Vivaldi Antenna Push-Pull Power Amplifier Design

Loïc MARNAT, Dominique LO HINE TONG, Philippe MINARD, Ali LOUZIR
Thomson R &D France - Technology Group
Corporate Research - Network & Communication
1, Avenue Belle-Fontaine, CS17616, 35576 Cesson-Sévigné Cedex. France
{dominique.lohinetong; philippe.minard; ali.louzir}@thomson.net

Abstract

This paper presents a new design of a push-pull power amplifier (PA) structure integrated in a Vivaldi antenna. This structure responds to the demand of power and linearity required by modern wireless communication systems. The new approach presented here is based on a microstrip to slotline transition aiming to divide and combine the transmitted signal. This concept is applied here for the design of a compact push-pull PA in the 5GHz Wireless-LAN (IEEE 802.11a) frequency band. The design based on the low-cost FR4 substrate has been electromagnetically fully simulated using a commercial software.

1. INTRODUCTION

The Wi-Fi technology working at the 802.11a/b/g standards, in the 2.4 and 5 GHz bands, is nowadays well established in high rate wireless communication systems, and more particularly in consumer premises equipments. This technology has to address for instance the increasing demand in video streaming between a Set Top Box (STB) and several terminals (PC, TV set,…) which requires the use of high spectral efficiency modulations to reach the highest rate allowed by the norm (54 Mbps).

Those modulations such as the 64QAM are very constraining regarding the power amplifier features of the transmit chain, the higher the order of modulation and the lower the linearity tolerances. Moreover, multi-carriers OFDM modulations used in almost all wireless communication systems, which are based on non-constant envelope modulation, are particularly sensitive to the power amplifier non linearities. It leads to a large back-off, around 6dB, of the output power from its 1dB compression point in order to satisfy the linearity requirement.

It is difficult today to find out power amplifiers capable of emitting the maximum power allowed by the standards, taking into consideration the cost constraints and power consumption of the targeted products. For instance, emitted EIRP (Equivalent Isotropic Radiated Power) of 30 dBm and 35 dBm allowed respectively in EU and US is difficult to achieve, considering common printed antenna directivity of around 5-6 dBi and commercial 20dBm linear output power based on low-cost InGaP/GaAs HBT (Heterojunction bipolar transistor) technology.

One way for achieving the best cost to output power trade-off is to set several PAs in parallel. Among the combination techniques, the push-pull configuration offers several advantages, and for one of the most important the linearity yield of the power amplifiers. Moreover, as demonstrated in previous works [1-2] it allows integrating the PA with the antenna design, lessening by this way the output losses and compacting at the same time the transmitter front-end.

In this paper a new concept for the realization of the push-pull power amplifier integrated in a Vivaldi antenna is presented in the whole 5GHz band (4.9GHz-5.9GHz). Vivaldi antenna is selected thanks to its features in terms of directivity and frequency bandwidth [3]. The paper deals first with a conventional approach based on hybrid couplers, and then the new concept based on microstrip to slotline transitions is explained in detail, showing its interest in term of size and performance. This study tackles also potential oscillation issues for PA structure featuring high gain, and gives solutions to overcome them. Fully electromagnetic simulated results of an optimized structure are presented.

2. CONVENTIONAL PUSH-PULL PA

Fig. 1a shows the general principle of the push-pull PA and the complete conventional design associated with a Vivaldi antenna is presented in Fig. 2. The push-pull amplifier is typically used to easily provide theoretically an additional power of 3 dB. This structure shows excellent properties at low frequencies where implementations are well known and controlled. At microwave and millimeter wave frequencies, hybrid couplers or baluns [4] are used to feed the amplifiers and to combine the output signals. For proper push-pull operation, the feeding must be done in such a manner that the desired fundamental mode is excited 180° out-of-phase by each feed. As depicted in Fig. 1b, this circuit inherently cancels even harmonics in the output and leaves the third-harmonic term as the principal source of distortion. Therefore, this structure features an inherent spurious-signal rejection of even orders and less distortion.

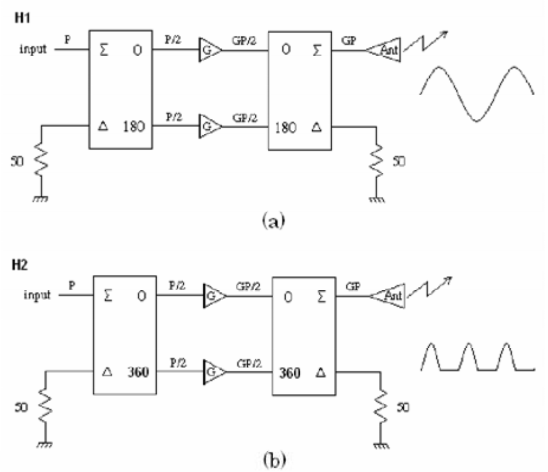


Fig. 1: Architecture of conventional Push-Pull PA for: a) first Harmonic and b) second Harmonic

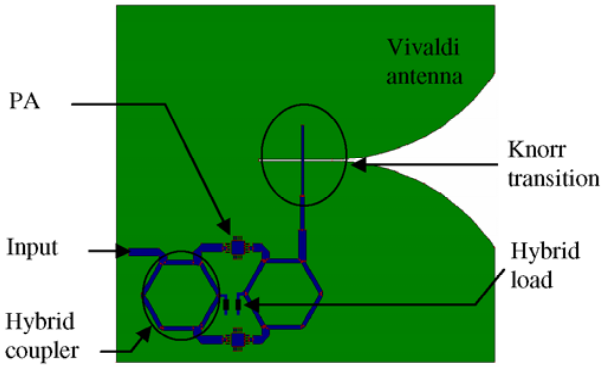


Fig. 2: Push-pull amplifier feeding a Vivaldi antenna

The divider and combiner elements can limit the performances of the push-pull PA. The critical losses appear to be on the power combination. Indeed, a combining loss of 0.5 dB will decrease overall power-added efficiency of two single-end amplifiers operating at 60% to 53% [1].
As illustrated in Fig. 2, the push-pull configuration uses two 0/180° hybrid couplers in microstrip technology to feed a Vivaldi antenna. The following implications can be highlighted with this conventional structure:

- A non negligible size because of two hybrid rings are used
- More insertion losses through these hybrids
- Bandwidth limitations due to these hybrids

The idea to overcome those drawbacks is to integrate the push-pull PA to the antenna. This integration offers minimal matching and interconnects. Multiple recent works have demonstrated their interests [1-2]. Several types of antenna were integrated such as patch and slot antennas, leaky-wave antennas and printed quasi-Yagi antenna. This paper deals for the first time with a particular type of tapered-slot antennas (TSA) called Vivaldi antenna. The idea is to keep the same technique to feed the antenna and to combine the power in order to reduce the size and to improve the performances of the push-pull PA integrated into a front end antenna. In this novel topology hybrid couplers are replaced by microstrip to slotline transitions.

3. NEW APPROACH DESCRIPTION

Fig. 3 shows the new topology of the proposed integrated-antenna push-pull power amplifier using microstrip to slotline transitions. The division and combination operations are both realized with this technology in order to enhance the performances. In this newly proposed integrated-antenna push-pull design, hybrid couplers are replaced by a microstrip-to-slotline transition divider at the input and by the same transition feeding the tapered-slot antenna.

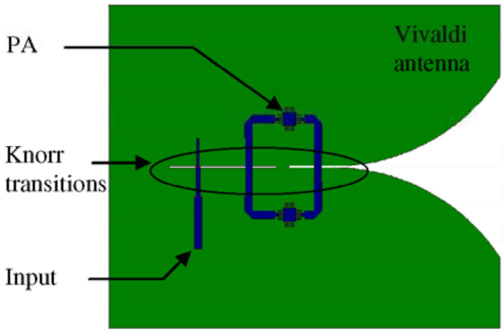


Fig. 3: Topology of the integrated-antenna push-pull transmitter front end

So as to achieve the best coupling on the transition (Fig. 4), on the one hand, the microstrip open circuit (OC) stub should appear as a short circuit (SC) at the reference plane at the central frequency. On the other hand, the slot-line short circuit stub should appear as an open circuit at the crossing reference plane at the central frequency. As a result, the microstrip-to-slotline transition as described by Knorr [5-7] cancels inherently all even harmonics.

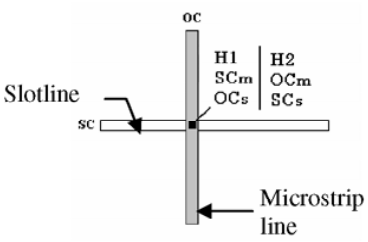


Fig. 4: Coupling condition of the microstrip to slotline transition

Moreover, frequency bandwidths of the targeted applications are relatively wide. This leads to another advantage of using this kind of transition as its frequency behavior complies with this requirement.
The use of slotline is the critical point of this concept. In effect, the slotlines feature radiation loss that can yield potential couplings between the input and the output of the amplifiers, and else potential oscillations. So, an optimization is necessary to obtain a stable system with the achieved performances.

4. PUSH-PULL PA DESIGN

This concept has been applied for the design of a push-pull PA integrated with a Vivaldi antenna using a FR4-based multilayer substrate such as to comply with the low-cost technology demanded by high volume market. Definition of the FR4 (ε_r = 4.4, tanδ=0.02) layer stacking is shown in Fig. 5, where microstrip lines are printed on the top layer (Layer 1), slot lines and antenna printed on the middle layer (Layer 2), PA bias lines printed on the bottom layer (Layer 3).

Fig. 5: Multilayer FR4-based substrate

The push-pull structure is based on two elementary functions such as the power divider and the power combiner.

A. *Power divider*

The power divider (Fig. 6) is based on a double transition between microstrip line and slotline. The first transition permits to transmit input signal from the microstrip line to the slotline. The signal is guided through the slot and transmitted by the other transition to the two sides of the output microstrip line. Using a commercial 2.5D simulation tool (Agilent Momentum™), insertion loss of less than -0.8 dB has been obtained. So, insertion loss per transition of around 0.4 dB can be estimated, which is close to the hybrid performances. To achieve good performances, couplings between microstrip lines and slotlines have to be maximized using open and shortcut stubs of about $\lambda/4$ long as mentioned in [5].

At the divider output ports, both microstrip lines are kept equal length in order to achieve good amplitude balance, while inherently a 180 degree phase difference is achieved in a very wide frequency band. The Fig. 7 shows this performance and demonstrates clearly that microstrip/slot line divider shows better performance that a conventional hybrid coupler in term of operating bandwidth.

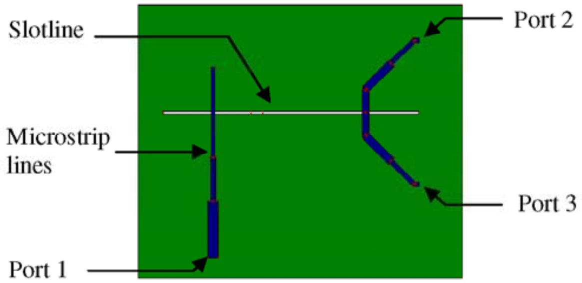


Fig. 6: Power divider based on microstrip-to-slot line transitions.

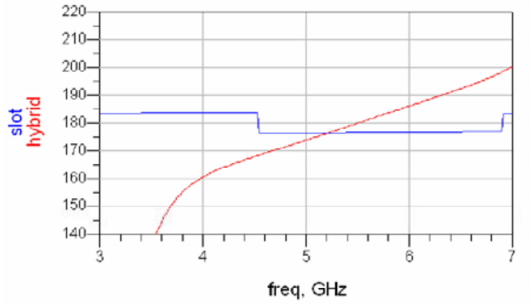


Fig. 7: Discrepancy between output ports of the power divider

The power divider using microstrip to slotline transition can be described as a four-port structure where the port 1 is the input port, the port 2 and 3 are the divided output and the fourth port correspond to an invisible radiation port. It is proved that for a three port structure it is impossible to match all the ports simultaneously. Therefore, a trade-off has to be found out between input and output return loss, and slotline radiation loss

Fig. 8 and Fig. 9 show respectively the return loss and the insertion loss performance of the power divider design which has been optimized in the whole 4.9-5.9 GHz wireless IEEE-802.11a band. The output return loss obtained is less than -15dB, the input return loss less than -7dB and insertion loss close to -0.8dB.

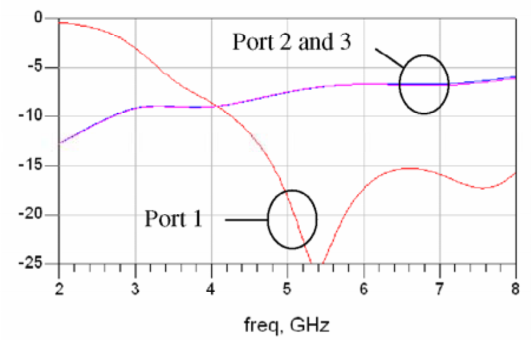


Fig. 8: Return loss of the power divider

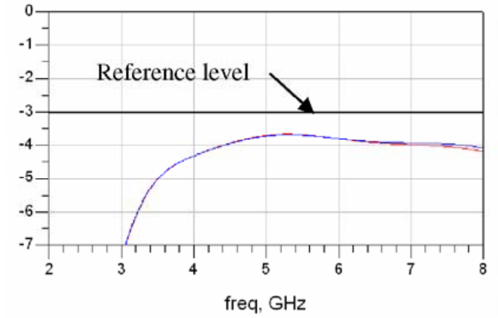
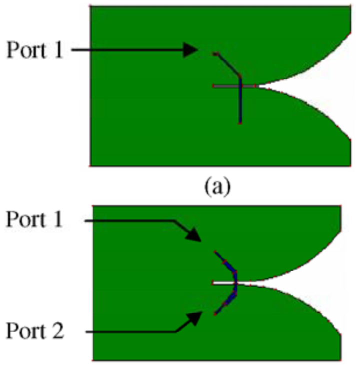


Fig. 9: Insertion loss of the power divider

B. Power combiner integrated to the antenna

The power divider previously presented is reciprocal. Indeed, two 180° out-of-phase signals injected in ports 2 and 3 are combined optimally in port 1. For the new approach targeted the combined power must feed a Vivaldi antenna or any antennas that can be fed by a slotline. The antenna has been simulated with the electromagnetic software IE3D™ (Zeland) (Fig. 10). Here, the combiner comes down to a dual 180° out-of -phase microstrip line crossing the antenna feed slot at its middle.



(a)
(b)

Fig. 10: Vivaldi antenna: a) single and b) dual feed antenna

Table 1 points out the difference between a single excitation (Fig. 10a) and a double excitation (Fig. 10b) of the Vivaldi antenna. The use of the microstrip to slotline transition to combine the power to the antenna exhibits a gain of 3 dB, demonstrating by this way that the power combination features quite no loss.

Such as to achieve the best radiated power, the isolation level between the two input ports and their matching level must be optimized simultaneously while finding out the best trade-off between these levels. Effectively, a well matched input port yields a lower isolation and lower transmitted power, alternately high isolation yields high reflection at the input port.

TABLE 1: FEED COMPARISON OF A VIVALDI ANTENNA @ 5.4GHZ

Power	Single feed (dBm)	Dual feed (dBm)	Discrepancy (dB)
Incident	10	13.01	3.01
Radiated	7.87	10.93	3.06

The final design maximizing the antenna efficiency has the return loss and isolation levels presented in Fig. 11, at around -6.5 dB in the 5 GHz band.

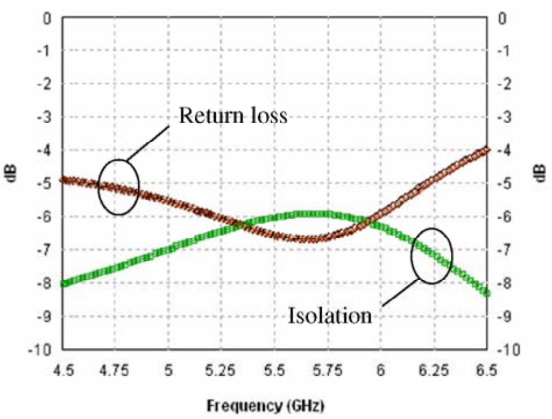


Fig. 11: Isolation and return loss of the combiner feeding a Vivaldi antenna

C. Whole structure

The principle of the power combination and division using the new approach has been presented. This section deals with the description and the simulation results of the whole structure.

ADS™ and Momentum™ softwares have been used to perform the global co-simulation taking into account the measured S-parameters of the commercial power amplifiers used. In order to give an idea of the behavior of the push-pull PA a back-to-back configuration of the global architecture has been first simulated, as presented in Fig. 12.

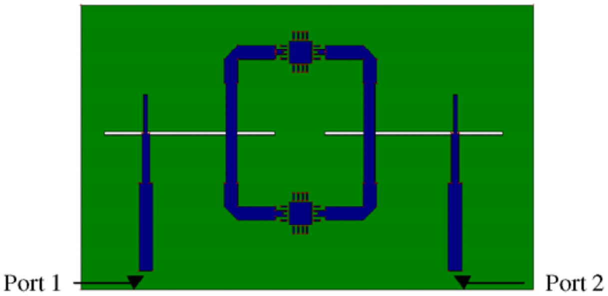


Fig. 12: Simulated global structure

Fig. 13 shows the simulated performance, with input and output return loss lower than -12dB in the frequency band of interest. Gain of the global structure is close to the one of the standalone PA, higher than 20dB. Compared to a conventional structure based on hybrid, the size of this total push-pull structure is about 30 % lower.

A complete push-pull PA integrated with the Vivaldi antenna, based on the 3-layer FR4 substrate, has been designed and launched in fabrication. Fig. 14 shows the four main blocks of the whole circuits: the power divider, the PAs, the power combiner and the Vivaldi antenna. The fabrication of this circuit is ongoing; also the measured performances of this design will be presented only later at the conference.

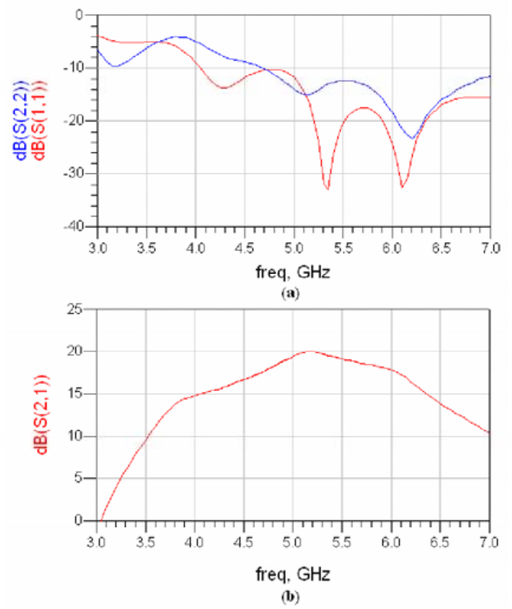


Fig. 13: S-parameters or the global structure using microstrip to slot transition: a) return loss parameters and b) transmission parameters.

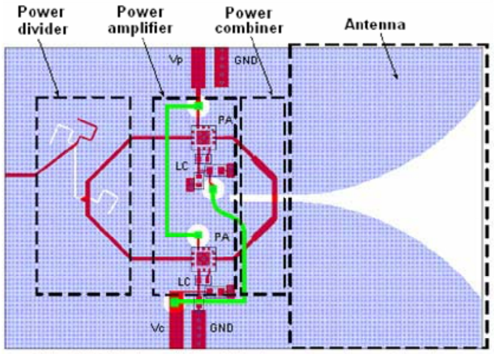


Fig. 14: Design of the global structure for realization

5. CONCLUSION

A novel push-pull power amplifier integrated with a Vivaldi antenna has been presented is this paper. The new design based on microstrip to slotline transitions, compared to a conventional approach based on hybrid couplers, aims to reduce the combination loss while achieving 30% of size reduction. Moreover wider frequency band characteristics have been demonstrated with this new concept. In order to proof the concept and to address the consumer market a low-cost FR4 based design has been launched in fabrication.

REFERENCES

[1] Cynthia Y. Hang, William R. Deal, Yongxi Qian and Tatsuo Itoh, “High efficiency transmitter front-ends integrated with planar antennas and PBG”, Microwave Conference, 2000 Asia-Pacific, pages 888 - 894, Sydney, December 2000.

[2] William R. Deal and al., “Integrated antenna Push-Pull power amplifiers”, *IEEE transactions on MTT*, Vol 47, N°8, Aout 1999.

[3] P.J. Gibson, “The Vivaldi Aerial”, Proc 9th European Microwave Conference, pp101-105, 1979.

[4] Pang-Chen Hsu, Cam Nguyen, and Mark Kintis, “Uniplanar Broad-Band Push-Pull FET amplifiers”, *IEEE transactions on microwave theory and techniques*, Vol 45, N°12, December 1997.

[5] P. Minard, P. Chambelin, A. Louzir, “Cost/ performance optimized IEEE a/b/g front end with integrated antenna diversity”, European Conference on Antennas and Propagation, Nice, Nov 2006.

[6] J. B. Knorr, "Slot-Line Transition", IEEE Trans. Microwave Theory and Techniques, pp. 548-554, May, 1974.

[7] B. Schuppert, “Microstrip/slotline transitions : modeling and experimental investigation” IEEE transactions on microwave theory and techniques, Vol.36 N°8 August 1988.