Frequency Mixer Based on Doppler Effect

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***Abstract*— In this letter, we have proposed and demonstrated a novel mixer that requires no local oscillator (LO), but mixes the radio frequency (RF) with its Doppler shifted frequencies on a nonlinear reconfigurable composite right/left-handed transmission line, on which a moving reflective surface is controlled by an external digital circuit. An incident RF encounters a frequency shift when reflected from this moving surface and a difference frequency between the incident frequency and Doppler shifted frequency is generated on this nonlinear transmission line. This kind of mixer has the advantage in high frequency and cognitive radio applications since an LO is not required, meanwhile the intermediate frequency is also tunable electronically.**

***Index Terms*— Mixer, nonlinear transmission lines.**

I. Introduction

A MIXER is the key component in the heterodyne type of receivers and transmitters, which have been widely adopted in communication, radar, and imaging systems [1]–[4]. By down converting the received signal to lower frequency band, where it can be amplified or processed more effectively, the mixer in the heterodyne receiver enables demodulating the information carried by the high-frequency signal. Traditional mixers apply the nonlinearity of the Schottky barrier diodes or field-effect transistors to generate the difference frequency between the input radio frequency (RF) signal and a local oscillator (LO) [5], which could be expensive and difficult to realize in high frequency [6], [7].

The rapidly evolving wireless communication is addressed by the cognitive radio (CR) approaches, which require a frequency synthesizer with an LO to span over a wide-frequency band. Whereas, an LO supports a wide tuning band could be very challenge and its harmonics are considered as the primary source of signal distortion [8]–[10]. Early studies on reducing the complexity of LO include self-heterodyne system and self-oscillating mixers (SOMs). In the former scheme, the transmitter sends the LO with the modulated RF and

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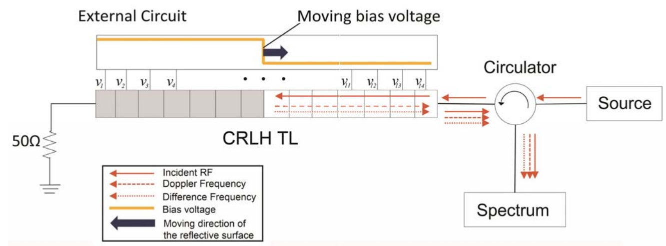

Fig. 1. Schematic of the proposed mixer structure with signal flow. The $v_i\,(i = 1, 2 \ldots 14)$ are the bias voltages supplied by the external circuit. The white TL units lie in right-handed (normal) passband, while the gray units lie in band gap. The reflective surface is between the two different kinds of TL units and can be tuned by the external circuit. The circulator is a unidirectional device for detecting the reflected wave.

the intermediate frequency (IF) is generated in the receiver by self-mixing [11], [12], which eliminates the need of the receiver LO. However, half of the transmission power should be used for LO carrier transmission to get the highest IF power [13]. This significant drawback limits the wide use of the self-heterodyne mixer.

An alternative way to down convert the RF signal into IF signal without employing any LO is to make use of the Doppler effect inside a circuit. We have recently demonstrated that a Doppler shifted frequency can be generated on a tunable nonlinear composite right/left-handed transmission line (CRLH TL) loaded with varactors. By fast switching the bias voltages provided by an external digital circuit, a moving reflective surface on the transmission line is bouncing the injected RF signal and generating a Doppler shifted frequency [14]. Due to the nonlinearity of the circuit varactors, a difference frequency between the Doppler frequency and incident RF frequency will be generated. The experimental setup for demonstrating this mixing process is shown in Fig. 1. Naturally, this kind of mixer can be named as a Doppler effect-based mixer.

Different from the SOM, which utilizes a single block to function both the oscillation and mixing [13], [15]–[17], this Doppler effect-based mixer does not need any LO functionality and can down convert the input RF signal to any IF over a certain range, only limited by switching speed of the external digital circuit.

II. Composite Transmission Line Design

We have built such a tunable nonlinear CRLH TL to prove the concept of Doppler effect-based mixer in experiment. The TL is composed of 14 identical units that are fabricated on FR-4 (relative permittivity $\varepsilon_r = 4.75$) substrate with a thickness of $h = 1.6$ mm. As shown in Fig. 2(a) and (b), each unit has a parallel inductor [18], two inductors in series, and three variable capacitance diodes (varactors) BB135 made

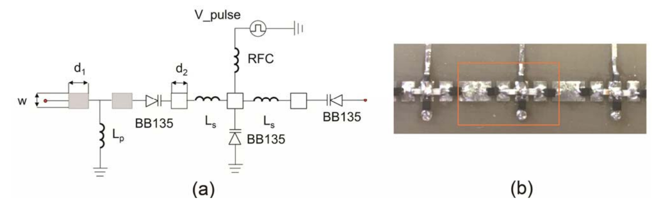

Fig. 2. (a) Schematic of one unit of the CRLH TL, $w = 3$ mm, $L_p = 6.3$ nH, $L_s = 1.5$ nH, $d_1 = 2.5$ mm, and $d_2 = 2$ mm. The RF choke, which is a ferrite bead in this case. (b) Photograph of a part of the transmission line with the orange frame indicating one TL unit.

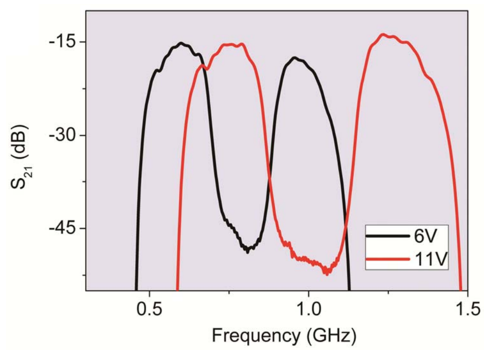

Fig. 3. Transmission in terms of $|S_{21}|$ of the transmission line.

by NXP, whose capacitance is tunable under different bias voltages.

With these tunable varactors, the unit exhibits either right-handed (normal) passband or band gap at 1 GHz under 6- and 11-V bias voltage separately, as depicted in Fig. 3. By setting the bias voltages of the left part of the TL at 11 V and the right part of it at 6 V, a reflective surface is formed on the TL.

Switching the bias voltage of the unit on the right of the reflective surface from 6 to 11 V, the reflective surface moves one unit rightwards. Repeating this switching successively, a reflective surface approaching the right port of the TL is built [14].

III. IF Measurements

According to the Doppler effect, there would be a shifted frequency (Doppler frequency) in the reflected wave, accompanied by the original input frequency reflected at the interface between the TL and the circulator. Following the setup in Fig. 1, we measured the reflected wave with the Keysight spectrum analyzer by using its gate function that can analyze the signal in a certain chosen time domain and frequency range. By injecting 10-dBm RF signal at 1 GHz into the CRLH transmission line, both Doppler frequencies and difference frequencies are observed, shown in Fig. 4. The Doppler frequency varies with the moving velocity of the reflective surface, which could be tuned by the external digital circuit. Due to the nonlinearity of the varactors BB135, the input frequency 1 GHz would mix with the Doppler frequencies as shown in Fig. 4(a) to generate a set of IFs shown in the lower band in Fig. 4(b). The response nearby 0 Hz displayed in Fig. 4(b) is the LO feedthrough. The 1.65-GHz frequency

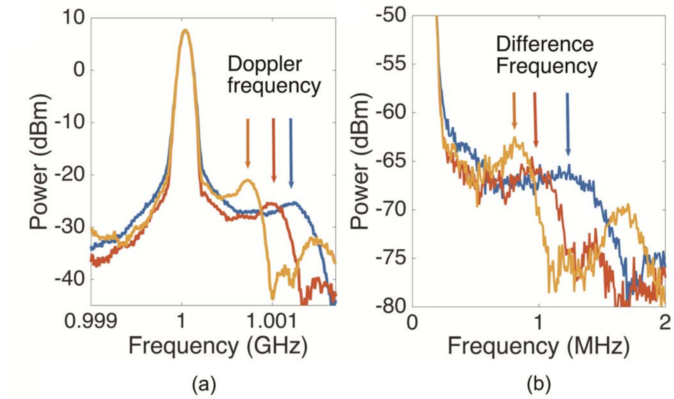

Fig. 4. (a) Measured Doppler frequencies and (b) corresponding difference frequencies at three different velocities of the reflective surface, with blue, red, and yellow curves representing 64.5, 47.3, and 35.5 km/s separately.

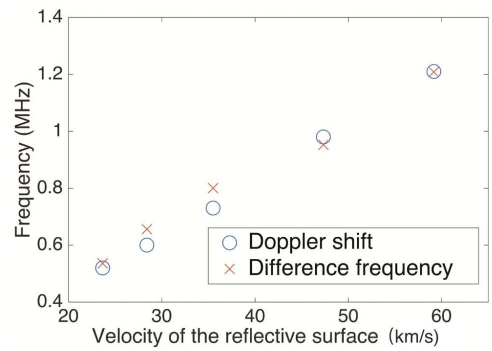

Fig. 5. Comparison of the measured Doppler shifts (blue circles) and the measured difference frequencies (red crossings) when the reflective surface is approaching the source at different moving velocities.

at 35.5 km/s in Fig. 4(b) is the second-harmonic frequency of the IF.

The Doppler frequency can be calculated from the following equation:

$$\frac{f_D}{f_i} = \frac{\upsilon + \upsilon_s}{\upsilon - \upsilon_s} \tag{1}$$

where f_D, f_i, υ, and υ_s are the Doppler frequency, incident frequency, phase velocity of the wave on the CRLH TL, moving velocity of the reflective surface that is positive when the reflective surface is moving toward the source. The phase velocities of the incident and reflected waves are considered the same in the Doppler shift range (about 1.5 MHz). The velocity of the wave can be obtained from the dispersion relation of the CRLH TL with the transfer-matrix method that treats the TL unit as a two-port network with 12 elements [14].

Fig. 5 compares the measured Doppler shifts (difference of the measured incident and Doppler frequencies) and the difference frequencies measured in the lower frequency band. It can be seen that the RF is down converted to lower desired frequencies by tuning the moving velocities of the reflective surface. Though there are some RF signal harmonics and noises from the digital board, the desired IF can be easily filtered out and amplified [19]. The peaks of the difference frequencies at some speeds are not easy to be recognized, which may lead to some slight differences between the Doppler shifts and difference frequencies.

IV. Conclusion

We have demonstrated in experiment a new principle of mixing frequencies by applying Doppler effect instead of loading LO. This Doppler effect-based mixer can be extended to other frequency bands as long as a proper tunable nonlinear CRLH TL can be built. In addition, the IF tunability enables to reduce the number of mixers for different narrow-bandwidth standards in a receiver system [20]. This approach for frequency mixing is attractive in millimeter-wave and terahertz-wave bands since the up-conversion-based LO is expensive and power limited and also in CRs requiring a challenge frequency synthesizer to span over a wide frequency band.

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