Recent Developments in Solid-State Microwave Heating

John F. Gerling

Gerling Applied Engineering, Inc. (a Muegge GmbH company)
PO Box 580816 Modesto, CA 95358
Email: john.gerling@muegge-gerling.com

The first in this two-article series on solid-state technology for microwave power generation and applications was published just over two years ago in AMPERE Newsletter (Issue 80, March 2014)[1]. Since then, the industry landscape has changed as leading device manufacturers jockey for position. NXP announced in March of last year an agreement with Freescale to a merger[2], then a few months later announced the spin-off of its RF-Power business unit to a Chinese state-owned investment company[3]. Both transactions were completed in December, shortly followed by the creation of Ampleon from the former NXP business unit. NXP and Ampleon now produce the lion's share of high-power RF transistors for ISM applications, while a handful of other manufacturers (e.g. Qorvo, Wolfspeed, Toshiba, Sumitomo) focus primarily on telecom and defense markets.

Device performance has improved but perhaps not at a pace some might have expected. Indeed, only a few years ago, breakthroughs in transistor manufacturing technologies enabled a leap in output power to 250 W for a single S-band (2.4-2.5 GHz) device. Distributors are now quoting price and delivery from stock for 300-W devices[4], such as shown in Figure 1. Such progress is certainly welcome but perhaps not quite enough to significantly challenge magnetrons for dominance in microwave generators.

Figure 1. A 300-W, 2.4-2.5 GHz RF-power transistor by Ampeleon[4].

While LDMOS (laterally-diffused metal-oxide semiconductor) is still the state-of-the-art technology for high-power RF transistors, apparently it may be relatively low manufacturing yields that result in a wide range of prices for the same device. According to sales sources, a lengthy qualification protocol for 250-W RF transistors results in prices as high as €140/piece, which may be acceptable for industrial microwave sources requiring high performance and reliability. In contrast, the same device may be purchased for as low as €8 in high volume but without the rigorous qualification testing, yielding in a wide range of performance (as low as 200-W output) and, presumably, potentially reduced life expectancy. This "you get what you pay for" compromise may indeed be manageable for use in consumer appliances.

Not surprisingly, both NXP and Ampleon see a bright future for solid-state devices in consumer microwave appliances. NXP is promoting its *Sage* RF cooker[5] (Figure 2), a compact appliance that takes advantage of the inherent versatility of solid-state RF source compared to larger conventional heat sources. While only a design concept, Sage illustrates some of the possibilities available to appliance developers.

Figure 2. NXP's *Sage* concept RF cooker5.

Not to be outdone, in March of this year Ampleon and Chinese appliance manufacturer Midea jointly introduced what they believe to be the world's first commercially available solid-state microwave oven (Figure 3) following a year-long collaboration between the two companies[6]. At a rated 200-W power it appears to be a good application for the low-cost devices mentioned above. While distribution channels seem to be rather stealthy, this author hopes to be one of the first to take this ground-breaking appliance for a spin around the block.

Figure 3. Microwave oven with solid state RF source developed jointly by Midea and NXP[6].

Of course, consumer microwave appliances may not be the only "killer app" for high power solid-state RF sources. NXP has investigated methods for plasma ignition in automotive internal combustion engines[7]. The business end of this technology is a High-Q coaxial resonator configured as a typical spark plug (Figure 4). Plasma ignition has been demonstrated to have significant benefits over conventional methods, but due to difficulties associated with frequency sensitivity practical implementation has not been possible using magnetron based sources. Solid-state technology overcomes these difficulties by near instantaneous real-time impedance measurement and frequency adjustment to optimize coupling efficiency and operational stability.

Figure 4. Prototype coaxial resonator for plasma automotive ignition[8].

Previously reported commercially available 2.45-GHz solid-state microwave generators included products offered by Sairem (200 W) and MKS (450 W). More recently, Chinese manufacturer Chengdu Wattsine introduced a line of generators delivering up to 1 kW output power (Figure 5), while German manufacturer Muegge plans to offer a 900-W product later this year (Figure 6). New products displayed at the recent IMPI-50 Symposium include products by Ampleon, MKS, and Richardson Electronics, delivering up to 1.2-kW output microwave power.

Figure 5. Solid-state microwave generator manufactured by Chengdu Wattsine[9].

Figure 6. Concept rendering of the SSMG to be introduced by Muegge (courtesy Muegge GmbH).

As further evidence that high power solid-state RF technology is gaining momentum, a number of influential players in the microwave heating industry banded together in October

2014 to form the RF Energy Alliance (RFEA)[10], a non-profit association "dedicated to realizing solid-state RF energy's true potential as a clean, highly efficient and controllable heat and power source." The membership of this organization is truly impressive, comprising major manufacturers representing a broad range of consumer and industrial markets.

No doubt that high-power solid-state RF technology will have a continually growing impact on our daily lives.

For further reading:

1. See Pages 3-9 at: drive.google.com/file/d/0B6OqoiA18sYDVzZqLVpzaWYwREE/view
2. www.wsj.com/articles/nxp-freescale-agree-to-merger-1425245923
3. media.nxp.com/phoenix.zhtml?c=254228&p=irol-newsArticle&ID=2118055
4. www.ampleon.com/products/rf-energy/2.45-ghz-rf-power-amplifiers/BLC2425M8LS300P.html
5. www.nxp.com/products/rf/rf-sage:RF-SAGE-PG
6. www.ampleon.com/news/news-articles/ampleon-and-midea-collaboration-results-in-world-s-first-solid-state-oven.html
7. R. Williams, Y. Ikeda, "Real-time impedance measurement and frequency control in an automotive plasma ignition system," 2015 IEEE MTT-S Int'l Microwave Symp., May 2015.
8. www.rfglobalnet.com/doc/noteworthy-technologies-from-ims-0001
9. www.wattsine.com/power-source/solid-state-mw1.html
10. See an article by K. Werner in this issue.

About the Author:

John F. Gerling has over 30 years of experience in engineering and development of products for microwave heating in consumer, commercial, industrial and scientific applications. His work has included engineering and development of standard and custom products, such as microwave clothes dryers, vending ovens, single and multimode applicators, batch cavity and conveyor systems, instrumentation and process controls. Mr. Gerling's work has led to the development of novel apparatus and methods used in basic materials science and research. Mr. Gerling is the founder and the Vice President of Gerling Applied Engineering (GAE) Inc. (Modesto, USA), which was acquired in July 2015 by Muegge GmbH (Reichelsheim, Germany), a leading manufacturer of microwave equipment for industrial heating and plasma processing. Mr. Gerling is also a leading member of several professional associations, including the International Microwave Power Institute (IMPI) and the Microwave Working Group.