Freescale Semiconductor
White Paper

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Advances in Freescale Airfast RFICs

Setting New Benchmarks in LDMOS for Macrocells through Small Cells

By: Margaret Szymanowski and Suhail Agwani

Introduction

Since it was first developed by Motorola in 1993, Laterally Diffused Metal Oxide Semiconductor (LDMOS) technology has defied analysts' efforts to define its potential performance. Whether the metric is maximum frequency, RF output power, gain, efficiency or ruggedness, LDMOS RF power transistors and RF integrated circuits (RFICs) have continually exceeded the expectations of those attempting to place limits on what this technology can achieve. As this white paper will show, LDMOS technology continues its evolution, as exemplified by the second generation of Freescale's Airfast family of RFICs, which have recently been enhanced to increase RF bandwidth extension and isolation and to improve Doherty amplifier performance.

The Airfast name was coined by Freescale in 2011 to describe what would become a portfolio of discrete RF power transistors and RFICs. Many of these transistors are housed in over-molded plastic packages that meet stringent requirements in all areas of performance important in the applications they serve. The overarching goals were to improve efficiency, gain, peak power and signal bandwidth while simultaneously reducing and standardizing the device footprint as well as the number of devices required to deliver a specific level of RF output power.

Most of the RFICs would be designed to be pin-compatible with the same footprint throughout the Airfast product family using Freescale's TO package platform to allow OEMs to rely on these devices across their product lines. All of these goals were to be achieved while reducing cost to the end user at the device, RF amplifier, and system levels.

Today, Airfast RF power solutions are delivering on this promise throughout a portfolio consisting of more than 40 RF power transistors and 7 RFICs that span frequencies from 728 MHz to 2.7 GHz at RF power levels from 5 to 500 W. The latest devices in the second-generation Airfast family take these achievements even further with a new TO-270 package style (Figure 1), in some cases exceeding what even the most optimistic industry pundits have predicted could ever be attained with LDMOS technology.

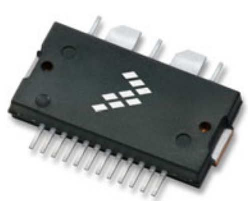

Figure 1. Freescale's over-molded plastic-packaged Airfast RFICs continue to push the boundaries of LDMOS technology (TO-270WB-17)

The Challenges Ahead

The transition from third-generation (3G) to fourth-generation (4G) cellular technology, which, generally speaking, began with the deployment of LTE, placed much more onerous demands on the receive and transmit portions of base station transceivers than ever before. This is true of base station transceivers of all sizes, from macrocells to small cells. Higher-order modulation schemes such as orthogonal frequency division multiple access (OFDMA) are highly intolerant of non-linearities, poor signal-to-noise ratios, and associated performance metrics. In addition, RF signal bandwidths have increased to provide greater capacity in the face of higher volumes of data traffic. These bandwidths have increased from less than 5 MHz to 40 MHz today, and are expected to reach up to 100 MHz with LTE-Advanced.

For the user, these advancements are obviously welcome. From the perspective of RF power amplifier designers and developers of RF power transistors and RFICs, these advancements present challenges that must be overcome.

Meeting the Challenges Head-On

Freescale is uniquely prepared for dealing with the challenges faced by cellular infrastructure providers. These challenges are being addressed through the following:

Enhanced TO Package Design

Freescale's second-generation Airfast RFICs continue to be housed in TO packages, but several improvements have been made to facilitate increased bandwidth and isolation. These changes are highlighted in Figure 2, which compares the previous version (the TO-270WB-14) with the latest one (the TO-270WB-17). Note that the output leads have been spaced farther apart, which reflects internal device changes and has the effect of increasing isolation and increasing the frequency range of the RFIC.

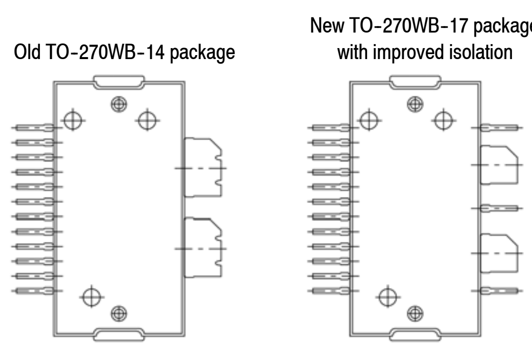

Figure 2. Differences between Freescale's previous and latest TO-270 packages dramatically improve many aspects of second-generation Airfast RFICs

Figure 3 shows the addition of two pins to the package's lead frame, one that originates at the device input and terminates at ground on the board and another that serves the same function at the output. This addition, in combination with a novel "wire bond fence" described later, significantly improves isolation between the Doherty carrier and peaking amplifiers in the IC.

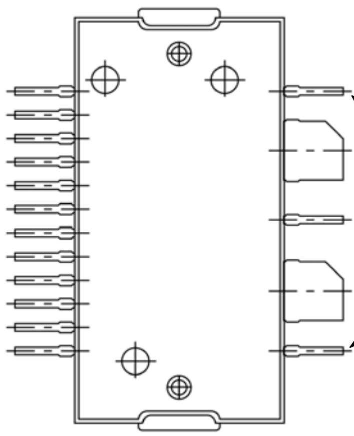

Figure 3. Extra leads on second-generation Airfast RFICs in combination with the wire bond fence enhance Doherty amplifier performance while increasing bandwidth

Broadband Operation

In many areas, cellular networks must operate over an extraordinarily wide range of frequencies, from about 700 MHz to 3.8 GHz. Several amplifiers are required to cover this entire range, and anything that reduces their number is a major benefit, as it simplifies design and lowers costs while potentially reducing the size of the amplifier and its power consumption. The latest products in the Airfast family make significant strides in solving this problem as they operate multiple adjacent frequency bands such as those from 703 to 960 MHz or 1805 to 2170 MHz. Certain ultra broadband Airfast devices such as AFT27S006N can even cover RF bandwidths from 728 to 3600 MHz. In the past it has been very challenging for plastic-packaged LDMOS devices to operate at such high frequencies, but advances at Freescale in device, package and design techniques have made this possible while also delivering a flat gain response and high efficiency over the entire frequency range.

Wider Signal Bandwidths

Airfast devices already in production have demonstrated their ability to handle signal (or channel) bandwidths as high as 150 MHz, wider than any wireless network currently in use, and are able to support the projected 100 MHz bandwidths of LTE-Advanced and the IEEE 802.11ac standard.

Higher Gain and Efficiency in Doherty Amplifiers

Thanks to its ability to achieve very high efficiency, the Doherty amplifier has in the past five years become the architecture of choice in macrocell base stations and now small cells, and even some smartphones and other wireless-enabled devices. Second-generation Airfast RFICs deliver significantly higher gain (up to 31 dB) and two-stage efficiency (up to 44%) over wider frequency ranges than do competitive devices in symmetric and asymmetric Doherty amplifiers at 8 dB output back-off.

Increasing the Maximum Frequency of LDMOS

The prevailing industry sentiment has been that LDMOS technology was incapable of delivering its inherent benefits at frequencies above 2.1 GHz. Now that Freescale is manufacturing LDMOS RFICs operating at frequencies as high as 2.7 GHz with excellent performance and is working toward producing devices for 3.8 GHz operation, this projection has been thoroughly dispelled. These higher frequencies have been achieved while also reaching levels of efficiency that are unprecedented—and increasing.

Improvements in Impedance Matching

The input of Airfast RFICs is internally matched to 50 ohms and blocked with a capacitor, eliminating the need for input impedance matching. The RFIC output is pre-matched to an impedance typically ranging from 4 to 10 ohms, which is higher than the 1 to 2 ohms typical of a discrete device. This matching significantly shrinks the range of required impedance matching to achieve the 50 ohm impedance on the circuit board and allows designers to more easily optimize the performance of an Airfast device over a specific frequency range.

Because this matching is performed within the RFIC, variations associated with the use of external matching components during the assembly of the power amplifier can be minimized. Matching components embedded in the devices are optimized using electromagnetic simulation to improve the Q factor in order to minimize losses.

Improving Isolation between Carrier and Peaking Amplifiers

A Doherty amplifier consists of independent but complementary carrier and peaking amplifier circuits that in a compact RFIC are very close to each other. As both of these amplifiers have high levels of gain, their close proximity creates crosstalk. Left unchecked, this crosstalk would degrade the performance of one or both of these amplifiers and make linearization using digital predistortion (DPD) circuits much more difficult. Of course, this crosstalk would not occur if the amplifiers were physically isolated, but this is obviously contrary to the goal of reducing device footprints and is an unacceptable trade-off.

Various approaches have been suggested to solve this isolation problem, but Freescale has succeeded using a new, recently patented technique — which has been incorporated in second-generation Airfast RFICs — called a *wire bond fence*. This method reduces crosstalk between the two paths, which in turn translates to as much as 6 to 10 dBc improvement in linearized ACP. Figure 4 illustrates the wire bond fence placed between the amplifiers that acts as a shield between them and is connected to the grounding pins that have been added on the input and output of the package.

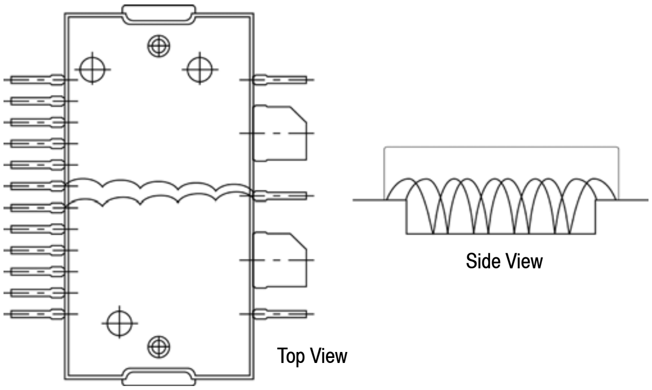

Figure 4. Wire bond fence effectively acts as a wall between the carrier and peaking amplifiers, sending signals from the amplifiers and their associated wire bonds to ground

Eliminating a Space-Consuming Component

Previous Airfast RFICs used a large quarter-wave bias line to feed DC voltage applied to the transistor. This consumed a large space on the circuit board. The addition of dedicated bias leads on the new Airfast devices not only reduces the board space required to design the DC bias network but also presents the benefit of increasing the RF signal bandwidth supported by the device. The space saved by removing this element ranges from 30 to 90 mm^2 depending on operating frequency.

Summary

Freescale's second-generation Airfast RFICs represent the state of the art in satisfying the needs of PA designers for compact, cost-effective RF power devices that can meet the challenges of the next generation of base stations. Not only do these RFICs operate at frequencies previously considered impossible for silicon LDMOS to achieve, but they provide many other significant benefits that together make them the best choices, whether as driver amplifiers in macrocell base stations or final-stage amplifiers in small cell systems.

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