An Nth-harmonic Oscillator Using An N-push Coupled Oscillator Array with Voltage-clamping Circuits

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Abstract — **Push-push oscillator is commonly used for implementing a second-harmonic oscillator. By combining two out-of-phase oscillators, their fundamental frequency components are canceled and the second-harmonic components are enhanced. This structure can be extended to triple-push, quadruple-push and hence N-push harmonic oscillators. From the oscillator injection-locking phenomenon, the relative phase between coupled oscillators can be controlled by the oscillator free-running frequency. As the output phase-shifted version signals are properly shaped and combined, the desired harmonic components are constructively added and lower-order harmonic components are canceled. This structure can be viewed as the general case of push-push oscillators. Since the output power is combined in a passive circuit, it does not suffer from the power limit of the output device in the cascade structure. The desired harmonic component can be selected by tuning the relative phase of the coupled oscillators and the conductive angle of the voltage-clamping circuit. The second-harmonic, third-harmonic and fourth-harmonic oscillators are designed and verified experimentally.**

I. INTRODUCTION

For microwave and millimeter-wave communication and radar systems, higher frequency signal sources are required in pace with the constantly increased data rates. There are two main approaches to achieve high frequency signal source. One is to design an oscillator with high fundamental frequency. Another is to design a harmonic oscillator.

At millimeter-wave, fundamental oscillators suffer from low Q-factor, insufficient device gain and higher phase noise. For harmonic oscillators, since the oscillators are operated at lower frequency, the high Q-factor, high device gain and low phase noise are more reachable. Furthermore, the output frequency can even excess the device maximum oscillating frequency (f_{max}) [1].

There are two major structures for harmonic oscillators, cascade structure, and parallel structure. Taking the second-harmonic oscillator as an example, oscillator-doubler topology is the cascade structure and push-push oscillator [1] utilizes parallel structure. Both of them are widely used to double a fundamental oscillation frequency. Although they share the same advantage mentioned above, push-push oscillator has less functional blocks such as frequency doubler and filter. This leads to a compact circuit size. Additionally, the output signals from two oscillators are combined in a passive circuit without suffering from the power limit of the output device in a frequency doubler.

In a push-push oscillator, two identical oscillators are arranged anti-symmetrically. By combing the two out-of-phase oscillation signals, the fundamental frequency components are canceled out, and the second-harmonic components are added constructively.

In this paper, this structure is extended to an Nth-harmonic oscillator. For an Nth-harmonic oscillator, N oscillators with proper phase relation are arranged in parallel. The relative phases among the signal paths are properly controlled by a coupling network and tuning the oscillator free-running frequencies. In addition, the desired nonlinear effect is enhanced by the voltage-clamping circuits.

Triple-push oscillator in [2] is reported by describing the three identical oscillators operated with one even mode and two odd modes. However, the coupling phenomenon among oscillators is analyzed by nonlinear injection-locking theory [3] in this paper rather than the linear mode analysis in [2]. From this point of view, the relative phase is controlled by tuning the oscillator free-running frequencies instead of by suppressing or enhancing the three linear modes using a symmetric topology or impedance analysis.

Followings in this paper, Section II describes the design principle. Section III is the detailed circuit implementation. Section IV shows the experimental results and Section V gives the conclusions.

II. DESIGN PRINCIPLE

The operation of the proposed Nth-harmonic oscillator is illustrated in Fig. 1. For an Nth-harmonic oscillator, an array of N coupled oscillators is used to produce N

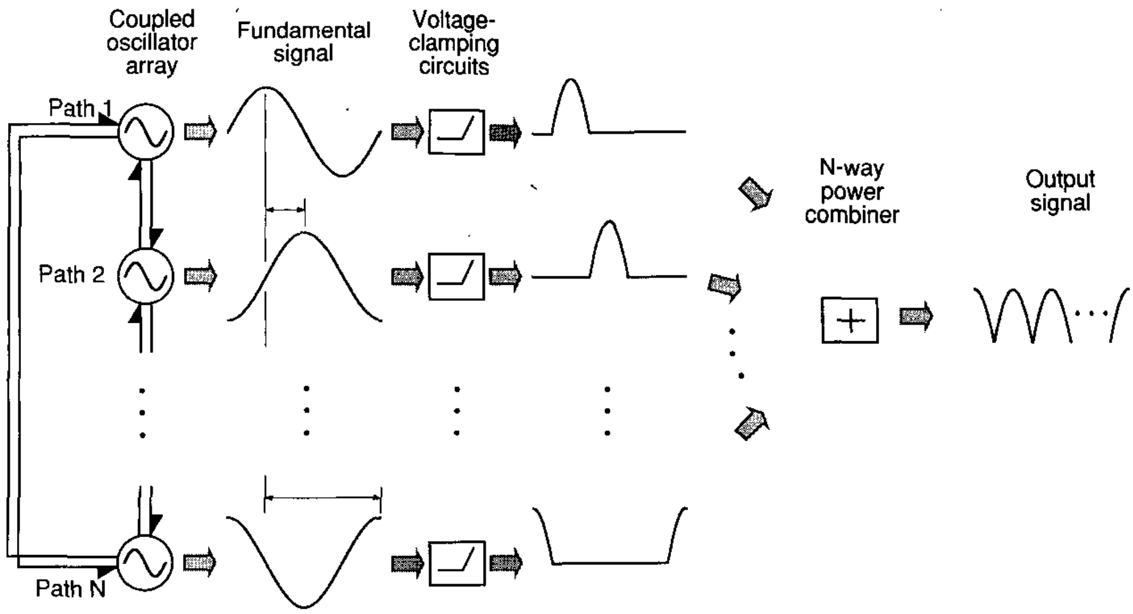

Fig. 1. Block diagram of an Nth-harmonic oscillator.

duplicates of oscillation signals with 360°/N phase difference between adjacent elements.

Following the oscillator in each path, a voltage-clamping circuit is used to control the conductive angle of the output signal. Comparing to the conventional push-push oscillator, which only utilizes the harmonic component in the oscillation signal, this voltage-clamping circuit can enhance the nonlinear effect. The optimal clamping voltage depends on which harmonic is desired [4]. Usually, the voltage-clamping circuit is operated as a class C amplifier (or class B for the second-harmonic oscillator). Another advantage of the voltage-clamping circuit is that the transistor operated as a class C amplifier is closed to a unilateral two-port network. Therefore, the output power combining circuit and inter-stage matching circuits can be designed independently. The pulling effect is also reduced due to the isolation between the load and the oscillators.

While combining the output signals from N signal paths, the desired harmonic components are added constructively and the lower-order harmonic components are canceled out due to the symmetry of the signal phases. The typical phasor diagrams for a third-harmonic oscillator are shown in Fig. 2. For push-push oscillators, anti-symmetric phase between the two oscillators is easy to achieve. Some of them are achieved by using dielectric resonators (DR) [5]. As N>2, the phase control should be treated as a nonlinearly coupled oscillators problem [3]. For Fig. 2, in

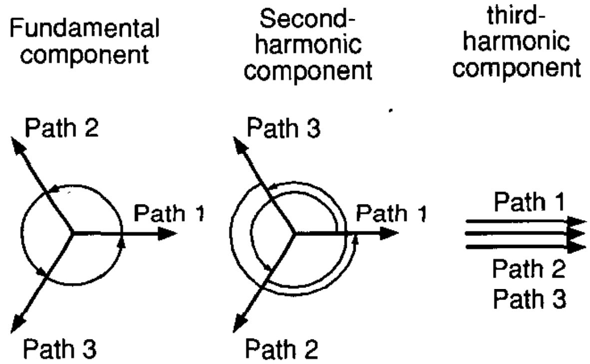

Fig. 2. Phasor diagrams for a third-harmonic oscillator.

practice, these three oscillators are not identical, and the relation of oscillation signals does not follow Fig. 2 as the DC power is turned on. Instead, the relative phases are tuned to the desired situation in Fig. 2 following the theory of injection-locked oscillator.

From [6], the total phase noise of the N coupled oscillators can be lowered by 1/N under proper coupling condition. After multiplied by the harmonic relation, the phase noise of the harmonic output signal becomes degraded by an N factor as that of the fundamental signal of a single oscillator. With a stable reference signal, the harmonic oscillator can operate at injection locked mode.

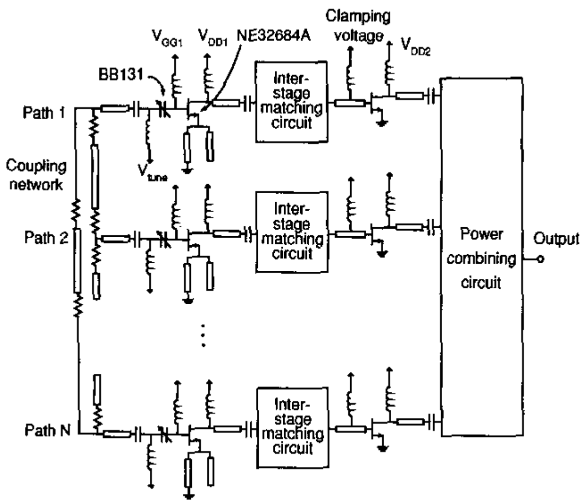

Fig. 3 Schematic diagram of an Nth-harmonic oscillator.

The phase noise is then determined by the reference signal in this condition.

III. Circuit Implementation

The schematic circuit diagram of the proposed Nth-harmonic oscillator is shown in Fig. 3. In this paper, second-harmonic, third-harmonic and fourth-harmonic oscillators are designed. NE32684A HEMT devices are used for the oscillators and voltage-clamping circuits in a FR4 substrate.

Series feedback at transistor source terminal is used to produce negative resistance for oscillation. A short stub provides a DC return path, and an open stub makes the source terminal series with desired impedance. BB131 varactor diode is used for tuning the oscillator free-running frequency. The coupling network is implemented by transmission lines terminated with resistors. Common-source class C (or class B) amplifiers are utilized in the voltage-clamping circuit.

IV. Experimental Results

Since the harmonic oscillator structure proposed is general for any order of the harmonic signals, second-harmonic, third-harmonic and fourth-harmonic oscillators are verified experimentally in this paper. Figure 4 shows the output spectrum of a second-harmonic oscillator. The clamping voltage is –0.7 V, which is closed to class B operation. The second-harmonic signal level is 5.67 dBm, and the fundamental signal level is –36.88 dBm with about 42 dB lower.

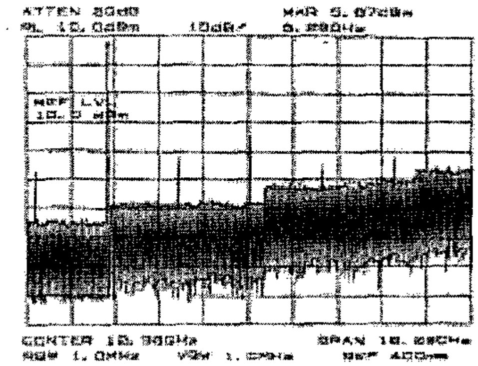

Fig. 4. Output spectrum of the second-harmonic oscillator.

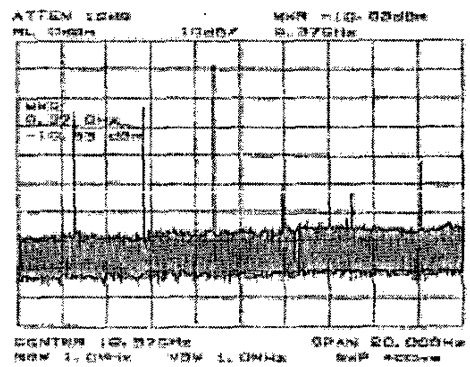

Fig. 5. Output spectrum of the third-harmonic oscillator.

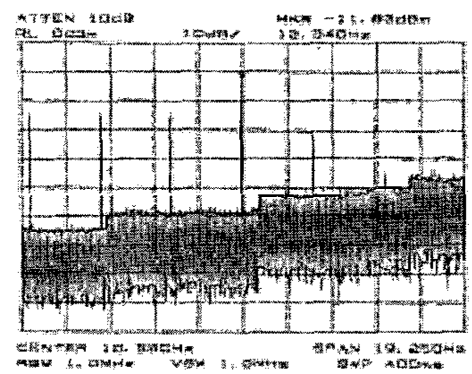

Fig. 6. Output spectrum of the fourth-harmonic oscillator.

Figure 5 shows the output spectrum of a third-harmonic oscillator. The clamping voltage is –0.95 V. The third-harmonic signal level is –10.83 dBm, and the fundamental signal level is –25.67 dBm, which is about 15 dB lower than the third-harmonic signal level. The second-harmonic component is also suppressed according to Fig. 2.

Figure 6 shows the output spectrum of a fourth-harmonic oscillator. The clamping voltage is –1.1 V. The fourth-harmonic signal level is –10.83 dBm, and all the fundamental signal level, the second-harmonic signal level and the third-harmonic signal level are below –25 dBm.

The result of second-harmonic oscillator shows good performance with high desired signal level and suppressed fundamental signal. For the third-harmonic and fourth-harmonic oscillators, although the output signal levels are not as high as expected, the suppression of undesired harmonic components are all about 15 dB. The low output signal level is caused by the high dielectric loss of FR4 substrate. The lower-order harmonic suppression levels are affected by the unequal power level in each signal path.

V. CONCLUSION

By extending the operation principle of push-push oscillators to triple-push, quadruple-push and hence N-push oscillators, an Nth-harmonic oscillator is developed using a coupled oscillator array and voltage-clamping circuits. From the injection-locking phenomenon of oscillators, relative phase between coupled oscillator array elements can be controlled by the coupling network and the oscillator free-running frequencies. As the phase-shifted version signals are properly shaped and added, the desired harmonic components can be combined constructively with lower-order harmonic components suppressed. This structure can be viewed as the general case of push-push oscillators. The desired harmonic component is selected by tuning the relative phase of the coupled oscillators and the conductive angle of the voltage-clamping circuit. The second-harmonic, third-harmonic and fourth-harmonic oscillators are designed and verified experimentally.

ACKNOWLEDGEMENT

This work is supported in part by the National Science Council, Republic of China, under Grant NSC 91-2219-E-002-030 and by the Ministry of Education under Grant 89-E-FA06-2-4-6.

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