NRAO MMIC-Based Receiver Developments for the Next Decade of Radio Astronomy

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Outline

1. Improving Front-End Architecture
2. MMIC Wish List
3. Supporting Technologies

IMPROVING FRONT-END ARCHITECTURE

Focal Plane Arrays are the Future!

FPAs offer significant advantages:

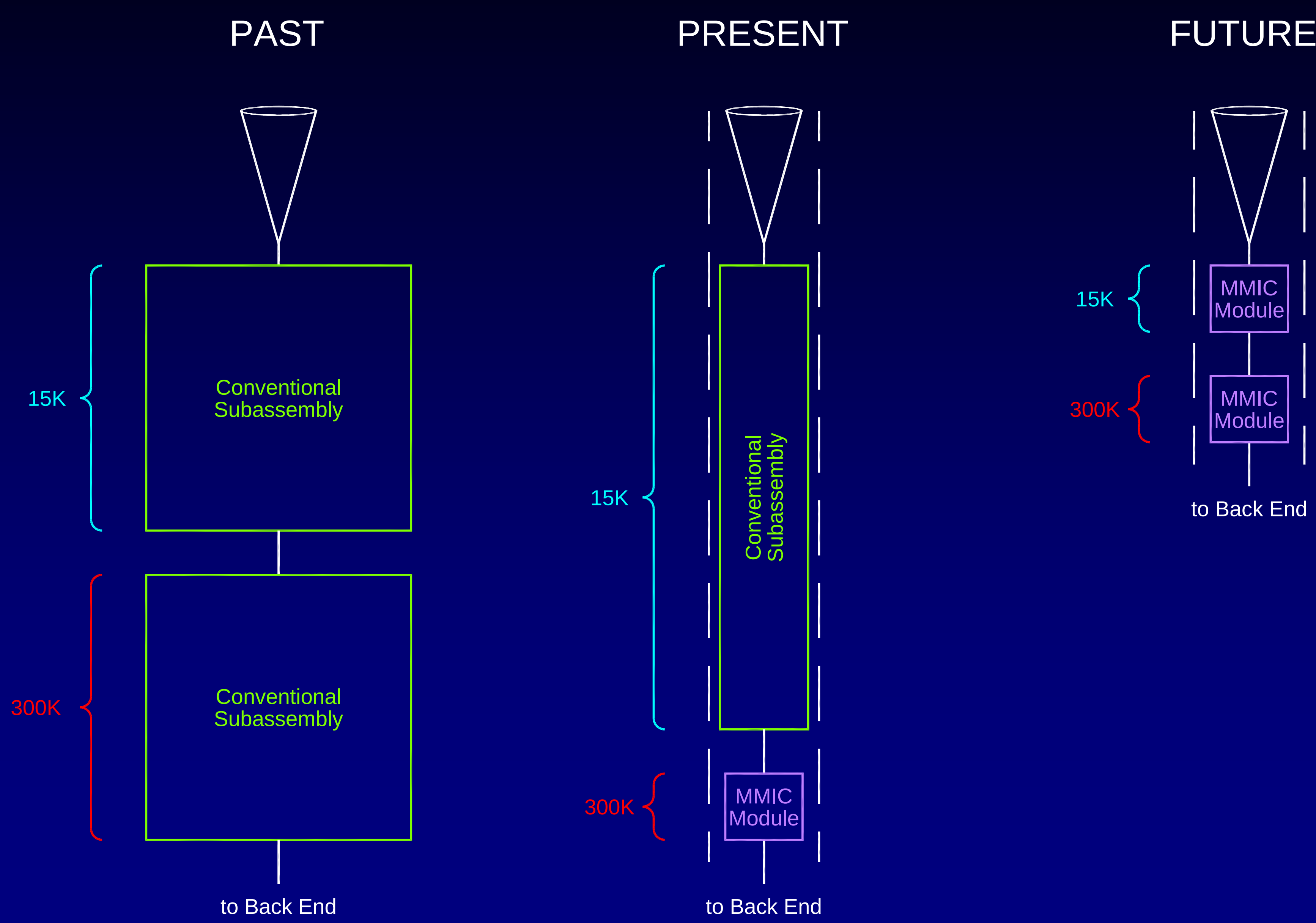
1. greater instantaneous field of view
2. faster mapping of large objects
3. redundancy and graceful degredation

However, they place tighter constraints on the receivers:

1. mass
2. cross-section
3. power dissipation
4. thermal isolation
5. modularity
6. wiring complexity
7. computation
8. cost!

But there are a number of ways we can improve on receiver implementation and architecture to alleviate these problems...

Lesson #1: Integration



Could We Put the Whole Front-End in One Package and Cool Everything?

Not I think if it is a heterodyne receiver, because

- LO amplification dissipates too much power for cryogenics
- inexpensive 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

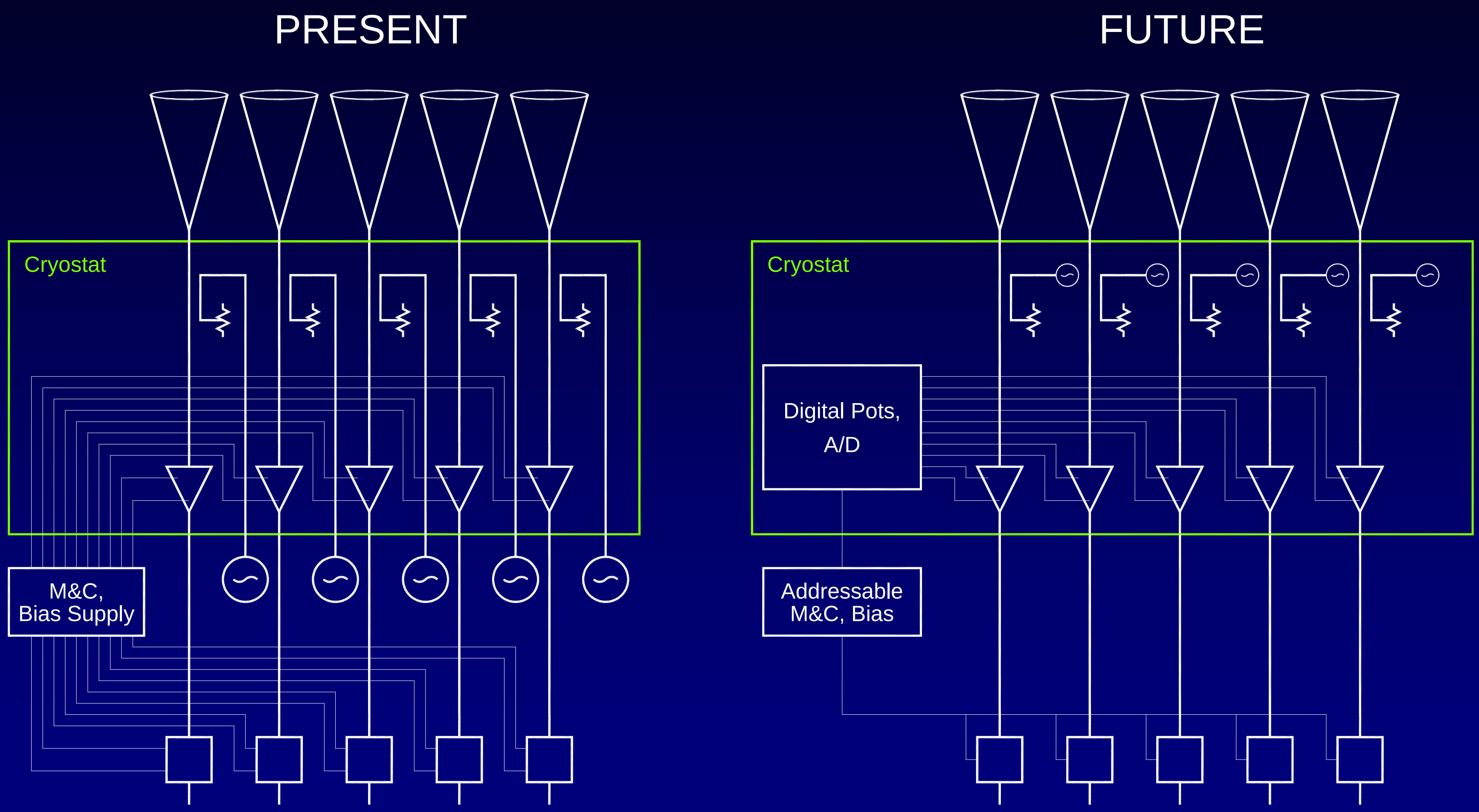
Should we take integration a step further: Receiver-on-a-Chip?

Possibly, if the frequency is low enough that Si or SiGe components provide nearly-optimal performance.

But not, in my opinion, in much of the cm-wave range or above...

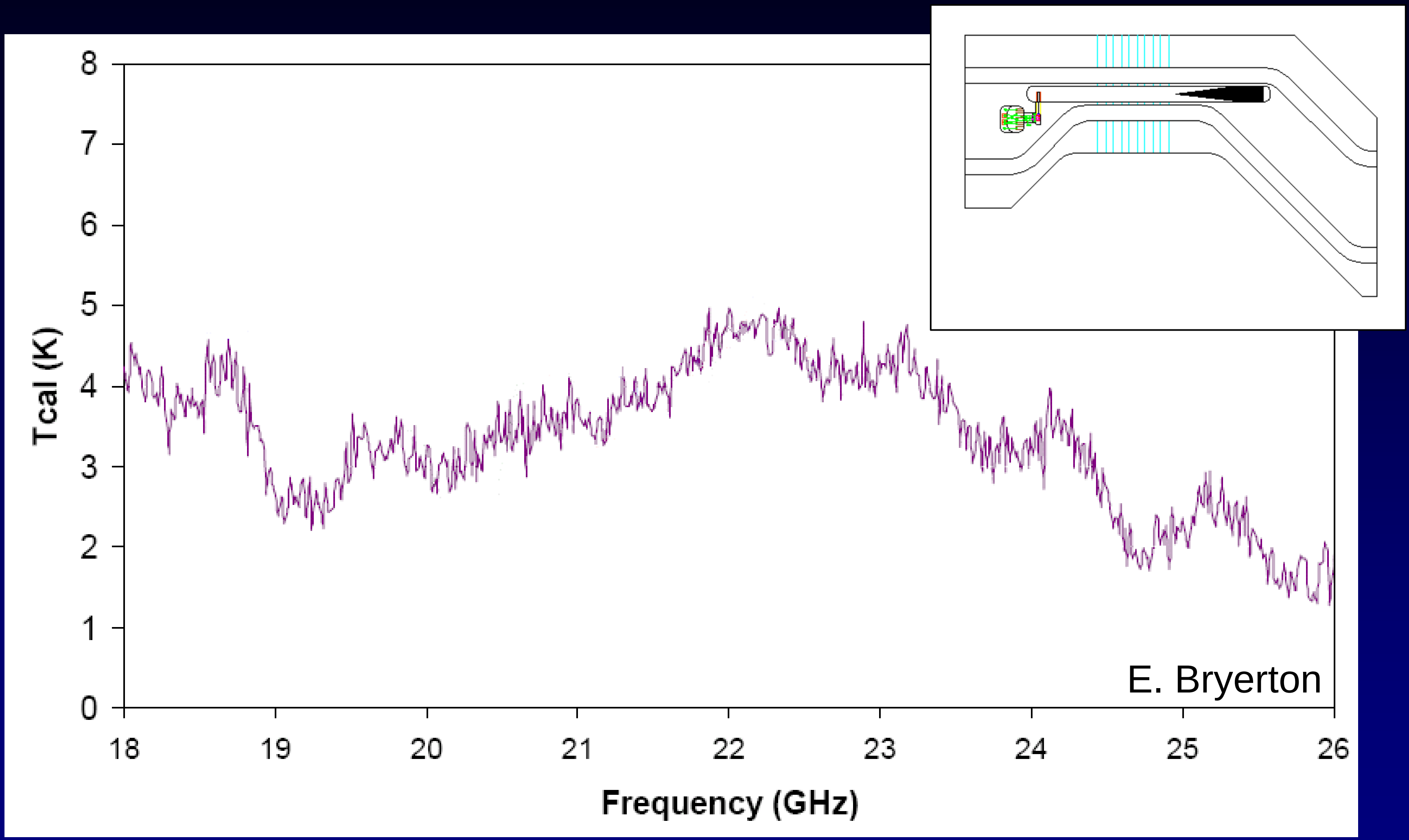
- LNAs, mixers, and multipliers would all have to be implemented with the same semiconductor technology. This has been done, but only with compromised performance – better to pick the right MMIC process for the right chip
- even if it works, the yield is too low on III-V semiconductors for large-scale 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.

Lesson #2: Simplify Wiring and Signal Distribution



Using addressable M&C simplifies wiring and reduces dewar penetrations.
"Nature abhores a vacuum, but she loves a vacuum leak." – Galen Watts

Integrated Cold Noise Source and Cal Coupler



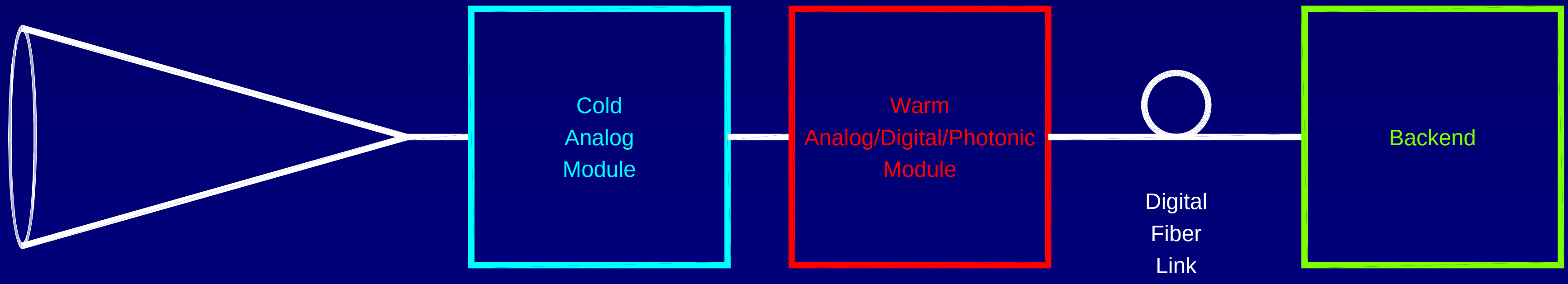
- Uses a CHA2092b MMIC amplifier from UMS ($21) as a noise source.
- Flatter output than the existing GBT noise cal using an external diode.

Lesson #3: Get Digital Sooner!

Heterodyne focal plane arrays will generate many Tb/s of data!

- generally not enough room inside the telescope to process that much data
- must get that data from the telescope to a control building on the ground
- large-bandwidth digital fiber links are cheaper and easier to deal with than large-bandwidth analog fiber links
- commercial industry is pushing forward digital fiber components more than analog

Conclusion: It would be wise to try integrating analog-to-digital and digital-to-fiber functionality in the warm-package of the receiver.

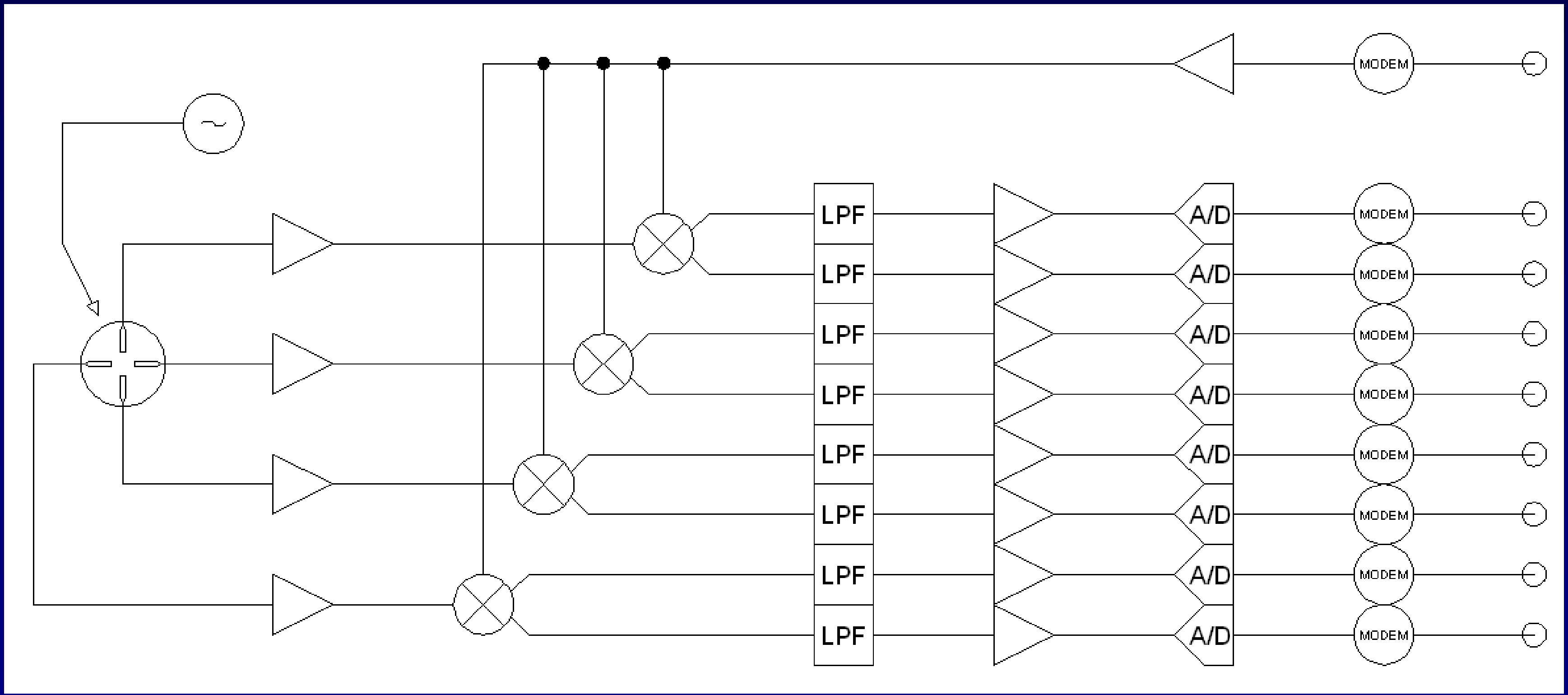


We must break down the boundaries between analog, digital, and photonic subsystems

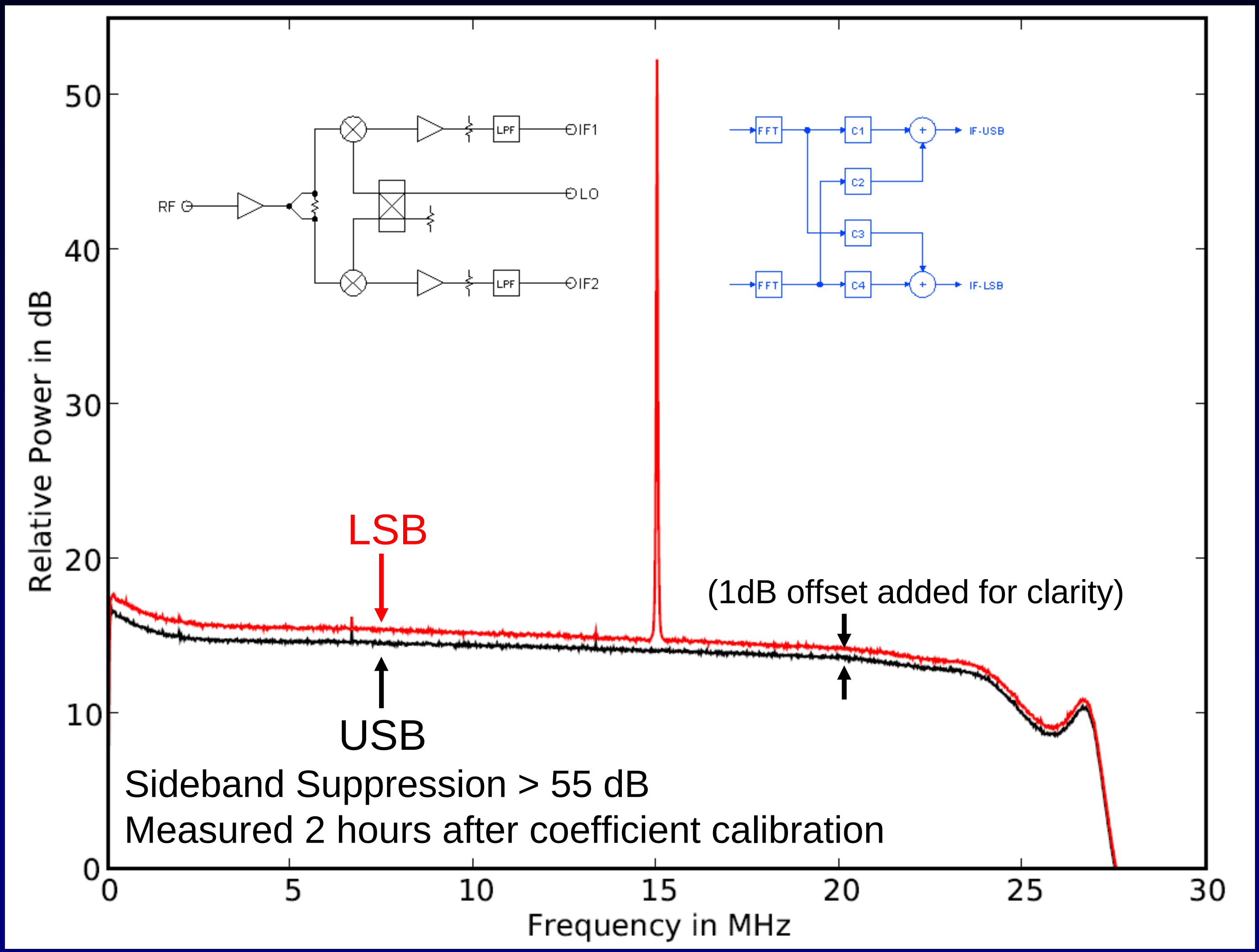
Digitally-Enhanced Polarization-Isolation, Sideband-Separation, and Leveling

We should replace analog components with digital components wherever possible...

- takes full advantage of commercial development in digital technology
- improves baseline stability and calibration accuracy

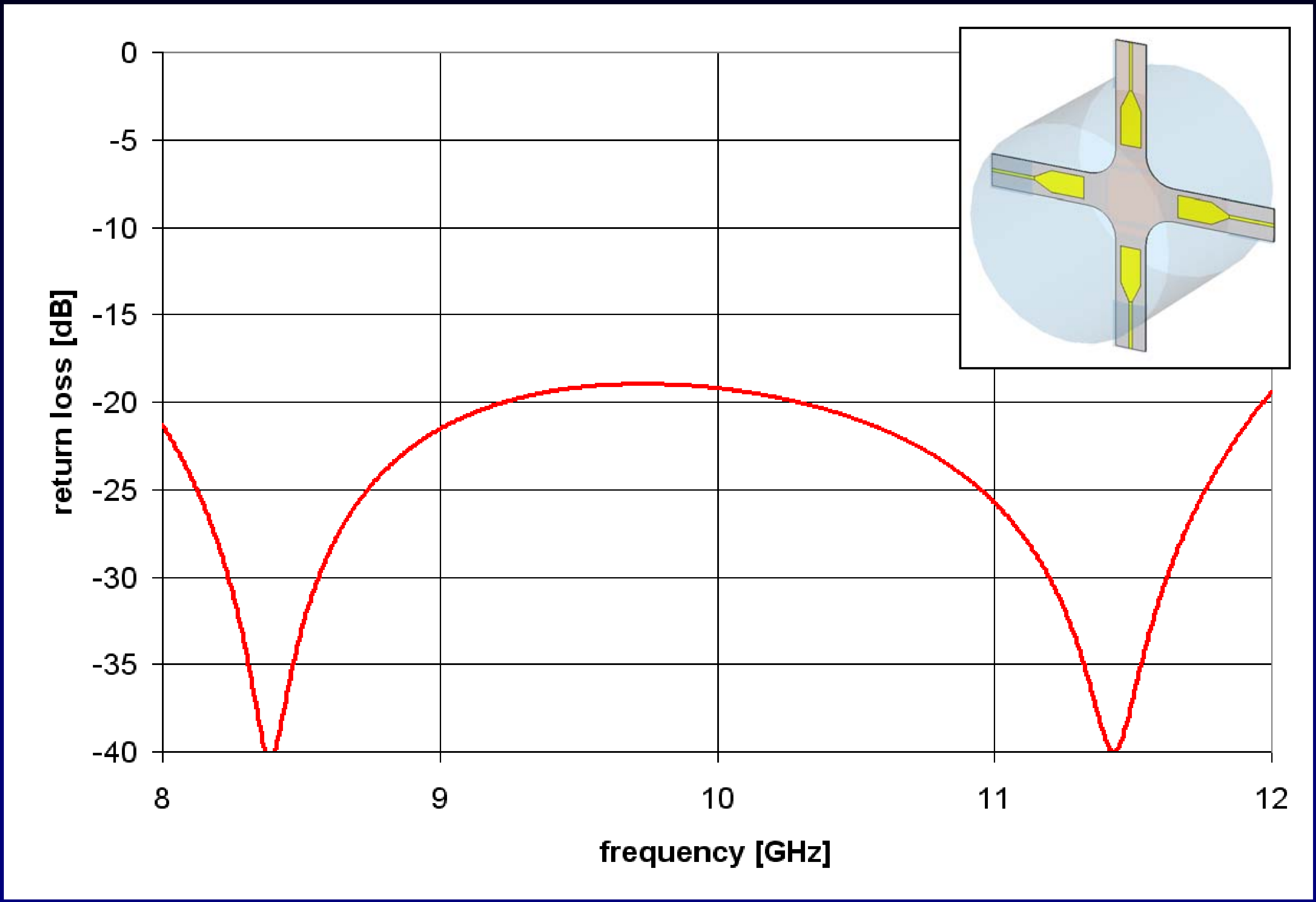


Experiments with Digital-Enhanced Sideband-Separation



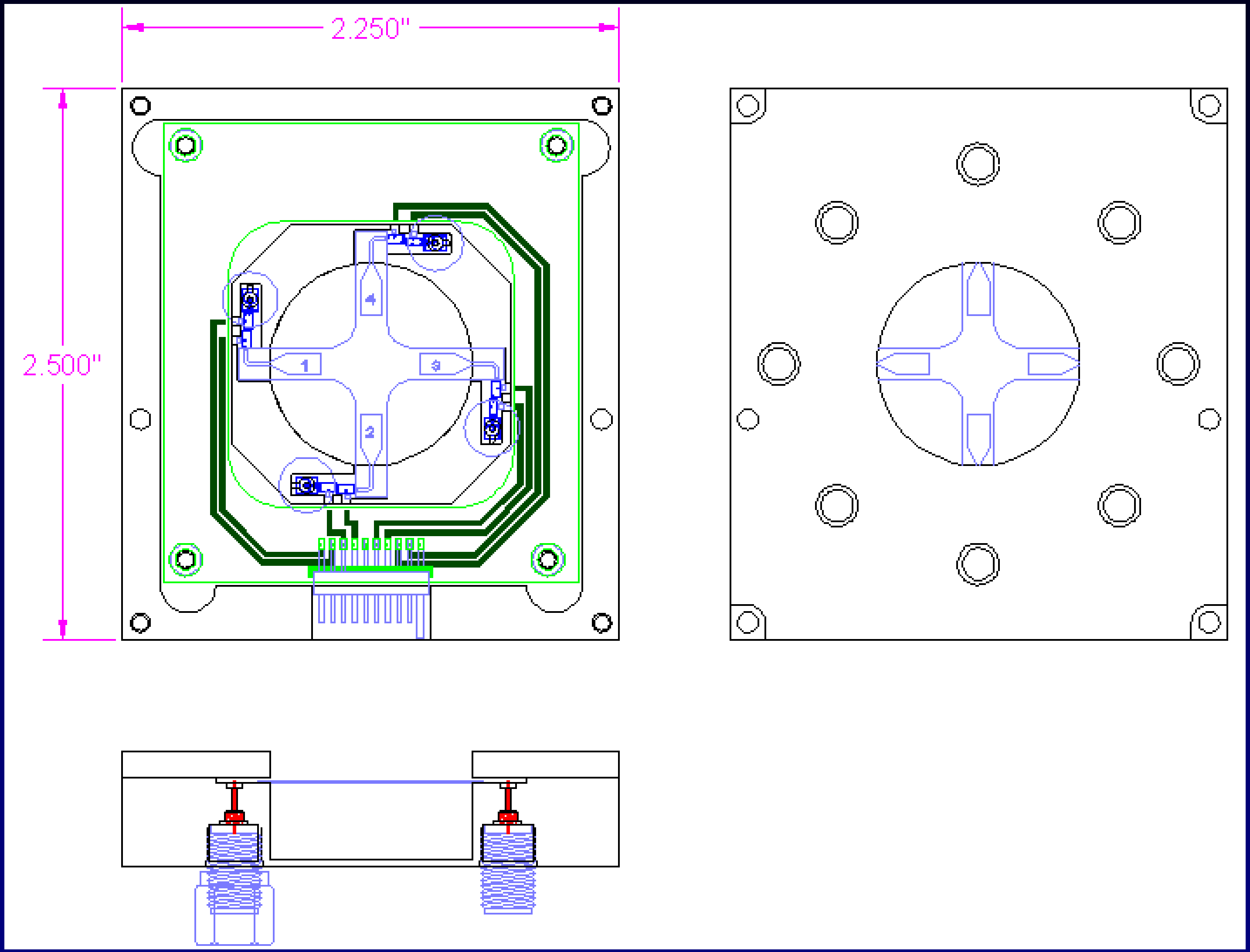
J. Fisher and M. Morgan, "Analysis of a Single-Conversion, Analog/Digital Sideband Separating Mixer Prototype," *Electronics Division Internal Report #320*, June 2008.

Experiments with Digitally-Enhanced Polarization Isolation

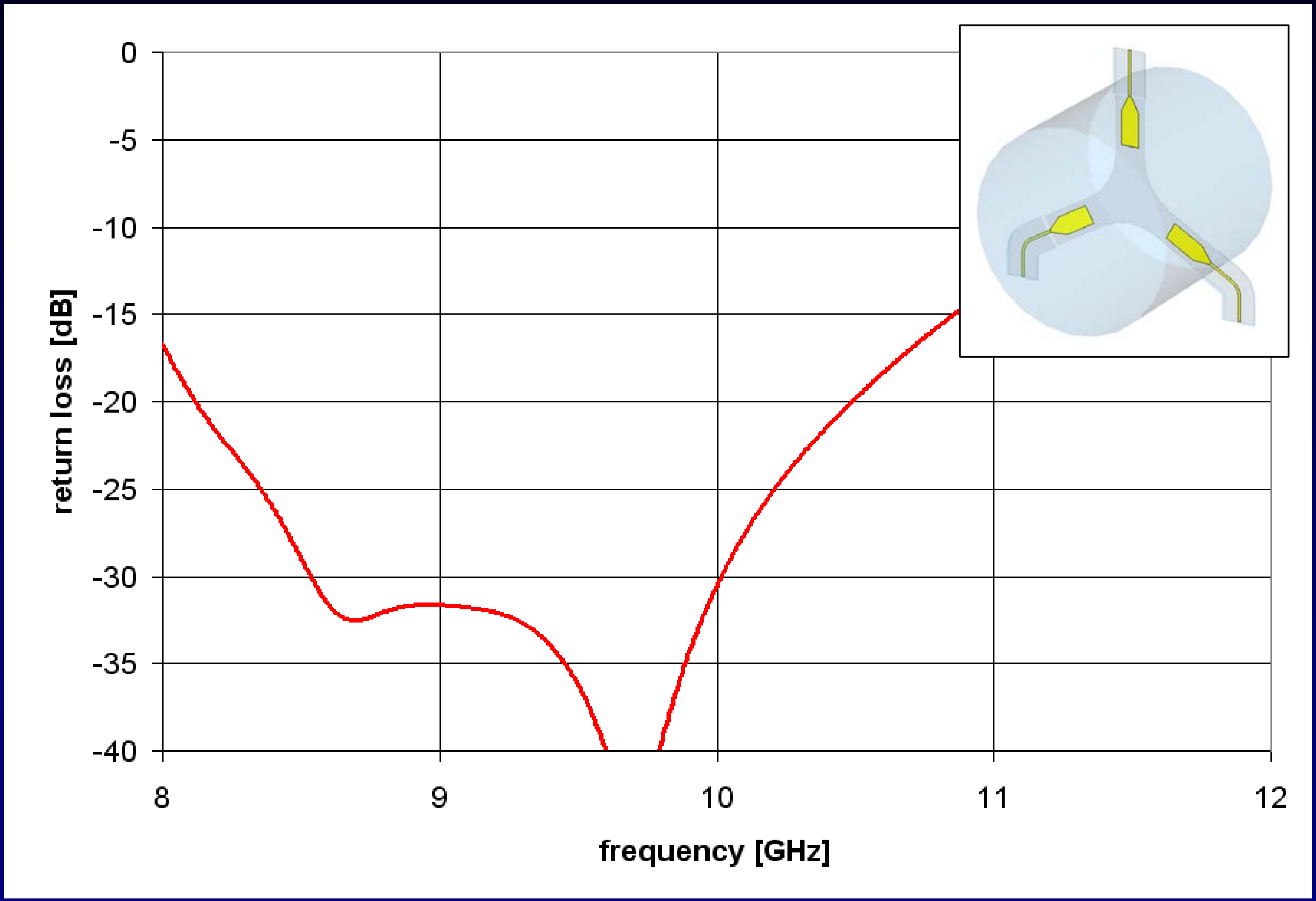


Four-Probe OMT return loss as seen from the circular waveguide.

Experiments with Digitally-Enhanced Polarization Isolation



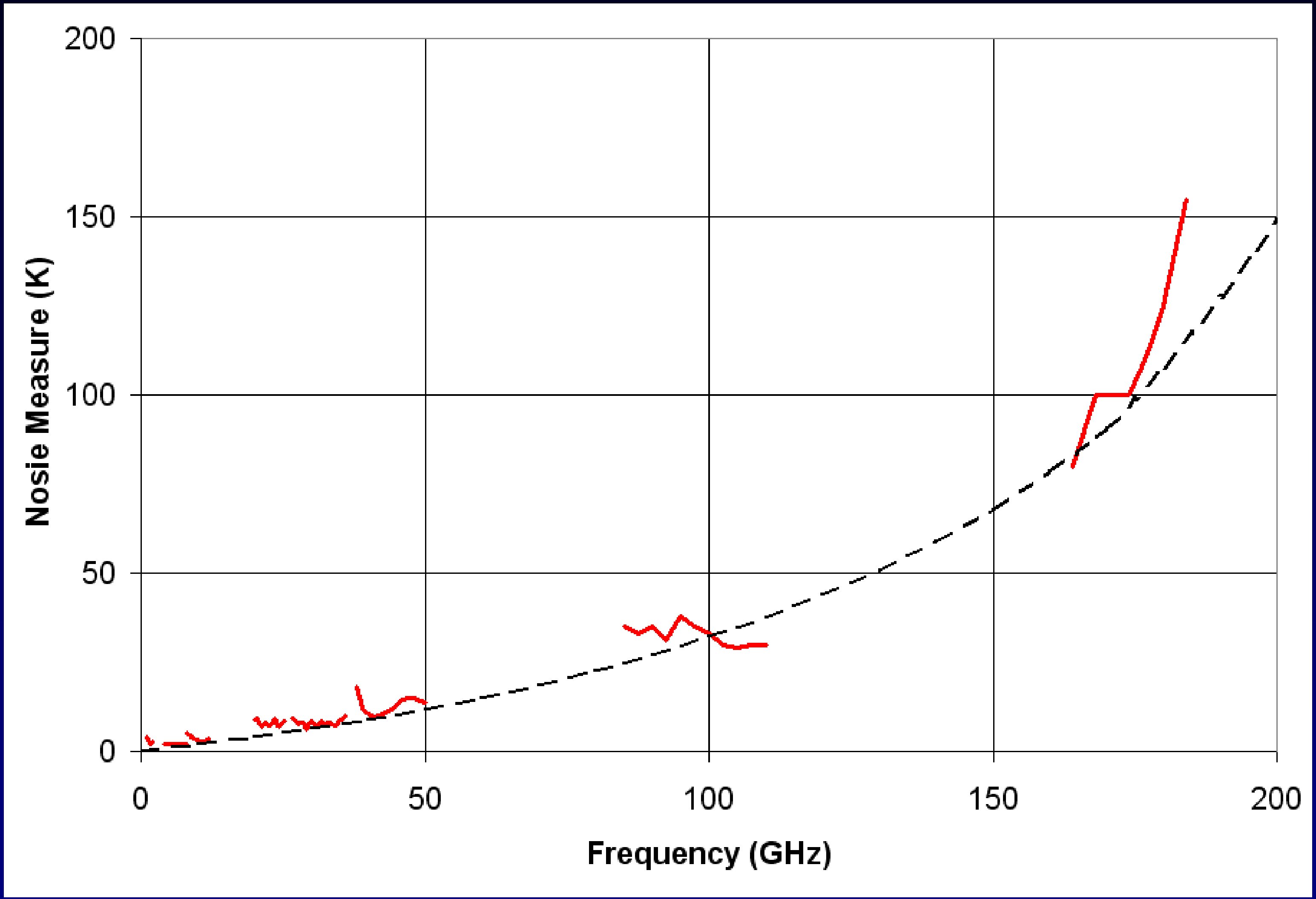
Experiments with Digitally-Enhanced Polarization Isolation



Even three probes is sufficient to provide match at all polarization angles and synthesize any desired polarization as a weighted sum of the three components.

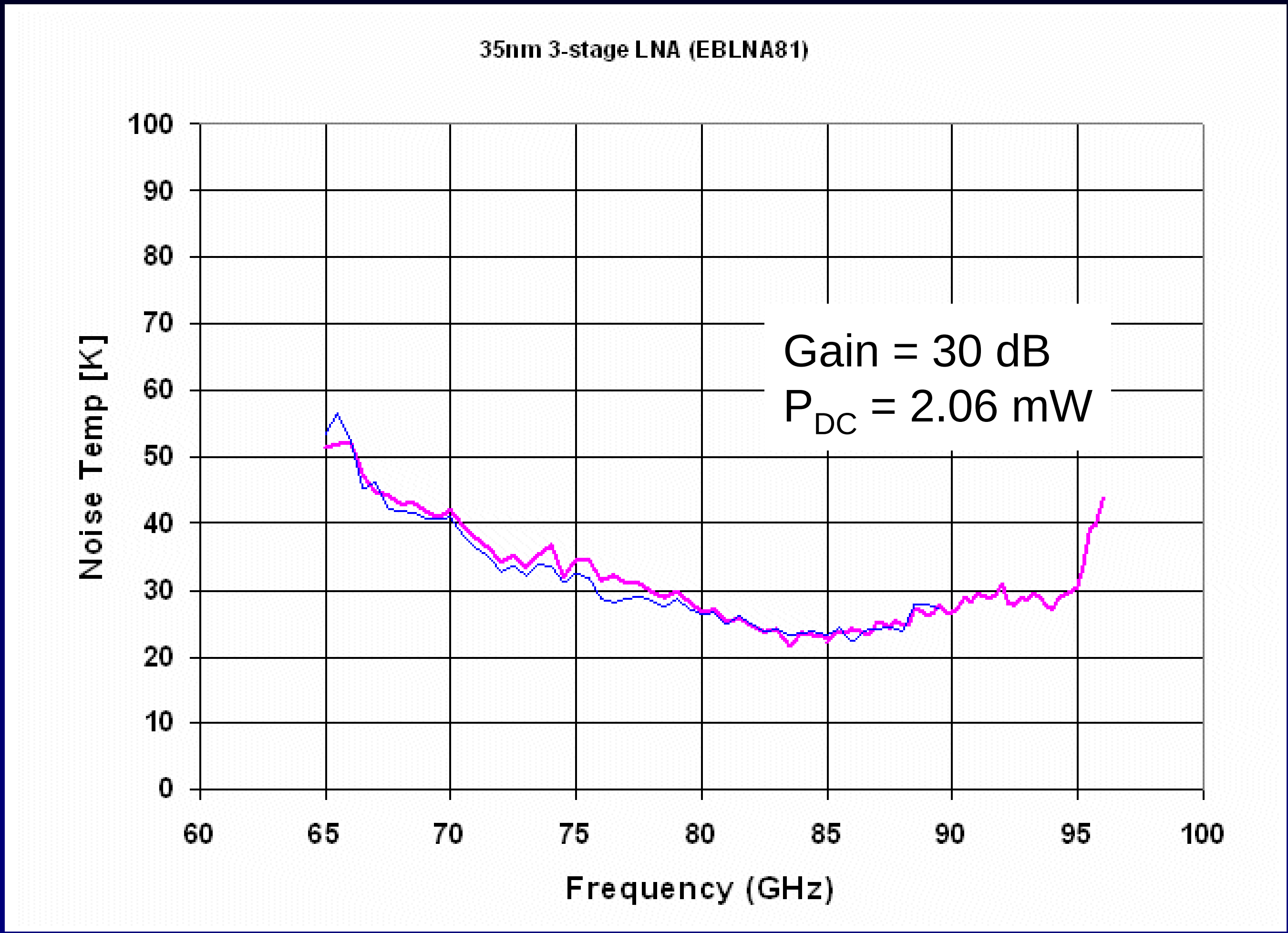
MMIC WISH-LIST

#1: Competitive Cryogenic MMIC LNAs



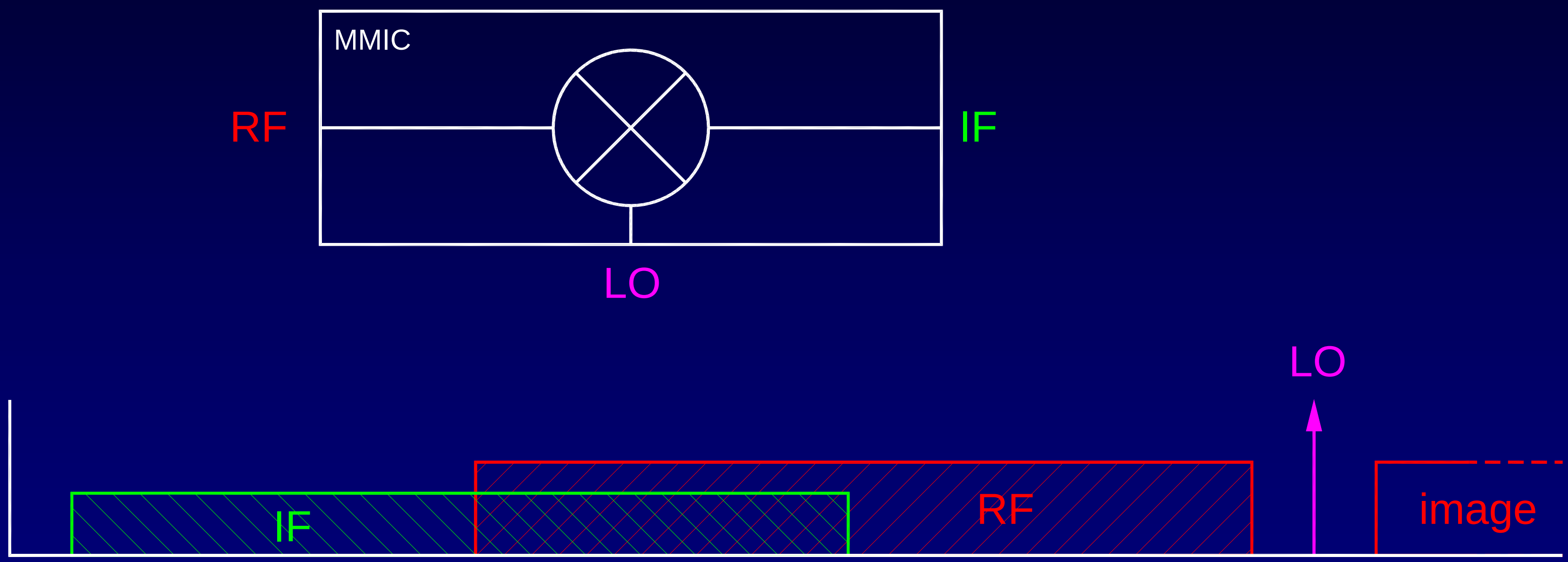
MMIC LNAs must be competitive with the very best MIC LNAs, both in terms of noise performance AND power consumption.

New MMIC Results With 35 nm InP pHEMTs from NGST



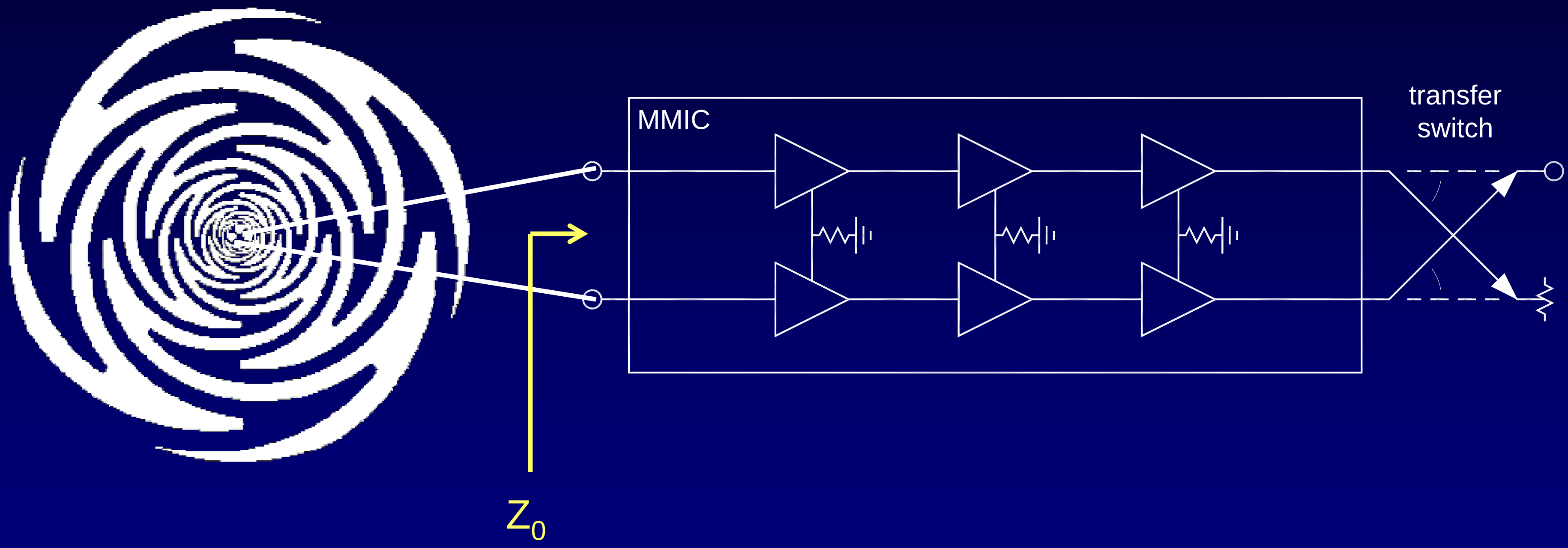
MMIC design by Eric Bryerton at the NRAO Central Development Laboratory.

MMIC Wish List:
Wide-IF Block-Conversion Mixers



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

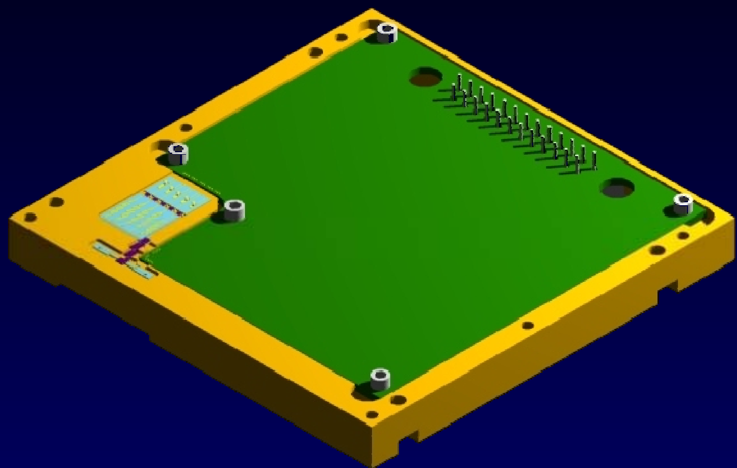
Wideband Differential LNAs

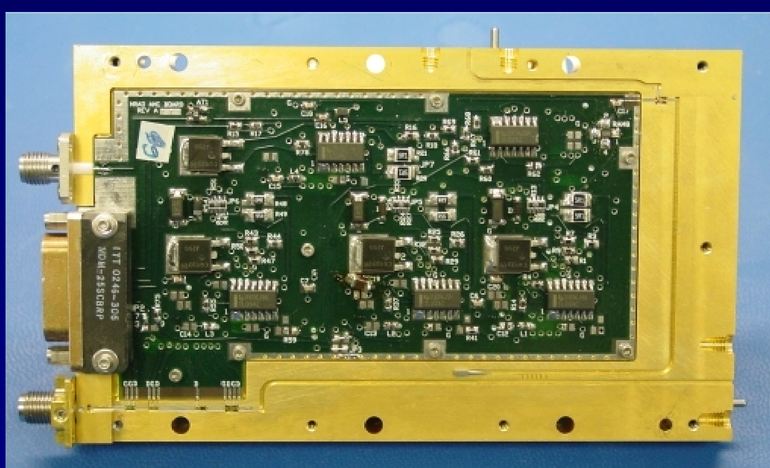


Should be impedance-matched to self-complementary log-periodic antennas (Z_0 = 100 – 270 Ω)

SUPPORTING TECHNOLOGIES

Problem: Why are those bias boards so big?





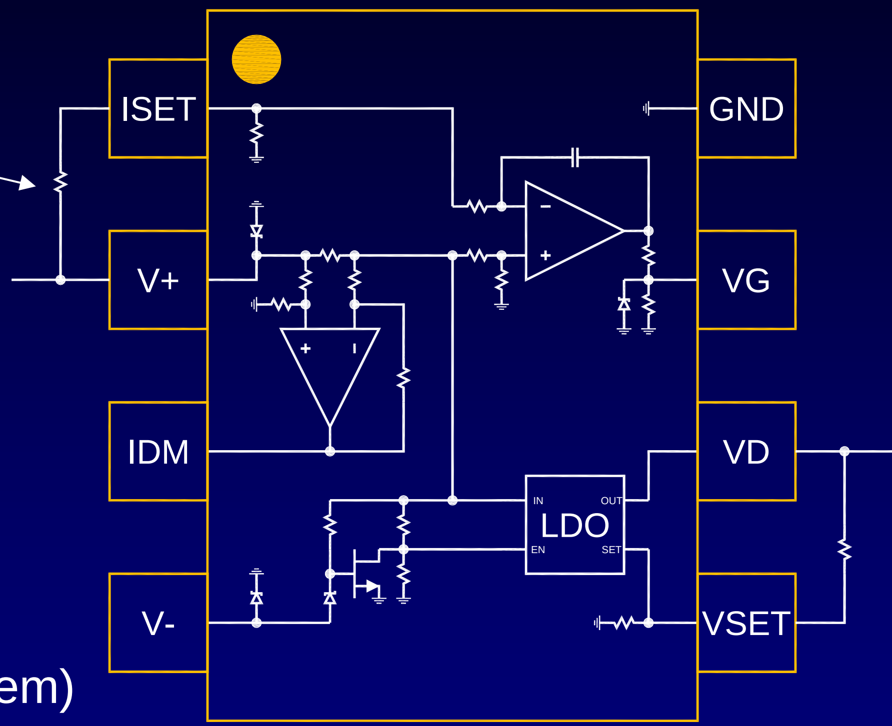
Because we put a lot on them!

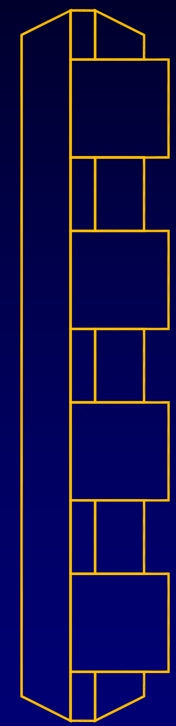
- linear regulators
- potentiometers for tuning and gain control
- digital logic for configuration switching and channel selection
- Op-Amps for gate servo loops and monitor points
- IF circuitry

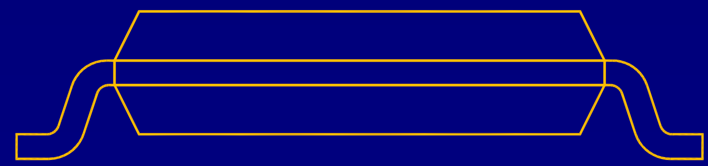
It makes for a user-friendly module, but if we're serious about compactness, particularly for focal plane arrays, then we must find a way to trim this part down.

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.

Surface Mount ICs That Would Be Useful

- HEMT Bias Control IC with the following functions:
  - supply sequencing (negative than positive)
  - supply clamping and regulation
  - closed-loop gate control
  - buffered voltage/current monitoring
  - desired drain voltage and current set by external resistors
- Multi-Channel Programmable Bias Supply
  - several constant-voltage channels
  - several gate-controlled constant-current channels
  - addressable bus interface
- High-speed (2-4 Gs/s), low bit-resolution A2Ds