Linearization of 1.85 GHz Amplifier Using Feedback Predistortion Loop

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Abstract— **A new feedback circuit topology was proposed for the cancelling loop of linear power amplifier. This circuit could cancel the intermodulation terms the same way as a typical feedforward techinque but the tolerance of the cancellation is enhanced. To verify this circuit topology, an amplifier was designed and two tone test was performed at 1.85 GHz. This experiment showed about 20 dB reduction of intermodulation.**

I. Introduction

The digital modulation method, such as multilevel quadrature amplitude modulation(QAM), quadrature phase shift keying(QPSK), becomes more and more popular in wireless communication. These digital modulation systems require the highly linear devices, especially the power amplifiers [1].

Although several linearization approaches have been developed, the feedforward technique and digital predistortion methods are the most popular ones. The combination of linearization techniques are used for a highly linear power amplifier. But the feedforward approach becomes the main linearizing technique because of its ability to produce very low distortion amplifier[2]. However, the feedforward techque is sensitive to component tolerance and drift, or to the change in power level[2,3,4]. Therefore, the feedforward method needs adaptive control to compensate for these variations. But the tolerance margin is so tight that the feedforward system is very hard to implement.

In this work, a new feedback linearization method is suggested. Because of feedback loop, this linearizer is more tolerable than the feedforward case. This circuit is analyzed and a linear amplifier is made using this circuit technique at 1.85 Ghz. The two tone test results showed the intermodulation reduction of more than 20 dB.

II. Theory

Fig 1 shows the feedback linearization system. The circuit consists of three blocks, 'feeding block', 'cancelling block' and 'main amplifier'. At the cancelling block, the error signal, e(t), is obtained by eliminating the estimated input signal component, u(t), from the main amplifier output, y(t). This nulling loop is similar to the feedforward main signal nulling. But the fundamental component does not need to be eliminated completely, which is very advantageous and this negative feedback component determines the gain of this amplifier. The estimated signal u(t), which is an input of the main amplifier, contains intermodulation components. This intermodulation signal functions as a predistortion signal of the main amplifier. Therefore, the intermodulation components of the main amplifier itself becomes a distortion correction signal. If its loop gain is 1, then intermodulation terms are completely canceled. The pass filter is used at the feeding block to prevent unwanted oscillation. Although in-band oscillation is suppressed by the negative feedback cancelling loop, the out of band oscillation is possible with positive feedback. But with properly designed feeding amplifier, the band pass filter could be removed.

The estimated input signal u(t) comes from the input signal x(t) and amplified error signal e(t) and is expressed in frequency domain as

$$\mathrm{U} = \mathrm{X} + \mathrm{G_f} \cdot \mathrm{E} \tag{1}$$

where G_f is the complex signal gain of the feeding block from port 3 to port 1 and the capital letters denote the frequency domain notation of each signal.

And the error signal, e(t), is obtained in frequency domain by

$$\begin{aligned} \mathrm{E} &= G_u \cdot U + G_{y1} \cdot G_{y2} \cdot Y \\ &= G_u \cdot U + G_y \cdot Y \end{aligned} \tag{2}$$

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where G_u and G_{y2} are the complex signal gains from port 1 to port 3 and from port 4 to port 3, respectively in the cancelling block. G_{y1} is the complex signal gain from port 5 to port 4 in the main amplifier block and G_y is $G_{y2} \cdot G_{y1}$.

Then the main output signal y(t) can be expressed as

$$\mathrm{Y} = \mathrm{G_m} \cdot \mathrm{U} + \mathrm{X_d} \tag{3}$$

where G_m is the complex signal gain from port 1 to port 5 through port 2 and X_d is the intermodulation signals of the main amplifier.

From equations 1, 2 and 3, U and Y have following expressions:

$$\mathrm{U} = \frac{X}{1 - G_f \cdot G_u - G_f \cdot G_y \cdot G_m} + \frac{G_f \cdot G_y \cdot X_d}{1 - G_f \cdot G_u - G_f \cdot G_y \cdot G_m} \tag{4}$$

$$Y = \frac{X}{(1 - G_f \cdot G_u)/G_m - G_f \cdot G_y} + \frac{(1 - G_f \cdot G_u) \cdot X_d}{1 - G_f \cdot G_u - G_f \cdot G_y \cdot G_m} \tag{5}$$

In equation 5, the first term is the fundamental signal component and the second term is the intermodulation. To reduce the intermodulation signal, the $G_f \cdot G_u$ in the second term should be adjusted close to 1. This condition also guarantees the negative feedback condition of the feedback signal path. Since G_u and $G_m \cdot G_y$ should be 180° out of phase, the phase of the close loop gain, $G_m \cdot G_y \cdot G_f$ becomes 180°. This nulling is comparable to the cancelling loop of feedforward amplifier. However, the intermodulation component is further reduced by factor of $G_f \cdot G_y \cdot G_m$. And the cancellation tolerance is increased by that factor. The overall gain of this amplifier is determined by the feedback loop gain only, i.e. $-1/(G_f \cdot G_y)$. Therefore the system gain is less sensitive to power level or ambient temperature variations. But to obtain high gain, the amplifier gain should be high because the output tapping ratio G_y is determined by the main amplifier gain and tapping ratio of the estimated signal for signal cancellation condition. And this high gain of the main amplifier stabilizes the global gain. Since the main amplifier is operating at a high power level, the gain of the main amplifier is varying according to the operating conditions. But in this circuit, this variation of the main amplifier does not seriously affect the overall circuit performance because the intermodulation cancelling is determined by feeding block gain, G_f, and the tapping ratio of the estimated signal, G_u.

In feedforward circuit, the performance of the error amplifier is critical to the overall system performance[3]. This error amplifier has its inherent nonlinearity. Because of this nonlinearity, the error amplifier distort the error signal also[4].

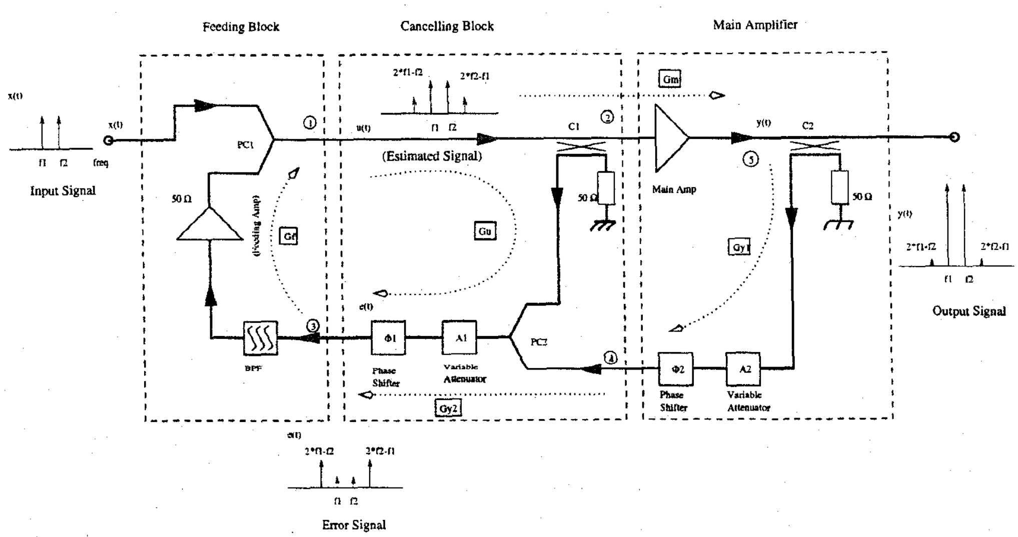

Fig. 1. A new circuit topology for linear amplifier

And this error amplifier output power level should be high because the combining point is the output stage of the main amplifier and also decreased by the combiner coupling loss. Therefore the exact cancelling of fundamental cancelling at nulling loop is very important. But in this circuit, the combining point is input stage of main amplifier and the signal can be combined through 3 dB hybrid because the input stage loss is serious problem compared to the output stage loss. This lower power level of feeding amplifier is very attractive one.

III. Experimental Result

To verify this circuit topology, a linear amplifier is built. At first, main amplifier and feeding block are made. The main amplifier is made by gain block mini-circuit ERA5SM and Rockwell power amplifier module with gain 38 dB, P_{1dB} of 27 dBm and the feeding block amplifier was made by gain block mini-circuit ERA5SM. In this experiment, two-tone test was performed and the test results are shown in Fig 2 and Fig 3. It showed more than 20 dB cancellation of intermodulation from -22 dBc to -42 dBc.

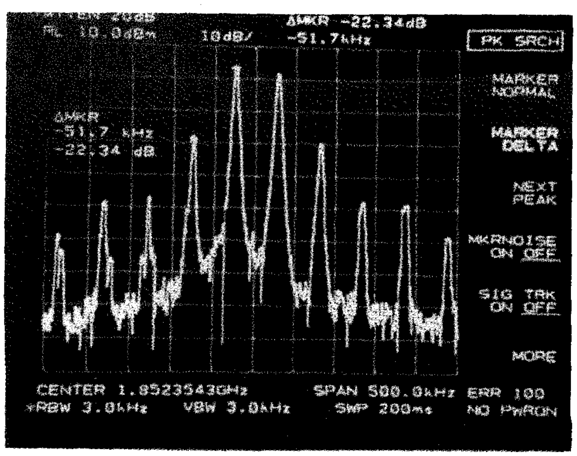

Fig. 2. Two tone output spectrum without linearizing

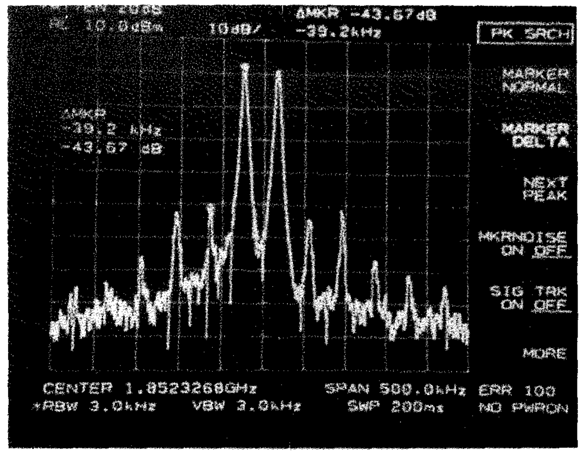

Fig. 3. Two tone output spectrum with linearizing

IV. Conclusion

A new circuit topology was proposed for linear power amplifier. From the analysis of the circuit, the tolerance is far better than that of the feedforward technique. And the specification of linearity in the feeding amplifier is lower than the error amplifier of the feedforward system. These can make the circuit works without the tight component control circuit accuracy.

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