High Frequency PIN-Diode Switches for Radiometer Applications

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***Abstract* — Internally calibrated radiometers are needed for ocean surface topography and other missions. Typically, internal calibration is achieved with Dicke switching as one of the techniques. We have developed high frequency single-pole double-throw (SPDT) switches in the form of monolithic microwave integrated circuits (MMIC) that can be easily integrated into Dicke switched radiometers that utilize microstrip technology. In particular, the switches we developed can be used for a radiometer such as the one proposed for the Surface Water and Ocean Topography (SWOT) Satellite Mission with three channels at 92, 130, and 166 GHz to allow for wet-tropospheric path delay correction in coastal zones and over land. This is not possible with the current Jason-class radiometers due to their lower measurement frequencies and consequent lower spatial resolution. The MMIC chips were fabricated at NGST using their InP PIN diode process and measured at JPL using high frequency test equipment. Measurement and simulation results are presented.**

***Index Terms* — Dicke switched radiometer, microwave radiometry, monolithic microwave integrated circuits (MMIC), indium phosphide (InP), PIN-diode**

I. INTRODUCTION

Total power radiometers are limited in accuracy due to the variation in gain of the receiver with changes in temperature and other receiver conditions. Fortunately, system gain variation typically has a relatively long time constant (on the order of 1 second) and therefore an alternative to the total power radiometer topology that allows for correction of such variation is the Dicke switched radiometer, which requires a single-pole double-throw (SPDT) microwave switch. The RF switch switches the input of the receiver between the signal from the antenna and a signal from a fixed reference load internal to the radiometer. Once the switched signal has been amplified and detected, the reference load signal is subtracted from the antenna signal. If the Dicke switching is performed at a rate much faster than the time constant of the gain variation, the fluctuations in gain (or loss) and noise figure of components down-stream of the switch are removed, greatly increasing the stability of the radiometer and resulting in improved target brightness temperature measurement capability. In order to maximize the effectiveness of the gain variation correction, the Dicke switch is located in the front-end of the receiver before any amplification.

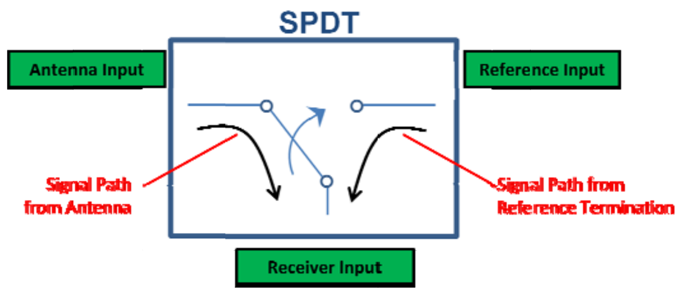

Figure 1: Dicke Switch Function

Figure 1 is a diagram of how a SPDT switch is used in a Dicke switched radiometer. It switches the input to the receiver chain between the antenna and a reference termination. Since the Dicke switch is located before the first low noise amplifier (LNA), the loss of the switch adds directly to the receiver equivalent noise temperature and must therefore be minimized. Furthermore, to minimize the effect of standing waves in the front end on the radiometer calibration, the return loss at the antenna input of the switch must be maximized. The noise from components down-stream of the Dicke switch will radiate toward the front end and reflect back toward the receiver chain if the switch is poorly matched at the receiver input, and therefore this port must also be well matched for both switch states.

We designed and tested monolithic microwave integrated circuit (MMIC) SPDT switches that operate at 80-105 GHz, 90-135 GHz, and 160-190 GHz. These MMIC switches can be easily integrated into receiver systems utilizing microstrip or coplanar waveguide (CPW) technology. Given the small size and low mass inherent to MMIC and microstrip/CPW components, such technology is highly advantageous for space applications. In particular, the high frequency MMIC switches we developed can be used in a radiometer such as the one proposed for the Surface Water and Ocean Topography (SWOT) Satellite Mission, since the operating frequencies of the SWOT radiometer would be 92, 130, and 166 GHz. The current in-operation Jason-class altimeters such as Jason-1 and Jason-2/Ocean Surface Topography Mission (OSTM) measure sea level heights, providing information on speed and direction of ocean currents and heat stored in the ocean. In order to measure and correct for the wet-tropospheric path delay, the Jason-class missions include a nadir-viewing co-located 18-37 GHz microwave radiometer [1]. However, the Jason-class radiometers have reduced accuracy within ~40 km of the coasts. Furthermore, they cannot provide wet path delay correction over land and therefore are used only for ocean sea level measurements. Due to the finer spatial resolution of high frequency radiometer channels, the SWOT radiometer would allow for wet-tropospheric path delay correction near coastal zones and over land, providing the ability to characterize ocean mesoscale and submesoscale processes (on a 10-km scale and larger) in the global oceans, for the first time, and to measure the global water storage in inland surface water bodies, including rivers, lakes, reservoirs, and wetlands [2].

The microwave switches were fabricated using Northrop Grumman Space Technology's (NGST) 75-µm thick InP MMIC PIN process. The use of 75-µm thick InP technology minimizes RF parasitics, enabling high performance microwave designs. PIN diodes are ideal for radiometer switch applications due to their low loss and fast switching speeds. Several variations of each SPDT design were fabricated using PIN diode sizes ranging from 3-8um to determine which size(s) performed most optimally. The small size of the PIN diodes and precise lithography of the InP substrate process lead to stable and repeatable RF performance, which is key in radiometer applications.

Two different versions of the 80-105 GHz switches were developed: a symmetrical version and an asymmetrical version, both of which will be discussed in more detail. Both versions have achieved <2 dB insertion loss, >15 dB return loss (>18 dB for the asymmetric design), and >15 dB isolation. However, post-fabrication on-chip tuning of the asymmetric design improved the isolation to >18 dB across the entire frequency range and to >20dB from 85-103 GHz, easily meeting the isolation requirement at 92 GHz. This tuning can also be used on the symmetric design to improve the isolation.

The 90-135 GHz SPDT switch has achieved <2dB insertion loss, >15 dB return loss, and 8-12 dB isolation. However, it has been shown that the isolation of this switch design can most likely be significantly improved via the tuning method used in the 80-105 GHz design.

The 160-185 GHz has been fabricated, but not yet measured. Simulation results predict this switch will have <2 dB insertion loss, >20 dB return loss, and >20 dB isolation.

II. Design Topology

All of the SPDT switches used PIN diodes as the switching elements. The advantage of using PIN diodes is that their IV characteristics make them ideal for RF switching. This is because when they are reverse-biased, a high impedance is obtained due to the relatively small junction capacitance of the diode, while when they are forward biased, the junction resistance decreases significantly thus providing a low impedance path. This can be exploited in two different ways: either two shunt diodes can be used (Figure 2) so that when

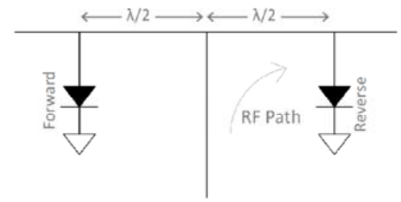

Figure 2: Shunt PIN SPDT Switch

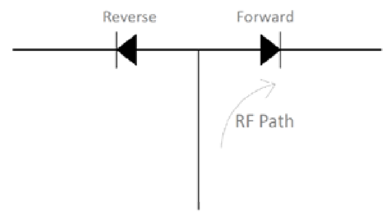

Figure 3: Series PIN SPDT Switch

one is forward biased it provides an RF short to ground (OFF state) while the other one is reverse biased and does not affect the RF signal (ON state) or two series diodes are used (Figure 3) so that when one is forward biased it provides a low impedance RF path (ON state) while the other diode is reverse biased, providing a high impedance RF path (OFF state).

In addition, the two topologies can be combined to obtain the topology in Figure 4. This was the topology used for the switches described in this paper. However, the 160-185 GHz switch used two shunt diodes on each side to add a second axis of symmetry.

The SPDT switches were implemented as shown in the circuit schematic in Figure 5. The RF terminals are shown in blue. Essentially, an RF signal can be viewed as starting from the common leg port and traveling toward either the antenna leg or the reference termination, depending on the state of the switch. This defines the RF path. DC bias is applied at the bias points and travels through the quarter-wave lines, through the PIN diodes, and out the DC resistor in the common leg bias circuit. These quarter-wave lines prevent the RF signal from propagating toward the DC bias points and define the DC bias lines. Each bias line has bypass capacitors to provide further RF isolation. On the RF path, there are DC blocking capacitors that prevent DC current from exiting the Dicke switch and saturating subsequent components.

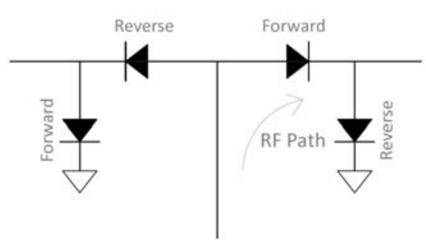

Figure 4: Series-Shunt PIN SPDT Switch

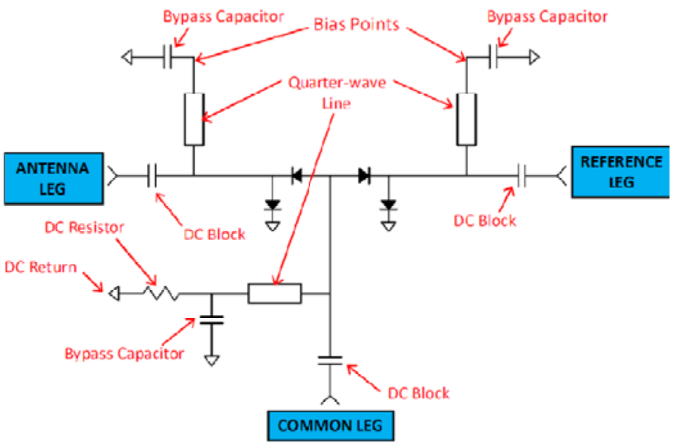

Figure 5: SPDT Circuit Schematic

III. Switch Designs

80-105 GHz MMIC Switch

Both of the 80-105 GHz versions were implemented using microstrip technology and are shown below. The symmetric version is shown in Figure 6 and the asymmetric version in Figure 7. The difference between the two versions is that the symmetric version has the antenna and reference RF legs aligned, while the asymmetric version has the antenna and common legs aligned, with the reference leg off to a 90° angle. While the symmetric version is the more traditional implementation and benefits from the inherent symmetry, the asymmetric designs can be a more practical implementation for radiometer receiver design since the “inputs” and “outputs” are aligned (as most other microwave components are), and the reference leg is off to the side where it can be terminated with a fixed 50Ω termination.

A variation of the asymmetric design is shown in Figure 8. This variation has the 50-Ω reference termination already incorporated onto the MMIC, eliminating the need to connect an external termination to the switch. This ensures a well matched load on the common port since the necessity for a ribbon bond (which has a large parasitic inductance at these frequencies) is eliminated. However, the reference

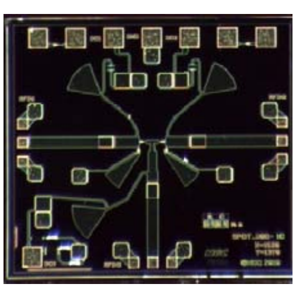

Figure 6: Symmetric SPDT

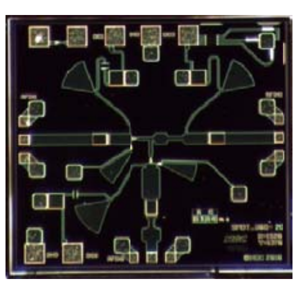

Figure 7: Asymmetric SPDT

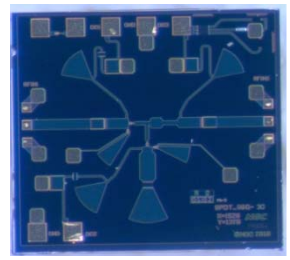

Figure 8: Symmetric SPDT with Integrated Reference Load

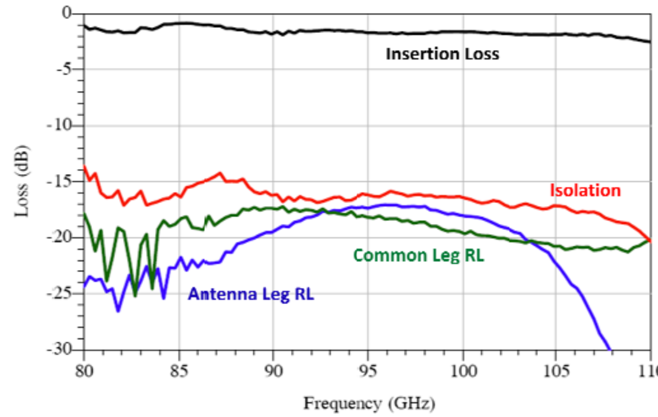

Figure 9: Symmetric SPDT Measured Performance

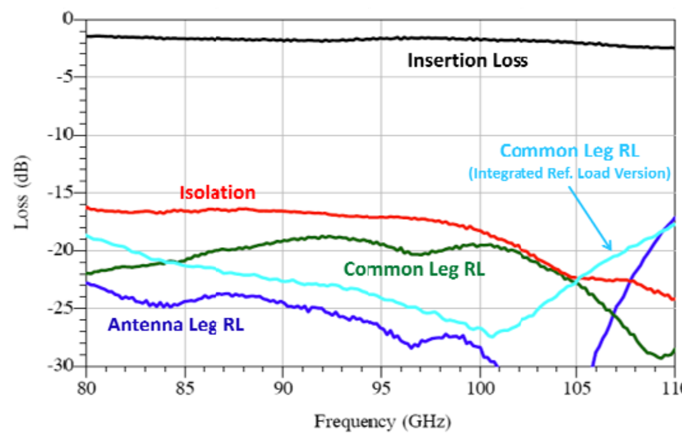

Figure 10: Asymmetric SPDT Measured Performance

termination is now more susceptible to changes in temperature due to DC bias of the SPDT, which should be considered.

The switches have SiN 2-layer MIM capacitors for both the DC blocking and bypass capacitors. The resistors were implemented using a NiCr thin-film process. In order to mitigate the effect of the large parasitic inductance of vias to ground, radial stubs were used to provide well-defined virtual RF shorts.

Figure 9 shows the measured performance of the symmetric design. The insertion loss was measured to be <2 dB across the entire frequency range, return loss at both the antenna and common legs >17 dB, and isolation >15 dB.

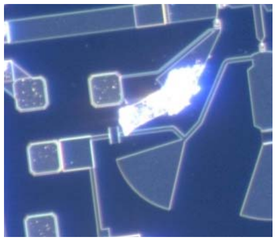

Figure 11: Tuned 80-105 GHz MMIC Switch

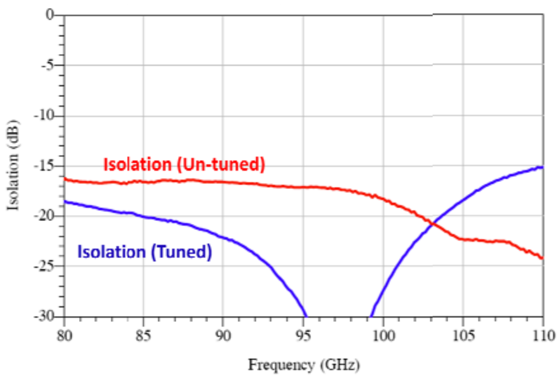

Figure 12: Tuned 80-105 GHz Measured Isolation

Figure 10 shows the measured performance of the asymmetric design. With this design, we achieved <2 dB insertion loss, >18 dB return loss at the common leg, >23 dB return loss at the antenna leg, and >16 dB isolation. The integrated load version provided the common port with a >20 dB match from 83-105 GHz when in the "reference state". As mentioned above, we were able to significantly improve the isolation of this design by performing post-fabrication on-chip tuning. Higher frequency measurements of this design demonstrated that the isolation had been optimized at a considerably higher frequency. Therefore, tuning ribbon was added to the radial stub (whose purpose is to provide a virtual short to the shunt diodes), therefore increasing the effective electrical length of the stub. This can be seen in the tuned MMIC in Figure 11. The improved isolation of >20 dB from 85-103 GHz is shown in Figure 12.

90-135 GHz MMIC Switch

The 90-135 GHz SPDT switch (Figure 13) is very similar to the symmetric 80-105 GHz switch design. It was also implemented using microstrip technology and utilizes radial stubs to minimize parasitic inductances.

The 90-135 GHz switched has achieved <2 dB insertion loss, >15 dB return loss, and 8-12 dB isolation (Figure 14). As was done for the 80-105 GHz design, we expect to significantly improve the isolation of this design. Preliminary measurements support this theory (Figure 15).

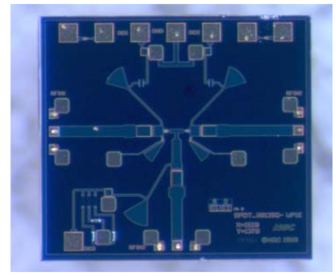

Figure 13: 90-135 GHz MMIC SPDT Switch

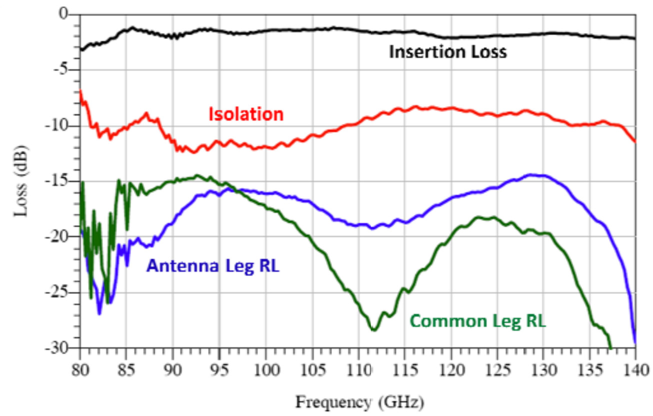

Figure 14: 90-135 GHz Switch Measured Performance

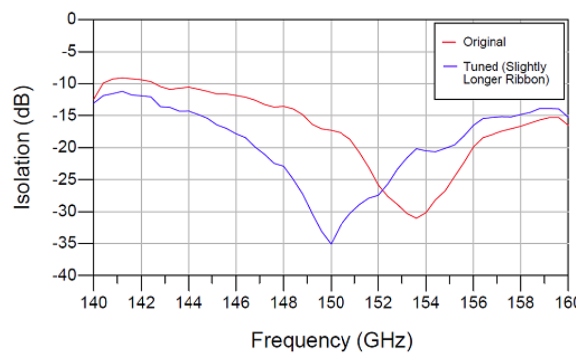

Figure 15: Preliminary Tuning Results of 90-135 GHz Switch

160-185 GHz MMIC Switch

The 160-185 GHz switch was implemented using coplanar waveguide technology, which is often a preferred choice for high frequency designs. The MMIC is shown in Figure 16. This switch has yet to be measured, so simulated results are shown in Figure 17. Simulation results predict this switch will have <2 dB insertion loss, >20 dB return loss, and >20 dB isolation.

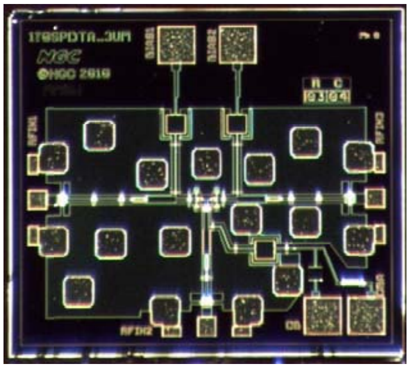

Figure 16: 90-135 GHz MMIC SPDT Switch

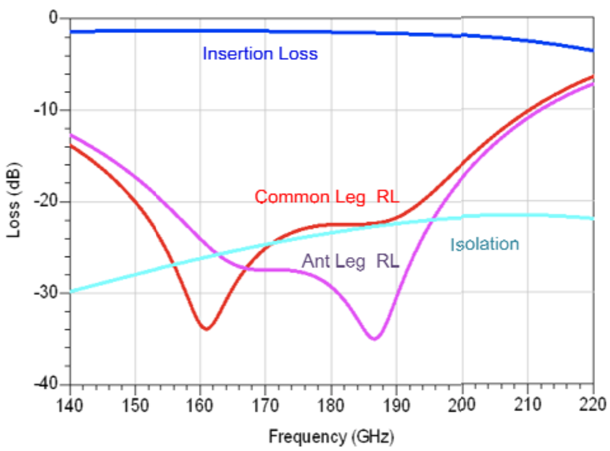

Figure 17: Simulated Results of 160-185 GHz Switch

IV. Conclusion

High frequency SPDT MMIC switches have been developed that operate at 80-105 GHz, 90-135 GHz, and 160-185 GHz. These switches were designed and tested at JPL and fabricated at NGST using their 75-µm InP PIN-diode process. The 80-105 GHz switches have been tested and have achieved <2 dB insertion loss, >15 dB return loss (>18 dB for the asymmetric design), and >15 dB isolation. The isolation can be tuned to achieve >20 dB isolation from 85-103 GHz.

These microwave switches can be easily integrated into Dicke-switched radiometers that utilize microstrip or coplanar waveguide technology. In particular, the switches we developed can be used for a radiometer such as the one proposed for the Surface Water and Ocean Topography (SWOT) Satellite Mission whose three channels at 92, 130, and 166 GHz would allow for wet-tropospheric path delay correction near coastal zones and over land.

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