Load Variation Tolerant Balanced Amplifier with Two Elements LC-Coupler

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Abstract—This paper presents the architecture of a new balanced amplifier with two elements LC-coupler tolerant to load variations at input and output. At first this paper presents an overview of four existing solutions to implement a load variation tolerant front-end. Later the detail description of new proposed amplifier architecture are given. In order to verify the performance of new proposed design ADS simulations are made both for an existing design and the new design. The simulations result show a very good input and output matching, gain flatness, PAE, and ACPR performance of the proposed amplifier design under various load mismatch conditions. The proposed design has linear output power up to 27 dBm and ACPR value better than -50 dBc over the linear region. With less part count, cost, complexity, and losses the new balanced amplifier with LC-coupler can be the choice for UMTS, WLAN, and other mobile radio communication devices.

Index Terms—Isolator, balanced antenna, balanced amplifier, load invariance, LC-coupler, power added efficiency, adjacent channel power ratio.

I. INTRODUCTION

In mobile communication modules for standards like UMTS, WCDMA, UWB, etc., one of the great emphases is the strict linearity requirements of RF power amplifiers. The high linearity is required to insure low error vector magnitude (EVM) for complex modulation modes like 64QAM and minimum interference between different mobile communication devices [1].

The linearity of an amplifier is dependent upon different design parameters. Such as an amplifier class, bias point, and load match. The optimum load match conditions are usually determined by the time consuming load pull measurement method, [2]. Based on these measurements result a particular load condition is selected for an amplifier to give highest linear output power and lowest inter modulation distortion level. Therefore the linearity of RF amplifier is greatly effect by the degree of matching between the amplifier and the load impedance. The load impedance in wireless mobile communication devices changes with the changes in surrounding environment. This drifts the amplifier load from its optimum load value. It will effect the matching of an antenna (load) with RF amplifier resulting in the loss of amplifier linearity. It will cause the re-growth of spectral components and will degrade the adjacent channel power ratio (ACPR) performance. These conditions give a challenge to design an amplifier which is tolerant to load variations. This is one of the important areas of research for power amplifier designers. Different solutions are proposed to overcome this problem. However, at the same time these solutions have increased the amplifier cost, complexity, and expensive integrated chip area.

The following section will present some of the existing techniques applied to achieve amplifiers tolerant to load variations. The techniques described here includes the use of isolators, balanced antenna, [3], and amplifiers with phase shift approach, [4]. In the next section the detail description of new proposed load variation tolerant balanced amplifier with LC-coupler is presented. It also includes the ADS simulation results of an existing solution and new proposed design. The ADS results include amplifier performance parameters like input and output matching, power added efficiency (PAE), gain, linearity, and adjacent channel power ratio (ACPR) under the various load mismatch conditions. The results showed that the new proposed design has high degree of tolerance to load variations. It has comparable efficiency and ACPR performance to existing designs but with less part count, complexity, and cost.

II. EXISTING SOLUTIONS

This section gives an overview of some of the existing solutions to overcome amplifier linearity problems due to load mismatch. These solutions include amplifiers with isolators, balanced antenna and phase shift approach (PSA) to cancel out the reflections due to antenna mis-match. It will also develop the background necessary to understand and evaluate the concept of new balanced amplifier with LC-coupler presented in this paper.

A. Amplifier with Isolator

In mobile communication devices antenna mis-match can produce reflections that travels toward the amplifier and result in standing wave pattern. One classical way to prevent standing wave pattern due to reflections is by the use of isolators, [5], shown in Fig. 1.

![Fig. 1. The classical way to realize load variation tolerant amplifier](image)

Although isolators provide better isolation but at the same time they are suffered by the number of disadvantages. Which includes large integration space required by the isolators, high component cost, and difficulty of realizing the isolator with different technologies. The insertion loss of isolators will also introduce losses in RF path and will decrease the power added efficiency of an amplifier. This effect will reduce the battery operating time in hand held devices.
**B. Amplifier with Balanced Antenna**

Another quite new concept to overcome the impedance mismatch at power amplifier output due to antenna mismatch is presented in [3]. It uses a balanced antenna [6] including two elements LC-coupler, shown in Fig. 2. The 90° LC-coupler [7] consists of one inductor and one capacitor. The phase variation from port 1 to port 2 is -45° and from port 1 to port 4 is +45°. The power amplifier is attached to port 1 and port 3 is terminated in 50 Ω matched load. Port 2 and port 4 are connected to two similar symmetrical antennas, placed close to each other. The impedances \( Z_1 \) and \( Z_2 \) are given by

\[
Z_1, Z_2 = Z_o^2
\]

and

\[
|Z_1| = |Z_o| = \left| \frac{1}{j\omega C} \right| ,
\]

\[
|Z_2| = |Z_o| = \left| j\omega L \right| .
\]

The mis-match at antennas due to environmental changes will affect the two antennas in same order. The wave traveling from port 1 to port 2 and reflected back due to mis-match at antenna will suffer total phase change of -90°. In the same manner wave reflected from port 4 to port 1 will suffer total phase change of +90°. Now the two reflected waves are 180° out of phase and will cancel each other at port 1, preventing the standing wave pattern due load mis-match. The reflected power will dissipate in 50 Ω matched load connected to port 3.

**C. Amplifier with Phase Shift Approach (PSA)**

One approach to avoid ACPR degradation due to amplifier non-linearity caused by load mis-match is presented [4]. In this technique two amplification paths are used with phase shifting and matching networks at the input and output section, as shown in Fig. 4.

Under the load mis-match conditions a matching network at the output stage of each amplifier behaves complementary to each other. In case of impedance mis-match one path of the amplifier presents high impedance to the output of amplifier and second path presents the low impedance to the output of second amplifier. Therefore increasing the ACPR performance of amplifier in one branch and decreasing in the other branch. The resultant ACPR performance under the mis-match condition lies between the ACPR performances of individual amplifiers. This gives an overall improved ACPR performance under various antenna mis-match conditions.

In Fig. 4 the reflected wave due to antenna mis-match is divided equally into two paths and travels toward the amplifiers. The wave in each path is reflected again by the amplifier output and causes the standing wave pattern. However the wave traveling from antenna to amplifier output and back undergoes through the phase change of 90° in one path and -90° in other path. The two waves are now 180° out of phase and are canceled by each other at output of power combiner. And also due to 180° phase difference the reflected energy is dissipated in the resistor of the power combiner.

**Fig. 3.** The magnitude of reflection response of balanced antenna with metal reflector in the direct vicinity over frequency

**Fig. 5.** The input reflection S(1,1) and output reflection S(2,2) response of PSA
The ADS simulations are performed by using the TriQuint library for the PSA amplifier. The matching response of PSA amplifier is shown in Fig. 5. It shows the input and output matching is better than -17 dBm. Fig. 6 shows PSA has in-band transmission gain of 29 dB with gain flatness of ± 0.4 dB.

Fig. 6. The transmission coefficient S(2,1) of phase shift approach (PSA) amplifier

Fig. 7 shows reverse isolation response of PSA amplifier. It has an in-band reverse isolation value better than -60 dB.

Fig. 7. Reverse transmission coefficient S(1,2) (isolation) of PSA amplifier

Fig. 8 shows the stability factor (k) of PSA amplifier. The stability factor k is higher than 19.

Fig. 8. The stability factor (k) of PSA over frequency

The drawback of PSA approach is the excessive use of inductors and capacitors in the input and output phase shift circuits. Also inductors are required for the implementations of input power splitter and output power combiner circuits. This will use expansive chip area, and is expensive.

D. Adaptive Matching Network

Adaptive matching network [8] is another new concept to overcome load mis-match conditions. The larger benefit of this technique is that, any primitive antenna can be used to achieve a good match for any desired frequency band while using the same mis-antenna. The mis-match caused due to environmental changes, e.g. in the vicinity of large metallic objects will be dynamically compensated by the matching network, shown in Fig. 9. The figure shows a \( \pi \)-matching network with variable element values. The adaptive matching network can be realized in the form of step matching network.

Fig. 9. The dynamic L- or C-matching network

Fig. 10 shows a possible complete front-end solution implemented with adaptive matching network. It uses directional coupler to separate the reflected wave from incident wave. The magnitude of the reflected wave is measured with the detector attached to the coupled arm of the directional coupler. The magnitude information of the reflected wave is processed by the logic control unit. Which alters the value of variable elements in the adaptive matching network in such a way to reduce the magnitude of reflected waves. In this way it is then possible to achieve good load match conditions under changing environmental conditions. The drawback of this technique is the use of lot of hardware for additional matching control loop.

Fig. 10. Adaptive matching network

III. BALANCED AMPLIFIER WITH LC-COUPLER

This section presents the operational principle and simulation results of proposed balanced amplifier (BA) with two elements LC-coupler.

A. Operating Principle

The concept of the new balanced amplifier is illustrated in Fig. 11 [9]. The realization of a balanced amplifier with two elements LC-coupler is shown in Fig. 12. The power is feed to the amplifier through the unbalanced port 1 of LC-coupler (input). The differential inputs of amplifiers PA1 and PA2 are connected to the differential grounded-unsymmetrical port 2 and port 4 of LC-coupler, respectively. The port 3 of LC-coupler is matched to 50\( \Omega \). The output of amplifiers PA1 and PA2 are connected to differential grounded-unsymmetrical
Fig. 11. The concept of balanced amplifier with LC-coupler

Port 2' and port 4' of LC-coupler. Port 3' is matched to 50 Ω and port 1' gives the unbalanced amplified output. In the actual design cross mode blockers [13] are added at the input and output section of balanced amplifier.

The power applied to the input port 1 of balanced amplifier configuration Fig. 12 is divided equally into two paths. The LC-coupler will introduce a phase difference of 90° between the power at port 2 and port 3 so that the phase of the wave at the input of amplifier PA1 is lag by 45° and at the input of amplifier PA2 is lead by 45° with respect to the phase of applied signal. From the output of amplifier PA1 to the output port 1' the phase change is +45° and -45° from the output of amplifier PA2 to output port 1'. This will cancel the effect of phase change introduced in the input section of the balanced amplifier. Hence the waves reaching to port 1' from each amplifier are in phase and will add constructively. Under the matched conditions total power delivered to the load is equal to the sum of the output power from each amplifier, [10].

In case of mis-match present at the output port 1’, reflections will occur traveling toward the differential amplifiers. The wave traveling from the output of PA1 to output port 1’ and reflected back will undergo the total phase change of 90°. In the similar manner total phase change of -90° will occur for the wave traveling from the output of amplifier PA2 to output port 1’ and reflected back to PA2. The two reflected waves are now 180° out of phase and will superimpose destructively at the output of differential amplifiers. Due to 180°phase difference between the reflected waves, current will flow in 50 Ω matched load connected to port 3’, dissipating the reflected power. This principle provides isolation to amplifiers from the reflected waves and makes the balanced amplifier configuration tolerant to load variations. The concept well known from the classical balanced amplifier theory [11]. The performance of proposed design is presented in next section.

B. Simulation Results

The proposed design of new balanced amplifier is simulated in Advance Design System (ADS) using the TriQuint Semiconductor design library.

Fig. 13 shows the amplifier input and output matching response. At 1900 MHz the input matching S(1,1) is better than -15 dB and output matching S(2,2) is better than -29 dB. Fig. 14 shows the transmission S(2,1) response of BA over the frequency sweep. The plot shows that balanced amplifier has in-band transmission S(2,1) gain of 28 dB. The plot also shows the in-band gain has flatness of ±0.2 dB at 1900 MHz.

Fig. 15 shows the plot of BA stability factor (k) over a wide frequency band of 5 GHz.

Fig. 16 shows the linearity response of the proposed balanced amplifier and phase shift approach amplifier (PSA). The
balanced amplifier has higher output power and compression starts at 27 dBm output power. The PSA has lower output power and similar compression point. The overall response of two architectures is close to each other.

![Fig. 16. The linearity response of balanced amplifier and phase shift approach amplifier](image)

Fig. 16. The linearity response of balanced amplifier and phase shift approach amplifier

Fig. 17 shows the ACPR performance of balanced amplifier. It showed the BA has ACPR value of -49 dBc at the linear output power range of 27 dBm. The value is suitable for the EDGE application and communication devices requiring amplifiers with high output power and low adjacent channel interference.

![Fig. 17. The ACPR of balanced amplifier over the output power](image)

Fig. 17. The ACPR of balanced amplifier over the output power

Fig. 18 shows the ACPR performance of two architectures under the mis-match conditions. It shows under the perfect VSWR value of 1 the ACPR of both amplifiers is around -54 dBc. Now due to the load variation tolerant property the performance of ACPR does not fall rapidly with increasing VSWR values. This is an important requirement for power amplifiers in hand held devices to behave well under mismatch conditions.

Usually the amplifier design requires good linearity and low harmonics up to VSWR of 4:1. [12]. The plot shows that ACPR value of BA is below -43 dBc for VSWR 4:1. This plot also shows the comparison of ACPR values of BA and PSA amplifiers. At higher VSWR 5:1 the ACPR response of BA is around 5 dBc better as compared to PSA amplifier.

Fig. 19 shows the efficiency of balanced amplifier and PSA amplifier. The plot shows the two approaches have nearly the same efficiency of 33% at maximum linear output power.

![Fig. 18. The ACPR performance of BA and PSA amplifier over VSWR at an output power of 26 dBm](image)

Fig. 18. The ACPR performance of BA and PSA amplifier over VSWR at an output power of 26 dBm

![Fig. 19. The efficiency of BA and PSA amplifier over an output power of 28 dBm](image)

Fig. 19. The efficiency of BA and PSA amplifier over an output power of 28 dBm

IV. CONCLUSION

A new concept of load variation tolerant balanced amplifier with two elements LC-coupler has been presented. The paper started with an overview of existing amplifiers with load variation tolerant techniques. The performances of existing techniques were examined with ADS simulation. The main features and drawbacks of these techniques were also described. After that the concept of the new balanced amplifier has been presented. The design has been simulated in ADS, using the TriQuint Semiconductor design library. In order to verify the performance of new design the results of important amplifier design parameters like input matching, output matching, stability factor, linearity response, efficiency, ACPR over the input power, and ACPR over the varying VSWR were also included. These results showed the proposed design has a stability factor higher than 25, output linearity of 27 dBm and ACPR value better than -50 dBc at maximum output linear power. Further the load variation tolerant feature of balanced amplifier was tested over the VSWR 5:1. All said parameters were also compared with other load variation tolerant amplifier designs. The proposed design has similar performance to other designs but with much reduced architecture complexity and cost which makes it preferable choice for high integrated circuit solutions of the mobile RF communication devices.

REFERENCES


