Moving to GaN for Commercial Markets

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Gallium Nitride (GaN), a binary III/V direct bandgap semiconductor compound that provides superior efficiency and wider bandwidth, is steadily becoming recognized as the optimal solution for a variety of multi-market mainstream applications, and is predicted to explode into every aspect of the commercial and consumer markets.

Enabling higher power and performance, GaN technology is transitioning from niche market uses to the commercial power applications. Offering superior performance, greater than 70% efficiency and wider bandwidth, GaN has fundamental characteristics that make it exceptionally well suited to RF power applications. It has the highest power density and can reliably operate at higher temperatures than other semiconductor technologies, which together allow for physically smaller devices. Combine this with electron mobility that is similar to GaAs, and the result is transistors which deliver high power to high frequencies, with comparatively small parasitics.

Power amplifier designers generally face two challenges. First, the output load line impedance is naturally low, and drops with increasing power. The power amplifier designer must craft matching circuits that interface to 50 Ohms and the ratio of that impedance to the transistor impedance determines bandwidth, efficiency, and complexity. One way to counter this trend, and raise the transistor impedance, is higher operating voltages. For example, at 12V the load impedance at 100W is sub-Ohm, but at 48V that number becomes a reasonable 12 Ohms. GaN naturally supports operating voltages higher than both GaAs and LDMOS, which allows more power to higher frequencies.

The second challenge facing power amplifiers designs are low parasitics, which are especially important in wideband designs. At lower frequencies the resistive elements of the FET equivalent circuit tend to dominate, but at higher frequencies the input Cgs and output Cds dominate, both lowering the impedance and raising the Q. Because they are physically smaller, GaN devices have lower Cgs and Cds which maintains a higher impedance to higher frequencies, lowers the Q, and allows revolutionary wideband designs.

Around a decade ago, military radio and EW designers were the first to embrace GaN technology. Given these applications’ penchant for mature processes with considerable heritage, this was a surprising move. However, similar to the GaAs revolution of a few decades ago, GaN demolished the existing power-bandwidth envelope just in time to meet the requirements of new software driven wideband radios and IED jammers. Multiple LDMOS lineups could be replaced by a single GaN chain that offered comparable gain, power, and in many cases, better efficiency. Designers could now extend frequency coverage and increase output power within existing box outlines and at similar overall costs.

Like their commercial counterparts, the military requires more bits/Hz to move an avalanche of high bandwidth video from both optical and radar sensors. UAVs, for example, can beam high resolution video directly or via satellite to boots on the ground. The simple modulation schemes of the past are not suitable to this new task, so the military is deploying OFDM and other commercial-like high linearity waveforms across their networks.

Today, new software-defined modems behind the green panels can support the needed digital pre-distortion or other linearization techniques that make this possible. GaN has a soft compression behavior that shows less-than-expected intermod improvement in back-off; it does not follow the classic OIP3 intercept model that relates IMD levels to Pout, yet the inherent linearity near compression is better than GaAs and LDMOS. The compression knee is continuous, rounded, and mathematically it is comparatively well behaved across the upper operating region where power and efficiency are highest. Properly matched, instantaneous power can well exceed the stated device capability, approaching almost 2X in high PAR applications.

With digital compensation, this GaN weakness becomes a key feature as it delivers the best available performance at the system level. GaN lineups using these techniques typically show a 5% efficiency advantage over LDMOS. As an example of the raw efficiency available, 100W class GaN devices in Class AB at 2.5 GHz can exceed 70%, while the best LDMOS devices struggle today to reach 60%. Properly exploited, that delta can have a big impact at the system level in military, commercial, and industrial applications.

Despite the compelling advantages of GaN, the higher cost structure has often slowed the mainstream adoption. At times GaN has cost as much as 5-10x the cost of incumbent technology LDMOS, which has slowed its breakthrough into commercial applications. However, MACOM’s GaN-on-Silicon (Si) with its unique cost structure is enabling commercial applications and markets to benefit from the exceptional GaN performance at cost structures in line with LDMOS. As MACOM scales the GaN-Si technologies to larger wafer sizes, the migration to GaN by commercial applications will continue to accelerate. Mainstream applications including medical ablation, microwave oven magnetron replacement, and wireless communication are all realizing the benefits of GaN’s superior efficiency and bandwidth.

Wireless Charging

Today's wireless charging market is in its early stages of development. While we have seen low power consumer grade wireless charging for handsets, the larger scale wireless power generation and harvesting is in the prototype stage of development. With power measured in kilowatts of radiated power efficiency and physical size constraints- the higher the frequency of transmitted power, the smaller the physical antenna- GaN is the technology of choice, enabling as much as 10% efficiency over LDMOS at a frequency of 2.45 GHz, an optimal frequency for antenna size.

Plasma Lighting

The existing market for plasma lighting using RF power excitation is largely serviced with LDMOS technology. Plasma lighting is generally a lower frequency RF operation, typically using frequencies in the hundreds of MHz. Plasma lighting has been slow to make inroads in the overall lighting market and has found its best niche in grow lighting applications, where the fact that the color temperature very closely matches that of natural sunlight makes it an ideal lighting source.

There are now developments underway in plasma lighting that will increase the frequencies and efficiencies toward 6 GHz and >70%; regions that are incredibly challenging for LDMOS but a natural fit for GaN technology. With GaN's higher power densities, the size of the transistors can be reduced, generating yet another key value as vendors drive plasma lighting into the indoor light bulb replacement market to compete head on with LED lighting.

Microwave Ovens

Emerging magnetron replacement prototypes have utilized LDMOS technology. Challenges to achieve target efficiency numbers stand between the current concepts and mainstream magnetron replacement; GaN addresses those challenges and bridges the gap between today's LDMOS based module efficiency and the desired target, which requires 10% greater efficiency.

MACOM's GaN-on-Si technology offers the unique benefit of GaN efficiency at silicon cost structures ideal for enabling market-wide magnetron replacement to become a reality. Meeting both the technical challenge with 70% efficiency at 2.45GHz and the economic challenge of displacing a tube based 1940's legacy technology and the associated manufacturing optimizations that have occurred over the years, MACOM's GaN-Si technology provides the new benefits of significantly longer system life, constant output power, and zone controllable heating. GaN-based microwave oven lifetimes should improve 10X from current magnetron models.