A High Linearity Chireix Outphasing Power Amplifier Using Composite Right/Left-Handed Transmission Lines

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***Abstract*— A high linearity Chireix outphasing power amplifier using composite right/left-handed transmission lines (CRLH-TL) is proposed at 2.4GHz. The 180° hybrid power combiner including CRLH-TL is designed to suppress the second and third harmonics. The output matching circuit is optimized for suppressing the second and third harmonics. The output power at the fundamental frequency shows 32.1 dBm, whereas the second harmonic shows -19.5 dBm and the 3rd harmonic -22.3 dBm as simulation results with 20 dBm input power excited. The class-E amplifiers are utilized for maintaining high efficiency for this work.**

I. Introduction

Complex and bandwidth-efficient digital modulation methods used in modern wireless communication systems have considerably increased the linearity requirements of power amplifiers. The substantial loss of transmitter efficiency due to the stringent linearity requirements has forced the industry to look for alternative solutions to alleviate the tradeoff between efficiency and linearity [3]. In particular, power efficiency and linearity of power amplifiers are two key parameters that must be maximized to optimize the communication system's performance. One of the techniques that has been touted as a potential candidate for providing both high linearity and high efficiency is the linear amplification with nonlinear components (LINC) technique. This technique was first introduced under the LINC name by Cox [1] in 1974, but it has roots in the much earlier work of Chireix [2] in 1935. Outphasing LINC amplifier has been the subject of several recent papers.

In the outphasing system, an input signal containing both amplitude and phase modulation is divided into two constant envelope phase-modulated signals. An amplified version of the original signal is achieved by varying the phases of these two signals and summing the amplified branch signals with a passive power combiner. The maximum envelope condition is obtained when the branches are in-phase and the low envelope condition is achieved when the branches are almost antiphase [7]-[10].

In this paper, a CRLH-TL is capitalized to suppress the second and third harmonics for enhancing the linearity. The use of CRLH-TL allows for the manipulation of phase slope and phase offset at desired frequencies. This attribute can be exploited to specify the phase delay of a CRLH-TL at different harmonic frequencies to create the necessary impedance for proper matching network. Using this method a CRLH-TL network can be employed to suppress the second and third harmonics [4].

II. Chireix Outphasing System

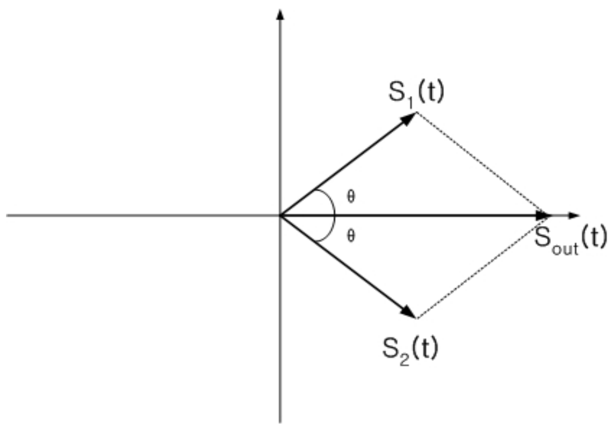

Fig. 1. Vector representation of the outphasing operation.

In the outphasing system, an arbitrary input signal $S_{in}(t)$ is separated into two constant envelope signals $S_1(t)$ and $S_2(t)$, as illustrated in Fig. 1. If the input signal is defined as

$$S_{in}(t) = A(t)\cos[\omega t + \varphi(t)], \qquad (1)$$

then,

$$S_1(t) = V_0 \cos[\omega t + \varphi(t) + \theta(t)] \quad (2)$$

$$S_2(t) = V_0 \cos[\omega t + \varphi(t) - \theta(t)] \quad (3)$$

$$\theta(t) = \arccos[\frac{A(t)}{V_0}] \quad (4)$$

where V_0 denotes the amplitude of the branch signal at peak envelope power. The output signal $S_{out}(t)$ can be written as the sum of $S_1(t)$ and $S_2(t)$ as follows:

$$S_{out}(t) = 2V_0 A(t) \cos[\omega_t + \varphi(t)] \cos\theta(t). \quad (5)$$

Basically, this ideal representation means that if the two amplifier branches are perfectly matched, i.e., their gain and phase characteristics are precisely the same, an amplified replica of the original signal can be achieved as the in phase components add together and the out of phase components cancel each other. A simplified block diagram is shown in Fig. 2 [5].

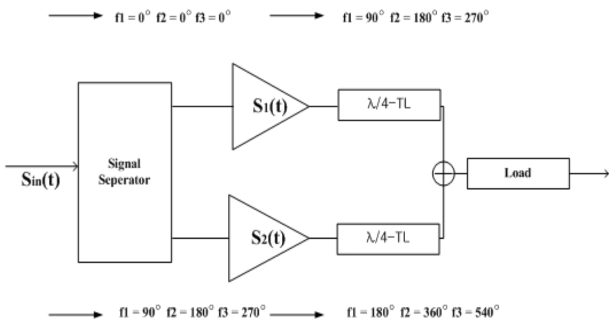

Fig. 2. The conventional outphasing LINC amplifier using 180° hybrid power combiner.(f_1 = fundamental harmonic frequency, f_2 = the second harmonic frequency, f_3 = the third harmonic frequency)

III. POWER COMBINERS

A. 180° *HYBRID COMBINER*

From the signal separator, two input signals have anti-phase signals ($S_1(t)$,$S_2(t)$). In this paper, the phase difference between two inputs is 90°. The phase difference is maintained until passing through the power combiner. Fig. 2 illustrates the phase change for the fundamental, second harmonic and third harmonics after passing through each branch. Each phase of the anti-phase input signals changes so that the output phases of the fundamental, second and third harmonics for $S_1(t)$ are $90°, 180°, 270°$ and those for $S_2(t)$ are $180°, 360°, 540°$ after λ/4-TL power combiner. At the combining section, the fundamental and the third harmonic components of $S_1(t)$ and $S_2(t)$ are combined maintaining 90° phase difference. However, the second harmonics of $S_1(t)$ and $S_2(t)$ are suppressed because phase difference between two signals is 180°. This method has benefit that all even harmonics can be cancelled or decreased. Linearity is therefore improved by this method. However, the fundamental component is also decreased by phase difference. Therefor, we try to improve the linearity by suppressing the third harmonic using CRLT-TL and not decreasing the fundamental component at the same time.

B. *COMBINER USING CRLH-TL*

The CRLH-TL, which is the combination of a left-handed (LH) TL and a right-handed (RH) TL, is proposed in [4]. The equivalent lumped elements model of the LH-TL exhibits positive phase response (phase lead). On the other hand, the RH-TL has negative phase response (phase lag). Therefore, the CRLH-TL can be substituted for the matching network using microstrip lines. For example, Fig. 3 shows the lumped elements model for the CRLH-TL when one unit cell (N = 1) [4] is used.

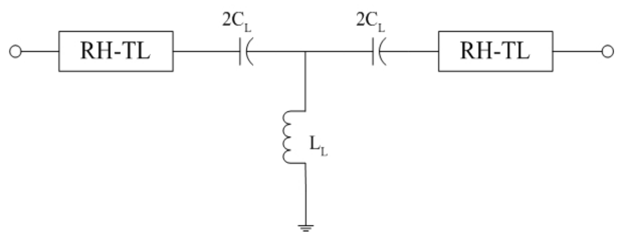

Fig. 3. The lumped elements model for the CRLH-TL when N=1.(L_R is the inductance of RH-TL)

When the series and shunt resonances are equal : $L_R C_L = L_L C_R$, the structure is said to be balanced [5]-[6]. In the balanced condition, we can approximate the phase response :

$$\phi_C = \phi_R + \phi_L \quad (6)$$

$$\phi_R \approx -N2\sqrt{L_R C_R} \quad (7)$$

$$\phi_L \approx \frac{N}{2}\sqrt{L_R C_R} \quad (8)$$

Z_{0L} and Z_{0R} are the characteristic impedance defined as

$$Z_{0R} = \sqrt{\frac{L_R}{C_R}} = Z_{0L} = \sqrt{\frac{L_L}{C_L}} = Z_0^{CRLH} \quad (9)$$

If the operating frequencies are chosen to be f_1 and f_2, the phase response will -ϕ_A be at f_1 and -ϕ_B at f_2 in unit matching TL [4]. The phase response of the CRLH-TL at two frequencies can be written as

$$\phi_C(f_1) = -\phi_A \quad (10)$$

$$\phi_C(f_2) = -(\pi + \phi_B) \quad (11)$$

From (6)-(8), (10) and (11) can be written as

$$P = 2\sqrt{L_R C_R} \quad (12)$$

$$Q = \frac{N}{2}\sqrt{L_L C_L} \quad (13)$$

$$-Pf_1 + \frac{Q}{f_1} \approx -\phi_A \quad (14)$$

$$-Pf_2 + \frac{Q}{f_2} \approx -(\pi + \phi_B) \quad (15)$$

For given f_1 and f_2, solving for P and Q in (13) and (14) to obtain [4] :

$$P \approx \frac{(\pi + \phi_B)f_2 - \phi_A f_1}{f_2^2 - f_1^2} \quad (16)$$

$$Q \approx \frac{\frac{(\pi+\phi_B)}{f_2} - \frac{\phi_A}{f_1}}{\frac{1}{f_1^2} - \frac{1}{f_2^2}} \quad (17)$$

Choosing N to satisfy the conditions [4], P, Q, Z_{0R} and Z_{0L} are used to determine C_L, L_L and physical length of the RH TL. Finally, the CRLH-TLs were placed in combiner network instead of microstrip lines to implement the suppression of the 2nd and 3rd harmonics. Fig. 4 shows the combiner using CRLH-TL. When $S_1(t)$ passes through the CRLH-TL, the phase of $S_1(t)$ has 180° at the fundamental frequency and 180° at the second harmonic. When two signals ($S_1(t)$, $S_1(t)$) are combined, fundamental components are in phase. Phase difference between the 3rd harmonics is almost 180°, therefore the third harmonic is effectively suppressed.

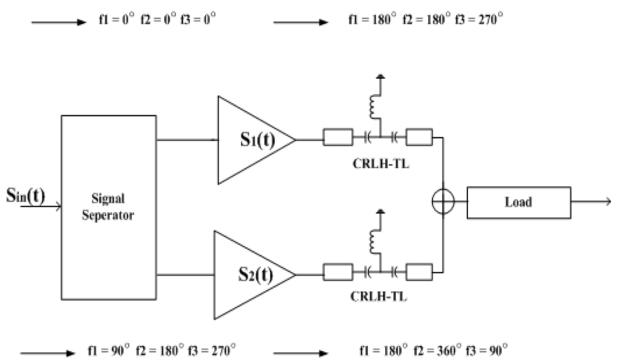

Fig. 4. The proposed LINC amplifier using CRLH-TL combiner.(f_1 = the fundamental harmonic frequency, f_2 = the 2nd harmonic frequency, f_3 = the third harmonic frequency.)

IV. SIMULATION RESULT

The proposed LINC power amplifier was simulated using Agilent ADS at 2.4GHz. The transistor model used is Mitsubishi MGF2430 and the substrate used is RT Duroid 5880 substrate. At first, two class-E power amplifiers are employed with 180° hybrid combiner, Then the $\lambda/4$ transmission line is converted by CRLH-TL as shown in Fig. 4.

Fig. 5 shows that the proposed LINC power amplifier suppresses the second and third harmonics successfully. Using CRLH-TL, the third harmonic is suppressed successfully and the fundamental component decreases by about 1dBm.

Fig. 6 shows the simulated output powers and PAEs of proposed LINC power amplifiers using CRLH-TL and $\lambda/4$-TL for the combiner. In simulated results, maximum PAE of 48.2 % at 2.4 GHz frequency was obtained for the LINC with CRLH-TL. This result shows improvement compared to the

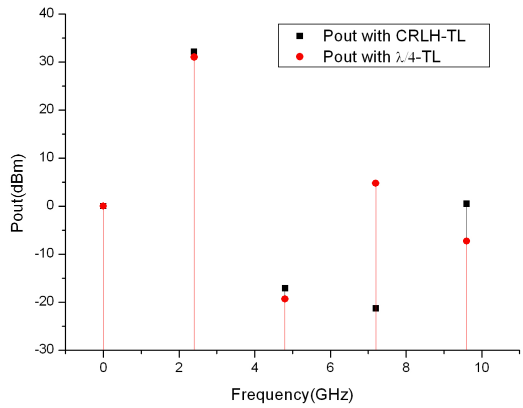

Fig. 5. Output powers of the proposed and conventional LINC amplifiers.

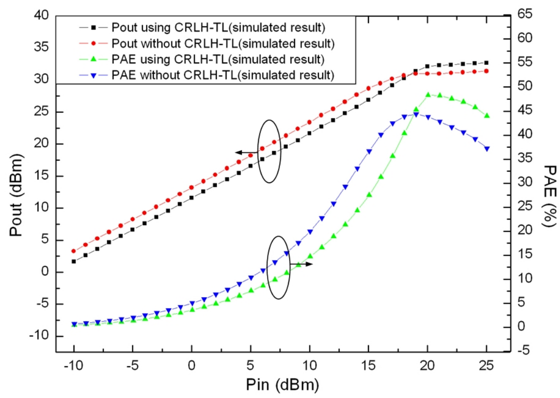

Fig. 6. Simulated results (2.4GHz) of LINC power amplifiers using CRLH-TL and $\lambda/4$-TL

maximum PAE of 44.2 % of the LINC power amplifer with $\lambda/4$-TL. At the input power of 20dBm, the output was observed maximum 32.1 dBm at 2.4 GHz. This result is about 1 dBm greater than that of conventional LINC power amplifer with $\lambda/4$-TL. It shows that the phases of two branch amplifiers are equal.

Fig. 7 shows that the third intermodulation distortion (IMD3) of the proposed LINC amplifier with CRLH-TL was considerably improved compared to that of the LINC amplifier with λ-TL. Maximum improvement is 11dB at 15dBm output. It proves the improvement of linearity. It is because the second and third harmonics were suppressed successfully by incorporating CRLH-TL.

V. CONCLUSION

The high linearity Chireix outphasing power amplifier using CRLH-TL was presented at 2.4GHz. The 180° hybrid power combiner employing CRLH-TL was designed for suppressing the 2nd and 3rd harmonic frequencies. The output matching

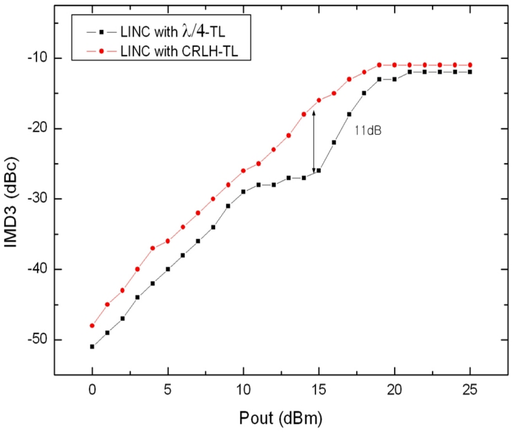

Fig. 7. IMD3 of the proposed LINC amplifier with CRLH-TL and the LINC amplifier with $\lambda/4$-TL.

circuit was designed for suppressing the 2nd and 3rd harmonic frequencies. The output power of the fundamental shows 32.1 dBm, whereas the 2nd harmonic shows -19.5 dBm and the 3rd harmonic shows-23.3 dBm as a simulation result at 20dBm input power.

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