Welcome and Introduction

Presentation to

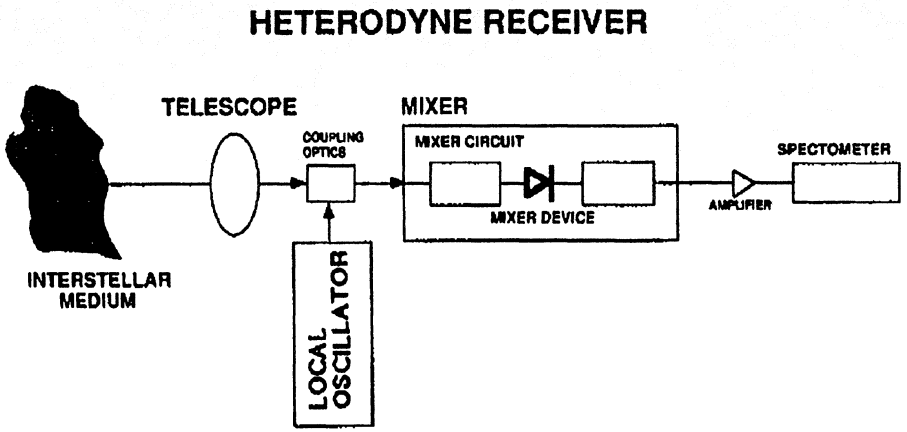
Eighth International Symposium on Space Terahertz Technology

Carl Kukkonen
Director, Center for Space Microelectronics Technology

JPL

March 24-27, 1997

Submillimeter Heterodyne Sensor



Why Submillimeter Technology

Addresses fundamental questions of astrophysics

- Birth and death of stars
- Galactic evolution

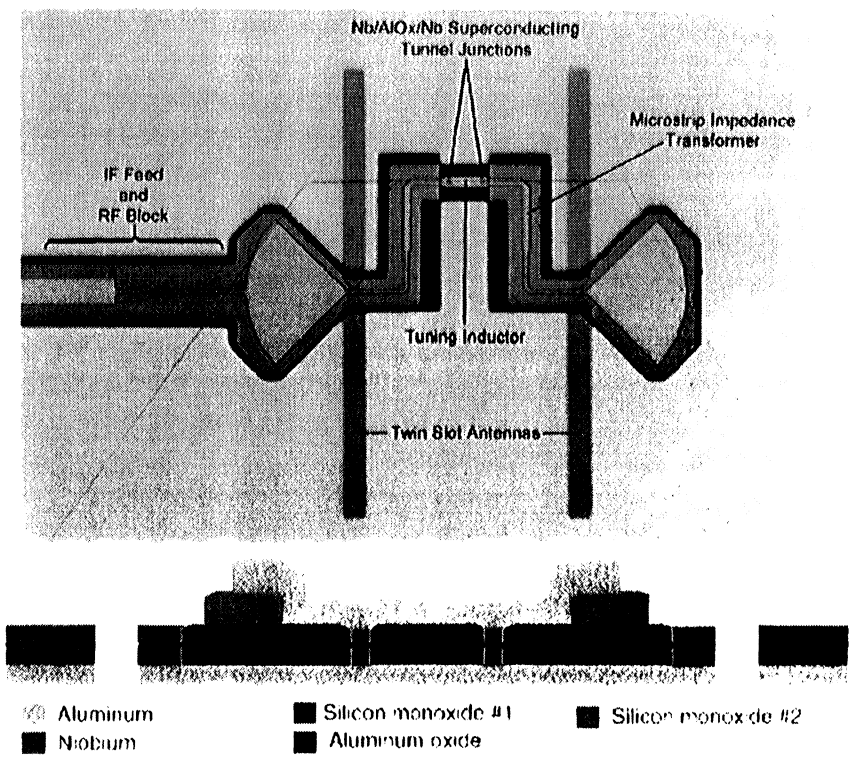
Required data

- Composition (H_2O, O_2,O, C) mass, density, temperature and velocity of material in interstellar medium

Challenge

Demonstrate 1.2 THz Key Component Technology

- Mixer
- Local Oscillator



Terahertz Astrophysics Observing Platforms

- **Submillimeter Wave Astronomy Satellite (SWAS)**
  - Small Explorer Mission
  - Heterodyne receivers near 480 and 560 GHz
  - Observe interstellar water, oxygen, and carbon
  - Launch date 1998

- **Far Infrared Submillimeter Telescope (FIRST) - ESA Mission**

  <u>Baseline Capabilities</u>
  - Passively cooled 3 m telescope 250-600 GHz SIS mixer
  - High resolution spectroscopy 85-300 μm, photoconductor and bolometer arrays
  - Broad band photometry 85-900 μm bolometer arrays

  <u>Potential NASA Contributions</u>
  - Orbit: Increase observing time and sensitivity
  - 4 m telescope
  - Enhanced detectors: SIS to 1.2 THz; HEB Channel (1.9-2.7 THz)
  - Vibrationless sorption cooler system

Terahertz Astrophysics Observing Platforms

- The Stratospheric Observatory for Infrared Astronomy (SOFIA)
  - 2.5 m aperture airborne telescope for wavelengths between 1 mm and 10 microns
  - Funded by NASA
  - Successor to the Kuiper Airborne Observatory
  - First flights in 2000-2001
- Antarctic Submillimeter Telescope and Remote Observatory (AST/RO)
  - South Pole Observatory operational this year funded by NSF
  - 1.7 m aperture for 0.5 mm wavelengths
  - Built, running and taking data
- Heinrich Hertz / SubMillimeter Telescope Observatory (HHT/ SMTO)
  - Located on Emerald Peak of Mt. Graham, approximately 75 miles north-east of Tucson, Arizona
  - 10 m aperture for wavelengths between 1.3 mm and 350 microns
  - Joint University of Arizona / Max-Planck Institut fur Radioastronomie project
  - Operational and taking data

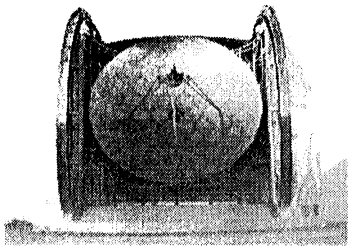
Terahertz Astrophysics Observing Platforms

- NRAO - Millimeter Array in Chile
  - 40 Telescopes
  - 8 m diameter
  - Construction start 1998
  - Operational 2005
  - Frequency: 200 -850 GHz
- South Pole 10 m Telescope
  - Operational 2003
  - AST/RO - NSF Funded Program
  - Frequency SIS & Bolometers up to 1.5 THz

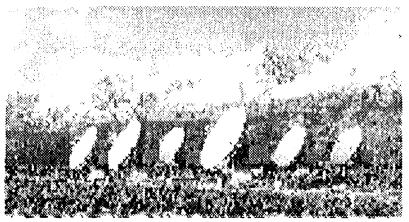
Terahertz Astrophysics Observing Platforms

- **Microwave Instrument for the Rosetta Orbiter (MIRO)**
  - **Approved for the Rosetta Orbiter - Launch 2003**
  - **Two channel continuum and spectroscopic heterodyne receiver system**
    - **Submillimeter Wave Receiver - Frequency: 540 GHz**
    - **Millimeter Wave Receiver**
- **Submillimeter Array (SMA)**
  - **Harvard Smithsonian Center for Astrophysics**
  - **6 telescopes upgraded to 9**
  - **6 m diameter**
  - **On Mauna Kea, Hawaii**
  - **Operational 2000**
  - **Operational under (200 - 800 GHz)**

Terahertz Astrophysics Observing Platforms



- **Caltech Submillimeter Observatory**
  - **A cutting-edge facility for astronomical research and instrumentation development**
  - **Located on "submillimeter ridge" near the summit of Mauna Kea, Hawaii**
  - **10 m Telescope**
  - **Frequencies: 200 - 800 GHz**



- **Owens Valley Radio Observatory**
  - **Largest university-operated radio observatory in the world**
  - **Located five hours north of Pasadena, near the Sierra Nevada range**
  - **Six 10m telescopes**
    - **Frequency ranges 80-116 GHz and 210-270 GHz**
  - **40m Telescope**
  - **5m Telescope**
  - **Two 27m Telescopes**

Status of NASA Submillimeter Sensors Astrophysics Program

- Superconducting Mixers
  - Nb SIS Mixers meet needs of FIRST for frequencies up to 1 THz
  - Challenge is to improve performance to 1200 GHz
    - Approach
      - Nb or NbTiN SIS mixers
      - Hot Electron Bolometers
  - Above 1 THz Hot Electron Bolometer
    - Diffusion Cooled (Nb)
    - Phonon Cooled (NbN)
- Solid State Local Oscillator Sources
  - Multiplier chains meet power requirements of FIRST for frequencies up to about 1.2 THz
  - Challenge is to provide
    - Wide bandwidth with fixed tuning
    - Reliability
  - Higher Power and Stable Photomixer L.O. (1-3 THz)

NASA Terahertz Space Missions for Earth Observations

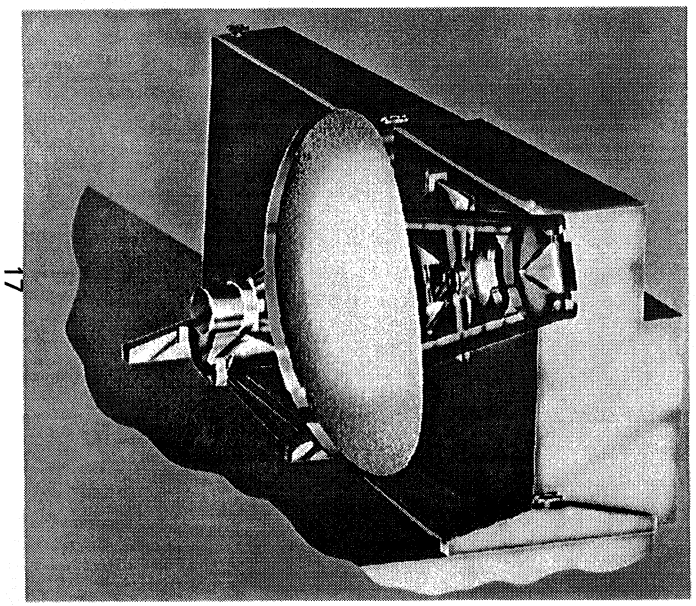
- **Earth Observing Satellite Microwave Limb Sounder**

  Study of chemistry of stratospheric ozone on a global scale

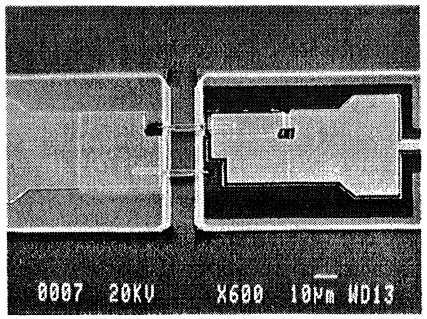
  - **118 GHz**
    - **Temperature and Pressure**
  - **190 GHz**
    - **Continuity with UARS MLS for O_3, ClO, and H_2O**
  - **240 GHz**
    - **O_3, CO - Temperature and Pressure**
  - **640 GHz**
    - **Ozone chemistry (O_3, HCl, ClO, NO_2 and others)**
  - **2.5 THz**
    - **Ozone chemistry (OH), Temperature and Pressure**

- **Approved mission, instrument engineering model build in 1997**
- **Launch date 2002**

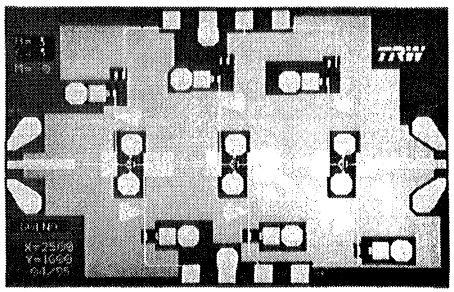
Mission to Planet Earth
Technology Insertion



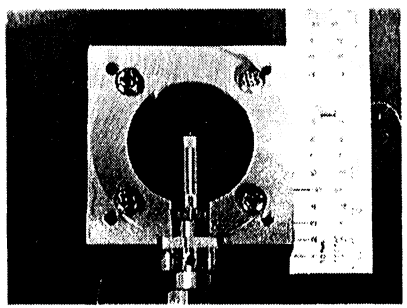
Microwave Limb Sounder



JPL 640 GHz QUID (Quartz upside-down integrated Device) Diode Pair



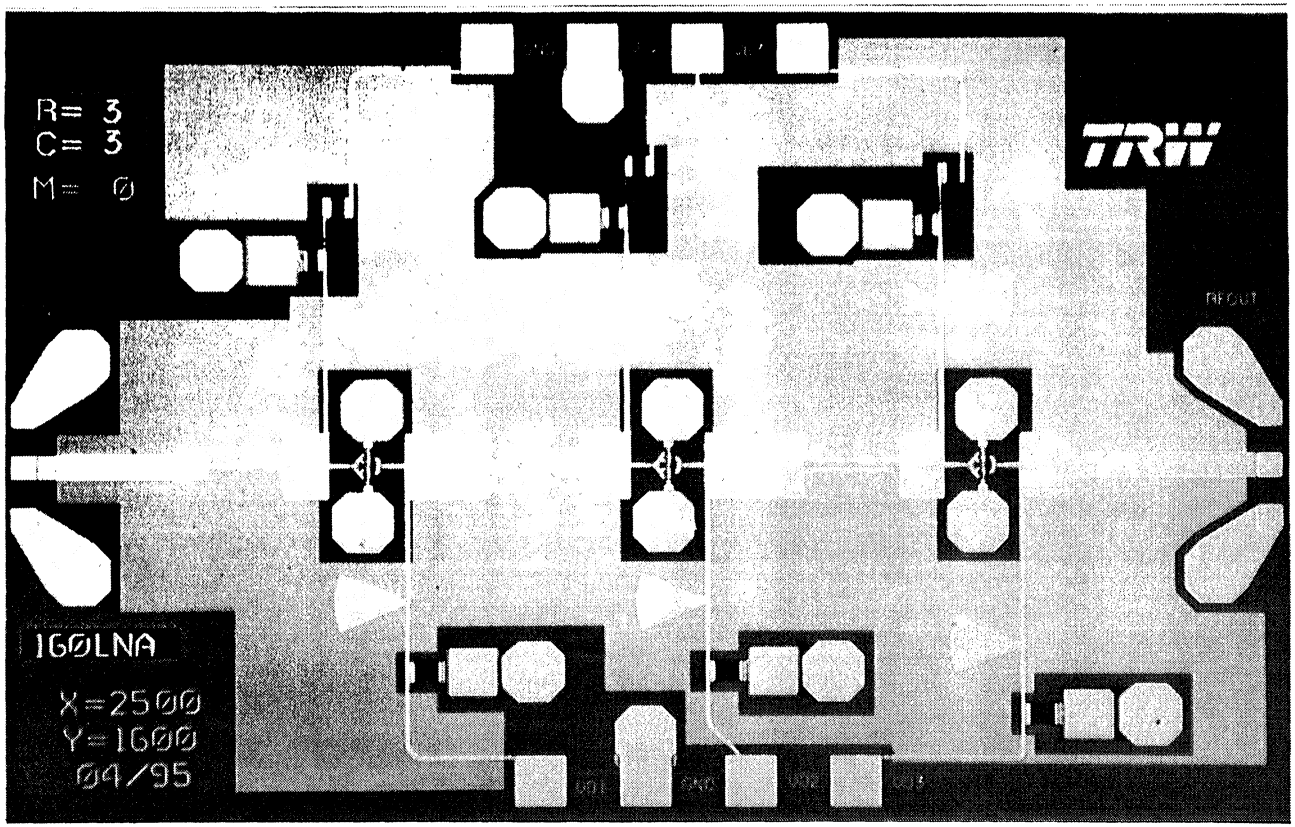
TRW 160 GHz InP MMIC LNA Chip (3 stage)



JPL MMIC Mixer Prototype for 2.5 THz

MMIC Development for IMAS

IMAS: Integrated Multispectral Atmospheric Sounder to Measure Temperature and Pressure of the Atmosphere with MMIC Radiometer at 54, 118 and 183 GHz



TRW 160 GHz InP MMIC LNA Chip (3 stage)

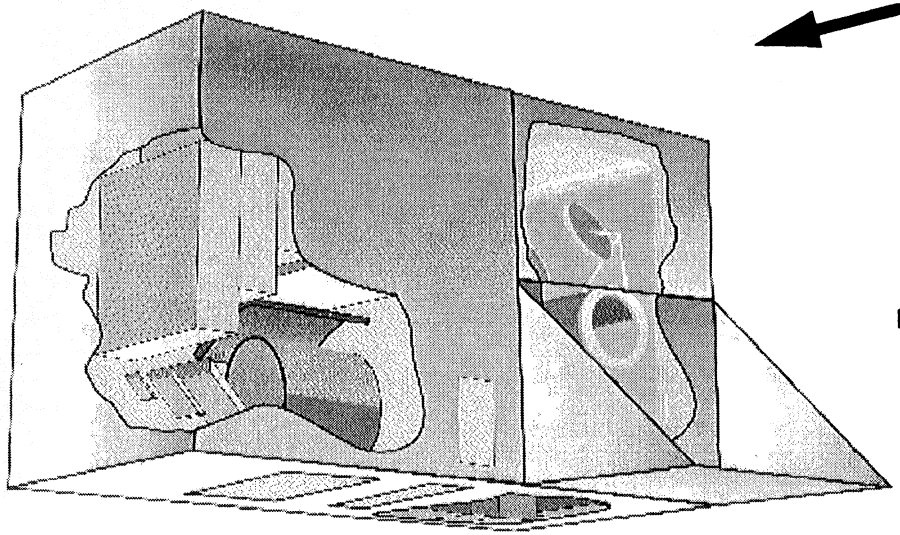
Measured gain: 8 dB at 155 GHz (including waveguide-to-chip input and output transition and input horn)!

Measured noise figure: 6.4dB (965K) at 155 GHz !

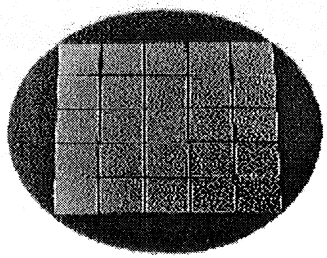
- World's highest frequency LNA with measurable gain
- World's first noise measurement on a MMIC amplifier above 140 GHz
- World's lowest noise room temperature amplifier above 120 GHz

H. Wang (TRW), P.H. Siegel, T. Gaier, R.J. Dengler (JPL)

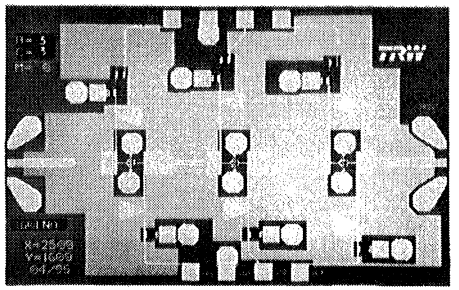
Mission to Planet Earth
Technology Insertion



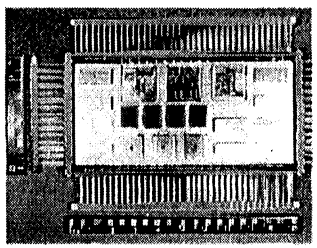
Integrated Multi-Spectral
Atmospheric Sounder



Twenty Five 256 x 256 QWIP Focal PlaneArrays (FPAs) on 3 inch GaAs Wafer



TRW 160 GHz InP MMIC LNA Chip (3 stage)



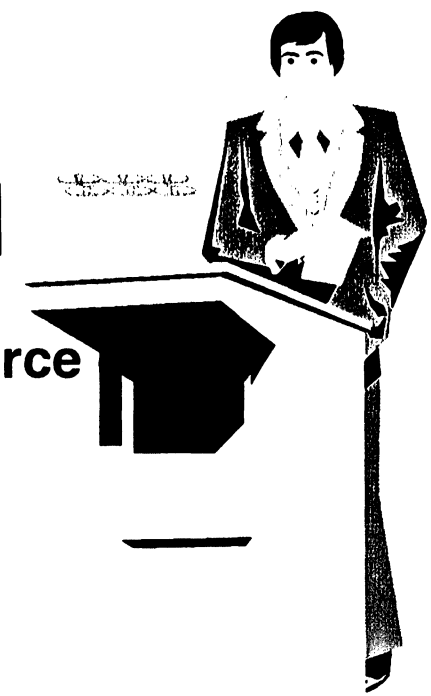
Advanced Flight Computer: 33-chip Module

Kukkonen Challenge 1993

- First SIS mixer with
  - Frequency > 1 THz
  - T_{sys} < 1000 K DSB

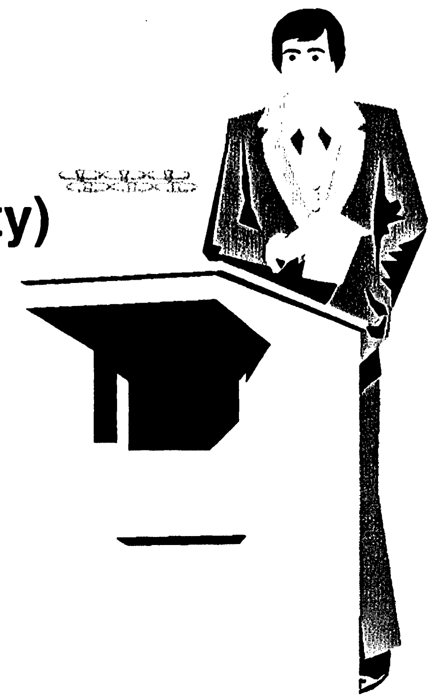
Awarded 1995

- First Solid State Local Oscillator Source
  - Frequency > 1 THz
  - Output power > 100 microwatts
    (100 GHz Bandwidth) Unclaimed




Kukkonen Terahertz Prize
Terahertz Prize
Awarded
September 11, 1995
to
J. Zmuidzinas, M. Bin,
G.A. Blake, M.C. Gaidis, D. Miller,
T.G. Phillips, D. Stockman
California Institute of Technology
Rick Leduc, Bruce Bumble,
Krekor Megerian, Jeff Stern
Jet Propulsion Laboratory
for
Developing the First Mixer to Operate
above 1 THz with a Noise Temperature of
less than 1000K
1.042 THz, Noise Temperature
840K, double-sideband
Budweiser
KING OF BEERS
Anheuser-Busch, Inc.

1997
Kukkonen Challenge



Local Oscillator

- Frequency: 1-3 THz (500 GHz Tunability)
- Power: 10-50 μwatts