

QUASI-OPTICAL POWER AMPLIFIER

Andrew C. Guyette
Department of Electrical Engineering
University of Hawai'i at Manoa
Honolulu HI 96822

ABSTRACT

A device capable of both transmitting and receiving, as well as tracking, was designed and built. The device consists of a transmit/receive (T/R) module, a digital controller, and a stepper motor. The device was shown to successfully track a microwave source. Due to problems with the microwave switch, the T/R module did not perform well enough to include the transmitting function. However, the T/R module was shown to successfully switch between transmit and receive modes. Such a device would be ideal in the implementation of a communication link between locations that are moving with respect to one another, such as satellites.

INTRODUCTION

The original objective of this project was to create a quasi-optical planar amplifier that received a plane wave, amplified it, and then transmitted the amplified signal. Suggested applications included space exploration missions such as the Mars Pathfinder. A quasi-optical system would increase the efficiency of the probe's communication system. However, during the course of the project a more novel design was realized. In addition to receiving and transmitting, this new design includes a tracking function.

The Mars Pathfinder lander used an omni-directional monopole antenna to communicate with the rover. This limits the speed at which data can be transferred, and also uses power inefficiently. A high-gain antenna module capable of locating the direction of the rover would result in higher communication speeds and more efficient power use. The new design accomplishes this with the ability to locate a microwave source by finding the direction of highest incident power. This microwave source would be located on the rover, functioning like a beacon.

METHODS

The T/R tracking device is composed of three basic modules (see Fig. 1). The transmit/receive (T/R) module is composed of a patch-antenna array, a PIN-diode switch, a 5-GHz oscillator, and a two-stage amplifier/Schottky diode component. The patch-antenna array is used both for receiving and transmitting. The PIN-diode switch serves to change between receive and transmit modes. The 5-GHz oscillator is used to generate the transmitted signal.

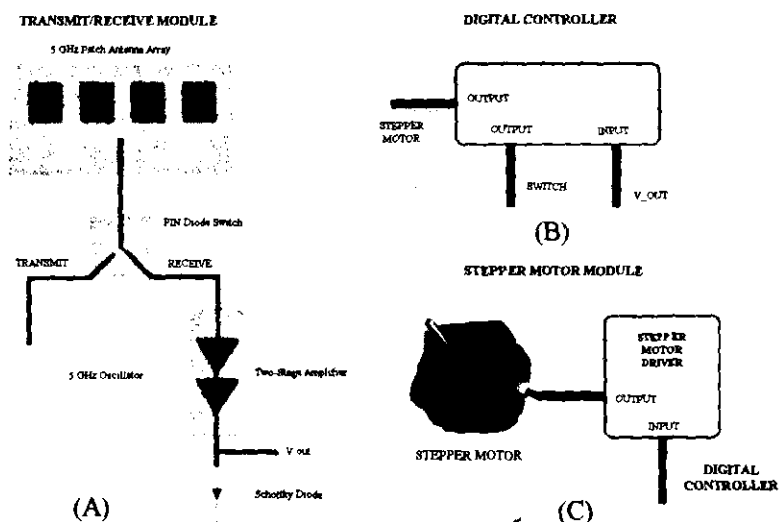


Fig. 1 T/R tracking device modules

The two-stage amplifier amplifies the received signal from the microwave source (the tracking signal). This signal then rectified by a Schottky diode to DC.

The digital controller controls the operation of the stepper motor and the PIN-diode switch. The controller takes the DC voltage that is the output of the Schottky diode as an input. The controller has two outputs: the DC biases to the PIN diodes in the switch, and the control sequence to the stepper motor.

The third module, the stepper motor, rotates the T/R module until the direction of the tracking signal is found.

T/R MODULE

5-GHz Linear Broadside Array

The antenna is a one-dimensional linear broadside array of microstrip patch antennas. The array is composed of patch antennas, Wilkinson power dividers, and a via hole.

The T/R module requires an antenna that has a narrow main lobe with a peak located at $q = p/2$, where $p/2$ is defined as normal to the surface. A single patch antenna does not satisfy this requirement, but an array of patch antennas does. The antenna configuration chosen for this characteristic is a 4-element one-dimensional linear array. The array spacing was arbitrarily chosen to be approximately 0.6 λ . This spacing turned out to be close enough to avoid grating lobes. A *MATLAB* plot of the calculated relative magnitude (not normalized) of the space factor [1] is shown in Fig. 2. The width of the main lobe can be characterized by the angles where radiation goes to zero (the nulls bordering the main lobe). The distance separating these nulls is referred to as the first-null beamwidth. The first-null beamwidth shown in Fig.2 is by inspection about 56°. The measured antenna pattern is shown in Fig. 3.

The mask used to fabricate the patch antenna array is shown in Fig. 4. The lengths and widths of the microstrip lines were determined using the *PUFF* microwave CAD package. All paths leading to the via from the individual patch antennas are of equal length. This ensures that all the power received is added (or divided) in phase. The mask was drawn using *Corel Draw 8*.

The output of the antenna array is through a via hole located near the center. A chip capacitor mounted vertically is used a via. At 5 GHz a chip capacitor is essentially a short circuit, without the problem of fringing fields that would occur with a wire or copper tape via.

5 GHz Two-Stage FET Amplifier/Schottky Diode

To amplify the received signal to a level where the sensitivity of the Schottky diode is adequate, a two-stage amplifier is used. The amplifier is composed of two cascaded HP

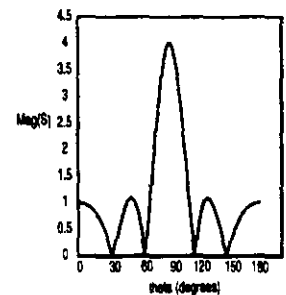


Fig.2 Space factor plot

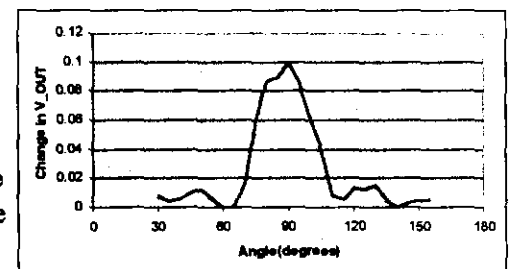


Fig. 3 Measured antenna pattern

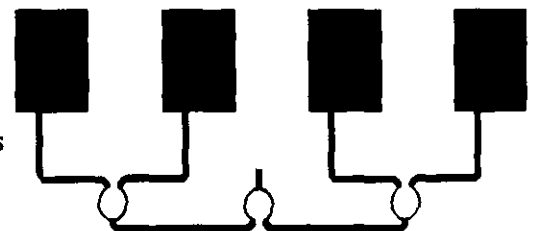


Fig. 4 Patch antenna array mask

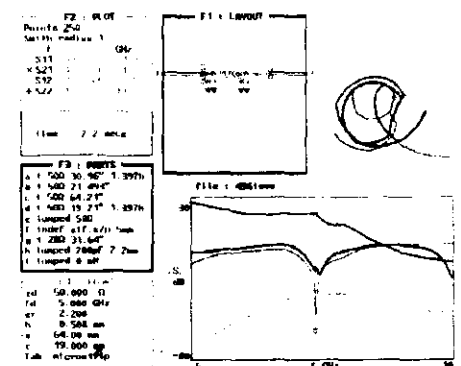


Fig. 5 Two-stage amplifier *PUFF* simulation

ATF-10736 transistors. The design procedure [2] went as follows:

- 1) An HP ATF-10736 MESFET is used at the 4V/70 mA bias point. Although this transistor is unconditionally stable at 5 GHz at this bias point, it is required to further stabilize the device. This amplifier will be used in conditions where both the input and output may not be 50W, and the ground may not be ideal. It is required to make the transistor unconditionally stable for all frequencies. This is done with a 50W shunt resistor placed at the gate.
- 2) The S-parameters of the stabilized transistor are used to create bilateral conjugate-matching networks at the input and the output. These input and output matching networks will serve as the input and output matching networks for the two-stage amplifier. The two stages are matched by using the known input impedance of the second stage and conjugately matching that to the output impedance of the first stage. This interstage matching network transforms G_{OUT} into G_{IN}^* . This matching network is implemented with only a 63° 28W transmission line. The amplifier design in PUFF is shown in Fig. 5.
- 3) The discontinuities are taken into account. There are two kinds of discontinuities present in this design: the tee junction and the open stub. To compensate for these discontinuities, the lengths of the microstrip transmission lines are adjusted.
- 4) Blocking capacitors are used to isolate the bias between the input, the two stages, and the Schottky diode. The mask was created in *Corel Draw 8* using the dimensions determined in PUFF. To bias the transistors, RF choke inductors are used.

Schottky Diode

The purpose of the Schottky diode is to rectify a 5-GHz signal to DC using envelope detection. This allows the magnitude of the microwave signal to be measured by the digital controller. The Schottky diode used is the HP HSMS-2850. Due to the relatively high impedance of the diode, a rather extensive matching network had to be used to match the diode to 50W. The Schottky diode along with the matching network were tested using a sweep oscillator and a multimeter (to measure the DC voltage). The lowest power at which the diode was found to be adequately sensitive was found to be around -15 dBm. The two-stage amplifier is used to achieve this power level from the expected low level of power that the antenna will receive.

PIN-DIODE SWITCH

To change between transmit and receive operation, a single-pole double-throw (SPDT) microwave switch [3] is needed. It would also be possible to use a circulator to isolate the input and output channels, but a circulator was not readily available. The switch selects between transmit (5-GHz oscillator) and receive (two-stage amplifier/diode) channels.

The PIN-diode switch was fabricated on 20 mil 5880 *Rogers Duroid*. The PIN diodes are placed in a shunt configuration. The DC bias pads are connected to their respective diodes with the use of RF choke chip inductors. Chip capacitors are used to block the DC bias.

5-GHz OSCILLATOR

An oscillator requires a device with negative resistance. To implement such a device, an ATF-10736 transistor at the 2V/25 mA bias

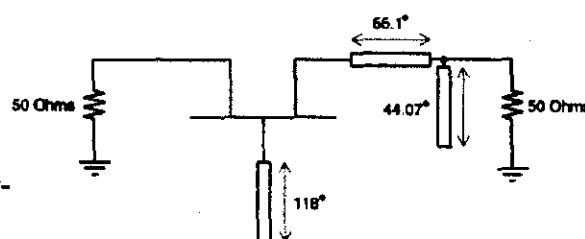


Fig.6 Oscillator schematic

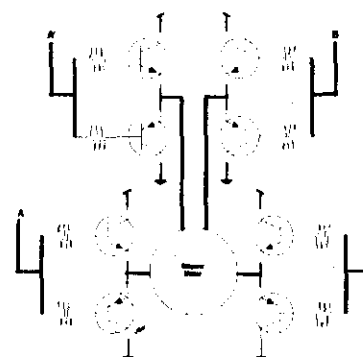


Fig.7 Stepper motor driver

point is placed in the common-gate configuration as shown in Fig. 6. An inductance is placed at the gate (in the form of an open stub) to further increase the device's negative resistance. The matching network at the drain is designed using the one-third rule. The one-third rule design procedure makes the assumption that the real part of the input impedance of the transistor decreases by two-thirds when changing from small-signal conditions to large-signal conditions. Therefore, when large-signal conditions are reached, the magnitude of the real part of the input impedance of the matching network is equal to the magnitude of the negative resistance of the transistor, and a stable oscillation occurs (at the design frequency).

STEPPER MOTOR

Fig. 7 shows the circuit diagram of the power transistor circuit used to drive the stepper motor. This stepper motor is of the bipolar type, requiring four inputs.

DIGITAL CONTROLLER

The algorithm the controller uses is shown in Fig. 8. The digital controller takes in the DC voltage from the Schottky diode as an input, and uses this information to ascertain the direction of the microwave source. The controller does this by causing the stepper motor to rotate the T/R module until the Schottky diode voltage reaches a preset maximum level. A maximum Schottky diode voltage indicates that maximum signal power is being received by the antenna array. At this point the controller changes switches the T/R module from receive mode to transmit mode, invoking the jamming function.

The digital controller basically consists of a voltage comparator and a NAND gate. The voltage comparator outputs a '1' when the input signal voltage is higher than a set reference voltage and a '0' when the input is lower than the reference voltage. The reference voltage is set to the quiescent voltage of the Schottky diode when no power is directed toward the antenna array. The voltage comparator chip is the MAX516 donated by MAXIM.

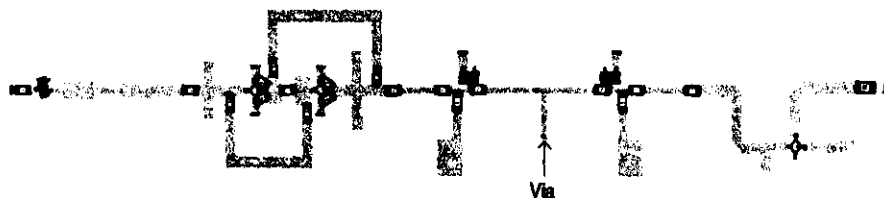


Fig.9 2nd Prototype assembly (not to scale)

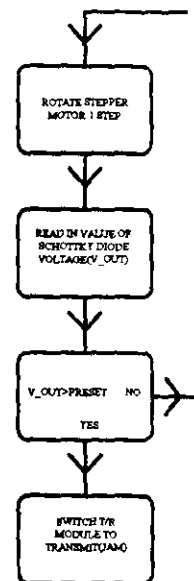


Fig.8 Controller flowchart

RESULTS

The first working model of the T/R tracking device included all the components previously described in this report, except for the 5-GHz oscillator and the PIN-diode switch. In other words, it functioned as a tracking device only. This model worked quite well, and was able to locate a 20 dBm source at a maximum distance of approximately 1 meter. It was found that the factor limiting the tracking device's range was the sensitivity of the digital controller, specifically the voltage comparator chip. When the DC voltage across the Schottky diode was monitored using a multimeter, a 20 dBm source placed as far as 3 meters from the tracking device resulted in a detectable change in voltage. The tracking device was found

to be extremely sensitive to the polarization of the tracking signal, as expected.

The second prototype of the T/R tracking device was an attempt to include transmit capability into the first prototype. The oscillator and PIN-diode switch are included together with the two-stage amplifier/diode module and patch antenna array. Unfortunately, due to the poor performance of the PIN-diode switch (large insertion loss), the T/R module did not function well enough to fully implement a fully operational T/R tracking device.

The two-stage amplifier/diode module, the PIN-diode switch, and the oscillator are secured to the ground plane of the patch antenna array in the configuration shown in Fig. 9. The chip capacitor via is soldered to the output port of the PIN-diode switch. Copper wires are attached to provide DC bias to the modules as well as to monitor the Schottky diode voltage V_{OUT} .

Due to the high insertion loss of the PIN-diode switch, the T/R module did not perform well enough to fully implement the T/R tracking device. When in the receive mode, the T/R module was only sensitive enough to detect a 20 dBm source from a distance of around 30 cm. This was largely a result of the 7.37 dB loss that occurs as the received signal travels through the switch.

CONCLUSIONS

All of the components of a microwave T/R tracking device were successfully designed and built. A fully-operational tracking-only device was assembled, and it performed very well. Due to limitations associated with the PIN-diode switch, a fully-operational T/R tracking device was not completed. With an improved microwave switch, a complete T/R tracking device could be easily realized with the components described in this report.

ACKNOWLEDGEMENTS

The author would like to thank his advisor, Dr. Wayne Shiroma, for providing the opportunity and the guidance necessary to complete this project. Kevin Leong was an invaluable help with all aspects of this project. Greg Kodani donated the stepper motor.

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