

60KW Solid-State Booster Amplifier

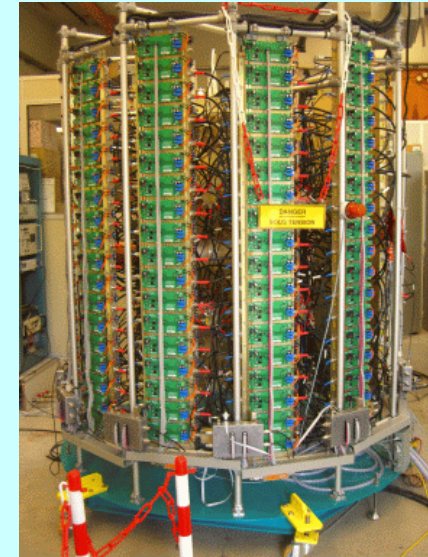
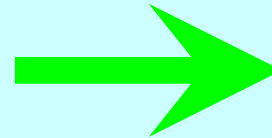
Development at PSI



Booster Klystron Amplifier



Test Stand



Booster Solid-State Amplifier



60KW Solid-State Amplifier

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Target Specifications

Output Power: 60KW

Center Frequency: 499.652MHz

Efficiency: ~ 50%

Price: Cheaper than Klystron Amplifier

Lifetime: Longer than Klystron Amplifier

Maintenance: Easier, Hot Swap Possible

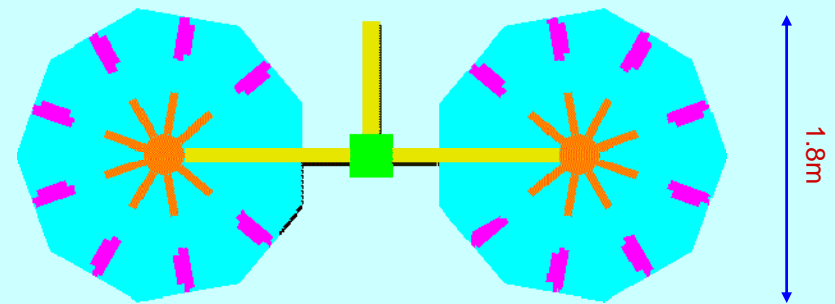
Construction: In House

Proposed Design Configurations

1- 2 Tours = 16 Bars = 256 times 250W Modules → Pout = 64KW max

- Advantages:
- Extra Power to Compensate Losses
 - Uses Developed 250W Amplifier
 - Easier Maintenance
 - Only Half of the Amplifier may be used if needed

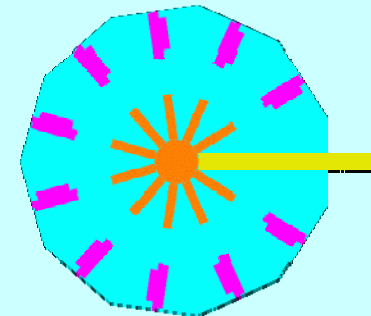
- Drawbacks
- Slightly Bigger Size



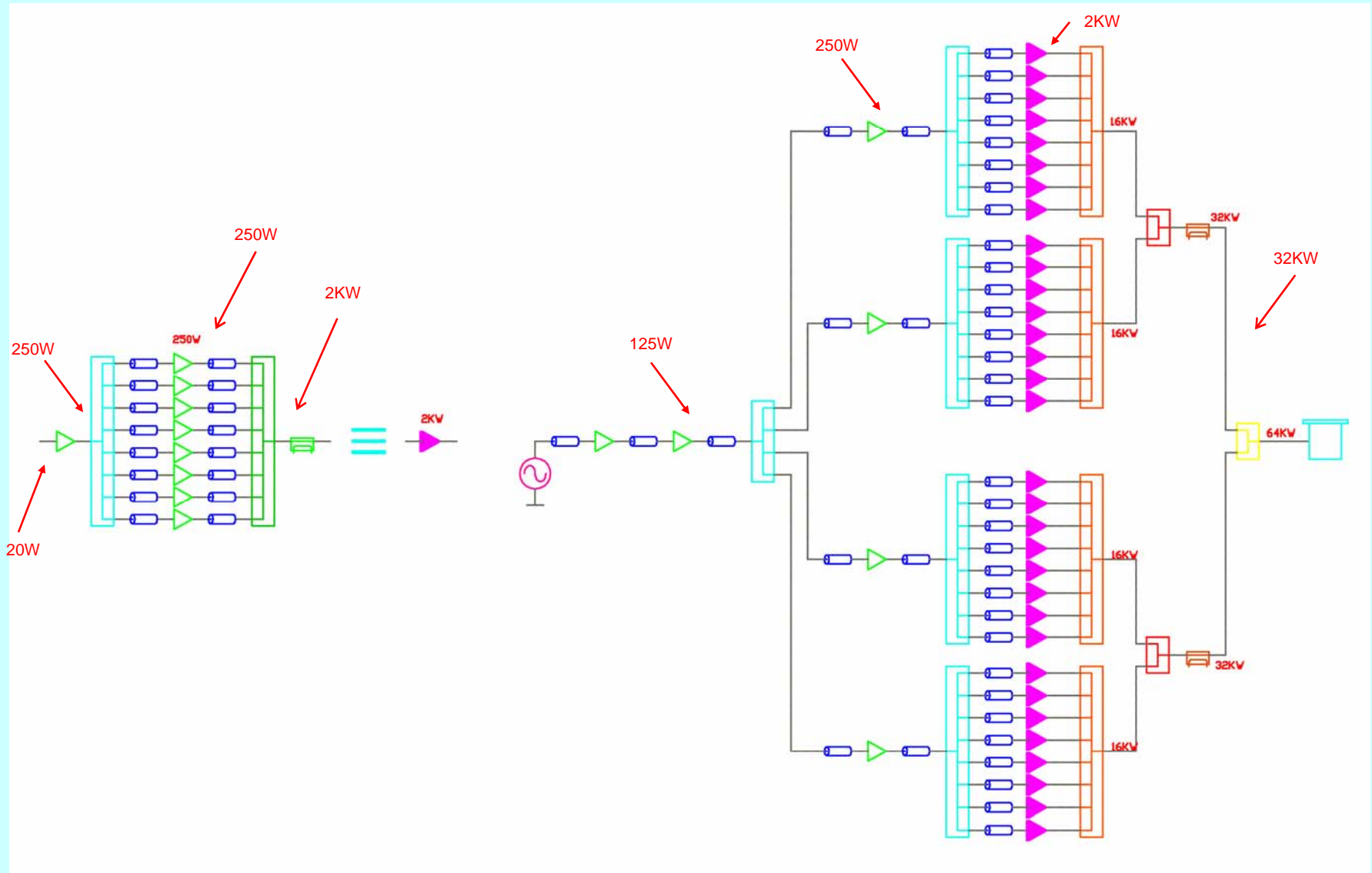
2- 1 Tour = 10 Bars = 160 times 250W Modules → Pout = 40KW max

- Advantages:
- Lower price possible (may save 20%)
 - Smaller size

- Drawbacks
- Requires Higher Gain Amplifier (not yet available)
 - No extra Power to Compensate Losses
 - Too Compact, Worse Maintenance



60KW Amplifier Schematics



Components Available

Power Supply: 3 Different Models Commercially Available (Industry)

Power Splitter: 2 8-Way, 1 4-Way and 1 2-Way Prototypes working (PSI Design)

250W Amplifier Module: 2 Finished Amplifier Modules working (PSI Design)

Cooling Bar: Use Soleil Design (Should Keep Compatibility) (Industry)

Circulator + Load: Commercially Available (Industry) (Already Tested)

Components Under Development @ PSI

Control System: Local (Amplifier Module) and Main Controllers

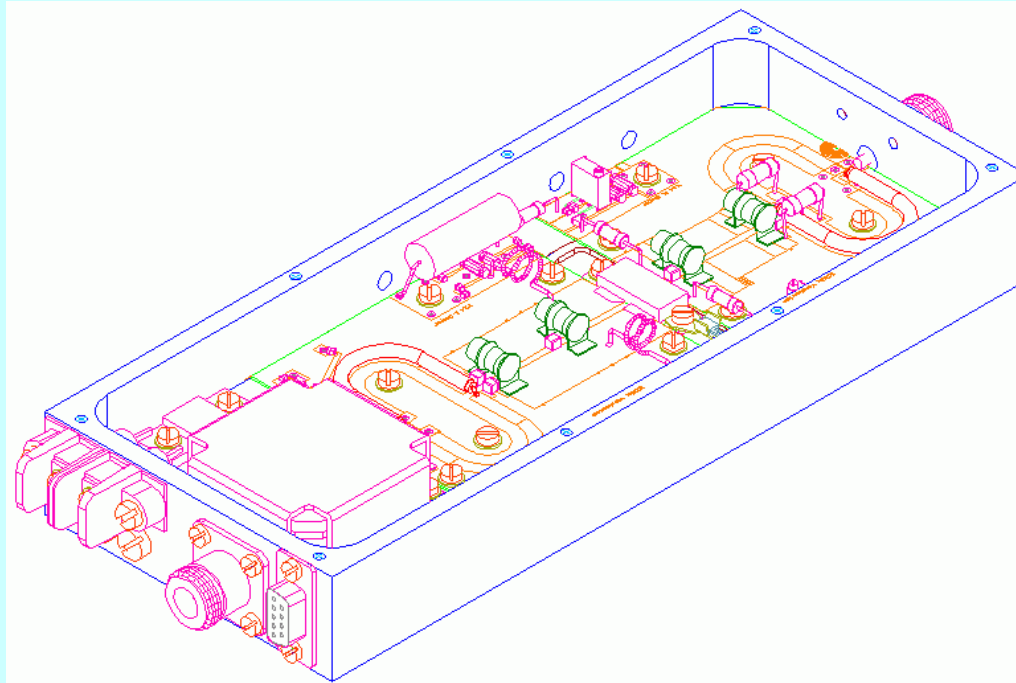
Power Splitter: 1 4-Way and 1 9-Way Low Loss High Isolation

250W Amplifier Module: New design using 2 new transistors

Power Combiner: 8-Way 9-Way and 4-Way Coax

Power Coupler: 2KW and 32 KW Types

250W Amplifier - The Key Component



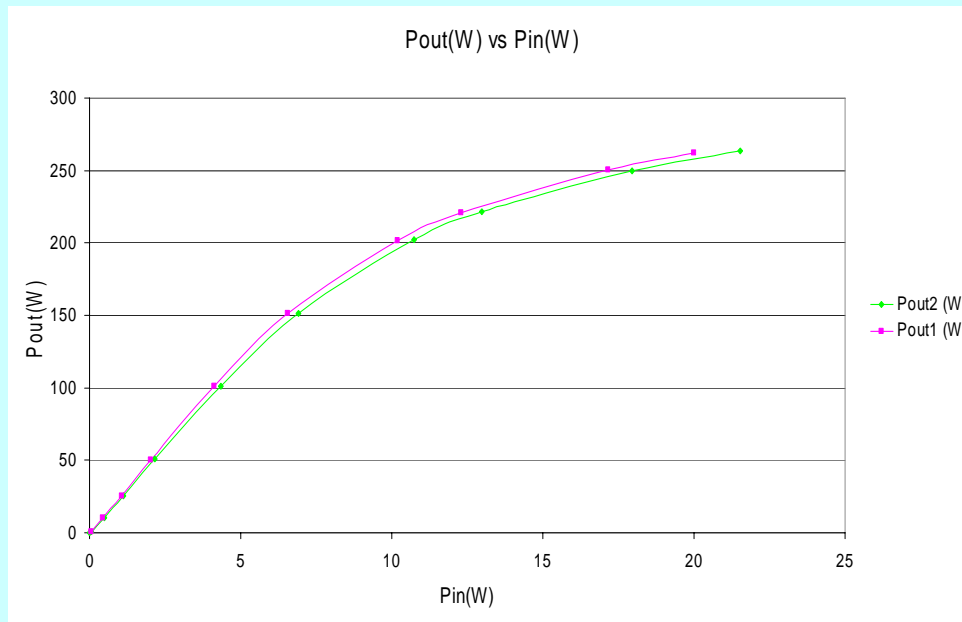
3D-View of 500MHz Amplifier Module

Key Performance Parameters

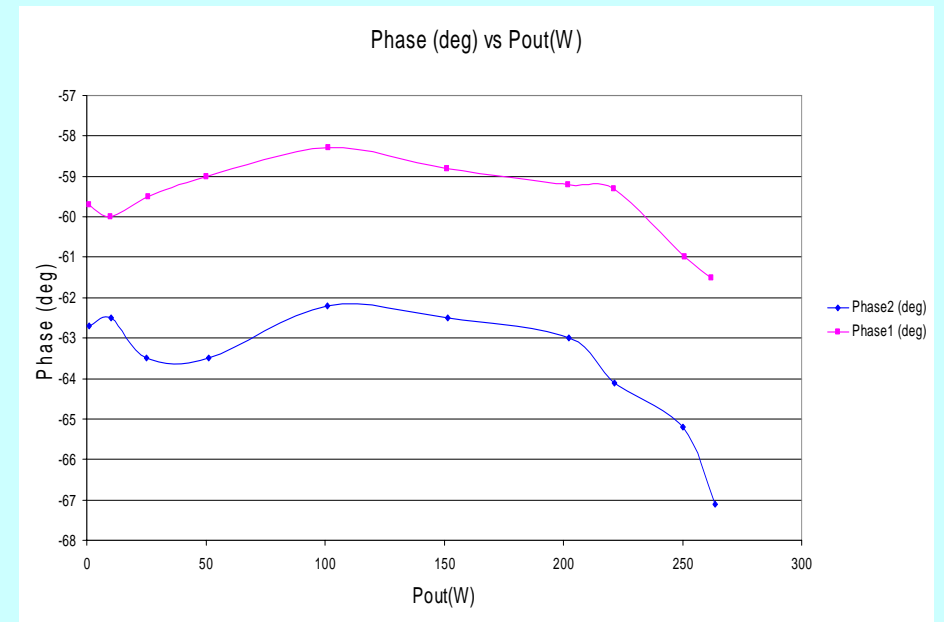
	Operation	Max
Output Power (with Circulator)	250W	280W
Gain	12dB	10dB
Efficiency	~ 56%	~ 55%

250W Amplifier - Measurement Results

CW $f = 506\text{MHz}$
Modules #1 & #2 Separated



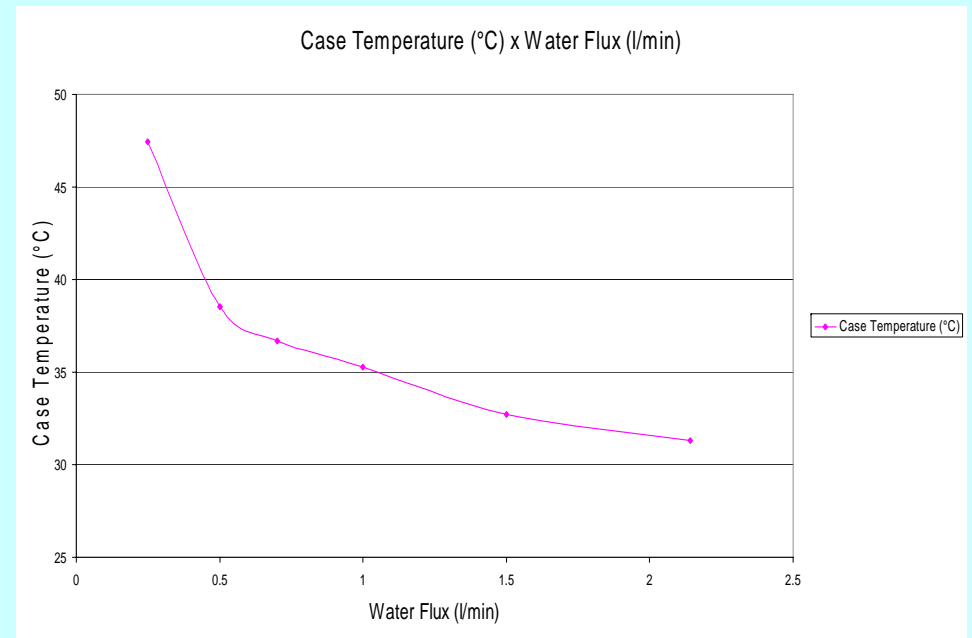
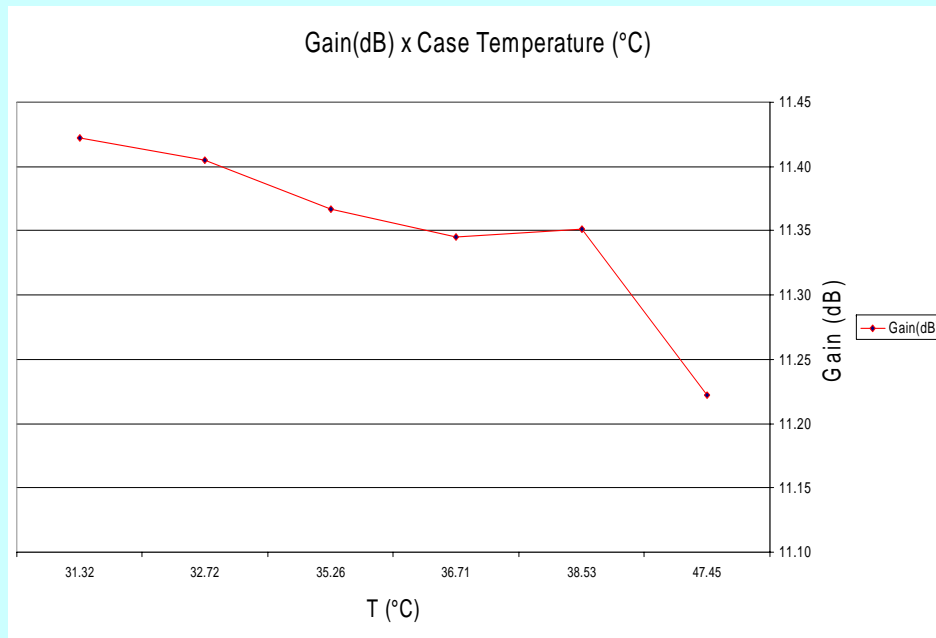
Output Power (W) x Input Power (W)



Output RF Phase (deg) x Output Power (W)

250W Amplifier - Measurement Results

CW f= 506MHz Module #2



Gain (dB) x Case Temperature (°C)

Case Temperature (°C) x Water Flux (l/min)

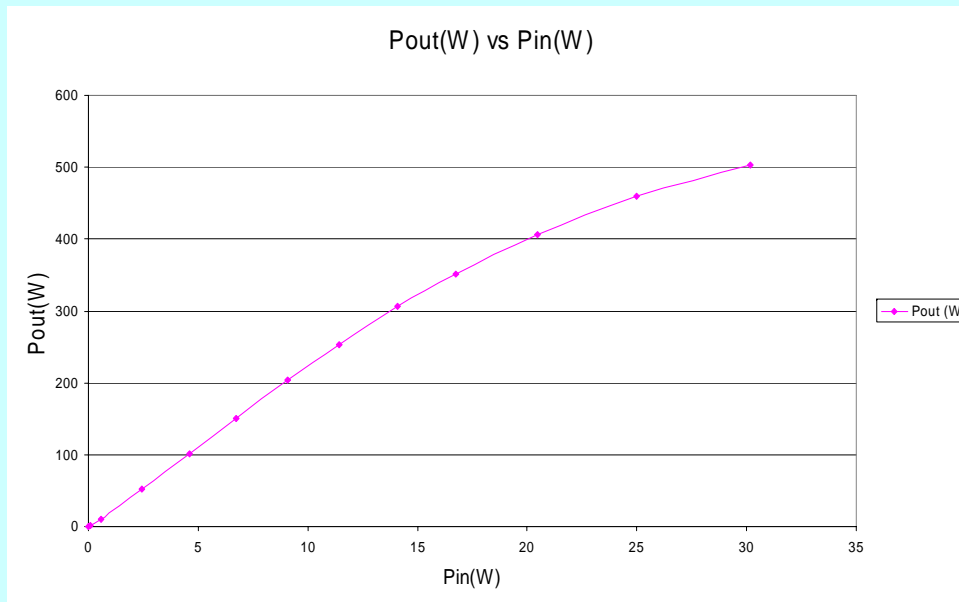
Inlet Water Temp 17.2 °C

Input Power 18.1 W

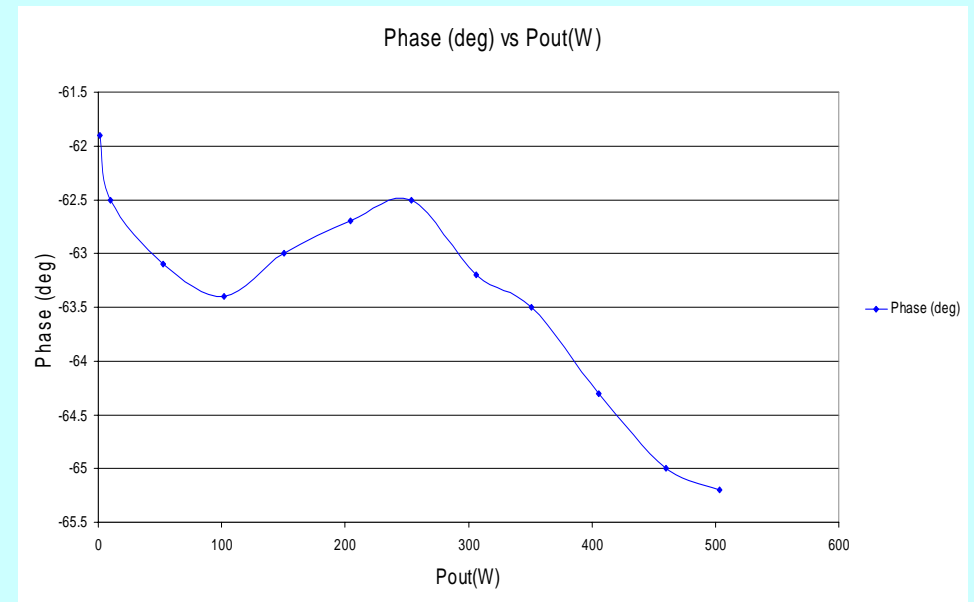
Module #2 Using Graphite

500W Amplifier - Measurement Results

CW f= 506MHz
Modules #1 & #2 Combined



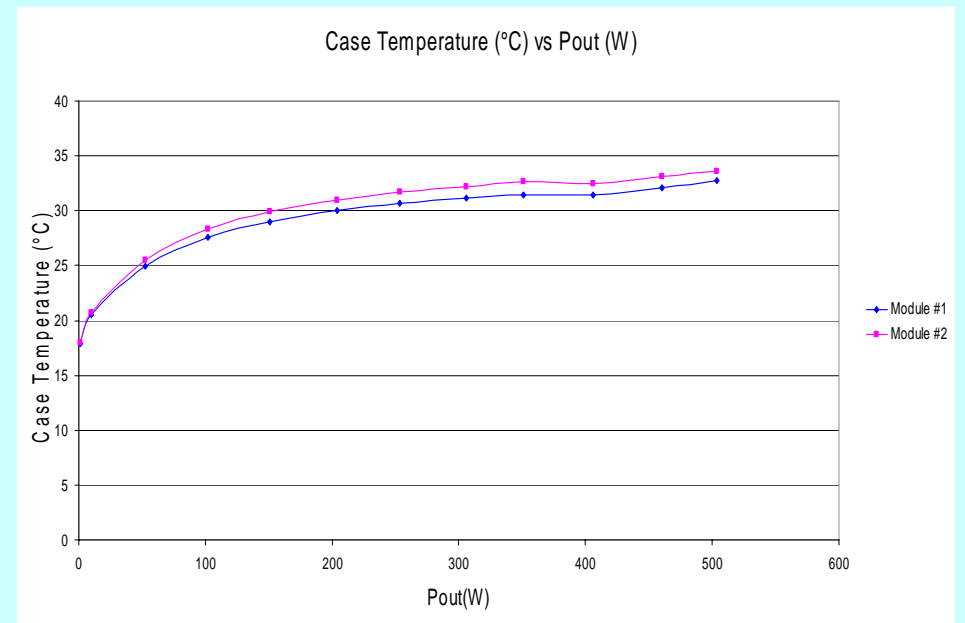
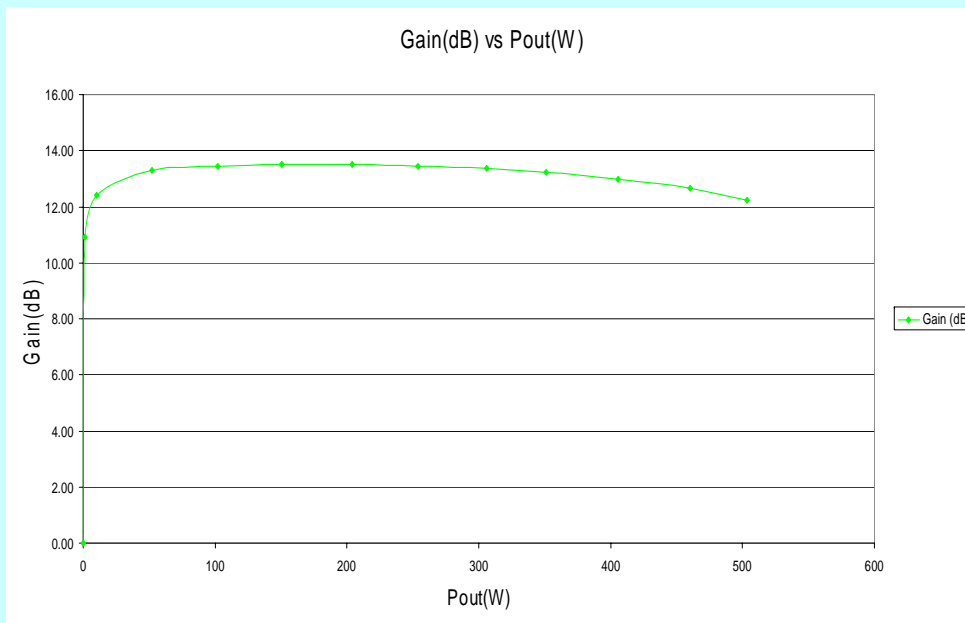
Output Power (W) x Input Power (W)



Output RF Phase (deg) x Output Power (W)

500W Amplifier - Measurement Results

CW f= 506MHz
Modules #1 & #2 Combined



Gain (dB) x Output Power (W)

Case Temperature (°C) x Output Power (W)

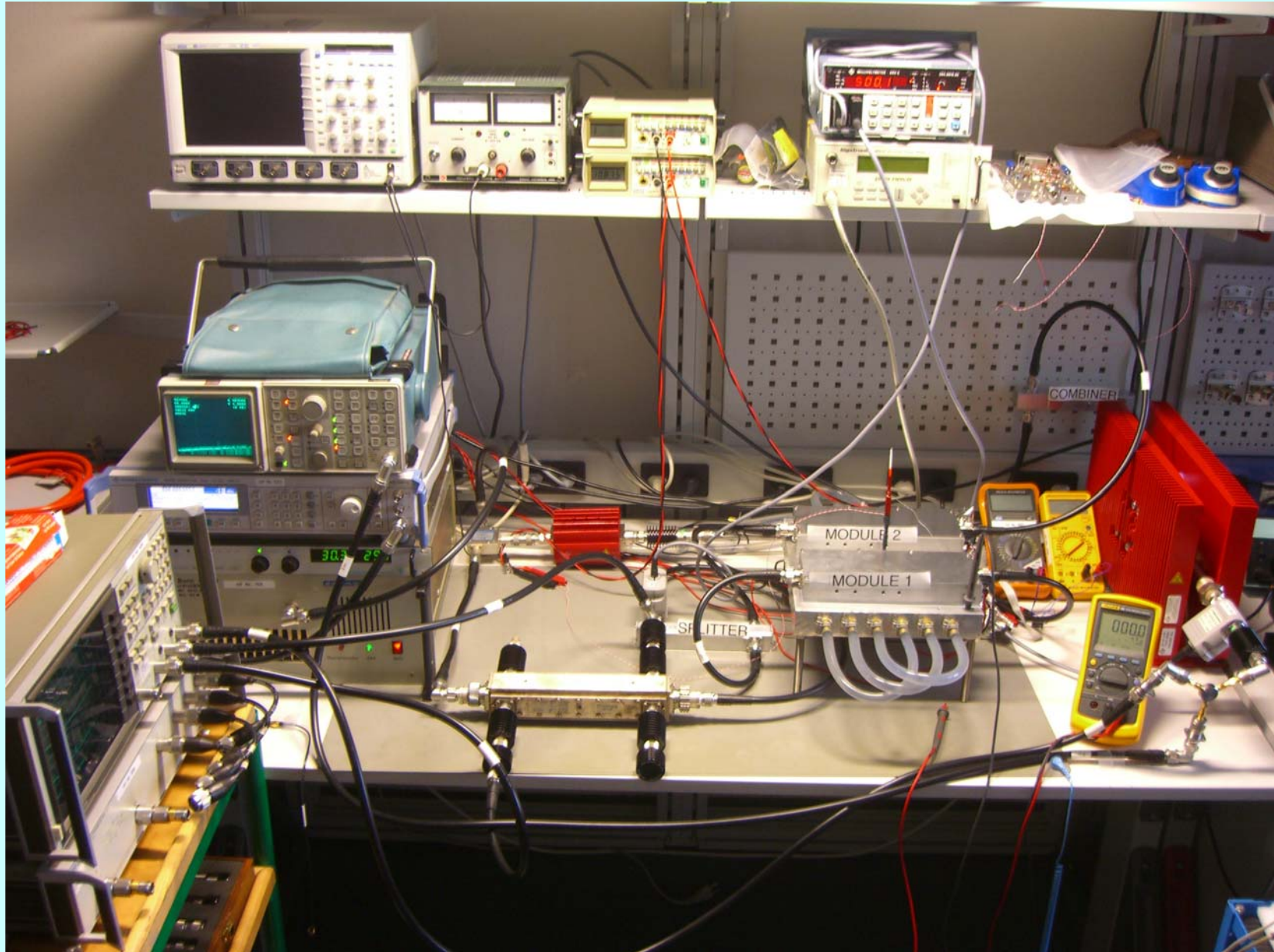
Inlet Water Temp 19 °C

Module #1 Using Silicone Paste

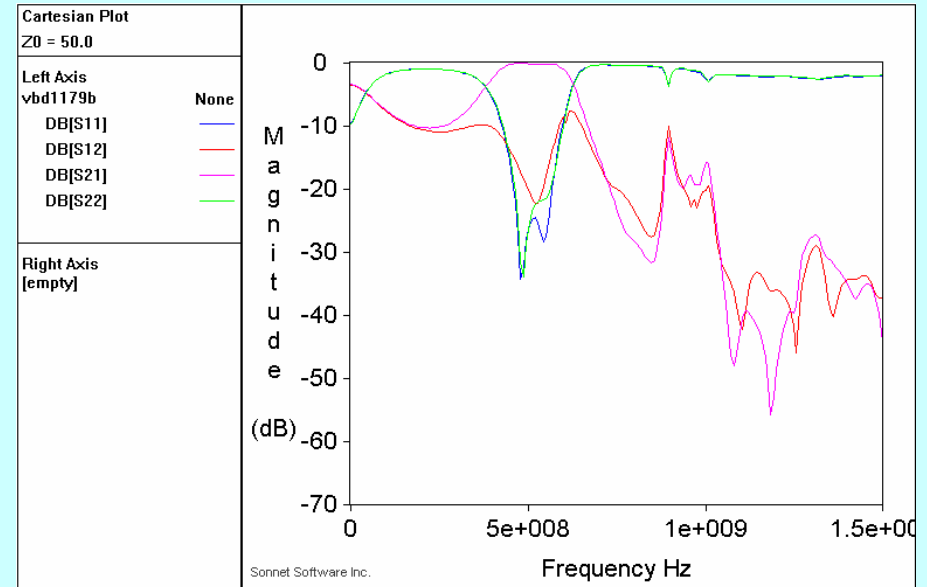
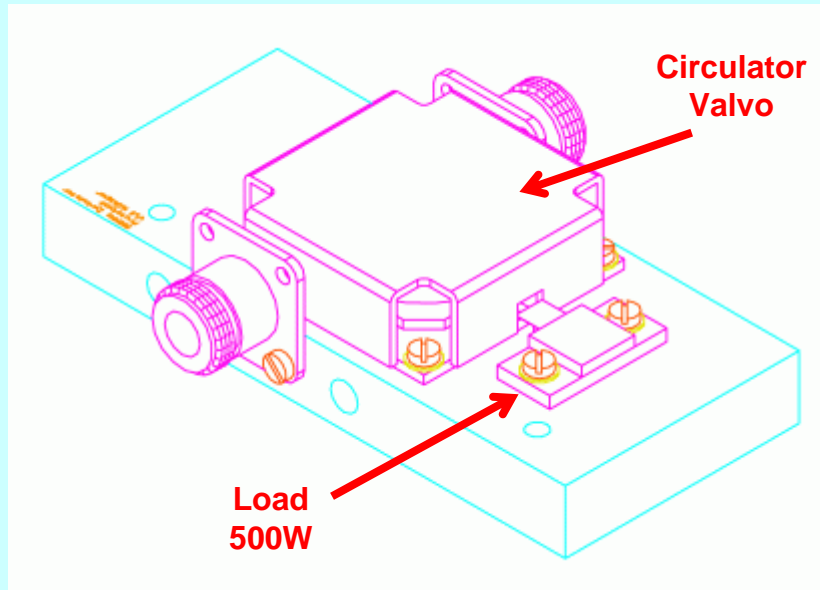
Water Flux 2l/min

Module #2 Using Graphite

500W Amplifier - Test-setup



Circulator



Key Performance Parameters

$$S_{21}BW_{0.2\text{dB}} = 60\text{MHz}$$

$$IL = -0.14\text{dB @ } 500\text{MHz}$$

$$S_{11}BW_{<-20\text{dB}} = 100\text{MHz}$$

$$RL = -27\text{dB @ } 500\text{MHz}$$

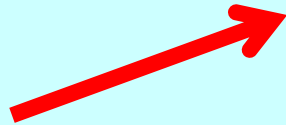
$$S_{12}BW_{<-20\text{dB}} = 50\text{MHz}$$

$$DF = -1^\circ/\text{MHz @ } 500\text{MHz}$$

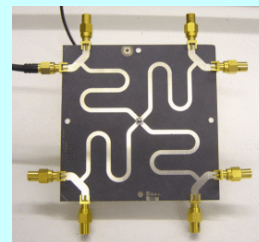
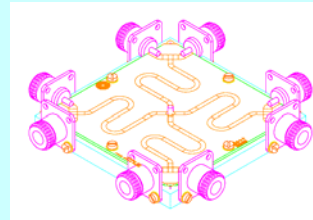
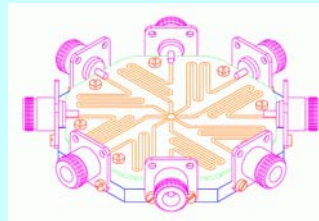
Power Splitter

3 Configurations Available

- 4 Channels – FR4
- 8 Channels – Teflon
- 2 Channels – Coax



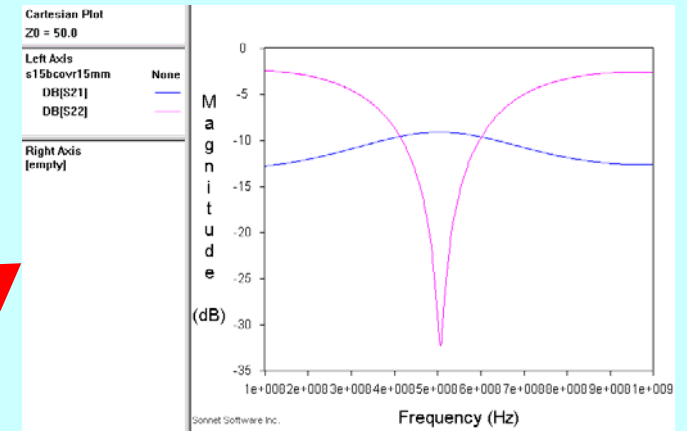
Prototypes



Designs in Progress

- 2 Channels – Teflon 3mm
- 9 Channels – Teflon 3mm improved isolation
- 4 Channels – Teflon 1.6mm

Measurement Results – 8-Channels Teflon



$$S_{21}BW_{-0.1\text{dB}} = 80\text{MHz}$$

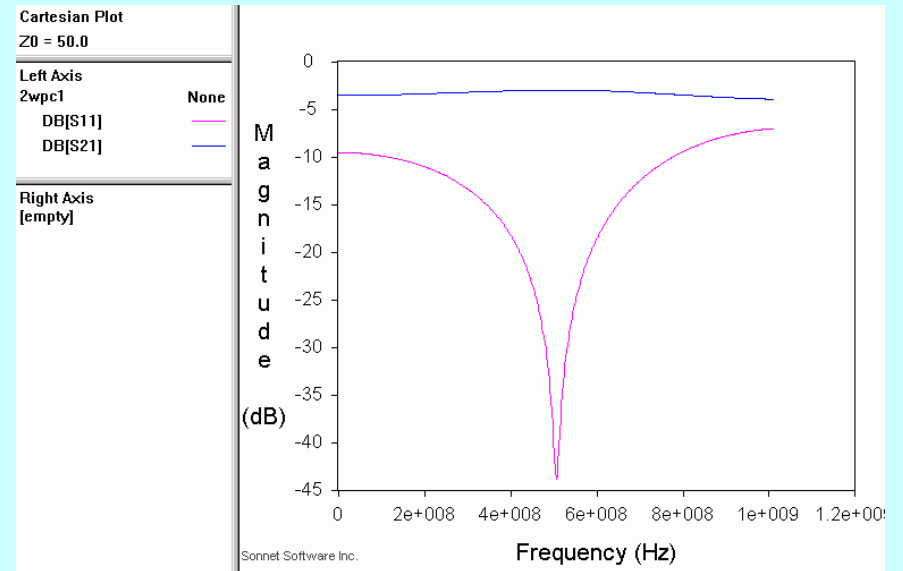
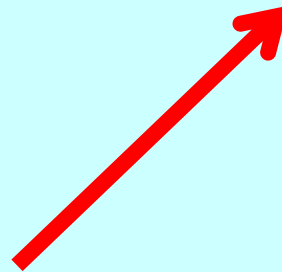
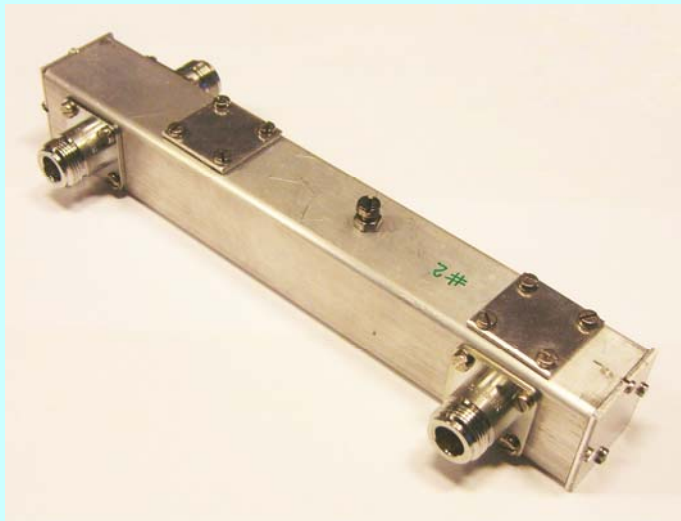
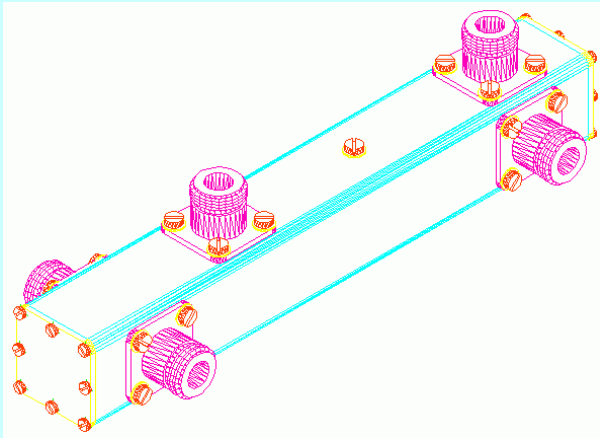
$$S_{11}BW_{<-20\text{dB}} = 100\text{MHz}$$

$$IL = -0.02\text{dB} @ 506\text{MHz}$$

$$RL = -32\text{dB} @ 506\text{MHz}$$

$$DF = -0.3^\circ/\text{MHz} @ 506\text{MHz}$$

Power Combiner - 2-to-1 Coax

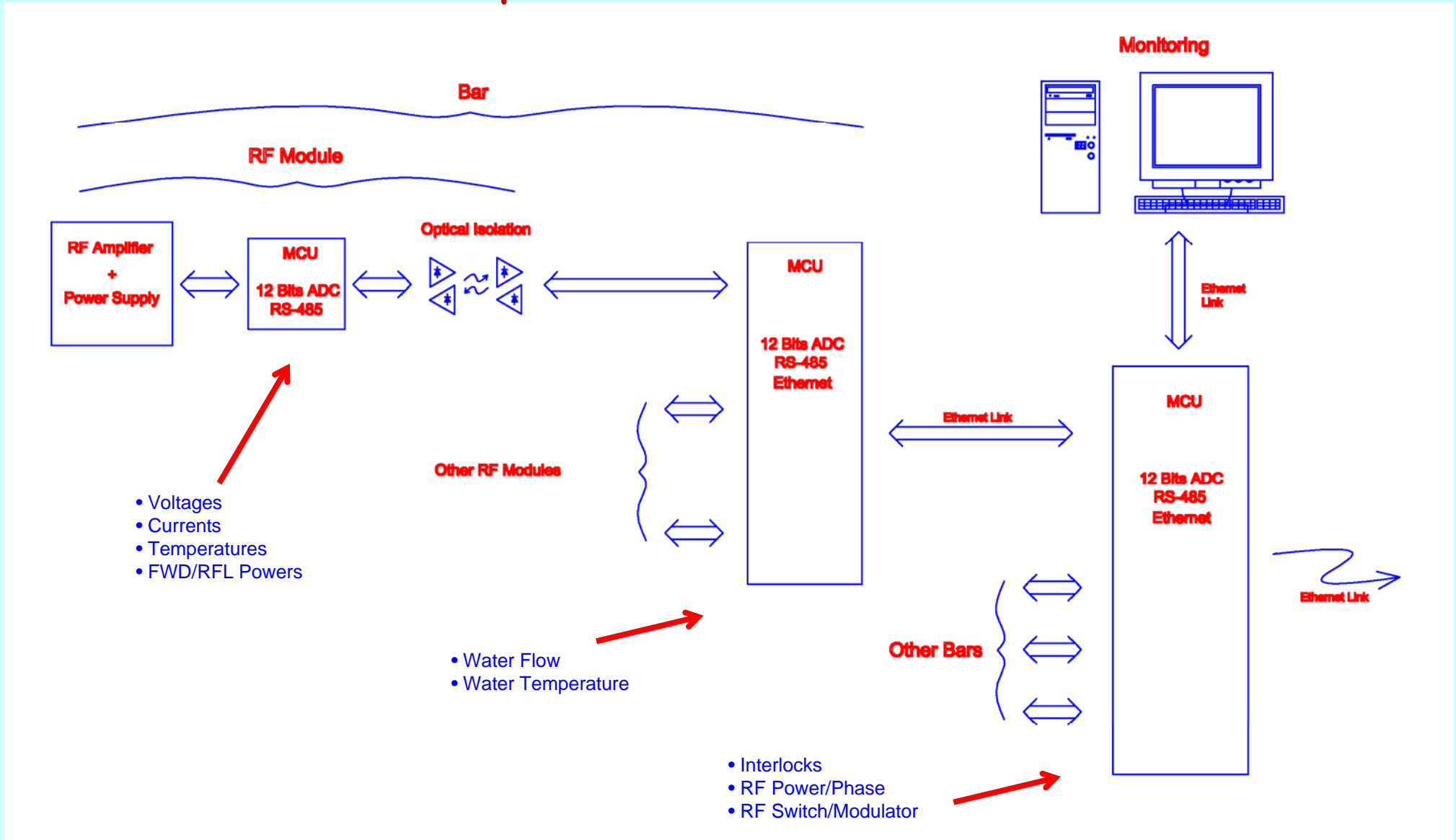


IL < -0.01dB @ 506MHz

RL < -44dB @ 506MHz

DF = -0.26°/MHz @ 506MHz

Supervision and Control



Estimated Project Budget in CHF

Power Amplifier Modules:	200'000
Power Supply:	70'000
RF Cabling:	10'000
General Assembly:	30'000
Cooling System:	30'000
Supervision and Control:	10'000

Estimated Total: 350'000  In house technology

As comparison: 180 kW klystron: ~390'000
Lifetime: up to 60'000 hours