Novel Frequency Doubler using Feedforward for Fundamental Frequency Component Suppression

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Abstract — **Feedforward techniques are applied to a microwave frequency doubler for the first time. The feedforward branch is composed of 2 couplers and 1 phase shifter to adjust the phase and cancel the fundamental signal at the output of a single-ended doubler. This technique is experimentally demonstrated in the 1-to-2 GHz frequency. Compared to the single-ended doubler, the experimental results show more than 50 dBc fundamental signal suppression with only a small drop in conversion gain.**

I. INTRODUCTION

There is a great demand for high spectral purity signals in microwave and millimeter-wave communication and radar systems. Frequency multipliers are widely used in a variety of applications, especially in frequency translation circuits, in order to extend the frequency limit of fixed- or variable-frequency low phase-noise oscillators. Several doubler techniques have been studied in the literature [1]-[6]. Active multipliers, in general, provide conversion gain and wider bandwidth compared to the varactor diode type. The nonlinear transconductance is the most important mechanism for a harmonic generator. Active doublers, such as FET doublers, are normally used at a bias point in the vicinity of pinch-off, allowing the active devices to generate a high level of the even harmonic. There are many doubler circuit design techniques. A quarter-wavelength open-circuit stub is often used in a single-ended doubler to suppress the fundamental frequency at the output [1]. Another popular doubler design is a balanced doubler. In this topology, the fundamental frequency is canceled out because of the summation of odd harmonics which are out-of-phase at the output of the circuit [2]-[3]. However, these doublers generally provide only 25dBc of fundamental signal suppression due to the practical limitations of open-stubs and balun circuits in the single-ended and balanced doublers, respectively. For fully monolithic transceivers it is highly desirable to increase the fundamental suppression without employing filters.

In this paper, a new method of fundamental frequency suppression in a frequency doubler is proposed. The use of the feedforward technique is demonstrated for the substantially elimination of the fundamental frequency component at the output. By adapting the feedforward technique widely applied for distortion cancellation in amplifiers [7]-[9], the fundamental signal at the output of the doubler is dramatically reduced. The design of the doubler and the fundamental frequency component suppression using the feedforward technique are presented in section II. The circuit implementation is presented in section III. The measured results and a discussion are given in section IV. The measured results show that more than 50dBc fundamental frequency suppression can be achieved.

II. DESIGN

A. *Single-ended doubler design*

The doubler design is based on an FET active device biased in the vicinity of pinch-off. This leads to an output signal rich in harmonics. Fig. 1 shows the doubler circuit configuration. The output of the active device is optimally matched so that maximum output power can be obtained at the designed harmonic, $2f_0$. This output matching network also functions as a bandpass filter, providing some suppression of the fundamental and other harmonic frequencies.

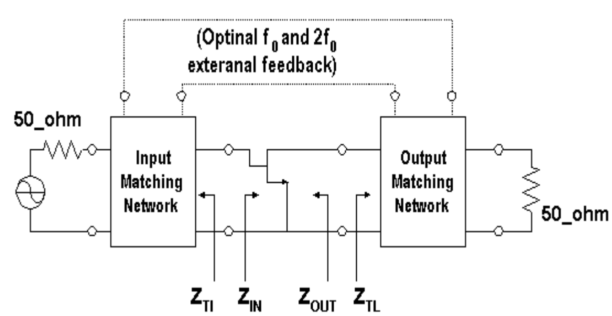

Fig. 1. Single-ended doubler circuit configuration.

The input matching network is used to achieve matching into the gate of the device at the fundamental frequency. Practically, the input port and output port of the doubler are conjugately matched at the fundamental frequency and second harmonic frequency, respectively. An important aspect of this circuit is that this doubler configuration utilizes external feedback. Due to the transistor internal feedback, external feedback is incorporated for counteracting the parasitic feedback effects [5]. This eliminates the second harmonic parasitic feedback loss [6]. However, the use of second harmonic feedback involves a direct trade-off between the conversion gain and bandwidth. In this case the external feedback is employed in order to increase the conversion gain for the 1-to-2 GHz doubler. The doubler design in this work focuses on using the feedforward technique to dramatically reduce the fundamental signal at the output.

B. Feedforward technique for fundamental frequency suppression in frequency doublers

The feedforward technique is widely used for distortion cancellation in feedforward amplifiers [7]-[9]. It is adapted here to cancel the unwanted fundamental signal at the doubler output. Fig. 2. illustrates the feedforward technique for fundamental signal suppression in the frequency doubler. The input signal is coupled into a variable phase branch, before being fed into the doubler. At the output, the two branches both produce a fundamental component. By using two couplers and a phase shifter, the signal in the variable phase path can be tuned to almost completely cancel the unwanted fundamental signal component from the doubler.

If the amplitude and phase of the fundamental frequency components from the two paths are equal and 180° different, respectively, the two signals cancelled in the output coupler, resulting in near-perfect fundamental frequency suppression.

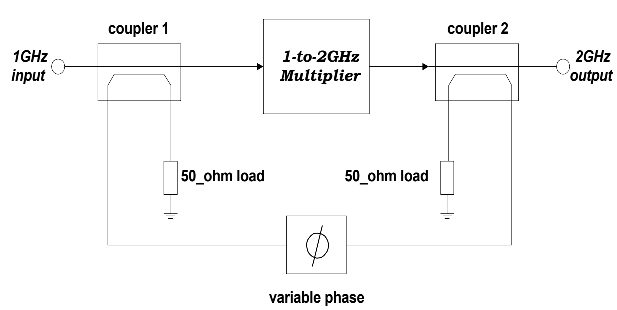

Fig. 2. Feedforward technique for fundamental signal suppression in frequency doubler.

In other words, the degree of fundamental frequency suppression in the frequency doubler is dependent on the amplitude and phase balance of the fundamental frequency component between the feedforward branch and the doubler itself.

III. IMPLEMENTATION

The 1-to-2 GHz frequency doubler is designed and constructed on FR4 using SIEMENS CFY30 GaAs FETs. A transmission line with coupling capacitors is used to implement the external feedback. The input and output matching at the fundamental and second harmonic frequency, respectively, were designed using harmonic-balance CAD to achieve the optimum conversion gain.

Next, a pair of 10dB couplers and the phase shifter were constructed, operating at 1 GHz. A reflection-type analog phase shifter was implemented using a Lange coupler and varactor diodes. Fig. 3 shows the phase shifter layout configuration. Due to the tuning voltage at the varactor diode, the phase is variable between -35° and +140° and the insertion loss is varied between 1.9 and 0.07 dB as shown in Fig. 4.

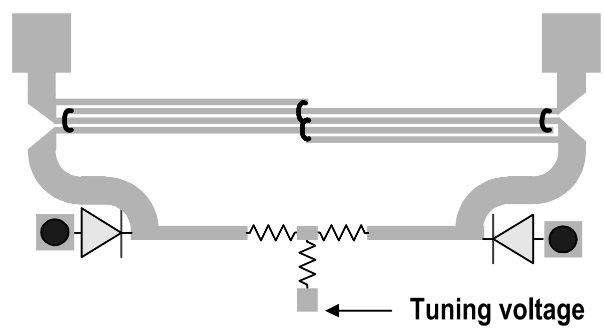

Fig. 3. The layout of phase shifter at 1 GHz

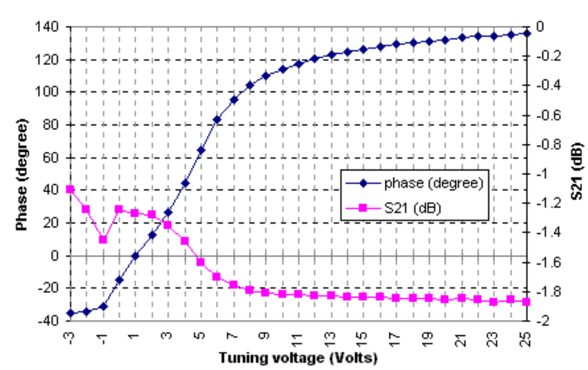

Fig. 4. Phase and insertion loss of phase shifter.

IV. Measurement Results and Discussion

The doubler circuit was biased at V_{DS} = 3.0 V and V_{GS} = -2.2 V, relative to a pinch-off voltage of -2.0 V. An input power level of –1dBm was applied to the doubler. Fig. 4 shows the output spectrum of the frequency doubler without the feedforward applied. The power level of the fundamental component is –26.17 dBm in this case. This measured result is taken from an HP8563E spectrum analyzer, which is connected via a 3 dB attenuator and a cable with 0.5 dB loss. Therefore, this doubler provides 0.5 dB gain.

To investigate the fundamental frequency suppression technique, the two couplers and phase shifter were connected as shown in Fig. 2. The phase shifter was tuned by varying the voltage applied to the varactor diodes. After adjusting the relative phase of the fundamental frequency components from the feedforward path and the doubler path, the signals from the two paths are combined using the second coupler.

Consequently, the output of the second coupler is observed. Fig. 5 shows the output spectrum of the doubler using the feedforward technique. The power level of the second harmonic component is –5.17 dBm whereas that of the fundamental frequency component is now –65.17 dBm, with the phase of the feedforward path set to about 85°. A conversion loss of 0.67dB was obtained from this experiment.

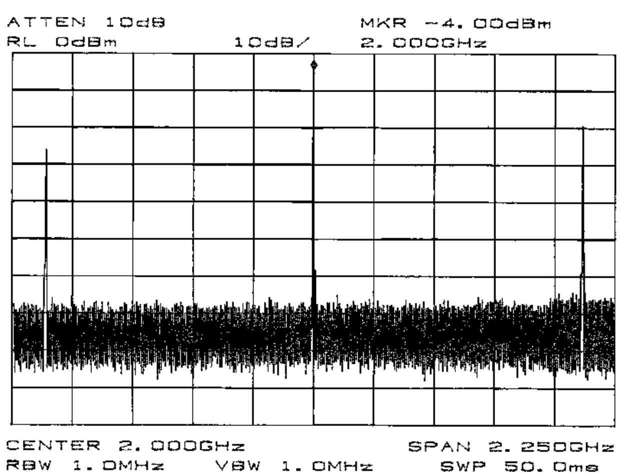

Fig. 4. Output spectrum of the 1-to-2 GHz doubler without the feedforward technique (with a 3 dB attenuator and 0.5 dB cable loss at the ouput)

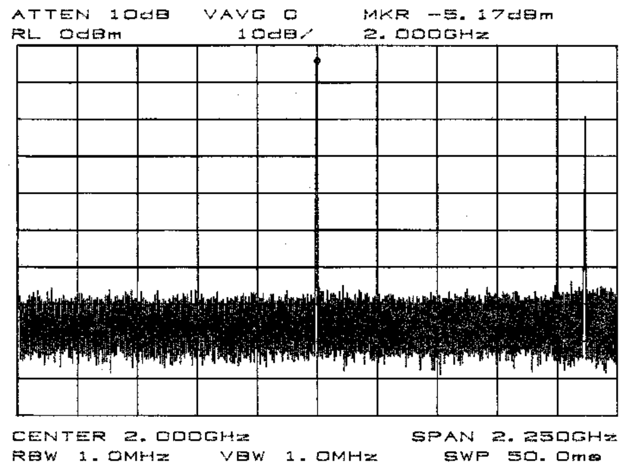

Fig. 5. Output of the 1-2 GHz doubler with feedforward (with a 3 dB attenuator and 0.5 dB cable loss at the output)

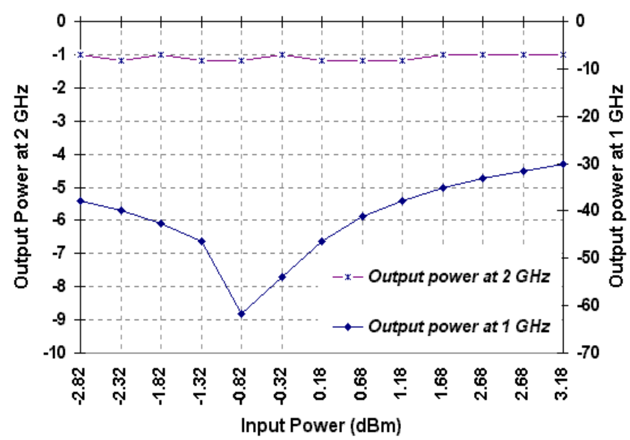

Fig. 6. Measured output of the frequency doubler as a function of the input power level.

Comparing the fundamental frequency power level of the doubler with and without the feedforward branch, the fundamental frequency component is substantially improved, with more than 50 dBc achieved at an input power level of –0.82 dBm. Owing to the loss in the additional components, the second harmonic power level is attenuated by 1.17 dB.

Finally, the proposed frequency doubler with the feedforward technique is also measured as a function of input power. Fig. 6 shows a graph of the output power at the fundamental and second harmonic frequencies vs. the input power, and more than 25 dBc is achieved across the whole range.

V. Conclusion

This paper presents a technique to eliminate the fundamental frequency component in a frequency doubler. The use of the feedforward technique is proposed to be a convenient way to solve the problem associated with the purity of the output signal of the frequency doubler. The concept of this technique is dependent upon the amplitude and phase balance of the fundamental frequency component between the feedforward and doubler branches. The measured results demonstrate the effectiveness of this proposed technique. It is shown that the fundamental frequency component at the output of the second coupler is dramatically reduced, with more than 50dBc being achievable. In addition, this design technique is simple and can be wide-band. However, the drawback in the use of the feedforward technique in the doubler is the tuning sensitivity, and further work is needed to address this.

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