A Dual-Gate FET Subharmonic Injection-Locked Self-Oscillating Active Integrated Antenna for RF Transmission

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***Abstract*—A planar subharmonic injection-locked GaAs dual-gate MESFET (DGMESFET) self-oscillating active integrated antenna (AIA) is presented for RF transmission. The oscillation is obtained with one gate of the DGMESFET at 2.052 GHz, and the stabilization of the oscillation is achieved by injecting a small subharmonic low-noise signal into the other gate of the DGMESFET. Phase noise was measured to be −98 dBc/Hz at the 10 KHz offset. The structure was shown to have the potential in performing triple functions of radiation, low noise oscillation and mixing (or modulation), a capability required for low cost wireless systems such as RFID tags and indoor positioning systems.**

***Index Terms*—Active integrated antenna, dual-gate MESFET, self-oscillation, RF transmission, subharmonic injection locking.**

I. Introduction

Active integrated antenna was developed to meet the need for low-cost and high-compactness RF/microwave front-end modules [1]. In particular, in a self-oscillating active integrated antenna (AIA), passive radiating elements and active devices are integrated to achieve the functions of both radiation and oscillation simultaneously. Nevertheless, such an antenna structure normally has less stability and higher phase noise than a traditional system that is constructed with a separated antenna, oscillator and mixer.

To overcome the problems, techniques such as injection locking [2], [3], cavity control [4], phase lock loop [5], [6] and dielectric resonator [7] have been employed to stabilize free running oscillations and to reduce noises. Among the techniques, subharmonic injection locking was studied with the use of a single-gate GaAs MESFET [8]. It was shown that the stronger current-voltage nonlinearity of the device, the better subharmonic injection locking range [9]. However, the stronger nonlinearity is at the cost of sufficient oscillation amplitude [10]. As a result, two single-gate FETs in series connection were then used since they give more tuning freedoms to satisfy both conditions of high nonlinearity and sufficient oscillation amplitudes as well as the locking range [11].

In this paper, further to our work on the dual-gate FET self-oscillating and mixing AIA circuit for RF receivers [12], a dual-gate MESFET self-oscillating AIA structure for RF transmission is presented, with the addition of subharmonic injection. The novelty of the structure lies in the fact that it integrates a dual-gate FET, a subharmonic injection locking, and a radiating antenna into a single low-cost highly compact RF transmitting structure. Such a circuit can be used in RFID tagging systems, indoor wireless positioning systems and Doppler transceivers.

Compared with the single-gate MESFET structure [8], the proposed dual-gate MESFET configuration gives designers more design flexibilities, with one gate being used for the self-oscillation and another gate being tuned for optimal subharmonic injection locking. In comparison with the two single-gate FET structure [11], the proposed DGMESFET design is more compact since a single active device is used. To the authors' knowledge, there have been no reports so far on applications of DGMESFET to AIA transmitting structures.

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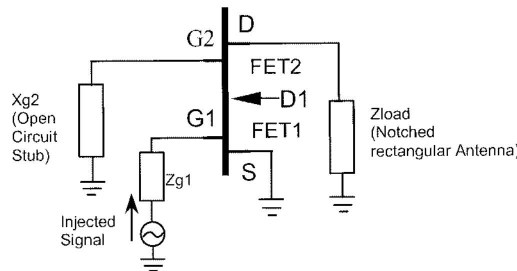

Fig. 1. Schematic of the proposed dual-gate FET subharmonic injection locked self-oscillating active integrated antenna.

II. Dual-Gate MESFET (DGMESFET)

The schematic of the proposed circuit is shown in Fig. 1. The radiating antenna is a notched rectangular patch antenna. It is connected to the drain of the DGMESFET. Together with gate #2 (G2) and the open circuit stub, the radiating antenna and the drain form the oscillation as well as the radiation parts of the structure. Gate #1 (G1) is connected to an external low-frequency source for subharmonic injection locking and oscillation stabilization. Since a stable low frequency source is readily available, such a stabilization technique is quite economical.

To theoretically simulate the structure, DGMESFET is modeled as two single-gate FETs in series, FET 1 and FET2, with a separating reference plane at the center point D1 (see Fig. 1). Different combinations of biasing on FET1 and FET2 provide different nonlinear characteristics [13]. In this design,

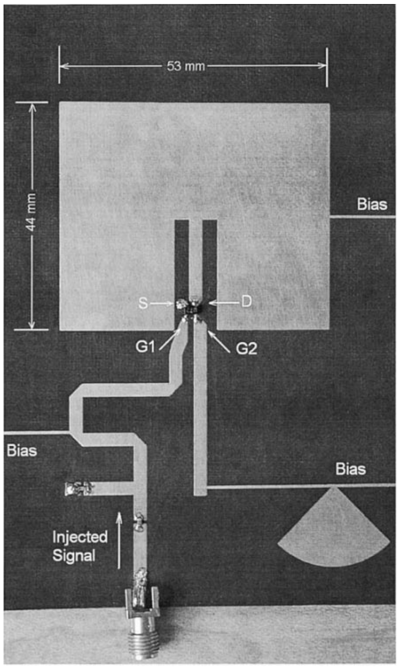

Fig. 2. Layout of the circuit.

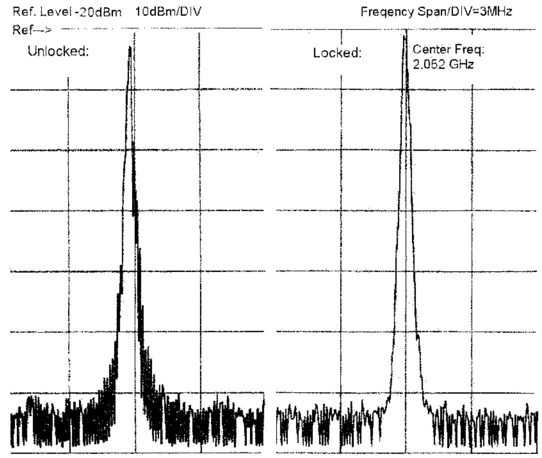

Fig. 3. Active antenna spectra before and after the injection.

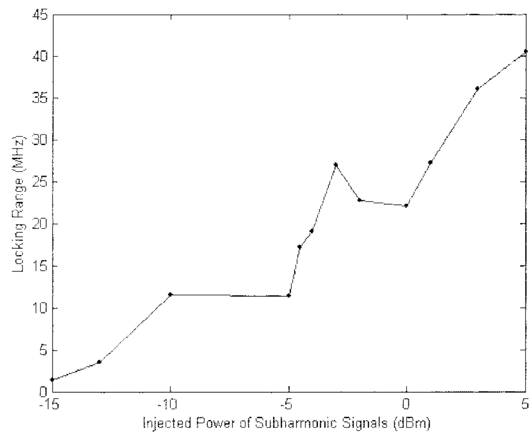

Fig. 4. Locking range versus the injected power.

the equivalent FET1 was biased slightly above pinch off for high nonlinearity in order to efficiently generate the harmonics of the injected signal. The bias and the open circuit stub on FET2 are tuned for the best self-oscillation performance parameters (e.g., self-oscillation frequency and amplitude). In other words, simultaneous achievements of both a good oscillation performance and a wide injection locking range can be obtained, which is not easily implemented with a single FET.

III. Design of the AIA Circuit

The circuit was designed on a printed circuit board for the purpose of proof-of-the-concept. The active device used was a CEL NE25139 general-purpose dual-gate GaAs MESFET. A RT-Duroid 5870 substrate ($\varepsilon_r = 2.33$) with a thickness of 0.787 mm was employed for circuit fabrications. Since the notched rectangular patch antenna has been widely used in other self-oscillating AIA structures and was found to be effective [14], it was selected as the radiating element in this design. The antenna size is 44 mm $\times$ 53 mm and can be scaled down by using higher dielectric constants and higher operation frequency. The frequency of the injection signal was made around 684 MHz.

Pre-testing simulations were performed with the design methodology described in [15]. Small signal designs were carried out for initial calculations and then large-signal simulations were performed for more precise modeling. In our case, Agilent-ADS 2001 was used for both the initial design and the large signal simulations. With the ADS-built-in harmonic balance functions, operation frequency, output power level and phase noise can be predicted.

The open circuit stub together with the second gate (G2) generates a small signal impedance of -39.4–$92.6i\ \Omega$ at the drain port whose load is the notched rectangular patch antenna. The input impedance of the notched rectangular antenna was computed with Ansoft Ensemble 7. By changing the depth of the notch on the antenna, the real part of the antenna impedance is made smaller than 39.4 Ω to ensure that the start-on oscillation condition is satisfied [15]. The free-running oscillation frequency was theoretically predicted to be 2.1 GHz.

IV. Measurement Results

The circuit designed was fabricated and then tested. The layout is shown in Fig. 2. First, the oscillation frequency was measured. To do so, a simple receiver attached with a HP 8559A spectrum analyzer was built to detect the signal radiated from the designed structure. The measurement was started first without the injected signal. The free-running oscillation frequency was measured and found to be 2.052 GHz, close to the simulated 2.1 GHz.

A low power level low frequency signal of approximately 684 MHz was then injected into gate 1. Its 3rd harmonic was in the vicinity of 2.052 GHz. By fine-tuning the frequency of the injected signal, the 3rd harmonic can be made to move around 2.052 GHz. As it was close to the frequency, mixing phenomenon was observed. As it continued to move closer to the free running oscillation, subharmonic injection locking took place.

For comparisons, the center parts of the locked and unlocked spectra are plotted side by side in Fig. 3. As can be seen, the

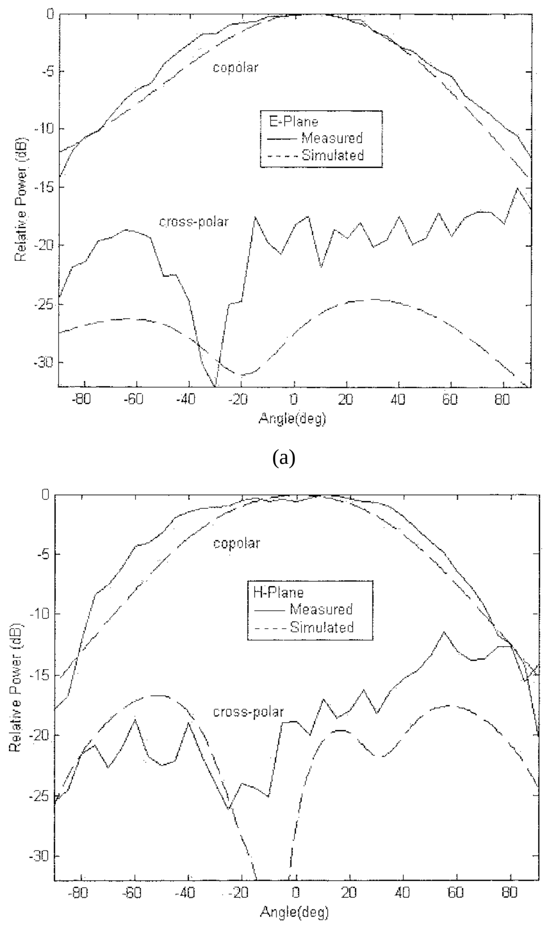

Fig. 5. Radiation patterns of the proposed structure. (a) E-plane and (b) H-plane.

locked signal is much purer and more stable than the free running signal, implying the much smaller noises with the injection locking.

Attempts were made to measure the phase noise of the unlocked and locked signals using a spectrum analyzer, Rohde & Schwarz FSP. However, because of strong frequency drifting of the unlocked signal, values of its phase noise could not be obtained. This indicates that the unlocked signal was not stable. On the other hand, when the subharmonic injection locking was on, the frequency drifting was greatly reduced and the phase noise was found to be −98 dBc/Hz at 10 KHz offset.

The locking range was also measured. Under the bias condition that $V_{ds} = 5$ V, $V_{g1s} = -0.95$ V and $V_{g2s} = 0$, the measured result are plotted in Fig. 4. The locking range is as high as 1.27% when the injected signal is at the level of −3 dBm.

The effective isotropic radiated power (EIRP) of the active antenna was measured to be 5.6 dBm. The radiation patterns of the structure were measured in an anechoic chamber and also simulated with Ansoft HFSS 8.0. The measured and simulated patterns corroborate with each other quite well, which validates the experimental results. Results are shown in Fig. 5. The measured E-plane 3 dB beamwidth is about 60° and the H-plane about 80°. The cross-polarization in both planes were less than −15 dB within the beamwidth.

V. Conclusion

A dual-gate MESFET self-oscillating active antenna for RF transmission is successfully demonstrated. It was found that the free running oscillation can be locked by an injected low power signal at its subharmonic frequency, leading to a low-noise and stable self-oscillating AIA. Without much complexity in biasing and layouting, the dual-gate MESFET provides adequate design flexibility to achieve both a good oscillation performance and a wide locking range in a single design, which is not the case with a single-gate MESFET. Although further optimization of the circuit is possible, the proposed design shows a new use of DGMESFETs for RF and microwave integrated circuit designs in low-cost RF transceiving applications.

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