RF FPGA for 0.4 to 18 GHz DoD Multi-function Systems

Mike Lee, Mike Lucas, Robert Young, Robert Howell, Pavel Borodulin, Nabil El-Hinnawy

Northrop Grumman, Baltimore, Maryland 21040

Abstract: *Northrop Grumman Electronic Systems (NGES) is developing a dynamically reconfigurable, wide band programmable RF FPGA transceiver which, if successful, will provide reduced life cycle cost, reduced re-design cost, and service for multiple DoD platforms, while maintaining near-optimal performance for each application. This RF FPGA transceiver has the flexibility to implement communications, radar, EW, EA, and other functions covering the 0.4 to 18 GHz band.*

Keywords: RF FPGA; Phase Change Switch; Low Loss switch; GaN; SiGe; adaptable; reconfigurable.

Introduction: State of the art RF ICs achieve high performance via custom circuit elements with dedicated signal paths for application-specific functions, but long design lead times and non-recurring fabrication costs increase cost and schedule for new applications and limit reuse. The key to developing an RF FPGA (radio frequency field programmable gate array) is to provide RF switching components with very low insertion loss and high isolation, which can be integrated with high performance RF circuits in SiGe and GaN technologies, and integrating these circuits in a reconfigurable topology to allow an RF FGPA to perform a wide variety of functions.

Summary of Approach: Key elements of the RF FPGA approach are:

- Extremely low loss, high isolation RF switches using phase change materials (PCM). Multiport RF switch designs that optimize thermal design to improve PCM performance, and integrate arrays of these switches on thermally and electrically optimized substrates.

- Multiport switch designs with low simulated RF losses of 0.1 - 0.2 dB up to 20 GHz and have 35dB - 60dB isolation between ports, based on measured and extrapolated PCM data. They consume no prime power except for 100 nsec heater pulses during reconfiguration.

- An architecture that connects these switches in a fully interconnected matrix to allow total flexibility in interconnecting and switching between RF elements and to inputs / outputs.

- Dynamically RF tuned banks of wideband (~3:1 BW (band width)), high performance LNAs (low noise amplifiers), mixers, vector modulators, driver amplifiers, and power amplifiers using programmable circuit bias and circuit mission reconfiguration techniques.

- Development of a family of RF FGPAs that can be configured in a variety of ways; e.g., as a standalone RF transceiver, as T/R (transmit receive) elements in an AESA (active electronic scanned array), or as an IF (intermediate frequency) or baseband receiver. Packaging in 12mm x 12mm QFNs (quad-flat no-leads packages) with matched RF I/O for low package insertion loss is used to allow multiple RF FPGAs to be integrated in flexible configurations.

- Demonstration of the RF FPGA technology against multiple DoD system applications with transition potential to a wide range of DoD systems.

Detailed Technical Approach

Robust Low Loss Switch Technologies: To produce an efficient RF FPGA, a compact low loss RF switch is the essential technology needed. Our unique solution for the switch leverages previous completed GeTe/GeSbTe phase change material RF switches. These phase change materials have demonstrated a dynamic range for R_{off} to R_{on} ratio of 10^7. We have designed 4 to 12 port multiport RF switches (8 port design shown in Figure 1) with RF losses in the 0.2dB range, which need a R_{off}/R_{on} range of only 2 x 10^5. This margin in dynamic range requirement improves switch producibility and cycle lifetimes.

Distribution Statement "A" (Approved for Public Release, Distribution Unlimited) "The views expressed are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government." This is in accordance with DoDI 5230.29, January 8, 2009.

Report Documentation Page						Form Approved OMB No. 0704-0188

1. REPORT DATE **MAR 2013**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**
4. TITLE AND SUBTITLE **RF FPGA for 0.4 to 18 GHz DoD Multi-function Systems**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Northrop Grumman, Baltimore, Maryland 21040**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES

See also ADB387878. GOMACTech -13 Government Microcircuit Applications and Critical Technology Conference (38th) on Microelectronics for Net-Enabled and Cyber Transformational Technologies. Held in Las Vegas, Nevada on 11-14 March 2013

14. ABSTRACT

Northrop Grumman Electronic Systems (NGES) is developing a dynamically reconfigurable, wide band programmable RF FPGA transceiver which, if successful, will provide reduced life cycle cost, reduced re-design cost, and service for multiple DoD platforms, while maintaining near-optimal performance for each application. This RF FPGA transceiver has the flexibility to implement communications, radar, EW, EA, and other functions covering the 0.4 to 18 GHz band.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**SAR**	**4**	

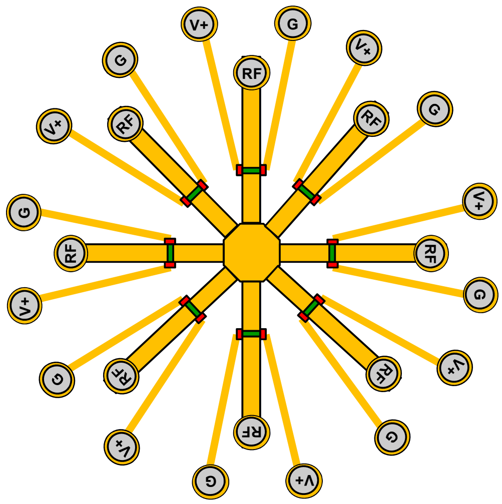

Figure 1: 8-port phase change RF Switch design with ~0.15dB loss at 18GHz.

Flexible Switch Matrix: The phase change RF switches will be used to create a fully interconnected switch matrix (Figure 2). These switches will connect banks of RF components (e.g., LNAs, mixers, filters, vector modulators) on the RF ICs to each other, and also allowing routing from any of these circuits to the RF FPGA I/O. The RF switches are fabricated on separate SiC wafers, optimized for RF and thermal phase change performance, and then flip chip bonded to the RF component IC.

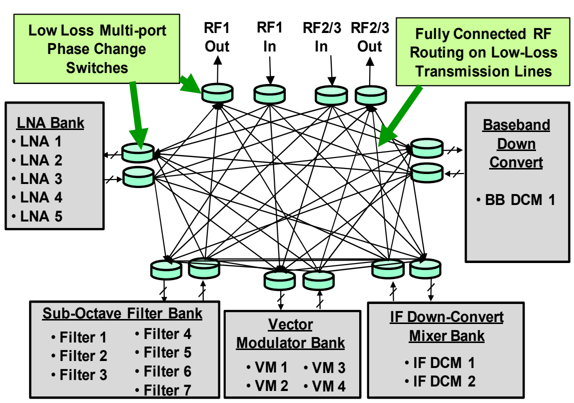

Figure 2: Flexible switch matrix connects RF circuit banks with each other and I/O for high level of reconfigurability.

To further minimize RF losses due to the switch matrix, the routing lines between switches are fabricated using high conductivity metal (such as copper) 50 Ohm transmission lines on low loss dielectric, such as BCB. The transmission lines will be configured as microstrip, with lines over and under the ground plane to provide the isolated RF signal crossover capability required by the fully interconnected matrix. The stackup showing the integration of the RF IC, interconnect matrix, and switches in a QFN package is shown in Figure 3.

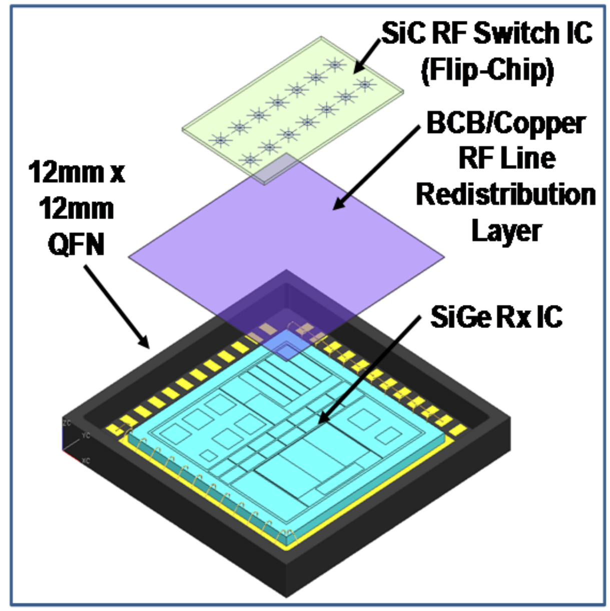

Figure 3: RF FPGA integrates SiGe RF IC with SiC Phase Change switch.

High performance RF architecture: Our RF FPGA uses a coarse grained architecture consisting of major functional blocks with reconfigurability both within the blocks and between the blocks. This approach provides higher RF performance than a fine grained architecture, and has the degree of flexibility needed for a wide range of applications due to our fully connected RF switch matrix. The **Receiver FPGA** (Figure 4) contains banks of LNAs, sub-octave filters for RF filtering, vector modulators for beam steering, down conversion mixers, and digital control. We are using Jazz SiGe as our integration platform because the RF performance is very good (Ft over 200GHz), digital control and power supply circuits for the phase change heaters can be easily integrated into the same IC, and device fabrication is relatively inexpensive. The number of RF elements and their bandwidths in each bank have been selected to provide the 0.4 to 18 GHz range, based on previous SiGe designs. **Filter FPGAs** contain receiver filtering required for application specific needs.

The architecture of the **Transmit FPGAs** is shown in Figure 5. The **Transmitter FPGA** contains banks of upconverters, vector modulators for beam steering, filters, output amplifiers, and digital control, and is baselined as a SiGe IC. The **Power Amplifier FPGA** contains a bank of GaN power amplifiers with up to 8 W output power, with controllable bias and switchable gain stages to service a wide range of frequency, power output, and class of operation.

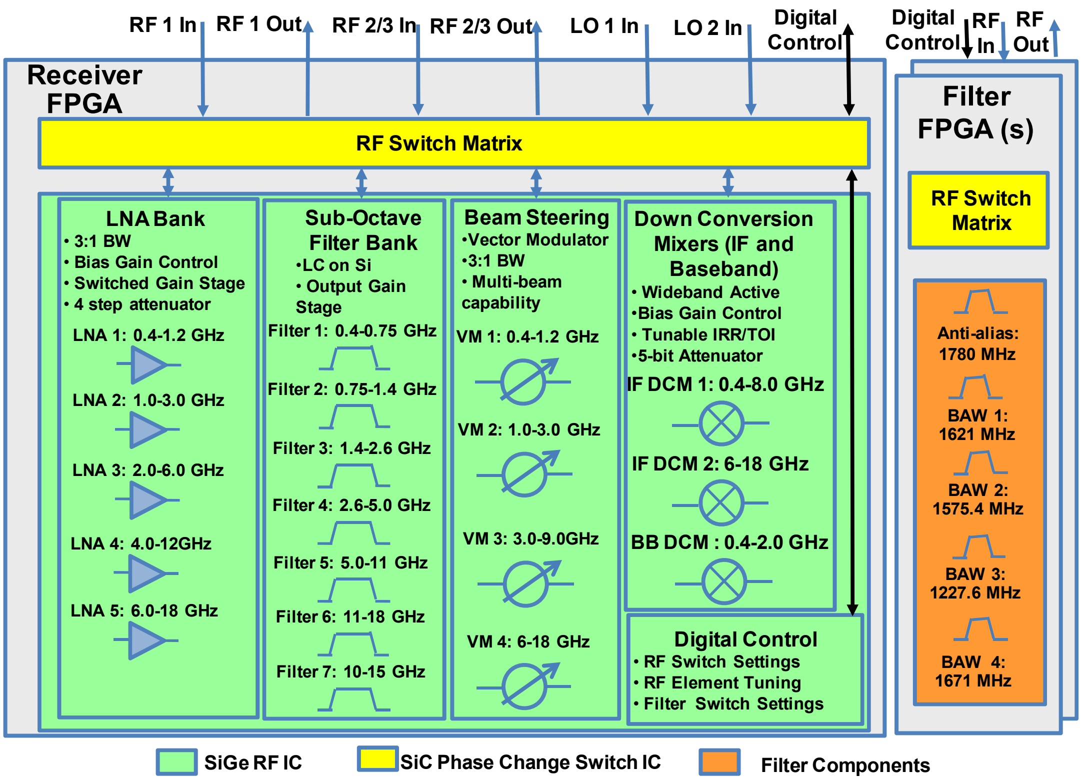

Figure 4: NGES Receiver FPGAs provide 0.4 to 18 GHz configurable RF circuit banks with multiple RF inputs and outputs, plus configurable notch and bandpass filtering.

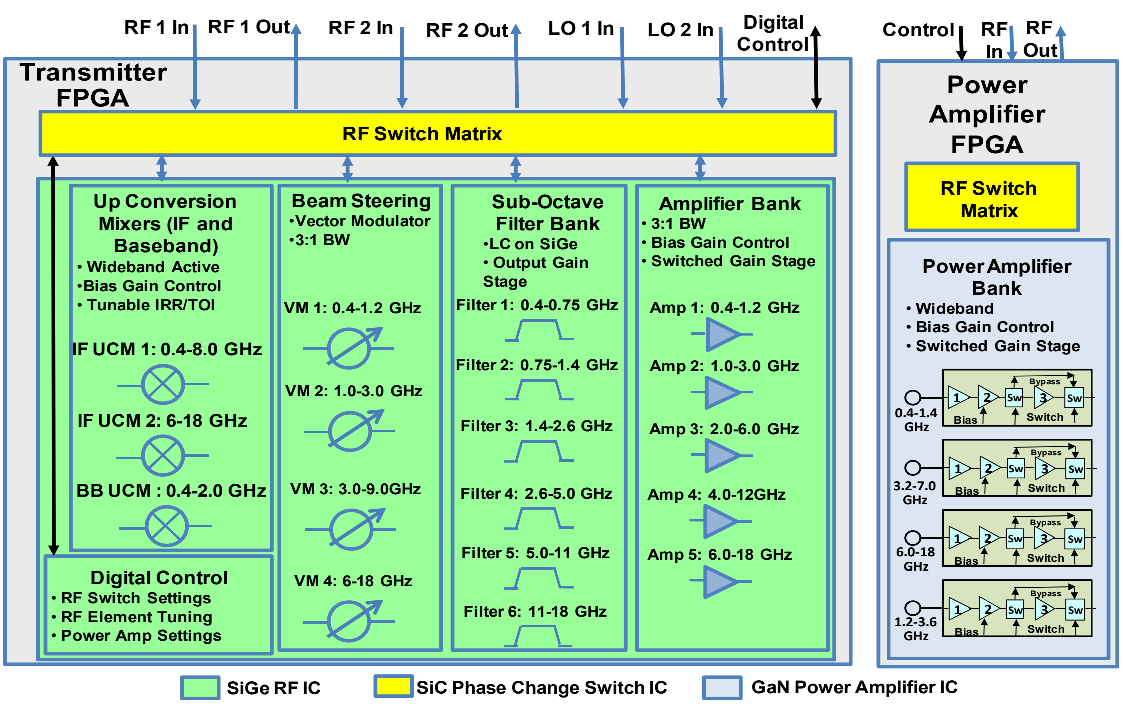

Figure 5: NGES Transmit FPGAs provide configurable upconversion functions and configurable high power amplifier outputs over 0.4 to 18 GHz range.

Wideband RF Building Blocks: We are using relatively wideband RF components and incorporating performance configurability within these components. This gives high performance with wide frequency application range. For example, our design experience has shown that we can achieve very nearly equivalent performance in 3:1 bandwidth SiGe LNAs as that achieved in narrow band LNAs. Our mixers and vector modulators can function over even wider bandwidths with very good performance. A small bank of LNAs, mixers, and vector modulators can perform over 0.4 to 18 GHz. We also incorporate tuning within these components; for example, the LNAs have adjustable bias and switchable gain stages to optimize gain, noise figure, and TOI versus power dissipation as required by the application.

Wide Frequency, Scalable Transmit Power*:* The **Power Amplifier RF FPGA** contains a bank of GaN reconfigurable power amplifiers with >3:1 bandwidth capability covering 0.4 to 18 GHz frequency. Using switched-in amplifier stages, it provides up to 8W CW RF output. High efficiency of a class AB PA can be maintained as the input drive is reduced by varying the drain and gate bias with the drive signal. We have demonstrated >40% efficiency over a 10:1 range of power levels. For an 8W RF output, our thermal analysis shows an acceptable <100C temperature rise in the final output RF switch due to self heating. Lower power level applications (up to 100 mW) can be met with drive amplifiers in the Transmit FPGA.

Digital Configuration and Control*:* The RF FPGAs are completely reconfigurable in the field via control with digital control words coming into the SiGe RF ICs, based on the widespread RS-232 standard. To control performance within a circuit block (e.g., LNA or mixer), there are embedded DACs and control registers to control bias and other settings. The SiGe ICs also provide the controlled voltage pulses needed for phase change switches. The power control circuitry for each switch is located on the SiGe IC under the switch location to minimize parasitics and provide 20 nsec power turn-on and 20 nsec power turn-off, which provides for high performance phase change switch operation and <1 microsecond reconfiguration times.

Conclusion: The RF FPGA approach uses arrays of these high performance RF IC circuit elements, and achieves flexibility by reconfiguring the signal path between desired elements with minimal degradation, due to use of low loss phase change switching technology. This enables multiple applications of the same RF FPGA components with near-custom performance. This shortens procurement cycles, improves affordability, and provides mid-mission reconfigurability.

Acknowledgment: This work is supported by DARPA. The authors would like to thank Dr. William Chappell for his help, support and useful feedback.