Analysis of the Cancellation Performance of a linearization loop

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Abstract

The expression for the effects of an amplitude imbalance, a phase imbalance and a delay mismatch on the characteristics of a linearization loop in feedforward amplifiers is derived and analyzed. The simulation results are compared with the results obtained by means of using a commercial simulation tool and the exact agreement is reported.

Key words : feedforward, cancellation performance, linearization bandwidth

I . Introduction

Feedforward has several advantages in linearization bandwidth, cancellation performance and dynamic range over other linearization methods, such as feedback, predistortion and LINC(linear amplification with nonlinear component)[1]. Therefore feedforward amplifiers are widely used in mobile communication systems. Feedforward amplifiers are generally composed of two linearization loops, which are the signal cancellation loop and the error cancellation loop. The design of a linearization loop and the prediction of the performance of the linearization loop could be possible if we realize what parameters limit the performance of a linearization loop and how the performance of the linearization loop is limited by the parameters.

The performance of a linearization loop limited by an amplitude imbalance, a phase imbalance and a delay mismatch is described in [2,3]. However, the effects of those parameters on the cancellation performance of a linearization loop are separately explained, that is, the effects of the amplitude and phase imbalance on the cancellation performance and the effects of the delay mismatch on the linearization bandwidth and cancellation performance of the linearization loop. In this letter we derive and analyze the expression for the limitation of the cancellation performance caused by the degree of an amplitude imbalance, a phase imbalance and a delay mismatch in linearization loops at the same time. The validity of the derived expression is demonstrated by comparing with the results obtained by Libra series IV.

Ⅱ. Theoretical analysis

The basic operating principle of a linearization loop in feedforward amplifiers is to add two anti-phase equal signals at the output port of the linearization loop in order to cancel out a specific signal. Fig. 1 shows the basic configuration and the operation of a linearization loop.

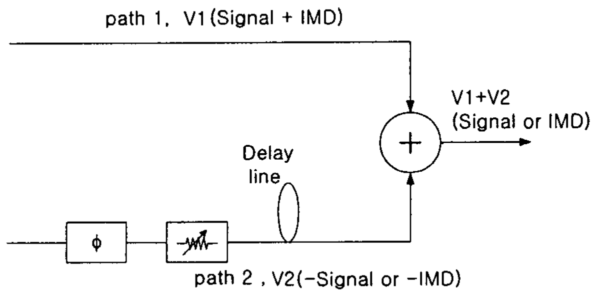


Fig. 1 The operation principle and the configuration of a linearization loop

The signal at the output port of the linearization loop passing through path1 can be written as

$$v1 = V_{1m}\cos((\varpi - \varpi_s)(t-\tau_1)+\phi) \quad (1)$$

Eq(1) shows that $v1$ passing through path 1 is come out at the output port after lapsing the delay time of τ_1. And $v1$ has the frequency of f_s, the amplitude of V_{1m} and the phase of ϕ at the output of the linearization loop. In order to cancel $v1$ at the output port, the amplitude and phase of $v2$ from path 2 must be adjusted to the same amplitude and anti-phase of $v1$ at the output port and the delay time of path 2 must be the equal delay of path 1. At the output port of the linearization loop, the signal passing through path 2 can be described as

$$v2 = (V_{1m} \pm V_{a\_m})\cos((\varpi - \varpi_s)(t-(\tau_1 \pm d_m)) + \phi + 180^\circ \pm \theta_m) \quad (2)$$

where V_{a_m} and θ_m are the amplitude mismatch and the phase mismatch, respectively. And d_m is the delay mismatch of unit in time between two paths. If all the mismatch parameters are zero, then $v1$ is cancelled out at the output port. The average power of the sum of two signals delivered to the normalized resistor can be written as

$$\begin{aligned} P_{avg} &= \int_0^T (v1+v2)^2 dt \\ &= \frac{V_{1m}^2}{2}\Big(1+\Big(\frac{V_{1m}\pm V_{a\_m}}{V_{1m}}\Big)^2 \\ &\quad -2\Big(\frac{V_{1m}\pm V_{a\_m}}{V_{1m}}\Big)\cos(2\pi(f-f_s)(\pm d_m)\mp\theta_m)\Big) \\ &= \frac{V_{1m}^2}{2}(1+\alpha^2-2\alpha\cos(2\pi(f-f_s)(\pm d_m)\mp\theta_m)), \end{aligned} \quad (3)$$

$$\alpha = \Big(V_{1m} \pm V_{a\_m} \big/ V_{1m}\Big), \quad (4)$$

where α is the amplitude imbalance between $v1$ and $v2$. The cancellation performance of a linearization loop is defined as a ratio of the signal power that should be cancelled out to the output power of the linearization loop.

The average power of eq (1) is $V_{1m}^2/2$. Therefore the cancellation performance, CP, can be represented as

$$CP = 1 + \alpha^2 - 2\alpha\cos(2\pi(f - f_s)(\pm d_m)\ \mu\ \theta_m)$$
$$= 1 + \alpha^2 - 2\alpha\cos(2\pi(\pm\frac{\lambda_{err}}{\lambda_s})(1 - \frac{f}{f_s}) \pm \theta_m) \quad (5)$$

where λ_{err} and λ_s are the delay mismatch and the wavelength in electrical length at the frequency of f_s, respectively and $d_m = \lambda_{err} / \lambda_s f_s$.

If the delay mismatch between two paths is zero, then eq(5) can be described as

$$CP = 1 + \alpha^2 - 2\alpha\cos(\theta_m) \quad (6)$$

When the linearization loop has a delay mismatch without an amplitude and a phase mismatch, then eq(5) gives as

$$CP = 2(1 - \cos(2\pi(f - f_s)(\pm d_m)))$$
$$= 2(1 - \cos(2\pi(\pm\frac{\lambda_{err}}{\lambda_s})(1 - \frac{f}{f_s}))) \quad (7)$$

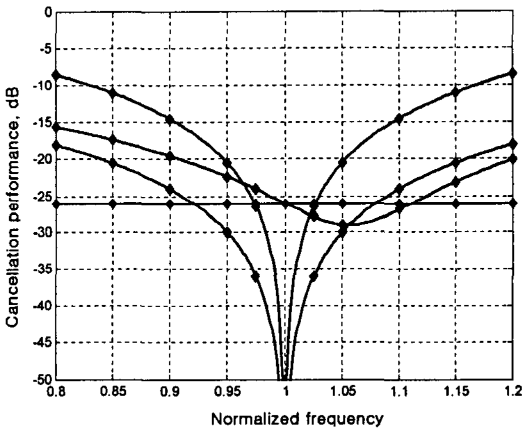
Eq(7) shows that even if there is no amplitude and phase mismatch between output signals of each path and there is only a certain amount of delay mismatch in the linearization loop, the phase balance is maintained only at the frequency of f_s. The delay is defined as the variation of phase versus frequency. If a linearization loop has a delay mismatch, the amount of a phase mismatch would be increased as the frequency offset from f_s is increased. Therefore a delay mismatch limits the linearization bandwidth and cancellation performance of a linearization loop.

The cancellation performance of a linearization loop in dB, CP_dB, can be written as

$$CP\_dB = 10\log(CP) \quad (8)$$

Ⅲ. Simulation Results

Fig. 2 shows the cancellation performance of a linearization loop versus frequency when the linearization loop has a certain value of an amplitude imbalance, a phase imbalance and a delay mismatch. Fig.2 shows that the simulation results from eq(5) are exactly the same as the results obtained by using Libra series IV.



$\alpha = 0dB,\ \theta_m = 0^\circ,\ \lambda_{err} / \lambda_s = 0.1$; case 1

$\alpha = 0dB,\ \theta_m = 0^\circ,\ \lambda_{err} / \lambda_s = 0.3$; case 2

$\alpha = 0.3dB,\ \theta_m = 2^\circ,\ \lambda_{err} / \lambda_s = 0$; case 3

$\alpha = 0.3dB,\ \theta_m = 2^\circ,\ \lambda_{err} / \lambda_s = 0.1$; case 4

◆ Libra simulation data

Fig. 2 The cancellation performance of a linearization with an amplitude imbalance, a phase imbalance and a delay mismatch

In Fig.2, case 1 has larger linearization bandwidth than case 2. Because the steep slope of the phase variation versus frequency is produced by the increment of a delay mismatch. In case 3, the linearization loop has the cancellation performance of -26.03dB. And the cancellation performance is not changed by the frequency because the delay of the linearization loop is matched. The phase mismatch of 2° is maintained even though the frequency is changed in case 3. Fig.2 shows that the cancellation performance of case 4 is better than case 3 over the normalized frequency band of 1 ~ 1.111. The delay mismatch causes better phase balance than the case 3 over the normalized frequency band of 1 ~ 1.111 because case 4 has the delay mismatch of $0.1\lambda_s$. However the phase mismatch of case 4 is larger than the phase mismatch of case 3 at other frequencies, except for the frequency band of 1 ~ 1.111.

Table 1 Linearization bandwidth of a linearization loop according to the cancellation performance(no phase mismatch and the center frequency of 1GHz)

CP_dB	30dB	25dB
$\lambda_{err} = 0.1ns$, $\alpha = 0.1dB$	9.2%	17.4%
$\lambda_{err} = 0.3ns$, $\alpha = 0.1dB$	3.0%	5.8%
$\lambda_{err} = 0.5ns$, $\alpha = 0.1dB$	1.88%	3.48%
$\lambda_{err} = 0.3ns$, $\alpha = 0.3dB$	-	4.56%
$\lambda_{err} = 0.5ns$, $\alpha = 0.3dB$	-	2.76%

It is difficult to measure the delay mismatch of unit in λ. In general, the delay mismatch is measured in time. Therefore, eq (5) and eq (7) can be used for calculating and predicting the cancellation performance of a linearization loop with a delay mismatch unit in time. If the normalized frequency is 1GHz, then the delay mismatches of $0.1\lambda_s$ and $0.3\lambda_s$ correspond to 0.1ns and 0.3ns, respectively.

Some simulation results are listed in Table 1. There are the amplitude imbalance of $0.1dB$, the delay mismatch of $0.1ns$ and no phase mismatch and then the linearization loop has 30dB linearization bandwidth of 9.2% with 1GHz center frequency. When the amplitude imbalance is $0.3dB$, the linearization loop can't get the cancellation performance of 30dB.

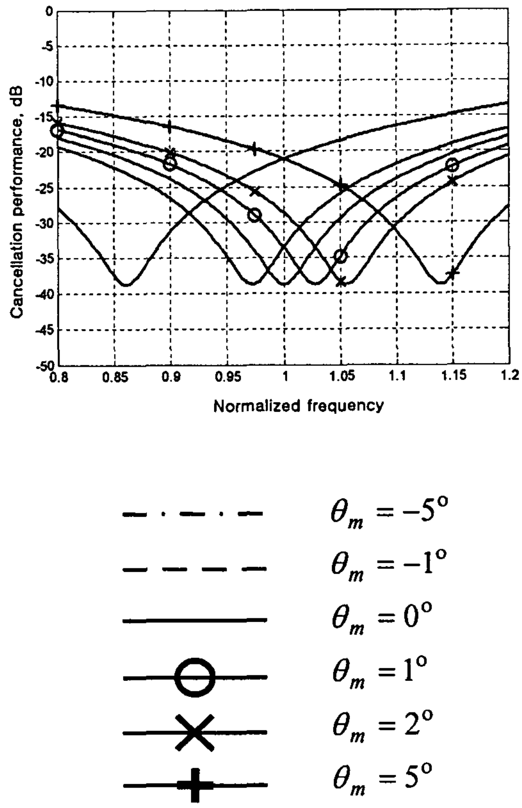


Fig. 3 The movement of the center frequency of a linearization loop by adjusting an amount of the phase mismatch($\lambda_{err} / \lambda_s = 0.1$, $\alpha = 0.1dB$)

Fig. 3 shows that the center frequency of a linearization loop can be changed by the amount of a phase mismatch. If the phase mismatch is increased, the center frequency of the linearization loop is also increased without any degradation in cancellation performance and linearization bandwidth. These results can be effectively used to change the operation frequency of a linearization loop without a manual tuning. If we want to change the operating frequency band of a linearization loop, then we can change the operating frequency band by adjusting the amount of the phase mismatch of the linearization loop without changing the values of other mismatch parameters.

Ⅳ. Conclusions

The cancellation performance of a linearization loop is limited by the degree of an amplitude imbalance and a phase imbalance. A delay mismatch causes a phase variation as a function of frequency. Therefore the cancellation performance and linearization bandwidth are limited by a delay mismatch. The derived expression could be used in designing a linearization loop and predicting the cancellation performance of the linearization loop usefully.

Reference

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