# Broadband, Low Spurious Single Sideband Modulation With a Linear Tunable Phase Shifter


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## Abstract

**This paper presents a broadband, low-spurious frequency translation method using a linear tunable phase shifter. The linear tunable phase shifter is based on the left-handed nonlinear transmission line (LH NLTL) and can achieve a very linear phase variation as a function of applied DC bias for a broadband frequency that facilitates a low spurious, broadband frequency translation. Our experiment demonstrates that the LH NLTL enables frequency shift with 30 dB maximum spurious suppression. For any frequency between 3 GHz and 3.8 GHz, the phase shifter can have 0° - 360° linear phase variation and is possible to achieve 100 kHz – 1 MHz frequency shift while the range of spurious suppression is between 21 dB and 30 dB. As the proposed LH NLTL can be fabricated with lumped-elements only, the size is very compact. This circuit will be very useful for microwave instrumentation or coherent communication system where single sideband modulation is required.**



**Keywords :** Frequency translator, linear phase shifter, single sideband, modulation


## 1. Introduction

One of the most important applications of the frequency translator is to generate a false target signal in a velocity deception electronic counter measures (ECM) system [1], in which the target translates the frequency of the incoming signal to give a false Doppler shift information. In addition, a microwave reflectometer system for network analyzers [2], microwave communication systems [3] and frequency scanned antennas [4] may need the frequency translation.

As a sawtooth signal is used to frequency-modulate a signal, a frequency translator should show a perfectly linear phase shift versus applied DC bias [1]. Also, phase variation should be exactly 360 degrees to suppress spurious signals at the output. However, the most phase shifters reported in the literature cannot satisfy all the properties mentioned above and they are not suitable to be a good frequency translator [5, 6].

In [2], the authors demonstrated a frequency translator with a nonlinear transmission line (NLTL) whose structure consists of varactor diodes placed periodically on a transmission line as shunt elements. The frequency translator made with this NLTL type phase shifter works for a wide frequency band, but it has a lot of spurious signals whose magnitudes are quite large at the output. One of the main reasons is that the phase variation versus control voltage is not linear. To minimize spurious signals, the authors had to adjust the modulation signal using a high resolution DAC card [2]. In other words, they used a complex waveform as a phase shifter modulation signal instead of a general sawtooth modulation waveform to minimize spurs.

In [7], the authors demonstrated a very linear phase shifter for a broadband frequency in a compact form. It is based on a device called the left-handed nonlinear transmission line (LH NLTL) [8]. In this paper, we demonstrate a novel method to make a compact, broadband and low spurious frequency translator based on the LH NLTL. Due to its linear phase variation versus bias voltage, spurious frequencies are greatly reduced.

## 2. Broadband, Low-spurious Frequency Translator Theory

### 2.1 LH NLTL for a frequency translator

Figure 1 shows a LHNLTL structure. A key reason to use LH NLTL based phase shifter as a frequency translator is due to its linear phase variation versus voltage and compactness. Figure 1 shows the unit cell of a LH NLTL phase shifter which has two series varactors and a shunt inductor. In [7], the authors demonstrated the phase variation in LH NLTL structure is very linear with the applied DC bias for broadband frequency. This applies to most abrupt and hyper-abrupt varactors.

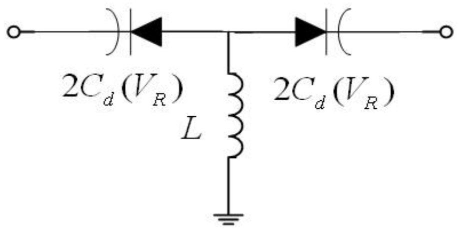


Figure 1. LH NLTL structure

### 2.2 Frequency translator theory

A frequency translator can shift up or down the frequency of a RF signal by a desired amount. A signal whose original frequency ($f_0$) can be increased or decreased by some amount ($f_m$) with a phase modulation. As can be seen in the following equation (1), it is possible to change the original frequency to a new (translated) frequency through the following equation.

$$V_o = \sin(2\pi f_o t + 2\pi f_m t) = \sin 2\pi (f_o + f_m)t. \quad (1)$$

where, $V_o$ is the output of a frequency translator. This function can be realized by applying a sawtooth modulation in a phase shifter, which changes the signal phase from 0º to 360º, then goes back to 0º instantaneously [5]. The amount of frequency shift is dependant on the frequency of sawtooth modulation ($f_m$). Thus, having a phase shifter whose phase varies at least 360º very linearly according to the applied voltage at a certain frequency is essential to minimize the spurs at the output. To have a broadband frequency translator, a phase shifter should show such properties over a broad frequency range.

### 2.3 Extracting a translated frequency

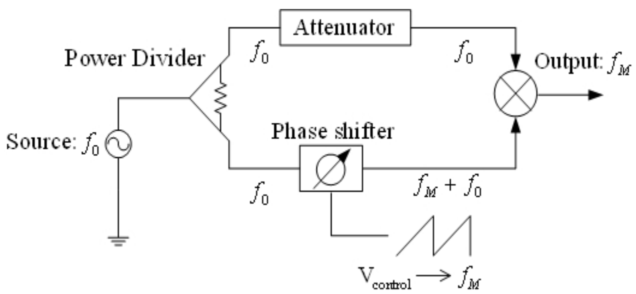


Figure 2. Schematic diagram of a frequency translator to get a modulated frequency ($f_M$).

Figure 2 shows a schematic diagram of our experiment to extract the modulated frequency. The phase shifter is serrodyne modulated at $f_M$. Then the input carrier frequency ($f_0$) changes to $f_0+f_M$ at the output of the phase shifter. By combining this signal with an unmodulated, original signal through a mixer, a pure modulated frequency ($f_M$) sinusoidal signal can be acquired at the output. Due to the insertion loss of the phase shifter, an attenuator is used in the other arm to maintain balance before mixing two signals.

## 3. Experimental results

Figure 3. Fabricated 7-section LH NLTL phase shifter using FR4 substrate.

Our phase shifter shown in Figure 3 is realized on a FR4 board. MACOM hyper-abrupt junction GaAs flip-chip varactor diodes (MA46H120) are attached using conductive silver epoxy. The diode capacitance variation range is from 1.9 pF to 0.67 pF when DC bias voltage changes from 0V to 5V. The capacitance range is different from the spice model given by the manufacturer's datasheet because of parasitic effects caused by the silver epoxy. According to [7], inductor value should be 1.6 nH. Inductors were implemented by connecting 0.11 mm diameter copper wire to the backside ground plane. The fabricated phase shifter shown in Fig. 3 has 7 sections of the LH NLTL unit cell. The circuit size is merely $9\ \text{mm} \times 13\ \text{mm}$.

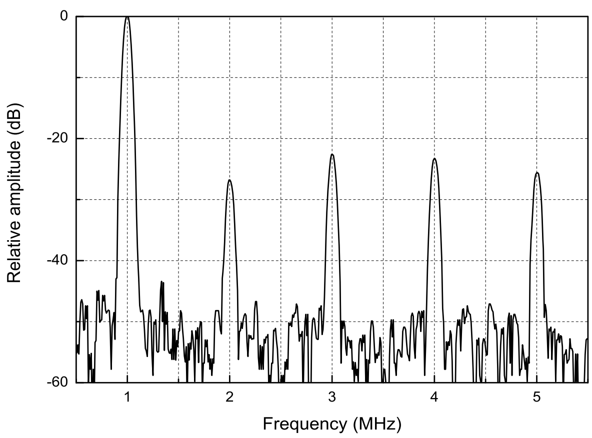


Figure 4. Spectrum of output signal at 3.2GHz when the modulation frequency is 1 MHz .

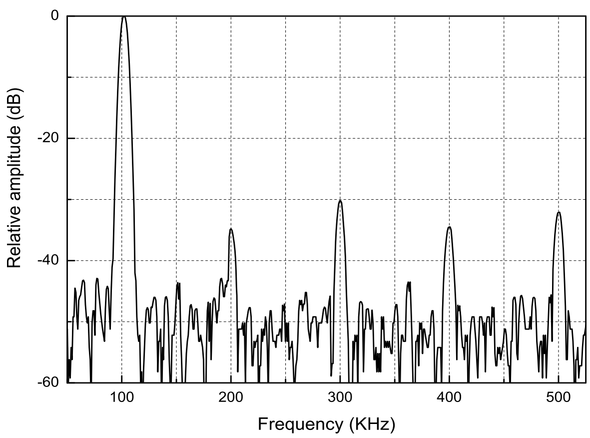


Figure 5. Spectrum of output signal at 3.5GHz when the modulation frequency is100 KHz.

The fabricated phase shifter has a very linear phase variation between 3 GHz – 3.8 GHz. For the frequency range, the phase deviation from a linear line is within ±5° range while it is possible to change the whole 360°. The insertion loss variation for the band is ±2 dB with a maximum loss of a 10.3 dB

For the frequencies between 3 GHz – 3.8 GHz, we have driven the frequency translator circuit shown in Figure 2 with 0 dBm input. The frequency translator worked fine for any modulation frequency between 100 KHz and 1 MHz. For those frequencies, the level of suppression between the translated frequency and the maximum spurious signal ranges from 21 dB to 30 dB. Figures 4 and 5 show frequency spectrum of output signals for 3.2 GHz and 3.5 GHz respectively. The best performance is obtained at 3.5GHz as shown in Figure 5. We used modulation frequency of 100 kHz. The magnitude of the translated signal is around -25 dBm. The maximum unwanted sideband is 30 dB below the desired translated output.

## 4. Conclusion

In this paper, we presented a frequency translator based on the LH NLTL and demonstrated our idea by experiment results. Due to its excellent linearity versus DC bias voltage, the frequency modulated signal has 30 dB difference between the carrier and the spurious without the adjustment of a modulation signal. In addition, the LH NLTL phase shifter is ideal as a frequency translator because this circuit can be made in a compact form and achieve more than 360º by cascading several unit cells. It can be easily made in a monolithic form as it requires only varactors and inductors. Due to its excellent performance as a frequency translator mentioned above, it is an ideal candidate for microwave instruments and velocity deception ECM systems where a compact, low-spurious frequency translator is needed.

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