A Broadband 100 GHz Phase Switch/Mixer Using a Uniplanar 'Slotline Transition

Todd Gaier, Douglas Dawson, Mary Wells

Jet Propulsion Laboratory, California Institute of Technology, Pasadena , CA 91109

ABSTRACT **We have developed a broadband 180° phase switch using one-sided planar grounded slotline design. The design is based upon a grounded coplanar waveguide (CPW) to slotline transition acting as a balun. This design offers several advantages over existing topologies making it well suited to monolithic microwave integrated circuit (MMIC) integration. The uniplanar construction allows for simple module integration and the slot transition with a cutoff frequency serves the same function as a waveguide transition used in multipliers and mixers. We fabricated a switch using flip-chip Schottky diodes and demonstrated the circuit as a W-band phase switch and a mixer. The switch has 5 dB insertion loss and phase flatness 10° from 90-110 GHz. As a mixer the circuit performs with 12 dB conversion loss from 76-112 GHz, with an IF bandwidth exceeding 25 GHz. This performance is comparable to commercially available waveguide mixers, which are incompatible with MMIC integration.**

I. Introduction

The development of millimeter wavelengths for telecommunications, military and radar applications has opened up new challenges for frequency conversion and signal modulation. Phase switches, used for direct signal phase modulation, and amplitude modulation through Mach-Zehnder configuration are a key component required for broadband millimeter wave systems. Mixers and multipliers at these frequencies require baluns for efficient broadband balanced operation. Historically, good performance has been obtained using waveguide based baluns. Alternative designs use double-sided stripline topologies to obtain a broadband 180° phase offset (ref PMP design).

The circuits described here were designed for application in an ESA/NASA mission to study the Cosmic Microwave Background. The receiver design for the Planck Low Frequency Instrument (LFI) requires a phase switch with 90-110 GHz bandwidth, phase balance of 10° and amplitude balance of 0.25 dB. These strict requirements were necessary to obtain receiver switch isolation, while canceling residual receiver 1/f noise. The MAP(Microwave Anisotropy Probe) experiment had similar requirements which were met with stripline base slot transition phase switches. On Planck, the density of receiver elements requires the use of MMIC integration and compact modules. The use of waveguide based components was not feasible.

It was recognized early on that the same component developed for LFI, using fast switching Schottky diodes, would function as a phase-switch, mixer and a multiplier. The design and development of this component is described below.

II. Circuit Design

This circuit uses a CPW line feeding anti-parallel diodes connected to the edges of a slotline. The slotline is then transitioned to CPW to bring the signal out. The design of the critical CPW-slotline transition is the key to the development of this component. Several CPW-slot transitions have been described in recent years [1-5]. This circuit has all elements located on one side of the substrate, making it compatible with MMIC processes.

The approach taken was to adapt the even-mode CPW transmission line to odd-mode slot, through an abrupt transition with CPW ground tuning to provide the necessary phase delay. Impedance tuning of the transition is accomplished through a high impedance section immediately before the transition. To design the tuner, the transition was modeled in HFSS and mode-matching techniques employed to provide an efficient coupling of energy to the slot. Grounding of the slot metal to bottom metal provides a cutoff frequency in the slot. This proved to be a valuable trait for the use of the circuit as a mixer or multiplier, separating the different frequency components.

The phase switch was designed to use a PIN or Schottky diode with less than 0.02 pF junction capacitance and 5 ohms on resistance. Such diodes are available commercially in beam-lead and flip-chip die as well as in commercial foundry processes. In this circuit demonstration, we opted for a Schottky diode pair produced by UMS (UMS part number DBES-105). We have also developed this circuit on TRW's InP PIN process and on Daimler-Chrysler's PIN process, with similar phase switch results. The diode has a capacitance

0-7803-7695-1/03/$17.00 © 2003 IEEE

of 0.015 pF and a resistance of 4 ohms, so the matching circuit was actually over-tuned.

III. CIRCUIT FABRICATION

Several variations of the circuit were produced on 4 mil thick alumina substrate with 4 mil diameter via holes. The variations allowed us to evaluate subtle effects of via holes, slot length and the impedance tuners. The inexpensive medium, readily available, made this a low cost approach. The circuits were designed with CPW inputs and outputs to allow for wafer probing and easy multichip module integration.

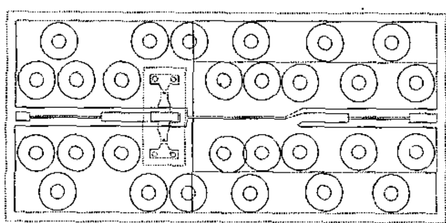

Figure 1. Basic circuit layout. The CPW input is shown on the left with the approximate location of the flip-chip diode shown. The transition from slot to CPW is shown on the right. The circles show the locations of the top metal grounding via holes.

Careful study of passive back-to-back transition structures revealed the presence of unwanted radiative modes propagating from the abrupt transition. Subsequent modeling of the structure confirmed the presence of these modes and also revealed that inductive shorting of the top-metal grounds, would eliminate the modes. We verified this with bond wires placed across the CPW grounds near the transitions (Figure 2).

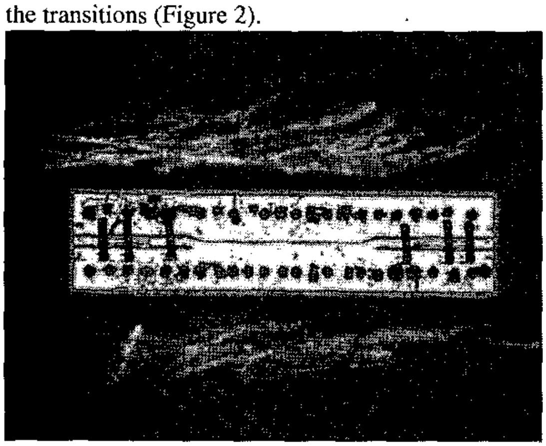

Figure 2. Back to back transitions showing with bond wires to reduce radiative effects.

The diodes are designed for flip-chip bonding, with ~5 micron high gold bumps. The diode pair is placed manually and attached to the substrate by thermosonic compression. The diode package could alternatively be soldered or epoxied into place. The assembled circuit is shown in Figure 3.

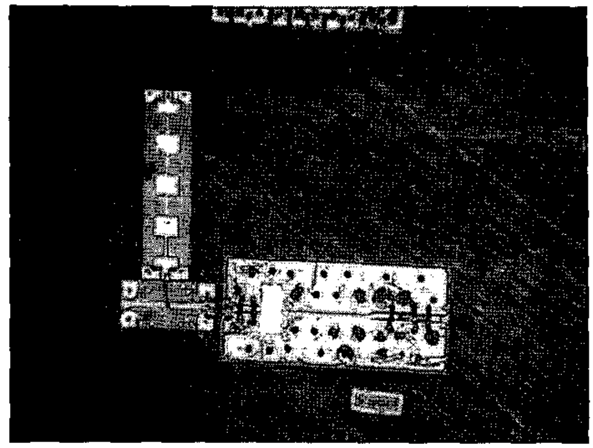

Figure 3. Assembled circuit with diodes installed. The circuit is also shown with the external bias tee used in the mixer tests. A second diode pair is shown face-up at the bottom of the photo.

IV. MEASURED PERFORMANCE

The phase switches were first measured using 65-115 GHz wafer probes and frequency extenders on an HP8510 vector network analyzer. The circuit was first tested as a phase switch. The measured performance is shown in Figure 4. The insertion loss increase at 91 GHz is due to substrate modes associated with the via hole spacing. Modification of the via holes was effective at moving the resonance frequency, but we were unable to eliminate it in this first iteration.

The circuit was subsequently tested as a mixer. A low-pass filter attached to the RF line with a bond wire served as an IF port. The local oscillator was provided by a multiplied amplified signal source connected to the circuit via wafer probe. The RF signal at –5 dBm was similarly connected. The IF was also connected with a wafer probe. Signal levels were calibrated with RF power meters at the probe waveguide ports. The loss of the probes was assumed to be –1.2 dB, as given by the manufacturer and back-to-back loss measurements. The IF port loss is assumed to be 0.5 dB. The conversion loss of the mixer is shown in Figure 5, as a function of LO frequency. The data are also shown in Figure 6 as a function of IF.

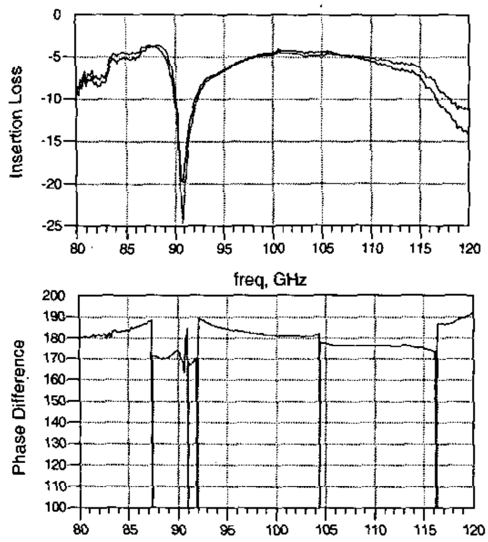

Figure 4. The top shows the measured insertion loss in dB from 80-120 GHz. The bottom shows the measured phase difference in degrees.

frequency. The conversion loss as a function of LO power are shown in Figure 7. The mixer conversion loss is comparable to commercially available waveguide mixers[6,7]. The circuit exhibits record simultaneous RF and IF bandwidth.

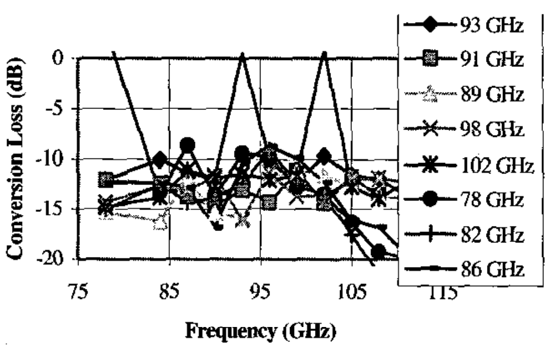

Figure 5. Measured mixer conversion loss as a function of RF frequency for 8 LO frequencies.

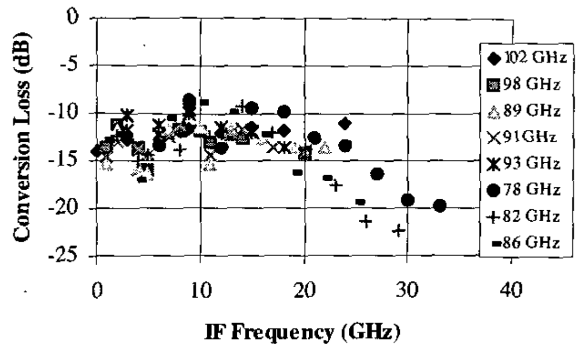

Figure 6. Conversion loss of the mixer as a function of IF frequency for 8 LO frequencies

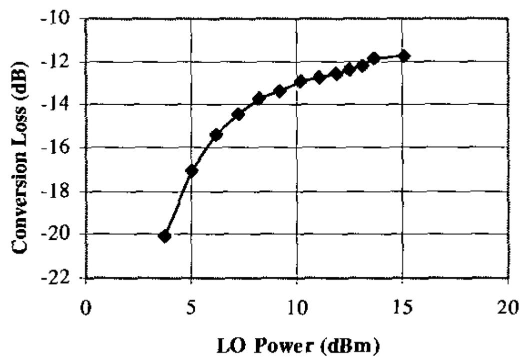

Figure 7. Conversion loss as a function of LO power. The LO frequency was 93GHz, 96 GHz RF

V. CONCLUSION

We have demonstrated a planar 90-110 GHz phase switch. The circuit has also demonstrated state-of-the-art performance as a fundamental balanced mixer from 78-

110 GHz with 25 GHz bandwidth. The circuit was fabricated using flip-chip GaAs Schottky diodes and has also been demonstrated using PIN diodes in a fully integrated MMIC process.

ACKNOWLEDGEMENT

The authors wish to acknowledge the assistance of Al Hislop of Pacific Millimeter Products for helpful discussions regarding phase switches. We also acknowledge Aaron Oki, Augusto Gutierrez-Aitken and Jack Eldredge of TRW for their assistance in processing PIN wafers. We also would like to acknowledge Pekka

Kangaslahti, Jussi Tuovinen and Volker Ziegler for their assistance in processing the designs at Daimler-Chrysler. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology under a grant from the National Aeronautics and Space Administration.

REFERENCES

[1] *Ho, C.-H.; Fan, L.; Chang, K.*, ."Experimental investigations of CPW-slotline transitions for uniplanar microwave integrated circuits" *Microwave Symposium Digest, 1993., IEEE MTT-S International*, v2, pp 877-880,1993

[2] Filipovic, D.F.; Bradley, R.F.; Rebeiz, G.M, "A planar broadband MIC balanced varactor doubler using a novel grounded-CPW to slotline transition" *Microwave Symposium Digest, 1994., IEEE MTT-S International*, Page(s): 1633 -1636 vol.3, 1994

[3] Ma, K.-P.; Qian, Y.; Itoh, T. "Analysis and applications of a new CPW-slotline transition" *Microwave Theory and Techniques, IEEE Transactions on*, Volume: 47 Issue: 4, Page(s): 426 –432, April 1999

[4] Hettak, K.; Dib, N.; Sheta, A.; Omar, A.A.; Delisle, G.-Y.; Stubbs, M.; Toutain, S., "New miniature broadband CPW-to-slotline transitions"*Microwave Theory and Techniques, IEEE Transactions on*, Volume: 48 Issue: 1, Page(s): 138 –146, Jan. 2000

[5] Lakshminarayanan, B.; Weller, T.; Oldenburg, M., 60 GHz coplanar waveguide couplers and slotline transition on polished beryllium oxide", "*Microwave Symposium Digest, 2001 IEEE MTT-S International* Volume: 2, Page(s): 1305 -1308 vol.2, 2001

[6] Millitech MXP Mixer datasheet, Millitech Corp

[7] Spacek Labs, MWU datasheet, Spacek Labs Inc.