Linear Power Amplifiers and Transmitter Modules for Mobile Applications

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Abstract

The advanced modulation formats used in 3G and 4G mobile systems have pushed the need for improved power amplifier linearity. The multi-function capability and sleeker form factor design of today's smart phones have added more stringent requirements to the size and current consumption of power amplifier modules. This paper discusses some of the linear power amplifier module market trends and the technical challenges. It also presents several of TriQuint's solutions, including the Tritium™ power amplifier and duplexer module (PAD) family, the Triton™ power amplifier module (PAM) family and WLAN front end modules (FEM) for handset.

Linear PA trend and challenges

Linear Power amplifier modules are widely used in mobile communication devices, not only for the traditional mobile phones but also in smart phones and mobile internet devices (MIDs).

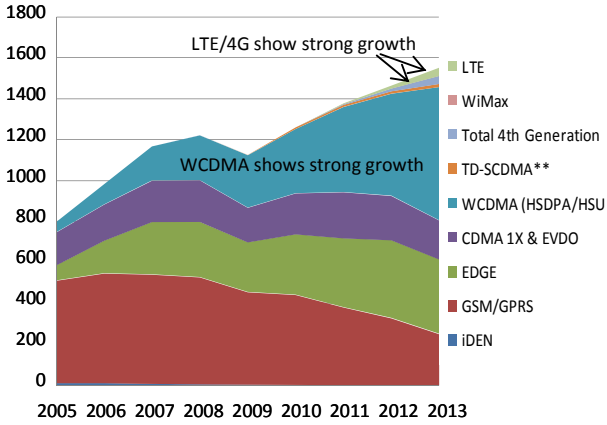

Figure 1. Annual handset shipment (M units)

The annual handset shipment volume is over 1 billion units per year (Figure 1.). Assuming each unit has at least two power amplifiers, the power amplifier requirement is over 2 billion pieces annually. The annual growth rate is currently over 10% and is expected to remain at this level for the foreseeable future. There are currently over 700 million mobile devices users in China alone.

The overall trend is towards cheaper, smaller, reduced power consumption and increased integration at the power amplifier module level.

To handle the higher data processing capability, in addition to voice communication functionality, 3G and 4G system are using modulations with higher peak to average power ratio (PAPR), which presents increased challenges to the power amplifier linearity requirements. This directly contradicts the reduced power consumption requirement. The final conclusion is that these more stringent requirements can only be achieved by advanced architecture designs, such as power amplifier duplexer modules.

WLAN functionality has been adopted in a growing number of smart phones to enable internet access and voice over internet protocol (VOIP) phone calls. The mobile phone market segment is now the largest segment for WLAN applications, exceeding the size of the laptop WiFi market segment.

With the accelerated development and widespread commercial applications of transmitters for the wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX), the power amplifier demand for these applications is increasing rapidly.

Because of the high PAPR signals in the WLAN and WiMAX transceivers, the linearity of the transmitter becomes one of the key factors and the greatest challenges in the system design. When the power amplifier operates close to the saturation region, where the highest efficiency is achieved, the degradation in linearity becomes significant. Consequently the WLAN or WiMAX PA must operate at a higher degree of power

back off from the peak output power to meet the linearity requirement, which results in degraded efficiency performance.

To improve the power consumption at backed off power levels, most of the systems are adopting a DC to DC converter which reduces the power amplifier battery supply voltage at lower output power levels. To accommodate this functionality, the power amplifier or transmitter module should include a directional coupler or power detector, so that the system will have feedback information about the output power level. With the size of the power amplifier and transmitter module getting reduced further with each generation, the inherent challenge becomes for the integrated directional coupler to have sufficient directivity so that the power detector will have less error as a result of antenna mismatch impedance.

Tritium™ PAD family

TriQuint is one of the market leaders in PA duplexer module (PAD) development. Most of the TriQuint's PAD includes the power amplifier, duplexer, interstage TX filter, coupler and bypass capacitors in a single package. In addition, some of the Tritium™ modules include a power detector that mates with an appropriate transceiver. The PAD is one of the highest demanded product groups for TriQuint, its primary application is for smart phone module applications.

In a discrete solution, additional matching components are required between the output of the power amplifier and the input of the duplexer to optimize linearity and current consumption. In addition, there is also a matching circuit between the output of the interstage filter and the input of the power amplifier. These matching structures are eliminated in all of the Tritium™ PADs, which results in a marked reduction in the size of the overall module footprint (Figure 2.). This high level of integration also simplifies the application for the end user since the need for external matching is removed.

One of the principal benefits of the PAD is the greatly improved power added efficiency (PAE), relative to that of a power amplifier module (PAM). As was previously mentioned, there is additional matching circuitry between the power amplifier and the duplexer. For a discrete power amplifier and duplexer circuit design, the output of the PA is matched close to 50 ohms, and then passes through the external matching circuit to duplexer transmit (TX) port. In addition, typically there is internal matching in the duplexer to match it to 50 ohms as well. The primary effect of this added external matching circuitry is additional loss after the power amplifier output. In order to achieve the same delivered power to the antenna, the power amplifier will have to operate at a higher output power, which will result in increased current consumption for the TX chain.

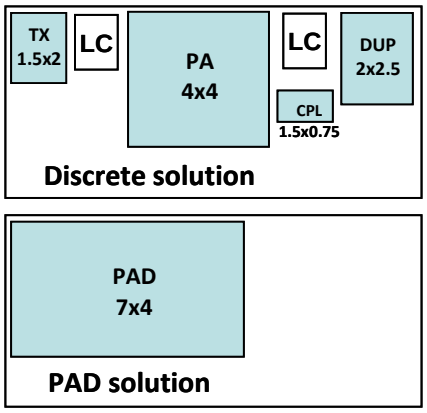

Figure 2. discrete solution versus PAD

In the Tritium™ PAD, the power amplifier is matched to the internally developed SAW or BAW duplexer's TX port with a single section matching network. By implementing this architecture, we can save approximately 1dB of output power, which corresponds to a reduction in current consumption of approximately 20%. This is a significant savings for the mobile device battery usage, since power amplifier is the primary consumption components in the handset.

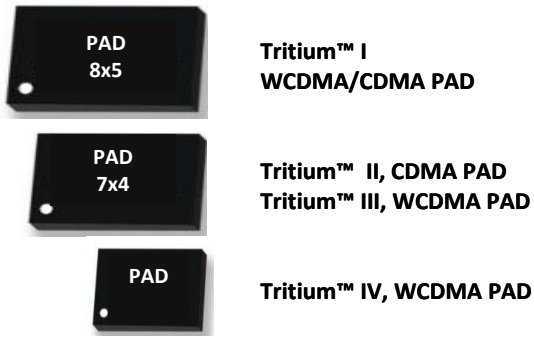

Figure 3. Tritium™ PAD history

The TriQuint Tritium™ PAD family history is shown in figure 3. The Tritium™ I family PADs, sized for 8mmx5mmx1.5mm, are 1-bit digital controlled PADs, have high power mode (HPM) and low power mode (LPM). The modules include an interstage filter, PA, and

duplexer, together with an integrated directional coupler and power detector.

The Tritium™ II PADs, sized for 7mmx4mmx1.1mm, are 2-bit digitally controlled CDMA PADs, which have HPM, medium power mode (MPM) and LPM. The modules have interstage filter, PA, and duplexer, and the directional coupler.

The TriQuint Tritium™ III family, also sized for 7mmx4mmx1.1mm, provides PAD module solutions for WCDMA bands 1, 2, 5 and 8. They utilize a 1-bit digital control for HPM and LPM, as well as an analog control for the LPM biasing to maximize the current saving at the back off power levels. They have an integrated interstage filter, power amplifier and duplexer, together with directional coupler and power detector.

For example, the Tritium™ III WCDMA B5 TQM616025 product performance is shown in figure 4. The high power mode (HPM) and low power mode (LPM) operate up to 25dBm and 16dBm at the Antenna port respectively. Besides the highly efficient HPM design, the LPM biasing current is extremely low at the back off power levels; therefore the back off current consumption is reduced dramatically. All of these features combine to result in a significant increase in talk time.

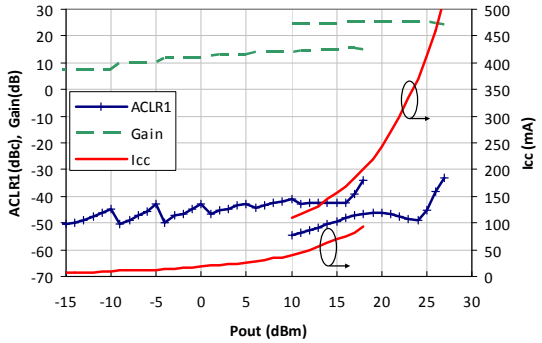

Figure 4. Tritium™ III B5 TQM616025 performance

The next generation of PAD modules, the Tritium™ IV family, has removed the interstage filter to be compatible with the 4G system design requirements. These products are still under development.

Triton™ 3x3 PA family

The TriQuint Triton™ PA Module family is a group of 3mm3mmx1.1mm 2-bit WCDMA power amplifiers using TriQuint's latest BIHEMT process and CuFlip® flip chip assembly technology.

The WCDMA B1, B2, B4, B5/6, and B8 power amplifiers have HPM max Pout between 28.2 dBm and 28.6 dBm, with PAE of approximately 40%, and a gain about 27dB. The medium power mode (MPM) and LPM's max Pout are 17dBm and 7dBm, with PAE of 15% and 9%, and the gain is approximately 19dB and 12dB respectively.

Besides the state of art linearity and PAE, this group of products also have integrated 20dB couplers, with best in class directivity.

TriQuint's new BiHEMT process provides a full integration of HBT and PHEMT technology, which makes it possible to have a multi-mode/multi-function power amplifier on a single die.

TriQuint's flip chip technology, CuFlip®, (Figure 5) provides greatly improved thermal impedance to the ground. It also results in significantly reduced die size with improved performance, and minimizes reduces the assembly variation.

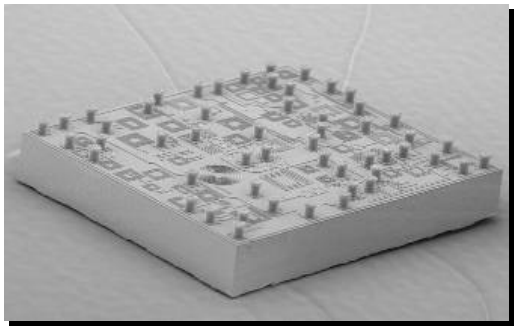

Figure 5. CuFlip® technology, a flip chip die picture

WLAN products

One of the leading WLAN and Bluetooth front end modules for the handset application is the 3mmx3mmx0.5mm TQM679002. This part includes a power amplifier, directional detector and single pole triple throw switch that supports WiFi TX, WiFi RX and BT operation. The RX path includes an integrated balun that mates with the silicon receiver. For 802.11g 64QAM, at max Pout of 15.5dBm, the typical power performance is 2.2% EVM with 33dB gain. The current consumption is 115mA for 15.5 dBm output power (Figure 6 and 7).

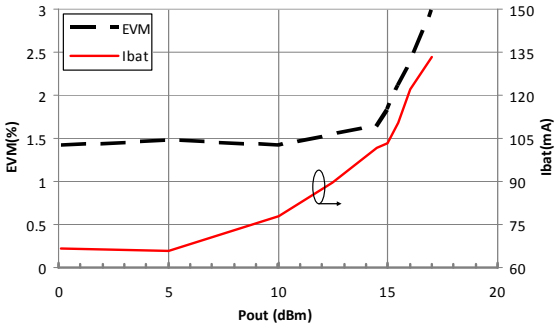

Figure 6. EVM and Current of TQM679002

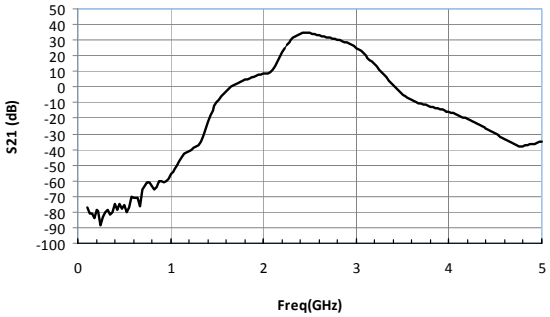

Figure 7. S21 of TQM679002

Since this power amplifier is used primarily in the cell phone environment, the efficiency is critical in terms of achieving optimal talk time performance. The trade-off between linearity and efficiency is even more severe when compared to the same module used in a notebook application environment. Moreover, the gain rejection of the adjacent bands is critical, especially when it is used in a cell phone environment. A high pass filter is added at the input of the power amplifier to meet this specification. Furthermore, this power amplifier is housed in an extremely thin leadless package and a single die is the only reasonable option, given the module size and height constraints. TriQuint's E/D pHEMT process was used to develop this and other WiFi front end modules because it allows the integration of power amplifiers, RF switches and low current CMOS compatible logic in a single die.

Summary

In this paper, we have discussed some of the handset power amplifier and transmitter module market trends and their corresponding challenges. A few of TriQuint's leading solutions have been introduced to address these design challenges.

Acknowledgments

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Speaker's biography

Wen Chen is a Senior RF Design Engineer at TriQuint Semiconductor. She is a lead designer for the TriQuint WCDMA Tritium™ PAD module family. In her years of work experience in RF and RFIC industry, her most recent focus is power amplifier development for mobile device applications. Prior to joining TriQuint, she had worked for both M/A-COM and Conexant Systems. Wen Chen received her MS degrees in ECE and Physics from UMass Amherst and UMass Dartmouth. She is a graduate of Fudan University Physics Department.