REFUELING THE CABLE PLANT – A NEW ALTERNATIVE TO GAAS

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Abstract

GaAs hybrid and MMIC technology has enabled improved distortion performance and bandwidth expansion capability up to 1 GHz for the past 10 years. Now a new HFC semiconductor technology, Gallium Nitride (GaN), is coming on line with significant improvements in surge voltage ruggedness, better thermal performance, and capability of higher output levels to extend reach and further bandwidth expansion for new and existing cable plants.

Higher output levels achievable with GaN technology enable operators to lower initial capital costs and operational expenses for fiber deep network deployments. This paper will describe the advantages of GaN technology compared to current GaAs devices and provide design examples showing the potential cost savings in high to low density green field applications. Brown field extensions and bandwidth extensions where GaN can help to minimize cost will also be covered.

INTRODUCTION

In the late 1990's Gallium Arsenide (GaAs) MESFET based gain blocks were first introduced into cable plant actives. Within a few years GaAs hybrids and MMIC's completely replaced the silicon devices that had been the mainstay of cable nodes and amplifiers for the previous three decades. The extended gain bandwidth, lower noise, and improved distortion performance advantages of GaAs enabled cable operators to expand BW from 750 MHz to 870 MHz to the 1 GHz systems that are being deployed today.

The benefits of GaAs hybrids and MMIC's have been significant. These devices contributed to a seamless forward path transition from 64 QAM to 256 QAM in the access network. GaAs also allowed the bandwidth extension to 1 GHz of legacy 750 and 870 MHz systems while maintaining > 90% of the current actives locations.

Now, after a successful run of more than 12 years, GaAs gain blocks are about to be succeeded by a new generation of semiconductor device technology that has already proven its capabilities in numerous military, space, and commercial applications.

Gallium Nitride (GaN) is another III –V group direct band gap semiconductor just like Gallium Arsenide but with unique properties that have allowed the development of daylight LED's, Blu-ray lasers, and high power / high frequency RF amplifier devices. Like many semiconductor device technologies, GaN development was initially funded by the government to take advantage of its high power RF amplification and radiation resistant capabilities in space based applications. More recently GaN RF devices have begun to challenge Silicon LDMOS in the 2 GHz WiMax power amplifier base station market.

The commercial applications and availability of GaN semiconductor devices continues to expand. Until relatively recently larger scale devices were primarily processed for high voltage (> 50 Volts) operation. Now the major GaN wafer fabrication vendors have qualified devices that are optimized for lower operating voltages that are compatible with cable node and amplifier electronic circuit packs.

The major impact of GaN on the access network is its capability for significantly increased output levels without sacrificing distortion performance. Extended reach for nodes and amplifiers means fewer total actives are required for a given system design and therefore a measurable reduction in capex and opex spending. The remainder of this paper will describe the basic technology benefits of GaN semiconductors, the impact to node and amplifier station performance, and the system cost savings implications for different HHP serving size areas.

GaN TECHNOLOGY

Gallium Nitride devices designed for amplifier applications are typically constructed as heterostructure FET's also referred to as High Electron Mobility Transistors (HEMT's). Using a deposited layer of highly doped AlGaN and a non doped GaN channel layer a junction is created with a large band gap. Electrons generated in the AlGaN layer are swept into the quantum well created between the different band gap material layers. The effect is the creation of high mobility electrons. These HEMT devices provide high current gains and power gains at frequency bandwidths not usually attainable with traditional MESFET structures.

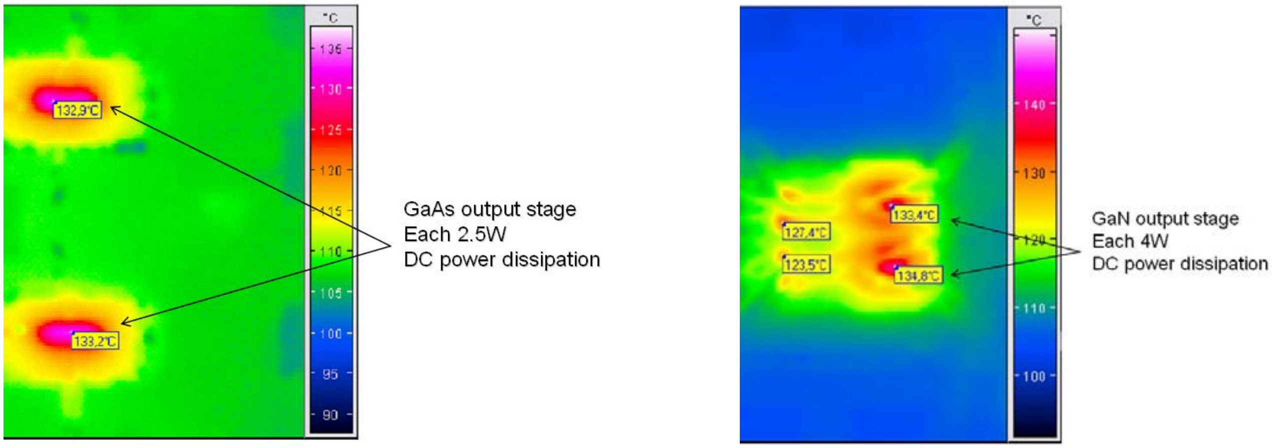
Gallium Nitride has a wider band gap (3.4 eV) than either Silicon (1.2 eV) or GaAs (1.4 eV). This property combined with the ability to operate at high voltages results in devices with roughly 10 times higher power density while maintaining wide bandwidths at frequencies up to 4 GHz.

Fabricating bulk pure crystalline GaN wafers proved to be so difficult that early applications for GaN was limited to small area devices such as LED's and specialized lasers or military applications which could absorb the higher costs of small area wafer processing. Advances in chemical vapor deposition and vapor phase epitaxy growth during the 1990's allowed GaN thin films to be deposited on silicon (Si) and silicon carbide (SiC) wafers achieving the possibility of large scale fabrication. Today, Gallium Nitride RF devices are primarily fabricated as discrete die or packaged as part of a multi-chip module to achieve a higher level functionality.

GaN devices processed on Si or SiC wafer substrates have significantly improved thermal performance compared to devices built on GaAs wafers. The thermal conductivity of Gallium Nitride is 2X higher than Gallium Arsenide. Fabricated on SiC wafer substrates (Tc = 4.9 W/cm*K), allows GaN devices to operate at higher output power levels while maintaining the same or lower junction temperatures than equivalent GaAs devices.

Figure 1 shows the worst case hot spot die temperature of a GaAs power doubled hybrid and a new replacement GaN power doubled hybrid. Like all cable gain block devices these hybrids are typically biased at nearly class A levels with the RF output backed down several dB in order to provide the best intermodulation distortion performance. The GaN output die operate at a significantly higher bias voltage level which in part explains its higher output power capability but also increases power dissipation >1.5X higher than the GaAs equivalent device. Even with this increase in DC power dissipation the higher thermal conductivity of GaN and its SiC substrate allow the GaN hybrid to stay at the same die temperature.

Starting with the initial introduction of GaAs devices in cable plant equipment, ESD and surge voltage ruggedness has always been a concern. The gate structure of typical GaAs FET's can not survive the high current flows usually produced by a transient pulse such as ESD. As a result, each manufacturer has incorporated a number of additional protection circuits and components to increase the raw withstand voltage capability of GaAs hybrids and MMIC's. The GaAs gain block devices deployed today are very rugged against the transient spike events that can occur in cable plant environments. The typical powered ESD values for today's GaAs gain blocks is ~ 1KV. GaN HEMT devices have a naturally higher ESD withstand threshold of 1600 to 1800 Volts. With additional protection circuitry as used with GaAs devices the ESD ruggedness could potentially increase even further.



Vcc=24V; IDC=478mA
T(heatsink)=100.0°C

Vcc=24V; IDC=462mA
T(heatsink)=100.2°C

FIGURE 1 – Worst Case Hot spot Temperature Measurements for GaAs and GaN PD Hybrids

GaN DEVICE IMPACT ON CABLE PLANT ACTIVES PERFORMANCE

The most significant performance limitation in access networks today is composite carrier to noise (CCN). Ever increasing digital loading up to 1 GHz creates carrier to intermodulation noise (CIN) which along with thermal noise generated in the various active components combines to produce CCN. While the other analog distortions (CSO, CTB) are still very important to the performance of the network the technology improvements due to GaAs implementation and gain block design over the past 10 years have leveled the playing field among amplifier and node vendors with respect to these 2nd and 3rd order distortions. CCN is now the dominant distortion that determines the maximum output level that nodes and amplifiers can achieve.

Cable gain block hybrids or multi-chip module MMIC's incorporating Gallium Nitride output stages provide higher output level capability while maintaining the same gain, power consumption, and physical dimensions as equivalent GaAs devices. In the following amplifier and node examples the impact of GaN on link and station performance will be clearly evident.

Figure 2 shows comparative data for CCN performance of a 1 GHz Line Extender tested with existing GaAs hybrid gain blocks and with Motorola's new GaN technology hybrid gain blocks. The testing was performed with a full analog + QAM channel load and typical amplifier tilt of 13.5 dB. Although this is single station data the plots illustrate the improved distortion performance of GaN particularly as the output level is increased. This enhanced performance allows the BLE output to be increased an additional 2 to 3 dB from typical GaAs operating levels without degrading end of line distortion.

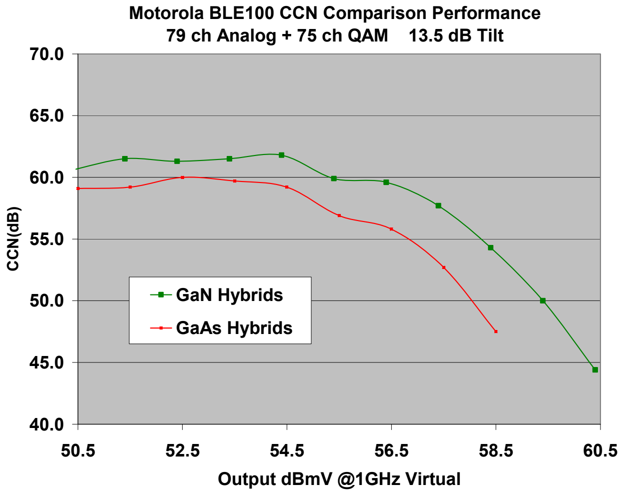


FIGURE 2
BLE Single Station CCN Test Results
(25C Data)

At lower output levels GaN still provides about 1.5 dB of CCN headroom compared to GaAs. This performance improvement with GaN could be used in existing brown field locations where legacy actives are stretched and additional CCN margin is desired.

In this example and the others that follow the CTB and CSO distortion performance with GaN is better or equal to the original GaAs amplifier values.

Figure 3 demonstrates link performance testing using the Motorola SG4 segmentable node in an N+0 configuration. With existing GaAs hybrid gain blocks the SG4 is capable of +58 dBmV (1 GHz virtual) output at 18 dB tilt and a full 1 GHz channel load. The same link utilizing Motorola GaN technology hybrid gain blocks provides 3 dB of additional output level for the same distortion performance. At lower levels the CCN results are dominated by the optical link and therefore the difference between GaAs and GaN is not as dramatic.

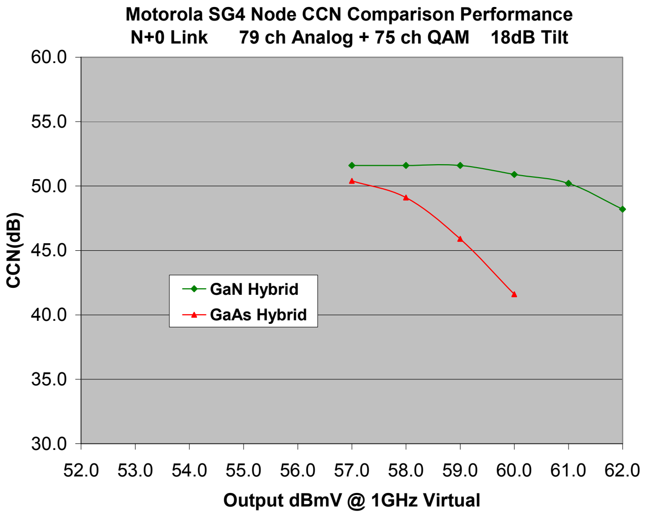


FIGURE 3
SG4 Link Performance, 20km Fiber + Passive Loss (25C Data)

The impact of GaN becomes even more apparent as the channel loading moves to all QAM and tilts are increased to maximize high frequency reach. Figure 4 compares the CCN performance of an N-split (85 / 108 MHz) three output Mini-Bridger amplifier station loaded to 1 GHz with only 256 QAM channel loading. At lower output levels the difference in performance is roughly 2 dB, similar to the results seen in the Line Extender example with analog + QAM loading. The real impact occurs as the output level is increased. Here the higher crash point of GaN allows 3 dB of added link margin.

Specifying the operating point for an all digital link requires careful consideration. As can be seen in Figure 4 the virtual level for either GaAs or GaN based amplifiers could be claimed at values as high as 61 dBmV or 63 dBmV and most likely produce acceptable BER / MER under ideal conditions. The problem is that operating on the right hand side of the graph or "crash region" for these devices means that any variations in gain level, temperature, aging, etc. would cause a large swing in the performance. In the worst case the link CCN could slip below the minimum acceptable level and severely degrade end of line performance. A conservative approach would be to operate at the peak of the curve or slightly to the right (~ 1 dB) of the peak.

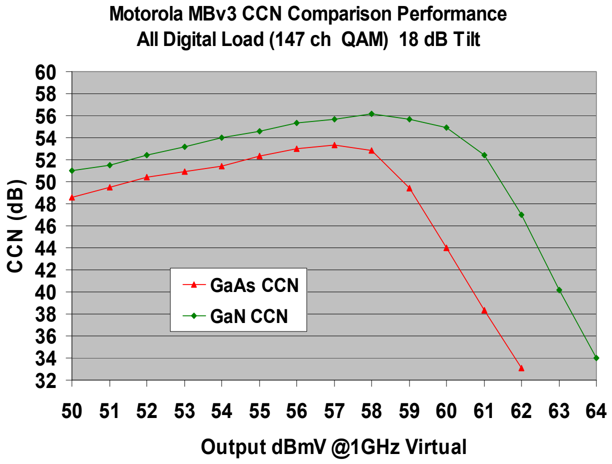


FIGURE 4
MB Single Station CCN Test Results
(25C Data)

GaN BENEFITS ARE IN THE APPLICATIONS

Now that the technical description and performance characteristics of GaN technology have been presented, it is time to discuss the various applications and subsequent results. The obvious method of proving the benefits of GaN is to perform a series of network modeling exercises designed to directly compare new GaN versus existing GaAs technology and let the chips fall where they may. In order to do this we have selected several sample design areas with varying density and topology to focus upon. These sample networks consisted of the following types:

1.) Urban Plus density Greenfield plant which averages 256 Homes per Mile (HPM).

2.) Suburban density Greenfield plant which averages 96 HPM.

3.) High-rise Multiple Dwelling Units (MDU) Greenfield consisting of 133 and 223 units per building.

4.) Rural density Brownfield 550 MHz to 1000 MHz plant up-grade which averages 18 HPM.

We also considered looking at rural Greenfield plant however, that did not make much sense since most rural Greenfield plant construction is moving towards RF over Glass (RFoG) as the predominant lowest cost architecture for sub 50 HPM densities.

NETWORK DESIGN PARAMETERS

All designs adhered to the following requirements:

1.) Technology:
GaN versus GaAs

2.) Architecture:
Traditional HFC with a variety of amplifier cascades deployed as necessary to permit maximum node sizes of 700 HPN in the Urban Plus area and 500 HPN for the Suburban and Rural areas.

3.) Frequency:
54-1000 MHz as the
Downstream (DS)
5-42 MHz as the
Upstream (US).

4.) Channel Loading:
78 analog to 550 MHz,
The remaining is
256 QAM to 1000 MHz.

5.) Cable Type:
Greenfield: P3-750, P3-500
Brownfield: P3-750, P3-500 & P3-625
MDU: RG-11 and RG-6

6.) Tap Port Level:
19 dBmV @ 1000 MHz Virtual
15 dBmV @ 550 MHz Actual
10 dBmV @ 54 MHz Actual

7.) Network Powering:
90 VAC

8.) Network Performance:
CNR: 49.0 dB
CCN: 48.0 dB
CTB: 57.0 dB
CSO: 56.0 dB

DESIGN OBJECTIVES

In all network design models, the objective was to produce the most efficient design from an equipment usage perspective. The same network designer was used for all sample design models in order to eliminate design talent diversity.

In all sample designs, we maintained the same service area boundaries. In other words, no attempts were made to expand the node serving area reach in order to reduce optoelectronics quantities and related cost. Although this could have been done, since the trend is moving towards smaller node size, we did not factor this into the modeling effort.

The MDU design utilized a tapped riser design approach. A tapped riser design usually has actives placed in a storage closet or stairwell with taps placed on each floor and drops run to each apartment. This is illustrated in the Figure 5 diagram.

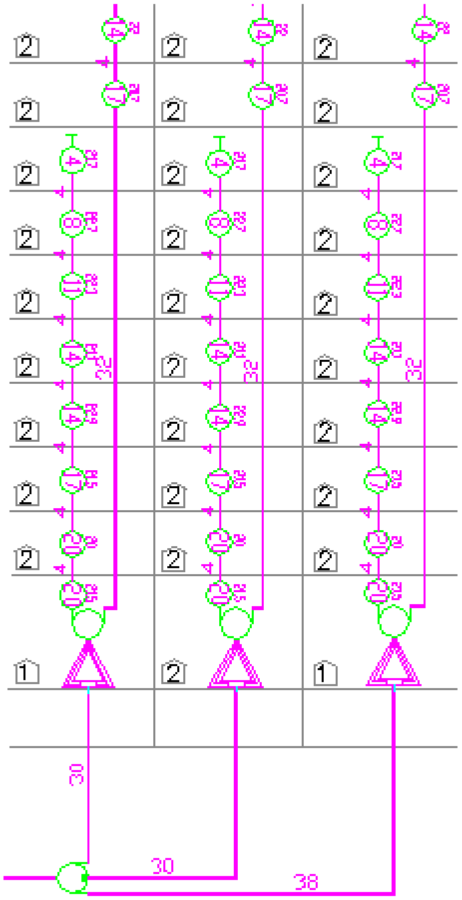


FIGURE 5

NETWORK MODELING RESULTS

Results of the sample design models indicated variations in four major areas: network active counts, network powering, cable usage, CAPEX and OPEX.

Let's discuss these individually prior to presenting Tables A, B and C which offers a detail level review of the results.

1.) Network Active Counts: two significant things occurred in this area. First, the total active counts were reduced in the GaN designs due to increased operating levels.

Typically, GaN enables a 2-3 dBmV higher output capability than the GaAs counterpart. The active count reduction ranged from 6% to 30% depending upon the design area considered.

Second, the types of active devices used also changed. High density areas used few amps with more outputs, while the suburban area used fewer outputs per active. Both of these elements reduce network CAPEX and OPEX.

2.) Network Powering: the GaN designs yielded a significant reduction in power consumption. This ranged from 12 % to 19 % for the various models. This power reduction can lower CAPEX for initial deployment by reducing P.S type from 15amp to 12 amp for example. Additionally, since plant powering costs can range from $200 to $400 per plant mile per year, a 12% to 19% power reduction may result in an annual OPEX savings of $76 per mile.

3.) Cable Usage: the quantity and mix of cable varied slightly from design to design, ranging from -2.5% to +2.5%

4.) CAPEX: overall network electronics cost were reduced in the GaN designs ranging from 7.3% to 8.7%.

GREENFIELD MODEL

Let us now take a closer look at specific results provided. In Table A we look at the impact that GaN has in a Greenfield environment.

GREENFIELD NODE	**Urban Plus GaAs**	**Urban Plus GaN**	**Suburban GaAs**	**Suburban GaN**
Plant Mileage	2.72	2.72	9.67	9.67
Aerial	2.72	2.72	7.08	7.08
UG	0	0	2.59	2.59
Total Actives	7	5	31	29
Actives/Mile	2.6	1.8	3.2	5.9
Cascade	N+1	N+1	N+4	N+4
House Count	695	695	924	924
HC/Mile	256	256	96	96
1GHz Design				
Actives Used	**7**	**5**	**31**	**29**
SG4000	1	1	2	2
BLE100			9	10
MB100	1		8	15
MBV3	4		11	3
BTD	2	5	3	1
Powering				
15 Amp Power Supplies	1	1	3	3
Total Power Draw (Amps)	9.27	7.51	30.4	25.97
% Power Savings		19.0%		14.6%
Cable Footage	**22,071**	**22,692**	**76,112**	**74,144**
Total Electronics	$ 10,999.27	$ 10,201.15	$ 26,983.19	$ 24,933.40
Per Mile Electronics	$ 4,043.85	$ 3,750.42	$ 2,790.40	$ 2,578.43
% Change to electronics		-7.3%		-7.6%

TABLE A – Greenfield Urban + and Suburban

In both cases studied there was a reduction in the number of actives used, power used and total equipment cost. Active types also changed in each design. In the high density area we found that due to the increased output capability of GaN devices, more multiple output devices were chosen for increased design efficiency. The lower output GaAs product for like amplifier types did not produce this same advantage. The suburban density showed a decrease in the number of outputs per active device. Without the multiple paths that high density areas provide to take advantage multiple output amplifiers, use of this type of active creates the need for dual cable feeds making for a less efficient design. Instead, the higher output allowed for fewer outputs per active, reducing the amount of dual cable. In all cases it was discovered that an equivalent area can be fed using a fewer output GaN amplifier as was covered with a GaAs active.

MDU MODEL

In Table B we look at the impact that GaN has when used in a Greenfield high rise MDU environment.

GREENFIELD NODE	MDU A GaAs	MDU A GaN	MDU B GaAs	MDU B GaN
Total Actives	3	3	9	6
Cascade	N+2	N+2	N+2	N+2
Unit Count	133	133	223	223
Floors	15	15	15	15
1GHz Design				
Actives Used	**3**	**3**	**9**	**6**
BLE100	2	3	8	3
MB100	1		1	3
Power Supplies				
15 Amp	1	1	1	1
Power Draw (Amps)	2.0	1.8	6.1	4.0
% Power Savings		10.0%		34.4%
Cable Footage	**1,568**	**1,568**	**4,893**	**4,893**
Total Electronics	$ 1,644.84	$ 1,502.15	$ 4,172.51	$ 3,816.72
% Change to electronics		-8.7%		-8.5%

TABLE B – Greenfield High-Rise MDU

The higher output achieved using the GaN amplifiers allowed for the use of multi-output devices in fewer locations, reducing the number of active locations needed in each MDU.

An additional advantage of the GaN amplifier not captured in this design is that the GaN amplifier increases the number of floors that can be reached. In both the MDU A and MDU B designs, using an equivalent GaN amplifier in place of the designed GaAs amplifier, an additional three floors could have been reached, increasing the possible number of units passed by 17%.

BROWNFIELD MODEL

One of the more significant advantages that GaN provides is the ability to cost effectively upgrade existing 550 MHz systems out to 1 GHz. Where GaAs allowed a near perfect drop in upgrade from 750 MHz to 1 GHz, GaN provides this same ability for 550 MHz systems.

BROWNFIELD NODE	**GaAs**	**GaN**
Plant Mileage	28.25	28.25
Aerial	26.81	26.81
UG	1.44	1.44
Total Actives	128	128
Actives/Mile	4.5	4.5
House Count	509	509
HC/Mile	18	18
EXISTING DESIGN		
Actives Used	**128**	**128**
Cascade	N+9	N+9
1000 MHz Design	**GaAs**	**GaN**
Actives Used	**136**	**129**
Cascade	N+6	N+6
ACTIVES OVERVIEW		
% Actives Held Location	98%	100%
% Actives Held w/ Epak	91%	94%
% New Actives	6.3%	0.8%
TAPS & PASSIVES		
Total Taps	347	347
% Taps Held	91%	99%
Total Passives	93	93
% Passives Held	91%	95%
Poweing		
15 Amp power Supplies	10	10
Power Draw (amps)	98.9	95.8
% Power Savings		3.2%
CABLE		
Existing Cable	198,518'	199,585'
New Cable	1,779'	712'
% New Cable	0.9%	0.4%

TABLE C - Brownfield

Looking at Table C, GaN technology allows the MSO to increase bandwidth of their existing 550 MHz systems to 1GHz, while maintaining their active locations and housings. The MSO can maintain 95% of their current active housings, using an E-pack to upgrade the existing amplifiers.

Assuming that the current taps and passives in the 550 MHz system are capable of passing 1GHz, 99% of the tap faceplates as well as 95% of the passives were maintained.

The GaN amplifiers held 94% of the current amplifier locations with just an e-pack upgrade. While this is just 3% better then an equivalent GaAs design, the GaN amplifiers were able to reach the end of line (EOL) taps with just the addition of one new amplifier. The GaAs design added 6.3% new actives to be able to reach all of the EOL taps.

A WORD ABOUT OPEX

Operational Expenditures (OPEX) are frequently ignored by some operators when deciding upon equipment purchases. The annual recurring expense to maintain and operate the plant can be a significant contributor to profit margins.

Reducing OPEX is a key metric that should never be neglected. Table D below illustrates the OPEX savings for just a few key contributors in a network – powering, battery maintenance and active device maintenance. There are certainly other areas such as plant sweep & balance, but we have focused herein upon the three main categories stated.

Note the overall reduction in OPEX ranging from 13% to 17% due to incorporating the advantages of GaN technology into a Greenfield plant design.

OPEX - Greenfield	Urban Plus GaAs	Urban Plus GaN	Suburban GaAs	Suburban GaN
Mileage	2.72	2.72	9.67	9.67
Powering Cost				
# PS	1	1	3	3
Wattage	981.53	795.18	3218.82	2749.76
Kwh/Year	8598	6966	28197	24088
Cost/Kwh	$0.10	$0.10	$0.10	$0.10
Annual Power Cost	**$859.82**	**$696.57**	**$2,819.69**	**$2,408.79**
P.S. Maintenance				
Batteries	4	4	12	12
Battery Cost	$150.00	$150.00	$150.00	$150.00
% Annual R&R	25%	25%	25%	25%
Annual Battery R&R Cost	**$150.00**	**$150.00**	**$450.00**	**$450.00**
Active Device Maint. Cost				
Actives Count	7	5	31	29
Average Cost/Active	$900.00	$1,085.00	$800.00	$775.00
Annual Replacement %	2%	2%	2%	2%
Annual Replacement Units	0.14	0.1	0.62	0.58
Annual Material Cost	$126.00	$108.50	$496.00	$449.50
MTTR (Hrs)	1	1	1	1
Labor Cost/Hr.	$100.00	$150.00	$100.00	$100.00
Annual Labor Cost	$14.00	$15.00	$62.00	$58.00
Annual Active Device Maint. Cost	**$140.00**	**$123.50**	**$558.00**	**$507.50**
Total OPEX	**$1,149.82**	**$970.07**	**$3,827.69**	**$3,366.29**
OPEX/MILE	**$422.73**	**$356.65**	**$395.83**	**$348.12**
% Difference		**-19%**		**-14%**

TABLE D - OPEX

CONCLUSIONS

Upon review of this paper, it becomes evident that there are numerous advantages of deploying GaN technology. Perhaps the key advantage is that deploying GaN yields a proactive ability to "Go Green" as fallout without really having to try to do so.

Going Green: reducing the Carbon Footprint of networks is a key objective that will continue to become a desirable goal for all things in life over time. It is the right and smart thing to do. Some areas that will benefit are:

- Fewer active devices to purchase and maintain
- Ability to maintain more existing active devices in existing plant upgrades
- Ability to improve system performance
- Reduced deployment cost
- Reduced powering cost for the life of the network
- Reduced transportation costs
- Reduced OPEX costs for the life of the network

References:

Motorola White Paper: “Lowering the Cost of Fiber Deep Networks with Motorola Gallium Nitride (GaN) Technology”. October 2009

LIST OF ACRONYMS

CAPEX – Capital Expenditures
CCN – Composite Carrier to Noise
CIN – Carrier to Intermodulation Noise
CSO - Composite Second Order
CTB - Composite Triple Beat
EOL – End of Line
GaAs – Gallium Arsenide
GaN – Gallium Nitride
HEMT - High Electron Mobility Transistors
HFC – Hybrid Fiber Coax
HPM – Homes per Mile
LDMOS - Laterally Diffused Metal Oxide Semiconductor
MESFET - Metal Semiconductor Field Effect Transistor
MMIC - Monolithic Microwave Integrated Circuits
OPEX – Operating Expenditures
RFoG – RF over Glass
Si - Silicon
SiC – Silicon Carbide