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DESIGN OF CARTESIAN FEEDBACK RF POWER AMPLIFIER FOR L-BAND FREQUENCY RANGE

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Abstract—A phase-alignment system is used fully integrate a power amplifier, Cartesian feedback linearization circuitry, and a phase-alignment system. The phase-alignment system employs a new technique for offset-free analog multiplication that enables it to function without manual trimming. This paper demonstrates how the phase-alignment system improves the stability margins of the fully integrated Cartesian feedback system. The power amplifier itself, integrated on the same die, operates at 1 GHz and delivers a maximum of 30 dBm of output power into a 50-load. The class AB design for open loop and close loop power amplifier with Cartesian feedback, demonstrated a good linearity of 50 dBc and 80 dBc, respectively. The operating power is 2 W at 1000 MHz frequency.

1. INTRODUCTION

RF power amplifier is the basic component in any wireless transceiver so its efficiency directly influences the complete communications system [1–5]. Power amplifier can be classified as most power hungry blocks in a wireless transceiver system. Communication technology is slowly moving towards digital system. Digital technologies now being introduced can increase capacity two to five times compared with analogue system. However, the application of power amplifier will be critical for the digital modulation [11–16].

For power amplifier of digital modulations, linearity is the most important figure of merit. To meet the stringent requirement for linearity, the power amplifier usually operates at class A or AB mode and is back off of output power to accommodate a high peak to average power ratio [6–9]. However, there is a tradeoff between efficiency and linearity. Power amplifier with high linearity has low efficiency [10, 18]. The level of power amplifier increases and the size becomes more compact, the lower efficiency causes severe thermal issue. Hence the efficiency of the amplifier has become an important issue.

If we apply a signal with a varying envelope to a power efficient non linear amplifier the performance of a radio communications system will be deteriorated in two ways [5]. Firstly, the distortion will make it more difficult for the receiver to correctly detect the information [5]. Secondly, as result of the inter-modulation distortion generated in the amplifier, the spectrum of the signal will expand into adjacent channel causing interferences for other users [5].

This paper discuss of designing a RF power amplifier operating power of 30 dBm and frequency of 1000 MHz for digital applications. The power amplifier has been linear using Cartesian Feedback method. The digital application is referred to digital modulation such as TETRA (Terrestial Trunked Radio — European Standard) which has a peak to average power of 3 dB ratio. Linear operating of power amplifier will ensure the operating power at allowable gain compression point and keep the inter-modulation distortion (IMD) within the requirement. Efficiency of the power amplifier will provide a good thermal solution. A proper bias method is taken into account to compromise the linearity and efficiency of the power amplifier.

2. DESIGN ANALYSIS

The design analysis for a PA basically requires dc network and impedance matching. DC network consists of dc feed and dc bias network. DC bias is to select the proper quiescent point and hold the quiescent point constant over variation in transistor and parameters and temperature. Basically, TETRA is a modulation that preserves amplitude and phase signal, therefore, class AB operation biasing is used here. DC feed line is important to prevent the RF from disturbing the dc supply lines. Impedance matching is necessary in PA design, in order to obtain maximum power transfer from source to its load.

For an efficient approach of impedance matching, z-match software is used. Then, the impedance matching can be simulated using Advanced Design System (ADS) simulation tools to calculate return loss performance and optimization with high number of iterations was done for perfect results. For accurate results of simulation, RCL component can be implemented during simulation. Stability design is necessary to ensure no oscillation happens during any conditions especially at mismatch condition.

3. CARTESIAN FEEDBACK SYSTEM

Typical Cartesian Feedback system is illustrated in Figures 1 and 2. Negative feedback is a basic concept behind this system. Cartesian feedback amplifiers are used to generate high output power signals with good adjacent-channel power ratios (ACPR). This is accomplish by coupling off part of the demodulated signal to pre-distort the input baseband I and Q signals via comparator or filter circuit [17–22].

In detail, the demodulated signal I and Q at the output of the power amplifier are feedback to the summing input of comparator or filter circuit after 180 degrees of phase shift. The comparator or filter circuit will pre-distort its output to main virtual ground at the comparator's summing node. This will occur when both inputs of the comparator circuit are in same phase when loop is open. When loop is closed, the input of the comparator or filter will be equal but in

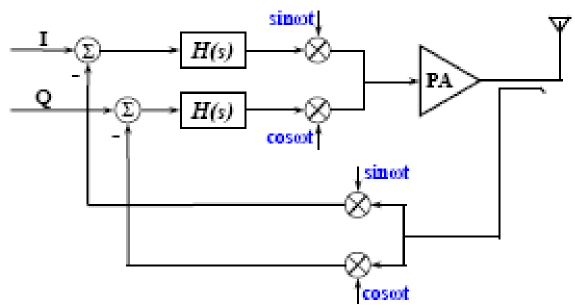


Figure 1. Typical Cartesian feedback system.

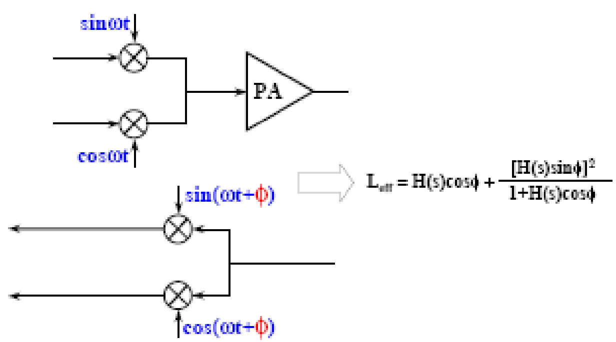


Figure 2. Phase alignment consideration in Cartesian feedback system.

different phase.

To get loop stability, the comparator circuit uses low pass filter circuit to limit loop bandwidth. The cut-off frequency must be sufficiently wider than the bandwidth spread due to the PA nonlinearity. This limits the upper modulation bandwidth, but is sufficient for mobile radio applications. Linearity is limited by two factors which are loop gain and the accuracy of feedback system.

The loop gain should as large as possible, but is limited by the loop stability, which in turn is closely dependent on phase response. Adjustment of the phase shifter is critical. With the loop opened, the phase should be adjusted so that there is no rotation of the demodulated I and Q signals with respect to the I and Q signal at the input of the comparator or filter circuit. The modulated signals are considered as sum [4]

$$A(t)\sin(\omega_o t + \phi(t)) = I(t)\sin\omega_o t + Q(t)\cos\omega_o t \tag{1}$$

where

$$I(t) = A(t)\cos\phi(t) \tag{2}$$
$$Q(t) = A(t)\sin\phi(t) \tag{3}$$

3.1. Phase Alignment in Cartesian Feedback System

Figure 1 shows a typical Cartesian feedback system. The loop driver amplifier is represented by the system block H(s) which provide the loop gain. The loop drivers feed the baseband inputs of the up-conversion mixer, which in turn drives the power amplifier. Coupling of the output of the power amplifier to the down-conversion mixer is employed. The output of the mixer is used to close the feedback system.

There are two identical decoupled feedback loops. One for the I signal component and the other one for Q signal component. This corresponds to the case where $\phi = 0$ as shown in Figure 1. A Cartesian feedback system in which ϕ is non-zero said to have phase misalignment. In such case, the two feedback loops are coupled and the stability of the system is compromised. Phase misalignment has a major impact on system stability which can be derived mathematically. The demodulated signal S' is rotated relative to S to an amount equal to the phase misalignment ϕ. The demodulated signals of Cartesian feedback can be expressed as follows [3].

$$I' = (I\sin\omega t + Q\cos\omega t)\sin(\omega t + \phi) \tag{4}$$
$$Q' = (I\sin\omega t + Q\cos\omega t)\cos(\omega t + \phi) \tag{5}$$

where ω is carrier frequency

By applying trigonometric identities, Equations (4) and (5) can be written as

$$I' = \frac{1}{2}(I\cos\phi + Q\sin\phi) \tag{6}$$

$$Q' = \frac{1}{2}(-I\sin\phi + Q\cos\phi) \tag{7}$$

Here $\phi \neq 0$. An excitation to the I input of the modulator results in a signal on the Q' downconverter output. Similarly Q input of the modulator results in a signal on the I' downconverter output. The two loops are coupled.

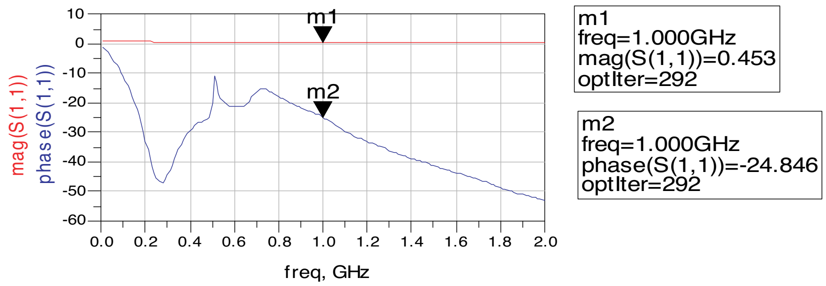
3.2. Cartesian Feedback Power Amplifier

The inter-modulation distortion gives the quality of an amplifier to withstand multiple signals without generating large inter-modulation products or when using amplitude-modulated signals (cross modulation) [2]. For cellular phone systems, digital modulation formats such QPSK and $\pi/4$ DQPSK is used. These modulation types combine phase and amplitude modulation. Amplifiers handling such signals must be carefully characterized and designed if adequate amplitude and phase linearity are to be maintained [2]. This work presents modulation analysis using $\pi/4$ DQPSK in a 1000 MHz power amplifier. This amplifier is designed using Advanced Design System (ADS) to demonstrate the Adjacent Channel Power Ratio (ACPR).

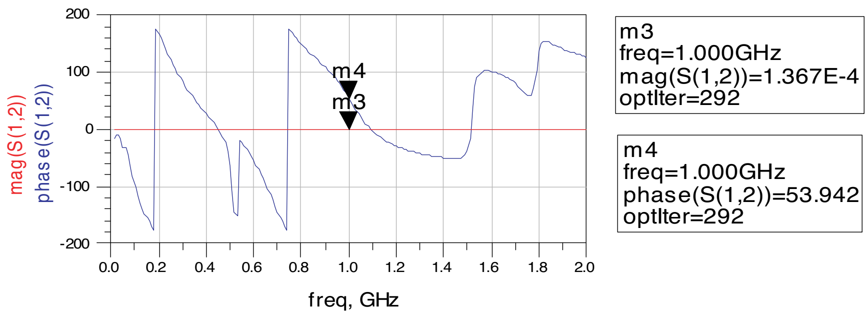
A modulation source ($\pi/4$ DQPSK) is connected to the RF source at the input port of the amplifier. The source specifies the carrier power and the modulation source specifies the modulation format and properties of the modulated signal [2]. For open loop power simulation, harmonic balance simulator controller is used and envelope simulator controller for open loop ACPR. Refer to Figure 11 for open loop ACPR. Envelope simulator combines features of time and frequency domain representation, offering a fast and complete analysis of complex signals such as digitally modulated RF signals.

4. POWER AMPLIFIER SIMULATION ANALYSIS

In order to fabricate the actual board, it is essential to predict the PA performance such as, maximum gain, stability, output power, inter modulation distortion and efficiency. Here, ADS software plays a significant role to predict the PA performance. The RF2173 model is used. Since device model is basically a transistor model, external



(a)



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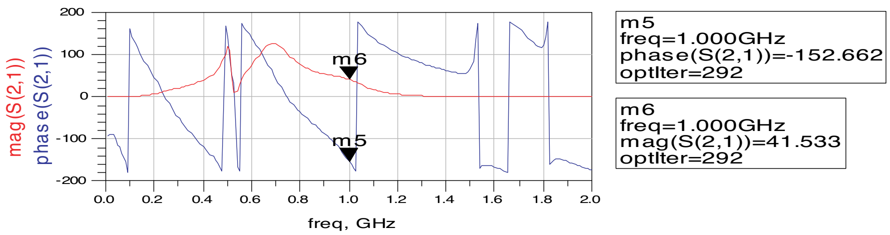

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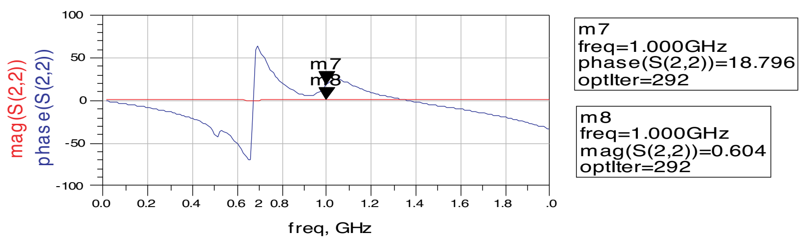

(d)

Figure 3. (a) S_{11} plot of the power amplifier, (b) S_{12} plot of the power amplifier, (c) S_{21} plot of the power amplifier, (d) S_{22} plot of the power amplifier.

dc biasing, dc feeds and impedance matching circuitry design must be done. In order to analyze the performance, DC and AC source was driven into PA device model. Hence the class of operation is set to class AB for optimum performance of linearity and efficiency. The following figures shown here are the simulation results of the power amplifier design. The PA performance is tested based on three different frequencies which are 800 MHz, 900 MHz and 1000 MHz. The simulation temperature is set to 16.85°C as the model temperature is 25°C as stated in the datasheet. In this section only the important results are displayed which reflects the characteristics of the designed power amplifier. These characteristics include output power, input power, minimum noise figure and scattering parameters.

Simulation of transmission coefficient, S_{21} of RF2173 power amplifier was done. Since the input match for the driver is 50 Ω, hence the input matching is not required. In order to generate transmission coefficient simulation, the input matching termination of 50 Ω must be included. As the results, the transmission coefficient simulated results can be obtained from Figure 4 for power amplifier. The simulated results indicating, the transmission coefficient for the driver is performing 32.368 dB at 1000 MHz.

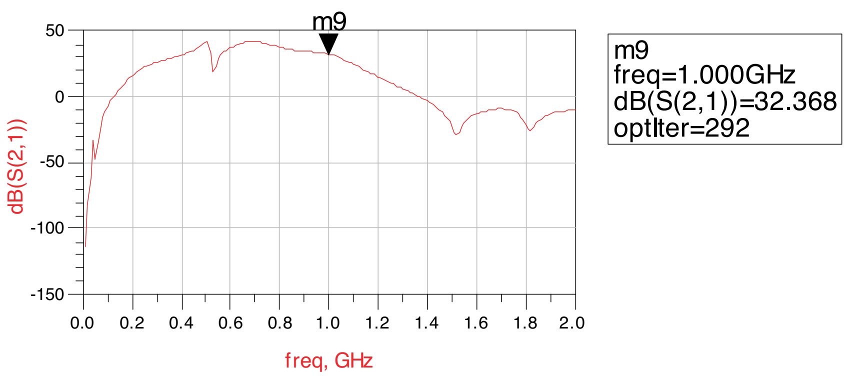

Figure 4. Results of transmission coefficient for the driver amplifier.

5. RESULTS AND COMPARISON

The simulation results of the open loop and close loop are presented to achieve a better understanding on the behavior of the Cartesian feedback power amplifier. The simulation results of the open loop and close loop for 800 MHz are shown in Figure 7 and Figure 8 respectively. The simulation results of the open loop and close loop for 900 MHz are shown in Figure 9 and Figure 10 respectively. Simulation results of open loop and close loop for 1000 MHz are shown in Figure 11 and Figure 12 respectively. The summary simulation performance of the

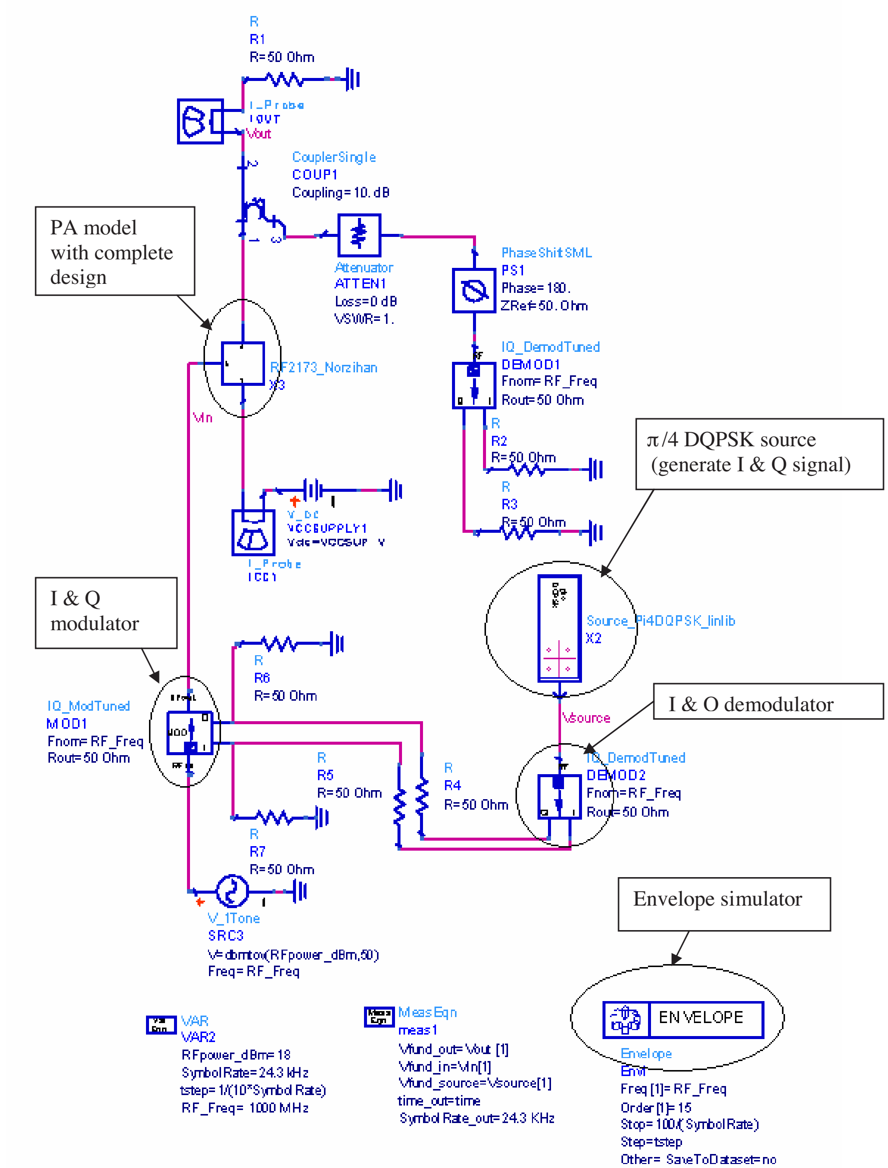

Figure 5. Simulator for open loop Cartesian feedback performance.

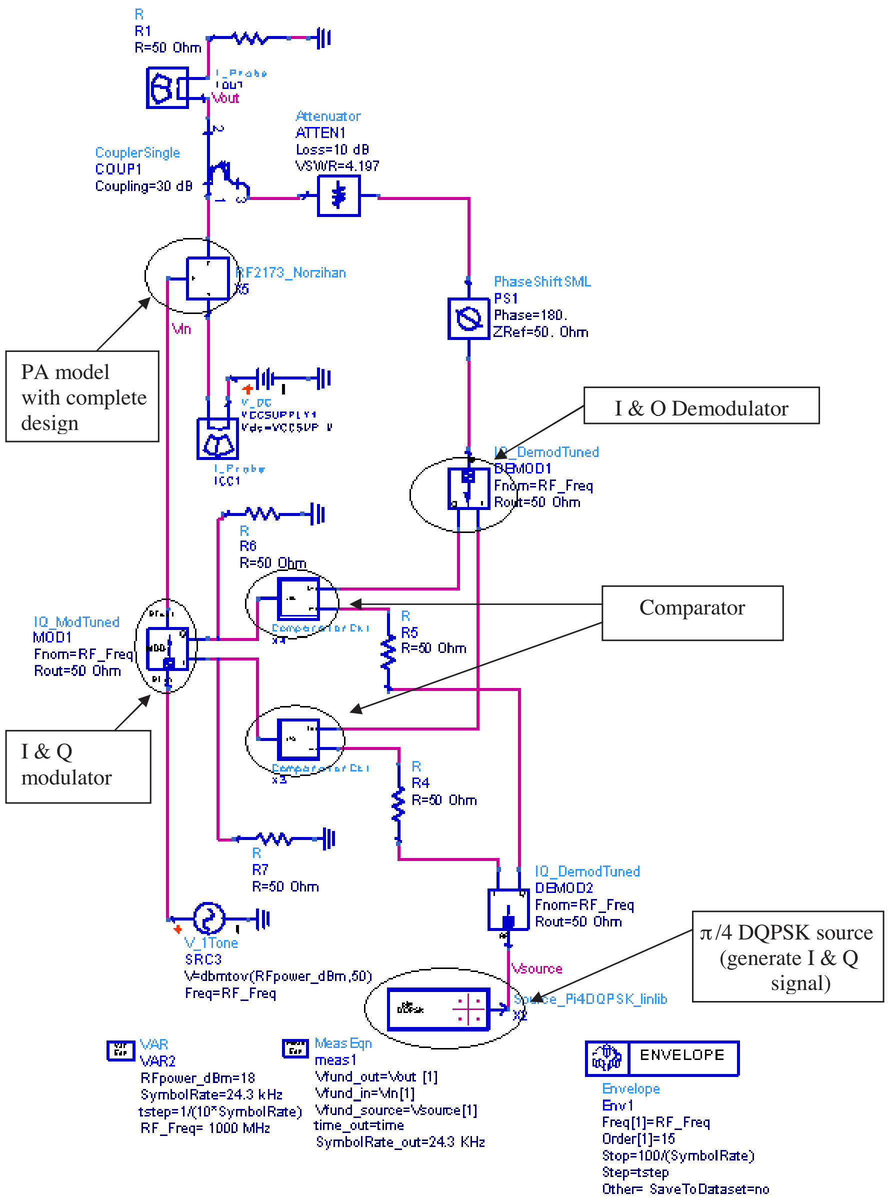

Figure 6. Simulator for close loop Cartesian feedback performance.

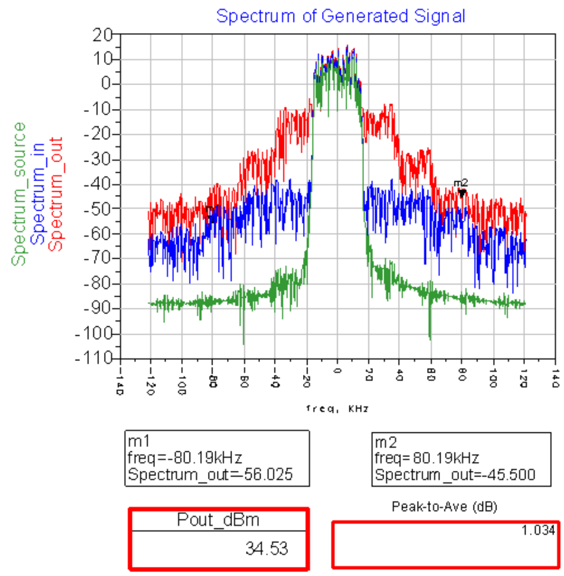

Figure 7. Open loop Cartesian feedback simulation results at 800 MHz.

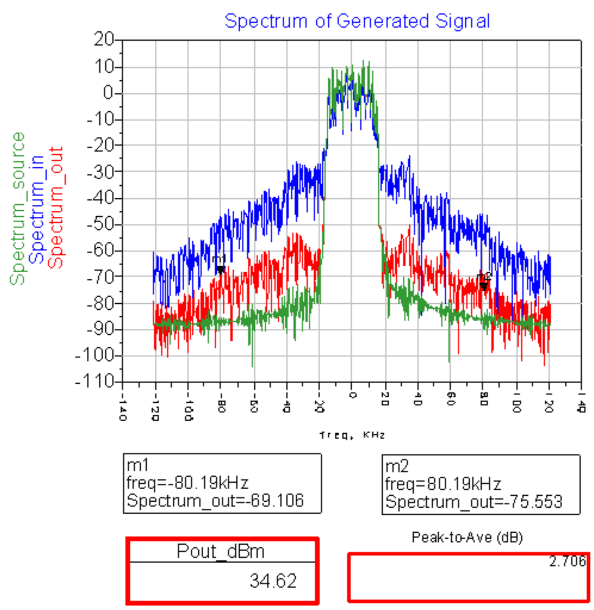

Figure 8. Close loop Cartesian feedback simulation results at 800 MHz.

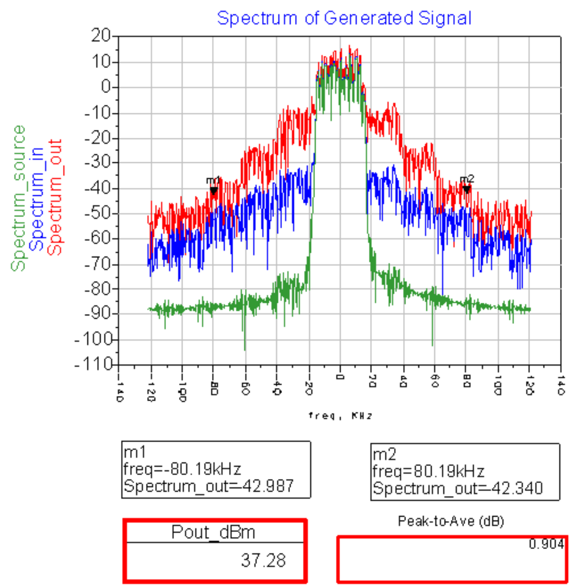

Figure 9. Open loop Cartesian feedback simulation results at 900 MHz.

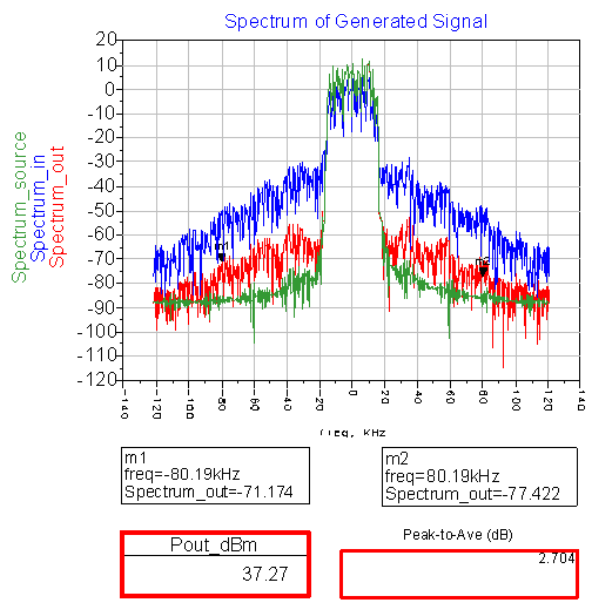

Figure 10. Close loop Cartesian feedback simulation results at 900 MHz.

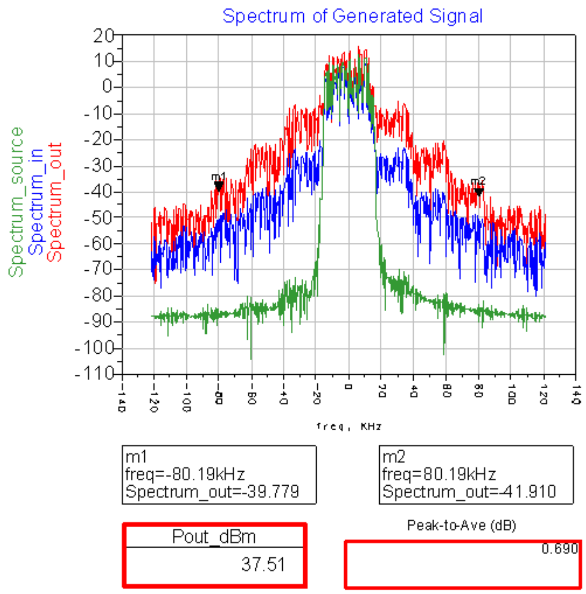

Figure 11. Open loop Cartesian feedback simulation results at 1000 MHz.

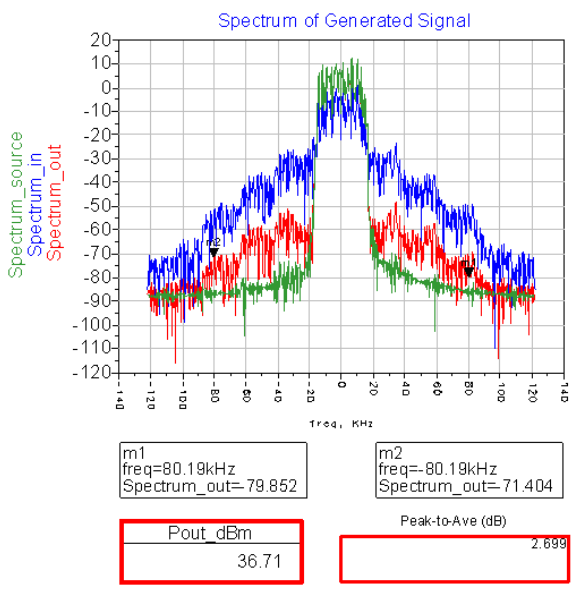

Figure 12. Close loop Cartesian feedback simulation results at 1000 MHz.

Cartesian feedback power amplifier is discussed further with aid of Table 1.

Table 1. Summary of open loop and close loop simulation result of Cartesian feedback power amplifier.

Parameter	800 MHz	900 MHz	1000 MHz
Output Power, dBm (open loop)	34.53	37.28	37.51
Output Power, dBm (close loop)	34.62	37.27	36.71
IMD for open loop, dBc (offset channel of 80 kHz)	−45.5	−42.3	−41.9
IMD for close loop, dBc (offset channel of 80 kHz)	−75.6	−77.4	−71.4
ACPR improvement, dB	30.1	35.1	29.5

Based on the simulation results shown in Table 1, a good ACPR performance is achieved by implementing Cartesian feedback around 30 dB worst case at 1000 MHz. If a signal with varying envelope is applied to a power efficient non linear amplifier, the performance of a radio communications system will deteriorated. As result of the inter-modulation distortion generated in the amplifier, the spectrum of the signal will expand into adjacent channel causing interferences for other users. This phenomenon is illustrated in open loop Cartesian feedback simulation where the IMD is −45.5 dBc, −42.3 dBc and −41.9 dBc at 800 MHz, 900 MHz and 1000 MHz respectively. These spectrums will cause interference for other users and the distortion will make it more difficult for the receiver to correctly detect the information.

These inter-modulation distortions have a debilitating effect on the performance of power amplifier as well as the telecommunication systems. To avoid the interference due to the nonlinearity of the amplifier, close loop has been implemented. The inter-modulation distortion has been compressed to −75.6 dBc, −77.4 dBc and −71.4 dBc at 800 MHz, 900 MHz and 1000 MHz respectively. ACPR performance has been improved by 30 dB for worst case at 1000 MHz. This verifies that a linear power amplifier has been designed with the aid of Cartesian feedback. These close loop architecture reduced the occurrence of inter-modulation distortion which degrades the communication system's performance. Hence, Cartesian feedback technique reduces the inter-modulation distortion by increasing the linearity of the power amplifier.

In order to implement the fabrication process of the PA design in a board, the layout artwork must be done in appropriate way.

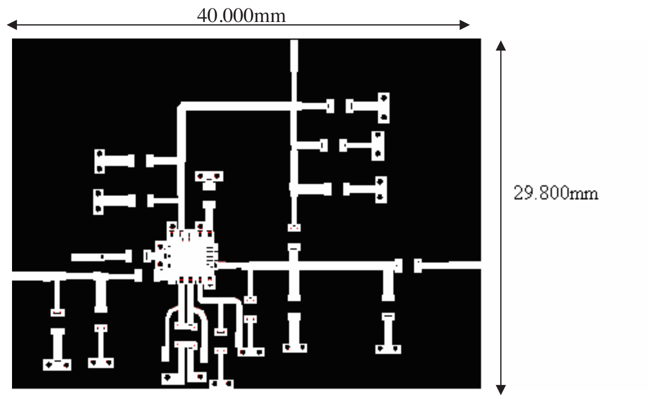

Figure 13. Layout of the RF2173 power amplifier design.

Layout artwork of the RF2173 power amplifier is done with the aid of Advanced Design System software. This final layout is prepared using Auto-Cad tools as shown in Figure 13. The ADS layout is unable to simulate because ADS momentum is an EM simulator. If we want to run a momentum simulation, we can't use the artwork of the PA as momentum simulator is an EM simulator and can't simulate the character of lumped parameter components.

6. CONCLUSION

The simulation analysis gives a good start to achieve our goal in Cartesian Feedback power amplifier design. Simulation analysis can make predication of the actual PA performance. This paper makes a good agreement for linearity and efficiency of the RF2173 power amplifier. As the output spectrum of the PA has been compressed 28.536 dB after close loop Cartesian feedback has been implemented, we can say that a good linearity is achieved. Or in other words, we can say that linearization performances 28.536 dB ACPR improvement at 80 KHz offset. ACPR Global System for Mobile Communications (GSM) which operates from 800–900 MHz. GSM increase the spectral efficiency but a high linearity is required. The spread spectrum technology used in GSM standards allows high spectral efficiency. So this design can be used widely in cellular phone which supports GSM.

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