GaAs based Terahertz Sources for Space Applications: Challenges and Prospects

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Presented at SPIE's 45th Annual Meeting
San Diego, August 1st, 2000

Acknowledgments

- Thanks to Barbara Nakamura for processing work
- Thanks to Dr. Neal Erickson for technical discussions
- Thanks also to Dr. Peter Siegel for initiating and supporting the planar diode work at JPL

- The research described in this publication was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration

Outline

- Introduction
- Requirements and current capability
- Technology development Road map
- Status of power sources in f<1000 GHz range
- Status of power sources in f>1000 GHz range
- Challenges
- Conclusion

Introduction

- Traditional space borne submillimeter-wave sources
  - Gunn diode + whisker contacted Schottky diode multipliers
- Limitations
  - Instantaneous bandwidth of Gunn diodes is very limited
  - Power combining is difficult
  - Whisker contacted diodes are extremely difficult to assemble
  - commercial availability of both Gunn diodes and whisker contacted high frequency diodes is limited
  - multiple diode configurations are not readily possible

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Prospective source to 2400 GHz

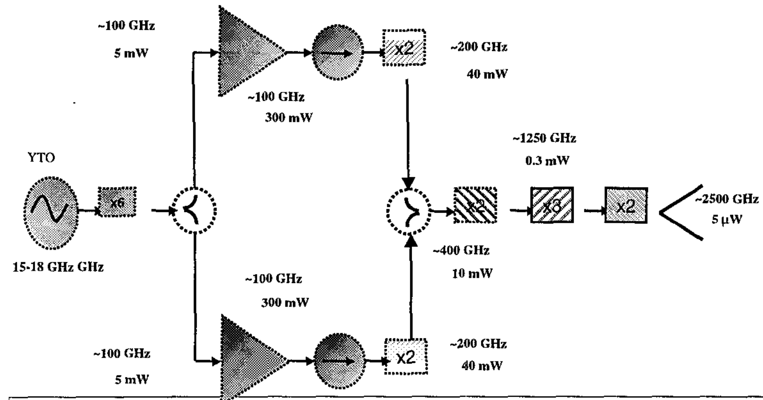

Figure 1. Schematic of the all-solid-state source to 2500 GHz. Dashed outlined components are either commercially available or have already been demonstrated in our laboratory. Solid outlined components are to be developed under this proposal.

Technology Development Roadmap

- Increase available power at 100 GHz
- Use balanced multiple diode arrays in the earlier stages
- Use planar technology
- Waveguide based circuits
- Enhance performance by radiative cooling

Increase available power at 100 GHz

- Current status: Gunn diodes limited to about 100mW at 100 GHz
- Solution: Power Amplifier technology
  - Utilize power combining
  - Issues
    - technology
    - efficiency
    - noise

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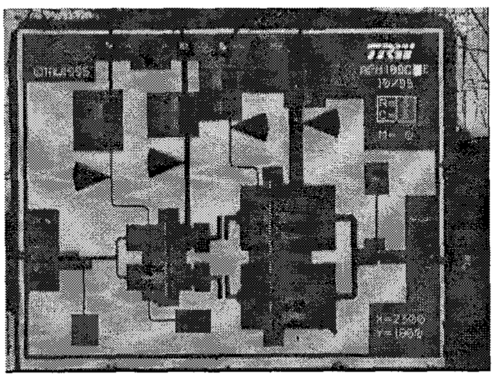
TRW MMIC PA Chip

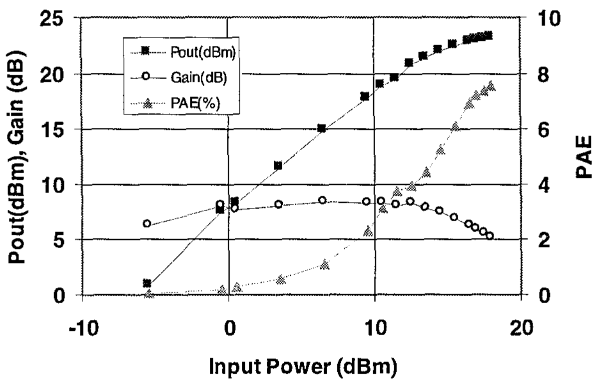


- 0.1 um PHEMT process
- 50 um thick substrate
- $f_t = 200$ GHz
- 64 finger device cell (output)
- on-chip bias network
- 50 ohm matching in/out
- 2.3 mm x 1.8 mm

Ref: R. Lai et. al, "A high efficiency 0.15 um 2-mil thick InGaAs/AlGaAs/GaAs V-band power HEMT MMIC," IEEE GaAs IC Symposium Digest, Nov. 1996.
M. D. Biedenbender et al, "A 0.1 um W-band HEMT production process for high yield and high performance low noise and power MMIC's," 16th GaAs IC Symposium, 1994.

Performance of prototype single chip module

Measured output power in Block B
(@91 GHz) Flange-to-flange



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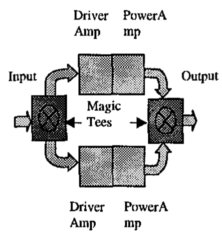
Power combined amplifier module



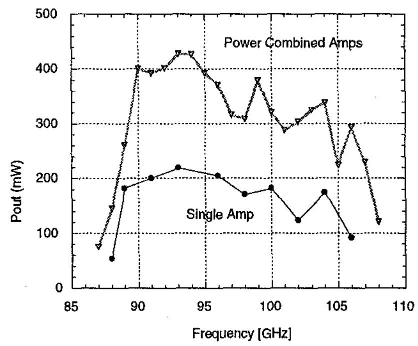


Figure 2. Power output from single and dual power combined packaged TRW MMIC amplifiers at W-band.

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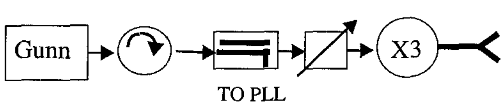
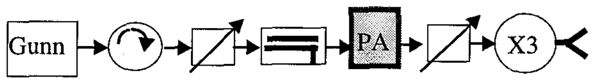
Noise considerations for power amplifiers

Test with a SIS 278 GHz receiver
at CSO on Mauna Kea, Hawaii



$T_{rec} = 22.5$ K

(a)



$T_{rec} = 21.3$ K

(b)

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Current status of planar Technology for initial stages f<1 THz

- Discrete chips
- Substrateless technology
- thermal issues
- cooling effects

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First stage multipliers

- Current status: whiskered devices
- Solution: Planar multiplier devices
  - Multiple diode configuration
    - Higher power handling
  - Balanced approach
    - Simplify design, circuit construction
  - Issues
    - Technology
    - Device yield
    - Thermal management

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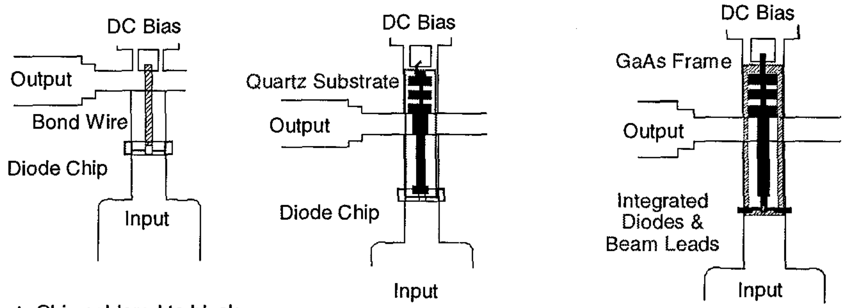
Planar Balanced Doubler Technologies Based on Neal Erickson Split- Block Concept

University of Massachusetts | Univesity of Virginia/VMI/ Millitech | JPL "Substrateless" Frame



University of Massachusetts:
- Chip soldered to block
- Bondwire connects chip to DC Bias Cap

Univesity of Virginia/VMI/ Millitech:
- Chip soldered to block or Quartz
- Bondwires connect quartz to Bias Cap and to block (for chip on quartz version)

JPL "Substrateless" Frame:
- All chip connections to block made with beam leads
- Diodes integrated into circuit
- GaAs under metal removed for low loss

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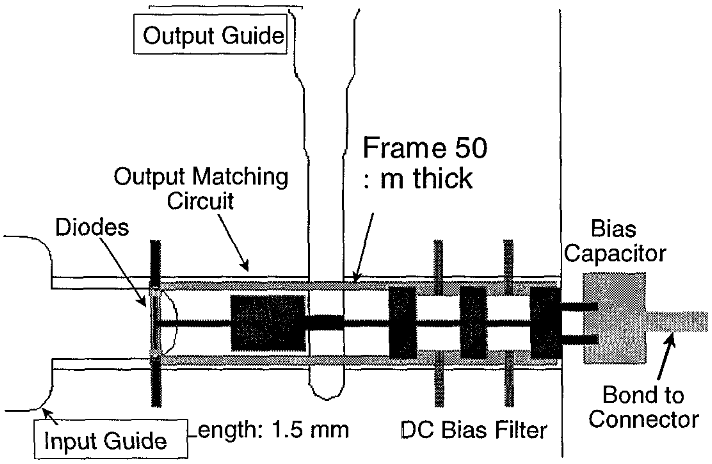
400 GHz Substrateless Circuit in Block



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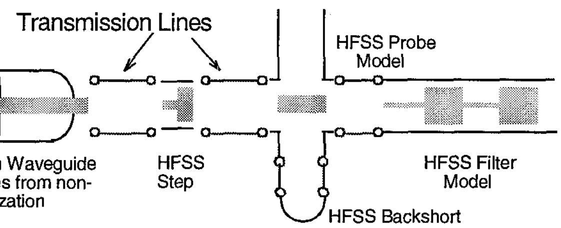
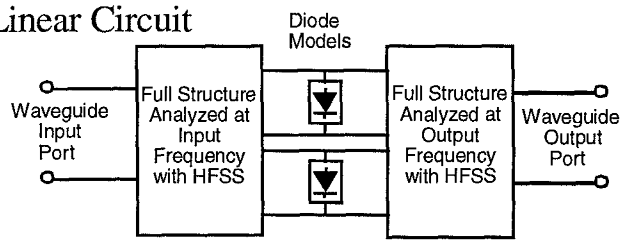
Doubler Design Strategy

Linear Circuit



Non-Linear Circuit



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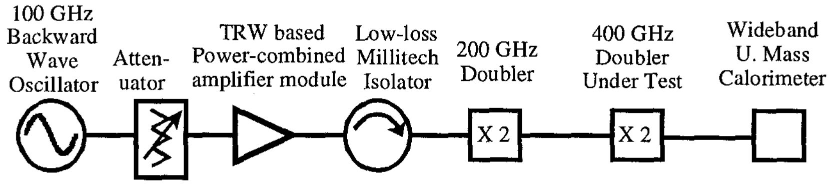
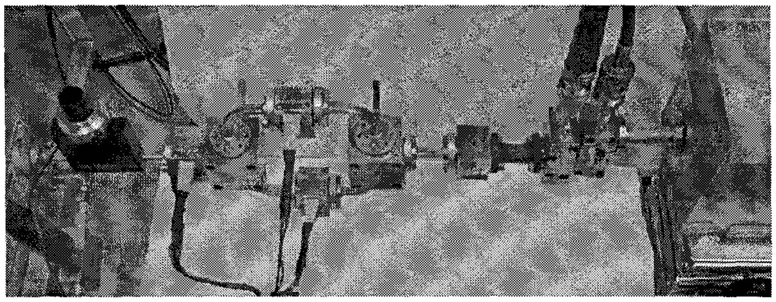
400 GHz Doubler Test Set





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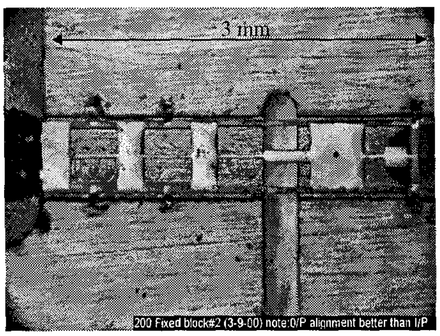
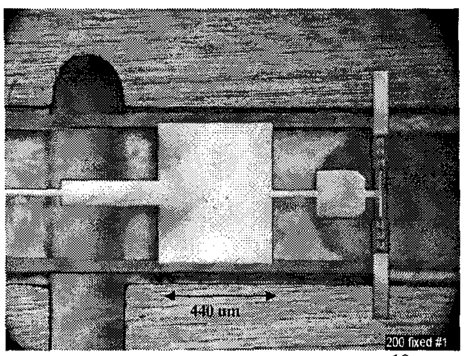
Substrateless Technology for 200 GHz MMCs



Full view of structure mounted in a waveguide block



Close-up of the anodes

Gives 8% efficiency, despite design flaw

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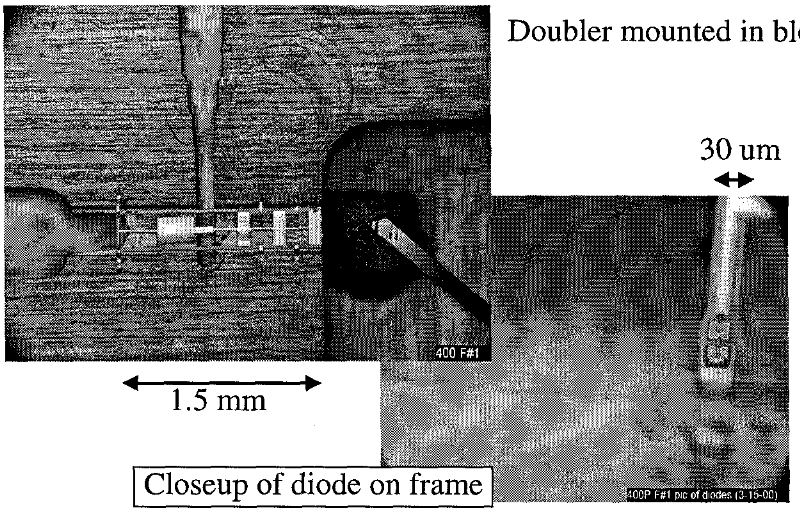
Substrateless Technology for 400 GHz MMCs



Doubler mounted in block

30 um

1.5 mm

Closeup of diode on frame

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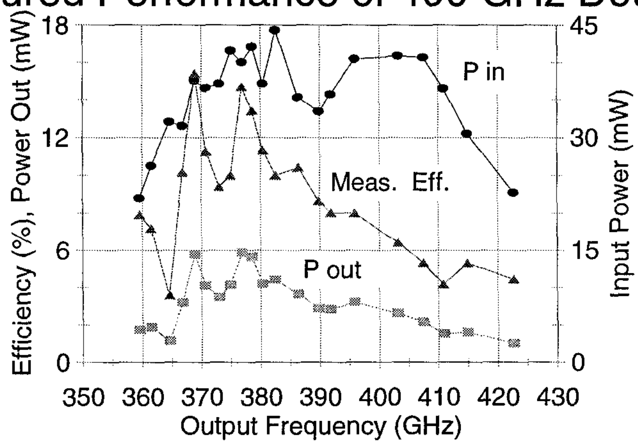
Measured Performance of 400 GHz Doubler



- Calculated performance 35 % efficiency
- Expected performance 25 % including circuit loss

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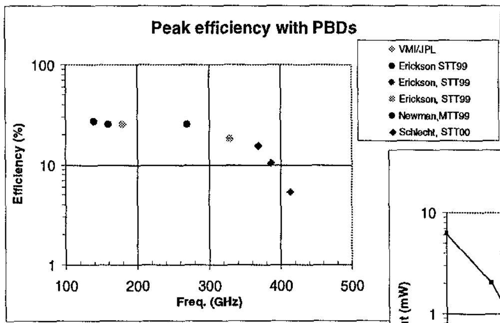
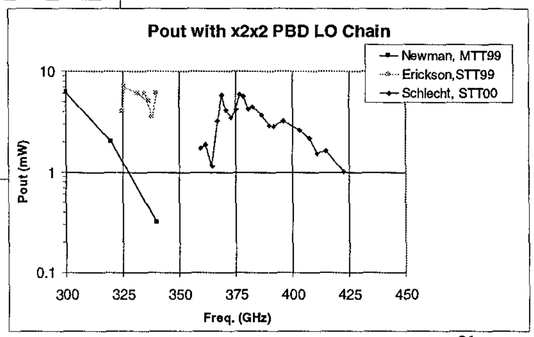
Fix tuned Multiplier State-of-the-art performance, (Apr 2000)





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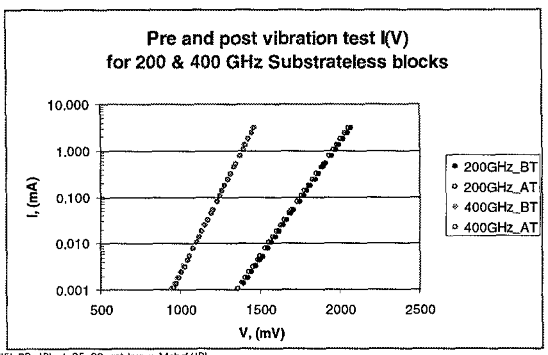
Vibration Test on the Substrateless MMCs

- 200 and 400 GHz blocks, block length parallel to x-axis, 1st order random test

Test I specifications	Test II specifications
20 Hz--0.001 g^2/Hz	20 Hz--0.001 g^2/Hz
20-100 Hz--+6dB/oct	20-100 Hz--+6dB/oct
100-500 Hz--0.1, 0.2,0.4,0.6,0.8,1.0,1.2 g^2/Hz	100-1000 Hz--0.8 g^2/Hz
500-2000 Hz-- -6dB/oct	1000-2000 Hz-- -6dB/oct
Overall: 7.9,10.9,15,18,21,23,28 GRMS	Overall: 28.7 GRMS
Duration: 60 seconds	Duration: 440 seconds



Specification for FIRST: 11.2 GRMS

- **no change in I(V)**
- **no change in RF**

(only 200 GHz measured)

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Multiplier Requirements for FIRST

- Efficient, accurate assembly of multiplier circuits in blocks — need over 100 for FIRST!
- Ruggedness, resistance to shock and vibration for space qualification
- Wide bandwidth (10 to 14 %)
- High power capability (200 – 250 mW)
- High efficiency for multiple cascaded stages
- Cryogenic (100 K) operation

Technology:
Frameless GaAs Membrane

Get rid of frame

- Advantages:
  - Increased design flexibility
  - All shapes possible
  - Split waveguide block implementation possible (no frame in the way)
- Drawbacks:
  - Handling (use of "sacrificial frame" possible)

Extensive use of Beam Leads

- Advantages:
  - Simplified assembly (no soldering, chip "dropped in")
  - Simplified bias scheme (no wire bonding)
  - Low loss, high bandwidth antennas/circuits (air dielectric)
- Drawbacks:
  - Fragile during handling

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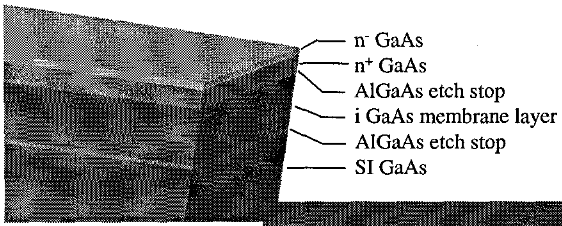
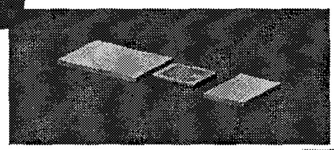
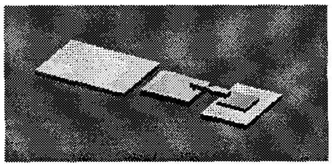
Technology:
Frameless GaAs Membrane flowchart

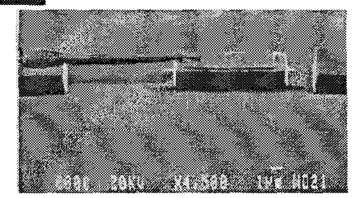




•recessed Ohmic
•Mesa definition
•Interconnect metal



•E-beam anode



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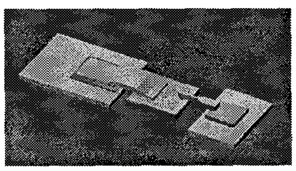
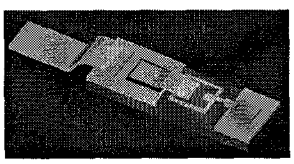
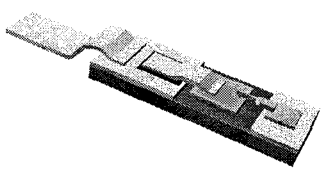
Technology:
Frameless GaAs Membrane flowchart 2



•SiN
•Bridge/capacitor metal



•Membrane definition
•Bridge metal/RF probe/
beam leads



•substrate removed

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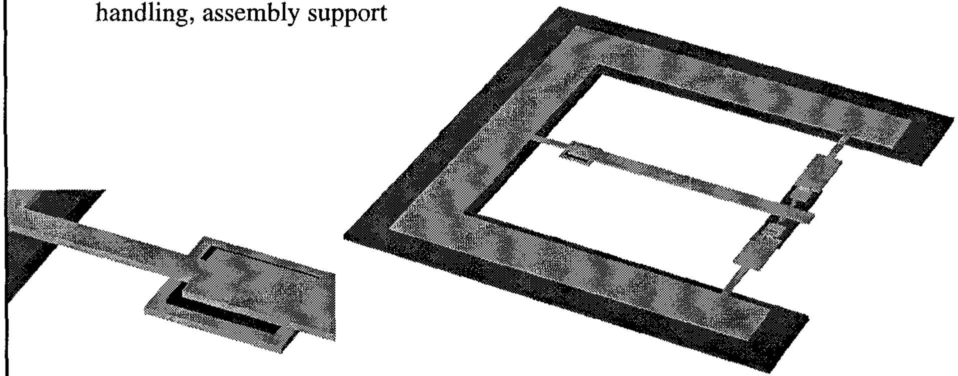
Technology:

Possible Features:

- Sacrificial handling membrane frame
- Substrateless thin film capacitor (for DC bias isolation)
- Multi purpose beam-leads: RF probes, RF ground/short, DC bias, handling, assembly support



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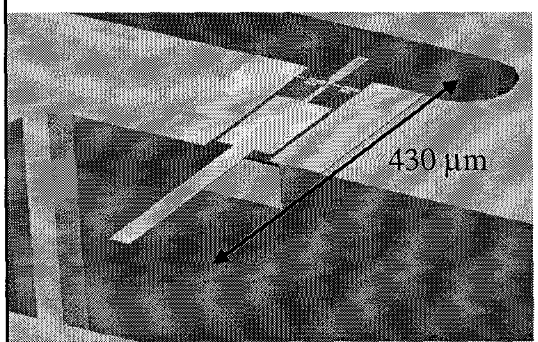
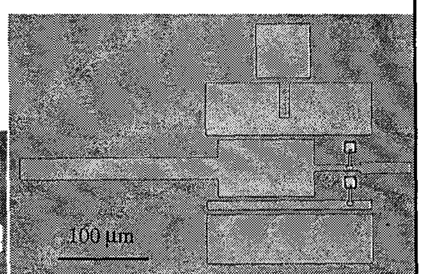
Application: Tripler to 1.2 THz on membrane

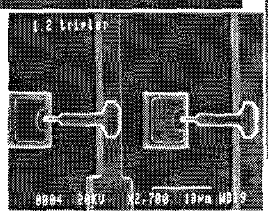


- Balanced tripler for idler tuning.
- Split waveguide block.
- Simple bias scheme.
- Predicted efficiency is 2%.



Pictures of the tripler under fabrication, after anode metalization

Planar Diode properties:
Epitaxial doping concentration: 5×10^{17} cm^{-3}
Anode size: 0.4 x 0.6 um



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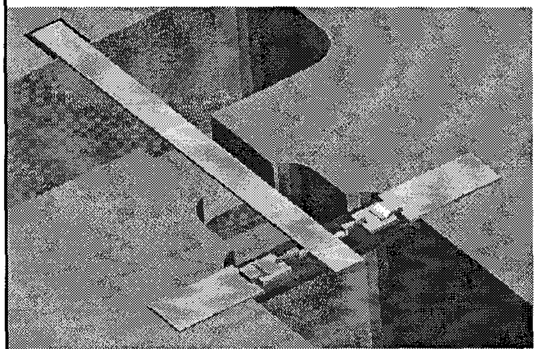
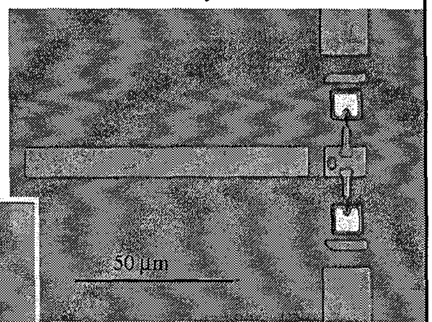
Advanced Local Oscillator Development for Millimeter and Submillimeter-wave Applications

Application: Doubler to 2.4 THz on membrane

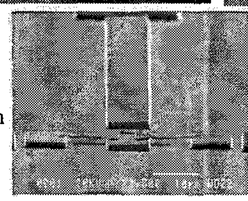


- Balanced doubler for simplified circuit (no filters).
- Split waveguide block.
- Low Power.
- Predicted efficiency is 2.5 %.



Planar Diode properties:

Epitaxial doping concentration:	5×10^{17} cm^{-3}
Anode dimensions:	0.14 x 0.6 um



Pictures of the doubler under fabrication, after anode metalization

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Conclusion

- High power amplifier technology has been demonstrated at 100 GHz enabling 250 mW in w-band
- Balanced doublers work with about 20% efficiency to 200 GHz, enabling 50 mW
- Balanced planar doublers to 400 GHz have demonstrated 15% efficiency, enabling 8 mW
- Devices are currently under fabrication that will extend the range of this chain to 1.2 and 2.4 THz
- Cooling is expected to improve the output power and efficiency of each stage (more drastically in the lower stages)

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