Detecting and Resolving $100 Million Avoidable Losses

ABSTRACT: Occasionally positive growth and expansion mask expenditures whose correction could eliminate a $100 million+ annual outflow. This paper focuses on identifying one such prevalent problem in telecommunications.

Spotlighting the Problem

Sometimes a rocket scientist isn't needed to discern a problem. On September 23, 1999 the Mars Climate Orbiter approached Mars, not from the planned altitude of 150 kilometers, but rather from the fatally low altitude of 60 kilometers. After traveling more than 9 months and 50 million kilometers from Cape Canaveral, it burned and disintegrated in the Martian atmosphere. The $150 million dollar loss … was a result of using Metric and English units in the same calculation.

Sometimes even recognizing a problem requires substantial investigation, research, nuance, and analysis. Consider a problem buried under much growth and success. A good example is mobile phone traffic in the telecommunication industry. One might think that such a dynamic and well serviced market ecosystem would be awash in easy data. Not so fast. In terms of different network generations, there is 2G, 3G, LTE, 4G, 5G E, and 5G, and more, … and of course, each generation operates at different bandwidths, different frequency ranges, some have different antenna requirements, different antenna reach, and a corresponding mix of different equipment in the base station. Nor are definitions consistent; sometimes a base-station is larger or smaller, sometimes multiple carriers use it and therefor each carrier counts it as its own base station. Different generational devices sometimes – not always – require different base station equipment. Simply said: aggregating global statistics is a world class mess. Even professional market data firms avoid the problem by collecting data from different vendors and discussing the market from the perspective of carrier percentage of market share. Nevertheless, with the assist of some reasonable and explicit assumptions, and some persistence, we will collect approximate numbers.

Let's zoom into the subject area at the tree top level:

- Globally, 2023 marked over 8.9 billion mobile phone subscriptions – (slightly larger than the 2023 world population.) [1]
- Worldwide there are over 9 million base stations to support these phones. [2 3 4 5 6]
- 5G mobile devices, 10 to 100 times faster than 4G, with dramatically reduced latency, and simultaneously amp-up available applications have created a very pleased user base.
- All this success comes with substantially increased power usage**.** [7] A typical 5G base station consumes up to twice or more the power of a 4G base station.[8] **Base stations power needs are rising disproportionately**. In 2019 the annual base station power tab was $19 Billion [9]; in 2023, $52 Billion[10]

The EE Times succinctly summarizes the essence of this picture:

> "In the wireless-communication world, it's all about power and efficiency, whether at the base station infrastructure or handset levels." [11]

This focus on power and efficiency *is a direct consequence* of the expanding wireless economy. To wit:

> "High data rates, achieved with complex RF modulation and higher average output power, reduce the efficiency of traditional RF power amplifiers (PA) to unacceptable levels, both for the thermal dissipation and the battery lifetime of existing smartphone designs." [12]

The Problem is crystalizing before our eyes: we have a thriving wireless marketplace making **increasing power demands *on power amplifier circuits* which are performing at unacceptable levels.**

Problem Focus: Billions Wasted on a Global Electricity Tab? … Who Do We Fire?

The telecommunications Industry has long recognized most of base station power is wasted. Examples:

- (2021) Nokia reports 90% of the electricity used **by base stations** is converted into waste heat [13]
- (2013) The MIT Technology Review, when referring to **base station power consumption**, says "Much of this is wasted by a grossly inefficient piece of hardware: the power amplifier, a gadget that turns electricity into radio signals [14]
- (2008) "today's high power **base stations operate** at 10 percent efficiency" [15]

From above, the 2023 electrical costs – for base stations - was $52 Billion. Of that total – $20 Billion - 38% of is wasted[16]. Maybe it's time to sack the power amplifier?

Alas, poor POWER AMPLIFIER, We Knew Thee Well

RF Power Amplifiers are far from dead; nor should they be – but power amplifiers need to be not just fixed, not just improved, not just redesigned, power amplifiers need to be fundamentally *re-conceived*. Dating from the vacuum tube days, there have been different improvements, but those improvements have been more oriented to problem solving for a specific instance. Much like motor vehicles have "solutions" like 2 passenger fast cars, and 8 passenger mini-vans, and off road vehicles, there are various power amplifiers - each engineered for specific solutions or uses, high power small space, high frequency lots of space, etc.

Critical for today's generation of wireless devices (3G, LTE, 4G, 5G,), P**ower amplifiers (PA)**, need to be considered through the lens of functional requirements: how do PAs need to behave operationally? What are the inputs and desired outputs? What efficacy might we reasonably expect? Addressing these questions will help narrow in on where the problems are.

1. Consumers demand shorter download times, higher quality video, eliminate delays, more bandwidth, higher data rates, longer battery life.
2. Providing greater bandwidth and spectral efficiency requires better modulation techniques and multi-carrier systems.
3. LTE, 4G, 5G generations support multi-carrier and use OFDM (Orthogonal Frequency Division Multiplexing) - the most spectrally efficient modulation technique, highly resistant to noise, interference, and propagation effects, is clearly a superior approach which has a key side effect: very high **p**eak to **a**verage **p**eak power **r**atio (PAPR)
4. LTE requires the PA feed transmissions at higher power levels per bit. The larger amount of LTE transmitted data likewise requires more power. The large number of LTE bands also have a very high peak-to-average power ratio (PAPR) and PA transistors optimized for high PAPR and high power are much less efficient at reduced power levels.[17]
5. High PAPR requires the transmit RF amplifier to handle the peaks while the average power is much lower, leading to inefficiency. Claims of PA efficiency are valid only when both calculated and then averaged across all points on the power curve, not just a maximum power point measurement.
6. The efficiency of traditional fixed supply PAs operating under high PAPRs and linear modulation is very poor. [18] PAs want to be linear – whenever the PA is not operating in a linear mode it is wasting more than half the power and a high PAPR is directly responsible for that. Wireless RF signals are complex waveforms with high PAPRs. The simple solution – a high-linearity amplifier – generally is a bad choice since it would be very inefficient and waste power most of the time.[19]

Market forces are shaping functional requirements which overwhelm the present structure of PAs.

Re-conceiving Power Amplifier Operations

The problem described above is well understood. Confronted with resolving a system of dismal performance (dismal efficiency in this instance) the easy path is to solve one aspect of the problem and gain some measure of improvement. Over the long period that our industry has both suffered and wrestled with this PA problem, several such solitary approaches have been tried: (i) envelope tracking, (ii) LINC Linear Amplification with Non Linear Control, (iii) Doherty PA, (iv) Predistortion, (v) and, EER Envelope Elimination & Restore. Although each has provided some improvement, each has also been found wanting – either in performance, or limitations, or both.

Given the complexity, scope, and interrelationships of the PA problem, the solution requires a *complete re-imagination* of the function of the PA. This isn't a job for a materials scientist, or an analog designer, nor does it demand a digital designer, nor a system engineer, nor a mathematician. The way a PA needs operate today has to be *re-imagined* from the ground up and a solution set tested and fitted thereto. In short: the problem calls for a multi-disciplined team approach. All five mentioned disciplines are needed.

QDA (Quantized Digital Amplification) is a promising amplification technique, which finally and finely, solves the trade-offs between power inefficiency and nonlinear distortion. This technique has demonstrated increasing RF-PA efficacy on wireless networks on the order of 3 to 5 times present levels. [20] [21] [22]

QDA changes the game of providing power amplification, from a PA circuity focus, to signal processing focus. Circuity uses discrete parts and silicon; signal processing uses high order mathematics, processing power, intelligent chips, some circuitry, and materials science. In short:

> This approach allows arbitrary waveforms to be constructed from sums of waveforms - constant envelope in nature. Desired output signals and waveforms may then be constructed from the amplified versions of substantially constant envelope constituent signals. These signals are created from two parts: (i) the knowledge and quantization of the time varying envelope of the input signal, and (ii) the amplified version of the quantized signal is generated by using multiple amplifiers with different power outputs. The outputs are summed and digitally combined via a unique method. [23]

(QDA) - Quantized Digital Amplification … Benefits Befitting a King

Rising from 10% average efficiency to 50% is nothing short of disruptive. That alone would be sufficient for adopting QDA. There are, however, a number of additional benefits, including:

- Accommodating a broad spectrum of applications by working with both single and multi-carrier signals, not tied to a specific constellation, bandwidth or signal as a target;
- Integrating and adapting to any existing standard, from 2G to 5G in wireless communications;
- Being suitable for any multi or single-carrier system with variable envelope;
- Achieving higher flexibility and scalability through programming flexibility and digital processing of the signals on FPGA (Field Programmable Gate Array) or DSP (Digital Signal Processor);
- Delivering large energy efficiency with no compromise to linearly transmitted signals;
- Dramatically lowering greenhouse gasses by eliminating waste electricity and heat.

Full Circle Storytelling

The story of power amplifiers reaches an end. We have identified, quantified, described, characterized, and re-imagined this problem on its trajectory from wasteful villain to responsible component and green-environment champion. The conclusion is clear; it is time to act to eliminate waste power.

[1] https://www.statista.com/statistics/262950/global-mobile-subscriptions-since-1993/

[2] https://blog.se.com/datacenter/cloud-and-service-providers/2019/11/11/massive-5g-electricity-costs-are-in-focus-ahead-of-the-global-build-out-at-the-edge/

[3] https://www.globaltimes.cn/content/1172513.shtml

[4] https://www.globaltimes.cn/page/202210/1277927.shtml

[5] https://www.marvell.com/company/newsroom/marvell-launches-breakthrough-end-end-solutions-for-5g-infrastructure-deployments.html

[6] Note 2 cites 5 million base stations for G2, G3, G4 alone in 2019; note 3 cites 6 million 4G base stations in 2019; note 4 cites 3 million 5G bases stations in 2022. Note 5 cites 10 million base stations combined in 2019. An industry rule of thumb is that each base station equates to 1000 subscribers. Considering above citations and 8.6 billion subscribers (note 1) then 9 million combined base stations is a very conservative number.

[7] https://www.fiercewireless.com/tech/5g-base-stations-use-a-lot-more-energy-than-4g-base-stations-says-mtn

[8] https://www.mtn-c.com/product/operators-facing-power-cost-crunch/

[9] (5.5 million base stations) * (3.27KW) * (24 hours) * (365 days) * ($0.121 kWh) & https://www.electricrate.com/data-center/electricity-prices-by-country/

[10] (9 million base stations) * (5.49KW) * (24 hours) * (365 days) * ($0.121 kWh) & https://www.electricrate.com/data-center/electricity-prices-by-country/

[11] https://www.eetimes.com/the-envelope-please-takes-on-new-meaning-with-nujiras-rf-pa-efficiency-approach-for-4g-handsets/

[12] https://eepower.com/technical-articles/envelope-tracking-for-cellular-rf-power-amplifiers/

[13] https://www.abiresearch.com/market-research/insight/7780135-what-are-the-innovative-technologies-for-o/

[14] https://www.technologyreview.com/2012/10/31/181953/efficiency-breakthrough-promises-smartphones-that-use-half-the-power/

[15] https://phys.org/news/2008-11-wireless-base-station-power-amplifiers.html#!

[16] "Wasted Electrical Power Lost by Power Amplifiers (PA)", QDAcomm.com, 2024

[17] https://eepower.com/technical-articles/envelope-tracking-for-cellular-rf-power-amplifiers/#

[18] https://www.eetimes.com/understand-and-characterize-envelope-tracking-power-amplifiers/

[19] https://www.eetimes.com/rf-meet-analog-and-his-friend-digital

[20] https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=9449894

[21] P. Viegas, J. Guerreiro, H. Serra, R. Madeira, R. Laires, P. Morgado, R. Dinis, P. Montezuma, and J. P. Oliveira, ‘‘A highly-efficient amplification scheme for OFDM signals,’’ in Proc. VTC Spring Conf., Feb. 2021.

[22] P. Montezum, M. Beko, R. Dinis, J. Guerreiro, and P. Viegas, ‘‘Apparatus for quantized linear amplification with nonlinear amplifiers,’’ USPTO Patent 10069467 B1, Sep. 4, 2018

[23] P. Carvalho, R. Dinis, C. Caparica, L. Campos, H. Serra, M. Martins, J. Oliveira, R. Madeira, R. Laires "Multi Quantized Digitally Controlled Power Supply Voltage For Multi Amplifier Stages," USPTO Patent 11211900 B1, Dec. 28, 2021