A New Architecture for AlGaN/GaN HEMT Frequency Doubler Using Active Integrated Antenna Design Approach

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***Abstract* — This paper presents a new architecture for an AlGaN/GaN HEMT frequency doubler using the active integrated antenna design approach. A microstrip patch antenna designed at the second harmonic is integrated with the HEMT. The antenna operates as a fundamental frequency reflector in this circuit. Using AlGaN/GaN with 1mm gate periphery, a 4 - 8 GHz frequency doubler was designed by the suggested design methodology, fabricated, and tested. For the AlGaN/GaN HEMT frequency doubler integrated with the patch antenna, conversion gain of 5 dB and output power of 25 dBm were achieved in pinch-off region with a drain voltage of 12 V.**

***Key words:* AlGaN/GaN, HEMT, Frequency Doubler, Conversion Gain**

I. Introduction

Microwave and millimeter-wave communication and automotive radar systems require RF signal sources with low phase noise, good frequency stability, and high output power performance. In general, a frequency doubler or a multiplier in conjunction with a low frequency oscillator has been used for this purpose to satisfy those requirements. Either a single-ended or balanced-type structure with broadband performance has typically been employed using FETs or diodes for frequency multipliers [1-4].

The active integrated antenna (AIA) design approach has been extensively employed in advanced RF front-end applications [5-6]. In this design approach, RF transmitting/receiving circuitry and antenna are designed as a whole entity and integrated without assumption of 50 Ω interface between the circuit and the antenna. One of attractive features of the AIA is that the antenna is serving as both an output load and a radiator over a certain frequency range, as well as providing circuit functions such as signal filtering and frequency tuning. This results in a functional compact design and eliminating the effect of any cable and feedline losses. Besides the improvement in circuit technologies such as the AIA concept, there is great interest in developing wide band-gap semiconductor devices such as GaN-based HEMTs and SiC for high power applications at microwave and millimeter-wave frequencies. This is due to their high breakdown voltage, high current density, and fast carrier characteristics [7-8].

In this paper, a new architecture for frequency doubler is investigated using the AIA design approach. An AlGaN/GaN HEMT is utilized for a single-ended frequency doubler integrated with a microstrip patch antenna.

II. New Architecture for Frequency Doubler

Conventional frequency doublers have typically been designed at the second harmonic for the output matching and at the fundamental frequency for the input matching network. The fundamental frequency is suppressed at the output matching network side using a $\lambda/4$ open circuited stub (at the fundamental frequency) as the reflector [1] [4].
In the suggested new architecture, a frequency doubler is designed based on the AIA design approach. This circuit schematic is realized by designing an antenna at a resonant frequency corresponding to the second harmonic and integrating an active device with the antenna. Therefore, the antenna as an output load in the circuit radiates the second harmonic generated by the active device in the strong nonlinear operation while efficiently suppressing the fundamental frequency signal power. The antenna operates as an equivalent fundamental frequency reflector in the conventional frequency doubler. This eliminates the necessity of a fundamental frequency reflector in the conventional frequency doubler. In addition, the cable and feedline losses are minimized when an external antenna is connected by employing the AIA concept. As shown in Fig. 1, the single-ended AlGaN/GaN HEMT frequency doubler consists of AlGaN/GaN HEMT and a microstrip rectangular patch antenna. The antenna was designed at the second harmonic frequency of 8 GHz and output matching network transforms output impedance of the HEMT to the conjugate of antenna impedance (Z_{ANT}) based on the AIA design concept.

In the input matching network, the second harmonic reflector using a λ/4 open circuited stub (at the second harmonic) was employed with input matching network designed at the fundamental frequency of 4 GHz [1] [4].

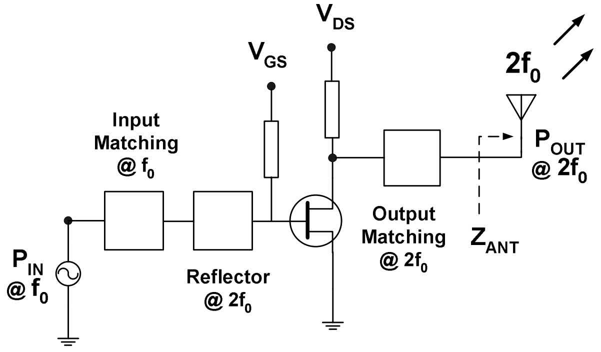

Fig. 1 Architecture of new frequency doubler using active integrated antenna (AIA) design approach

III. AlGaN/GaN HEMT Frequency Doubler integrated with a Rectangular Patch Antenna

The AlGaN/GaN HEMT epitaxial layer was grown by metallic organic chemical vapor deposition (MOCVD). The layer consists of 200 Å $Al_{0.3}Ga_{0.7}N$ doped cap layer followed by 30 Å $Al_{0.3}Ga_{0.7}N$ undoped layer, 500 Å GaN undoped layer, and 1.2 µm GaN buffer layers grown on SiC substrate. AlGaN/GaN HEMT was fabricated through device isolation, ohmic metallization, gate metallization, Si_3N_4 passivation, and air-bridge processes.

As the output radiator, a rectangular patch antenna was used with a microstrip feedline. The antenna was designed and fabricated on Duroid substrate with dielectric constant of 2.33 and thickness of 31 mils at the resonant frequency of 8 GHz. The measured Z_{ANT} was embedded to an Agilent ADS simulation as the final output port instead of a conventional 50 Ω load.

The design of the frequency doubler utilizing an AlGaN/GaN HEMT with gate width of 1 mm and gate length of 0.8 µm was done based on measured small signal S-parameters. The input matching network was fabricated on Alumina with dielectric constant of 9.8 and thickness of 15 mils. The output matching network with the antenna was built on the same substrate used for the passive antenna. The fabricated matching networks were combined with the AlGaN/GaN HEMT using Au bonding wire. The fabricated frequency doubler was mounted on a metal fixture for heat sinking. The photograph of the fabricated the antenna integrated AlGaN/GaN HEMT frequency doubler is shown in Fig. 2.

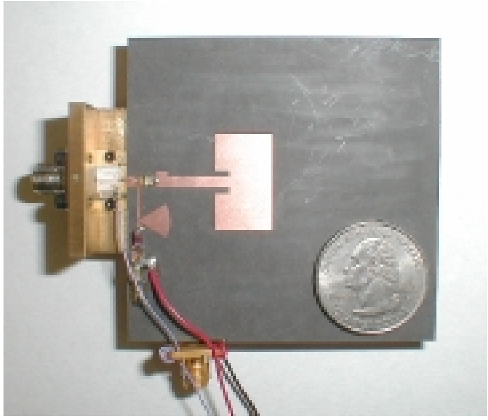

Fig. 2 Photograph of AlGaN/GaN frequency doubler integrated with the rectangular patch antenna

IV. Measurement Results and Discussion

Measurements were done in an anechoic chamber based upon the Friis transmission equation (1) [5-6] [9].

$$P_{rec} = (1-\left|\Gamma_{trans}\right|^2)G_t \frac{P_{in}}{4\pi R^2}(1-\left|\Gamma_{rec}\right|^2)\frac{\lambda^2}{4\pi}G_r \qquad (1)$$

In equation (1), P_{rec} and P_{in} are received power and input power delivered to the radiator, patch antenna, from the AlGaN/GaN HEMT. Γ_{trans} and Γ_{rec} are reflection coefficients of transmitting and receiving side, respectively. G_t and G_r are transmitting and receiving antenna gains and $\lambda^2/4\pi R^2$ presents free space loss.

To test the performance of the antenna integrated with the AlGaN/GaN HEMT frequency doubler, the bias voltages were set to V_{ds} of 12 V and V_{gs} of -5 V, corresponding to the pinch-off region rich in even harmonics. A frequency synthesizer with 4 GHz fundamental frequency was used for the RF source. The above equation (1) allows us to get output performance at the end of the frequency doubler after de-embedding the receiving antenna gain and free space loss. The measured conversion gain and output power at the second harmonic frequency with respect to the input power are shown in Fig. 3. Note that the output power is defined at the end of the frequency doubler. It embeds antenna gain with taking into account cable loss. A maximum conversion gain of 5 dB at an input power level of 14 dBm and saturated P_{out} of 25 dBm are obtained. In Fig. 4, the measured suppression characteristics of fundamental frequency and the 3rd harmonic at the output of the AlGaN/GaN HEMT frequency doubler integrated with the rectangular patch antenna is shown. The suppression is better than 10 dB and 25 dB for the fundamental and the 3rd harmonic frequencies, respectively.

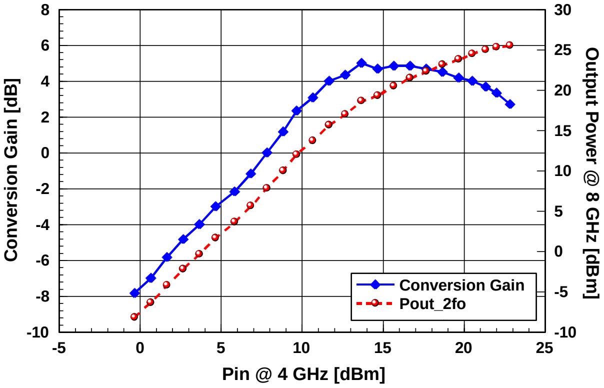

Fig. 3 Measured output power (P_{out}) and conversion gain for the AlGaN/GaN frequency doubler integrated with the rectangular patch antenna

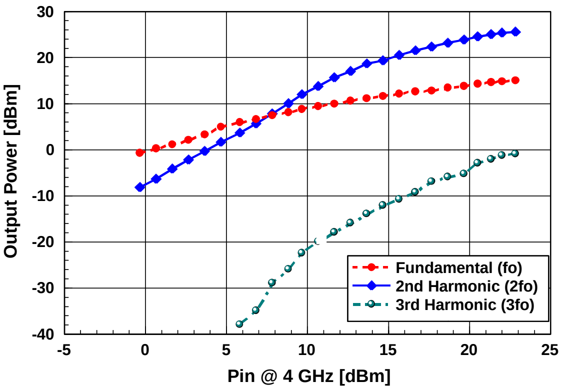

Fig. 4 Measured output power (P_{out}) at fundamental, the 2nd, and 3rd harmonics for the AlGaN/GaN frequency doubler integrated with the rectangular patch antenna

In addition, the E- and H-plane radiation patterns for the antenna integrated AlGaN/GaN HEMT frequency doubler with 4 GHz input frequency were measured at 8 GHz. Note that the radiation power is normalized to 0 dB and shown in Fig. 5.

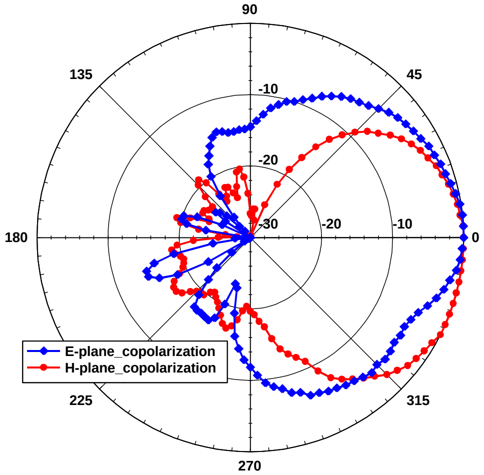

Fig. 5 Measured E- and H-plane radiation patterns for the AlGaN/GaN frequency doubler integrated with the rectangular patch antenna at 8 GHz

V. Conclusion

A new architecture for frequency doubler based on the AIA design concept has been presented. A microstrip rectangular patch antenna was integrated with AlGaN/GaN HEMT for the new frequency doubler. In this structure, the second harmonic signal radiates through the output antenna while the fundamental signal does not. This structure eliminates the necessity of a separate reflector for the fundamental frequency at the output of a conventional frequency doubler. The saturated P_{out} of 25 dBm and maximum conversion gain of 5 dB were achieved from the antenna integrated frequency doubler using an AlGaN/GaN HEMT with 1mm gate periphery. From the measured data, it is demonstrated that AlGaN/GaN HEMTs can be used as frequency doublers with high output power and good conversion gain. The AIA design concept can also be employed to frequency multiplier structures as well as amplifiers.

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