

# An Oscillator Type Active Integrated Antenna Using GaN/AlGaN HEMT with Maximum Power at Second Harmonic

Rakhi Kumari<sup>1, 2, \*</sup>, Ananjan Basu<sup>1</sup>, and Shibani K. Koul<sup>1</sup>

**Abstract**—In this paper an oscillator-type GaN HEMT based active integrated antenna is proposed where the active part of the circuit and patch antenna are in series. The patch antenna is designed to offer optimum impedance at second harmonic to generate maximum power at second harmonic and overall negative resistance at fundamental frequency for sustained oscillation. The circuit has been designed, fabricated, and characterized. The fundamental frequency of oscillation of this circuit is 1.5 GHz. This circuit has Effective Isotropic Radiated Power (EIRP) of 32.1 dBm at 3 GHz. Power at the fundamental frequency is suppressed due to mismatch of input impedance of patch antenna and deviation from optimum load required for maximum radiation at fundamental frequency. The power radiated at fundamental frequency is 15.7 dB lower than the power radiated at second harmonic. This design technique can be used for radiating useful high power much beyond the cutoff frequency of the transition of active device.

## 1. INTRODUCTION

Microwave and millimeter-wave communication system and radar system have several advantages over low frequency systems e.g., wide bandwidth and compact system. These systems require high power signal source with low phase noise [1]. To get the signal source at high frequency, multiplier is used in conjunction with low frequency oscillator due to limited power source at higher frequency which causes increase in phase noise of the signal source and increase in size of the circuit.

Power handling of solid state device decreases with increase in frequency. GaN/AlGaN HEMT has high power handling capability due to high breakdown voltage and high current density [2–8]. So, GaN/AlGaN HEMT is expected to generate high power. An active integrated antenna (AIA) approach has been employed in RF front end application. In this approach, active circuit and antenna are designed simultaneously with antenna performing multiple functions, e.g., load, radiator, filter, frequency conversion, and matching network. Active circuit and antenna are connected directly. Direct integration of antenna and oscillating circuit leads to elimination of feed line and some part of the circuit which minimizes circuit size and loss [8–14]. At millimeter wave power can be increased to very high level using spatial power combining technique and AIA concept [15]. As a radiating element patch antenna is used as it is simple and can be integrated with planar microwave circuit.

In this paper, a new technique for oscillator type AIA using GaN/AlGaN HEMT is proposed which can generate maximum power at second harmonic. So the frequency of the signal source can be increased without using multiplier, and high power can be generated, in principle much beyond  $f_t$  of the transistor using this technique.

---

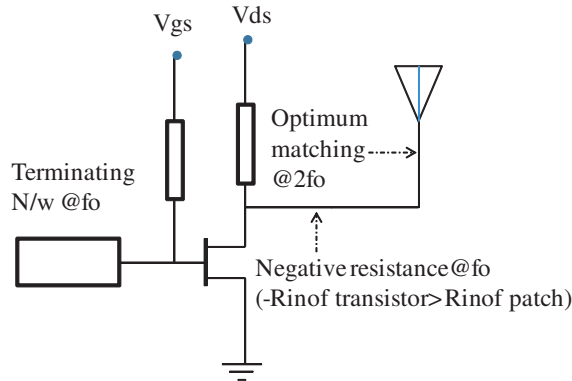
Received 2 July 2020, Accepted 29 July 2020, Scheduled 18 August 2020

\* Corresponding author: Rakhi Kumari (choudharyrakhi56@gmail.com).

<sup>1</sup> Centre for Applied Research in Electronics, Indian Institute of Technology Delhi, India. <sup>2</sup> Solid State Physics Laboratory Delhi, India.

## 2. DESIGN METHODOLOGY

At microwave frequency, oscillator is designed using negative impedance technique if the device is potentially unstable at desired frequency. In conventional design, terminating network is designed at fundamental frequency at one port to select potentially unstable region at another port. Matching network and load are designed at fundamental frequency of oscillation at another port [16]. In this architecture for oscillator type AIA terminating network is designed at fundamental frequency at input port, and based on terminating network, output impedance is calculated at the output of an active device at both fundamental frequency and second harmonic. Patch antenna is designed with resonance frequency above oscillation frequency of oscillator in such a way that input impedance offered by the patch antenna at second harmonic frequency also has optimum impedance for maximum power generation at second harmonic in an active circuit. The input impedance at fundamental frequency is lower than the magnitude of output impedance of oscillator at fundamental frequency to have overall negative resistance at fundamental frequency to maintain sustained oscillation. Patch antenna acts as matching network, resonator, harmonically tuned load at fundamental frequency and second harmonic and radiator for this oscillator type AIA. As shown in Figure 1, the architecture of this oscillator type AIA consists of terminating network, GaN/AlGaN HEMT with a biasing network and patch antenna. Terminating network is designed at 1.6 GHz, and the patch antenna is designed with resonance frequency above the fundamental frequency of oscillator with optimum impedance for maximum power generation at second harmonic and sustained oscillation. The antenna is directly connected to an active part of the oscillator. This circuit radiates maximum power at second harmonic frequency and acts to double the frequency of oscillator.

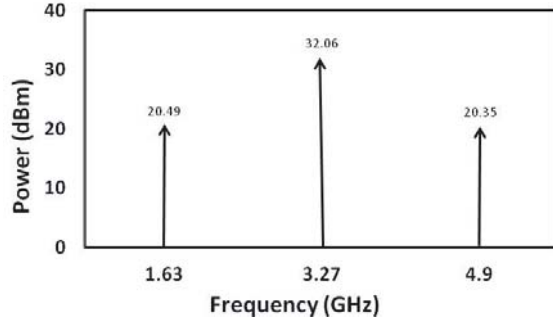


**Figure 1.** Architecture to double the frequency of oscillator using AIA.

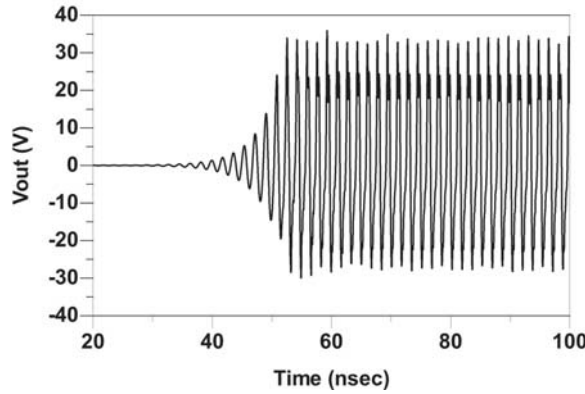
## 3. AIA SIMULATION

A GaN HEMT based negative resistance oscillator is designed at 1.6 GHz in Keysight Advanced Design System (ADS) software using Cree CGH40010 device on a Roger 4350 substrate. The first device is biased at  $V_{ds} = 29$  V and  $V_{gs} = -2.1$  V and simulated to check the stability factor in ADS. Since the device is potentially unstable at 1.6 GHz, the terminating network is designed at input port to generate negative resistance at output port. Output impedance of transistor with terminating network at fundamental frequency is  $(-2.3 + j * 4.25)\Omega$  and at second harmonic is  $(21.7 + j * 26.15)\Omega$ . The patch antenna is designed in CST Microwave Studio with resonance frequency and second harmonic at 1.642 GHz and 3.284 GHz, respectively. Input impedance of antenna at 1.6 GHz is  $(0.25 + j * 19.55)\Omega$  and at 3.201 GHz is  $(54.7 + j * 125.05)\Omega$ .  $S$ -parameter of patch antenna is imported into ADS, and the patch antenna is directly connected with the active circuit in ADS. This circuit has overall negative resistance at 1.6 GHz for sustained oscillation and nearly optimum load required for power generation at second harmonic. The patch antenna has a gain somewhat less than usual, since the frequency of oscillation of circuit does not match with resonance frequency of patch antenna.

$$P = 0.5 \text{Real}[V * \text{Conjugate}(I)] \quad (1)$$



**Figure 2.** Simulated generated power at input of patch antenna.



**Figure 3.** Transient Simulated voltage at input of patch antenna.

Harmonic balance simulation is done in ADS to simulate the frequency of oscillation, voltage, and current in circuit. Power generated at the input of patch antenna is calculated by Equation (1). In Eq. (1)  $P$  is the power generated at the input of patch antenna, and  $V$  and  $I$  are the voltage and current generated at the input of patch antenna at the frequency of oscillation for radiation.

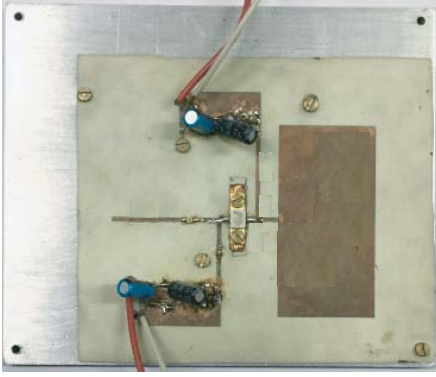
Figure 2 shows the frequency of oscillation and simulated generated power at the input of patch antenna in ADS. Simulated generated power at second harmonic is 32 dBm which is 11.5 dB higher than the power generated at fundamental frequency. Transient simulation is also done in ADS to see the sustained oscillation. Figure 3 shows the transient simulation of generated voltage at input of patch antenna in ADS. Generated voltage shows that this circuit has sustained oscillation.

#### 4. MEASUREMENT RESULT AND DISCUSSION

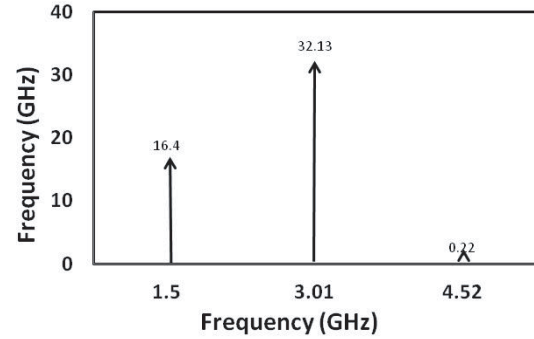
Oscillating AIA is fabricated. Active component GaN HEMT and passive components are mounted on the fabricated circuit substrate. The fabricated circuit is fixed on an aluminum plate for fast heat dissipation during measurement. Figure 4 shows a photograph of the fabricated circuit with all mounted components. Measurement is performed in an anechoic chamber. The output power of oscillating antenna is measured in far field using a horn antenna placed 2.25 meters away from the fabricated AIA. A Keysight EXA Signal Analyzer is used to measure the power radiated from antenna. Signal Analyzer is connected to receiving horn antenna via cable. EIRP is calculated using Friis transmission equation [2].

$$EIRP = \frac{(P_{rec})}{G_r \left(\frac{\lambda}{4\pi r}\right)^2 (Cable Loss)} \tag{2}$$

In Equation (2),  $P_{rec}$  is the received power in spectrum analyzer,  $G_r$  the gain of receiving Horn antenna used for measurement, and  $(\lambda/4\pi r)^2$  the free-space loss. Note that cable loss is taken care by dividing



**Figure 4.** Photograph of fabricated active integrated antenna.



**Figure 5.** Measured EIRP of active integrated antenna.

received power with measured cable loss. Measured received power in signal analyzer is  $-13.89$  dBm at second harmonic frequency  $3.016$  GHz. Measured cable loss at  $3.016$  GHz is  $-5.98$  dB. Free path loss is  $-49.138$  dB. The gain of horn antenna is  $9.1$  dB. EIRP calculated from Friis transmission equation is  $32.128$  dBm at  $3$  GHz. Figure 5 shows the spectrum of measured EIRP. The highest EIRP achieved is  $32.13$  dBm at bias voltages  $V_{ds} = 29$  V and  $V_{gs} = -2.1$  V. The EIRP achieved at fundamental frequency is  $16$  dB lower than EIRP at second harmonic. The highest dc to RF conversion efficiency achieved is  $24\%$  with  $V_{ds} = 27$  V and  $V_{gs} = -2.1$  V, and the EIRP calculated at highest conversion efficiency is  $32$  dBm. The comparison of EIRP of previously reported self oscillating AIA with this work is reported in Table 1. This GaN/AlGaIn PHEMT based circuit achieves the highest EIRP and very good DC to RF efficiency using single active device. Even excluding antenna gain which is not high, the power radiated is quite substantial. This circuit also proves the concept to double the frequency of oscillation of oscillator using AIA concept.

**Table 1.** Comparison of EIRP of previously reported self oscillating AIA with this work.

Refs	Frequency (GHz)	Active Device used	EIRP (dBm)	DC to RF Efficiency (%)	No of device
[17]	5.8	GaAs MESFET	12.83	25.7	1
[18]	0.87	HJ-FET	7.53	31	1
	2.77		5.1	43	1
[19]	5.05	HJ-FET	10.1	-	1
[20]	5.267	HJ-FET	18.37	31.3	1
[21]	69.6	GaAs PHEMT	$-13.2$	0.12	2
<b>This work</b>	<b>3.01</b>	<b>GaN PHEMT</b>	<b>32.13</b>	<b>24</b>	<b>1</b>

## 5. CONCLUSION

This paper presents a novel design technique to increase the frequency of oscillation and the EIRP of self oscillating AIA. An oscillator is integrated with a patch antenna which acts as resonator, output matching network, and harmonically tuned load, which leads to compact size and improved DC-RF efficiency. Improvement in matching of antenna at output of oscillator at second harmonic leads to the increase in EIRP at higher frequency. The proposed oscillator type AIA generates high EIRP of  $32$  dBm at  $3$  GHz (second harmonic frequency) of oscillator with  $24\%$  dc to RF conversion efficiency. Therefore, the proposed GaN HEMT based AIA concept can be used to generate useful power at higher frequency.

## REFERENCES

1. Raab, F. H., P. Asbeck, S. Cripps, P. B. Kenington, Z. B. Popovic, N. Potheary, J. F. Sevic, and N. O. Sokal, "Power amplifiers and transmitters for RF and microwave," *IEEE Trans. Microw. Theory Tech.*, Vol. 50, 814–826, 2002.
2. Mishra, U. K., P. Parikh, and Y.-F. Wu, "AlGaIn/GaN HEMTs—an overview of device operation and applications," *Proceedings of the IEEE*, Vol. 90, No. 6, 1022–1031, Jun. 2002.
3. Van Leeuwen, J. (ed.), *Computer Science Today. Recent Trends and Developments. Lecture Notes in Computer Science*, Vol. 1000. Springer-Verlag, Berlin Heidelberg, New York, 1995.
4. Kaper, V. S., et al., "High-power monolithic AlGaIn/GaN HEMT oscillator," *IEEE Journal of Solid-State Circuits*, Vol. 38, No. 9, 1457–1461, Sept. 2003, doi: 10.1109/JSSC.2003.815934.
5. Micovic, M., et al., "GaN MMIC technology for microwave and millimeter-wave applications," *IEEE Compound Semiconductor Integrated Circuit Symposium, 2005, CSIC'05*, 173–176, Palm Springs, CA, USA, 2005.
6. Hasegawa, N. and N. Shinohara, "C-band active-antenna design for effective integration with a GaN amplifier," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 65, No. 12, 4976–4983, Dec. 2017.
7. Pengelly, R. S., S. M. Wood, J. W. Milligan, S. T. Sheppard, and W. L. Pribble, "A review of GaN on SiC high electron- mobility power transistors and MMICs," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 60, No. 6, 1764–1783, Jun. 2012.
8. Kumari, R., A. Basu, and S. K. Koul, "Development of GaN HEMT based high power active integrated antenna," *2018 IEEE MTT-S International Microwave and RF Conference (IMaRC)*, 1–4, Kolkata, India, 2018, doi: 10.1109/IMaRC.2018.8877316.
9. Chang, K., R. A. York, P. S. Hall, and T. Itoh, "Active integrated antennas," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 50, No. 3, 937–944, Mar. 2002.
10. Qian, Y. and T. Itoh, "Progress in active integrated antennas and their applications," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 46, No. 11, 1891–1900, Nov. 1998.
11. Choi, D.-H. and S.-O. Park, "Active integrated antenna using T-shaped microstrip-line-fed slot antenna," *2005 IEEE Antennas and Propagation Society International Symposium*, 213–216, Washington, DC, 2005.
12. Qin, Y., S. Gao, and A. Sambell, "Broadband high-efficiency circularly polarized active antenna and array for RF front-end application," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 54, No. 7, 2910–2916, Jul. 2006, doi: 10.1109/TMTT.2006.877437.
13. Lee, J., C. T. M. Wu, and T. Itoh, "A power efficient active integrated antenna," *Microwave and Opt. Technol. Letters*, Vol. 55, No. 6, 1240–1243, 2013.
14. Ooi, S. F., S. K. Lee, A. Sambell, E. Korolkiewicz, and S. Scott, "A new approach to the design of a compact high efficiency active integrated antenna," *Microwave and Optical Technology Letters*, Vol. 50, No. 3, 585–589, Mar. 2008.
15. Wandinger, L. and V. Nalbandian, "Millimeter-wave power combiner using quasi-optical techniques," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 31, 189–193, Feb. 1983.
16. Ibrahim, S. H., "Design and analysis considerations of 4 GHz integrated antenna with negative resistance oscillator," *Progress In Electromagnetics Research B*, Vol. 13, 111–131, 2009.
17. Choi, D. H. and S. O. Park, "Active integrated antenna using a T-shaped microstrip coupled patch antenna," *Microw. Opt. Technol. Lett.*, Vol. 44, No. 5, 434–436, Mar. 2005.
18. Ma, T., Y. Chang, H. N. Chu, and W. Liao, "Frequency reconfigurable self-oscillating active integrated antenna using metamaterial resonators and slotted ground radiator," *2019 13th European Conference on Antennas and Propagation (EuCAP)*, 1–5, Krakow, Poland, 2019.
19. Cai, M., X. Li, and G. Yang, "C-band self-oscillating active integrated antenna," *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 1209–1210, San Diego, CA, 2017, doi: 10.1109/APUSNCURSINRSM.2017.8072647.

20. Wu, C. and T. Ma, “Self-oscillating semi-ring active integrated antenna with frequency reconfigurability and voltage-controllability,” *IEEE Transactions on Antennas and Propagation*, Vol. 61, No. 7, 3880–3885, Jul. 2013, doi: 10.1109/TAP.2013.2256095.
21. Liu, Y. and H. Chang, “Design of a V-band active integrated antenna (AIA) with voltage controlled oscillator,” *Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation*, 1–2, Chicago, IL, 2012, doi: 10.1109/APS.2012.6349417.