THPG-04

A Compact 600 GHz Electronically Tunable Vector Measurement System for Submillimeter Wave Imaging

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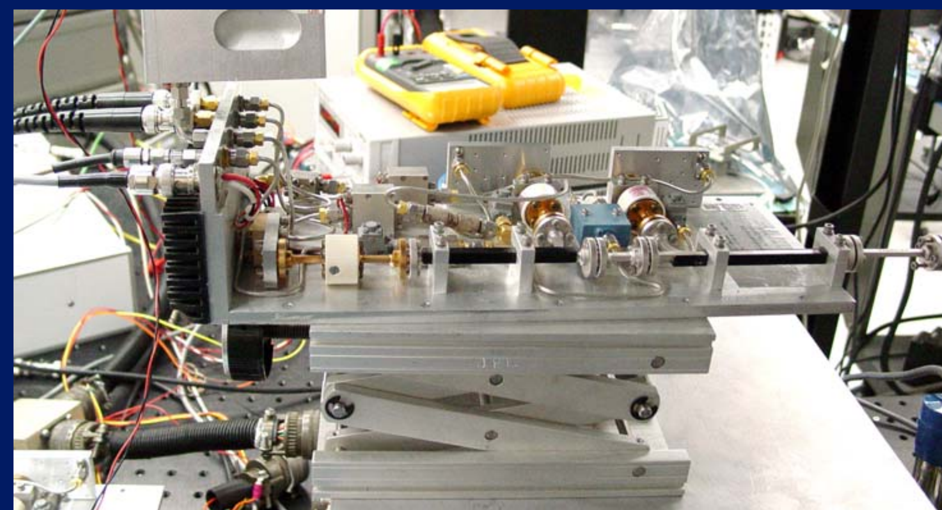
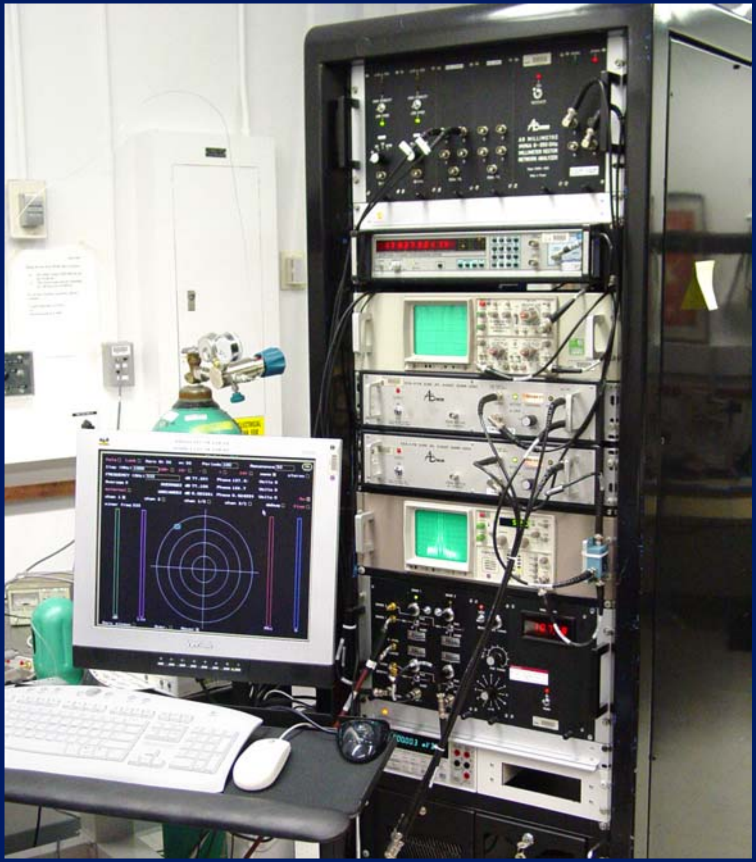
Current State-of-the-Art in Vector Measurements



Anritsu & Agilent VNAs: 325 GHz (with extensions from OML, Inc.)

Current State-of-the-Art in Vector Measurements



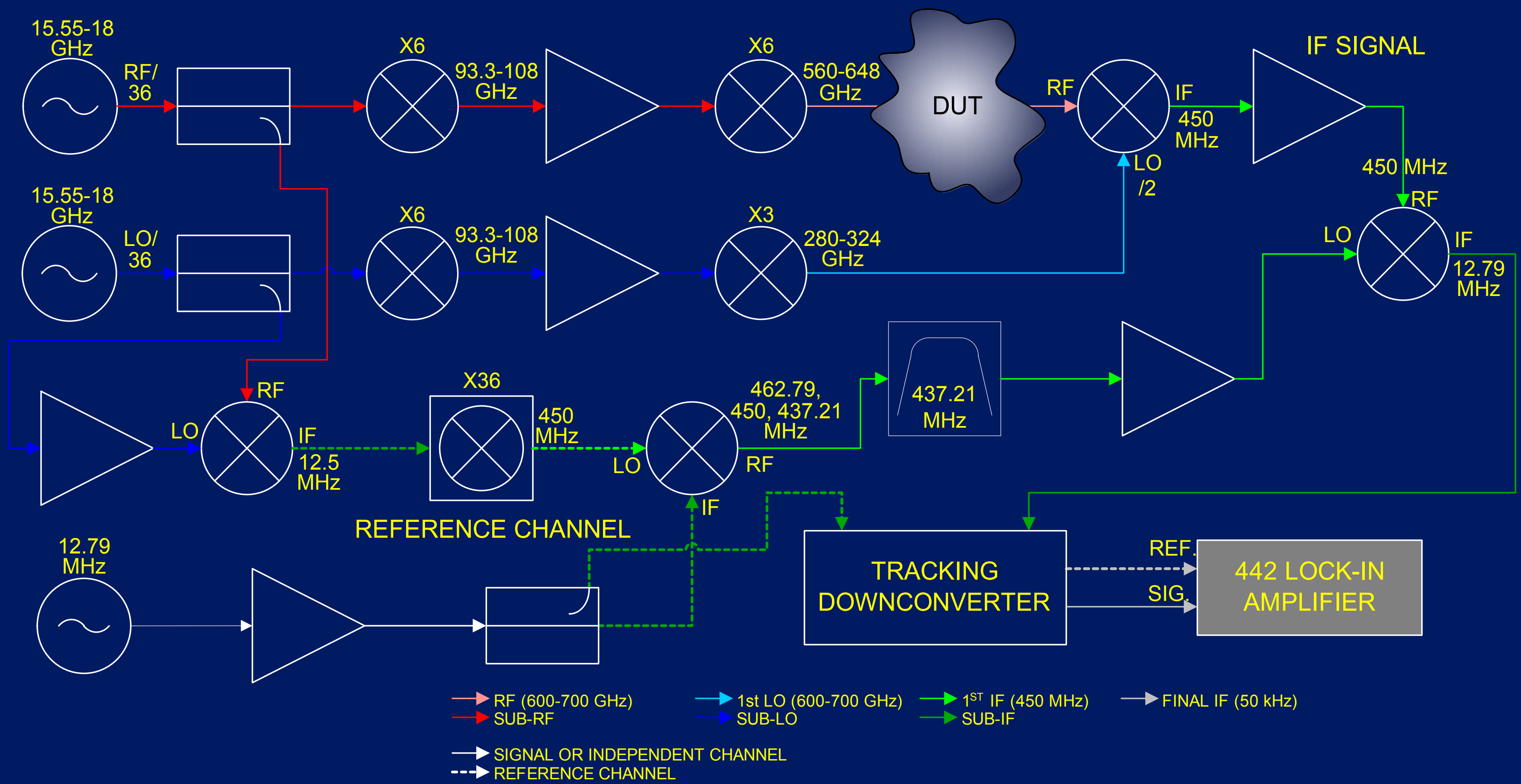
ABmm MVNA-8-350: up to 1000 GHz, narrow band, ~3 GHz max. sweep @ 600 GHz (2 wide-spaced harmonically related freqs. possible)

Submillimeter Active Imaging Requirements

- Focused vector (magnitude & phase) reflection measurement
- Large bandwidth (>50 GHz) in quasi-transparent portion of spectrum
- Small size

Existing commercial off-the-shelf (COTS) solutions are too low in frequency, narrowband & too bulky

600 GHz Vector Measurement System

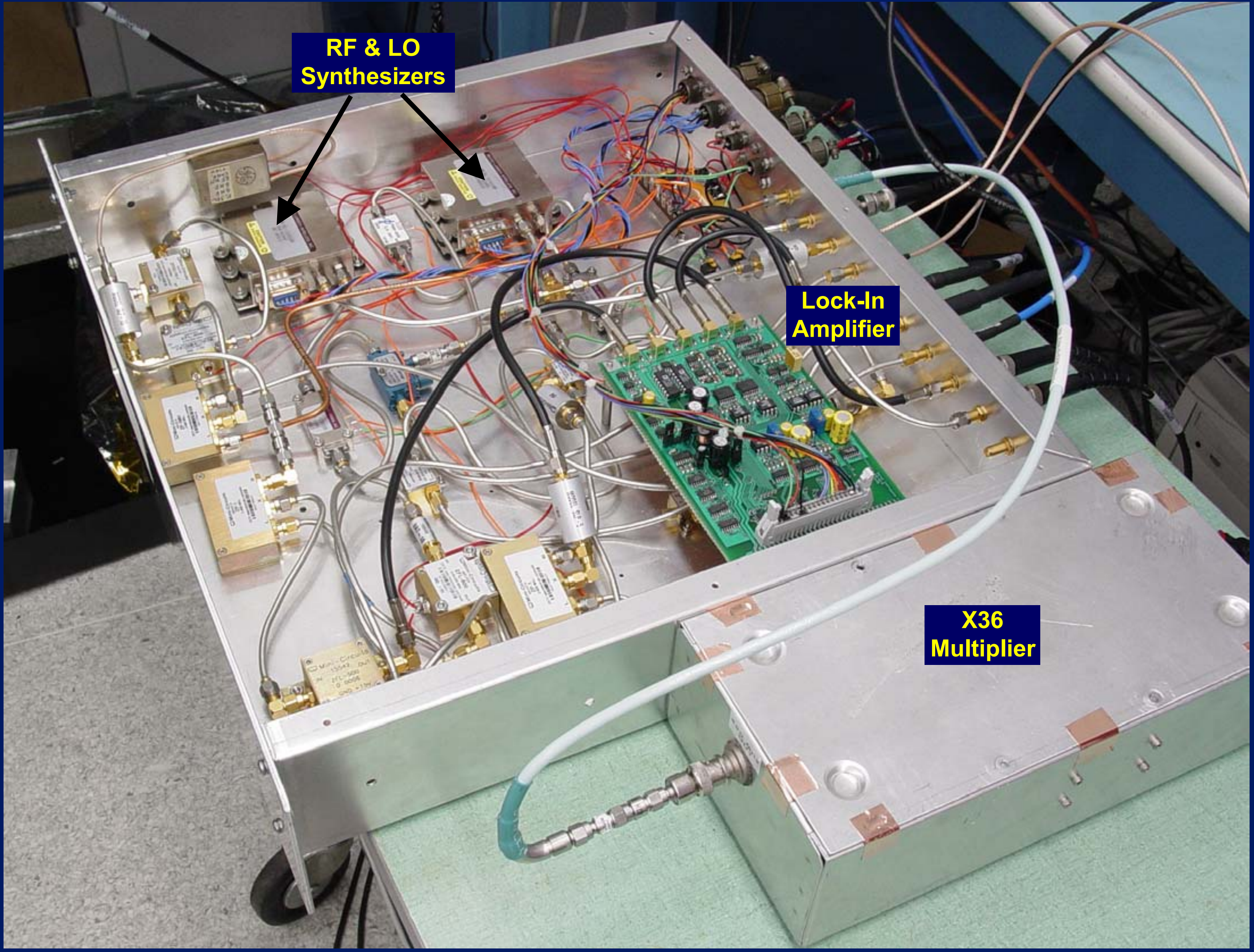


600 GHz Vector Measurement System

- Uses 2 inexpensive synthesizers & X18/X36 multiplier chains to provide measurement signal & LO for a subharmonically pumped mixer
- Synthesizer outputs directly mixed & multiplied to provide a phase reference for the IF system
- Phase reference signal is frequency shifted & mixed with the submillimeter mixer IF output, removing all phase noise

600 GHz Vector Measurement System

IF Section



450 MHz IF Signal

Synthesizer phase noise is multiplied by

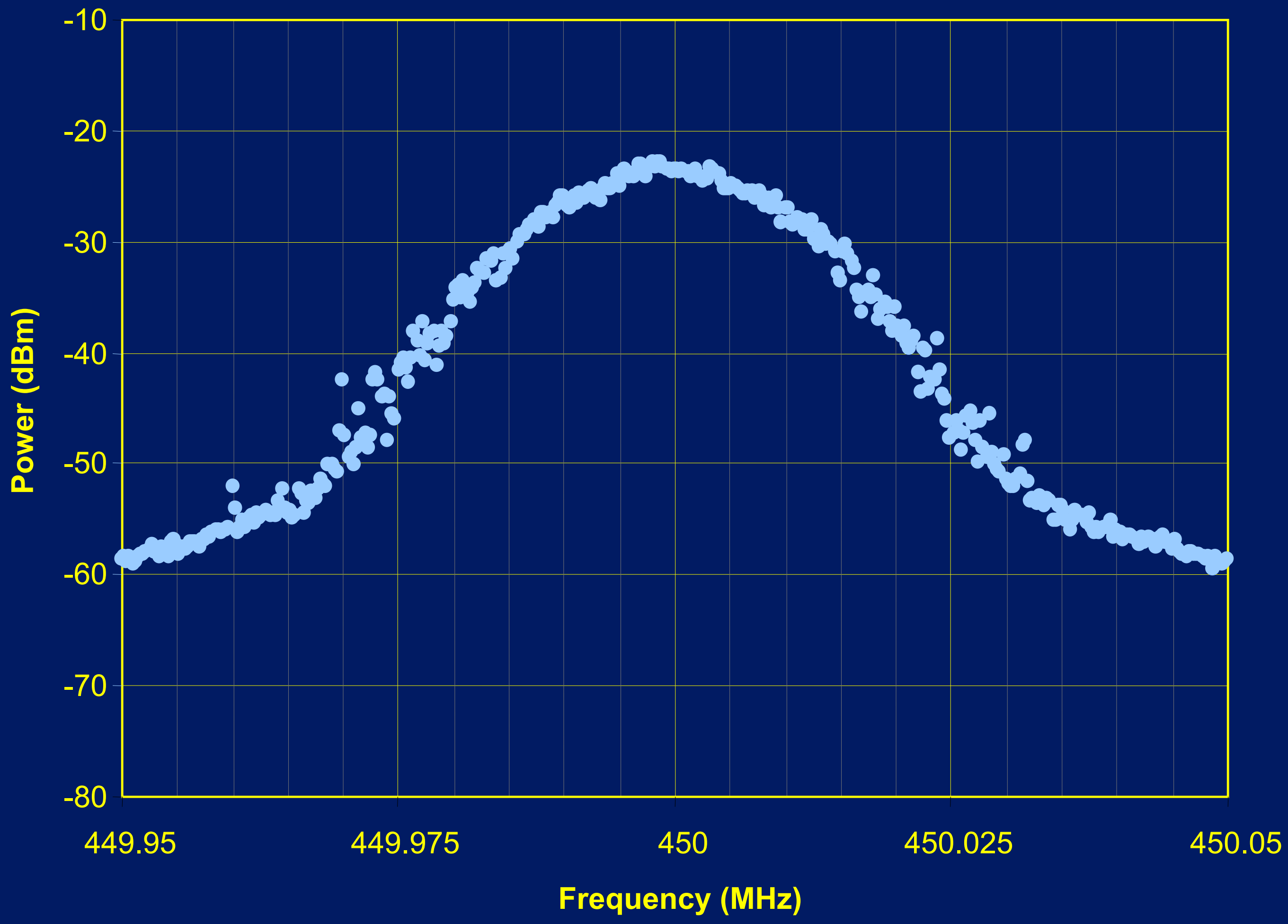
*20*log(N) dB* = 31 dB for signal
25 dB for LO

Synth. phase noise @ fundamental = -54 dBc/Hz @ 1 kHz offset

At the signal frequency, phase noise = -23 dBc/Hz

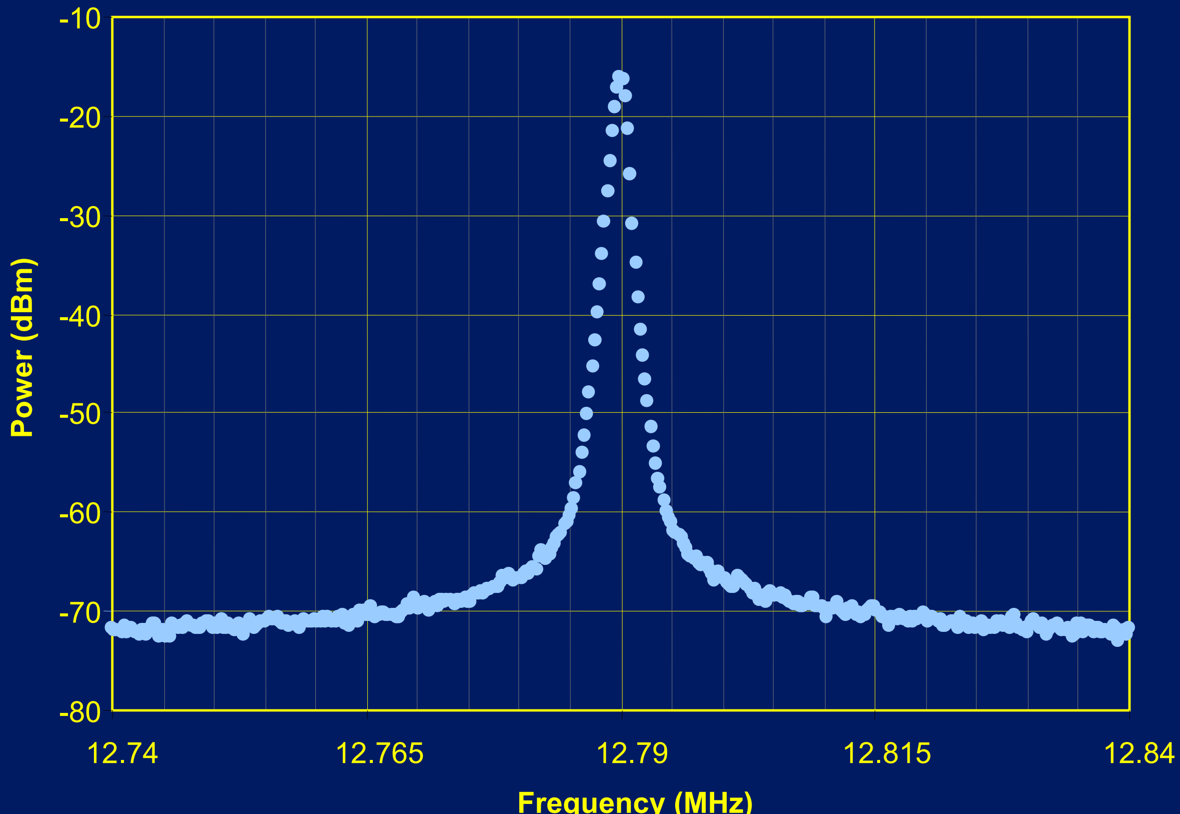
At 1 kHz resolution bandwidth, the carrier is 7 dB below the phase noise and <u>cannot be seen</u> on a spectrum analyzer!

450 MHz IF signal @ 1 kHz Res. BW



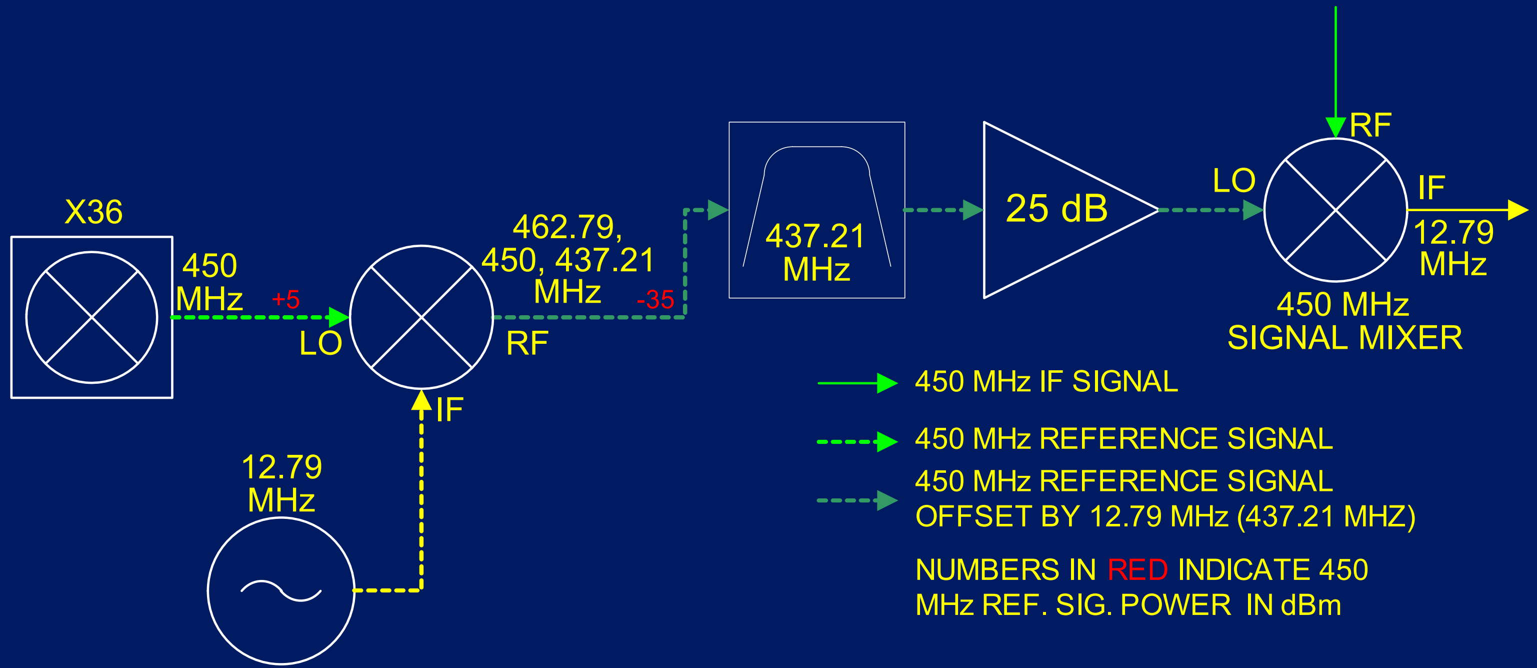
IF signal is “buried” within a 12 kHz wide noise signal

450 MHz IF Signal Mixed with Shifted 450 MHz Reference Signal



By mixing the IF signal with the offset reference signal, a 2nd IF signal (12.79 MHz) is produced that contains the magnitude & phase information of the submillimeter wave signal but with the stability of the 12.79 MHz offset oscillator.

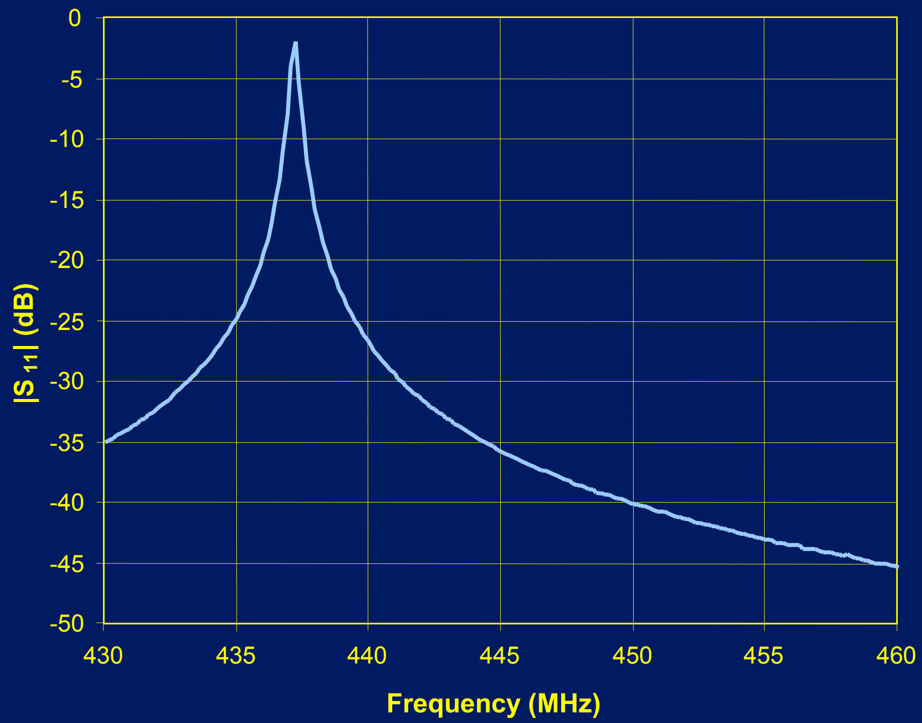
Reference Signal Offset Generator



System dynamic range is highly dependent on purity of the offset reference signal. Any 450 MHz present at the LO input of the 450 MHz signal mixer will be mixed down with the 450 MHz measurement signal, resulting in reference crosstalk.

To avoid crosstalk, the 450 MHz reference signal must be <-130 dBm at the LO input to the signal mixer, requiring a bandpass filter rejection of 120 dB at 450 MHz.

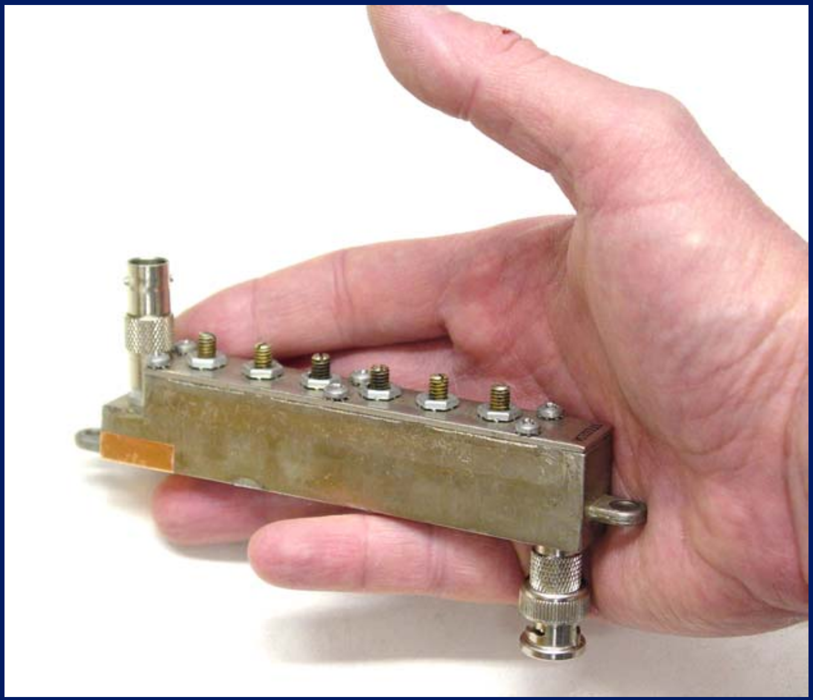
Cavity Bandpass Filter

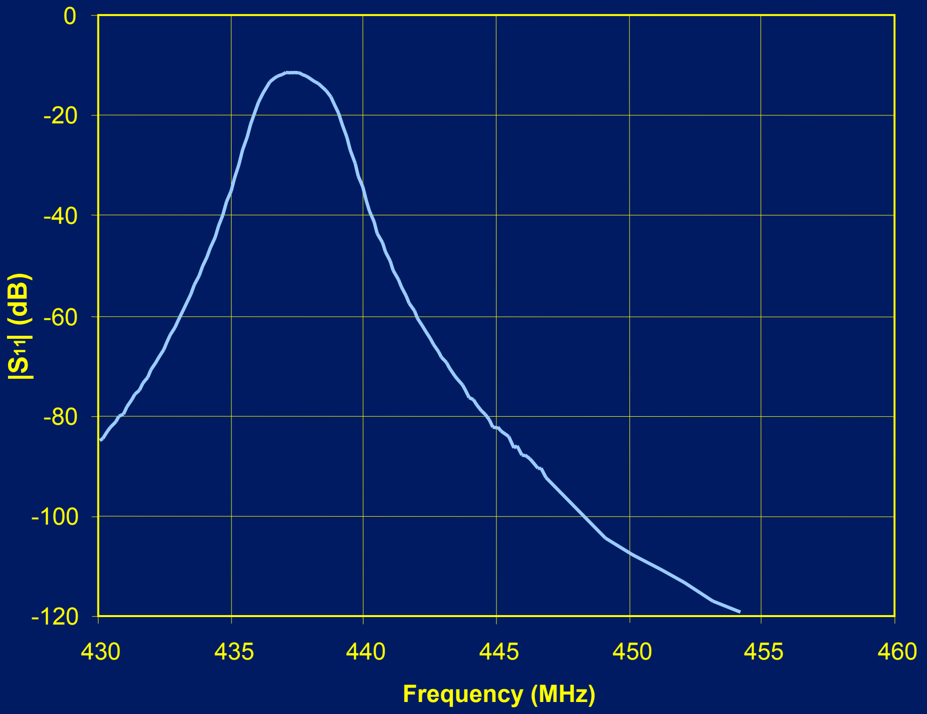


Low loss, high selectivity but bulky

Miniature Multistage Helical Filter

(Motorola "Micor" TFE6213A Exciter Output Filter)

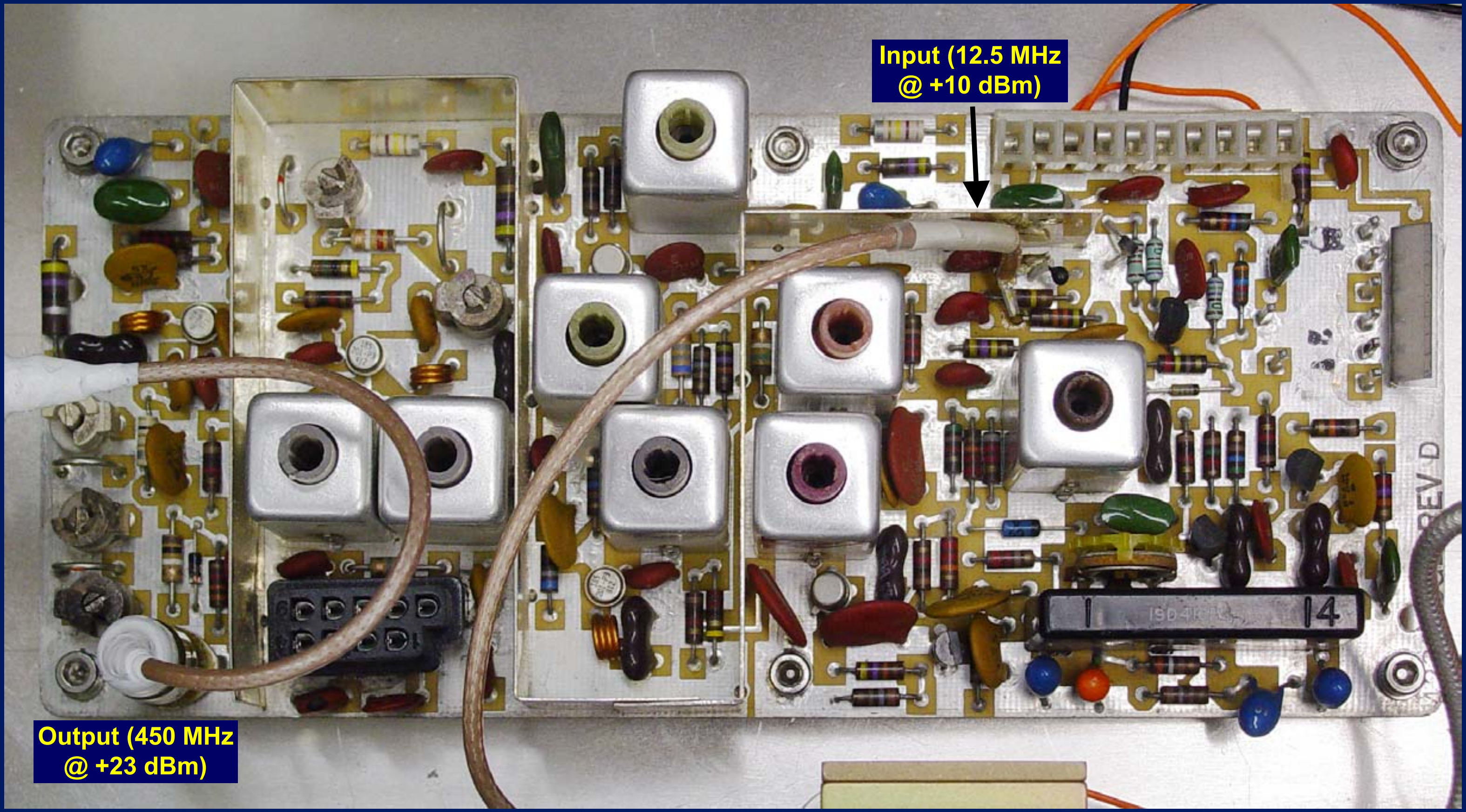




Extremely high selectivity & small size at the expense of loss (~10 dB), which is easily compensated for by an additional amplifier.

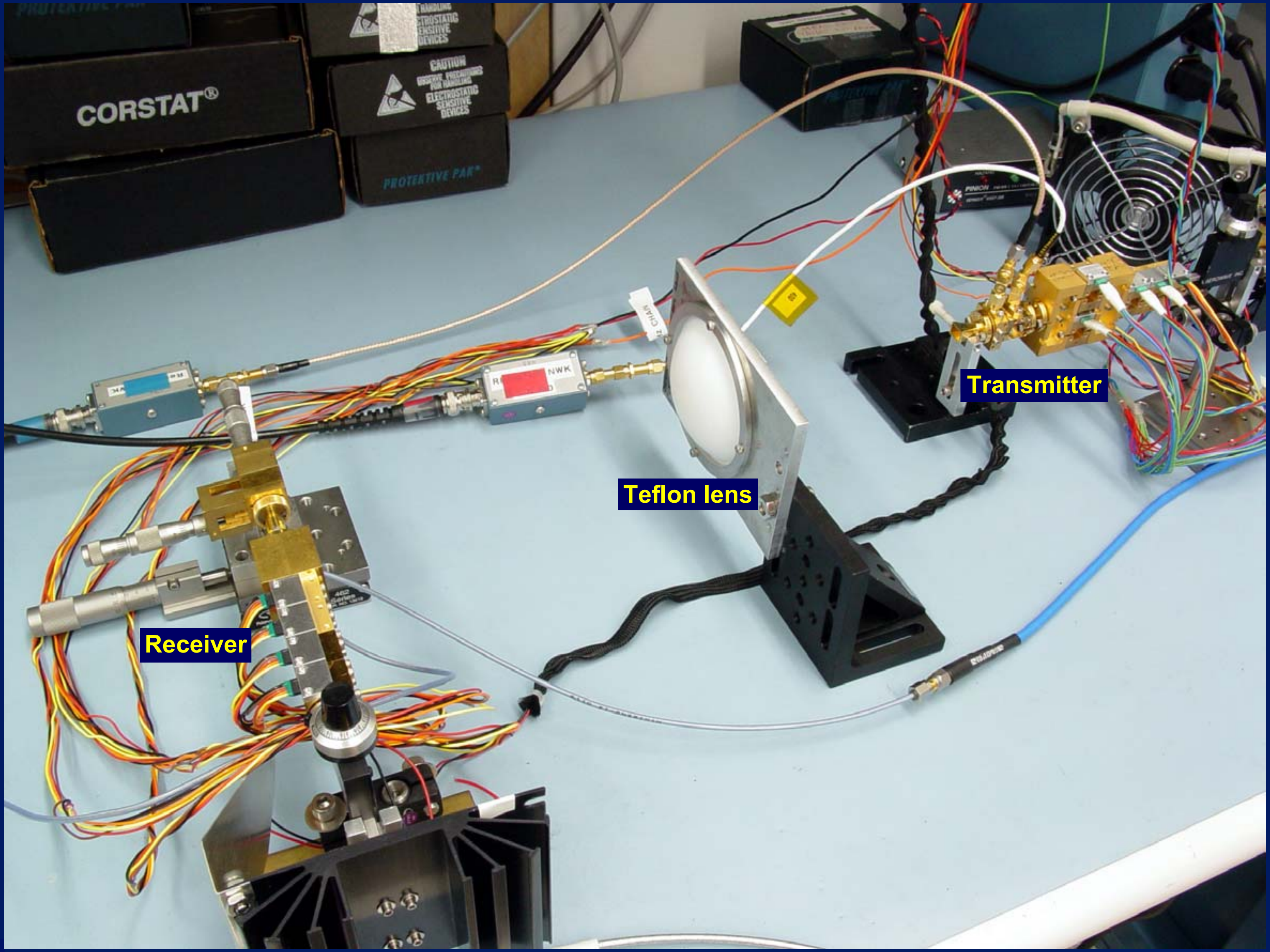
X36 450 MHz Multiplier

GE "Mastr Executive II" transmitter exciter board

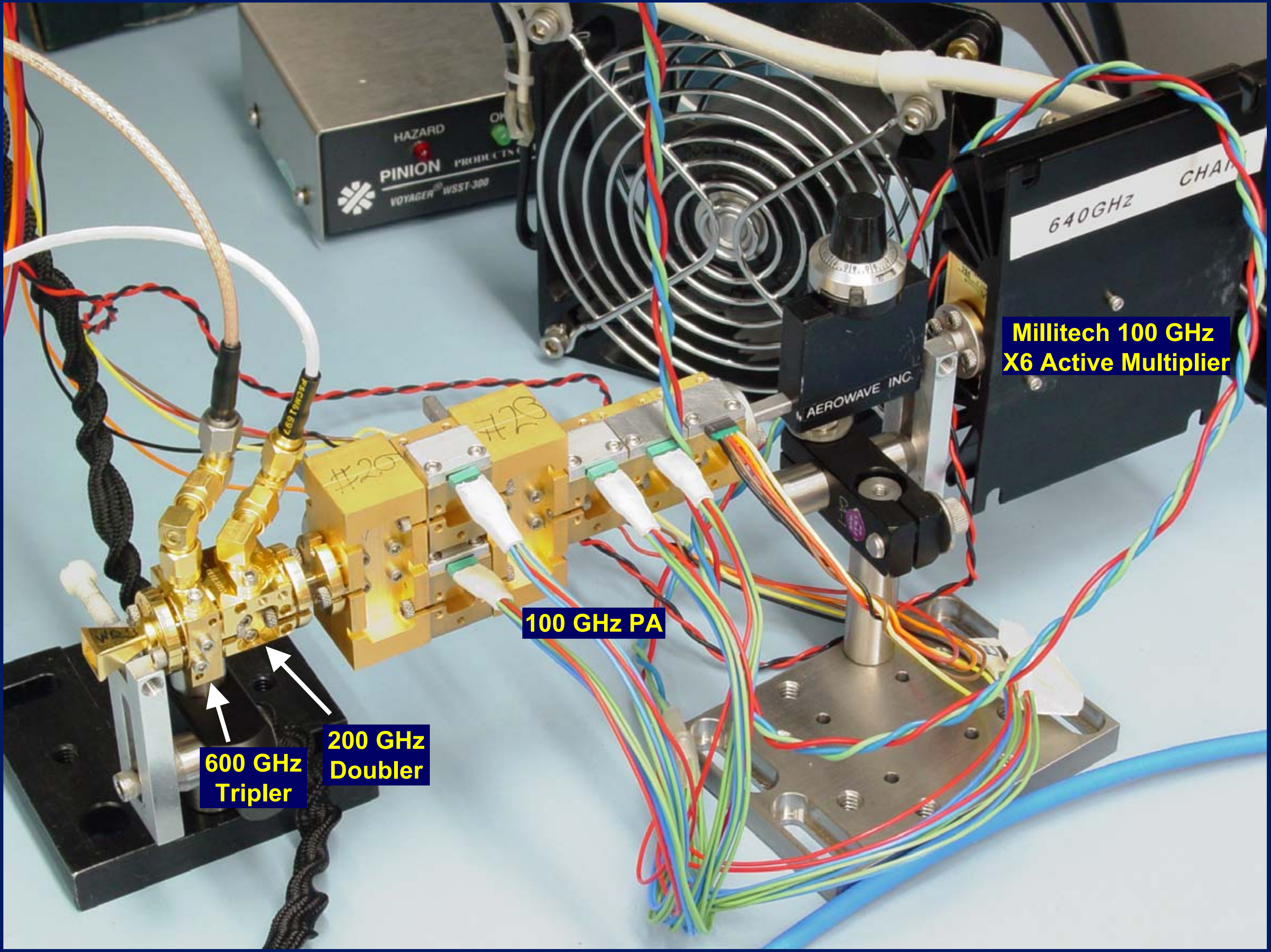


- Cost: ~$100 (Alternative: custom built X36 multiplier, ~$4,000
- All spurious <-45 dBc (non-harmonic spurious <-65 dBc)

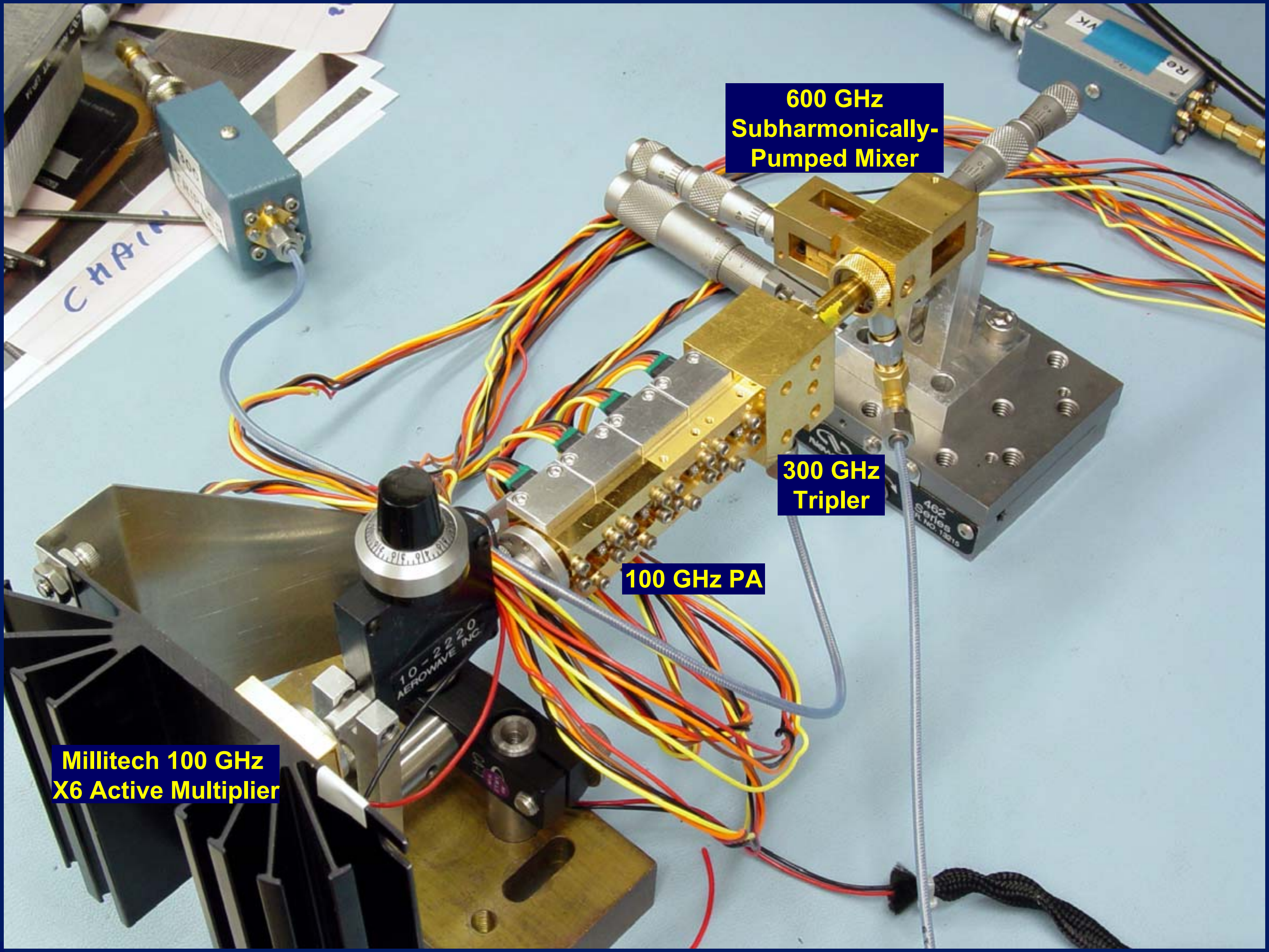
600 GHz Test Setup



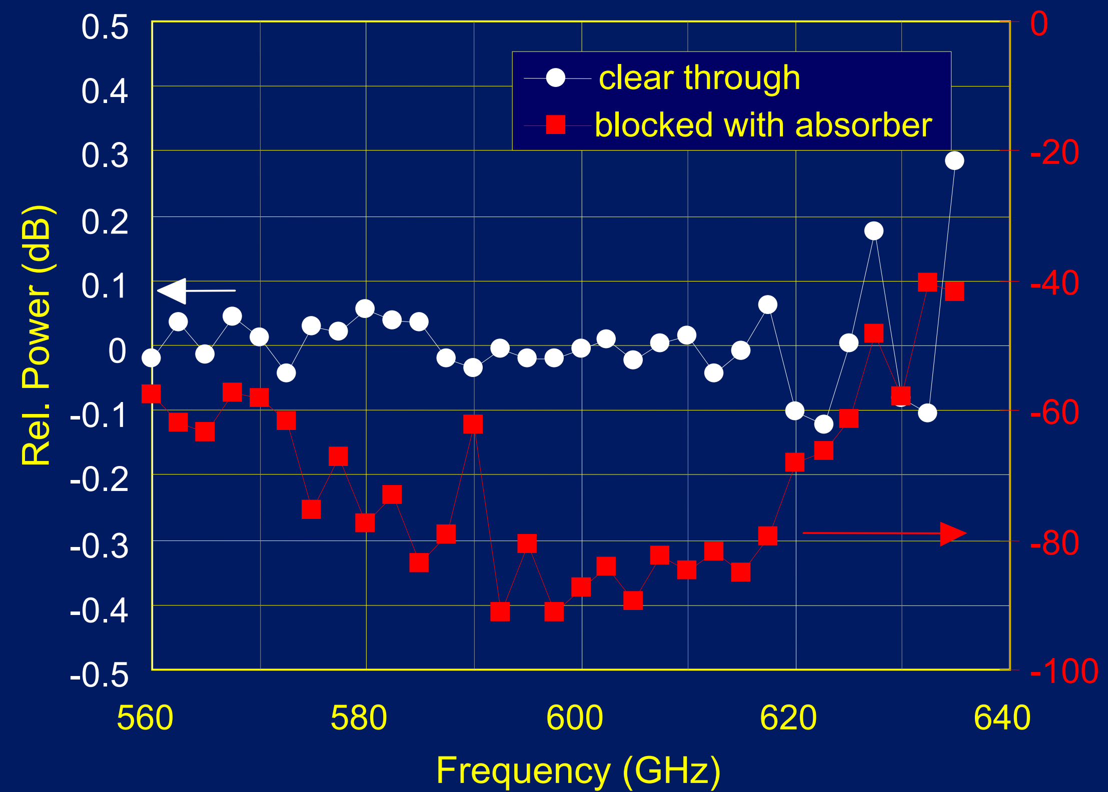
600 GHz Transmit Module



600 GHz Receive Module

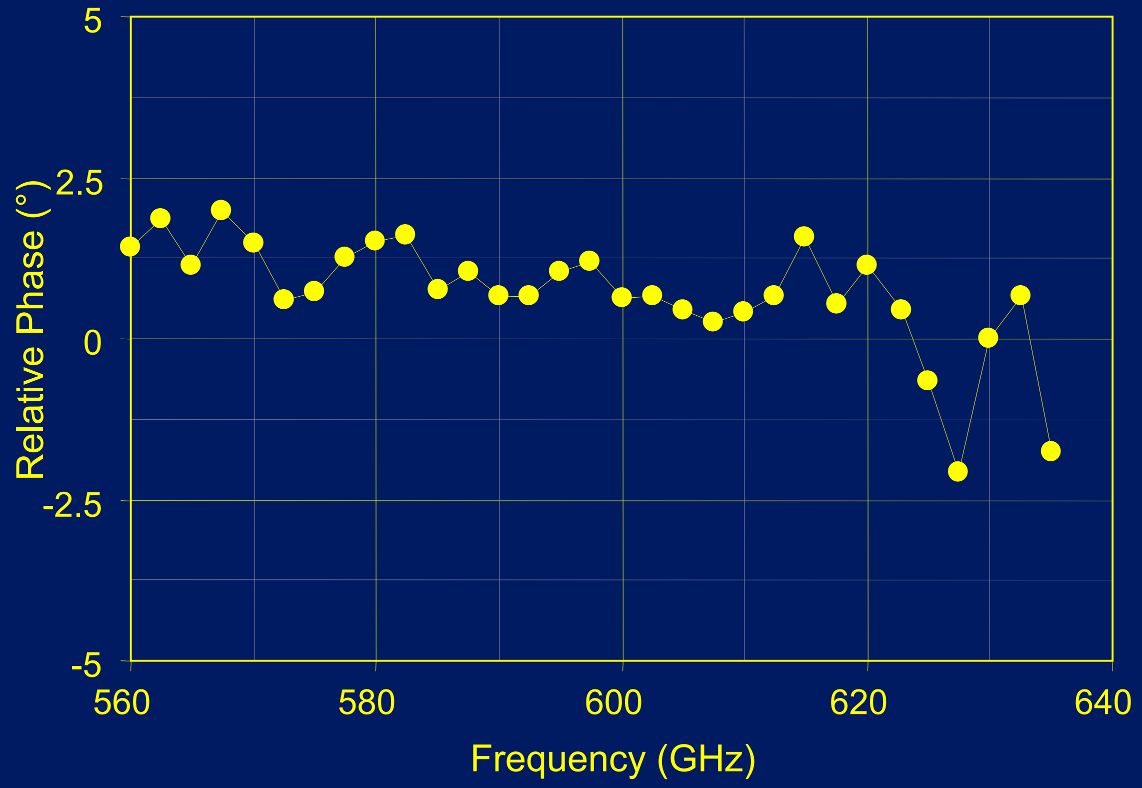


Performance Tests: Amplitude Stability & Dynamic Range



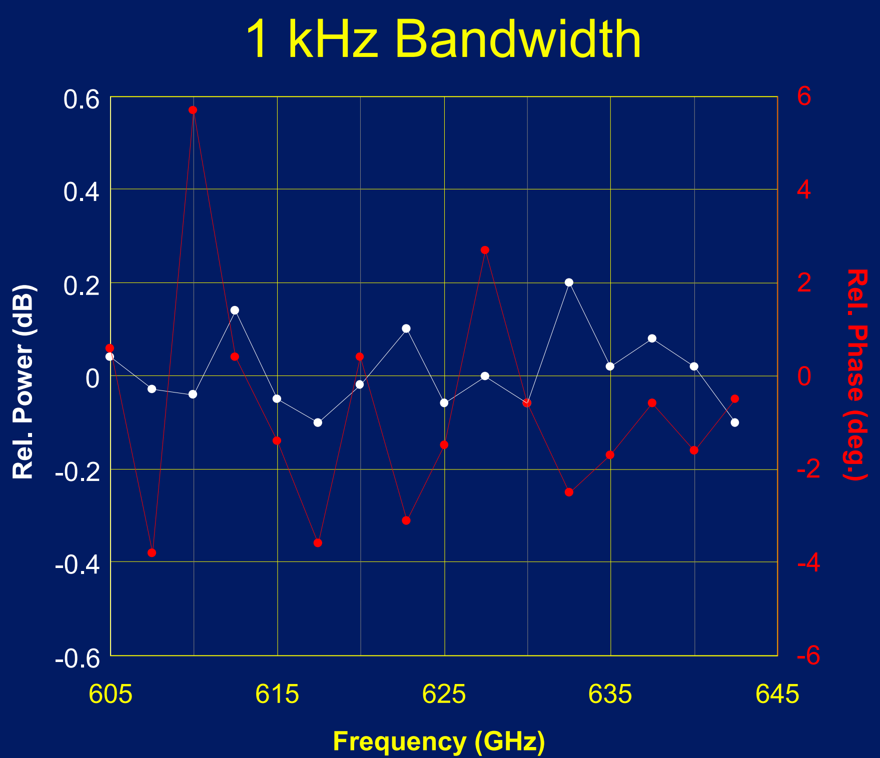
- Lock-in amplifier bandwidth: 100 Hz
- Dynamic range in 595-615 GHz region is limited by the 16 bit A/D reading the lock-in amplifier outputs (max. of only 96 dB possible)

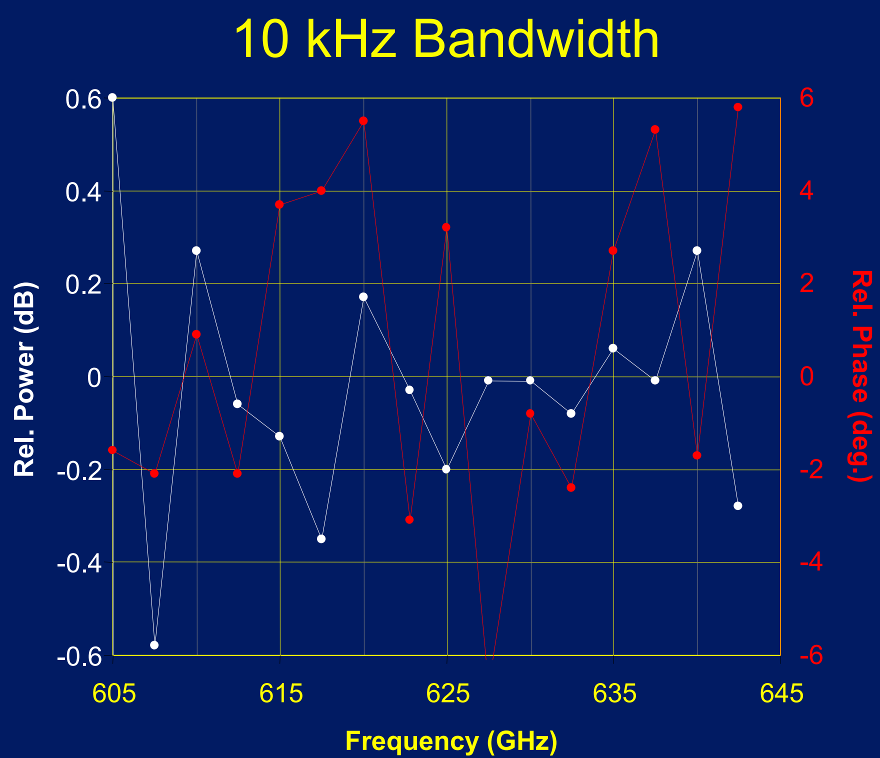
Performance Tests: Phase Stability



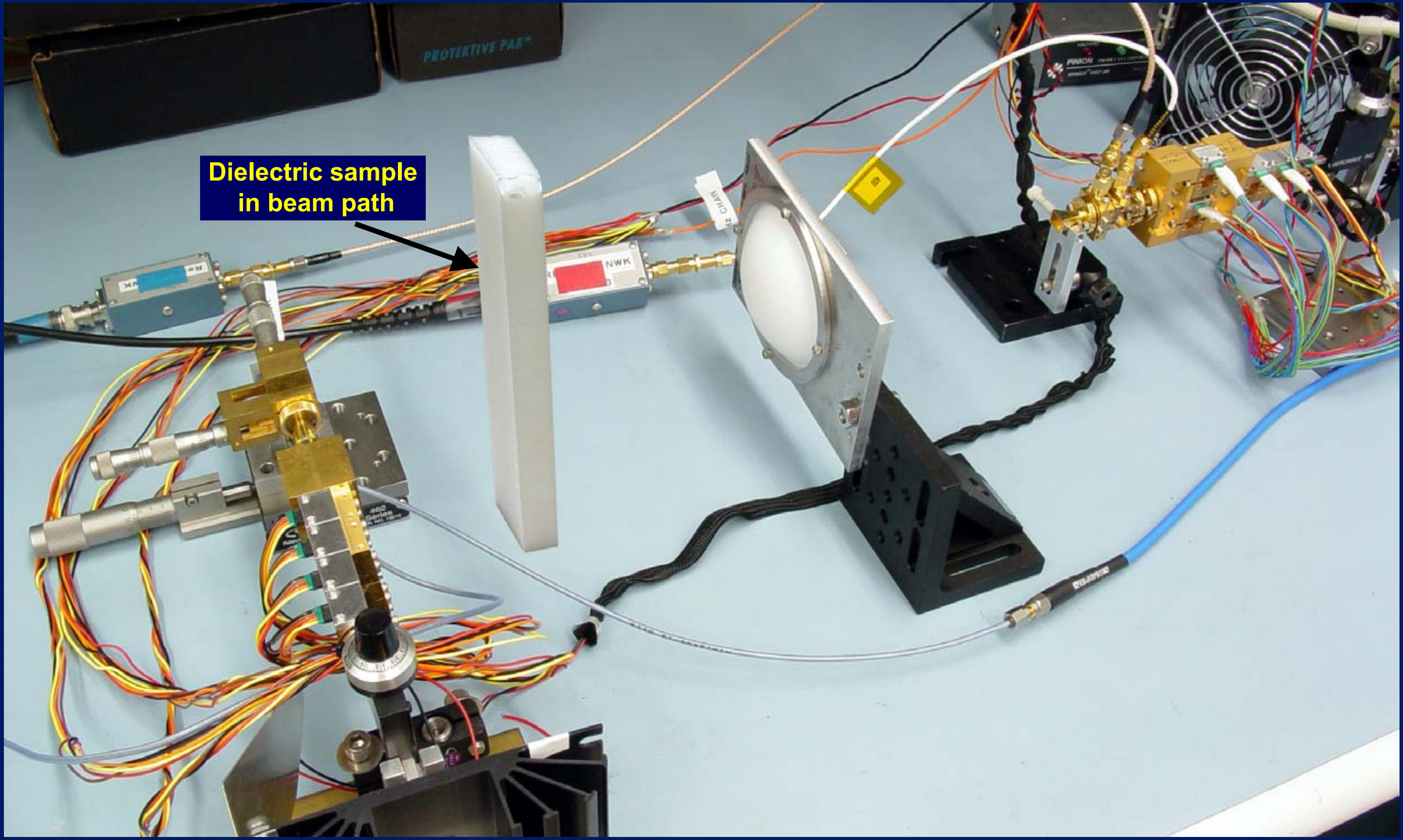
- Lock-in amplifier bandwidth: 100 Hz

Stability at Imaging Bandwidths



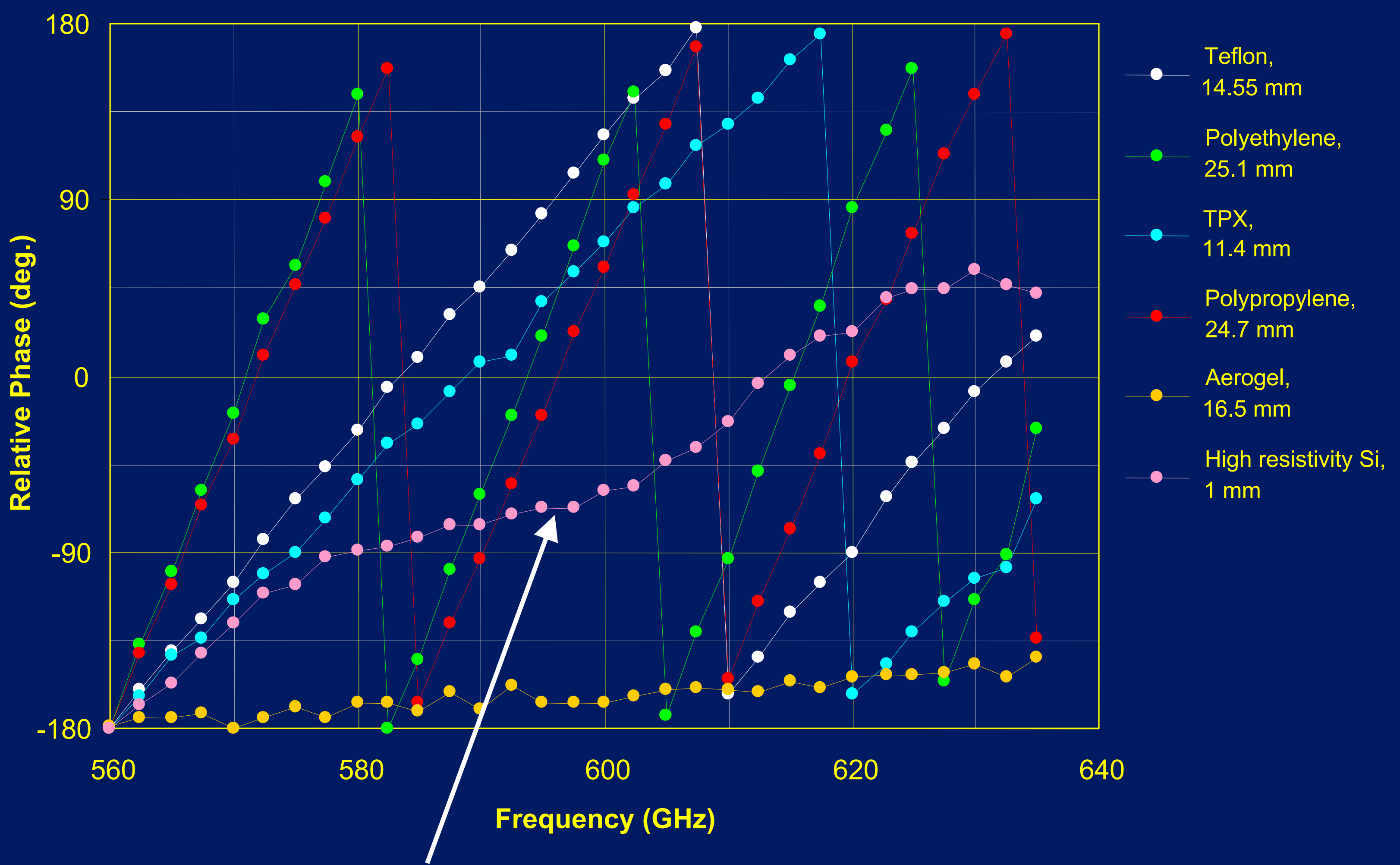


Phase Measurement Verification



Dielectric constant of known materials measured by measuring change in phase over 75 GHz bandwidth

Phase Measurement Verification



Note ripple in $\delta\phi/\delta f$ of high-resistivity Si due to standing wave caused by the high ε_r of silicon

Phase Measurement Verification

Determination of relative dielectric constant ε_r was found using

$$\varepsilon_r = \left(\frac{\partial \phi}{\partial f} \cdot \frac{c}{360 \cdot l} + 1 \right)^2$$

Where l = physical length of material (meters)

$\delta\phi/\delta f$ = rate of phase change (degrees/Hz)

Material	Thickness l (mm)	$\delta\phi/\delta f$ (°/GHz)	Measured Dielectric Constant	Dielectric Constant from [15], [17]	% Error from [15], [17]
Teflon	14.55	7.73	2.080	2.0532 [15]	1.3
Polyethylene	25.1	16.35	2.379	2.3247 [15]	2.3
TPX	11.4	6.36	2.144	2.1318 [15]	0.57
Polypropylene	24.7	15.14	2.284	2.255 [17]	1.3
Aerogel	16.5	0.47	1.048	-	-
Hi-Resistivity Si	1.0	2.96	12.03	11.67 [17]	3.1

Higher error due to standing wave

[15] National Physical Laboratory Report DES 69, Feb. 1981.
[17] A. Gatesman, University of Massachusetts Lowell.

The Next Step: Imaging

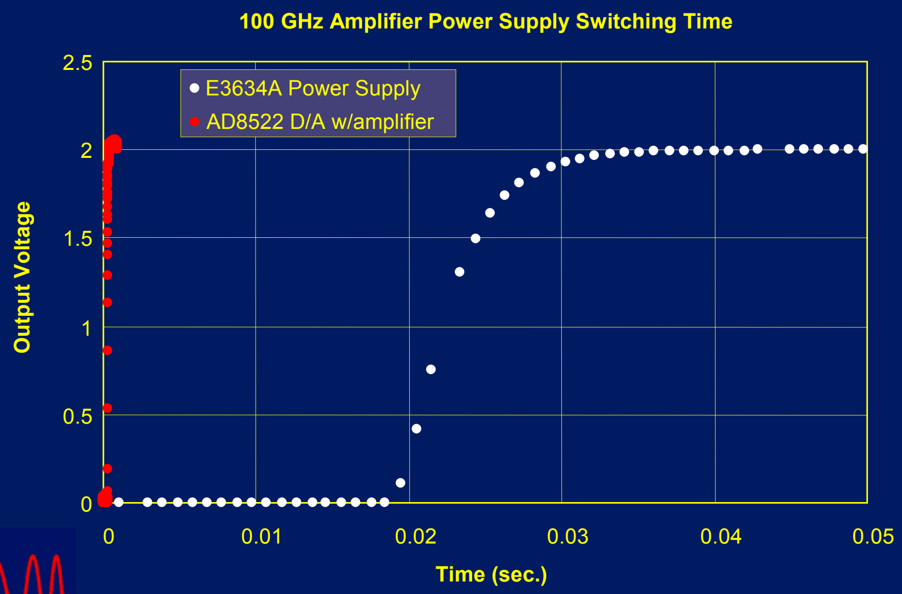
Fresnel lens designed by JPL & University of Delaware, built by Custom Microwave

- 20 cm diameter
- 4 m focal length

The Next Step: Imaging

Dispersive optics can be used in conjunction with fast frequency sweeping to rapidly scan the beam in one dimension. By scanning mechanically in the other dimension, near real-time active imaging can be realized. However, the frequency stepping speed must be improved in order to take advantage of electronic beam steering using dispersive optics.

The typical synthesizer lock time is 100 msec. During this time, the 100 GHz power amplifier supply voltage must be reduced to prevent damage to the submillimeter multipliers. Additional time following synthesizer relock is required to stabilize the supply voltage.



Replacement of the Agilent E3634A power supplies with amplified D/A converters resulted in a 20 msec. improvement in frequency switching speed. However, the slow synthesizers will need to be replaced with faster units in order to achieve the speeds required for electronic beam steering.

Conclusion

- A complete vector measurement system has been designed, constructed and tested over 560-635 GHz.
  - 60 dB dynamic range typical (maximum of 90 dB)
  - ~3000 points per second acquisition speed

Acknowlegements

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration. The authors wish to acknowledge the assistance and support of Mr. John E. Oswald and Mr. Robert H. Lin who provided the 640 GHz heterodyne mixer, and Dr. John Pearson and Ms. Mary Soria for providing the MMIC power amplifiers.

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