Solid-State Plasma Switches for Reconfigurable High-Power RF Electronics

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***Abstract*—This report summarizes the research outcomes that were supported by the 2023 IEEE MTT-S Graduate Fellowship Program. This work overviews the tremendous strides made in designing and modeling a high-power solid-state plasma switch (unit cell). Here, the unit cell is used as a reconfigurable reflective/absorptive switch and part of an HMSIW-based impedance tuner. In the former, a high-performance switch is created that can either reflect or absorb incident RF power up to 40 dBm. In the latter, the unit cells are used to periodically capacitively load an HMSIW-based impedance tuner, resulting in less than 1 dB loss and more than 50 dBm power handling, over an octave of bandwidth.**

***Index Terms*—Absorptive switch, HMSIW, high power, impedance tuner, reflective switch, solid-state plasma switch.**

I. Introduction

CONVENTIONAL RF switching technologies struggle to simultaneously achieve high-power handling, low loss, high isolation, broadband operation, quick reconfiguration, and high linearity, which are desirable for many applications, including communications, radar, and sensors. Moreover, they require electrical bias networks, which degrade performance and, in many cases, inhibit wideband applications, including dc operation. On the other hand, plasma (photoconductive) switches use an optical bias to generate free charge carriers. Recently these switches have begun to not only rival conventional technologies in terms of performance metrics such as switching speeds and loss but have exceeded what is possible in terms of power handling. This work details the strides made in placing solid-state plasma technologies at the forefront of advanced, high-power switching applications including a novel high-power tuner and an absorptive/reflective SPDT switch.

Solid-state plasma (SSP) technology can vary its resistance as a function of optical bias [1] that is not electrically coupled, greatly simplifying the design and avoiding performance degradation. Additionally, packaged SSP chiplets have already demonstrated low loss (<0.2 dB), high power handling (42+ W), high linearity (75+ dBm IP3), single-digit microsecond switching, and a flat-band response [2], [3], which is very attractive for many applications. Owing to its analog nature, shunt chiplets act as a variable (absorptive) resistor, dynamically matching any real impedance. As an extension, dynamically matching impedances can be expanded to any part of the Smith chart with a periodic structure. A section of a half-mode substrate integrated waveguide (HMSIW) is loaded periodically with a unit cell and series capacitor to ground. When the switch is activated, the capacitive loading can bring the impedance toward the edge of the Smith chart. The impressive high-power nature of the switches compounded with the low-loss nature of a waveguide creates an impressive impedance tuner.

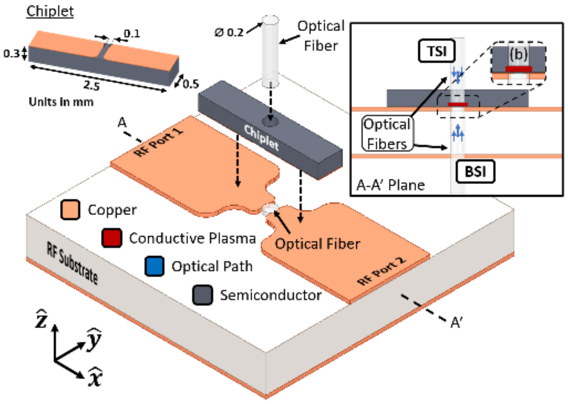

Fig. 1. Chiplet setup on in-line microstrip gap with optical excitation methods, where only one light path is present for any design.

II. Unit Cell Overview

The unit cell structure, design, optimization, and co-simulations are detailed in [3] and shown in Fig. 1. In this work, the series switch boasts less than 0.5 dB loss, 3.50 µs switching, 100+ W CW power handling, and 30 W hot-switching capabilities, from dc to 5 GHz. This truly remarkable performance displaces several technologies in terms of hot-switching and loss.

III. Reconfigurable Reflective/Absorptive Switch

A similar unit cell overviewed in the previous section can be implemented to produce a series-shunt switch. In [4], this is accomplished to create an SPDT switch utilizing five unit cells. When fully driven, the SPDT switch exhibited less than 0.43 dB loss, greater than 30 dB (RF-RF) and 28 dB (RF-Com) isolation, up to 4 GHz, while handling 35 W power. The optical power incident can be pulled back by 46× to create a 50 Ω (or Z_0) termination, leading the way for the switch to absorb incident and potentially harmful power. Fig. 2 plots the reflective and absorptive performance of the switch. For the absorptive operation, the shunt switch easily handles up to 33 dBm but becomes less effective up through 40 dBm, with no failures observed.

IV. Toward a High-Power, Low-Loss Impedance Tuner

Previous implementations of a high-power impedance tuner resulted in cumbersome integration and high transducer loss

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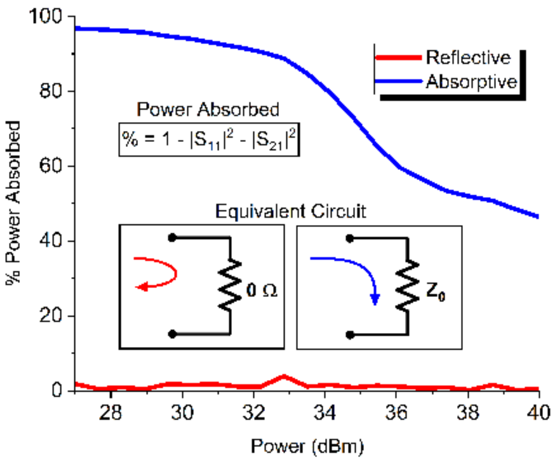

Fig. 2. The measured percentage of incident power absorbed by a shunted chiplet in the SPST switch in its reflective (red) and absorptive (blue) state.

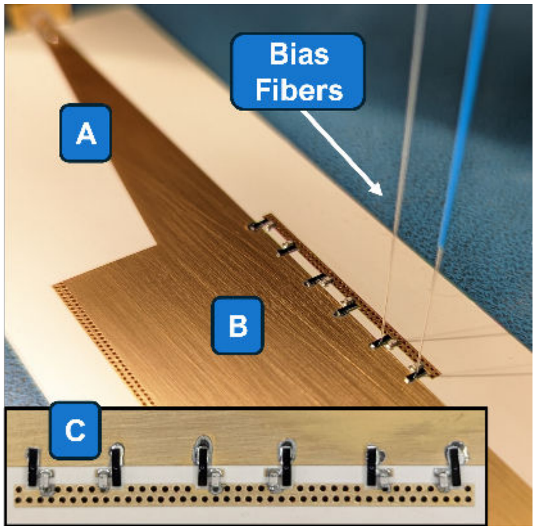

Fig. 3. Populated and optically-biased HMSIW impedance tuner where (A) is the microstrip to HMSIW transition, (B) the HMSIW region, and (C) the switched capacitive loading region.

[5]. To overcome these challenges, the design in Fig. 3 was implemented. This half-mode substrate-integrated waveguide (HMSIW) has the advantage of low loss and wide mono-mode bandwidth. Additionally, the periodic loading made for an elegantly simplistic integration. With the efforts from [3], the top-side fiber illumination made biasing easy and repeatable.

The simplified results can be seen in Fig. 4 where low transducer loss ($|S_{21}|^2/1-|S_{11}|^2$) can be seen between the 2 to 4 GHz octave range. Additionally, the coverage is modest and can be improved upon. This issue can be resolved by adding a larger loading capacitor which then reduces the Bragg frequency, reducing usable bandwidth, creating a tradeoff.

V. CONCLUSION

The objectives of the research proposal were met and exceeded expectations. The original goal of the work was to implement an impedance tuner with less than 1 dB loss, 30% coverage, less than 215 W power handling, and 3.5 µs speeds from 2-4 GHz. The ultimate loss averaged around 2 dB, with coverage and speeds as specified. However, although 100 W was confirmed with no degradation or failure, there was no way to measure beyond that, despite simulations supporting up to 215 W, given setup limitations. The culmination of this work puts solid-state plasma switches as an indisputable contender for high-power signal routing solutions suitable for radar applications, among others.

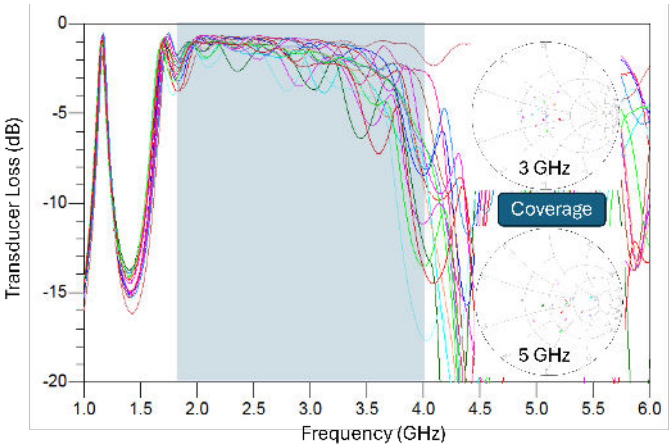

Fig. 4. Results of the HMSIW impedance tuner showing transducer loss and coverage for 22 of the possible 64 states.

VI. CAREER PLAN AND FELLOWSHIP IMPACT

I would like to thank MTT-S and IEEE for their continued support for this research effort and investment in me, and all the other graduate fellows. After completing my PhD, which included several insightful summers attending IMS, I plan to pursue a career in telecommunications. It's clear that if I want to take a large bite out of the world of RF, the most impactful endeavor is to work for an industry leader that pushes the bounds of what is achievable now while making possible the dreams of tomorrow.

ACKNOWLEDGMENTS

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