A PHASE SHIFT TECHNIQUE FOR INTERMODULATION CANCELLATION

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ABSTRACT

In a multi-carrier transmission system, intermodulation distortion (IMD) is generated because of amplifier non-linearities. The presence of IMD degrades the performance of such systems. In this paper, an IMD cancellation technique based on phase shift is presented. The technique depends on applying pre-determined phase shifts to each carrier signal before they are combined. Then, an increased number of amplifiers are used to enable the cancellation of chosen IMD components. The amount of phase shift depends on the frequency components to be cancelled. Simulation results are presented to show the effectiveness of the technique proposed.

INTRODUCTION

Amplifiers introduce non-linear distortions due to a non-linear input-output power characteristic, known as the amplitude modulation to amplitude modulation (AM/AM conversion), and a non-linear input power-output phase characteristic known as the amplitude modulation to phase modulation (AM/PM conversion). When a signal composed of more than one carrier is applied to such a system, integer multiples of main frequencies are summed to form unwanted frequency components. These components have a degradation effect on the performance of the system concerned.

Amplifiers are widely used in communication systems to amplify the signals to be transmitted over a distance as well as amplifying received signals prior to processing of the signal. Various techniques have been developed to combat the degradation effects of non-linear amplification in communication systems [Gemikonakli (1), Aghvami and Robertson (2), and Berman and Mahle (3)]. Baseband pre-distortion, IF or RF linearisation are the main techniques proposed. These techniques are widely used in satellite communication systems using Travelling Wave Tube Amplifiers (TWTAs). TWTAs are preferred on board because of their capability, high reliability, long space life time, light weight, and a high dc-to-radio frequency (RF) tube conversion efficiency at a given level of RF output power. When these devices are operated near saturation for maximum efficiency AM/AM and AM/PM conversions occur. Solid-state High Power Amplifiers (HPAs) exhibit less AM/AM AND AM/PM distortions but still intermodulation distortion is introduced. HPAs employed at earth stations present similar problems. This problem is not limited to satellite systems, any communication system employing non-linear amplifiers present similar characteristics. Cable TV and line of sight microwave digital radio are other examples of such systems.

When the IMD components fall within the bandwidth of the desired signal, filtering cannot be used to suppress them. In Frequency Division Multiplexed (FDM) systems the IMD components may even overlap original carrier frequencies because of the equal distances between adjacent carrier frequencies.

IF or RF linearisation techniques can be effectively used to combat this problem. However, even mild non-linearities would introduce IMD. The techniques used do not completely linearise channel characteristics but improve the performance of non-linear systems.

A phase shift technique together with additional amplifiers can be used to suppress chosen IMD components. The proposed solution can be used for systems with two carriers such as TV signals (video and audio carriers) or stereophonic radio signals as well as multi-carrier systems.

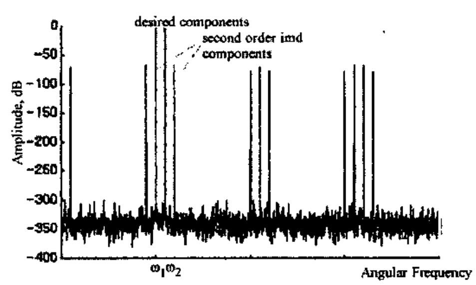

Figure 1: The signal spectra at the output of a non-linear amplifier assuming two carrier signals at the input of the system.

ANALYSIS

Mathematical modelling can be used to show the effectiveness of the proposed technique. Consider an amplifier having an output v_o given as

$$v_o(t) = c_1 v_i + c_2 v_i^2 + c_3 v_i^3 \tag{1}$$

where, c_1, c_2 and c_3 are the coefficients and v_i is the input signal defined as the sum of two carrier signals,

$v_i(t) = k_1\cos(\omega_1 t) + k_2\cos(\omega_2 t)$ (2)

where, k_i and ω_i $(i=1,2)$ represent the amplitude and angular frequency of the two carrier signals forming the input signal.

Substituting *Equation 2* into *Equation 1* produces the following output:

$$\begin{aligned} v_0(t) &= c_1\{k_1\cos(\omega_1 t) + k_2\cos(\omega_2 t)\} \\ &+ c_2\{\frac{k_1^2}{2}[1+\cos(2\omega_1 t)] + k_1k_2[\cos[(\omega_1-\omega_2)t] \\ &+ \cos[(\omega_1+\omega_2)t]\} + c_3\{\frac{k_1^3}{4}[3\cos(\omega_1 t)+\cos(3\omega_1 t)] \\ &+ \frac{3k_1^2k_2}{4}[\cos[(2\omega_1-\omega_2)t] + \cos[(2\omega_1+\omega_2)t] + 2\cos(\omega_2 t)] \\ &+ \frac{3k_2^2k_1}{4}[\cos[(2\omega_2-\omega_1)t] + \cos[(2\omega_2+\omega_1)t] + 2\cos(\omega_1 t)] \\ &+ \frac{k_2^3}{4}[3\cos(\omega_2 t)+\cos(3\omega_2 t)]\} \end{aligned} \tag{3}$$

As it can be seen from Equation 3, intermodulation products having frequencies such as $2\omega_1+\omega_2$, $2\omega_2+\omega_1$, $2\omega_1-\omega_2$, and $2\omega_2-\omega_1$ are produced and some may fall within the bandwidth of the desired signal. *Figure 1* shows the spectra of the output signal. As it can be seen from this diagram, the third order products $2\omega_1-\omega_2$, and $2\omega_2-\omega_1$ are too close to the original frequencies, hence, it is difficult to filter these components out. The analysis can be expanded to include more than two carriers at input to the amplifier and a variety of amplifier input-output characteristics. All analyses present some unwanted frequency components within/close to the bandwidth of the original signals.

Cancellation of Selected IMD Components

The cancellation of the IMD components within the bandwidth of the original signals would improve the performance of the communication system considered significantly. In what follows, a system is proposed to suppress the third order products in a non-linear system having two carriers at input. The block diagram of the proposed system is shown in Figure 2. The original carrier signals are shifted by φ_1 and φ_2 degrees, added, and then amplified. The signals are also added together and amplified without any shift. Then, the outputs of the two amplifiers are added together. It is obvious that $\cos(2\omega_1-\omega_2)$, $\cos(2\omega_2-\omega_1)$, $\cos(2\omega_1-\omega_2+2\varphi_1-\varphi_2)$ and $\cos(2\omega_1-\omega_2+2\varphi_2-\varphi_1)$ will be present in the final output $v_o(t)$. For cancelling out these components, the added phase shifts should give ±180 degrees. Solving the two simple equations for the two unknowns, φ_1 and φ_2 are obtained as 60 degrees and –60 degrees respectively. Hence, 2 x 60 – (-60) = 180 and 2 x (-60) – 60 = -180. Obviously the two third order IMD products will diminish. *(2)*

Simulation Results

Matlab has been used to simulate the response of the original non-linear system (no-cancellation) and the proposed system. The spectra of the output signals have been obtained using Fast Fourier Transform (FFT) techniques and then compared to the theoretical results presented above. Figure 3 presents the results obtained comparatively. As it can be clearly seen from the diagram, the selected components can be completely removed without degrading the original signals. This would certainly improve the performance of a non-linear communications system significantly.

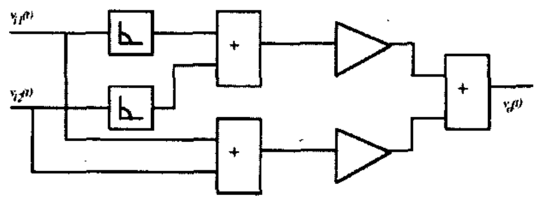

Figure 2: The proposed system

Equations have also been derived for n-input systems and simulations have been performed. Initial findings show that the proposed system works for any number of input signals and two amplifiers only. There would be one phase shift circuit for each carrier signal. On completion of the simulations, the results will be presented in another publication.

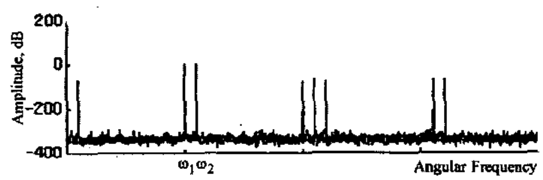

Figure 3: The spectra of the output signal.

CONCLUSIONS

A system is proposed to cancel selected IMD components in a non-linearly amplified communication environment. The system makes use of a simple phase shift technique to cancel out selected IMD components.

Matlab has been used to simulate a conventional and the proposed system and the results have been compared graphically. A general model is accepted for the non-linear device.

The proposed system can be used for a various systems ranging from cable TV to satellite communications. The only disadvantage of the system is the increased cost and hardware complexity.

Further work is under way to show that the system can be used for any number of inputs. Preliminary results are encouraging. Practical implementation should also be considered to test the effects of problems such as feedback especially at microwave frequency range.

Acknowledgement

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