GaN Powered RF Frontend for High-Power Tactical/Mil Comm Radios

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Traditional Tactical/Mil Comm Radio utilized LDMOS PA and PIN diode RF Switch technology to realize RF Frontend section. These technologies were adequate as the number of frequency bands were limited. Each band had dedicated PA, a Harmonic filter, followed by PIN diode RF switches to connect to an antenna. Modern Tactical/Mil Comm/LMR Radios are required to cover many bands to meet the demand for secure voice and data communication. These bands are spread in a wide frequency range; mostly between 50MHz to 2.6GHz. For many proprietary Software Defined Radio (SDR), continuous coverage of frequency is essential or required. It is unfeasible to realize multiple bands spread over a wide frequency range with traditional LDMOS PA and PIN diode switches due to limited board space and efficiency requirement. This article explains how GaN Powered RF Frontend architecture is solving many challenges presented by Modern High-Power Radios. We introduce how Broadband GaN PA and GaN RF Switch technology enables efficient realization of multi-band Software Defined Radios; both in terms of power and board space.

Modern MilComm/LMR/PMR radio has evolved since its invention. Operational frequencies have steadily increased from VHF and UHF frequency to new bands, allocated in 700MHz and 900MHz for LMR/PMR radios. Proprietary Military radios are SDR and need coverage up to at least 2.6GHz. Specific bands are not always disclosed, thus requiring continuous coverage from 30MHz to 2.6GHz. Many of these radios operate at much higher power compared to cellular radios. Table 1 summarizes frequency, power and harmonics requirement seen in datasheet of these devices from leading suppliers [1,2,3]. From the table, it can be seen that these devices operate from low frequency of 50MHz to 2.6GHz. Harmonics requirement varies quite a bit based on type of radio. Tactical/Milcomm radio, which typically support MIL-STD-461G standard, has a relaxed harmonic requirement compared to LMR/PMR radios, which support FCC Part 90. Harmonic requirement presents a very stringent linearity requirement for post harmonic filter switches in the RF frontend part of the radio. Available board space is one of the most challenging constraints to overcome for a solution that support such a wide frequency spectrum. Figure 1 shows comparisons of various RF Front End Architecture. The traditional approach when the number of bands were limited, used LDMOS PA for each narrow frequency band, followed by harmonic filter and RF switch. RF switch technology for such solution is PIN diode or High Power SOI.

Table 1: Frequency, Power and Harmonics Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LMR/PMR</th>
<th>MilComm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>700/800</td>
<td>UHF</td>
</tr>
<tr>
<td>Frequency(MHz)</td>
<td>763-870</td>
<td>136-174</td>
</tr>
<tr>
<td>PowerOut(W)</td>
<td>1-3</td>
<td>1-6</td>
</tr>
<tr>
<td>Harmonic/Spurious(dBc)</td>
<td>75/80</td>
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Tagore Technology Inc., Con’t on pg XX
High Power SOI technology is limited to less than 20W average power for higher throw count switches. The traditional approach would have required eight PA to cover 50MHz - 2.6GHz; whereas the same frequency range could be covered by one or two GaN based PA architecture. RF Front End architecture powered by GaN technology bring many benefits for Broadband radio and solves many of these issues.

**GaN Technology**

GaN Benefits in high power PA is very well known. GaN devices have a much higher power density due to its very high break down voltage, and a high carrier density property. Higher power density allows GaN devices to be much smaller, making all device capacitances significantly reduced compared to existing LDMOS technology. Lower input and output capacitance helps make realizations of broadband match much more attainable. Higher voltage operation also increases the load line impedance to achieve a desired output power, which further help realization of broadband output match. As shown in Figure 1, required frequency coverage of 50MHz to 2600MHz can be realized with one or two GaN Power Amplifier. Selection of either one or two PA architectures depends on total post PA loss and number of bands required to cover.

GaN benefits in high power switch technology is not as well-known as PA. However, properties of GaN that help improve performance of power amplifier also applies to realize much superior high-power RF switches. There are two requirements for RF devices used in high power RF switch. The ON arm of the RF switch is required to handle very high RF current, whereas the OFF arm devices needs to handle very large voltage. For example, 10W of RF power in 50ohm system produces 52V peak voltage and peak current of 600mA. Adding VSWR of 4:1 — which is typical for front-end section of the radio — produces more than 50V peak voltage and 1A of peak current. So, the same property that help PA is also beneficial for RF switch.

GaAs is typically technology of choice for very low NF LNA design. However, MilComm radio operates in a very harsh interference environment. Co-site interference levels could be very high due to presence of many high power radios in close proximity as well as jamming signals from enemies, making the ruggedness requirements of LNA a must. In such scenario high power limiters are typically added in front of LNA to protect receiver. Limiter in front adds to NF of overall receiver. LNA designed using GaN technology brings advantage in terms of power handling. Carefully designed GaN LNA could handle high input power and achieve low NF [5]

**RF Front End Requirement**

Figure 2 and Figure 3 represent typical single GaN PA and two GaN PA line-up respectively. Selection of single or dual PA line-up depends on post PA losses and coverage of number of bands. If there is a need for continuous coverage — which is essential in many proprietary Software Defined Military radio — between 50MHz to 2.6GHz or 6.5 octave bandwidth, theoretical minimum 7 bands are needed. However, harmonic filter requires guard band to reject 2nd harmonics of lower end of the frequency within the band. For example, first band cannot be 50MHz to 60MHz, one octave, since the 2nd harmonic of 50MHz falls within the band. Assuming there is 10 MHz of guard band, the first band would be 50 MHz to 60MHz. Assuming a minimum 10MHz guard band, eight discrete bands are needed to get continuous coverage of

![Figure 1: LDMOS PA vs single and dual GaN PA RF front end architecture](image1)

![Figure 2: Single GaN PA RF front end lineup](image2)

![Figure 3: Dual PA RF front end lineup](image3)

![Figure 4: PIN diode based vs GaN based SP4T RF switch schematic](image4)
50MHz to 2.6GHz. Implementation of 8 bands starting from VHF band, which requires large passive components, is a significant challenge for available board space for portable and manpack radios. Cases where space is very limited, a tunable filter can be employed to reduce the number of frequency band splits. Trade-offs between fixed frequency filters and tunable filters are usually IL. A tunable filter would have a higher IL compared to fixed frequency filters due to ON resistance of switches in series with tunable capacitors or inductors. The two PA lineup shown in Figure 3 assumes some of the VHF bands are realized using tunable filter using Tagore’s high peak voltage, low Rdson tuning switch products (TS6xxxx). Higher loss from lower band requires WC 20W power out of PA. Based on IL of current generation of Tagore switch product (TS7xxxx), and 2-4dB IL of the harmonic filter, 20W is required for a lower band PA and 15W is adequate for a higher band PA to meet 5W and 3W power respectively at an antenna port.

Harmonics requirement is another critical factor for RF Front End. LMR/PMR radios are specified to meet 75 – 80 dBc harmonic requirement at rated power [2, 3]. Power amplifiers are operated in deep saturation to get better efficiency that has harmonic level of 10 – 20dBc. Thus, harmonic filters are required to provide minimum 60-70dB rejection to meet regulatory requirements. Military radios are typically relaxed [4] compared to LMR/PMR radios. Switches used after harmonic filters do not get benefit of harmonic filter rejection, thus their harmonic performance needs to be better than overall requirement to meet total Tx-lineup requirement. Based on the harmonic performance of (PA + Filter), harmonic performance of switches needs to be better than 80dBc to meet regulatory requirements. Figure 5 also demonstrates another critical issue associated with Isolation performance of the switches. Isolation of switch at lower frequency is typically very high, so it is not an issue, however it could pose a problem for high band if careful attention is not paid. For example, 2nd harmonic of 1GHz signal path, shown with green arrow in Figure 3, could pass through 2GHz signal path, shown with red arrow. 2GHz path harmonic filter does not provide any rejection, thus combined input and output switch isolation need to be higher than rejection provided by harmonic filter to meet overall harmonic requirement.

Co-site interference scenario discussed earlier could pose an additional issue for switches located near the antenna. In the actual field, it is possible that radio is in close proximity of high-power radio. For example, porta-
ble radio in Humvee — with high power radio installed — is exposed to very high power at the antenna. It is also possible that the portable radio is switched off and exposed to high power radio nearby. Thus, the switch needs to be able to handle close to rated power even when there is no supply to switch present. Tagore’s TS7xxxxx series switches are designed and tested to meet such harsh conditions even when supply for the switch is not present.

RF Switch Technology

Tagore’s first generation TS72xxxxx series RF switches are designed with GaN HEMT technology. GaN HEMT with high breakdown voltage has saturation current close to 1A/mm. So, 2mm-5mm device theoretically meets the peak current requirement of 100W power in 50ohm condition. Unlike existing PIN diode-based RF switches — which requires high bias current to achieve low RDS(on) during ON state and high reverse bias voltage to keep it OFF — GaN HEMT are voltage control device. It does not require high currents to achieve low RDS(on), and can be turned-off with negative voltage. The negative voltage generator circuits, and logic decoding circuit are all integrated within a small QFN package. Figure 4 compares GaN HEMT based SP4T switch schematic vs PIN diode based SP4T switch. As can be seen from the figure, the PIN diode would require 52 passive components — not even counting boost converter circuit to generate high voltage — GaN HEMT are voltage control device. It does not require high currents to achieve low RDS(on), and can be turned-off with negative voltage. The negative voltage generator circuits, and logic decoding circuit are all integrated within a small QFN package.

PA Technology

Broadband Power Amplifier bandwidth is limited by two factors; required load line impedance transformation ratio and reactive component of device — especially for higher frequency. Lower the impedance transformation ratio, easier it is to achieve wider bandwidth. At higher frequency, device capacitance, Cgs and Cds, limits required Q of input and output matching network. Theoretical load-line impedance can be calculated by following equation:

$$RL = \frac{(V_{supply}-V_{knee})^2}{2*P_{out}}$$

Where Vsupply is drain supply voltage of device, Vknee is knee voltage of device, and Pout is desired output power. Figure 6 shows required load impedance vs Output power assuming knee voltage of 3V for GaN device and 1.5V for 12.5V LDMOS device. From the plot, 15W Pout requires load impedance of 28 ohm at 32V for GaN device whereas 12.5V LDMOS would require 4 ohm — 12.5:1 impedance transformation vs GaN.

All these issues are non-existent in GaN based High power Tagore switch, which could realize the same function with 1/10th of board space and uW DC power. Many of this switch performance can found in the product datasheet [6].

The second generation of Tagore GaN switches are further optimized for RF Performance. Figure 5 shows small and large signal performance. It can be seen that SP4T switch in 4x4 package could realize >50W power and harmonic level far exceeding requirement. IL performance is significantly reduced; further enhancing efficiency and reducing power dissipation in the frontend section of high-power radio.

Figure 7: TA9210D 30MHz – 512MHz match EVB

Figure 8: TA9210D 30MHz – 512MHz match gain, efficiency data

Figure 9: TA9310E 500MHz – 2700MHz match gain, efficiency data
for 50-512MHz match for 15W GaN PA device is shown in Figure 7. The circuit shows simple two section output match and single section input match can achieve more than decade of bandwidth. Figure 8 shows measured Gain and Efficiency of same sampled application circuit. The data shows that the efficiency in the range of 60-80% can be achieved, which is equal or better than what can be achieved with narrowband LDMOS devices. Figure 9 shows measured gain and efficiency plots of the TA9510E device matched for 500MHz-2700MHz. The data is split into multiple plots for clarity, but they are with single match. The data shows that the efficiency in the range of 52-70% can be achieved. This two-sample example illustrate that desired band can be covered with two PA line-up compared to 8 narrowband line-ups required for LDMOS devices – saving significant board space without sacrificing efficiency of transmitter.

Summary
High power frontend designed using GaN technology is demonstrated in this article. We demonstrated that GaN based RF switch and PA technology address all complexity and issue presented by broad band radio; saving significant board space without sacrificing efficiency. With next generation RF switch products, efficiency will be further enhanced and will open door for new front-end architecture for not only Milcomm but also application such as Cellular base station and Radar.

References: