Compact Integrated Receivers Using MMIC Technology

Sino-NRAO Bilateral Workshop
4/24/2008

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Outline

1. Why use MMIC Technology?

2. Past MMIC Developments at NRAO

3. Roadmap to Smaller, Lighter, and Cheaper Receivers

4. Future Developments

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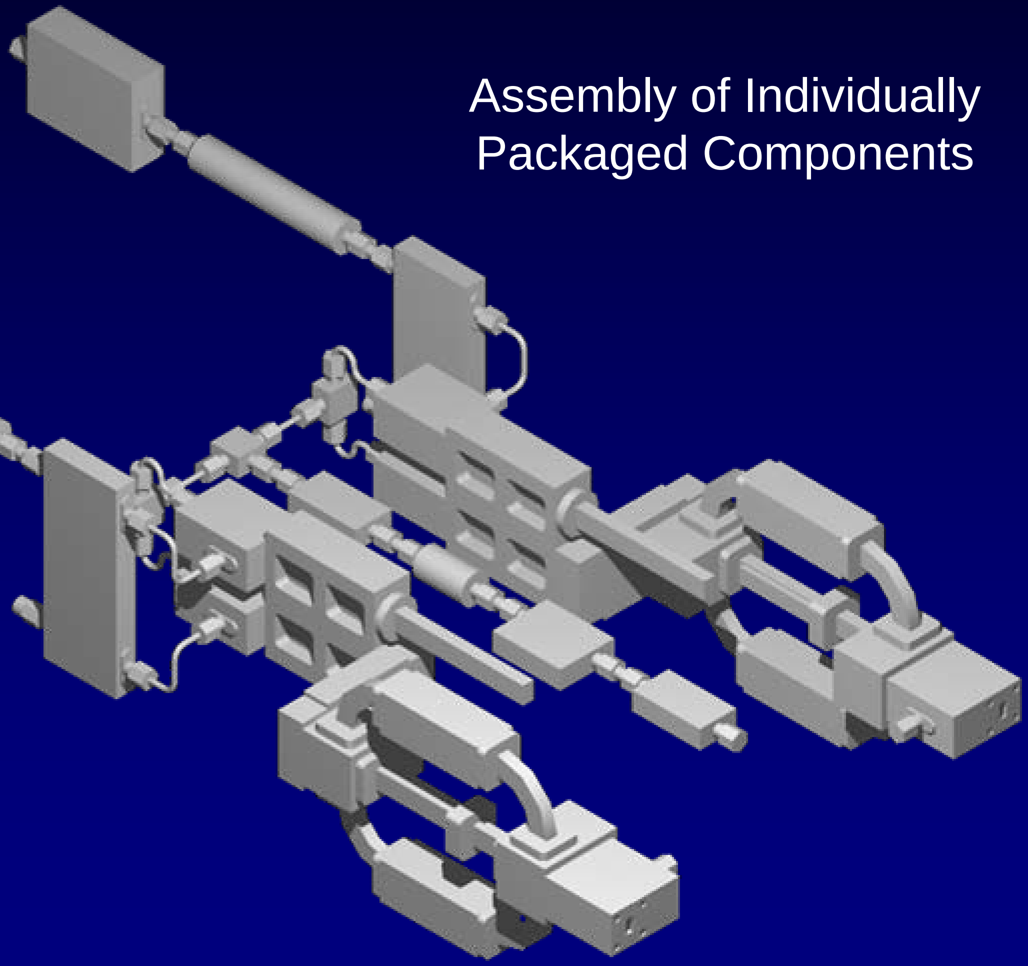
Compact Integrated Receivers

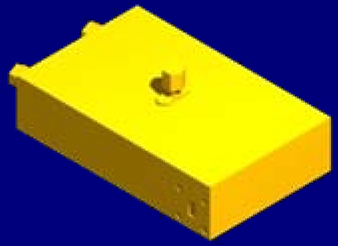
1. critical for focal plane arrays
   - beam spacing
   - field of view
2. lower mass
   - more efficient cryogenics
   - tighter temperature control
   - reduced mechanical load
3. fewer connectors and cables
   - greater reliability
   - reduced VSWR effects
   - reduced gain slopes
   - fewer entry points for RFI

MMIC Modules are More Compact, Lightweight and Manufacturable than Conventional Assemblies

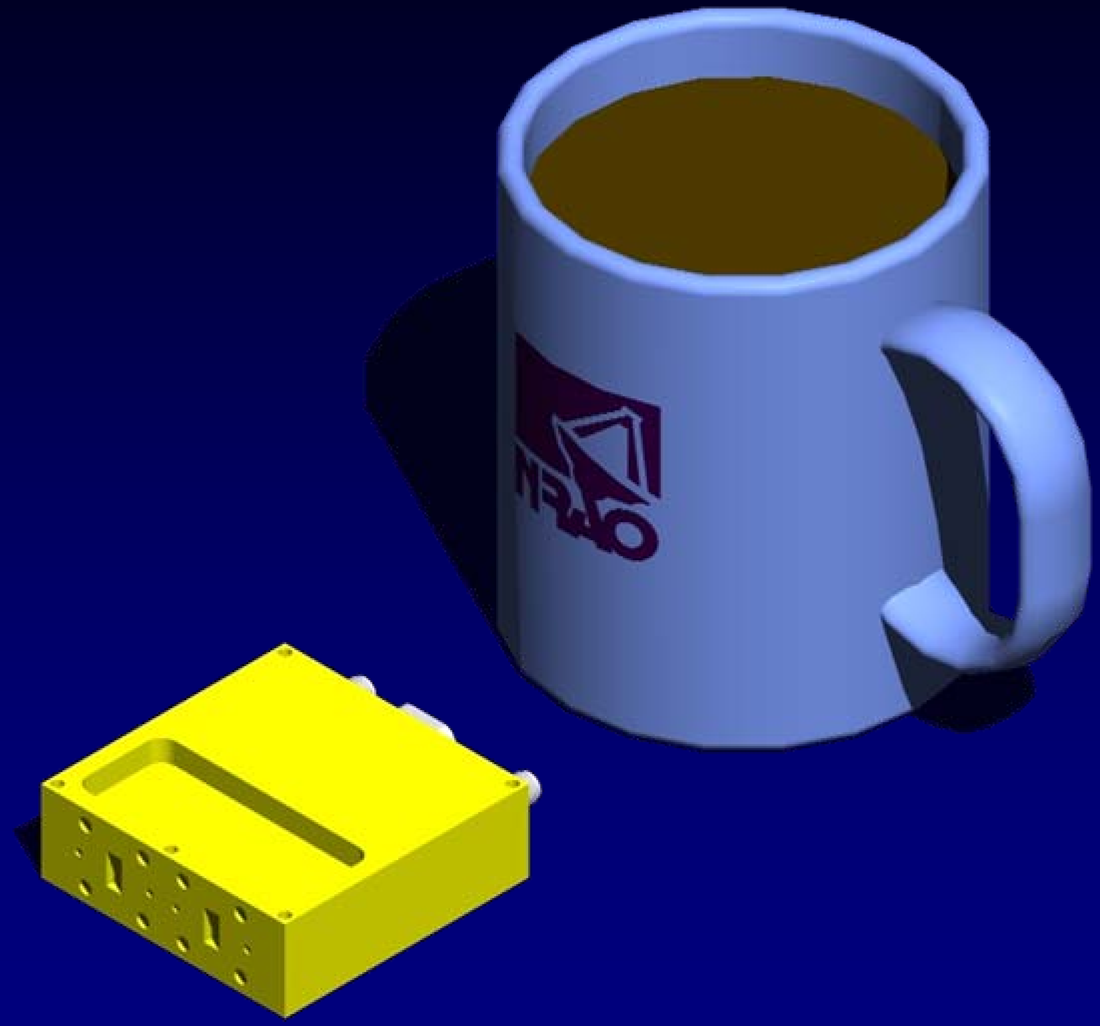
Assembly of Individually Packaged Components



Multi-Chip Module



MMIC Modules are Compact Enough for Focal Plane Arrays



The size of a well-designed MMIC module is typically dominated by connectors and waveguide flanges.

Many MMICs Available Commercially

Most things below 50 GHz are available off-the-shelf for less than $50
Exceptions include:

- balanced/differential port configurations
- non-standard impedance
- some block-conversion mixers

Some things in the 50-100 GHz range can be found in commercial product listings, but

- sparse frequency coverage
- usually narrow-band, targeted for specific applications (communication and radar bands, etc.)
- some exotic functions not supported (compound switches, etc.)

Finally, there is a large pool of proven custom designs to draw from, designed by research labs around the world (but obtaining these would generally require purchasing a new wafer run).

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   - Compact Water Vapor Radiometer
   - ALMA Local Oscillator Assemblies

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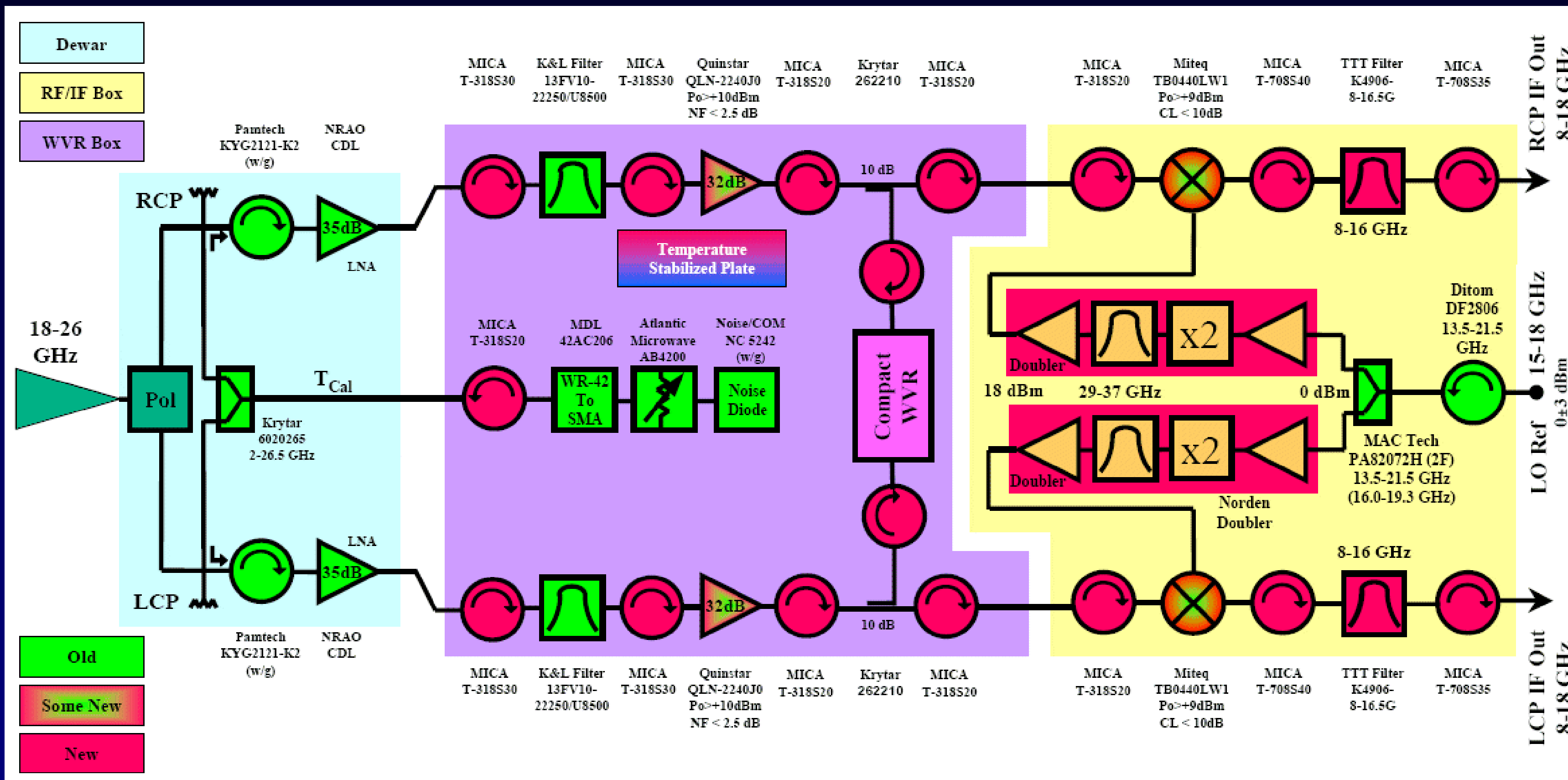
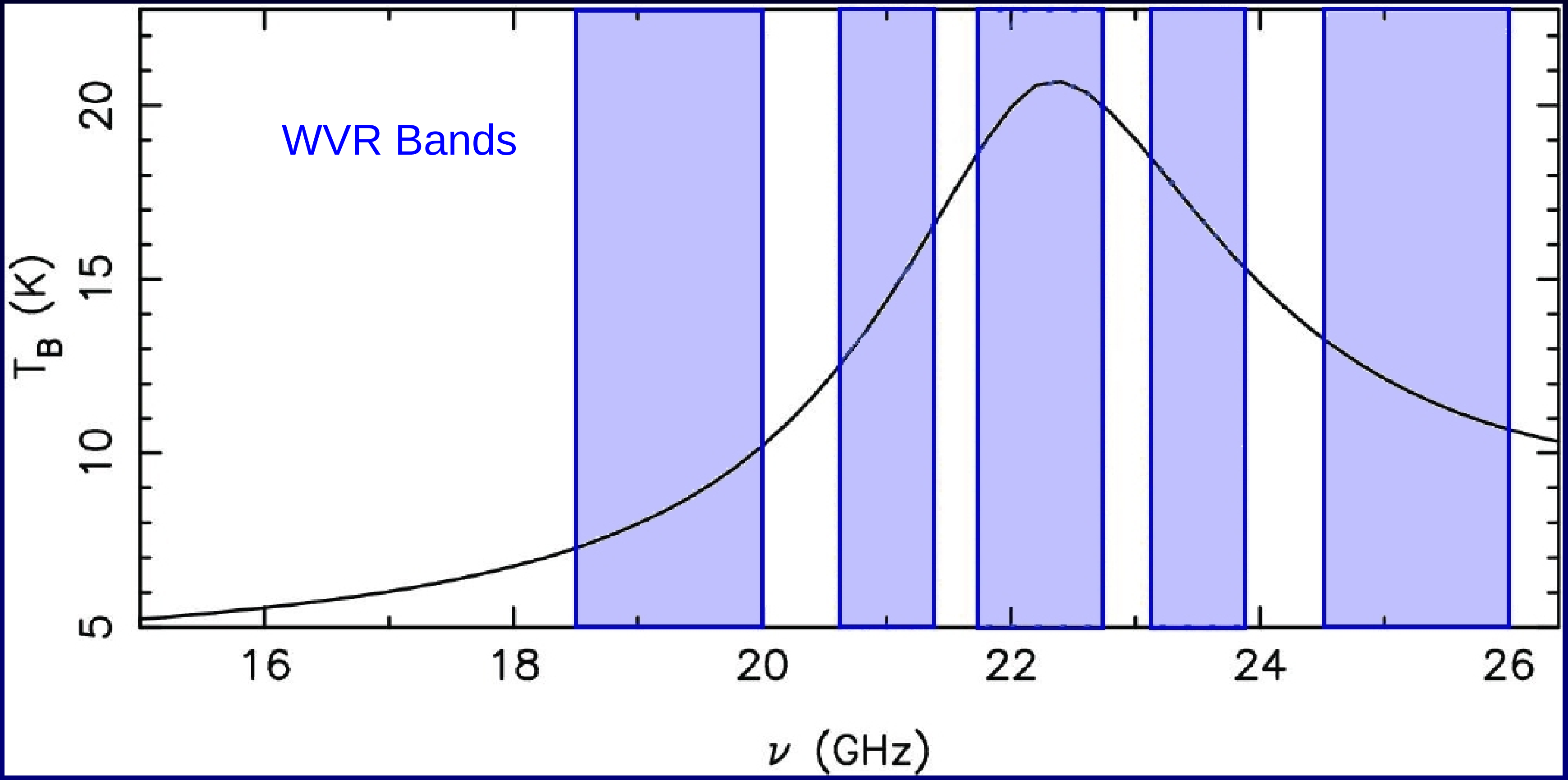
Compact Water Vapor Radiometer



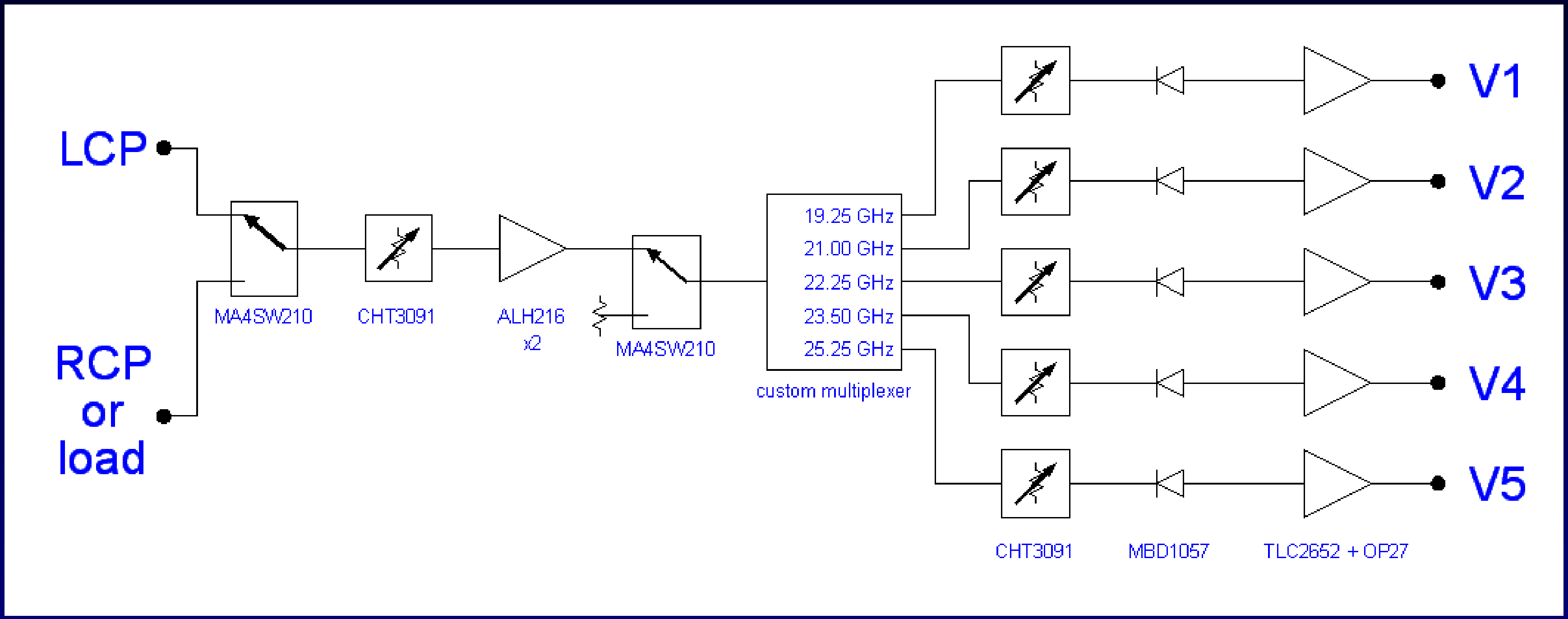
R. Hayward

The Compact Water Vaopr Radiometer Module was designed as an add-on to the K-Band receivers on the EVLA.

Compact Water Vapor Radiometer



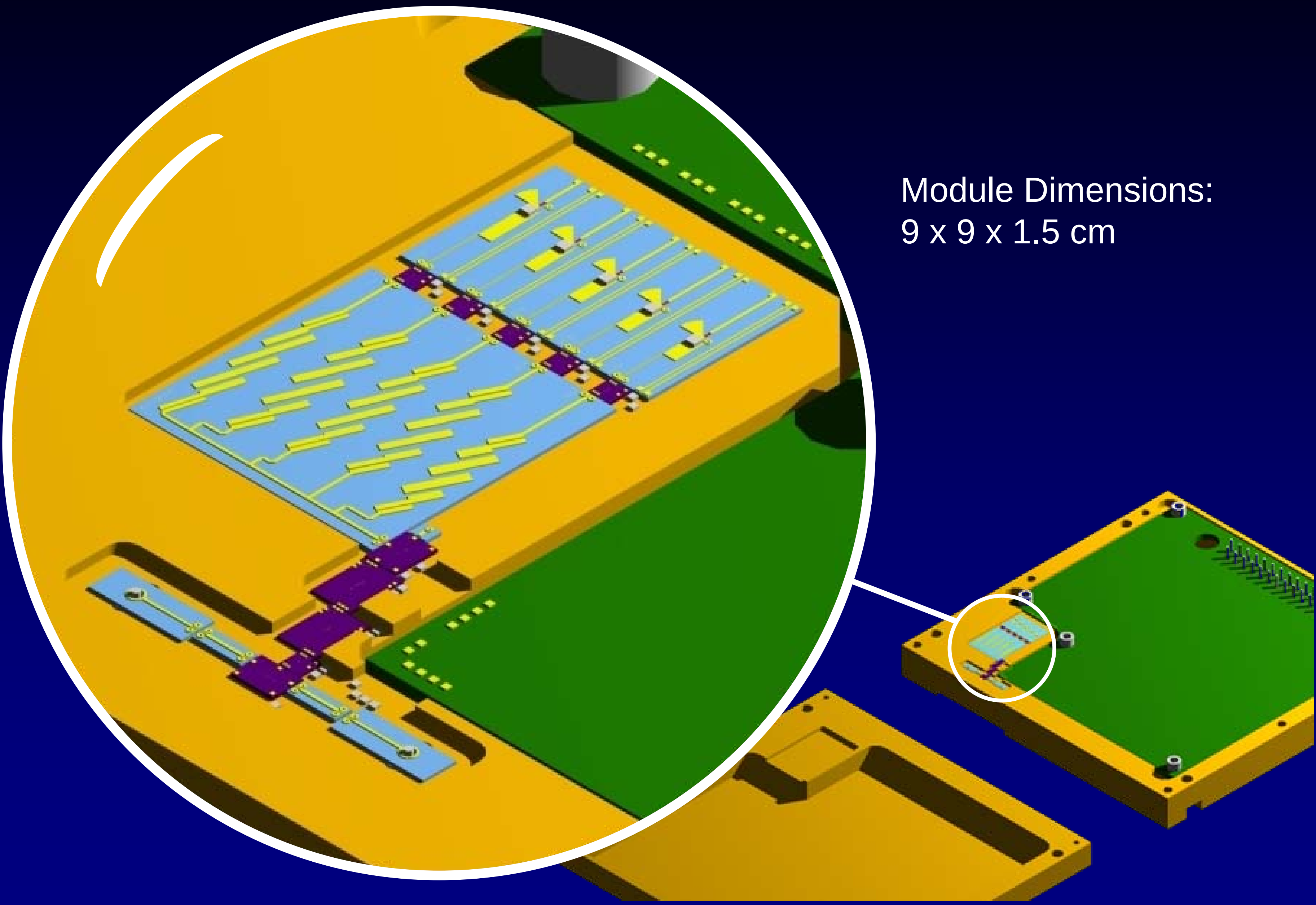
Compact Water Vapor Radiometer



- input pol switch
- leveling step attenuators
- RF gain
- dark-current switch
- 5-channel multiplexer
- detectors
- chopper-stabilized op-amps

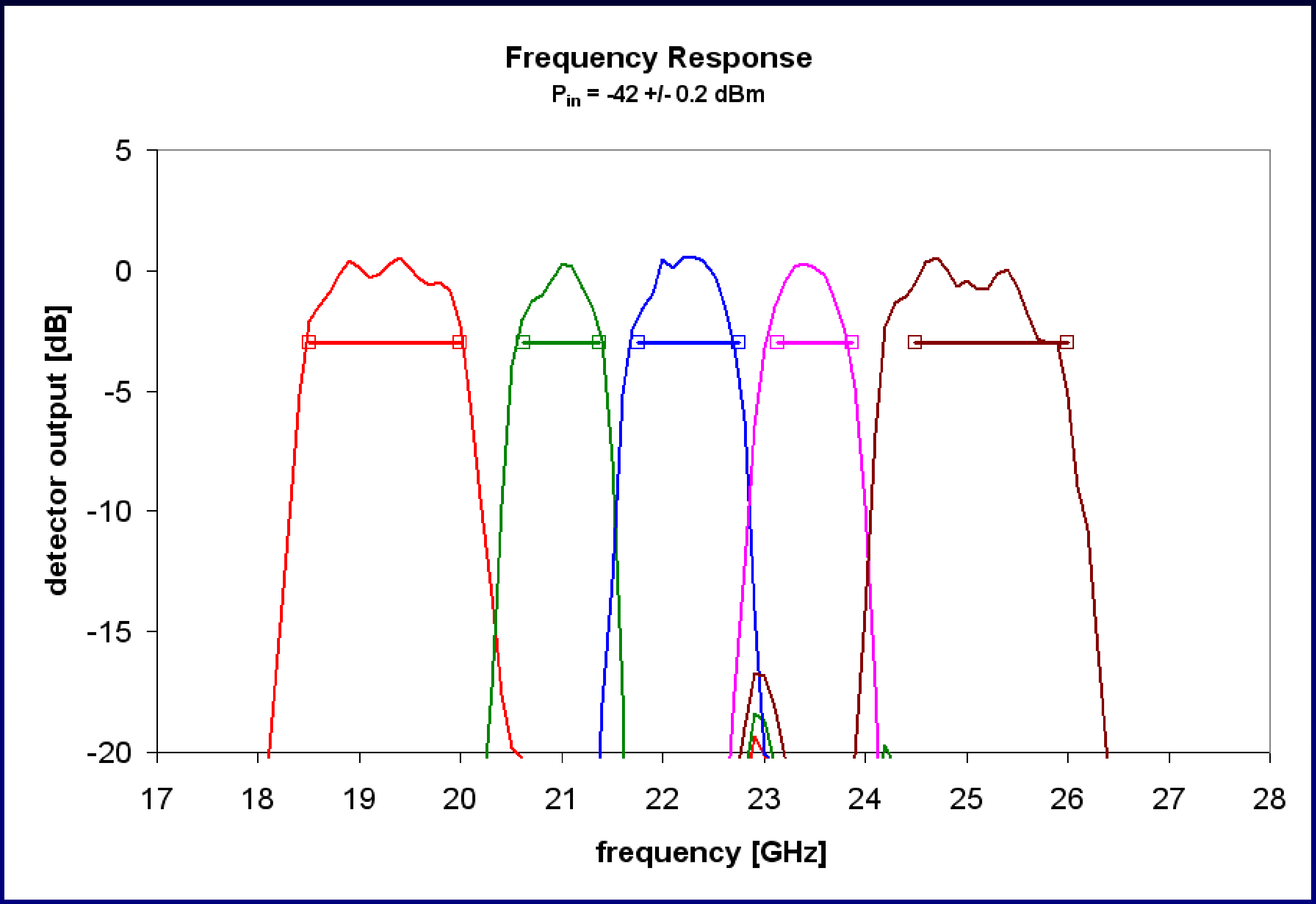
All Commercially available MMICs!

Compact Water Vapor Radiometer

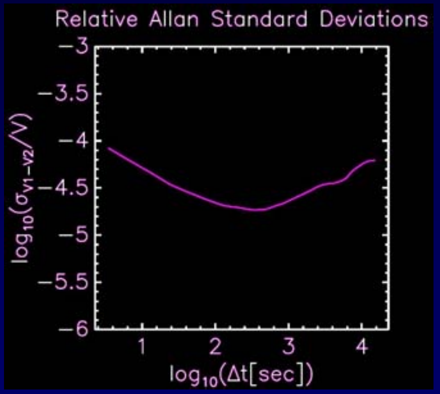


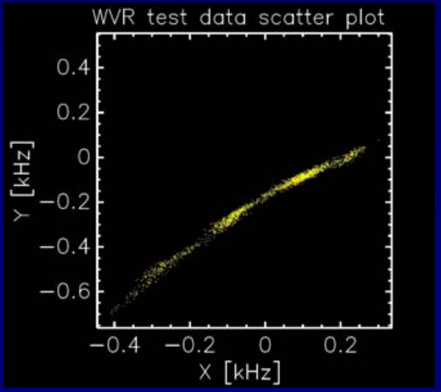
Module Dimensions:
9 x 9 x 1.5 cm

Performance of Compact Water Vapor Radiometer



Stability:





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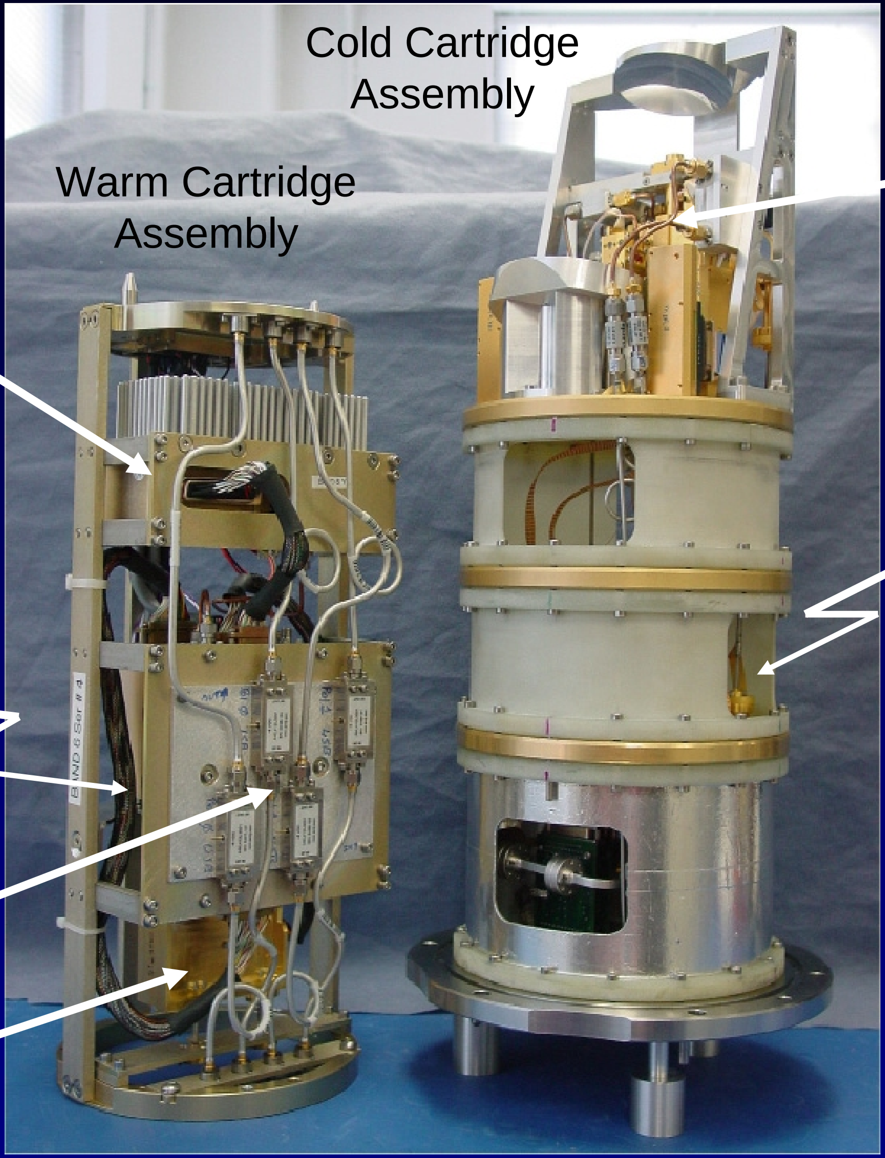
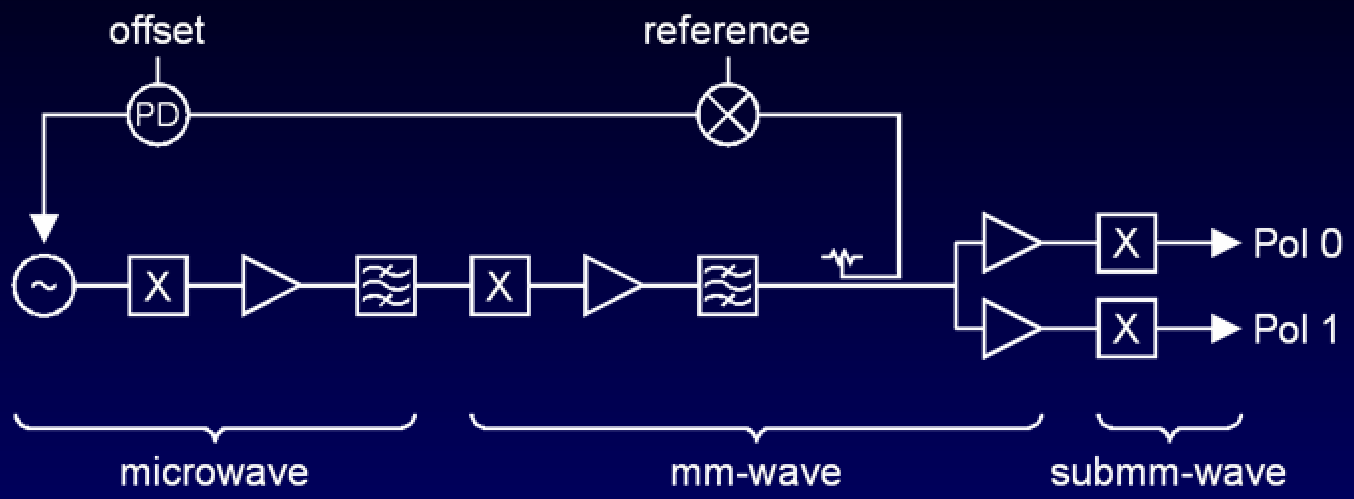
ALMA Receiver Cartridge



ALMA Local Oscillator Assemblies

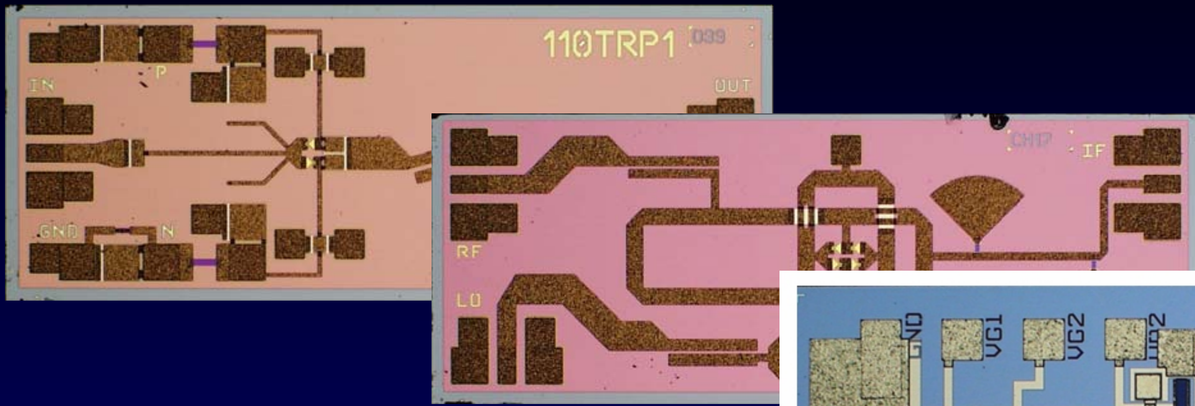


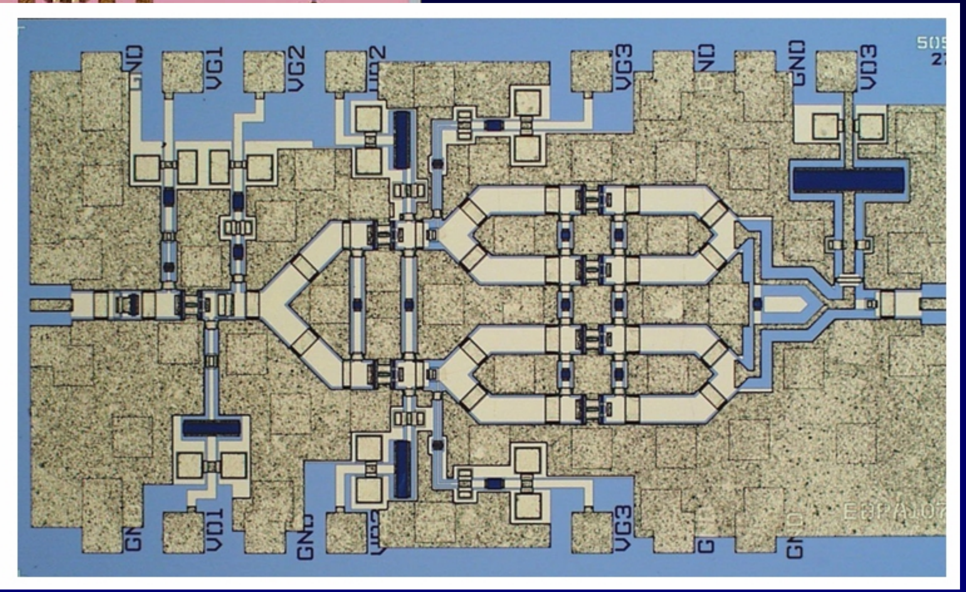
Band #	RF Frequency	Final Multiplier	IF Range	mm-wave LO Frequency
Band 1	31.3 – 45 GHz			
Band 2	67 – 90 GHz			
Band 3	84 – 116 GHz	x1	8 GHz	92 – 108 GHz
Band 4	125 – 163 GHz	x2	8 GHz	66.5 – 77.5 GHz
Band 5	163 – 211 GHz			
Band 6	211 – 275 GHz	x3	12 GHz	74.3 – 87.7 GHz
Band 7	275 – 373 GHz	x3	8 GHz	94.3 – 121.7 GHz
Band 8	385 – 500 GHz	x6	8 GHz	65.5 – 82 GHz
Band 9	602 – 720 GHz	x9	8 GHz	67.8 – 79.1 GHz
Band 10	787 – 950 GHz			

ALMA LO Assemblies:

- wideband CW source
- no mechanical tuning
- no added noise (<1K/uW)
- coherent across the array

Custom MMIC Components for ALMA LO Chains





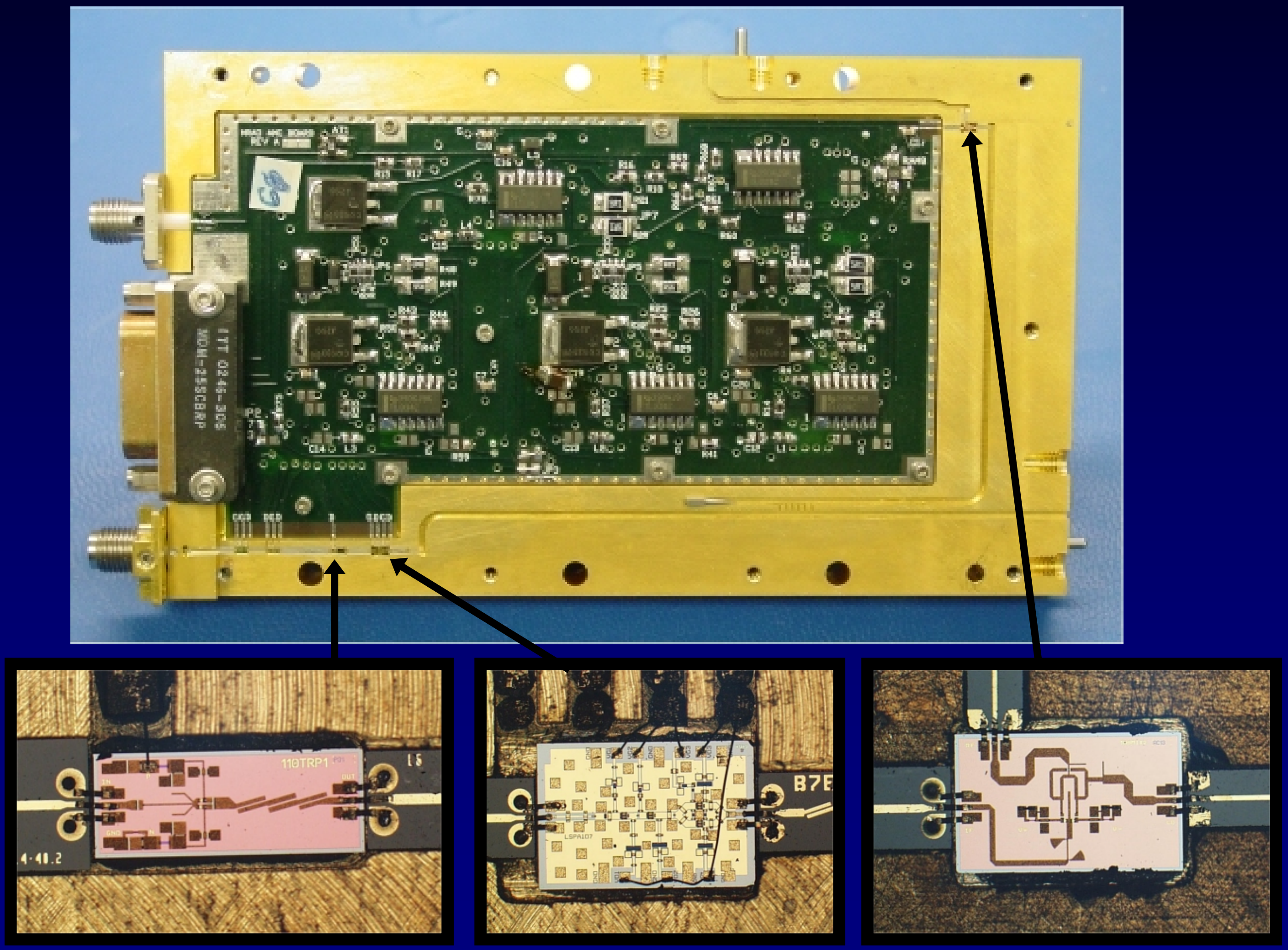
A large number of custom W-Band MMICs had to be developed for the ALMA LO subsystem. These included

- GaAs Schottky Diode Triplers
- GaAs Schottky Diode Balanced Mixers
- GaAs and InP 0.1 μm pHEMT Broadband Medium Power Amplifiers

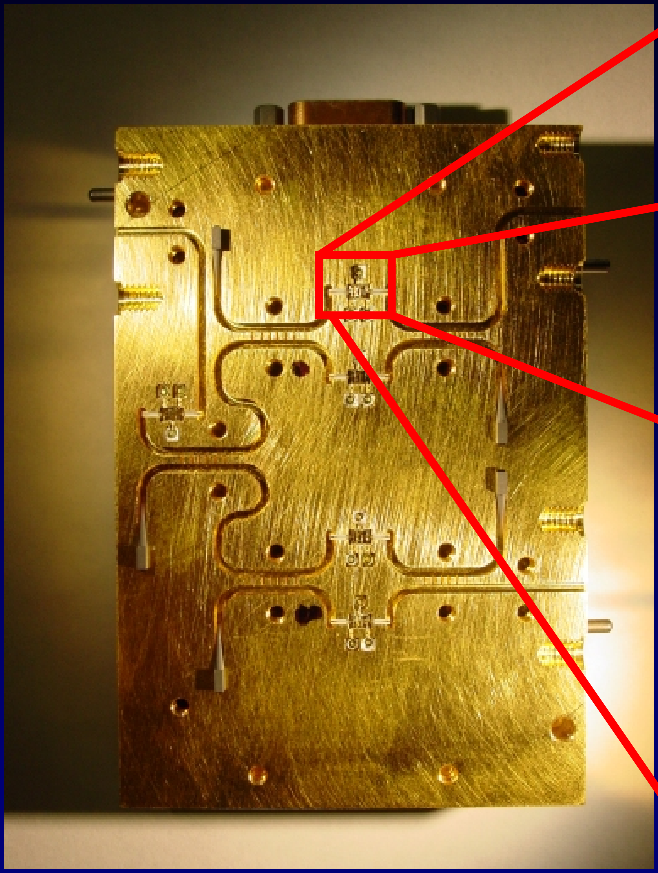
M. Morgan, E. Bryerton, P. Cesarano, T. Boyd, D. Thacker, K. Saini, and S. Weinreb, "A Millimeter-Wave Diode-MMIC Chipset for Local Oscillator Generation in the ALMA Telescope," IEEE Int. Microwave Symposium, Long Beach, CA, June 2005.

L. Samoska, E. Bryerton, M. Morgan, D. Thacker, K. Saini, T. Boyd, D. Pukala, A. Peralta, M. Hu, and A. Schmitz, "Medium Power Amplifiers Covering 90-130 GHz for the ALMA Telescope Local Oscillators," IEEE Intl. Microwave Symposium, Long Beach, CA, June 2005.

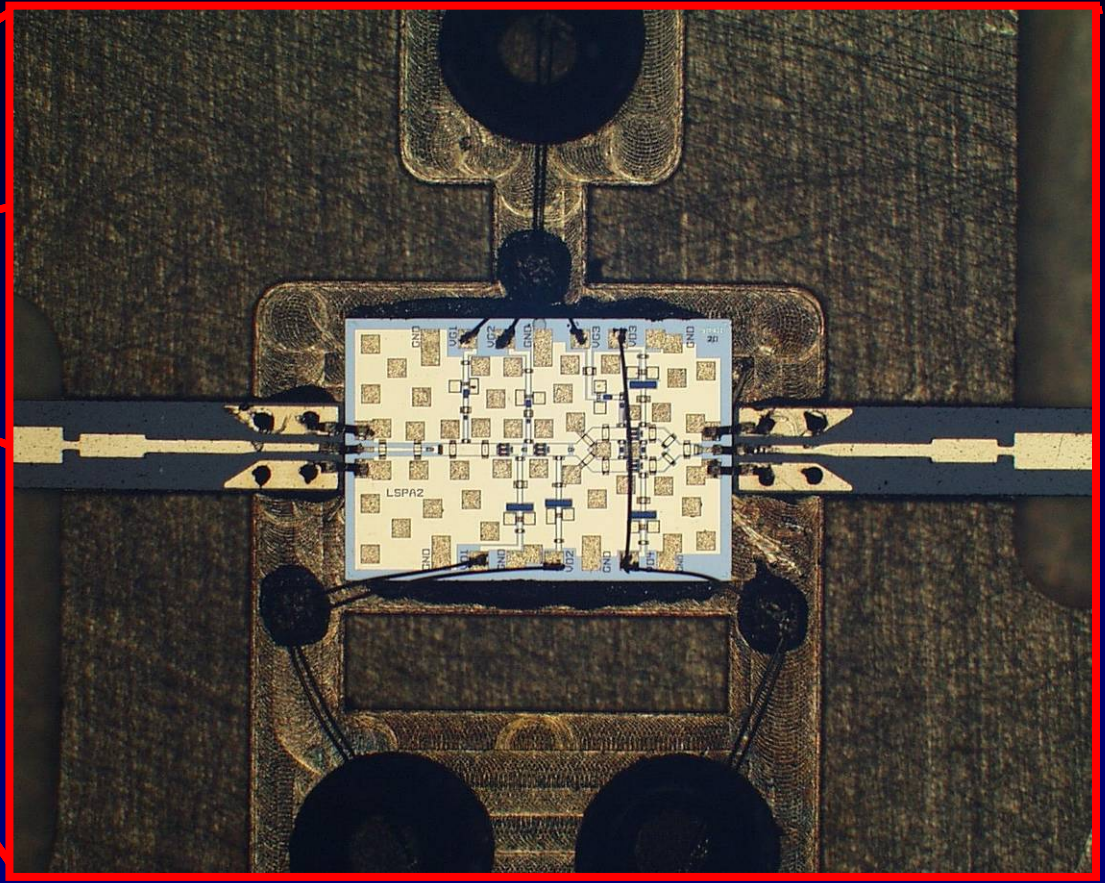
ALMA Active Multiplier Chain



ALMA LO Power Amplifier Modules



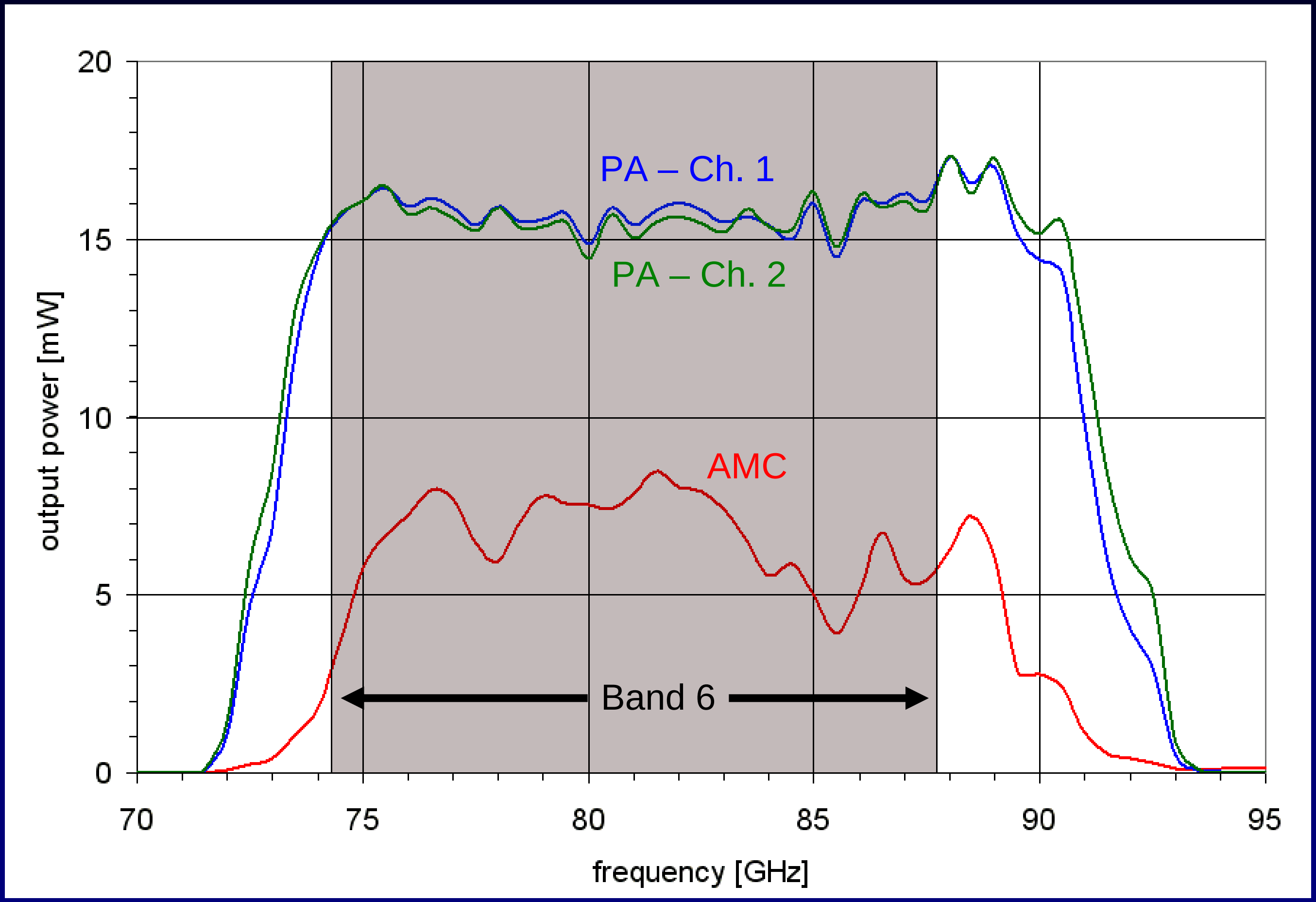
Dual-channel, power-combined MMIC PA module.



Detail of the MMIC PA with waveguide probes.

Preceding the final submm-wave multipliers in each band is a dual-channel power amplifier module.

Performance ALMA Active Multiplier Chain



The output power required from the mm-wave LO system varies from about 10-100 mW depending on the multiplier it must drive to reach the submm-wave band.

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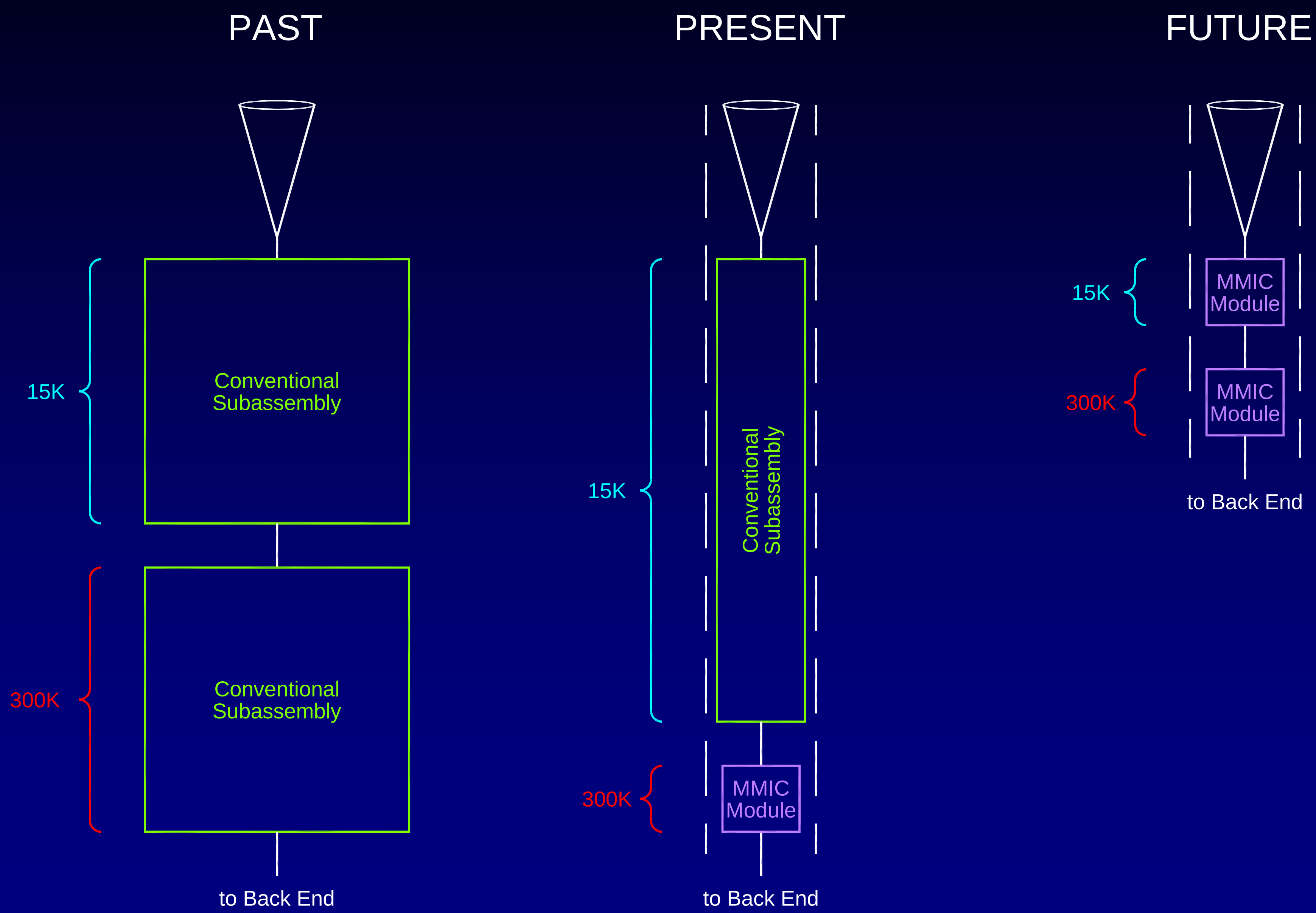
Working Toward an All-MMIC Receiver

1. Once a design is set, MMIC components and assemblies can be mass-produced with exceptional repeatability
   - especially in the cm-wave range, where most MMICs are commercially available – chips are screened by the manufacturer and their specs guaranteed.
   - module assembly is insensitive to small variations – bondwires are used for 50 Ω interconnects, not for tuning!
2. Failures are relatively easy to diagnose and repair
   - because of the inherent uniformity in performance, device failure is usually apparent from the DC bias alone.
   - when it isn't, one can usually open up the module and probe-test the chips in-place to find the culprit
   - the chips are cheap enough (<$50) to simply scrape out and replace

It is therefore reasonable to think about implementing even very sophisticated front-ends in a single module using all MMIC technology.

- no internal connectors!
- no internal cables!
- small, lightweight, manufacturable

Progression from Conventional to Integrated Receivers



Could We Put the Whole Receiver in One MMIC-Module and Cool Everything?

Not if it is a heterodyne receiver, because

- LO generation dissipates too much power for cryogenics
- IF components are usually Silicon, which will not function cold

However, special-purpose direct detection receivers could occupy a single cold module

- even more compact
- better sensitivity
- better temperature stability
- better component lifetime

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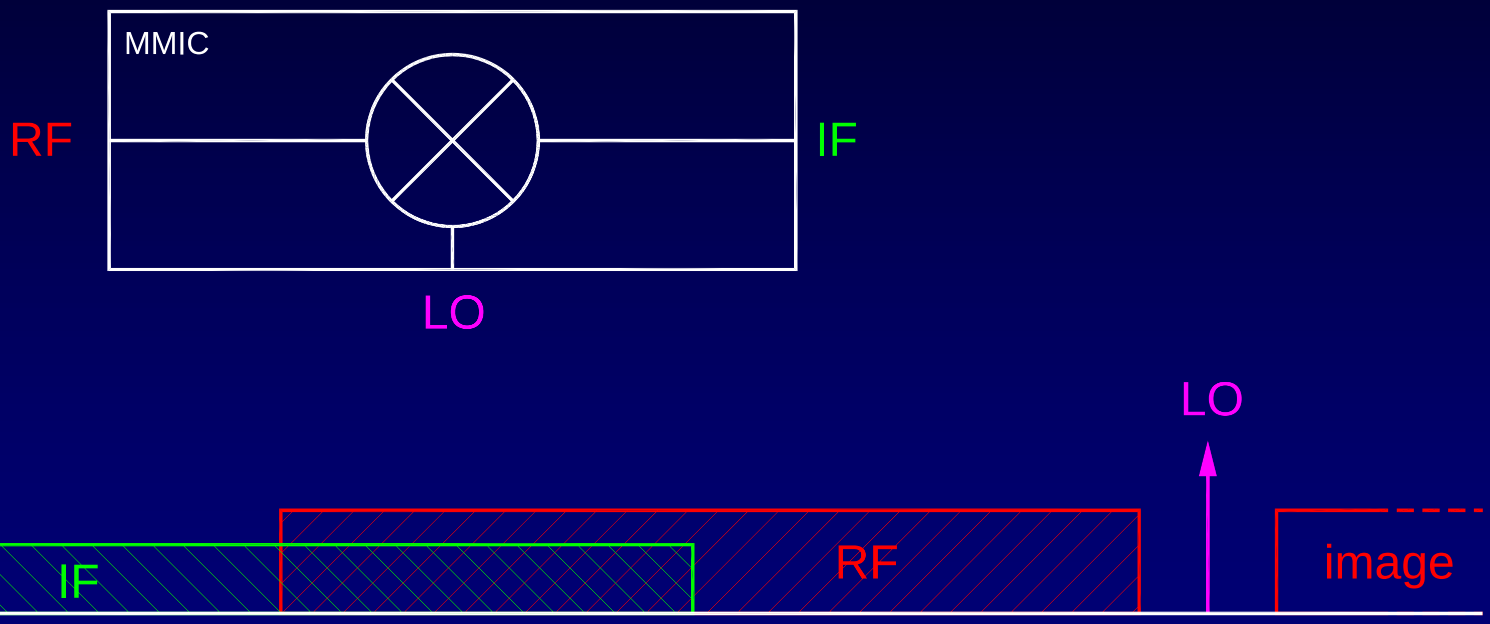
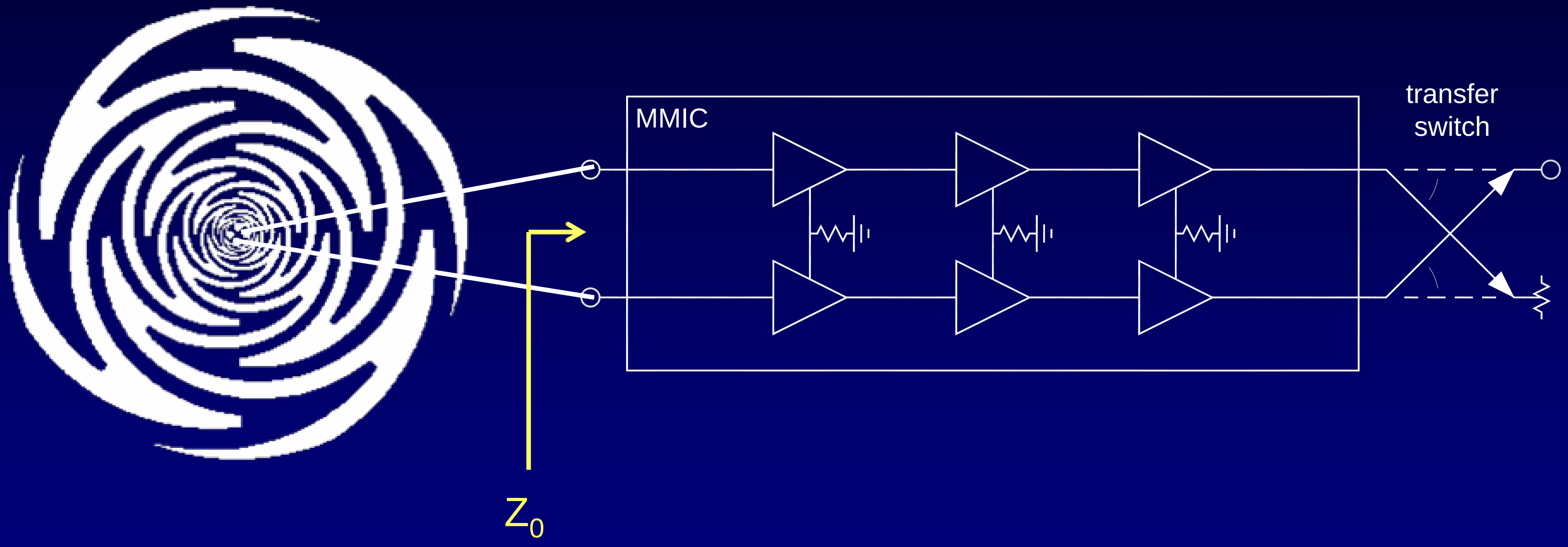
MMIC Wish List:
Wide-IF Block-Conversion Mixers



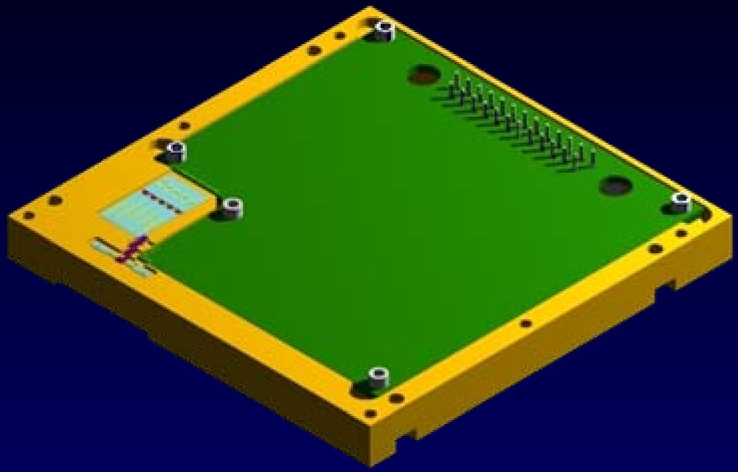
Overlapping RF and IF Bands – requires triple-balanced topology?

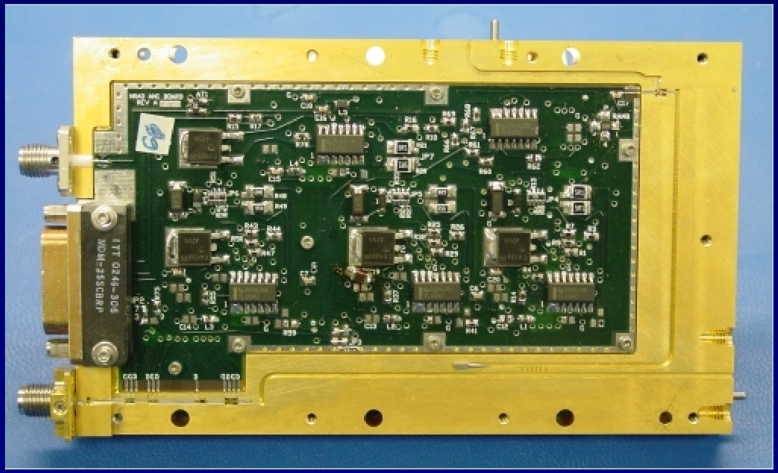
Wideband Differential LNAs



Should be impedance-matched to self-complementary log-periodic antennas ($Z_0 = \eta_0/2 = 189\ \Omega$)

Another Problem: Why are those bias boards so big?





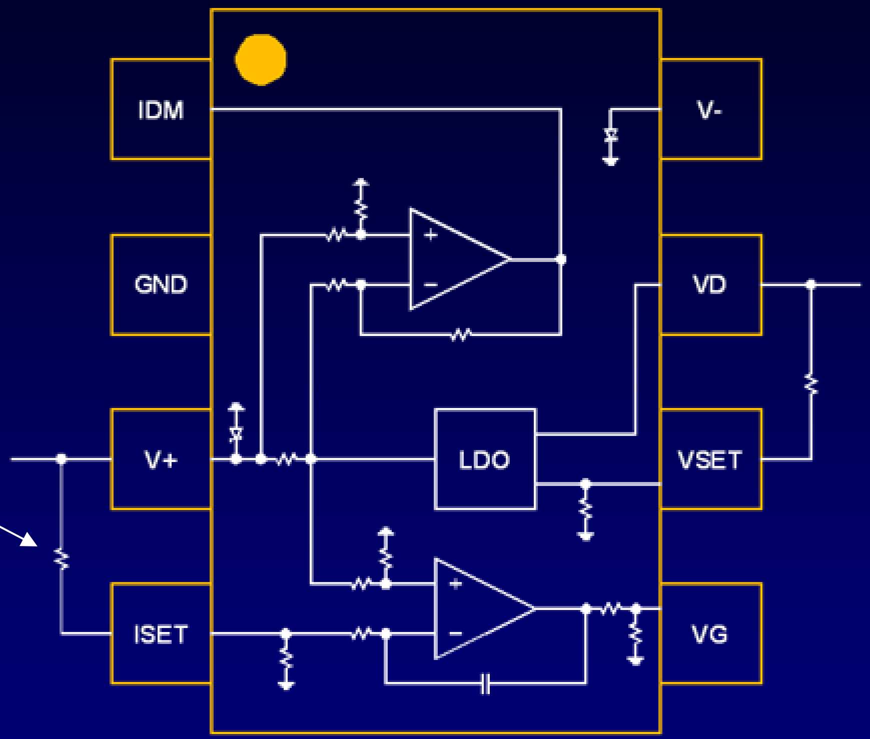
Because we put a lot on them!

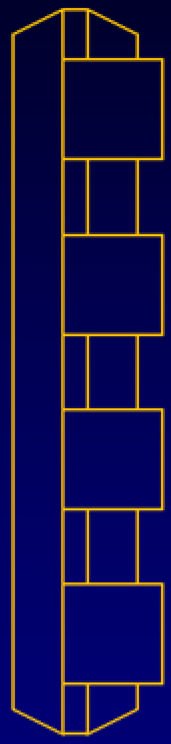
- linear regulators
- potentiometers for tuning and gain control
- digital logic for configuration switching and channel selection
- Op-Amps for gate servo loops and monitor points
- IF circuitry

It makes for a user-friendly module, but if we're serious about compactness, particularly for focal plane arrays, then we must find a way to trim this part down.

One Solution: Develop Common Bias Blocks in Die Form or Integrated SMT Packages

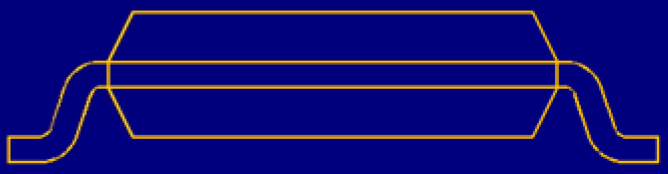
Two external resistors set the desired drain voltage and current.





Probably very expensive!
(unless we buy millions of them)

Not suitable for cooling if done in Silicon.



Shall we take integration a step further: Receiver-on-a-Chip?

Personally, I would say no...

- LNAs, mixers, and multipliers have all been demonstrated on common semiconductor technologies, but with compromised performance – better to pick the right MMIC process for the right chip
- even if it works, the yield is too low on III-V semiconductors for large-scale integration
- a lot of expensive wafer real estate is wasted on passives
- can no longer take advantage of commercial components – have to design it all from scratch
- little or no opportunity for chip reuse
- Microwave substrates are thin! A large, floppy chip would be too hard to handle and mount without damaging it.

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