Benefits of Active Transmit Balanced Antenna Fed by Differential Power Amplifier

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***Abstract*— A differential amplifier feeding a balanced antenna is investigated experimentally. This approach would suit modern RFIC design rather than using a 50Ω unbalanced connection. As such the balun or power-combining network is eliminated resulting in a compact RF front-end design with wider bandwidth and lower losses. Experimental result shows that this technique promises higher output power compared to conventional feeding approach while using same RFIC and same power supply.**

Keywords—balanced antenna, differential amplifier, power amplifier (PA), free space path loss.

I. INTRODUCTION

With continuing advancements in personal communications in this era of digital economy, the demand for wireless connectivity has grown radically. This increasing number of portable devices creates a need for high spectral density, more power efficient topology, wider impedance bandwidth but maintaining excellent radiation performance. Currently the preferred choice of antenna for handset designers is the compact, low-profile planar inverted-F antenna (PIFA)) However, the PIFA is a narrowband, unbalanced design that requires a current flowing onon the ground plane. An implication of this is that external objects such as a human head or hand can influence the ground plane current, which eventually degrades antenna radiation characteristics [1]. A balanced structure has been proposed as a solution to avoid this degradation[2]. In this type of antenna, balanced currents only flow on the antenna element, thus dramatically reducing the effect of current flow on the ground plane (i.e. phone chassis) [3].

Differential circuits are also preferred by RFIC designers as they offer improved noise, larger signal handling capability and improved linearity [4]. An obvious design approach is therefore to use a balanced antenna fed by a differential amplifier. However, recent published works on mobile antenna [5-6] show that researchers still tend to sidestep balanced circuits and antennas. Although balanced amplifiers are being widely used in the RFIC because of their benefits, but they use single ended PAs and LNAs for the feeding part [7].

Feeding a balanced antenna with a differential amplifier can imply numerous benefits for 4G mobile applications, but this area appears to have been ignored, maybe due to the eccentricity of the approach and complex measurement techniques. Some research has been conducted recently on this topic where [8] discussed about enormous benefits of AIA, but the principal approach was with single ended devices. In [9], a two amplifiers working in a 'differential manner was used to provide a hybrid feed to a patch antenna but balanced antenna wasn't been considered. [10] treated differential antenna like a two port component and measured the return loss of a differential antenna using 2 coaxial port simultaneously, but didn't use an active device or a power amplifier for feeding balanced antenna. Few researchers have reported the integrated-antenna concept applied to push–pull power amplifiers [11-13] but push-pull is not a true differential feed, which consists 2 output terminals along with a third common ground terminal. The benefits of using a true differential amplifier fed by a balanced antenna as a receiver have been demonstrated already in [14], so our interest was to explore a transmit antenna.

In this paper, we investigate differential feeding of a balanced antenna as an alternative to a single ended amplifier feeding an unbalanced antenna. The same differential power amplifier is used throughout but using a balun to provide a with single ended output. Circuit tests on the bench are compared to radiated power. The motivation is to apply RFIC differential feeding techniques and develop balanced antennas for future mobile devices applications.

II. EXPERIMENTAL COMPONENTS

A. Amplifier Design

A circuit diagram of the experimental differential amplifier, using a Texas Instruments LMH6881 RFIC, is shown in Fig 1(a). It can be seen that a 2:1 impedance transformer has been used at the input to convert the 100Ω differential input to an unbalanced 50 Ohm input, for connection to conventional test equipment. The differential output is 100 ohms, balanced with respect to ground, so can provide two 50Ω ports for circuit testing However, the expected load impedance is no longer the usual 50Ω to 'ground', but a true balanced 100Ω. A second prototype single-ended amplifier can be provided by adding a second 2:1 impedance transformer to the output, as indicated I nFig 1(a). The RFIC with associated biasing and decoupling components was constructed using microstrip technology on a 0.8mm FR4 PCB. The prototype differential amplifier is shown in Fig 1(b) and the single ended in Fig 1(c).

It is a common practice to use a 'balun' as a converting feeding mechanism between a differential circuit and an unbalanced circuit structure. The use of a balun introduces losses and bandwidth restrictions. However the RFIC can be placed directly at the antenna feed point.

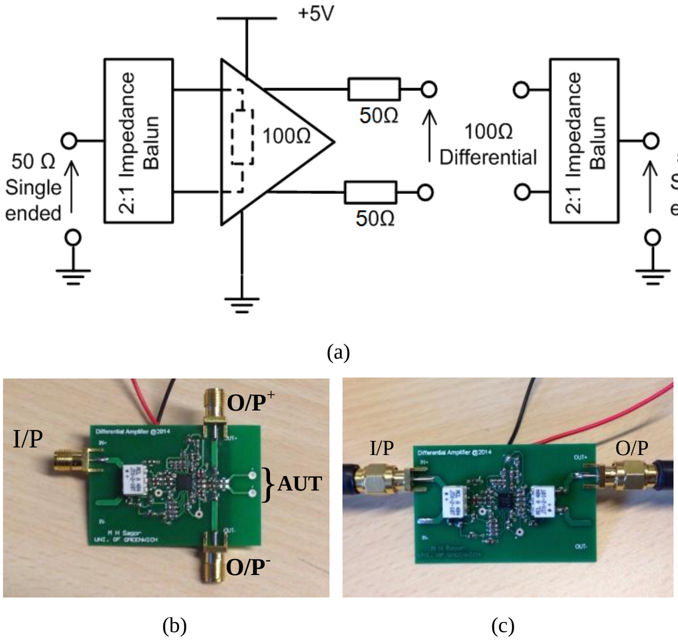

Fig. 1. Proposed amplifiers configuration
(a) Circuit diagram showing impedances
(b) Photograph of Differential Amplifier
(c) Photograph of single-ended output

The measured frequency responses of the two amplifiers as 2-port circuits are presented in Fig. 2. For this the outputs of the differential amplifier are fed to 2 separate 50 Ohm ports, as discussed above. It can be seen from the graph that these two outputs give virtually identical magnitudes (Red & Black). Not shown in Fig. 2, the phase difference between these ports was measured at 179 degree phase difference throughout this measurement range, as expected. Theoretically, the power gain of the amplifier with balun should be double (3dB higher) compared to the gain at each port of the differential amplifier but is seen to be only ~2 dB higher in Fig. 2 – indication of balun loss. Also, the gain rolls off earlier for the single-ended amplifier due to the additional balun – the balun is rated to work till 1GHz. For completeness the return loss for each amplifier is also included in Figure 2 – giving a good match up to 1 GHz. All measurements are made under small signal conditions.

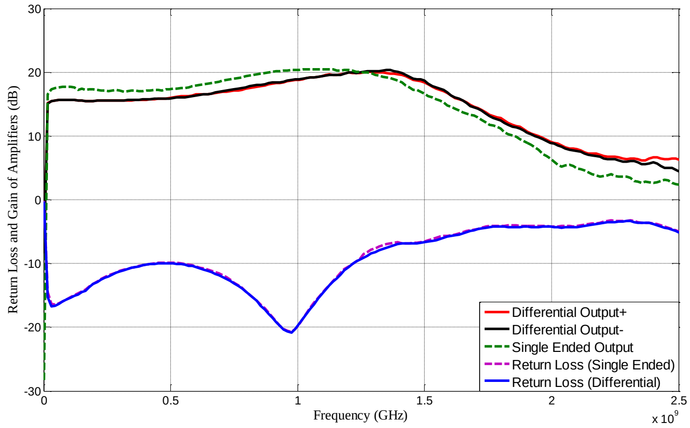

Fig. 2. Return Loss (S11) and Gain (S21) of differential amplifiers

B. *Antenna*

The antennas used here are the simplest form of monopole and dipole operating in the frequency range of 855MHz-945MHz. It is well known that the impedance of a monopole (~37Ω) is half that of the corresponding dipole (~73Ω) which conveniently provides matching to the corresponding amplifier (the differential amplifier also having double the impedance). 8cm long solid wire was mounted on a metal ground plane which is a few wavelengths in size around the monopole to keep the impedance of the antenna minimally affected. Two identical conductive elements were chosen to construct the dipole form. These forms were chosen to keep the measurement simple and make sure nothing else is affecting the measurement.

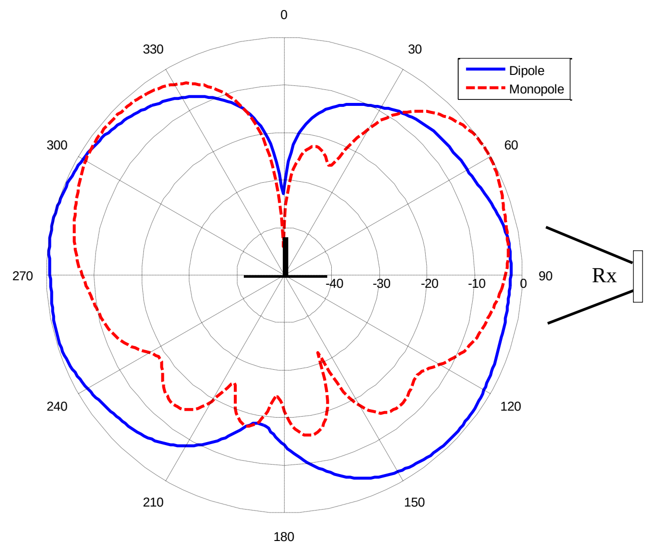

Fig. 3. Crosspolar radiation pattern of the simple monopole and dipole antenna and antenna direction during P_{in} vs P_{out} measurement.

Radiation patterns were measured for both antennas and are presented in Fig. 3. Assuming the elements are in the 'vertical direction', plots for co-polar 'vertical' polarization in the vertical plane are presented. In the horizontal plane the antennas are omni-directional. Although unbalanced monopole and balanced dipole antennas are 'complementary', but in practice patterns are seen to be significantly different. For the case of the monopole with a ground plane, the energy tends to radiate into one half-plane only, so we get 3dBi more peak power compared to same dipole configuration, but at an angle to the 'horizontal'.

III. Measurement of Active Antennas

To compare the active antenna configurations the radiated power as a function of input power was measured using a signal generator and a spectrum analyzer. Firstly, the single ended power amplifier was characterized on the bench (as had 50 Ohm output port). Then the amplifiers were attached to the antennas and radiated test were made inside an anechoic chamber. The amplifier with single ended output was connected to the monopole antenna using 50Ω coaxial cable. However, the dipole was soldered directly to the differential terminals (at AUT in Fig 1(a) – disconnecting the 50Ω feed lines to the SMA test ports). These active antennas were placed 2.5m from the receive horn antenna inside the chamber, which is connected to a spectrum analyzer to observe the output signal. A signal generator, generating 900 MHz signal, was connected to the input port of the amplifier. Fig. 4 shows the measurement setup of both active antennas.

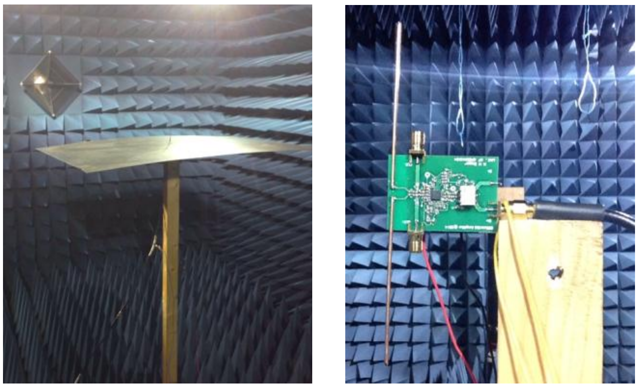

Fig. 4. Measurement setup of conventionally fed monopole antenna (left) and differentially fed dipole antenna (right)

To measure the Pin vs Pout characteristic the power level of the input signal was varied from -40dBm to the saturation of the amplifier. Fig. 5 shows the results of both the bench and radiated power tests. The effective radiated output power was calculated by adding the free space path loss (FSPL) and adjusting for antenna gain and any feed cable loss. Good agreement is observed between the bench test result and the radiated power for the single ended amplifier with monopole, verifying this measurement method. We can clearly observe 1.4 dB higher gain throughout the entire range and higher output power from the differentially fed active antenna. This is expected due to elimination of the balun loss. However, we also observed a significant dip in the peak power dips after saturation (see inset detail in Fig. 5). The difference between the two configurations is the elimination of the balun and antenna impedance – this effect is likely related to load impedance effects.

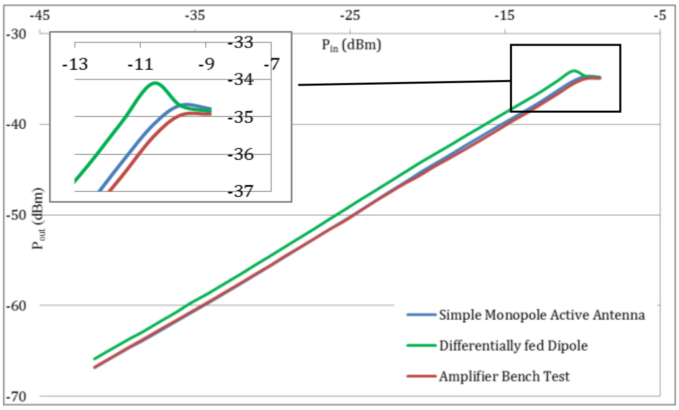

Fig. 5. P_{in} vs P_{out} results of the amplifier with conventionally fed and differentially fed antenna

IV. Conclusion

It has been demonstrated experimentally that higher gain and output power is achievable using the same RFIC and same power supply by using a differential feed to a balanced antenna instead of the 'usual' unbalanced 50 Ohm feed to an unbalanced antenna. The increase in power is due to elimination of the balun which can also give increased bandwidth. It was noted there was a doubling in impedance for both the amplifier and the antenna in the differential/balanced configuration facilitating matching. However there are notable differences between the two configurations. The radiation patterns exhibit significant differences – although antennas were omni-directional in the 'horizontal' plane, the unbalanced antenna radiates into one half-space only whilst the balanced radiates into both half-spaces, desired for portable devices. It was also noted the behaviour of the amplifier changed slightly as it went into saturation, thought due to a change in the wide-band load impedance - this needs further investigation.

Overall the differentially fed, balanced antenna not only offers improved performance in power and bandwidth but by eliminating balun will also result in reduced physical size and costs. These factors warrant further consideration of this design approach for more power efficient wireless devices by adopting differential feeding technique.

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