# Microfluidic Tuning of RF/Microwave Circuits on Low-Cost Multilayer Organic Substrates

George Alexopoulos, *Student Member, IEEE*, John Papapolymerou, *Fellow, IEEE*

***Abstract*—This report describes the investigation of the potential for using microfluidic channels to tune the frequency response of a GaN-based power amplifier (PA) circuit from 2.4 to 5.8 GHz. Source and load matching networks are designed using microstrip implementation on a liquid crystal polymer (LCP) substrate over a microfluidic channel containing acetone or air for 2.4 GHz and 5.8 GHz respectively. Additionally, a study of using varying volumetric mixes of the two fluids with the same matching networks is performed to determine whether this allows for operation not only at 2.4 and 5.8 GHz but also throughout that entire bandwidth. A coplanar waveguide (CPW)-to-microstrip transition on LCP is also developed to allow for probed measurements. All simulations are completed in ANSYS HFSS.**

***Index Terms*— microfluidics, power amplifiers, tunable circuits and devices, organic materials**

## I. INTRODUCTION

Research into microfluidics is becoming increasingly important as the advantages become more obvious. Microfluidic channels can provide for a cooling effect on circuits especially in high power applications where thermal losses are significant. They can also provide for increased circuit tunability and re-configurability. The use of multiple fluids with differing dielectric constants can change the frequency response of a circuit. This is useful for a wide variety of applications such as filters where the pass and stop bands may be tuned according to the dielectric constant of the fluid and also in power amplifier design where multi-frequency performance can be achieved simply by using microfluidic channels to tune the response of the source and load matching networks.

The system-on-package (SOP) approach has also become a popular RF integration technique with organic substrates such as LCP increasingly providing a lightweight, low cost, multilayer, and flexible platform. However, since LCP is a poor thermal conductor, the fluid injection can drastically improve cooling while adding the tunable aspects described above.

This report presents research into the tuning of both the source and load matching networks for a reconfigurable GaN-based PA that optimally works at 2.4 and 5.8 GHz. These frequencies are chosen for applications in wireless local area networks. In the future, this tunability will allow for switching between Bluetooth and Wi-Fi signals. Additionally, microfluidics will provide for the cooling of the amplifier circuits needed to broadcast these signals.

## II. DESIGN

### A. Matching Network Design

The tunable matching networks are set over a 2 mil thick LCP layer ($\varepsilon_r$ = 2.9), below which is a 20 mil thick microfluidic channel. The channel is injected with either acetone ($\varepsilon_r$ = 20.7) for 2.4 GHz or air ($\varepsilon_r$ = 1) for 5.8 GHz. The injection is done using a syringe and tubes that penetrate the LCP dielectric at a certain distance away from the matching network. These tubes are then sealed to prevent channel contamination. The channel and LCP topology are surrounded by a 20 mil thick Duroid ($\varepsilon_r$ = 3) side-wall to prevent leakages from the fluid channel. Below all of this is the ground plane.

The design of the matching networks is fairly complicated. The chosen design is a double stub matching network that in reality is two cascaded single stub matching networks. The single stub network closest to the amplifier for both the source and load matching networks matches the transistor's optimal input impedance to 50 Ω at 2.4 GHz (acetone). The next network, as we move closer to the 50 Ω input, matches the impedance presented by the first matching network to a quarter wave transformer at 5.8 GHz (air). At 2.4 GHz the stub in the second matching network has an electrical length of 180°, thus having no effect on the matching. Therefore, the constraint for that stub is that it must simultaneously be a λ/2 line at 2.4 GHz and also match the impedance presented from the first matching network to $Z_{o,\lambda/4}^2/50$ at 5.8 GHz. There is only one characteristic impedance that is a solution to this constraint for both the source and load matching networks. The quarter wave transformer and all series lines in each single stub network are 50 Ω at 2.4 GHz. On the next page, is a HFSS model of the source matching network. Additionally, a 50 Ω CPW-to-microstrip transition has been designed for the purpose of landing the GSG probes during measurement. The transition has excellent return loss (below -25 dB) from 1 to 7 GHz and a maximum insertion loss of approximately 0.013 dB/mm.

---

This work was supported by the IEEE MTT-S Undergraduate/Pregraduate Scholarship Program.

The authors are with the Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA 30332 USA (email: galexop@gatech.edu, email: john.papapolymerou@ece.gatech.edu).

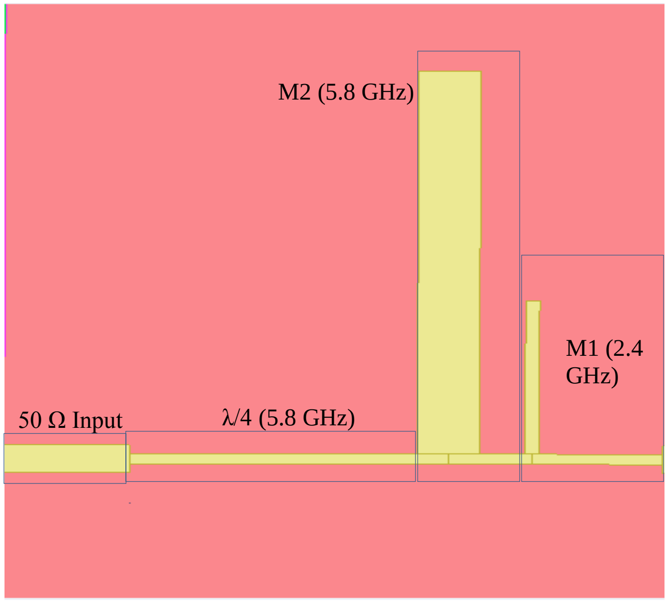

Fig. 1. Source matching network design.

### B. *Volumetric Mix Variation Response*

One important aspect to understand is the frequency response of the matching networks using varying volumetric mixes of acetone and air such as 10% acetone with 90% air or 80% acetone with 20% air. The goal is to see if both the source and load matching networks can still match the optimal transistor impedance to 50 Ω at frequencies between 2.4 and 5.8 GHz while varying the volume combinations of acetone and air. This response is simulated in HFSS for both the source and load matching networks though only the response for the source matching network is shown below:

TABLE I
SOURCE MATCHING NETWORK OPERATING FREQUENCY FOR GIVEN VOLUMETRIC FLUID MIX

| Volumetric Mix Percentage | Operating Frequency (GHz) |
|---|---|
| 0% acetone (air) | 5.8 |
| 10% acetone | 5.6 |
| 20% acetone | 5.4 |
| 30% acetone | 5.3 |
| 40% acetone | 5.0 |
| 50% acetone | 4.8 |
| 60% acetone | 4.6 |
| 70% acetone | 4.2 |
| 80% acetone | 3.8 |
| 90% acetone | 3.2 |
| 100% acetone | 2.4 |

The operating frequencies for the load matching network are identical to those of the source matching network. From these results we can see that by varying the volume percentages of acetone and air in the channel, the PA can be tuned throughout the 2.4 to 5.8 GHz bandwidth instead of just at the edge frequencies. While this result is significant, at the moment it is difficult to realize physically due to the flexible nature of the LCP layer on which the matching networks are fabricated. This flexibility results in a lack of precise fluid volume control in the channel making it difficult to tell if the exact desired percentages of air and acetone are being injected. The solution to this would be a thicker layer of LCP; however, that would reduce the effect that the channel's dielectric constant has on the frequency response of the matching network, thus reducing the overall tunability of the PA.

## III. CONCLUSIONS

In this paper, the importance of microfluidic tuning and a multilayer organic SOP approach is discussed. Power amplifier matching networks over an LCP substrate and a fluid channel injected with either acetone or air are designed to operate at 2.4 and 5.8 GHz respectively. ANSYS HFSS is used to simulate the double stub matching networks as well as a CPW-to-microstrip transition that is needed for probed measurements. Tunability for all frequencies inside the 2.4 to 5.8 GHz bandwidth is shown (at least in simulation) using varying volumetric mixes of acetone and air. At the moment, these mixes are proving difficult to physically realize due to the flexible nature of LCP. This result, however, is important in that it demonstrates that when coupled with better volumetric mix control as well as faster liquid switching techniques, a wideband PA design using microfluidic channels is possible and useful for WLAN applications.

## IV. MOTIVATION AND CAREER PLANS

The IEEE MTT-S Undergraduate/Pregraduate Scholarship motivated me to further pursue research in the RF/Microwaves area. This project and my trips to both IMS 2014 in Tampa, Florida and IMS 2015 in Phoenix, Arizona (funded by this scholarship) were important in showing me the influence of this research area in many applications, as well as the wide range of opportunities present in this field. At both IMS 2014 and IMS 2015, I had the opportunity to meet and interact with multiple well-known professionals and aspiring students whose frontier-pushing work and enthusiasm have thoroughly inspired my research efforts and motivation to seek a career in this field. This scholarship allowed me to work on a high-caliber project within the MiRCTECH research group at Georgia Tech under the guidance of Dr. John Papapolymerou, an experience that I believe was the most influential of all as an undergraduate student at Georgia Tech. Starting in the Fall of 2015, I will begin studies for a Ph.D. at Stanford University where I am looking at a wide variety of research topics including but not limited to wireless energy harvesting for IoT applications, wireless implants and pharmaceuticals, and applications of novel nanomaterials to RF circuit design.