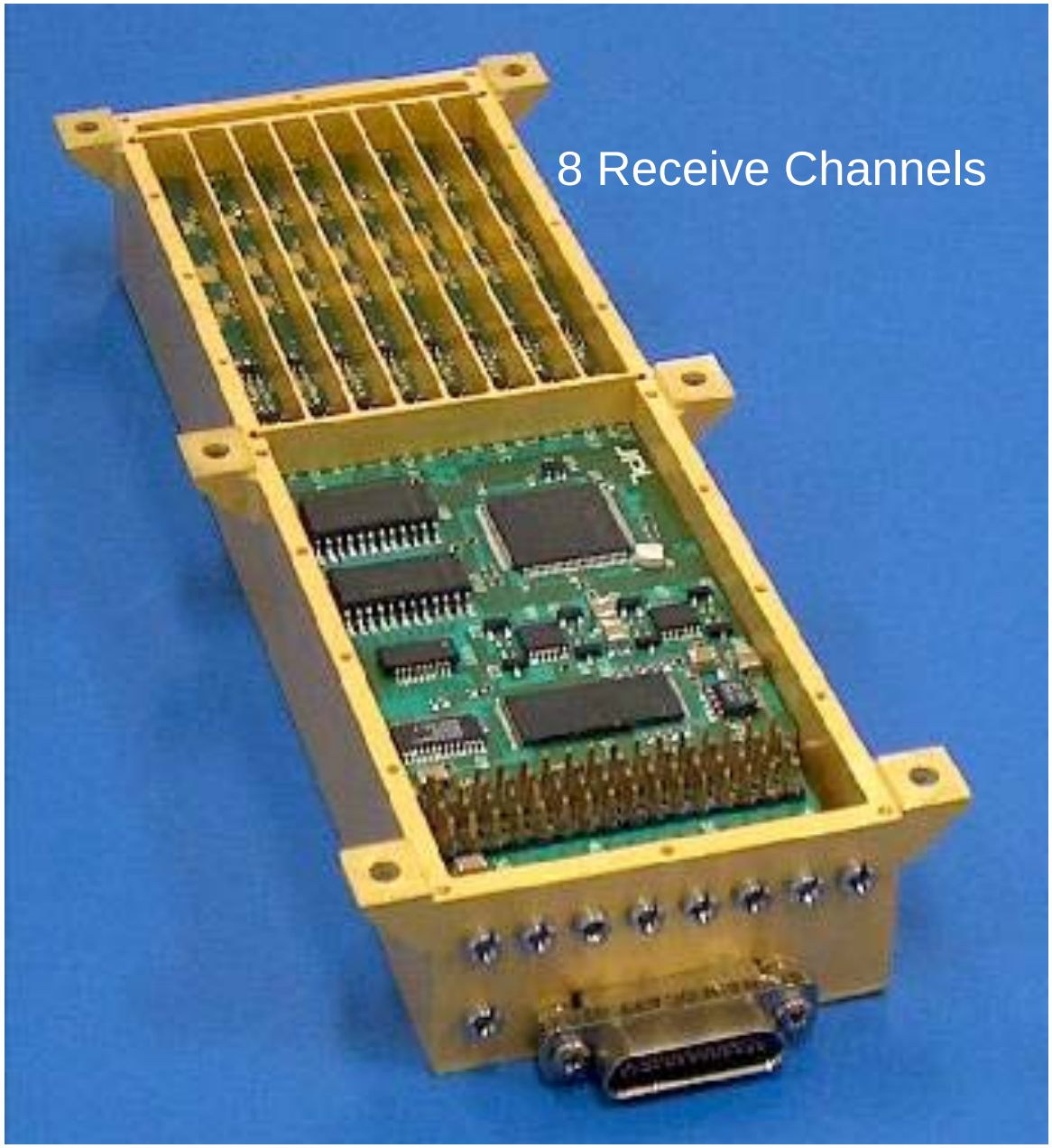
T/R MODULE 4 PACK HOUSING

Dimension: 6 in x 2 in x 1.5 in

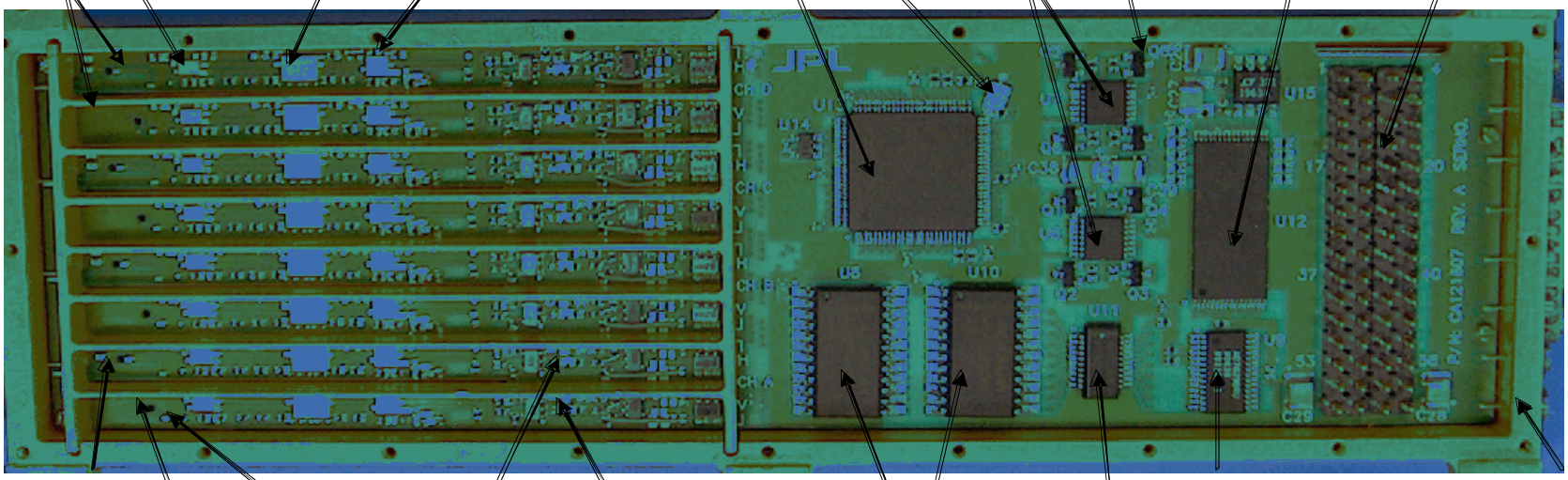




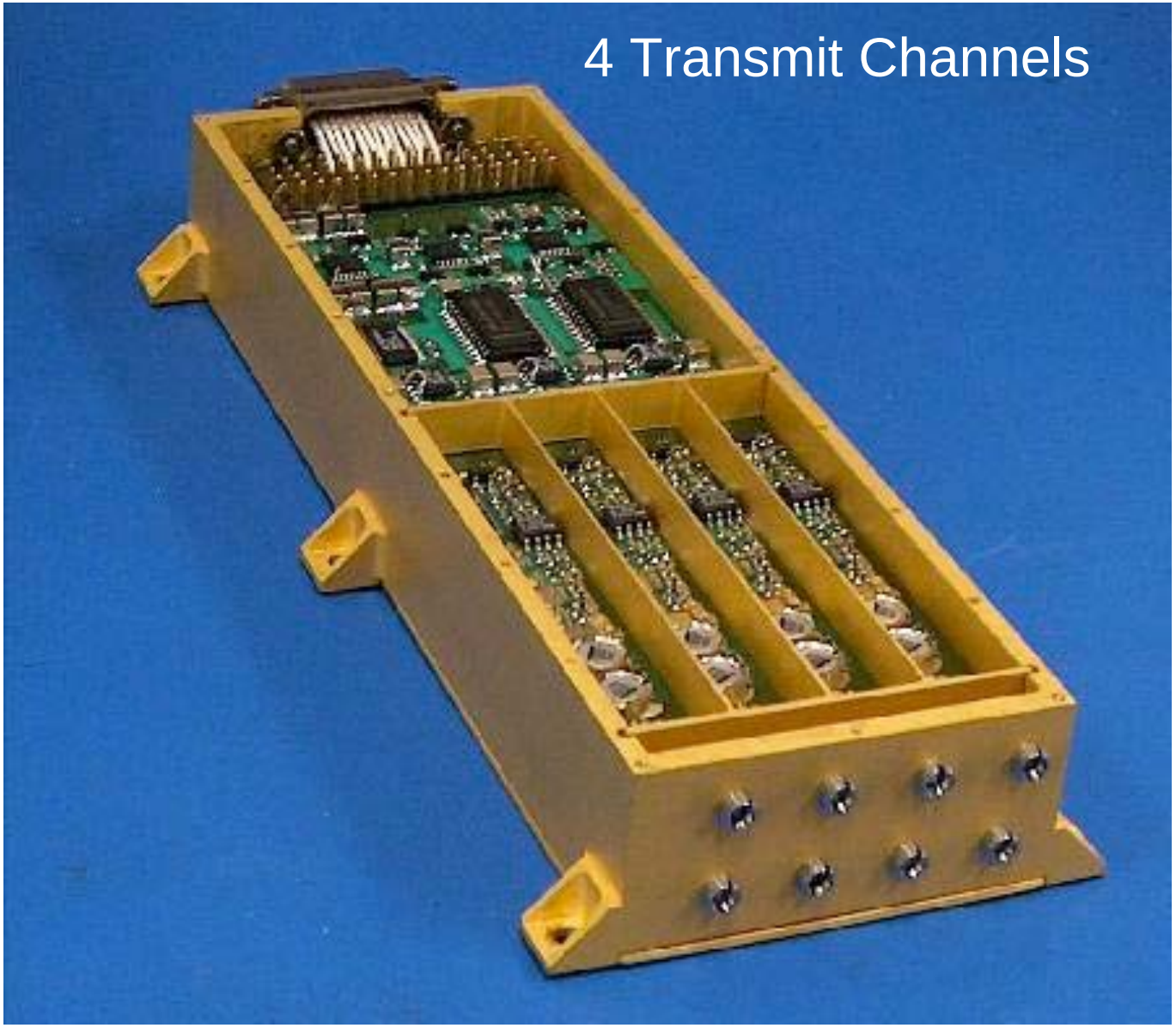
T/R MODULE RECEIVE SIDE



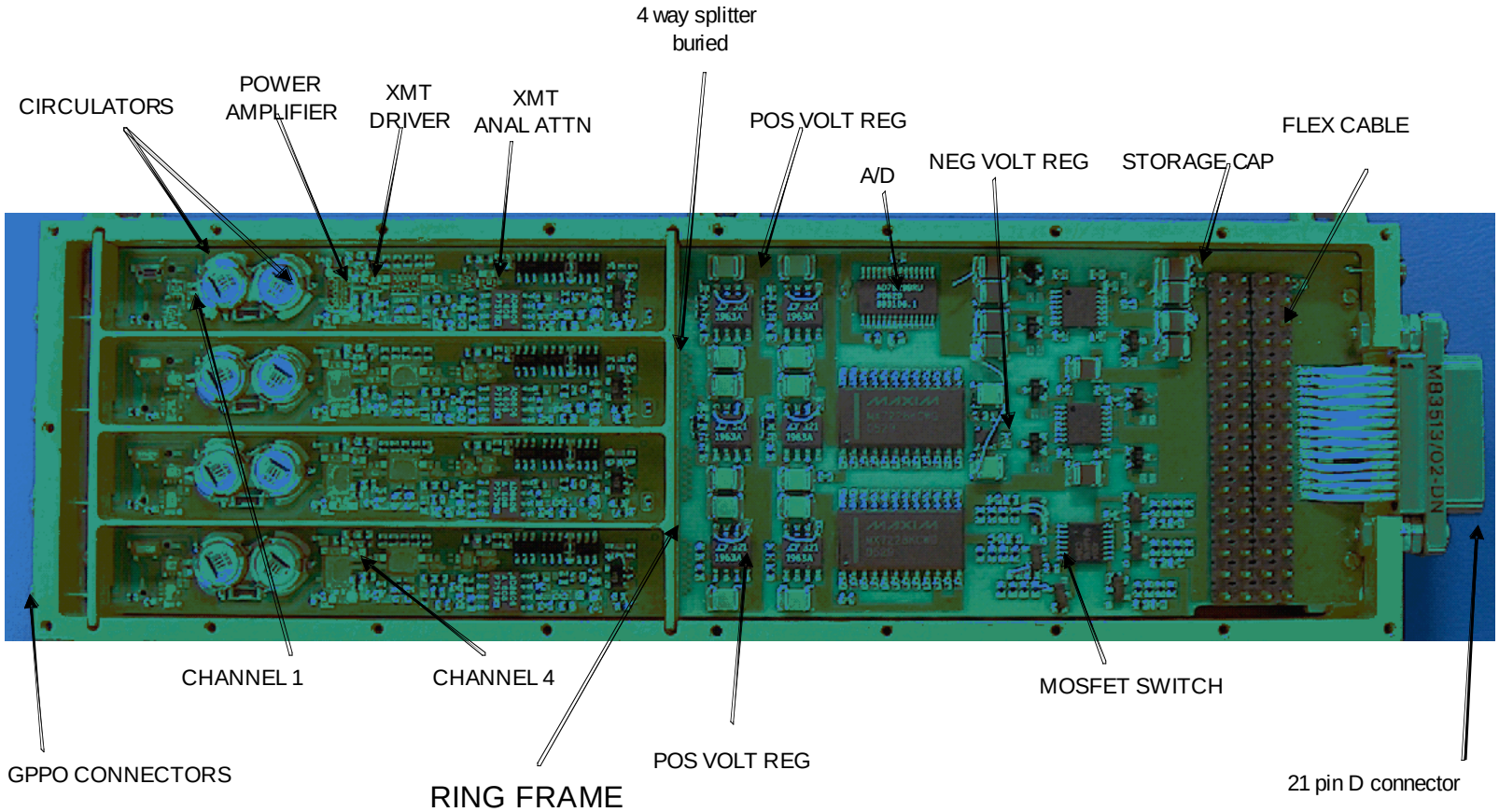
RECEIVE SIDE OF T/R MODULE SHOWING COMPONENTS



T/R MODULE TRANSMIT SIDE

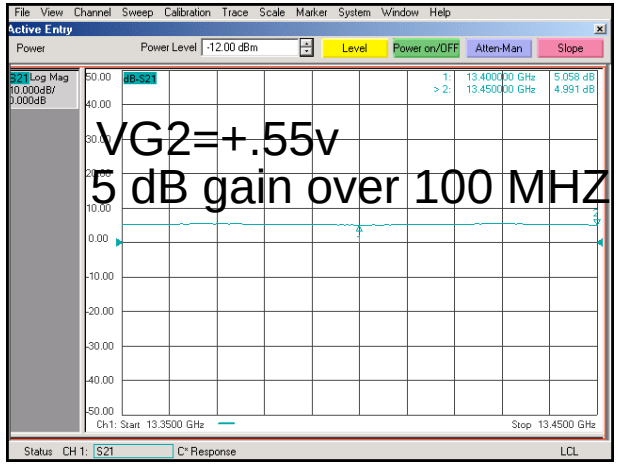


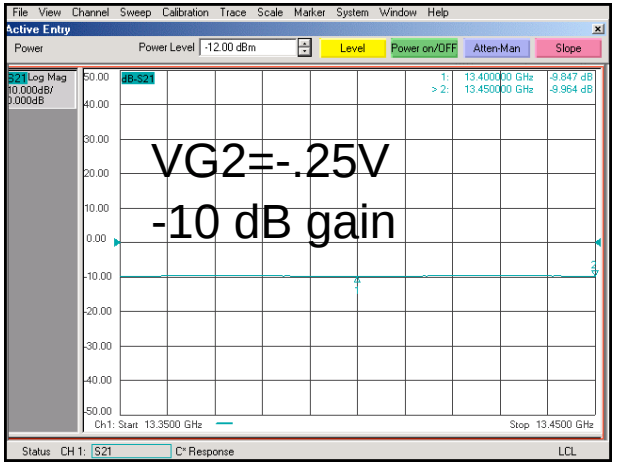
TRANSMIT SIDE OF T/R MODULE SHOWING COMPONENTS



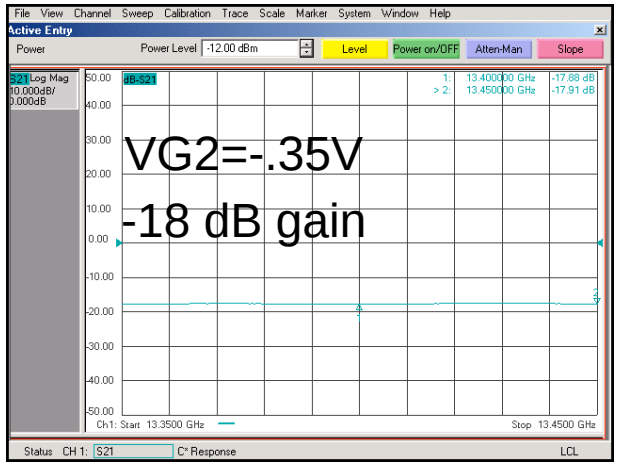
OPEN LOOP TEST of ASSEMBLED TR MODULE

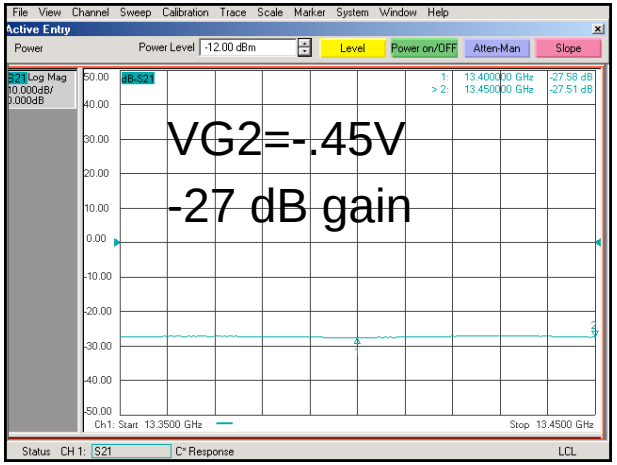
T/R MODULE RECEIVE GAIN vs CONTROL VOLTS





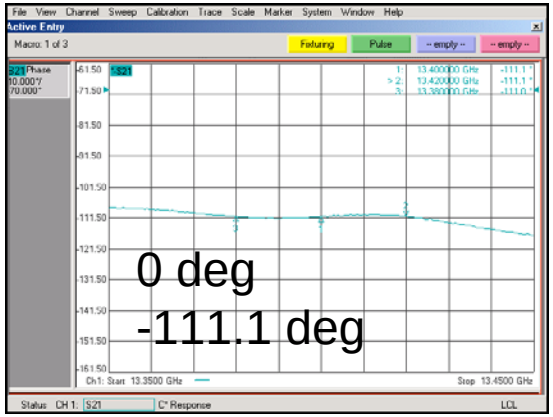
20 db input pad

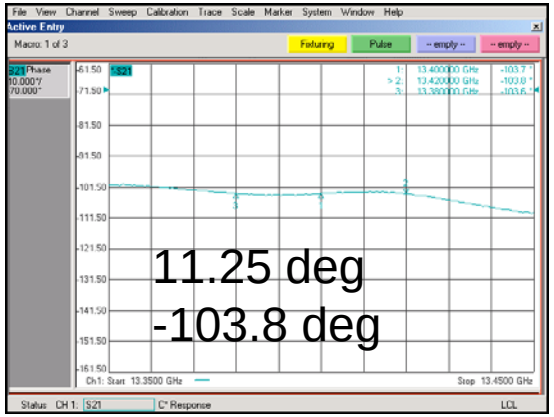


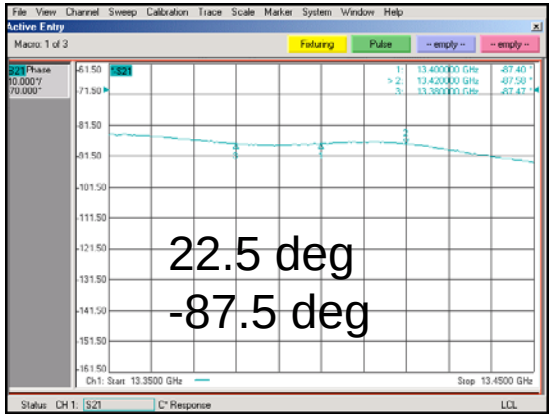


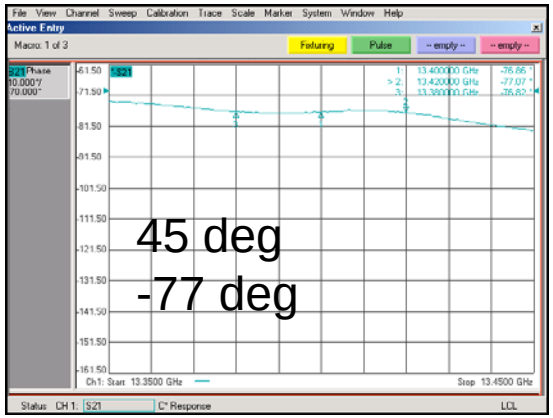
- The assembled module showing the receive gain as the control voltage is varied on the agc stage. The gain is flat over the 100 Mhz scan width.
- The attenuation range exceeds 30 dB for a 1 volt control voltage.

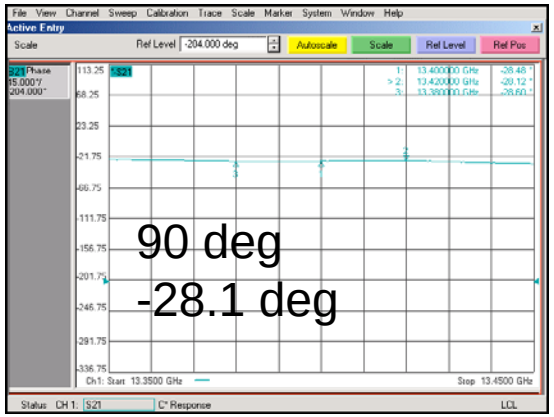
T/R MODULE RECEIVER PHASE

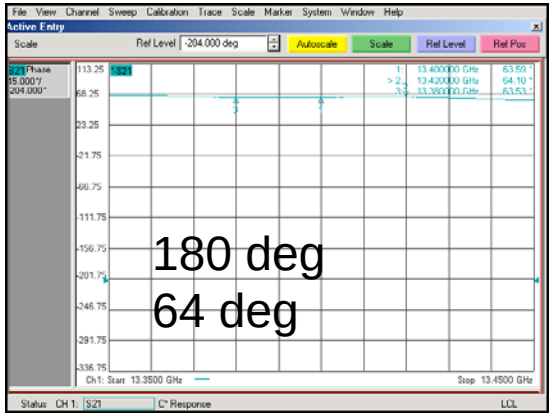








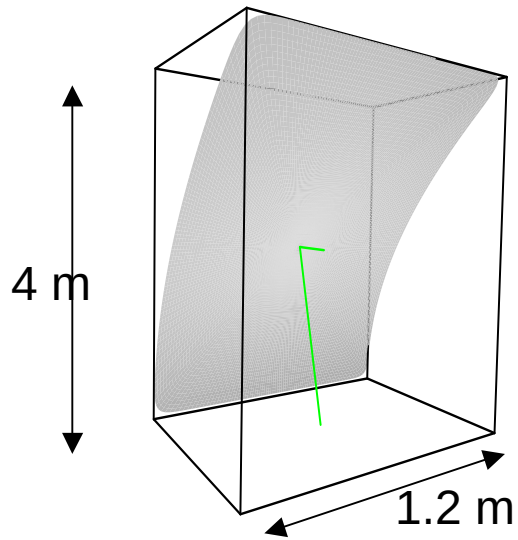


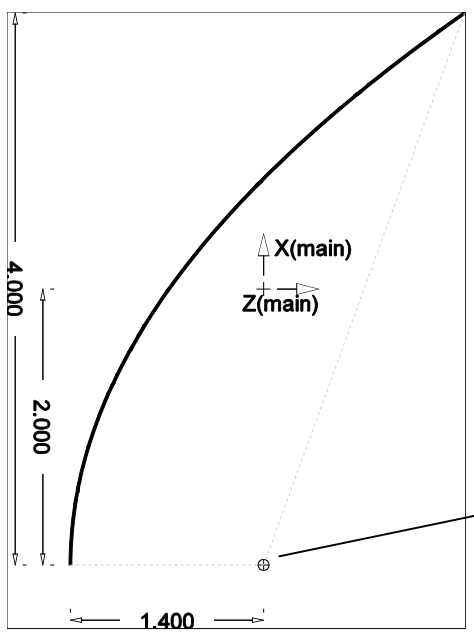


- The phase change agrees to within 5 deg of the commanded value for the programmed bits of the 5 bit phase shifter in the receiver.

Antenna Concept Trade:
Cylindrical Reflector/Phased Array Feed with T/R modules

4 x 1.2 m Cylindrical Reflector Antenna

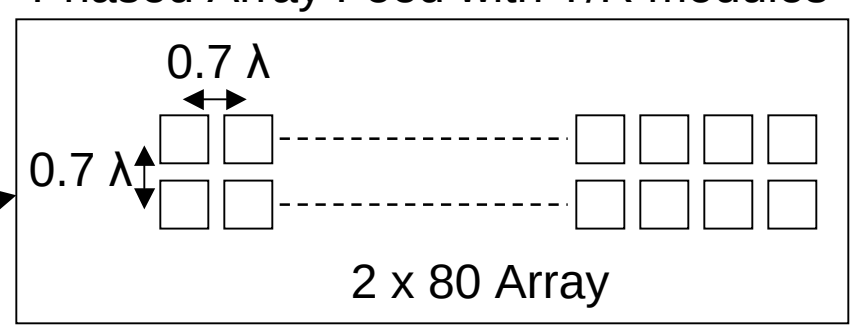




General Parameters of the Antenna:

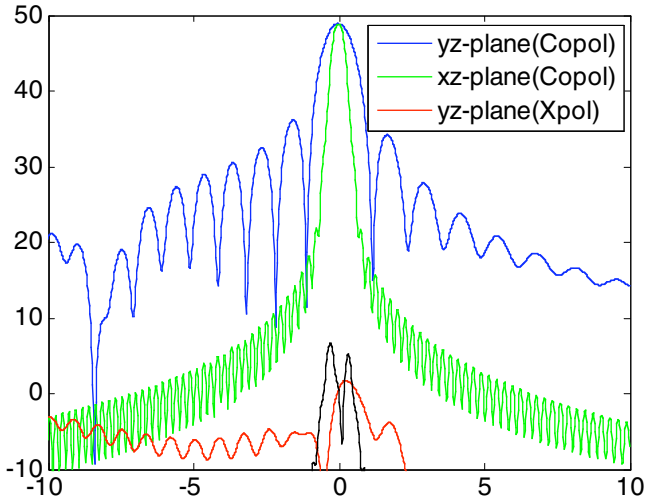
- **Aperture** **4 by 1.2 m**
- **Offset height** **2 m**
- **Focal length** **1.4 m**
- **F/D** **0.35**
- **Superquadric index** **10**
- **Frequency** **17.2 GHz**

Phased Array Feed with T/R modules

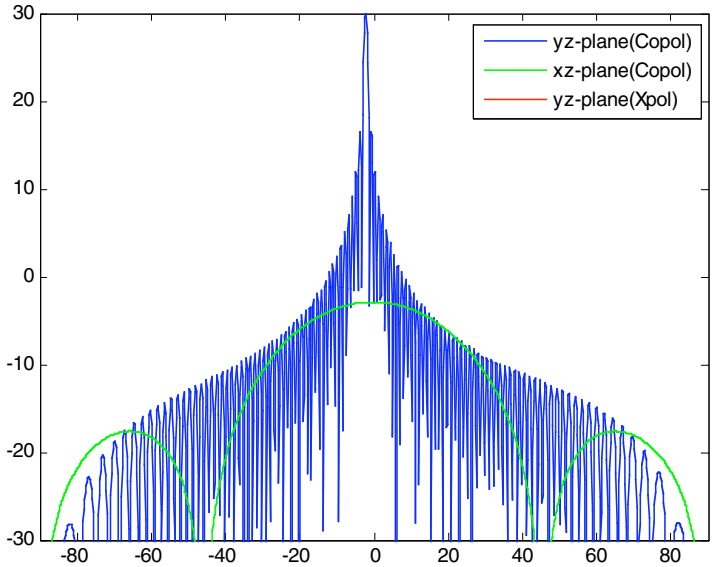


4x1.2 m Cylindrical Reflector Antenna
Freq.= 17.2 GHz, 5º Scan

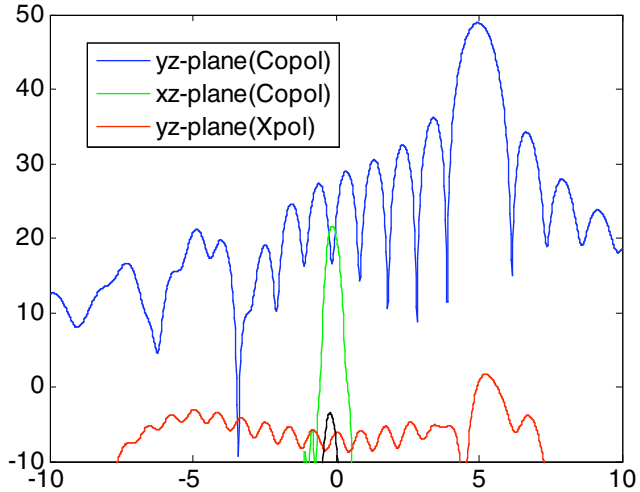
Reflector Pattern (Cut through boresight)



Feed Pattern



Reflector Pattern (Original Coordinate)



	Directivity (dB)	HPBW (deg.) (Vertical plane)	HPBW (deg.) (Horizontal plane)
Reflector	**48.8**	**0.42**	**1.0**
Feed Array	**29.8**	**-**	**0.92**

4x1.2 m Cylindrical Reflector Antenna
Freq. 17.2 GHz

- Directivity changes by less than 1 dB for +/- 5 deg scan
- Very small changes in HPWB

Scan Angle (deg)	Directivity (dB)	HPBW (deg) Vertical plane	HPBW (deg) Horizontal plane
0	49.7	0.4	0.88
2	49.5	0.42	0.92
5	48.8	0.42	1.0

Summary

- The breadboard dual-polarized microstrip antenna design is completed.
- Breadboard tests of T/R module assembly and components show promising performance
  - 5W transmit power output (> 2W)
  - >0.1 dB receiver gain control
  - >0.1 dB transmit amplifier gain
- Completed fabrication of transmit and receive boards and assembly of T/R module
- Performance testing of T/R module ongoing
- Evaluating the trades of two viable antenna concepts
  - Planar phased array
  - Cylindrical antenna phased array feed