LINEARIZATION OF TV TRANSMITTERS WITH IF PREDISTORTION

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Resumo

Neste artigo foi demonstrado o grau de Linearidade necessário aos equipamentos transmissores de sinais de TV, os métodos de medida de intermodulação aceitos internacionalmente e a necessidade de linearização dos amplificadores de potência para se obter as características desejadas a preços competitivos. Foi demonstrado também o princípio de funcionamento dos pré-corretores que atuam a nível de FI e uma proposta simples para implementação, usando-se modernos amplificadores operacionais. Apresentou-se também os resultados práticos obtidos em Laboratório, para um transmissor de UFH de 1 kW, usando-se Transistores LDMOS.

Abstract

The high degree of linearity needed for TV transmission the advent of digital radio, and many communicatons services have created a demand for highly linear high power amplifiers. In order to achieve power efficiency and better linearity, some kind of linearization must be introduced, otherwise the cost of the amplifiers become prohibitive. In this article we investigate the benefits of introducing IF predistortion in TV transmitters to reduce third order IMD inside the band as well as spurious outside the channel. We also compare the improvement of introducing IF predistortion in high power amplifiers built on LDMOS and the lineup of a IF predistortion circuit is presented taking advantage of the high frequency operational amplifiers now available in the market.

I. INTRODUCTION

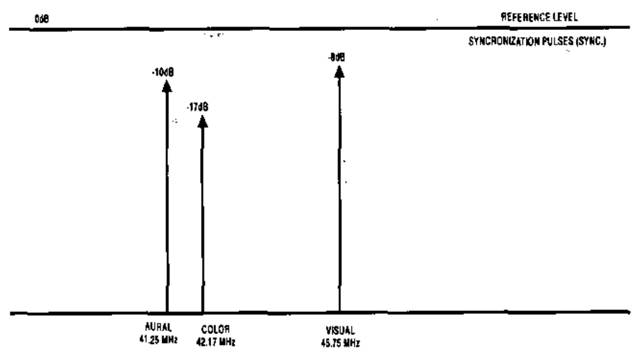
Engeneers encharged of TV transmitters design are always challenged by the need of high degree of linearity of the amplifiers. In a TV transmitter, we have to handle three carriers at same time; visual carrier; aural carrier and color carrier. The presence of these three carriers results in a very high peak envelope power and this non constant envelope signal demands a very high degree of linearity of the amplifiers. Although any stage of the transmitter can introduce distortion, the output amplifiers are the main source of intermodulation. In this article, we are considering common amplification where the problems associated with non-linearity are more severe as we have IMD products inside the channel as well as in the vicinity of channel where enough filtering must be provided if interference in other channels is to be prevented.

The beats among visual carrier, aural carrier and color carrier results in IMD products inside the channel, and these beats shall bee suppressed at least 52db bellow peak sync reference. we can check the in-channel intermodulation in two ways:

- Method A - Three tones representing the three carriers of the TV signal are injected in the transmitter and the IMD products are checked (EIAA - 508 page 59).
- Method B - A standard composite video signal is injected, consisting of: sync, blanking, ramp and color subcarrier (3.58 MHz signal) (EIAA - 508 page 60).

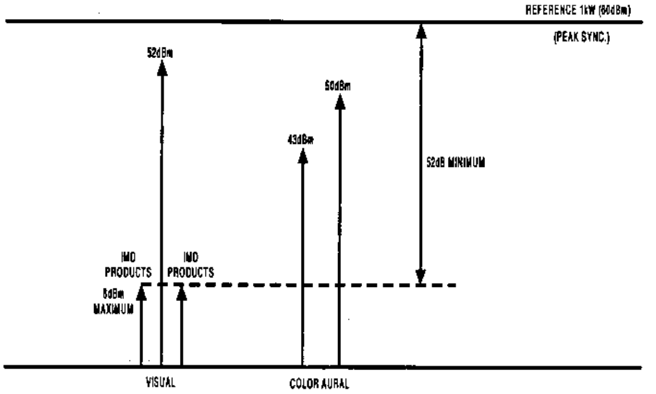
In this article our main concern is the method A. In this method, the amplitudes of the tones have been chosen to represent the typical power levels associated with the main components of a color TV signal, referenced to the top of the syncronization pulses, these levels are: (Figure 1).

- Vision carrier - 8dB
- Sound carrier - 10dB
- Color carrier - 17dB



(Figure 1 - Three tones signal at IF level; standard MF)

The average power of this composite signal is -5.55dB below the peak power (peak sync) and the net power goes periodically through zero. So, if we are testing a 1kW TV transmitter, the average output power must be 278W for the three tones signal and we have to check the third order IMD products inside the channel, as shown in Figure 2.



(Figure 2 - Third order IMD inside the channel)

The figures for IMD in the modern industry are between 55 and 60dB, and the modern transistors at nominal power present an IMD about 45 and 48dB. So the engineers are supposed to come up with linearyzers to improve IMD between 10 and 15dB. Fortunately, this is really possible using if predistortion.

Note: After the up-convertion the position of the carriers are inverted.

Assuming that the transfer characteristic of the amplifiers (transmitter) can be represented by a power series with three terms, we can find all the frequencies and amplitudes of all distortions that are important in TV transmission in a practical situation.

Let the entire TV transmitter be represented by:

$$e_o = K_1 e_i + K_2 e_i^2 + K_3 e_i^3 \qquad (1)$$

where K_1, K_2 and K_3 are coefficients describing the gain and distortion properties of the amplifiers, and e_i and e_o represent the input and output signal respectively.

Let the input signal be represented by:

- V cos v - Visual carrier
- A cos a - Aural carrier
- C cos c - Color carrier

Where: $v = 2\pi f_v t$

$a = 2\pi f_a t$

$c = 2\pi f_c t$

Let the instantaneous input signal e_i be represented by:

$$e_i = V \cos v + A \cos a + C \cos c \qquad (2)$$

By combining (1) and (2) the output signal will contain the following sinusoidal components.

First - order components:

$$K_1 e_i = K_1 [V \cos v + A \cos a + C \cos c]$$

We can see that K_1 is responsible for linear gain and the output signal is a replica of the input signal without any distortion. In fact, K_1 is the small-signal gain of the system.

Second - order distortion components:

$$K_2 e_i^2 = \frac{K_2}{2}\left(V^2 + A^2 + C^2\right) + \frac{K_2}{2} VA\cos(v \pm a) +$$
$$+ \frac{K_2}{2} VC\cos(v \pm c) + \frac{K_2}{2} AC\cos(a \pm c) +$$
$$+ \frac{K_2}{2}\left(V^2 \cos 2v + A^2 \cos 2a + C^2 \cos 2c\right)$$

The term $K_2 e_i^2$ works just like a mixer and we have three DC components due to second - order distortion, six sum and difference beat components and three second - harmonic components. We can see that second - order components do not represent a big problem as all the components are located far from the input components and a filter can easily reduce or eliminate all the products.

Third - order components:

$$K_3 e_i^3 = K_3\left(V^3 \cos 3v + A^3 \cos 3a + C^3 \cos 3c\right)$$
$$+ \frac{3}{4} K^3 [V^2 A\cos(2v \pm a) + V^2 C\cos(2v \pm c)$$
$$+ A^2 V\cos(2a \pm v) + A^2 C\cos(2a + c)$$
$$+ C^2 V\cos(2c \pm v) + C^2 A\cos(2c \pm a)]$$
$$+ \frac{3}{2} K_3 VAC\cos(v \pm b \pm c + \frac{3}{4} K_3 (V^3 \cos v$$
$$+ A^3 \cos a + C^3 \cos c) + \frac{3}{2} K_3 [V(A^2 + C^2)\cos a$$
$$+ C(V^2 + C^2)\cos a + C(V^2 + A^2)\cos c]$$

The term $K_3 e_i^3$ is the main problem, because it will produce components at the same frequency of the input signal and IMD components that fall inside the channel.

Let's assume for while that our main concern are the IMD's products inside the channel and consider that a filter is used to attenuate the products outside tthe channel. We are going to see that IF predistortion is also helpful to reduce spurious in the vicinity of the channel. We this assumption in mind the third-order components that we have to worry about are:

$$a) \frac{3}{2} K_3 VAC\cos(V \pm a \mp c)$$

These two terms represent IMD inside the channel regardeless if K_3 is positive or negative, and must be 52dB below peak sync reference.

For M standard the IF is 41 MHz to 47 MHz for a standard 6 MHz channel and the frequencies of the carriers at IF level are:

video carrier (v) → 45.75 MHz
aural carrier (a) → 41.25 MHz
color carrier (c) → 42.17 MHz

Therefore we have IMD products at the following frequencies at IF level:

(45.75 + 41.25 - 42.17) = 44.83 MHz
(45.75 - 41.25 + 42.17) = 46.63 MHz

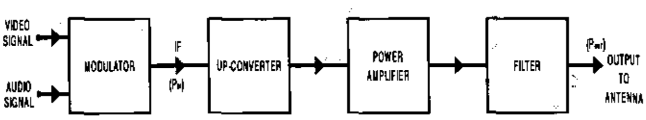
$$b)\frac{3}{4}K_3(V^3\cos v + A^3\cos a + C^3\cos c)$$

These three components at the same frequency of each input signal with amplitude determined by the input signal cubed produce self - compression when K_3 is negative because these components subtract from the first-order output, causing a decrease in gain when the input signal is high, this is called gain compression. when K_3 is positive we have self-expansion.

$$c)\frac{3}{2}K_3[V(A^2+C^2)\cos v + A(V^2+C^2)\cos a + C(V^2+A^2)\cos c]$$

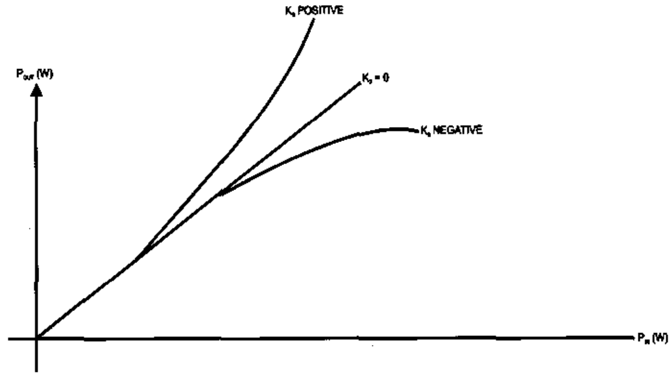
Here we have components at the frequency of each input signal, but with but with output amplitude of all input signals, causing cross compression when K_3 is negative, when K_3 is negative, and cross expansion when K_3 is positive.

The conclusion that only the third order distortion components play important role in a TV transmission, sugests that if we succeed in reducing this term we can linearize the transmitter. The simplified block diagram of a TV transmitter is:



(Figure 3 - Simplified block diagram of TV transmitter using commom amplification for audio and video signals)

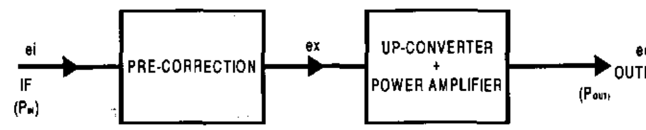
Figure 4 shows the transfer function of the transmitter when K_3 is negative; positive and zero, where P_{IN} and P_{OUT} represent the input and output power respectively.



(Figure 4 - Transfer function of the transmitter for $K_3 = 0$; positive and negative)

In most of the cases K_3 is negative and we have gain compression as well as cross compression. this conclusion sugests that if we have for instance at if level a stage with a transfer function with K_3 positive the complete system may present a linear transfer function, provided that we have the right transfer function at if level, and assuming that the up-conversion does not introduce any distortion.

- Pre-corrector development



(Figure 5 - Pre-corrector position in the system)

Assuming that non linearity above the third order intermodulation product is neglible at reasonable output powers, the amplifier and the if pre-corrector can be represented by:

$$e_x = P_1 e_i + P_3 e_i^3 \qquad (3)$$

$$e_o = K_1 e_x - K_3 e_x^3 \qquad (4)$$

Where P_1 and P_3 are the coefficients of the pre-corrector circuit and by combyning (3) and (4)

$$e_o = K_1 (P_1 e_i + P_3 e_i^3) - K_3 (P_1 e_i + P_3 e_i^3)^3$$

$$e_o = K_1 P_1 e_i + K_1 P_3 e_i^3 - K_3 (P_1^3 e_i^3 + 3 P_1^2 P_3 e_i^5 + 3 P_1 P_3^2 e_i^7 + P_3^3 e_i^9)$$

$$e_o = K_1 P_1 e_i + (K_1 P_3 - K_3 P_1^3) e_i^3 - K_3 (3 P_1^2 P_3 e_i^5 + 3 P_1 P_3^2 e_i^7 + P_3^3 e_i^9)$$

negleting the higher order terms we have:

$e_o = K_1 P_1 e_i + (K_1 P_3 - K_3 P_1^3) e_i^3$ (5)

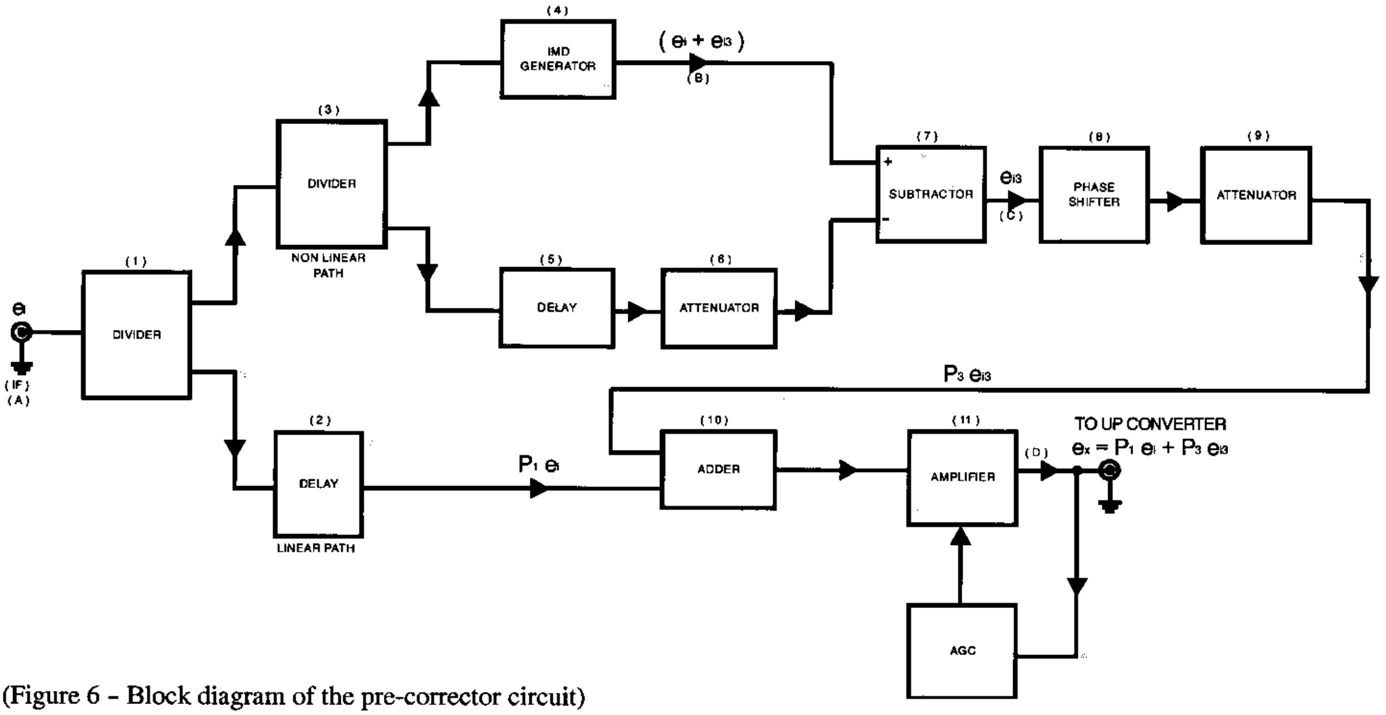
Therefore fom equation 5 it is evident that to fully supress the third order products, the following equation must be met:

$K_1 P_3 - K_3 P_1^3 = 0$ (6)

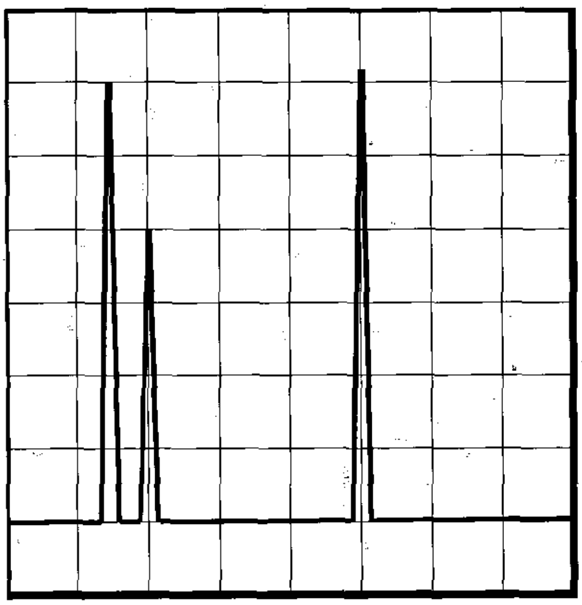
Implementation of the pre-corrector

The Figure 6 shows how to implement equation (3)

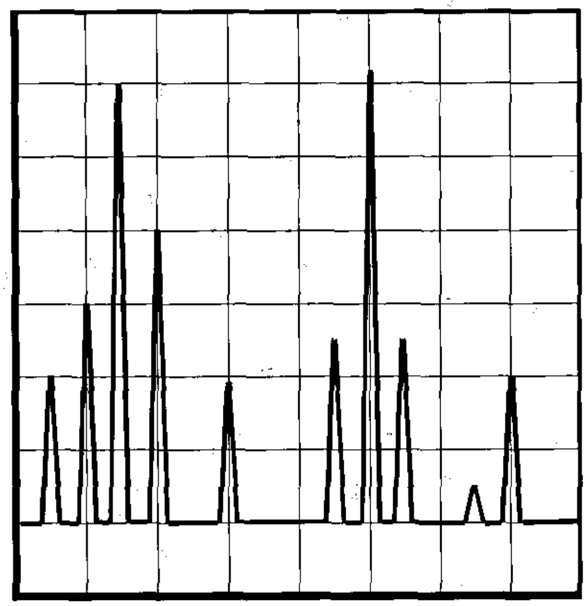
$e_x = P_1 e_i + P_3 e_i^3$



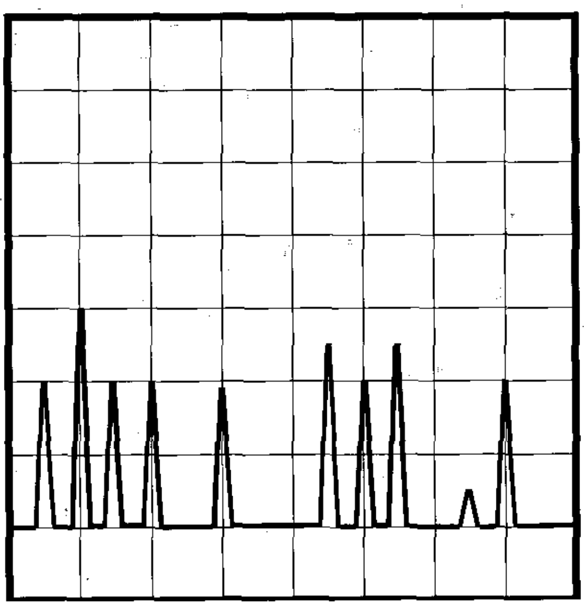
(Figure 6 - Block diagram of the pre-corrector circuit)



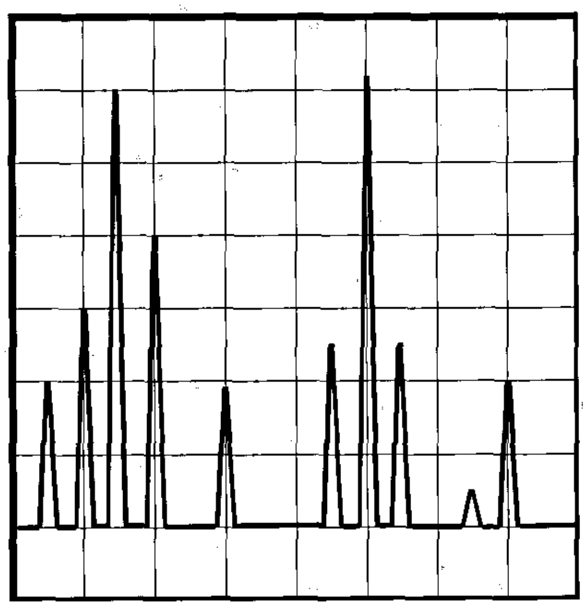
(A) Input Signal



(B) Intermodulated Signal



(C) Third-Order IMD



(D) Input Signal Plus Third-Order IMD

(Figure 7 - Spectrum analyser signals at points A ; B ; C and D of the block diagram of figure 6).

Function of the blocks

(1) Divide the input signal in two paths, linear path and non linear path.

(2) Normally this block is a length of coaxial cable so that we make the delay between linear path and non linear path exactly the same.

(3) This block is an amplifier and divider.

(4) Third-order IMD generator implemented by using schottky diodes.

(5) The delay adjustment in this path compensates for the delay in the third-order imdgenerator so that we can subtract the non intermodulated signal from the intermodulated signal. Normally this block is a Low-pass Bessel Filter.

(6) This block is an attenuator that adjusts the Amplitude of e_i so that $(e_i + e_i^3) - e_i$ results in signal e_i^3.

7) This is a wide band subtractor.

(8) This block adjusts the phase of e_i^3 so that equation (6) is met.

(9) This is an attenuator that controls the amount of IMD injected in the system.

(10) This block adds IMD to linear signal e_i.

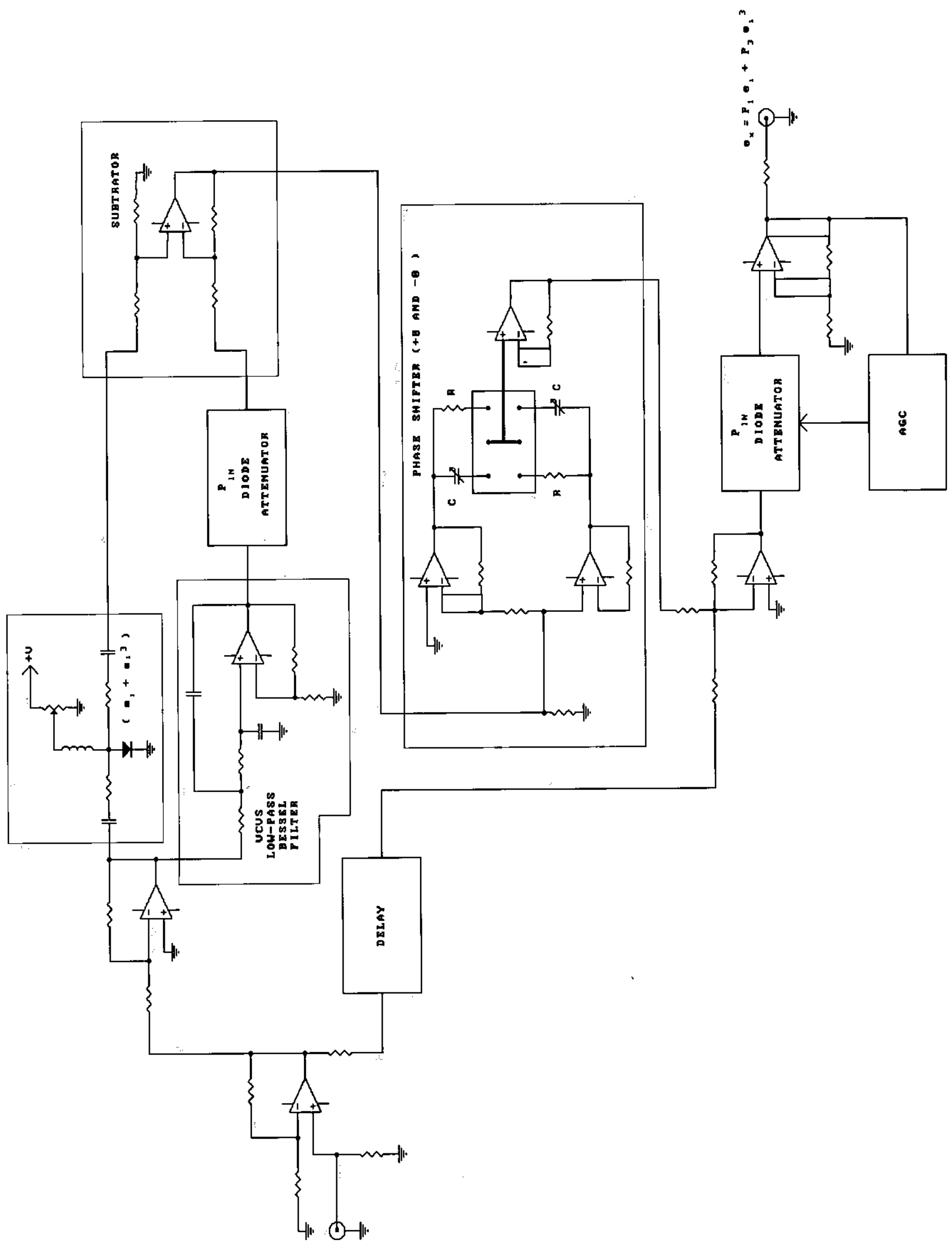
(11) This is an amplifier with agc, to maintain the output power constant as IMD is increased.

In a pre-corrector implementation the subtractor and the phase-shifter are the more critical parts because we have to subtract high frequency wide band signals and provide phase-shifter around 100 degrees with a minimum change in delay.

If the phases between paths are complementary we have cancelation but wide band cancelation is reached only when we have complementary phases and same delay between paths.

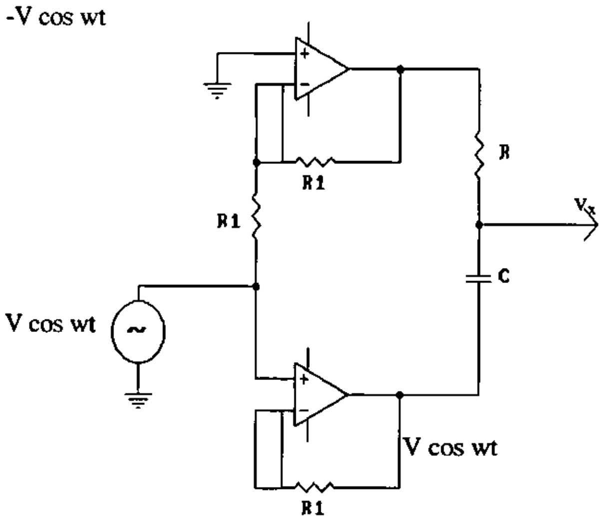
Experiments in the bench show that 40dB of cancelation is possible with good stability.

Although Line-ups of pre-correctors with hybrids, couplers and transistors are normally found in the market, we decide to take advantage of high frequency operational amplifiers and SMD technology in order to achieve small size, low cost and reliability. We have now available in the market many manufactures for high frequency operational amplifiers like; ANALOG DEVICE; ÉLANTEC HARRIS, CONLINEAR etc. We are going to present a line-up implemented with OPAMP's and some explanation for the phase-shifter that we believe must be carefully designed.



(Figure 8 - Simplified diagram with OPAMP's implemented by the author with excelent results)

The phase shifter is basically the implementation of the all-pass function H (s) = K (s - a) / (s + a) where for s = jw we have | H (jw) | = K, in order to implement this function we need a perfect complementary voltage source as follows:



(Figure 9 - Implementation of the phase shifter)

If v_X drives a high impedance, like a buffer with operational amplifier we have:

$$H(jw) = \frac{(1 - w^2R^2C^2) - 2jwRC}{(1 + w^2R^2C^2)}$$

$$T(w) = -RC$$

and

$$\phi(w) = t_g^{-1}\frac{2wRC}{(w^2R^2C^2 - 1)}$$

$$(w) = -\frac{d\phi(w)}{dw} = -\frac{d}{dw}\left[tg^{-1}\frac{2wRC}{(1 - w^2R^2C^2)}\right]$$

The expression for the delay is:

$$T(w) = -\frac{2RC}{(1 + w^2R^2C^2)}$$

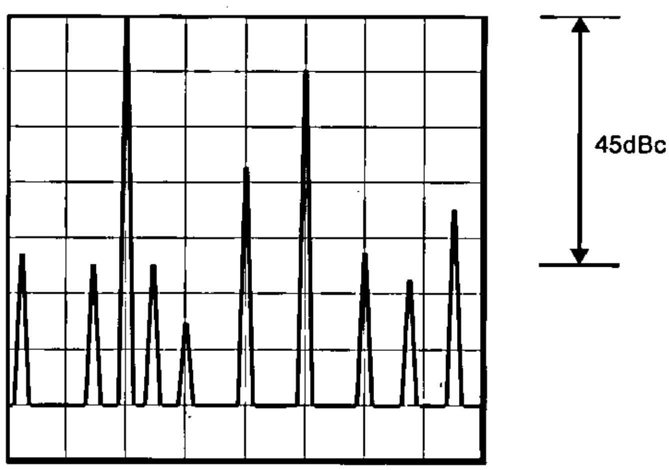
$$If\ W = \frac{1}{RC}$$

$$T(w) = -\frac{2\ RC}{1 + 1}$$

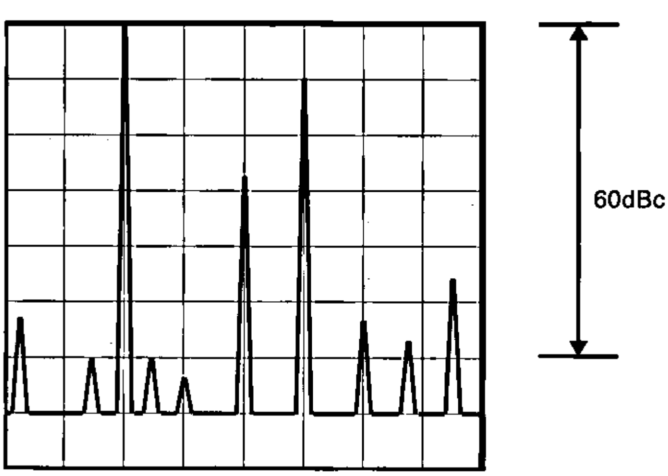
We simulated these results in a computer and confirmed that for w < 1 / RC the phase varies linearly with the frequency and delay changes a little bit but it is good enough for practical purposes.

Measurements

We performed some tests in a 1kW transmitter built on LDMOS transistors and the results are showed in figures



(Figure 10 - Output signal with the IF pre-corrector by passed. The IMD inside the channel is about -45dBc).



(Figure 10 - Output signal with the IF pre-corrector circuit inserted. The IMD inside the channel is about -60dBc)

II. CONCLUSION

With an IF pre-corrector circuit inserted in a TV transmitter we succeeded in reducing the third-order IMD products inside and outside the channel. For three tones the reduction inside the band was about 15dB and for a non modulated signal the results was about the same. Therefore for a modulated signal we had to optimize the imd generator and the improvement was about to 8 to 10dB

We also got some reduction of spurious outside the channel which simplifies the design of the output filter of the transmitter, a very expensive part of the system. The pre-corrector circuit also improves the overal efficiency of the transmitter as we need less transistors for a given output power. Less power consumption means that we save money in the cooling system. Therefore we see the huge impact in the design of TV transmitters when using Linearization. The author believes that linearization is going to be more and more important in the future as it also improves the bit-error-rate (ber) of digital modulated signals, and analog TV is going to be replaced by digital TV in few years. In general the greater the required BER, the greater the improvement provided by Linearization.

The author hopes that this article can be helpful somehow for those interested in this fascinating area of electronics.

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