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GaN Powers High Speed Wireline Networks

TRENDS IMPACTING WIRELINE NETWORK OPERATORS

Wireline networks and their operators face pressure as they attempt to adapt and react to subscriber demand for high-quality multimedia content delivered to them anywhere, anytime, on any device. Trends and events shaping wireline networks include analog reclamation, higher order digital modulation, new and increased use of channel bonding, DOCSIS® and Euro-DOCSIS 3.0 compliant and otherwise, bandwidth expansion over copper using legacy passives, increased return path capacity, component and hardware size reductions enabling an avalanche of head-end (HE), super HE and hub unicast transmission capacity, mandated and dramatically reduced energy usage, delivery of bits on-demand via narrow- and unicast methods versus traditional multi-cast and delivery of artifact-free all-digital content using legacy components designed for analog video carriers. Until now, wireline network operators faced these opportunities armed with electron tube, silicon bipolar and gallium arsenide (GaAs) die-based amplifier technologies, none of which completely satisfies often conflicting requirements. Gallium Nitride (GaN) die-based amplifiers, a new technology to the wired broadband market, offer the opportunity to solve many of today and tomorrow's most vexing wired network performance "musts," without the compromise of alternatives. This article illustrates the wireline network specifications and requirements, describes how GaN die-based amplifiers solve operator needs, compares and quantifies GaN die-based solutions versus alternatives and provides a glimpse of future wireline network capabilities when GaN die is enabled.

ANALOG RECLAMATION

While nearly every wireline network operator and service provider in the world is embracing high definition television (HDTV) and other digital services, their available bandwidth (BW) to implement new services most often remains fixed. An option available to most wireline network operators is the conversion of bandwidth employed today for analog signal transmission, such as analog National Television Standards Committee (NTSC) or phase alternating line (PAL) video, to all-digital signal delivery. The math of analog reclamation is compelling. If a North America-based wireline network system operator converts 40 of the 79 typically deployed six MHz wide analog channels to digital and compresses them, it provides enough capacity for approximately 80 to 100 high definition (HD) channels, HD video on demand (VoD) and downstream (DS) data delivery service at download speeds up to 1 Gbps.[1]

So, if analog reclamation is such a good thing, why not just change some HE and hub signal processing, transmitter and receiver hardware, install new software and increase network capacity? Although the trend is shifting and reclaiming traditional analog bands to digital, many network operators are retaining an analog video service of 20 to 25 channels for the foreseeable future to service millions of analog television sets and video cassette re-

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TABLE I

ANALOG VERSUS DIGITAL AMPLIFIER PERFORMANCE COMPARISON[2]

	Output Level in dBµV CENELEC 42 channels (CTB, CSO=60dB)	*Maximum Output in dBµV 256 QAM 96-channels (BER<1e10-9)*
Amp 1 (GaAs)	111	106
Amp 2 (**GaN**)	**114**	**110**
Amp 3 (Silicon)	98	98

▲ *Fig. 1 One GaN amplifier replaces two GaAs amplifiers in analog video, mixed signal and all digital wireline networks.*

corders operating throughout the world. Then, how does a GaN amplifier help in a traditional network?

Measurements were made to compare amplifier performance using three different primary device technologies, GaAs (referred to as "Amp1"), GaN ("Amp2") and Silicon ("Amp3") between an analog video loaded wireline network (42 analog PAL video channels of 8 MHz BW, measured against CENELEC standards[2]) and an all-digital loaded network (94 256 QAM channels of 8 MHz BW each from 40 to 862 MHz, measured against EN 60728-3-1 sub clause 4.1[3]). The goals of the measurements, made using an all-digital lineup, were to determine the maximum operating level in dBµV, referenced to a 75 Ω system, for BER free ($BER<1\times10^{-9}$) operation, in order to determine the behavior of the amplifiers with digital-only channel load, and find out rules for a system calculation of a HFC network with digital-only channel load. Measurements, for both analog video only and all-digital loading, were done with single amplifiers and a cascade of amplifiers using up to eight amplifiers.

The results, outlined in ***Table 1***, demonstrate that GaN technology-based amplifiers provide a 3 dB higher output power per carrier, when transmitting analog video at the same multi-carrier, a 3 dB higher output per analog video carrier at the same multi-carrier distortion level and a 4 dB higher output power per channel, when transmitting all-digital 256 QAM channels at the same BER versus a GaAs technology-equipped amplifier. The advantage of a GaN versus a silicon (Si) technology-based amplifier was 16 dB and 12 dB, respectively (analog and all-digital).

What this translates to, for the wireline network operator, is a new set of solution options that includes capital expense (capex) savings, through eliminating housed amplifiers within new ("Greenfield") installations (two for one in the case of GaN versus GaAs amplifiers, as shown in ***Figure 1***, and four or five to one in the case of GaN versus Silicon amplifiers) or reducing operating expense (opex) by replacing either GaAs or Si amplifiers with equivalent gain GaN amplifiers and operating the GaN amplifiers at 20 percent lower total power dissipation per device, with no sacrifice in multi-carrier distortion, CNR or BER performance, 15 years continuous operation between failures, or immunity to power supply surge and energy transients.

BANDWIDTH EXPANSION OVER COPPER USING LEGACY PASSIVES

One option wireline network operators would like to employ to improve their ability to meet demand from subscribers and consumers of high speed data (HSD), linear transcoded content and nonlinear, so called over-the-top (OTT), non-scheduled content, is expansion of legacy network BW without the replacement of installed plant coaxial cable, connectors and passives (including diplex filters, MoCA™ filters and taps (a.k.a. directional couplers)). Operators in North America have thousands of miles of coaxial cable installed within HFC networks rated to operate in the 54 to 750 MHz DS BW. What if an operator could replace a 750 MHz BW capable plant's amplifiers with 1002 MHz or higher frequency devices and upgrade subscriber consumer premises equipment (CPE) but not spend large amounts of capex replacing those miles of coaxial cable, connectors and installed passives originally specified for 750 MHz maximum upper frequency operation? This would permit adding 250 MHz or more of additional new BW at relatively low capex available for HSD, voice over Internet protocol (VoIP), 3DTV, compressed digital TV (DTV) and all forms of HDTV, including 3D-HDTV. Using present production GaN amplifiers, operators have the option to do just that. A latest generation GaN power doubler (PD) amplifier modules roughly 'double' the amplifier's RF P_{out} while providing lower multi-carrier distortion, improved composite intermodulation noise (CIN), better CNR and better BER.

- GaN PD amplifier modules make this option a reality through their ability to operate with a simultaneous set of desirable characteristics: Extremely high RF P_{out} capability (2 to 3 dB higher than most GaAs amplifier lineups, with the same distortion and BER performance) across the DS band (40 to 1600 MHz lineups using GaN are available commercially today). This ability permits the use of diplex filters and taps rated to 750 MHz, with relatively high insertion loss (IL) and attenuation above 750 MHz.
- Linear positive tilt of up to 18 dB from 40 to 1002 MHz (other positive tilt options are available at maximum frequencies to 1600 MHz). This type of tilt performance is available without penalty with regard to RF P_{out} and distortion performance at the highest rated frequency. This ability permits the continued use of installed coaxial cables and connectors, with significant and increasing attenuation as frequency increases above 750 MHz.[4]
- Wide range of gain options from 18 to 30 dB per GaN amplifier module. Combined with GaN amplifier high RF P_{out} capability, this feature allows most legacy 750 MHz capable DS plant to directly replace GaAs or Si amplifiers with GaN amplifiers, without re-spacing the existing installed housed amplifiers. This capability dramatically simplifies network upgrades with lower capex impact.
- Improved CNR performance at high RF P_{out} levels. This ability permits operators performing plant upgrades to employ high integer QAM in any portion or all of the DS BW, without affecting the delivered digital BER.

TABLE II

PHYSICAL CHARACTERISTICS OF SILICON (Si), GaAs AND WIDE BANDGAP SEMICONDUCTORS[18]

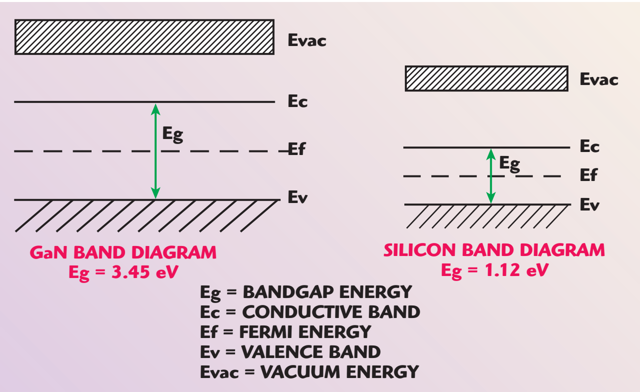
Property	Si	GaAs	6H-SiC	4H-SiC	GaN	Diamond
Bandgap, Eg (eV)	1.12	1.43	3.03	3.26	3.45	5.45
Electric Breakdown Field, Ec (kV/cm)	300	400	2500	2200	2000	10,000

$\varepsilon = \varepsilon_r * \varepsilon_o$ where $\varepsilon_o = 8.85 \times 10^{-12}$ F/m

MANDATED AND DRAMATICALLY REDUCED ENERGY USAGE

Today's typical HFC network HE consumes two to three million watts of electricity (that is 2 to 3 MW-hours) and operates with virtually no consideration of delivering subscriber content efficiently with a "bits delivered per $ or €" metric in mind. Under the auspices of Sustainability Management Subcommittee (SMS), the Society of Cable Telecommunications Engineers (SCTE) is creating a "critical facility" focused specification titled "Adaptive Power System Interface Specification" (APSIS). SCTE SMS crosses wireline network industry boundaries (NCTA, CableLabs®, CENELEC, EU, OEMs) and is tasked in the relative short term to create a set of meaningful requirements documents modeled after Telcordia specifications that improve cable industry energy usage efficiency. SMS activities in the next year are focused on specifications impacting energy usage within "critical facilities" including HEs, super HEs and hubs.

How can GaN device-enabled amplifiers help the wireline network operator meet new APSIS specifications, aimed at lowering overall energy usage? The wide range of GaN amplifier performance options, available today, offer operators several means of helping to meet APSIS requirements. Ultra linear GaN amplifiers, operating from 12 V DC and lower DC power supplies, will meet CMAP, DRFI and APSIS specifications simultaneously, while reducing installed volume footprint. GaN amplifiers based on very high breakdown voltage ($V_{bd} \geq 400$ V DC) are being shipped today, that have the capability to operate directly from any presently available wireline network power supply, with minimal power conversion or voltage regulation. Use of a "direct powered" GaN amplifier, within a next generation APSIS compliant network, simplifies network powering, while lowering energy usage. No other presently available amplifier technology can offer such a wide range of operating voltages.



▲ *Fig. 2 Band diagram showing GaN wider bandgap energy (Eg).*

WHAT MAKES GaN "GOOD"

GaN is a "binary" III-V direct bandgap semiconductor used in light emitting diode (LED) manufacture since the 1990s. GaN is a very hard material with a Wurtzite crystal structure, which is non-centrosymmetric (lacks inversion symmetry), giving GaN piezoelectric and pyroelectric properties which centrosymmetric crystals lack. GaN's bandgap of 3.45 eV affords it special properties in optoelectronic, high power and high frequency (HF) devices. As compared to other available materials suitable for manufacturing linear amplifiers for broadband wireline network applications, such as GaAs or Silicon, GaN properties give it unmatched capabilities (see ***Table 2***).

WIDE BANDGAP

GaN advantages versus Si and GaAs start with its wider bandgap material properties. Materials with small atoms and strong electronegative atomic bonds are associated with wide bandgaps. Only diamond, in today's process technologies, possesses a wider bandgap than GaN (5.45 eV for diamond versus 3.45 eV for GaN) for material useful as the basis for linear amplification. A material's bandgap determines how electrons (and "holes") behave within an amplifier's physical structure and what relative energy it takes to get these electrons (and "holes") excited ("excited" in the sense that they are willing to give up their energy). Electrons in an atom of a semiconductor material, such as GaN, can be thought of as being in various "states," including energy level, momentum and spin, with different probabilities of being in a given state. Two electrons cannot be in the same state at the same time, that is, at least one variable must differ. Some particular states are possible and some are forbidden by the laws of quantum mechanics. Sets of possible states form regions that are called bands. Sets of states that are not possible form regions between those bands and these are called bandgaps.

The higher energy gap of GaN material allows design and manufacture of amplifiers with the ability to operate at higher temperatures, withstand higher operating and transient voltages and to provide improved distortion performance at lower direct current (DC) power dissipation, versus amplifiers built using lower energy gap materials, such as silicon at 32 percent of GaN's energy gap level and gallium arsenide (GaAs) at 41 percent of GaN's energy gap level (see ***Figure 2***). Today's best amplifiers constructed using lower energy gap materials are reaching their limits of operating frequency, breakdown voltage and power density. GaN-based amplifiers have only begun to define performance boundaries. GaN's wide bandgap property has contributed to its ability to create linear and pulse application amplifiers, with demonstrated breakdown voltages (VBD) ≥ 400 VDC today and ≥ 1500 VDC in the future generation of devices. GaN's higher electric breakdown field allows more doping to be applied to the material, which further increases the gap between the upper breakdown voltage limits of the wide bandgap semiconductors compared to Si and GaAs.

THE FUTURE

GaN amplifiers, active switches, active splitters, laser drivers, detectors, modulators, ADC/DACs and DC-DC converter circuits will be operating in every part of future wireline networks. The operating voltages of these devices will span the range of less than 1 VDC to more than 1500 VDC (for DC-DC converter devices). Some of these GaN products will operate with usable bandwidths approaching a Terahertz (THz) for software defined radio (SDR) receiver front ends and ultra-high speed analog-to-digital converter (ADC) and digital-to-analog converter (DAC) applications. Wireline networks will enjoy the ability to power GaN circuitry directly from any available mains or distributed electrical power supply regardless of voltage level and voltage waveform type. Using GaN transmit power chains, all-digital content will be delivered to any multimedia display capable device anywhere in the world, artifact free. GaN circuitry will perform biocompatible radio frequency identification (RFID), monitoring and security functions and sophisticated sensor tasks, while operating from a fraction-of a volt with battery life measured in years not hours or days. ■

References

1. "Going All-Digital With DTAs," Light Reading Cable, April 6, 2009, www.lightreading.com.
2. CENELEC TC 209, "Cable Networks for Television Signals, Sound Signals and Interactive Services," October 5, 2009, www.cenelec.eu/Cenelec.
3. EN 60728-3-1 sub clause 4.1, "Cable Networks for Television Signals, Sound Signals and Interactive Services," Part 3-1: Methods of Measurement of Non-linearity for Full Digital Channel Load with DVB-C Signals," October 15, 2011.
4. "Lowering the Cost of Fiber Deep Networks with Motorola Gallium Nitride (GaN) Technology," Motorola White Paper, October 2009, www.motorola.com/Video-Solutions/US-EN/Solutions/Cable-Operators/Fiber-Deep-Category/GaN-Extended-Reach-Nodes-Amplifiers_US-EN.