Feedforward Amplifier using Equal Group-Delay Signal Canceller

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Abstract **— In this paper, a new signal canceller that can matches an out-of-phase and a group delay of two path signals simultaneously is proposed. The simultaneous matching of the out-of-phase and the group delay time between two paths can makes a broadband signal cancellation possible. A feedforward linearizing power amplifier that adopts the proposed signal cancellers is fabricated on IMT-2000 base-station transmitting band. The main signal cancellation (or the 1st) loop of the fabricated feedforward amplifier cancel input signal more than 26.3dB and the intermodulation distortion (IMD) signal cancellation (or the 2nd) loop cancel IMD signal more than 15.2dB for 200MHz bandwidth. With the two-tone signals amplification process, the C/I ratio of the amplifier is improved 20.8dB, where the two tones are 2115MHz and 2165MHz, respectively.**

I. INTRODUCTION

Modern wireless communication systems utilize digital modulation techniques employing complex coding schemes to maximize the channel throughput for the available capability. Also a broader channel bandwidth is used for more data transmission than before. These linear modulation schemes increase the peak to average ratio of RF signal and envelope variation of signal is changed seriously.

A power amplifier is usually operated at a saturation region for maximum efficiency and high output power. As the power amplifier operates close to the saturation region, a degradation of linearity becomes significant due to nonlinear characteristic of the power amplifier. Therefore, to the power amplifier designer, high linearity and high efficiency are critical issues. Hence compromise between power efficiency and linearity must be considered. Or a linearization technique to recuperate nonlinearity of power amplifier is the only solution.

Among numerous amplifier linearization techniques, a feedforward linearization has been extensively used in base-station amplifier because of its intrinsic advantages on providing a high linearity and a broadband linearizing bandwidth[1][2]. Although the feedforward method can linearizes over the broadband than any other linearizing methods, the bandwidth for more than 20dB reduction of IMD components is limited in practice.

Previously, several broadband feedforward applications having a phase equalizer of delay line or a multi-stage hybrid have been presented[3][4]. However, the phase equalizer has a difficulty in matching with phase characteristic of the power amplifier, because the amplifier consists of several transistor stages and its phase characteristic is changed according to the operating condition and different case by case. The multi-stage 3dB hybrid uses only broadband characteristics of 3dB hybrid. The previous approach focus an amplitude and an out-of-phase matching between two paths of the feedforward loop, but ignores a group delay matching of the feedforward loop.

In this paper, a new signal canceller that matches the broadband out-of-phase and group delay characteristic simultaneously between two paths of the feedforward loop is proposed. The simultaneous out-of-phase and group delay matching characteristics provides the broadband signal cancellation.

II. OPERATION THEORY OF LINEARIZER

A. Analysis of feedforward equivalent loop

Basically, the feedforward amplifier consists of two signal cancellation loops that have the same operating principle, and the same frequency components are cancelled in each loop. Fig. 1 shows a block diagram of the feedforward amplifier, where a principle of operation is well illustrated with two-tone spectrum. Fig. 2 shows an equivalent loop of the feedforward amplifier to analysis the amplitude, the phase and the group delay matching. Assuming that the signal in each path of the equivalent loop is sinusoidal, and then the signal in two paths can be written as.

$$V_1 = V_{1m}\cos(\omega_0 t - \varphi) \quad (1)$$

$$V_2 = V_{2m}\cos(\omega_0 t - \theta) \quad (2)$$

where $V_{1m} = V_{2m} + \Delta V$, $\theta = \varphi + \pi + \Delta\varphi$.

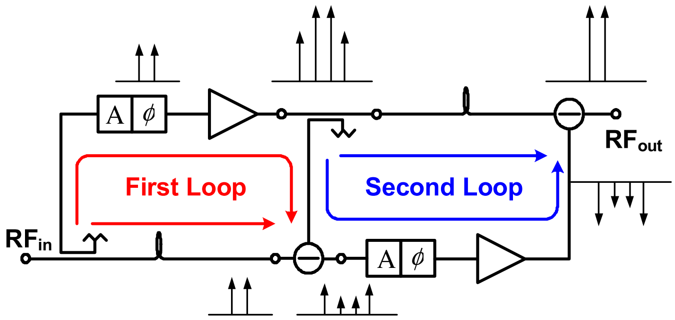


Fig. 1. The block diagram of the feedforward amplifier.

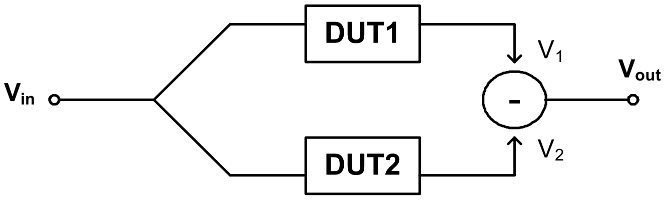


Fig. 2. The equivalent loop of the feedforward amplifier.

If there are amplitude, phase and delay mismatching between two paths, then the cancellation performance(CP) can be written as below[5].

$$CP = 10\log[1+\alpha^2 - 2\alpha\cos\{2\pi(\lambda_{err}/\lambda_o)(1-f/f_o)\pm\Delta\varphi\}] \quad (3)$$

Where f_o, λ_o are an center frequency and a wavelength, respectively. α , $\Delta\varphi$, λ_{err} are the amplitude, the phase, and group-delay mismatching parameter, respectively. The amplitude and the phase matching are important for single frequency component cancellation, but group delay time matching is also important parameter for broadband signal cancellation. Fig. 3 is a good example to show the importance of group delay matching, what is Wilkinson canceller that is one of the usual signal canceller. The phase and the group-delay transmission characteristic of Wilkinson canceller that one input port of Wilkinson combiner is connected $\lambda_o/4$ transmission line are measured. If the amplitude of two paths is matched, then a perfect signal cancellation would be obtained around the center frequency. But the signal at ±100MHz frequency offset would partially be cancelled. Though two input path have equal amplitude and a linear phase characteristics, but its group-delay time is different. As a result, we know that the group delay matching is also important on the broadband signal cancellation as well as amplitude and phase matching.

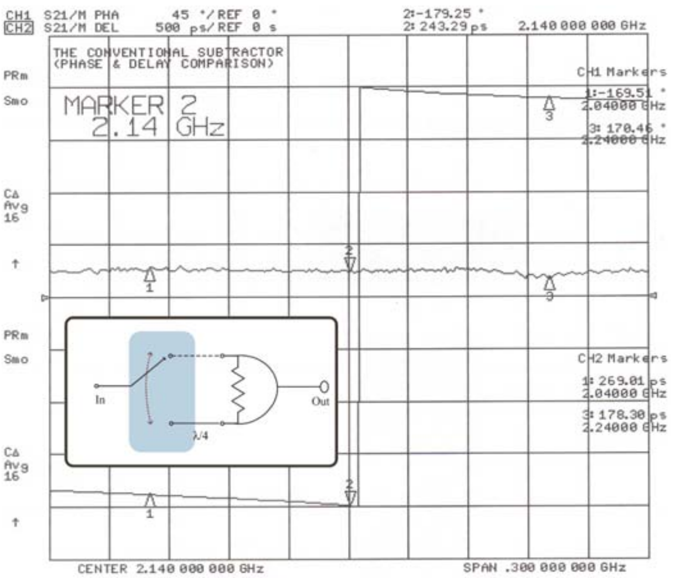
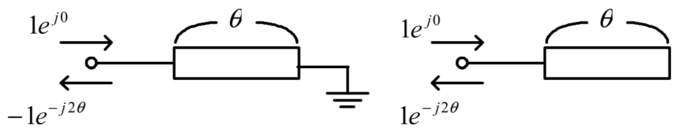


Fig. 3. The phase and the group-delay transmission characteristic of Wilkinson canceller.

B. Design of an equal group-delay signal canceller

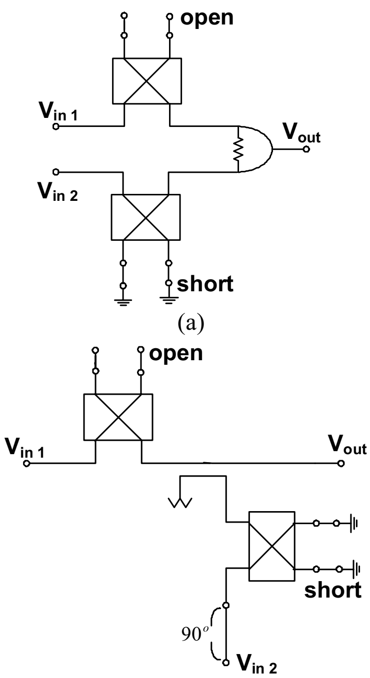
Fig. 4 shows a transmission line that is terminated with short and open condition, respectively. If the transmission line is the same electrical length, the reflection signals are $-1e^{-j2\theta}$ (or $1e^{-j(2\theta\pm\pi)}$), $1e^{-j2\theta}$, respectively. The phase difference between the reflection signals is out-of-phased, and the group-delay time is the same. Even though the input signal condition and the length of transmission line are changed, these properties aren't changed.



(a) (b)

Fig. 4. The reflection signal comparison of transmission line terminated with short and open condition.

Fig. 5 shows the 1st loop and the 2nd loop signal canceller block diagram of the feedforward amplifier. Two input signals in the 1st loop canceller are fed to a 3dB hybrid of which the coupling and the through port are terminated with open and short condition, respectively. Two output signals of the 3dB hybrid are out-of-phased, and fed into in-phase combiner. Since two input signals in the final output port experience the same group delay time and have out-of-phase, so a perfect signal cancellation is obtained. The 3dB hybrid is used to obtain good reflection characteristic. The operating principle of the 2nd loop canceller is almost the same except 90° phase compensation of a loose coupling hybrid. The match of magnitude between two paths is obtained with variable attenuator in front of the error amplifier.



(a)

(b)

Fig. 5. The proposed signal canceller in (a) the 1st loop, (b) the 2nd loop.

III. Measured Results

To show the validity of the feedforward amplifier that adopt the proposed signal cancellers, several circuits are fabricated such as main amplifier, error amplifier, variable attenuators and variable phase shifters as well as the proposed 1^{st} and 2^{nd} canceller. For comparison, the Wilkinson combiner and a 10dB hybrid are also fabricated as the conventional signal cancellers, where the operating frequency is 2.14±0.1GHz.

The fabricated main and error amplifier consists of 4-stage transistors. The measured gain, the maximum return loss, and 1dB compression point (P_{1dB}) are 44.7±0.3dB, -14dB, and 28.7dBm, respectively. The variable attenuator and the variable phase shifter are fabricated with reflection type for good reflection characteristics. The maximum attenuation and the phase shifting range are 15dB and 120^{o}, respectively.

Fig. 6 shows only the 1^{st} loop signal cancellation characteristic using the conventional canceller, Wilkinson canceller, and the proposed signal canceller. The input signal is cancelled more than 16.4dB within 2.14±0.1GHz with the conventional Wilkinson canceller. But the proposed canceller cancels signal more than 26.3dB within the same frequency range. The frequency bandwidth that the signal is cancelled more than 20dB is broader than 300MHz.

Fig. 7 just shows only the 2^{nd} loop signal cancellation characteristic using the conventional canceller, the 10dB hybrid, and the proposed canceller. The input signal is cancelled more than 11.7dB within 2.14±0.1GHz with the conventional canceller. But the proposed canceller cancels more than 15.2dB within the same frequency range. The frequency bandwidth that the signal is cancelled more than 20dB is improved from 94MHz to 173MHz.

With a two-tone signals amplification process, the improvement characteristic of a carrier-to-intermodulation (C/I) ratio is also measured. Where the two-tone signals are 2115MHz and 2165MHz, respectively. Before the error path of the 2^{nd} loop is connected, the $(C/I)_{3rd}$ of amplifier is just 26.84dBc and the output power level is 17.5dBm/tone. When the amplifier is linearized with the conventional cancellers, the $(C/I)_{3rd}$ of amplifier is improved to 42.63dBc. Fig. 8 shows the output characteristics of the feedforward amplifier with and without the conventional cancellers. When the amplifier is linearized with the proposed cancellers, the $(C/I)_{5th}$ of amplifier is improved to 48.03dBc. Fig. 9 shows the output characteristics of the feedforward amplifier with and without the proposed cancellers. With the measurement comparison of (C/I) characteristics between the conventional and the proposed feedforward amplifier, we know that the proposed cancellers improve (C/I) over more broadband.

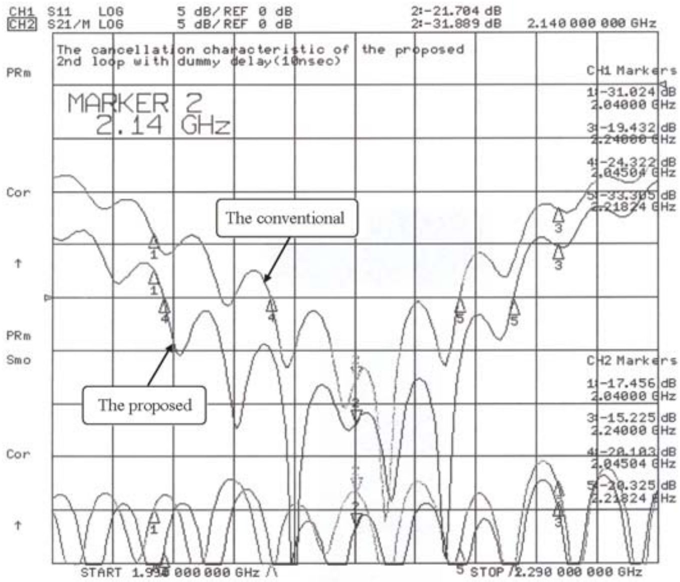


Fig. 7. The signal cancellation characteristic of the 2^{nd} loop with the conventional and the proposed signal canceller.

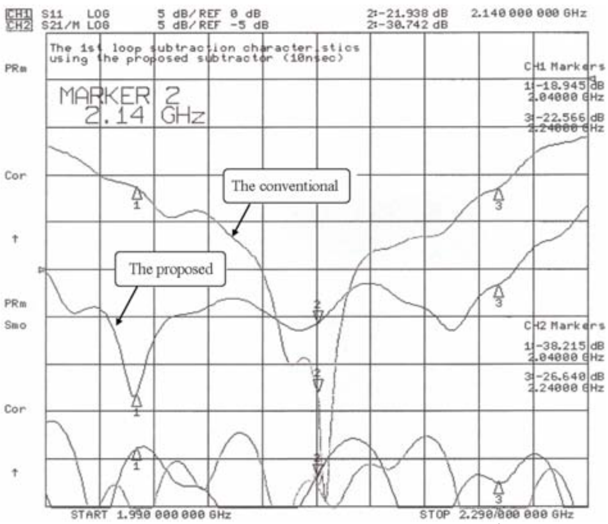


Fig. 6. The signal cancellation characteristic of the 1^{st} loop with the conventional and the proposed signal canceller.

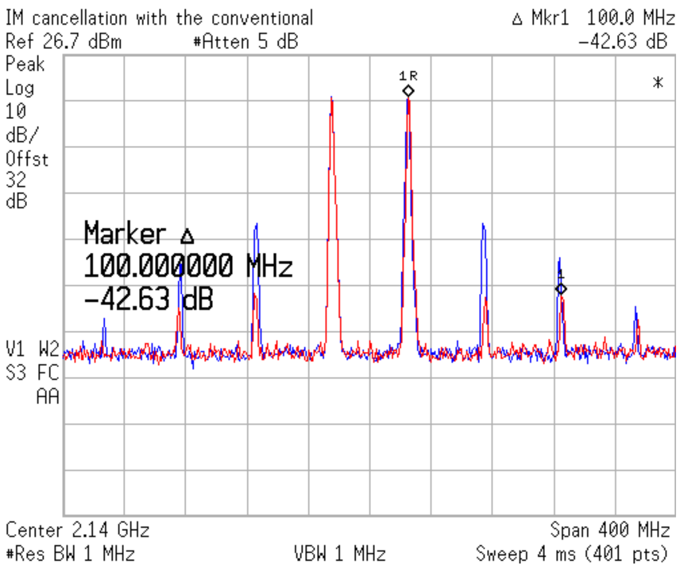


Fig. 8. The output characteristics of the feedforward amplifier with and without the conventional cancellers.

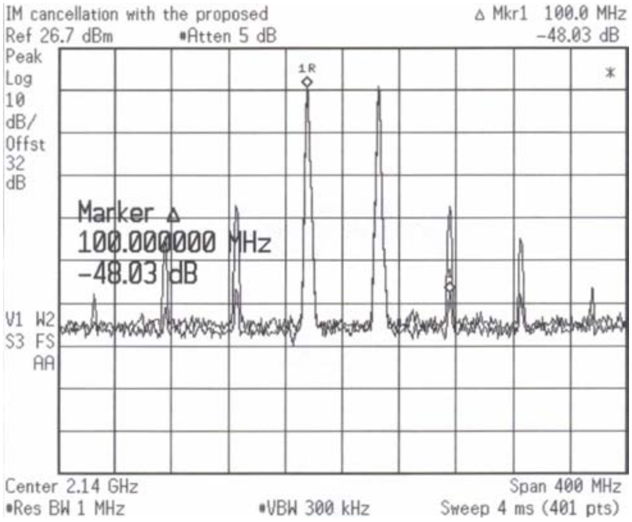


Fig. 9. The output characteristics of the feedforward amplifier with and without the proposed cancellers.

IV. Conclusion

In this paper, new signal cancellers are proposed that match the out-of-phase and the equal group delay properties of the feedforward loop simultaneously. Conceptually, the feedforward amplifier that adopts the proposed cancellers can cancel carrier signals at the 1st loop and IMD signals at the 2nd loop perfectly for overall band. IMT-2000, mobile

2nd loop perfectly for overall band. IMT-2000, mobile internet and wireless LAN using OFDM to be serviced have a broader service frequency bandwidth than the previous communication services. Hence the feedforward amplifier using conventional cancellers has limitation on linearization, so that it cannot fulfill on overall frequency band. However, the proposed feedforward amplifier can linearize on overall frequency band without a partition of the service band. Maybe the feedforward amplifier is profitable for communication service providers and amplifier manufacturers because of better operating convenience and good manufacturing yield.

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