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MILLIMETER-WAVE / INFRARED RECTENNA DEVELOPMENT AT GEORGIA TECH

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ABSTRACT

millimeter wave/infrared (mmw/IR)

The key design issues of the ~~MMW/IR~~ monolithic rectenna have been resolved. The work at Georgia Tech, in the last year, has focused and has been concentrated on increasing the power received by the physically small MMW rectennas in order to increase the rectification efficiency. The solution to this problem is to place a focusing element on the back side of the substrate. The size of the focusing element can be adjusted to help maintain the optimum input power density not only for different power densities called for in various mission scenarios, but also for the nonuniform power density profile of a narrow EM-beam.

- Underlying Technologies for the MMW Rectenna are in place.
- A key element in the rectenna design is an integrated focusing element.
  - Aids in optimizing the rectification efficiency
  - Can compensate power density variations of different mission scenarios.
  - Can compensate for the power density profile of a narrow EM beam.

Why go to higher frequencies?

Reduce the size of the transmit and receive apertures of point to point beamed power systems.

Take advantage of readily available sources at higher frequencies.

- D/He-3 fusion reactors emit synchrotron radiation that peaks at about 1000 GHz [1].

- Black body radiation from the Earth that peaks wave lengths in the 10 - 15 μm ranges [2].

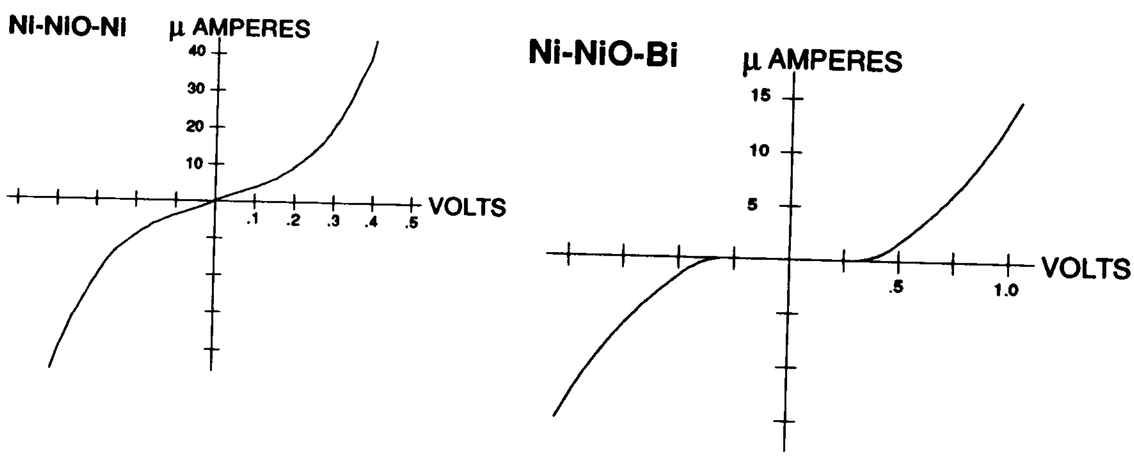
EARLY EXPERIMENTAL WORK

In the early work at Georgia Tech metal-oxide-metal diodes (MOM) were investigated as a rectifying element for the MMW/IR rectennas. While MOM diodes have been reported to show diode behavior up to optical frequencies, they do not appear to be suitable candidates for the rectenna elements.

Summary of Experimental Work

Metal-Oxide - Metal Diodes

- Originally proposed for the infrared rectennas; however, do not appear to be viable for rectifying element.
- Thin oxide layers are very susceptible to shorts.
- I-V characteristics are not suitable for efficient rectifications.

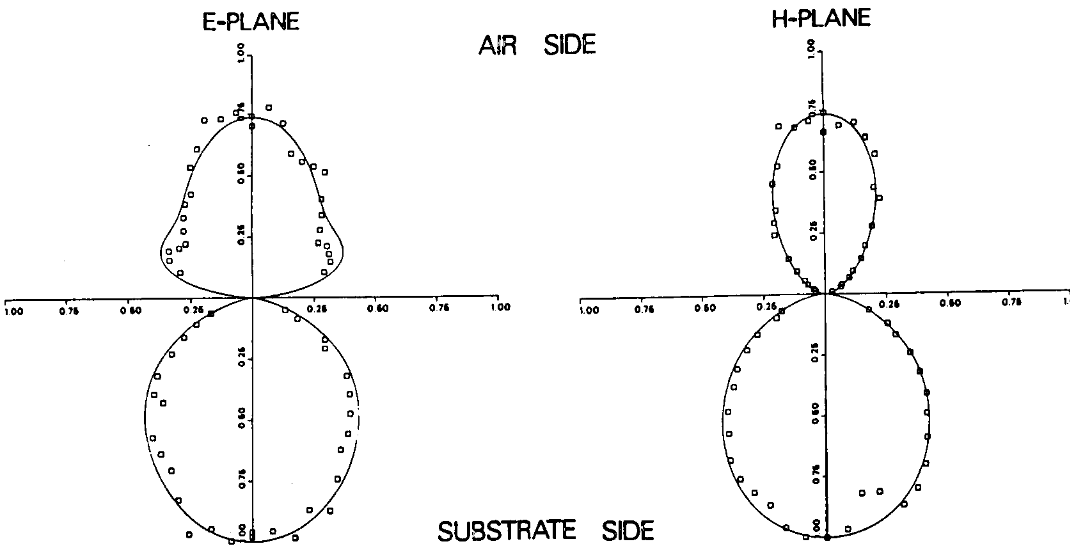


ANTENNA MEASUREMENTS AT 230 GHz

More recent experimental work includes measurements of substrate mounted dipole antennas at 230 GHz. The antennas at this frequency are 400 microns long and 10 microns wide. These antennas are physically much smaller than the dielectric slab on which they are mounted. In essence the antenna acts as a miniature field probe that detects how the EM-wave passes through the dielectric slab; therefore, the problem can be viewed as optics-like, and a focusing element can be used to increase the field strength in the vicinity of the antenna.

MMW Substrate Mounted Antenna Measurements

- Measured dipole antenna patterns at 230 GHz.
- The measured field pattern shapes are in agreement with a simple super position model of the antenna reception.
- In essence, the antenna receives the local field at the surface of the substrate.



MMW-IR RECTENNA DESIGN

The MMW/IR rectenna will have the same subcomponents as the 2.45 GHz rectenna (antenna, low-pass filters, and rectifying element); however, the large number of rectennas needed at these higher frequencies will make it necessary to use monolithic IC fabrication technics. The appropriate frequency range to begin the MMW/IR development is 100 GHz to 300 GHz, but the design should be able to easily scale to higher frequencies when suitable rectifiers become available.

MMW / Infrared Rectenna Design

An antenna feeding a rectifying element is still the most efficient conversion scheme.

- Conversion from EM wave to dc power will require a large number of conversion elements.
- The design should be monolithic using high throughput IC processing techniques.

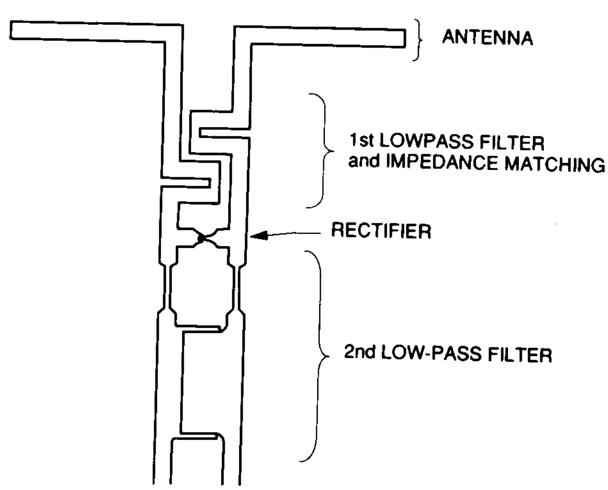
Appropriate frequency range to begin development is 100 - 300 GHz.

- Significant decrease in the size of the transmit and receive apertures.
- GaAs diode characteristics are known at these frequencies.

Note: There are some problems with GaAs diodes, but they are the best viable option at this time.

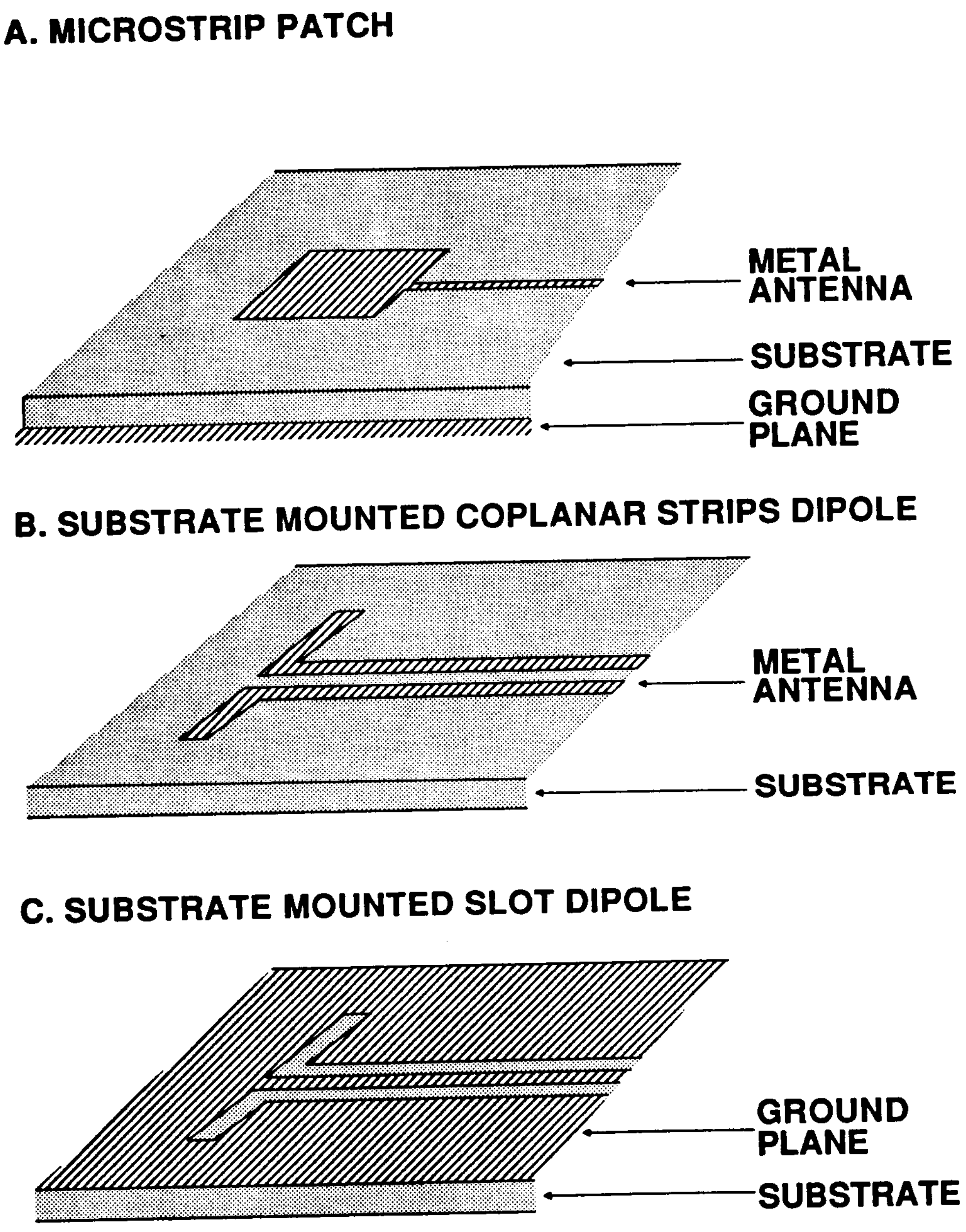
The rectenna design should scale throughout the MMW and infrared regions.

- Low-pass filters and impedance matching sections are proportional to wavelength.



INTEGRATED CIRCUIT ANTENNAS

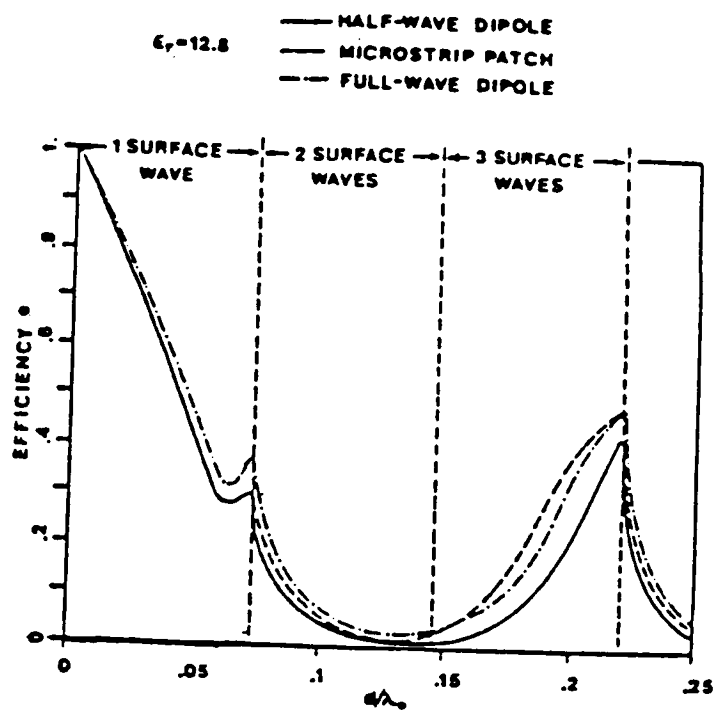
Among the antennas that should be considered for the MMW/IR rectenna are the microstrip and substrate mounted type antennas. The microstrip type antenna has metalization on both sides of the substrate while the substrate mounted type antennas have metalization only on one side of the substrate.



RADIATION EFFICIENCY

Microstrip antennas become inefficient in the millimeter wave region. At 300 GHz with a 2 mil GaAs substrate (thinnest practical substrate height for mechanical stability), the radiation efficiency is only 40%. These surface wave losses can be reduced in the substrate mounted antennas by placing a focusing element on the back side of the substrate.

- Microstrip antennas become inefficient in the MMW region [3].

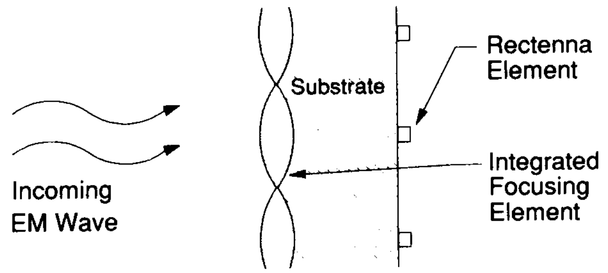


- A substrate mounted (coplanar type) antenna can be designed to maintain high radiation efficiency.
  - No ground plane on the back side of the substrate
  - A focusing element can be placed on the back side of the substrate:

    discourage the propagation of the surface waves

    adjust the power received by each antenna

Integrated Focusing Element - A Method to Optimize the Efficiency



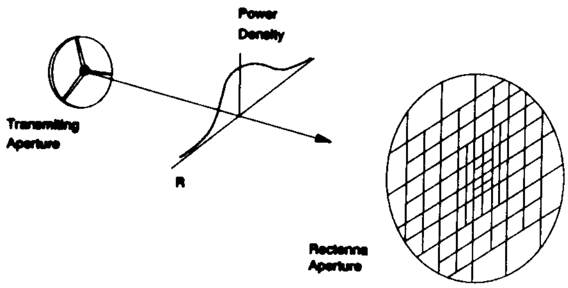
The integrated focusing element will reduce the loss to surface waves

- The surface wave modes will be discouraged by the irregular boundary condition of the focusing element
- The focusing of the incoming wave will make it more difficult for surface waves to be launched

The integrated focusing element can be used to adjust the power received by the antenna.

- Resonant antennas at MMW or IR frequencies have small physical size and thus small effective height.
- The focusing element can control the voltage levels developed at the terminals of the antenna.
- The voltage levels across the rectifier can be selected for the most efficient conversion.
- Rectenna performance can be optimized independent of the EM wave power density.
- Integrated focusing element serves as an adjustable interface between different power densities called for in various mission scenarios and the optimized power input to the rectenna element.

Various size focusing elements can be used to handle the changing power density of a beamed EM wave.



The focusing elements in the center of the rectenna array are smaller.

Integrated focusing elements take advantage of higher frequency instead of fighting it.

Efficiency

The EM capture efficiency should be very high with the integrated focusing elements

Transmission Line Loss [4]:

$$\alpha_{conductor} \propto f(\sigma, \text{geometry}) \frac{1}{\sqrt{\lambda}}$$

$$\alpha_{dielectric} \propto f(\varepsilon, \text{loss tangent}) \frac{1}{\lambda_0}$$

Filter size scales with wave-length, transmission line losses should remain reasonable - well into the submillimeter/far-infrared regions.

Rectification efficiency should remain high in the MMW region with GaAs diodes. Above these frequencies advances in semiconductor devices or new rectification technologies are needed.

Time Scale for Implementation of MMW Rectennas

A program to develop a monolithic, 100 GHz rectenna array could be accomplished within 3 years.

1st year	Develop hybrid rectenna elements with integrated focusing elements.
2nd year	Develop hybrid rectenna arrays.
3rd year	Develop monolithic rectenna arrays.

SUMMARY

MMW/IR rectenna elements will be made from monolithic construction of antenna and rectifier. An integrated focusing element increases the efficiency of the beamed power conversion, maintains voltage levels for optimum rectenna performance and adjusts for EM beam power density profile and for different mission scenarios.

Efficiency should remain high throughout the MMW region, and if higher frequency rectifiers are developed, well into the far-infrared region.

A monolithic, 100 GHz rectenna array could be realized within three years.

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