ON THE BEHAVIOR OF THE LINC TRANSMITTER

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In this paper we present a theoretical analysis of the effect of three different kinds of imbalances between the parallel signal paths in a real LINC transmitter. The system degradations are described in terms of the undesired response rejection at the system output (URR). A classical two tones test has been used.

INTRODUCTION

In mobile radio systems, the relatively inefficient use of the spectrum by the present FM-type modulations, like MSK, TFM, etc... has manifested itself as crowding on the available channels. However, they are still widely used because their constant envelope property is appropriate for using power efficient non linear amplifiers. In the most recent studies of digital mobile radio systems, the introduction of linear modulation methods, such as QPSK and M-QAM, is considered in order to improve spectrum efficiency. However, as M-QAM has a non-constant envelope, it will be necessary to consider the linear power amplifiers, which are less efficient that the classical class-C power amplifiers used with the FM-type modulations.

In order to achieve both spectrum and power efficiency, several techniques of linearizing power amplifiers have been presented in the literature, [1], [2], [3], [4]. Among all of them, one of the more promising appears to be the so called LINC transmitter. The basic principle of the LINC transmitter is to represent any arbitrary bandpass signal, which may have both amplitude and phase variations, by means of two signals which are of constant amplitude and have only phase variations. These two angle modulated signals can be amplified separately using efficient high-power non linear devices. Finally the amplified signals are passively combined to produce an amplitude modulated signals.

In a practical LINC transmitter there are three main mechanisms that degrade the overall performance: the power gain and delay (or phase) imbalance between the two RF paths and the different non-linear characteristics of both RF power amplifiers. Even though some practical implementations have pointed out the effects of these degradations in the system performances, with respect to the theoretical behavior there is not yet, to our knowledge, a closed expression providing a characterization of these effects.

In this paper we present a theoretical analysis of the effect of the above mentioned imbalances between the parallel signal paths in the system performance. The system degradations are described in terms of the undesired response rejection at the system output (URR). A classical two tones test has been used.

SYSTEM DESCRIPTION

Figure 1 shows the schematic drawing of LINC system, where:

$$S(t) = a(t)\cdot\cos[\omega_0 t + \theta(t) + \phi] \quad (1)$$

$$S_1(t) = V/2\cdot\sin[\omega_0 t + \theta(t) + \psi(t) + \phi] = S_{I1}(t)\cos[\omega_0 t + \phi] + S_{Q1}(t)\sin[\omega_0 t + \phi] \quad (2)$$

$$S_2(t) = V/2\cdot\sin[\omega_0 t + \theta(t) - \psi(t) + \phi] = S_{I2}(t)\cos[\omega_0 t + \phi] + S_{Q2}(t)\sin[\omega_0 t + \phi] \quad (3)$$

with:
$\psi(t) = \sin^{-1}[a(t)/V]$, being $\max[a(t)] \leq V$, and:

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$$S_{I1}(t)=\frac{1}{2}\left[\ a(t)\cos\theta(t)+\sin\theta(t)\sqrt{V^2-a^2(t)}\ \right]$$

$$S_{Q1}(t)=\frac{1}{2}\left[-a(t)\sin\theta(t)+\cos\theta(t)\sqrt{V^2-a^2(t)}\ \right]$$

$$S_{I2}(t)=\frac{1}{2}\left[-a(t)\cos\theta(t)+\sin\theta(t)\sqrt{V^2-a^2(t)}\ \right]$$

$$S_{Q2}(t)=\frac{1}{2}\left[\ a(t)\sin\theta(t)+\cos\theta(t)\sqrt{V^2-a^2(t)}\ \right]$$

In this scheme non linear operations are required only when the signals $S_{I1}(t)$, $S_{Q1}(t)$, $S_{I2}(t)$, $S_{Q2}(t)$ are generated. As this signals only depend on a(t) and θ(t), which are baseband signals, the non linear operations could be easily performed using a Digital Signal Processor (DSP). Then, we only need to use a DSP, four balanced modulators, and two combiners to generate the signals $S_1(t)$ and $S_2(t)$.

SYSTEM IMPAIRMENTS

In a practical LINC amplifier there are three main mechanisms that degrade the overall performance:

A: Imbalance between the path gains

In this case :

$$S(t)=G\cdot S_1(t)-(G+\Delta G)\cdot S_2(t)=$$
$$=G\ a(t)\cos[\omega_0 t+\theta(t)+\phi]\ -$$
$$-\ \Delta G\ \frac{V}{2}\ \sin[\omega_0 t+\theta(t)-\Psi(t)+\phi]$$

that is, a residual level of the one of the phase modulated signals appears in the system output.

In order to analyze the effect of this undesired signal on the system performance, we consider the classical two tone test. In this case: $a(t)=2A\cos(\omega_m t)$ and $\theta(t)=0$. Considering that $\phi\equiv 0$ (with no loss in generality) the useful output signal is :

$$S_U(t)=G\ [A\cos(\omega_1 t)+A\cos(\omega_2 t)]$$

with $\omega_1=\omega_0+\omega_m$ and $\omega_2=\omega_0-\omega_m$. The interfering signal is :

$$S_I(t)=-\Delta G\ \frac{V}{2}\ \sin[\omega_0 t-\psi(t)]=$$
$$=\frac{\Delta G}{2}\left[A\cos(\omega_1 t)+A\cos(\omega_2 t)\right]-$$
$$-\ \frac{\Delta G}{2}\sqrt{V^2-[2A\cos(\omega_m t)]^2}\ \sin(\omega_0 t)$$

In the above expression, the first part adds directly to the useful signal, but the second part generates a set of interfering spectral lines inside as well as outside the desired bandwidth.

The most important of all the interfering spectral lines is placed at ω_0. Its level is given by:

$$I.L.=\frac{2}{\Pi}\ \frac{\Delta G}{2}\ V\int_0^{\pi/2}\sqrt{1-A_x^2\cos^2(\vartheta)}\ d\vartheta=$$
$$=\frac{2}{\Pi}\ \frac{\Delta G}{2}\ V\ E(A_x,\pi/2)$$

with $A_x=2A/V\le 1$, $\vartheta=\omega_m t$, and E(x,y) being the elliptic integral of the second kind, [5].

Then, considering that the level of the useful spectral line is $A(G+\Delta G/2)\cong AG$, we can define the URR at the output as:

$$URR(dB)=-20\ \log\left[\frac{\Delta G}{G}\right]-20\ \log\left(\frac{2E(A_x,\pi/2)}{\Pi A_x}\right)$$

B: Imbalance between the path delays

If the two paths have different delays, the signals, at the input of the combiner are not in phase, and the resultant signal shows a high degree of distortion. We now consider that:

$$S(t)=G\cdot S_1(t)-G\cdot S_2(t-\tau)$$

where τ can be expressed as $\tau=\gamma/\omega_0$. After some algebraic operations, the above expression could be written as :

$$S(t)=G\ a(t)\cos(\omega_0 t)\ +$$
$$+G\ [1-\cos(\gamma)]\ S_2(t)\ +G\ \sin(\gamma)\ S_3(t)$$

with

$S_3(t) = V/2\cdot\cos[\omega_0 t - \psi(t)] =$

$= V/2\cdot\sin[\omega_0 t - \psi(t) + \pi/2]$

Comparing the expressions of $S_2(t)$ and $S_3(t)$ it is obvious that both signals have equal power spectrum. So, considering that $\gamma \ll 1$, we can write:

$$S(t) \cong G\ a(t)\ \cos(\omega_0 t) + G\ \gamma\ S_3(t)$$

As before, assuming that $a(t) = 2A\ \cos(\omega_m t)$, and considering that $S_3(t)$ is a phase modulated signal, the most relevant of all the interfering spectral lines is placed at ω_0 and its level is given by :

$$I.L. = \frac{G.\gamma.V}{\Pi}\ E(A_x, \pi/2)$$

with $A_x = 2A/V$. The URR can now be expressed as:

$$URR(dB) = -20\ \log(\gamma) - 20\ \log\left(\frac{2E(A_x, \pi/2)}{\Pi\ A_x}\right)$$

C: Imbalance in the non-linear characteristics of power amplifiers

The non-linear behavior of the power amplifiers can be characterized by means of the following expression :

$$v_0(t) = a\ v_i(t) + b\ v_i^2(t) + c\ v_i^3(t)$$

where "a" is the gain for low signal level. In this case, the input signal is $v_i(t) = S_1(t)$ or $v_i(t) = S_2(t)$. Then, defining $v_{01}(t)$ (resp. $v_{02}(t)$) as the output signal, it results in :

$$v_{01}(t) \cong a\left[1 + \frac{3\ c_1}{4\ a}\left(\frac{V}{2}\right)^2\right]\ S_1(t)$$

$$v_{02}(t) \cong a\left[1 + \frac{3\ c_2}{4\ a}\left(\frac{V}{2}\right)^2\right]\ S_2(t)$$

In the above expressions c_1 (resp. c_2) denotes the third order characteristic of the first (resp. second) non-linear power amplifier. c_1 and c_2 are negative constants.

From $v_{01}(t)$ and $v_{02}(t)$, the output signal S(t) can be written as :

$S(t) = v_{01}(t) - v_{02}(t) =$

$$= a\left[1 + \frac{3\ c_1}{4\ a}\left(\frac{V}{2}\right)^2\right]\ a(t)\ \cos(\omega_0 t) +$$

$$+ \frac{3}{4}\left(\frac{V}{2}\right)^3 \Delta c\ \sin[\omega_0 t - \psi(t)]$$

where $\Delta c = c_1 - c_2$. Considering again a two tones test, the interfering signal generates a set of undesired spectral lines, the most important being placed at ω_0. This line has a level given by :

$$I.L. = \frac{2}{\Pi}\ \left[\frac{3}{4}\left(\frac{V}{2}\right)^3 \Delta c\right]\ E(A_x, \pi/2)$$

Then, considering that the level of the useful spectral line is:

$$A\ a\ \left[1 + \frac{3\ c_1}{4\ a}\left(\frac{V}{2}\right)^2\right] \cong A\ a$$

The URR is:

$$URR(dB) = -20\log\left[\frac{\Delta c}{c_1}\right] - 20\log\left(\frac{2\ E(A_x, \pi/2)}{\Pi\ A_x}\right) -$$

$$-40\ \log\left[\frac{V}{2I_p}\right]$$

where I_p is the input third order intercept point of the first amplifier.

RESULTS

In figure 2 we show the evolution of the undesired response rejection at the system output against the relative gain imbalance, $\Delta G/G$, using A_x as a parameter. It is important to emphasize that the URR depends not only on $\Delta G/G$ but also on the relative level of the input modulating signal 2A/V. The smaller the relative level of the input signal (A_x) is, the more important is the degradation of the system performance. Then it is convenient to be sure that the input signal is as close as possible to the maximum permissible input level.

On the other hand, we can see that a small gain difference between both paths produces a significant degradation. For example, if the gain imbalance between paths is about 1 % and the relative input signal is equal to one, the output rejection decreases to 45 dB, but when the relative input signal is only 0.25 then the output rejection is as low as 28 dB.

In figure 3 we show the evolution of the URR behavior against the phase imbalance γ. We can observe that a small delay imbalance between both paths causes a high degree of non linear distortion. For example, a phase error between paths as low as 2^0 diminishes the undesired response rejection to only 33 dB, for the most favorable value of A_x, that is, for $A_x=1$ .In fact, this is the most important cause of the signal distortion on the LINC transmitter.

In figures 4, 5 and 6, we show the evolution of the undesired response rejection against the relative imbalance between both non-linear characteristics, $\Delta c/c_1$, using A_x as a parameter. We have considered three cases taking into account the signal level at the input of the amplifiers (V/2) with respect to the third order intercept point (I_p) of the first amplifier. From these figures we see that the influence of the value of A_x with respect to the degradation due to the non-linear characteristics imbalance is similar to the influence observed with respect to the previously analyzed impairments. On the other hand, when we consider the effect of the relative level of the input signal, we see that the higher this level the more sensitive is the LINC transmitter to the impairment of non-linearities. That is, if we can guarantee that both amplifiers have identical non-linear characteristics, we can use highly non-linear amplifiers, but as long as the previous statement isn't true we are compelled to increase the linearity of the amplifiers in order to keep good overall quality. For example, if we consider a relative imbalance of 10%, and $A_x=1$, for an input signal 10dB below the intercept point the URR is 45 dB, while for an input signal 3dB below I_p the URR is only 30 dB.

CONCLUSIONS

In this paper we have analyzed the effect of the R.F. signal processing impairments in a LINC transmitter. We have distinguished between three kinds of path imbalance. In all cases analytical expressions have been obtained in order to evaluate the effect of the imbalances on the performance of the LINC transmitter. The gain and the phase imbalance between both power amplifiers, appears as a serious constraint of the performances of the LINC transmitter. Certainly, they could produce significant reduction of the linearity of the transmitter. With respect to the imbalance between the non-linear characteristic of both power amplifiers, its effect is less meaningful even for high values of $\Delta c/c_1$ if the input signal level is kept at a reasonable margin below the I_p.

ACKNOWLEDGEMENTS

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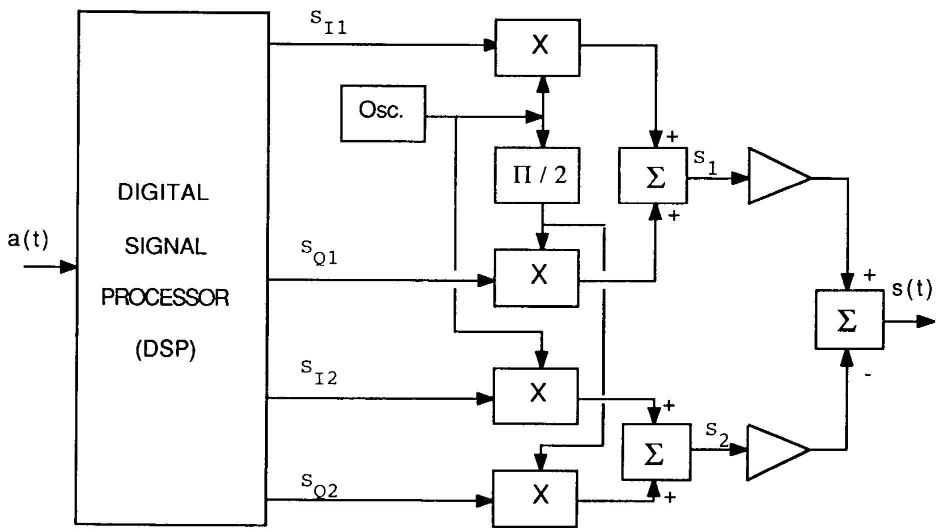

Figure 1.- Schematic Diagram of the LINC Transmitter

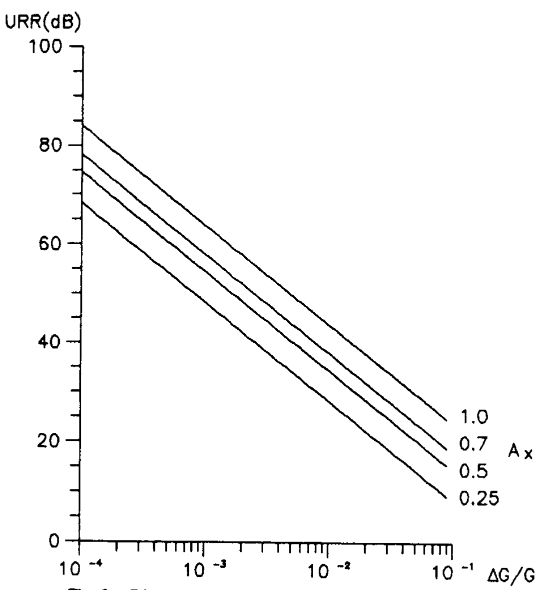

Fig.2: Effect of the imbalance between the path gains

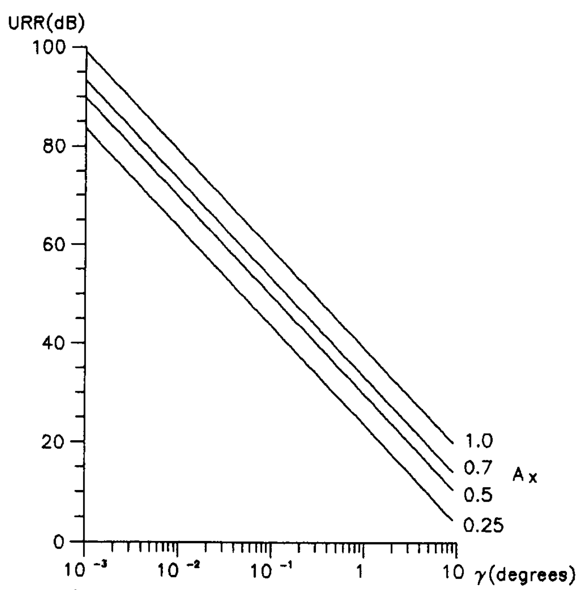

Fig.3: Effect of the imbalance between the path delays

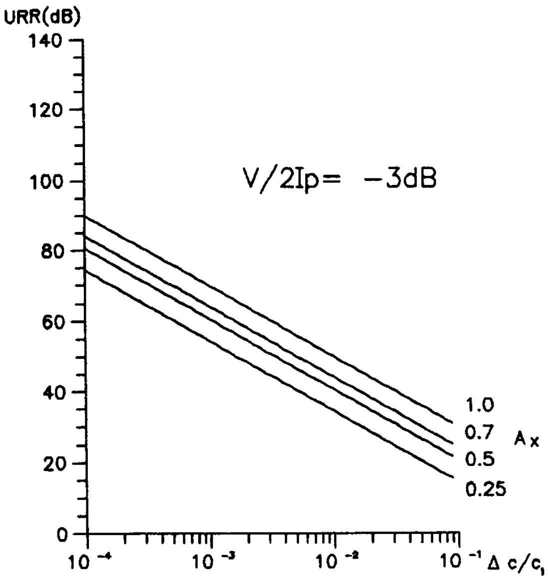

Fig.4: Effect of the imbalance in the non-linear characteristics of power amplifiers

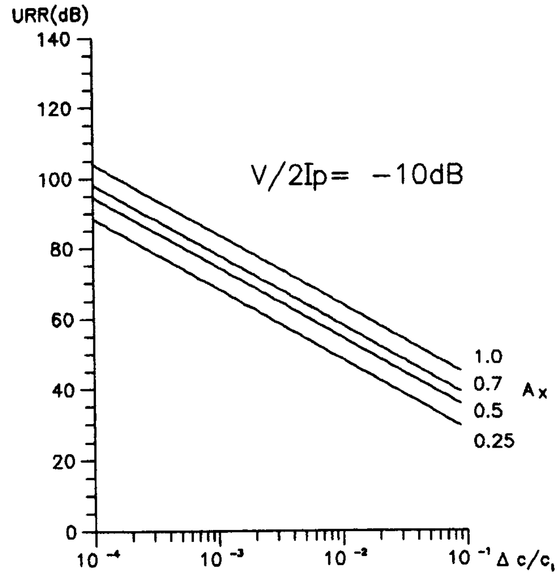

Fig.5: Effect of the imbalance in the non-linear characteristics of power amplifiers

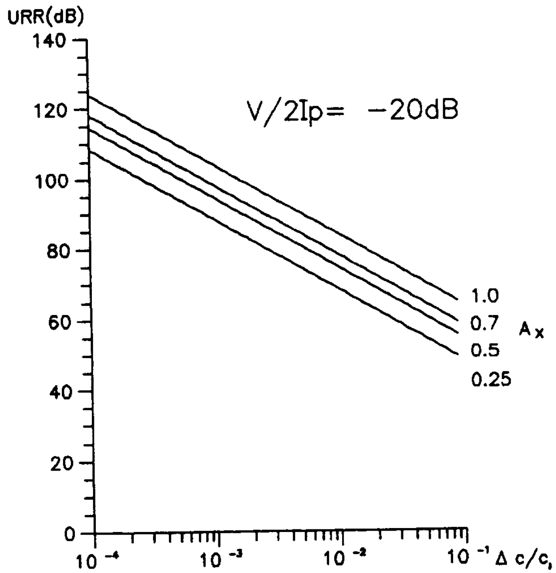

Fig.6: Effect of the imbalance in the non-linear characteristics of power amplifiers