INJECTION-LOCKED SELF-OSCILLATING DOUBLER (ILSOD) AND ITS APPLICATION FOR ACTIVE DOUBLER ANTENNA

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Abstract

In this paper, we present a novel design of frequency doubler and its application for active doubler antenna. Both frequency doubler and active doubler antenna are based on the injection-locking approach, therefore, they can yield with very high conversion gain. This injection-locked self-oscillating double (ILSOD) is analyzed using harmonic-balance (H-B) method to calculate its output spectrum and locking bandwidth. Simulation results are shown in good agreement with measurement results. For active doubler antenna, the patch antenna is shown not only a radiating element but also a resonator to reject the fundamental frequency in the self-oscillating doubler.

I. Introduction

Active antenna array is known an efficient approach to generate microwave or millimeter wave energy by combining individual active antenna elements [1, 2]. In order to synchronize each solid-state oscillator in the active element, injection locking becomes an effective method to lock all the solid-state oscillators to an external stable source [3, 4]. In this paper, a novel design of high conversion gain frequency doubler is presented based on the injection-locked oscillator (ILO) approach as an injection-locked self-oscillating doubler (ILSOD). The application of this ILSOD for active doubler antenna is also presented.

It is known that Volterra-series method is suitable for the analysis of MESFET ILO operated in the fundamental mode [5]. As for the subharmonically ILO, an efficient state equation method was developed in [6]. However, ILSOD is operated in a strongly nonlinear mode, usually with FET under pinched off. These two methods are then not adequate to accurately calculate the ILSOD output spectrum. In this paper, the formulation to analyze ILSOD is derived using harmonic-balance (H-B) method. In addition, circuits of ILSOD and active frequency doubler antenna are implemented. The measurement results of ILSOD are shown in good agreement with the simulation results to have a conversion gain about 25 dB.

II. Design of injection-locked self-oscillating doubler and active doubler antenna

The ILSOD and active doubler antenna are designed using NE32684A low noise package-type

PHEMT. The substrate has ε_r=2.5 and 62mil in thickness. The selection of low dielectric constant substrate is to have efficient radiation for active doubler antenna.

As shown in Fig. 1, both ILSOD and active doubler antenna use a series feedback to cause oscillation. In order to enhance the doubler output power, two different length of microstrip lines L1 and L2 are designed at the PHEMT source terminal. L2 is of quarter-wavelength long at the fundamental frequency. Hence, it becomes an open circuit, and L1, which is of shorter length, determines the oscillation frequency. For a series feedback oscillator, point A in Fig. 1 is required to have a low impedance. A five-section high-low impedance quarter-wavelength transformer is then designed at the output port. At the second harmonic (or doubler output) frequency, the PHEMT is source grounded to reduce the feedback loss, and the quarter-wavelength transformer becomes the output matching circuit.

For active doubler antenna design, the high-low impedance transformer is replaced by a rectangular patch antenna with resonant frequency at the second-harmonic frequency. The patch feed line is then properly designed to have a low impedance at point A as that for the ILSOD.

In the analysis, the nonlinear equivalent circuit of NE32684A is first extracted from the DC and RF measurements. The nonlinear elements in the PHEMT equivalent circuit are Cgs, ids, and Gds. In order to accurately predict the ILSOD output power, the DC I-V relation is fitted by the seventh-order Curtice model. The formulation of ILSOD using H-B method is derived with the nodal harmonics to the fourth-order in order to calculate the ILSOD output spectrum to the third-order harmonic frequency. In the simulation, the free-running oscillation solution of ILSOD is acquired first. It is then used as the initial condition to solve the ILSOD output spectrum.

III. Measurement and simulation results

Table 1 lists the simulation and measurement results of a free-running self-oscillating doubler. They are shown in good agreement. Figure 2 are the simulation and measurement results of ILSOD with injection signal power level at –20 dBm. They are basically shown in a good agreement. The conversion gain is shown over 25 dB.

In the measurement of active doubler antenna performance, the radiation power of active doubler antenna is measured with a spectrum analyzer. The measurement system is calibrated with reference horn antennas. The EIRP of active doubler antenna is then calculated using the Friis formulation to give about 14.4 dBm at 5.9 GHz. This agrees with the predicted value, since the patch antenna has a gain about 8.77 dB and ILSOD output power is about 5.63 dBm. The injection signal is –20 dBm at 2.95 GHz, hence the conversion gain is about 35 dB.

IV. Conclusions

In this paper, we develop the analysis of ILSOD using the H-B method. Compared with the Volterra-series method, H-B method is shown more suitable to analyze strongly nonlinear circuits and it can accurately calculate the ILSOD output spectrum and locking bandwidth. This novel ILSOD not only has a very high conversion gain but also can be integrated as an active antenna to find its applications for spatial power combining.

References

[1] K. Chang, K. A. Hummer, and G. Gopalakrishman, "Active radiating element using FET source integrated with microstrip patch antenna," Electronic Letters, vol.24, pp.1347-1348, Oct. 1988.

[2] J. A. Navarro and K. Chang, *Integrated Active Antennas and Spatial Power Combining*, John Wiley & Sons, New York, 1996.

[3] K. Kurokawa, "Injection locking of microwave solid-state oscillators," Proc. IEEE, vol.61, pp.1386-1410, Oct. 1973.

[4] R. Adler, "A study of locking phenomena in oscillators", Proc. IEEE, vol.61, pp.1380-1385, Oct. 1973.

[5] C. C. Huang and T. H. Chu, "Analysis of MESFET injection-locked oscillators in fundamental mode of operation," IEEE Trans. Microwave Theory and Tech., vol.42, pp.1851-1857, Oct. 1994.

[6] Y. R. Yang and T. H. Chu, "Locking performance analysis of MESFET subharmonically injection-locked oscillator," IEEE Trans. Microwave Theory and Tech., vol.47, pp.1014-1020, July 1999.

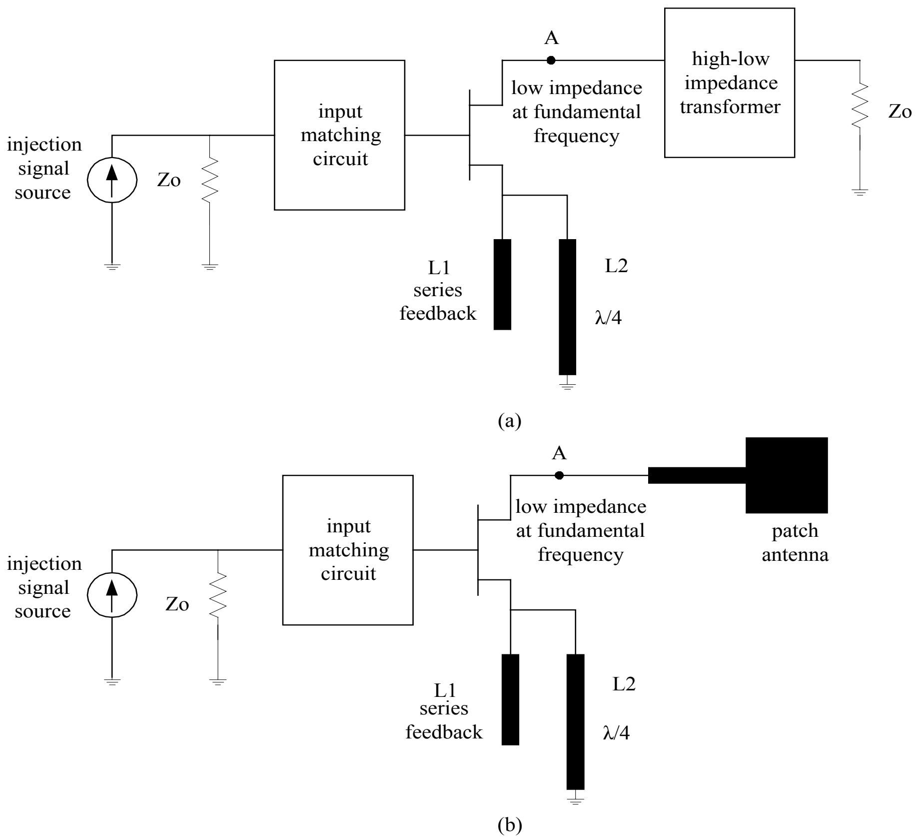

Fig. 1 Schematic circuits of (a) injection-locked self-oscillating doubler and (b) active doubler antenna.

	Free-running frequency (f_0)	Output power at f_0	Output power at $2f_0$	Output power at $3f_0$
Simulation results	3.065 GHz	-8.87 dBm	5.2 dBm	-14.1 dBm
Measurement results	2.952 GHz	-11.64 dBm	5.95 dBm	-19.74 dBm

Table 1 Simulation and measurement results of self-oscillating doubler.

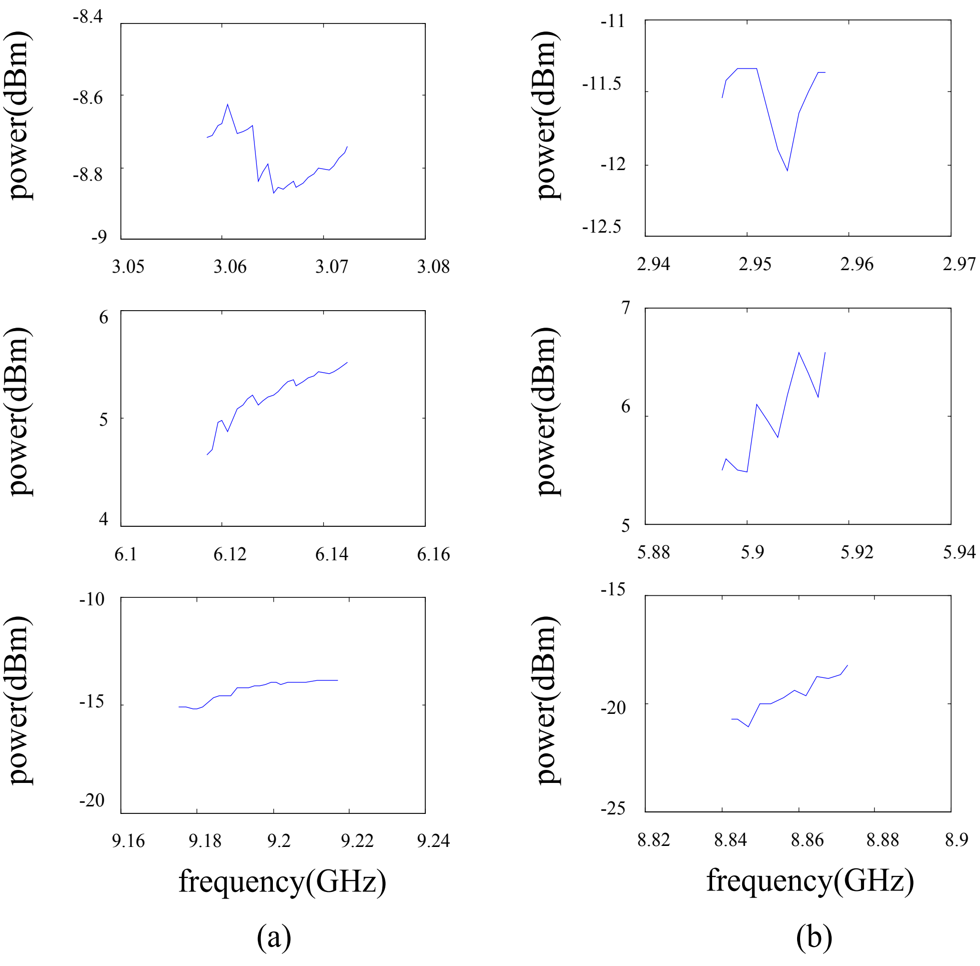

Fig. 2 (a) Simulation and (b) measurement results of ILSOD for the output power at fundamental, second harmonic and third harmonic frequencies. The injection signal power level is -20 dBm.