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A Novel Ka-band GaN Phase Shifter for SATCOM Phased-Array Antennas

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Abstract— A Ka-band phase shifter is a key component of phased array antennas for SatCom applications. By using GaN technology, large power handling capability and high frequency operation can be achieved. In this paper, a HEMT GaN switch using a metal gate of $0.15\mu\text{m}$ is designed at 30 GHz for signal levels up to 37 dBm. From this efficient GaN switch, a compact and innovative monolithic phase-shifter is proposed for Ka-band operation with a 2-bit phase resolution and attractive insertion loss, isolation and bandwidth performance.

Keywords—Gallium-nitride (GaN), phase shifter, Ka-band.

I. INTRODUCTION

Because satellite communication (SatCom) systems having large capacities are in demand, Ka-band phased array systems are being investigated. This higher operational frequency provides at the same time high data rate links and miniaturized antenna systems [1]. Traditionally, beam scanning is achieved through mechanical approaches [2-3], which are bulky, slow, and expensive. For this reason, an electrically controlled phase array antenna is preferred. A phase shifter behind each radiating element is desired to sweep the direction of the beam. Moreover, a compact and accurate 2-bit phase-shifter is required to allow an appropriate beam scanning and reduce the dimensions of the phase control circuit in T/R modules (which generally occupies a large area in SatCom systems).

In addition, research into wide-bandgap semiconductors has progressed significantly over the last few years. GaN based semiconductors have demonstrated excellent performance in comparison with the other wide band-gap semiconductor technologies [4]. Large power handling capability and high frequency operation are achieved with good efficiency and linearity. As a result, reconfigurable RF circuits with high power/frequency and excellent linearity are now realizable, especially for Ka-band SatCom systems.

In this paper, a compact Ka-band (30-32 GHz) 2-bit phase shifter employing GaN switches is proposed for a new generation of Ka-band phased array systems for satellite communication.

II. DESIGN OF KA-BAND GAN SWITCH

Fig. 1 shows a simplified cross-section of the GaN HEMT process, which has been developed by the National Research Council Canada (NRC). The NRC GaN technology is an aluminum – gallium – nitride / gallium – nitride (AlGaIn/GaN)

HEMT-based MMIC process. The technology features a metal gate length of $0.15\mu\text{m}$ (GaN150 process).

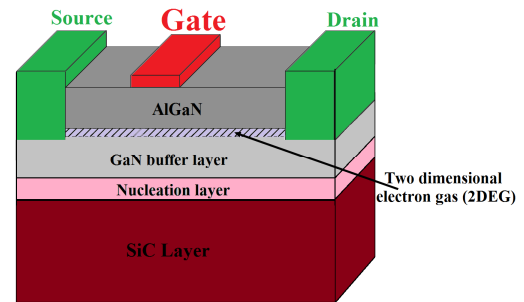
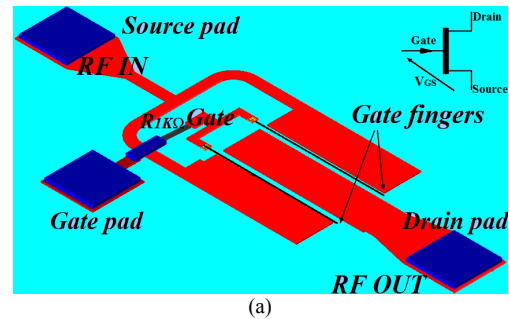


Fig. 1 Schematic cross-section of AlGaIn/GaN NRC HEMT

A Ka-band GaN HEMT switch has been designed (and laid out for fabrication at NRC) to be used in a phase-shifter system. The general characteristics, dimensions and performances for *On-* and *Off-Mode* GaN switch configurations are detailed in Table I and Fig. 2. N is the number of gate fingers, W and L are respectively the width and the length of gate finger. After optimization (insertion loss and isolation at 30 GHz), the optimal width of the gate W is found to be $120\mu\text{m}$. Note that the final dimensions of this innovative and efficient GaN switch in Ka-band are $220\mu\text{m} \times 450\mu\text{m}$.

Table I. GaN switch details and simulated performances in Ka-band

Ka-band GaN switch dimensions	Ka-band GaN switch characteristics	
	MODE OFF $V_{gs} = -6V$	MODE ON $V_{gs} = 0V$
$N=2$ $W=120\mu\text{m}$ $L=0.15\mu\text{m}$	Isolation $\leq 13\text{dB}$	Insertion loss $\sim 1.2\text{dB}$



(a)

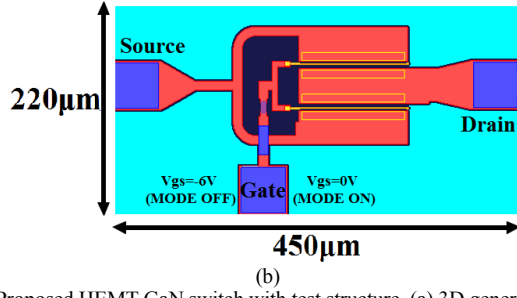


Fig. 2. Proposed HEMT GaN switch with test structure. (a) 3D general view of the layout. (b) Top view of the layout with dimensions.

To take into account the switch performances in the forthcoming phase-shifters, modeling has been conducted to extract the value of the parasitic element for each state (*On*- and *Off*-Mode). As described in Fig. 3, the physical equivalent circuit can be represented by a simple resistance for the *On*-Mode (optimal resistance $R_{on}=12\ \Omega$) and by a capacitance for the *Off*-Mode (optimal capacitance $C_{off}=12.3\text{fF}$). Fig. 3 shows the performances of the proposed GaN switch in *On*-Mode (Fig. 3a: insertion loss against frequency) and in *Off*-Mode (Fig. 3b: isolation against frequency) in comparison to the proposed simple equivalent circuit. Note that the insertion loss is around 1.2 dB and the isolation is lower than 13 dB for all frequencies respectively for the *On*- and *Off*-Mode. The component values have been correctly optimized: the curves are very similar over the entire bandwidth. Note that the 1-dB compression point is a little over 37 dBm.

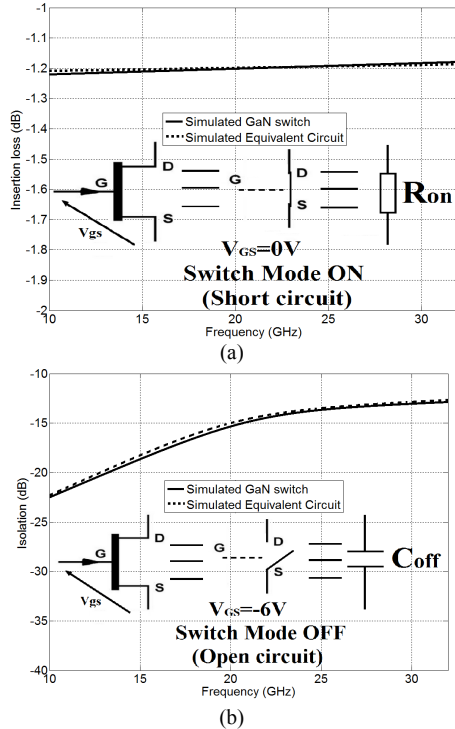


Fig. 3. Performances of the proposed GaN HEMT switch in comparison with a simple equivalent circuit. (a) *ON*-MODE: Insertion loss against frequency. (b) *OFF*-MODE: Isolation against frequency.

III. DESIGN OF A KA-BAND GAN PHASE SHIFTER

Generally, an active phased array antenna is required to operate over a wide scanning frequency bandwidth of more than 1GHz. The proposed approach is to associate a phase shifter for each element with an efficient true time delay. The true time delay performance is obtained by controlling the electrical path-length of each element. The proposed Ka-band compact phase-shifter is shown in Fig. 4. The length of each electrical meander microstrip path has been optimized to obtain four phase-states separated by 90 degrees and to reduce the overall size. Note that the GaN MMIC corresponds to a substrate with permittivity ϵ_r of 10 and a thickness of $75\mu\text{m}$. GaN switches are needed to select an individual path. So, to achieve four 90° -spaced phases (namely a 2-bit phase resolution), two GaN switches in *On*-Mode and six GaN switches in *Off*-Mode are required for each phase-state. The required gate bias circuitry to control each switch is not shown, but could be easily added without affecting the size or performance of the phase shifter. The frequency response computed in transmission with HFSS is represented in Fig. 5 both in amplitude (Fig. 5a) and in phase (Fig. 5b). In all simulations, for each phase-state (4 simulations/4 states: 1st: switches n°1 in *On*-mode and the others in *Off*- Mode, 2nd: switches n°2 in *On*-Mode etc.), the parasitic elements of GaN switches are included: resistance of $12\ \Omega$ for *On*-Mode and capacitance of 12.3fF in *Off*-Mode. Regardless of the active phase-state, the transmission coefficient is lower than 3 dB between 30 and 32 GHz. The transmission phase response is plotted in Fig. 5b between 30 and 32 GHz; four 90° -spaced phase configurations are obtained with the same frequency dispersion. The corresponding phase resolution is around 1.95bits.

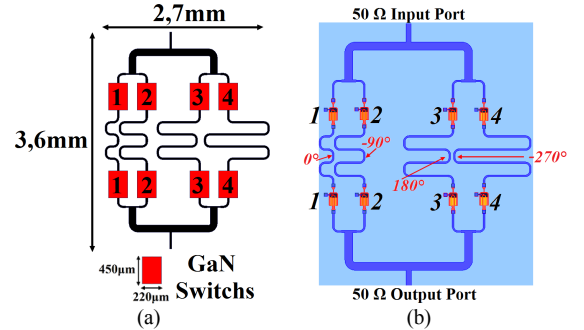
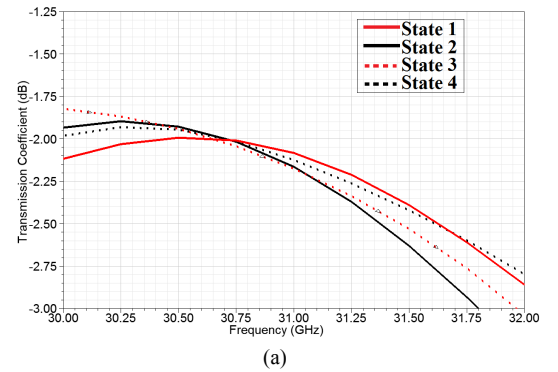


Fig. 4. Proposed Ka-band phase shifter using HEMT GaN switches. (a) Top view with general dimensions. (b) Top view of the layout with test structure



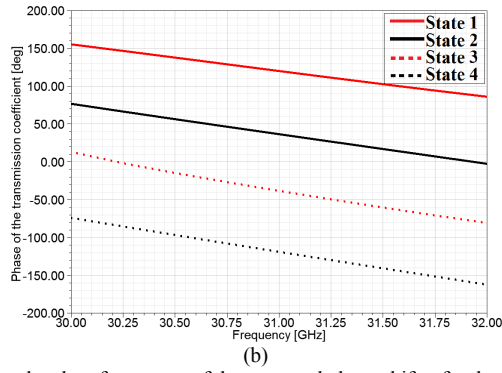


Fig. 5. Simulated performances of the proposed phase-shifter for the four phase states. (a) Magnitude of the transmission coefficient S_{21} . (b) Phase of the transmission coefficient S_{21} .

Prototypes of a nearly identical passive phase shifter (but realized on Duroid 5880 without GaN devices) have been fabricated and gave excellent measured results [DGA report], suggesting that experimental performance of the proposed GaN MMIC circuits will closely match simulations. Chip fabrication is planned in 2016.

To conclude, Table II compares the proposed phase shifter with those currently reported in the literature at Ka-band.

Table II. Ka-band phase-shifter comparison

[Reference] Simulated or measured results	Operating frequency (GHz)	Insertion loss (dB)	Isolation (dB)	Phase variation Continuous or Discrete	Size (mm)
[4] Measured	DC-33	8	10	360° Continuous	7.61×1.2
[5] Measured	30	5,8	12	157° Continuous	4.2×0.9
[7] Simulated	22-26	≤10	10	25,4° Continuous	1.45×0.98
[8] Measured	15-35	≤10	10	360° Discrete	0.52×0.37
[9] Measured	27-32	5 ± 0,8	10	360° Continuous	2×1.2
[10] Simulated	30-30,5	3,6 ± 1,8	10	315° Continuous	20×20
[11] Measured	30	5,8	12	157° Continuous	?
[12] Measured	20-25,75	1	20	330° Discrete	0.8×2.3
This work Simulated	30-32	2,5	13	360° (2bits) Discrete	2.7×3.6

This comparison demonstrates the value of this innovative phase-shifter. It is compact and efficient (insertion loss, bandwidth, phase resolution). Moreover, it includes GaN switches to handle high power at Ka-band.

IV. CONCLUSION

An innovative phase-shifter composed of GaN switches in Ka-band is proposed in this paper.

A HEMT GaN switch using a metal gate of 0.15μm (NRC GaN 150 process) has been designed and simulated in collaboration with the NRC. The simulated insertion loss is 1.2 dB and the isolation is lower than 13 dB at 30 GHz. Subsequently, a compact and efficient phase-shifter has been optimized and designed for Ka-band operation taking into

account the parasitic elements of the GaN switches. In comparison to the other Ka-band phase-shifters, performances are very attractive: the proposed phase-shifter is compact and efficient in terms of insertion loss, isolation, bandwidth and phase resolution.

REFERENCES

- [1] L. Marcellini, R. Lo Forti, and G. Bellaveglia, "Future developments trend for Ku and Ka antenna for satcom on the move," in *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on*, Apr. 2011, pp. 2346–2350.
- [2] J. S. Kot, I. M. Davis, C. Granet, G. Pope, 'Antenna concepts for Ka-band SATCOM on the move', *MilCIS 2009*, Canberra, 10-12 Nov. 2009.
- [3] J. S. Kot, I. M. Davis, C. Granet, G. Pope, 'Compact Shaped Dual-Reflector System For Military Ka-band SATCOM on the move', in *Antennas and Propagation (EUCAP), Proceedings of the 5th European Conference on*, Apr. 2011, pp. 3518–3521.
- [4] Runton, D.W., Trabert, B., Shealy, J.B., 'History of GaN: highpower, RF gallium nitride (GaN) from infancy to manufacturable process and beyond', *IEEE Microw. Mag., IMS Special Issue*, pp. 82–93, Vol. 14, 2013.
- [5] Huang J, Zhao Q, Yang H, et al. 'A monolithic distributed phase shifter based on right-handed nonlinear transmission lines at 30 GHz', *Chin Phys B*, 2013.
- [6] Erker E G, Nagra A S, Yu L, et al. 'Monolithic Ka-band phase shifter using voltage tunable BaSrTiO3 parallel plate capacitors', *IEEE Microw Guided Wave Lett*, 2000.
- [7] Kim W G, Thakur J P, Yu H Y, et al. 'Ka-band hybrid phase shifter for analog phase shift range extension using 0.13-μm CMOS technology', *Phased Array Systems and Technology (ARRAY)*, 2010.
- [8] Sah S P, Yu X M, Deukhyoun H. 'Design and analysis of a wideband 15–35-GHz quadrature phase shifter with inductive loading', *IEEE Trans Microw Theory Tech*, 2013.
- [9] C. Mendyi, L. Yang, W. Jiaxing, Z. Jiaxin, L. Xiaohua, H. Yue, 'ka-band full-360° analog phase shifter with low insertion loss', *Journal of semiconductors*, Vol. 35, n° 10, Oct. 2014.
- [10] T. Lambard, O. Lafond, M. Himdi, H. Jeuland and S. Bolioli, 'A novel analog 360° phase shifter design in Ku and Ka bands', *Microw. and Optic. Tech. Lett.*, vol. 52, pp. 1733-1736, 2010.
- [11] E. G. Erker, A. S. Nagra, Y. Liu, P. Periaswamy, T. R. Taylor, J. Speck, and Robert A. York, 'Monolithic Ka-Band Phase Shifter Using Voltage Tunable BaSrTiO3 Parallel Plate Capacitors', *Microwave and Guided Wave Letters*, Vol. 10, pp. 10-12, 2000.
- [12] C. Palego, Z. Peng, J. Hwang, D. Scarbrough and C. L. Goldsmith, 'Novel Ka-band phase shifters using MEMS capacitive switches', *Wireless and Microwave Technology Conference (WAMICON)*, 2010.