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Phase Noise Experimental Characterization of CRLH Distributed Oscillators

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ABSTRACT: The phase noise levels of the output signals provided by two CRLH (Composite Right-/Left-Handed) distributed oscillator configurations are measured and compared. The first CRLH oscillator configuration provides two output signals, drain-line and gate-line output signals, available at the ends of the drain-line and gate-line that are not used for connecting the oscillator feedback. The second CRLH oscillator configuration is obtained by adding a Wilkinson power combiner to the first configuration that sums the drain-line and gate-line output signals for a single-output signal, a combined output signal. The experimental results show that the best performance in terms of output power and spectral purity can be obtained for the single-output CRLH oscillator.

1. INTRODUCTION

The distributed oscillator is basically a distributed amplifier with a positive feedback element inserted between the idle drain line port and input gate line port [1–8]. In [9, 10], Composite Right-/Left-Handed (CRLH) circuits are used for the realization of the gate and drain unit cells. The oscillator produces two output signals that can be even added by means of a combiner [11], resulting in a single-output signal with a higher power level. This paper concerns the experimental phase noise characterization of these two CRLH configurations, with and without a power combiner. The paper is organized as follows. In Section 2, the two CRLH topologies are briefly summarized, and the experimental setup for their phase noise characterization is presented. Section 3 is focused on the analysis of the measured phase noise of the realized oscillators; the experimental results are used to compare the performance of these circuits. Concluding remarks are given in Section 4.

2. BACKGROUND AND EXPERIMENTAL SETUP

The microwave oscillator is a key element in high-frequency communication systems. The spectral quality of the produced signal is an important factor for the performance of the signal source, which in turn impacts the performance of the entire system. The parameter conventionally adopted to evaluate the spectral quality is the phase noise [12], which is usually symbolized by $\mathscr{L}(f_m)$, expressed in dBc/Hz, and can be calculated as:

$$\mathscr{L}(f_m) = P_m - P_c \tag{1}$$

where P_c is the signal power, and P_m is the power in a bandwidth of 1 Hz at a frequency offset f_m from the signal frequency, both in dBm.

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The two CRLH distributed oscillators that are compared in this paper in terms of phase noise values are shown in Figs. 1 and 2, where feedback transmission line (FTL) is a transmission line used as a positive feedback element. Note that the oscillator shown in Fig. 1 provides two output signals to the load impedances Z_0, hereafter referred to as the gate-line and drain-line output signals. If these two output signals are summed using a Wilkinson power combiner (WPC), as shown in Fig. 2, a single-output signal of a higher power level is available, hereafter referred to as the combined output signal. In Fig. 2, a transmission line section (TL) is used for phase matching of the two WPC input signals. A detailed description of the ap-

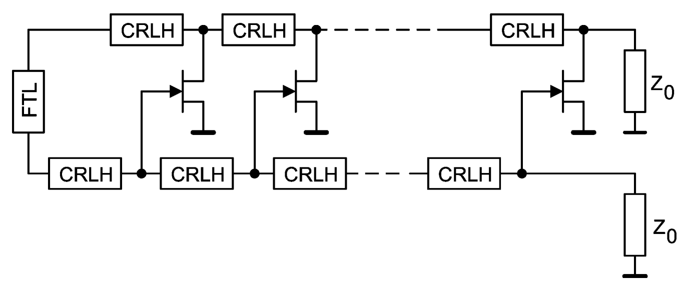

FIGURE 1. The CRLH distributed oscillator with two output signals (drain-line and gate-line output signals).

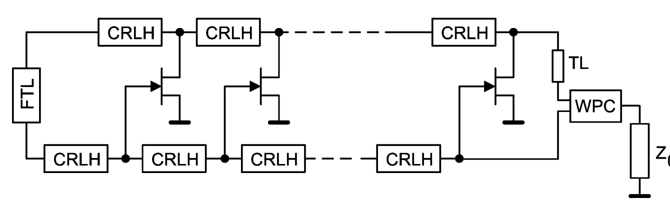

FIGURE 2. The CRLH distributed oscillator with a single-output signal (combined-output signal), obtained from the circuit shown in Fig. 1, by using a Wilkinson power combiner.

(a) (b)

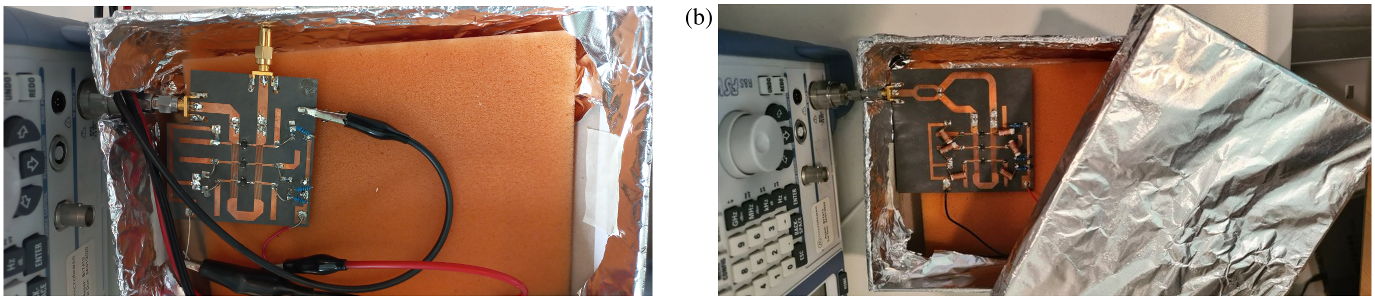

FIGURE 3. (a) The CRLH distributed oscillator with two output signals (drain-line and gate-line output signals) and (b) the CRLH distributed oscillator with a single output signal (combined output signal), both inside the shielding box (top cover removed), prepared for measuring the phase noise of the drain-line and combined output signals, respectively.

TABLE 1. Measured performance of the CRLH distributed oscillators.

Topology / f_m [MHz]	Combined output signal (see Fig. 2) [dBc/Hz]	Gate-line output signal (see Fig. 1) [dBc/Hz]	Drain-line output signal (see Fig. 1) [dBc/Hz]
0.4	-91.4	-91.9	-93.9
0.6	-97	-96.4	-99.5
0.8	-100.6	-98.1	-103.5
1	-101.8	-98.5	-106
Carrier power [dBm]	12.5	10.5	11.5

proach used for modeling and designing these circuits has been presented in [9–11].

For phase noise characterization of the two circuits, the Rohde & Schwarz FSV40-N spectrum analyzer has been used with the following settings: 5 MHz SPAN, 10000 trace points, 35 dB RF attenuator, 18 dBm reference level, 10 ms sweep time, 10 kHz resolution bandwidth (RBW), video bandwidth (VBW), and FFT mode enabled. The detector was set to auto peak mode, and the signal tracking function was activated to lock the sweep's center frequency to the signal. A total of 128 acquisitions were performed and averaged offline in a LabVIEW environment. The final figure of merit, $\mathscr{L}(f_m)$, was calculated based on formula (1), after applying corrections to account for the filter bandwidth and spectrum analyzer settings, including logarithmic display mode and filter shape. The experimental setups for measuring the phase noise at the output ports of the two CRLH distributed oscillators are shown in the two photographs in Fig. 3. Fig. 3(a) is for the two-output signals oscillator, while Fig. 3(b) is for the single-output oscillator. In Fig. 3(a), the drain-line output port is connected to the spectrum analyzer, while a 50 Ω load is connected to the gate-line output port, so that the phase noise of the drain-line output signal is measured. For measuring the phase noise of the gate-line output signal, the gate-line output port is connected to the spectrum analyzer, while a 50 Ω load is connected to the drain-line output port.

The oscillators under investigation have exhibited a non-negligible frequency drift in response to the proximity of a human hand, attributable to capacitive coupling and perturbations in the surrounding electromagnetic field. This phenomenon is consistent to a degree with the observations reported in [13], which underscore the influence of nearby conductive objects on the performance of oscillators based on LC networks. In the present configuration, the dimensions of the CRLH networks employed to define the oscillation frequency introduce susceptibility to external field variations. As demonstrated in [13], the implementation of a grounded metallic shield around key components can effectively mitigate such environmental effects. In accordance with established industry practices, where high-stability oscillators are commonly enclosed in metallic housings, a practical shielding solution was adopted in this work, consisting of a cardboard enclosure lined with aluminum foil (see Figs. 3(a) and (b)). This solution proved effective in suppressing proximity-induced frequency variations and contributed to improved measurement stability.

3. MEASUREMENT RESULTS

For the two oscillator configurations shown in Figs. 1 and 2, the phase noise of the output signal is plotted in Fig. 4 for comparison. These results are summarized in Table 1, where the phase noise measurement results are reported for four values of f_m. For the sake of completeness, the values of the carrier power are also included. From Table 1, the following aspects can be highlighted:

1. The drain-line output signal exhibits not only higher carrier power but also even lower phase noise with respect to the gate-line output signal. Thus, the advantage of using the drain-line output signal instead of the gate-line output

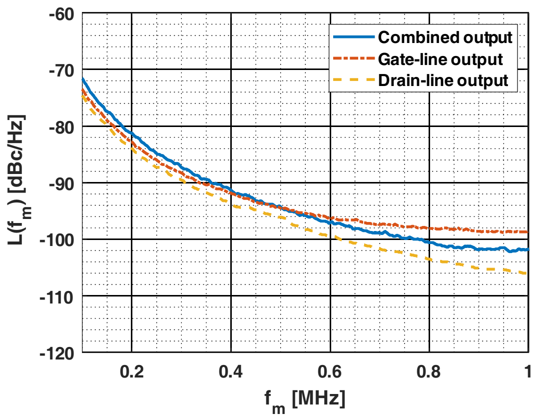

FIGURE 4. Phase noise of the output signals measured for the two CRLH-based oscillators analyzed in this paper.

signal is significant in terms of both output power level and phase noise.

2. The combined output signal exhibits a higher carrier power than both gate-line and drain-line output signals. On the other hand, the phase noise values for the combined output signal are slightly higher than the drain-line signal and slightly lower than or similar to the gate-line signal.

The characterized CRLH oscillator can be compared with published structures. To this end, the oscillator in [7] has been chosen, which is a distributed voltage-controlled oscillator (VCO) with an operating frequency of 2.5 GHz, very close to the frequency of the circuit analyzed in this paper (2.8 GHz). The VCO in [7] has an output power of -9.7 dBm and a phase noise of -106 dBc/Hz at a 1 MHz offset. Comparing these values with the results in Table 1, we can infer that the characterized CRLH configuration has better power performance, for the same phase noise level.

4. CONCLUSION

The performances of two CRLH distributed oscillator circuit configurations were analyzed in terms of the phase noise level. For the first CRLH oscillator, two output signals are available: drain-line and gate-line output signals, while the second CRLH oscillator uses a Wilkinson power combiner, so that there is only a single-output signal, a combined output signal. Analyzing the experimental phase noise values obtained for these resulting three possible output signals, the lowest phase noise was obtained for the drain-line output signal of the CRLH oscillator with two outputs, but the results are very close to those obtained for the single-output CRLH oscillator configuration (the circuit topology with a power combiner). On the other hand, the highest output power was obtained for the single-output CRLH oscillator. Therefore, the CRLH oscillator with a power combiner provides a good compromise between output signal power and spectral quality.

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