Powering 5G Radio Access Networks (RAN)

DESIGN CHALLENGES AND OPPORTUNITIES FOR EFFECTIVELY POWERING 5G RAN INFRASTRUCTURE

Introduction

With 5G network deployments, some of the most radical changes from earlier generation wireless systems will affect the Radio Access Network or RAN layer. The proliferation of small cells presents new opportunities and challenges to carriers, operators, and network equipment providers.

This white paper addresses the challenges designers face in ensuring that 5G RAN infrastructure is efficiently and effectively powered, with a focus on the capabilities of DC-DC modules.

The paper includes detailed technical discussions of system architectures and design tradeoffs, the most relevant DC-DC module features, and considerations for the various parts of the 5G antenna.

Power Management Architectures in 5G Radio Access Networks

In this white paper, we discuss power management architectures in 5G Radio Access Networks (RAN) focused primarily on DC-DC.

First, we must define 5G RAN. Cellular technology architectures have been using RAN since the early days from 1G analog to 5G. The RAN is made up of base stations/antennas that provide wireless communication creating a Heterogeneous Network (HetNet) over a specific geographic region. 5G RAN has evolved to include massive multiple-input, multiple-output (M-MIMO) antennas, bigger spectrum bandwidth than ever, ultra-reliable low-latency communications

Table of Contents

(URLLC), and multi-band carrier aggregation. The large base stations from 4G networks will mostly remain and will be upgraded to higher-speed capability with Massive MIMO.

The big opportunity for new infrastructure lies in small cells, which are being added on light poles, traffic lights, buildings, and other tall structures, especially in large cities. These are some of the places in which heterogenous networks will shine.

Heterogeneous Networks (HetNets)

5G uses higher spectrum frequencies, some as high as millimeter wave, which must be line-of-sight directed due to its propagation limitations. Many obstacles, such as trees and buildings, block or attenuate the signal and result in poor coverage for mobile users. Dotting the landscape with small cells to provide coverage over short distances addresses this blocking problem and has the added benefit of allowing efficient reuse of high-throughput spectrum over distance.

Very dense HetNets, low-power access points, are being deployed—comprised of macro-, micro-, pico-, and femto-cells. Densification will result in higher spectral efficiency and will most likely also reduce power consumption of mobile devices, due to the user's proximity to ubiquitous small-cells. Network coverage will significantly improve, especially for indoor and space-constrained locations because when the user moves behind an obstacle, their cell phone will automatically switch to these mini base stations—in particular, small cells to keep the connection intact. The challenge is that this solution will require innovation in hardware miniaturization and cost reduction in the design of small cell base-stations (Figure 1).

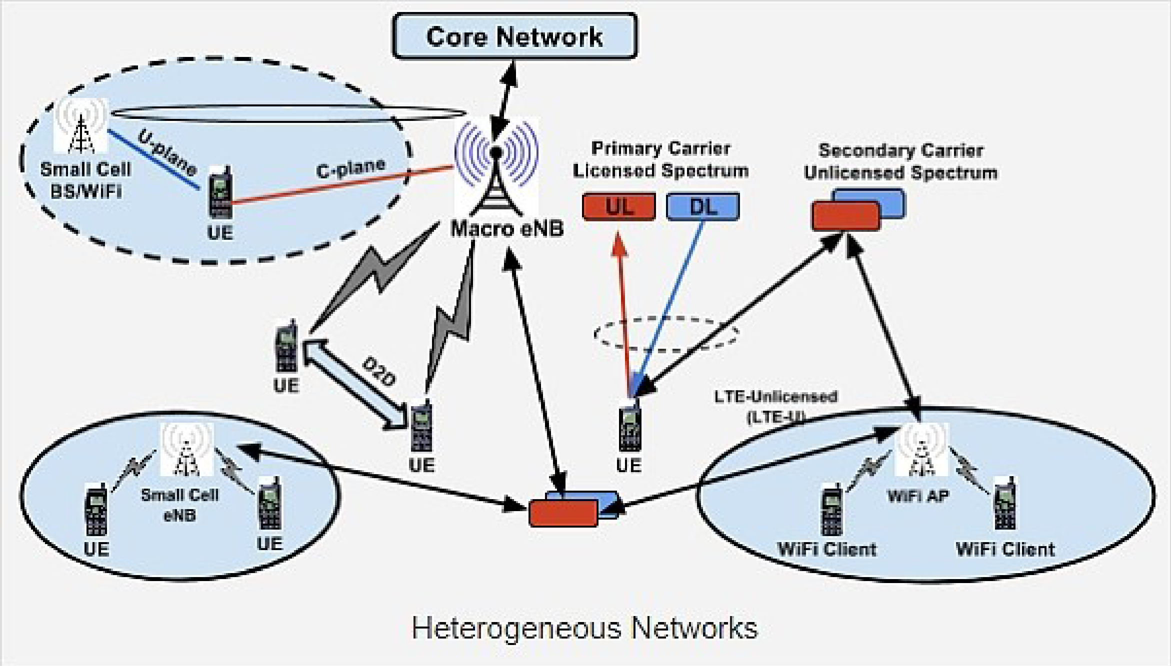


Figure 1: An example of Heterogeneous networks (HetNets) with User Equipment (UE), uplink (UL), downlink (DL), Base station (BS), evolvedNodeB (eNB), Control plane (C-plane) Device-to-Device (D2D), User plane (U-plane), and Access Point (AP) (Image by OpenAirInterface.org)

Small cells are energy- and cost-efficient base stations that bring subscribers closer to them, thereby increasing network throughput and improving the user experience. These small cell base-stations, when deployed as low-powered femtocells, can be used in enterprise and residential deployments. Higher-powered pico-cells will improve outdoor coverage of macro cells. A single small cell site/node, which covers three sectors and multiple frequency bands, may need 200 to 2000 W of power, depending on the size of the sector(s). Typical distances between these sites range from 200 to 500 m.

5G RAN Power Management

Small Cells

5G small cells are an excellent solution to deliver enhanced mobile broadband, low latency, and reliable service to users. Essentially, small cells serve as wireless transmitters and receivers designed to give network coverage to smaller areas. While tall, high-power “macro” towers keep the network signal strong across large distances, small cells are better served for more densely developed environments, such as in urban cities. Higher-order modulation techniques, MIMO technology, and millimeter wave spectrum will all enhance the performance of future small cell deployments (Figure 2).

5G Small Cell Types	Deployment	Number of Concurrent Users	Power Range	Distance Coverage
Femto cell	It is primarily used in residences and enterprises	4 to 8 users (residence) 16 to 32 users (enterprise)	10 to 100 mW (indoor) 0.2 to 1 W (outdoor)	10s of meters
Pico cell	Public areas such as indoors, outdoors, airports, malls, train stations	64 to 128 users	100 to 250 mW (indoor) 1 to 5 W (outdoor)	10s of meters
Micro cell	Urban areas to fill macro coverage gaps	128 to 256 users	5 to 10 W (outdoor)	Few 100s of meters
Metro cell	Urban areas to provide additional capacity	> 250 users	10 to 20 W (outdoor)	100s of meters
WiFi	Residences, offices, enterprises	< 50 users	20 to 100 mW (indoor) 0.2 to 1 W (outdoor)	Few 10s of meters

Figure 2: Types of small cells

Reliability is Essential

5G base stations and their antennas must always operate reliably; in many cases redundancy or even self-diagnosis and self-repair is necessary. A ‘truck roll’—meaning a service technician visiting the base station to repair or replace a component, circuit board, or other assembly—is a costly last resort and service providers want to avoid them. If a truck roll is the only solution, customers must not be affected and all service must continue.

To ensure service reliability, power supplies must have excellent Mean Time To Failure (MTTF) and/or Mean Time Between Failures (MTBF). The Artesyn AGQ500 DC-DC converter is a good example as it is designed for GaN RF power amplifiers on a 5G Remote Radio Head (RRH) tower and has an MTBF of 1.5 million hours (calculated according to Telcordia SR-332-2006).

Often times, thermal stress may be the cause of a failure. Proper thermal management in the design is paramount. Advanced Energy's Artesyn branded DC-DC converters are designed to be contact-cooled inside an Ingress Protection (IP) sealed enclosure. The RF PA bricks have a baseplate that is optimized for thermal bonding to the host enclosure. The full power rating of the unit is available as long as the baseplate remains less than 100°C (Figure 3).

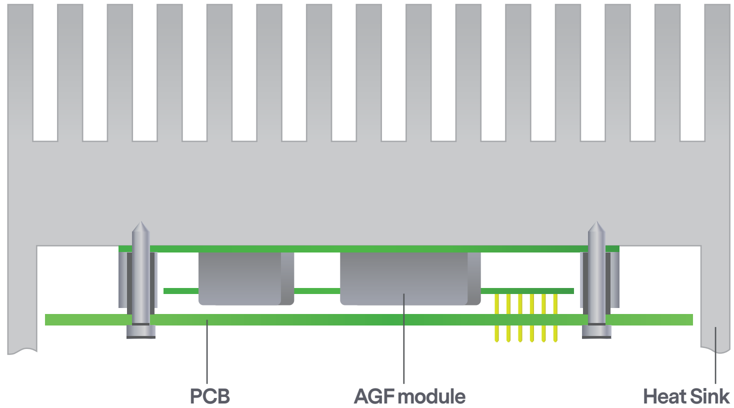


Figure 3: A cross section of the power supply baseplate which is thermally bonded to the heatsink shows an Artesyn AGQ power module as an example to demonstrate good thermal management. All of these components are typically sealed inside of an IP sealed enclosure.

If measuring the temperature at the center of the system enclosure yields approximately 75 to 80°C ambient air, the baseplate temperature would typically be slightly lower (even when taking into account the dissipation from the system, including solar loading), so at least 70°C would be expected at the baseplate.

The rule of thumb for MTBF is that every reduction of 10°C component temperature doubles the MTBF. Therefore, designers should factor in that lower component temperatures coupled with an optimized thermal management design approach will ensure higher MTBF.

Dealing with the Inefficiency of the Power Amplifier (PA)

Inefficiency of the overall system contributes directly to the overall expense. Remote Radio Heads (RRH) are notoriously inefficient. They typically range between 35 to 45% power-in to power-out, with most of that residing in the transmitter amplifier power transistor.

PA efficiency has improved significantly as well, due in large part to more sophisticated linearization techniques and newer design and component technology that enables higher output power capabilities. The problem is that next-generation "massive MIMO" active antenna unit (AAU) radios will need a large number of lower-power amplifiers for each AAU radio. Linearizing each of these small amplifiers is costly and marginally effective since the additional circuitry itself consumes much of the power that it is designed to save. Highly efficient DC-DC converters in the PA power supply contribute to improving the efficiency of the overall system. This is critical for reducing operational expenditures. See the Artesyn ADH700 efficiency curve (Figure 11). In addition, Advanced Energy's Artesyn bricks have a wide range of output voltage adjustment, from 50 to 118%, which improves PA efficiency and reduces the need for cooling. Design engineers can adjust the PA voltage to follow changes in the PA envelope by using the voltage output trim pin on the power supply.

A key design objective is continuous network coverage and operation. Redundancy and de-rating a power supply can often enable a system to be more resilient to failures if they occur; however, in a small cell network, the redundancy also comes from neighboring small cells. At any given time, massive amounts of data may need to be processed at the edge of the 5G network, to support mission-critical low-latency applications connected to the network via small cells. Network interruptions from, for example, failure of the RRU in the small cell is not an option.

Macro Base Station DC-DC Converter Power

Operators may choose to add cells to densify, add radio ports to leverage MIMO, or add radios to overlay new bands. More equipment—antennas, transceivers, power, and transport—will be needed. This also adds to the ongoing challenge of finding space on the cell tower and accommodating the weight of the additional equipment. Designers may choose multiport antennas with as many as 20 ports; and multi-frequency radios are now smaller and lighter.

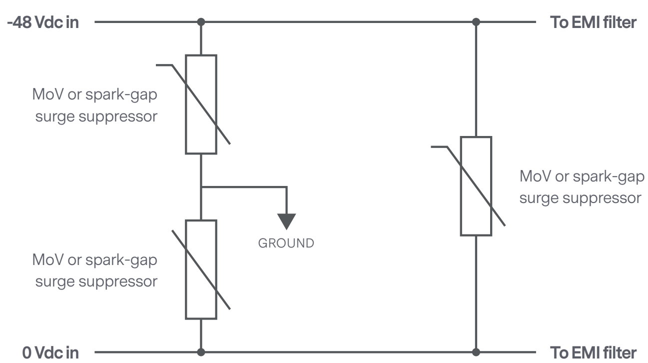


Figure 4: The input circuit for the front-end of the DC-DC converter requires a proper fuse and Metal Oxide Varistor (MOV) for surge suppression as well as a Negative Temperature Coefficient (NTC) inrush limiting power thermistor for protecting RF architectures.

As discussed previously, properly powering the PA also holds for macro base stations. The DC-DC converter efficiency is a critical part of the overall system efficiency and can enhance PA performance. Power designers, using DC-DC converters, need to match the dynamic load response to the system with regard to selecting the proper output capacitors. Designers will select a system voltage from which they can run the overall design at its most efficient point.

In designing an input circuit for the front-end of the DC-DC converter, we must implement a proper fuse and Metal Oxide Varistor (MOV) for surge suppression, as well as a Negative Temperature Coefficient (NTC) inrush limiting power thermistor for powering and protecting RF architectures (see Figure 4). In addition, Figure 5 shows an example of a two-stage filter typically employed for higher power

CIRCUIT CODE	DESCRIPTION
L1, L2	Pulse Engineering P0353 / 590uH
C1, C3, C4, C5, C6, C11, C12	0.01uF / 2000V
C2, C7, C9	100uF / 100V Aluminum
C13, C14	470pF / 100V Ceramic
C8, C10	2.2uF / 100V Film

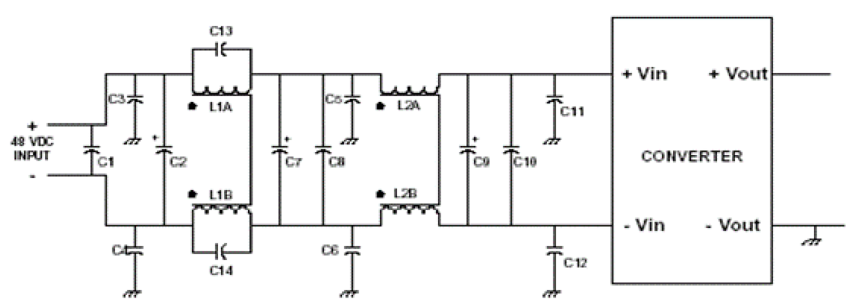


Figure 5: An example of a two-stage filter typically employed for higher power DC-DC conversion applications.

DC-DC conversion applications. The layout in Figure 6 shows an ideal implementation of the previous schematic resulting in best possible EMI suppression and filtering functions.

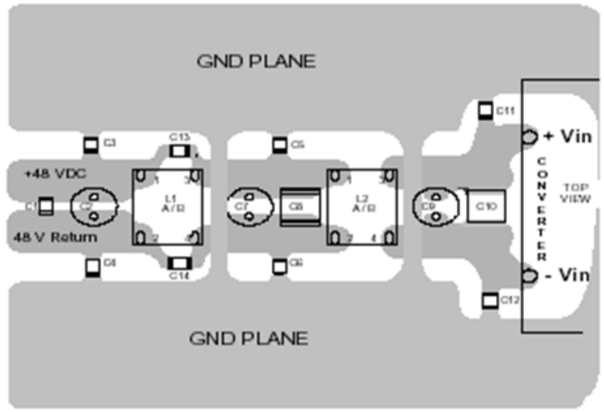


Figure 6: An ideal implementation of the previous schematic resulting in best possible EMI suppression and filtering functions.

Minimizing EMI is accomplished with good layout design. Fast-switching currents in associated circuitry can generate magnetic fields and fast-changing voltages create electric fields that may result in undesired coupling. Electromagnetic coupling can be minimized by the use of solid grounds and shield cases. Proper placement of vias is always a good practice and using multiple vias for bypass capacitors can reduce resistance and inductance. Also, designers should avoid a ground that has an unstable ground-voltage potential. Traces that carry high-frequency signals generate a time-varying electromagnetic wave that can propagate and cause interference. Two traces at a 90-degree angle will result in the least interference between the two signals. A good case ground also helps prevent outside signals from entering the system and also shields the circuit. Designers prefer to keep the ground loop for the RF separate from the ground loop of the more noisy digital components. RF designers are adamant about keeping digital noise away from their analog RF designs and rightfully so.

In the schematic, the reference C9 can be thought of as electrolytic capacitance, which is present to 'hold-up' the operation of the unit if a short-interrupt on the 48 V supply voltage is encountered. For example, if a protection component somewhere in the system is active, it will require milliseconds to isolate the fault, but the DC-DC converter must continue to operate through this fault-condition period. It does this by using energy stored in the capacitor. The DC-DC converter will continue to operate until the capacitor has discharged to the UVLO point of the DC-DC converter. The value of the capacitor required (in microfarads) is derived by knowing the following parameters in the formula below.

- Power required (P) watts
- Hold-up time required (T) ms
- Nominal input voltage (V1) volts
- UVLO voltage of the DC-DC converter (V2) volts

$$Capacitance\ (uF) = \frac{2(P)(T)}{1000((V1)^2 - (V2)^2)}$$

In cases where the power amplifier is 300 to 400 W, the 12 V rail might be 60 to 100 W. An LDMOS power amplifier will only need a 28 V input (for example, an Artesyn ADH700-48S50-6L can be used here).

A GaN PA will need a 50 VDC input (an Artesyn AGF800 series can be used with output voltage trim for setting the output to 50 V).

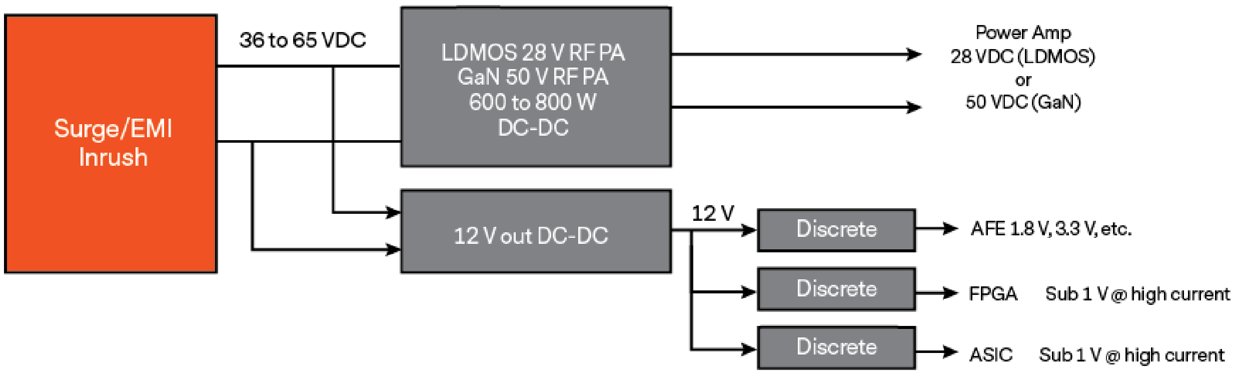


Figure 7: Power management is shown here with efficient DC-DC converters for the PA, communication circuitry (where a 'clean' ground is necessary), and low power digital logic from 12 V distributed power stepped down to lower voltages in the Analog Front Ends (AFEs), Field Programmable Gate Arrays (FPGAs), and Application Specific Integrated Circuits (ASICs).

DC-DC Converter Fold-Back Mode

The fold-back characteristic overload protection allows for some level of voltage output without shutting down, especially in a 'peaky' RF PA, which can affect the power supply. The designer does not want the DC-DC power supply to see a fast peak, because the power supply will see this as a fault and go into a 'shut down' mode and likely initiate a full restart of the system.

Some applications may have large output capacitance in the order of tens of thousands of microfarads, especially with low ESR, to manage the fast spiking load nature of the PA. Starting up a power supply in such a load is usually difficult because these capacitors will initially look like a short circuit upon startup. The fold-back characteristic will generally help in that case as well.

The fold-back current limiting characteristic of Advanced Energy's DC-DC modules is a continuous operation mode of over current protection even if the unit gets overloaded. This keeps the power supply and system from going offline needlessly (Figure 8).

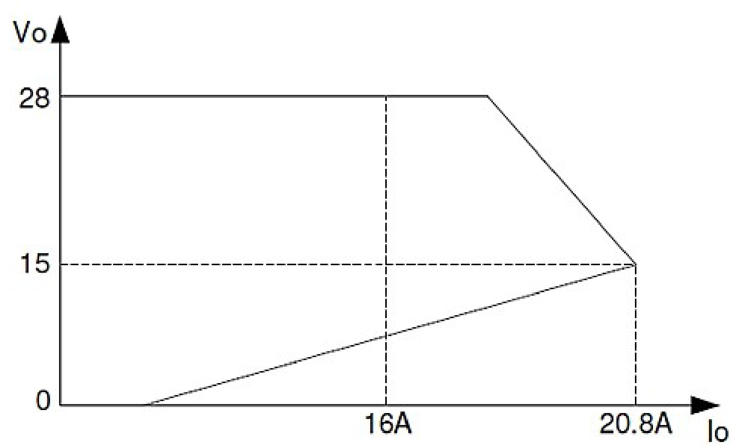


Figure 8: An example of fold-back mode overcurrent protection in a 48 V input / 28 V output power supply such as the Artesyn AVE450B-48S28

Various Inputs to the DC-DC Converter

There are various input power sources to these 5G nodes that designers need to consider:

- AC-mains
- 48 VDC in
- PoE
- 12 V_{in}
- And more

A 5G network may be comprised of: 1) Small cells mounted on streetlamp or traffic light poles, powered from AC; 2) On top of or inside buildings, powered from AC or -48 V PoE; or 3) Adjunct to an existing cell site, using the -48 V power already available. Some newer applications use HVAC or HVDC power. Herein lies the real challenge with so many input voltage variations.

Some wireless operators may want only a certain kind of power supply for one city and for a specific number of systems. This is a challenge for power supply manufacturers and suppliers need a myriad of solutions for various customer needs.

Efficiency is a major challenge when designing a small cell. Cost, power output, thermals, and time-to-market are also important considerations, intensified by what makes small cells so special —their compact size. A one-size-fits-all PSU will not meet the stringent expectations of efficiency, making the PSU choice important. As small cells comprise a larger part of heterogenous networks, so do the components that make up the small base station. Every component needs to shrink in size without affecting efficiency or performance.

Therefore, enclosure height is essential in small cells for 5G with a demand for a slim/compact power footprint. Advanced Energy's Artesyn DC-DC modules have a 12 mm height and are in IP-sealed cases that can handle temperatures higher than 85°C on the baseplates at full load when in the sun.

Figure 9: A small cell can be placed on a building in downtown areas, shopping centers, and college campuses.

A typical femtocell base station (Figure 9) will typically consume between 8 and 9 W when it is activated (mode ON), while it consumes around 3 watts in standby mode (sleep mode).

In a small cell, the power requirements usually come from the analog front end (AFE), field programmable gate array (FPGA), or application specific integrated circuit (ASIC). These usually consume 500 W.

Then, both the comparatively high voltages for the power amplifier voltage and the lower voltages for the digital communication voltages down to 1 or 2 V are needed by the AFE, FPGA, or ASIC as discussed above in Figure 5. The following should be considered for the various parts of the 5G antenna.

The Beamforming Transmitter

5G demands higher frequency radios than the previous 4G architecture. More data capacity can be realized in 5G with the use of microwave and millimeter wave transceivers, higher speed data converters, FPGAs, and low noise/high power PAs in a small cell architecture. The small cells now include more integrated MIMO antennas to ensure reliable wireless connection.

FPGAs

The FPGAs require power supplies at tight tolerance voltages sub-0.9 V with high current for higher speed capabilities. These FPGAs will also need higher voltages for the FPGA I/O interfaces, as well as an added power for Double Data Rate (DDR) memory. Proper sequencing of these rails is also needed.

High Speed Data Converters

The high speed data converters in a 5G RAN architecture require DC-DC power supplies that are low noise and low DC ripple, and have multiple power rails. Sometimes linear, low-dropout (LDO)/low-noise voltage regulators with high Power Supply Rejection Ratio (PSRR) are used after the DC-DC converter outputs to improve power quality to the converters. High speed RF designers are particular about having clean power to their devices. The LDO should also have good line and load transient response parameters.

Transceiver and Power Amplifier (PA)

The new 5G RAN system will see integrated transceivers and low-noise, high-power microwave LDMOS power amplifiers (PAs) with separate 12 V, 24 V, and 48 V power inputs and millimeter wave gallium nitride (GaN) PAs that have very wide bandwidth as well as digital control and management systems. These GaN PAs will require supply voltages of 28 to 50 V. The FPGAs and high-speed data converters will require multiple low-voltages with sequencing, monitoring, and also proper protection with efficiencies greater than 90 percent, high power density, low noise, and control for 5G PAs.

Digital power management capabilities enable integration of more sophisticated sequencing processes in complex high-current multiphase applications with multiple power rails. Designers can choose a design for the most effective sequence for powering up and powering down the various rails in the system.

State-of-the-art DC-DC converters are needed with greater than 95% efficiency, good power density, low noise, as well as solid control capability. Advanced Energy has a series of isolated DC-DC converters for RF applications.

Remote Radio Head (RRH)

The RRHs are deployed closer to the antennas located on cell towers or roof tops. The RRH radio signals are connected via fiber optic cable to a base band unit (BBU) typically located inside a shelter or cabinet at the base of the tower. The RRH is typically powered by a low voltage power line (typically 48 V and 52 VDC) at the top of the tower next to the antenna. Some newer applications use AC or HV AC-DC to lessen the cable size required, and hence reduce the weight of the cables the cell tower must support.

Power ratings of 100 to 800 W are typical. Advanced Energy's Artesyn ADH700 power supply is a 700 W ½ brick DC-DC converter used to power LDMOS RF power amplifiers in a 5G RAN base station as well as GaN 50V RF power amplifiers. This power supply has an efficiency of 95% at full load (Figure 10) and exhibits low output noise, making it perfect for powering an RRH amplifier. The ADH700 also has a fold-back characteristic and the RRH will continue to operate.

This power supply is in a standard half-brick outline and pin configuration. The Artesyn ADH700 converter has an installed height of just 12.7 mm (0.5 in). Small and lightweight are two important features for RRH power management (Figure 11).

The Artesyn ADH700 power supply is designed to meet the following Electromagnetic Compatibility (EMC) immunity specifications (Figure 12).

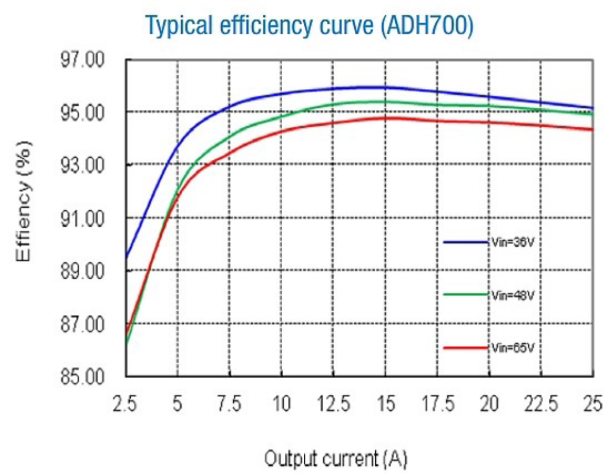


Figure 10: Artesyn ADH700 efficiency curve

Figure 11: Advanced Energy's Artesyn ADH700, 700 W DC-DC converter, powers GaN RF power amplifiers in a 5G RAN base station

Document	Description	Criteria
EN55032 Class B Limits	Conducted and Radiated EMI Limits, DC input port	/
IEC/EN 61000-4-2, Level 3	Electromagnetic Compatibility (EMC) - Testing and measurement techniques: Electrostatic Discharge (ESD) immunity test	B
IEC/EN 61000-4-4, Level 3	Electromagnetic Compatibility (EMC) - Testing and measurement techniques: Electrical Fast Transient (EFT) DC input port	B
IEC/EN 61000-4-5	Electromagnetic Compatibility (EMC) - Testing and measurement techniques: Immunity to Surges (Surges) - 600 V common mode and 600 V differential mode for DC input port	B
IEC/EN 61000-4-6, Level 2	Electromagnetic Compatibility (EMC) - Testing and measurement techniques: Continuous Conducted Interference. DC input port	A
EN61000-4-29	Electromagnetic Compatibility (EMC) - Testing and measurement techniques: Voltage Dips and Short Interruptions and Voltage Variations (Dips). DC input port	B

Criterion A: Normal performance during and after test.

Criterion B: For EFT and Surges, low-voltage protection or reset is not allowed. Temporary output voltage fluctuation ceases after disturbances ceases, and from which the EUT recovers its normal performance automatically.

For Dips and ESD, output voltage fluctuation or reset is allowed during the test, but recovers to its normal performance automatically after disturbance ceases.

Criterion C: Temporary loss of output, the correction of which requires operator intervention.

Criterion D: Loss of output which is not recoverable, owing damage to hardware.

Figure 12: Power supply specifications met by Artesyn's ADH700 power supply in RF power amplifiers inside an RRH enclosure

Towers can be very tall, especially for millimeter wave frequencies, which are very directional, and the lightning surges to these towers can be very high. To prevent RRH damage due to surges on the power feed, surge protection is needed to the RRH enclosure. This power supply is IEC62368 safety standard compliant.

Selecting Power Units

This paper has established the key criteria in selecting power conversion solutions for 5G RAN infrastructure:

- Reliability – the cost of network downtime and truck roll repairs
- Efficiency – operating a wireless network is an expensive business; power consumption can be reduced by improving power efficiency
- Technical characteristics – EMI and noise, surge suppression, inrush limiting, transient response, overload protection
- Size – higher power density means squeezing more power from ever-smaller spaces
- Thermal management – the end equipment is often outdoors in enclosures exposed to the elements, so efficient and effective cooling is critical to performance, reliability and efficiency

These are common factors for critical infrastructure, so it is important to select a vendor with a proven track record in supplying high performance and high quality power solutions across a range of industries.

Build or Buy

The age-old question of developing subsystems or components in-house versus buying standard products from external suppliers applies to the power conversion decision in 5G RAN infrastructure. Design engineers have two choices:

- A standard part with fixed specifications. Standard parts are available in a limited range of specifications, supporting the inputs and outputs which are most commonly specified in circuit designs.
- A full custom design to the user's exact specification for power, number of outputs, form factor, environmental protection, and any other required parameter.

Power supply specification applies a hierarchy to the decision flow. At the top of the hierarchy is the standard part. It is commonly assumed that, if a design can use a standard part, it should do. A standard part, so the traditional thinking goes, provides the optimal combination of cost, size and efficiency for any standard input/output combination. This is because the standard part is optimized for exactly one input/output specification; and because it is produced in high volumes for multiple customers, it benefits from economies of scale. Design teams also benefit from faster time-to-market when using standard solutions.

As you can see from the above examples, standard solutions are already available and are appropriate for the specific deployment scenarios and applications in a 5G RAN. The developers of these standard power modules have worked with some of the leading wireless network equipment companies to ensure the power module specifications and characteristics meet the needs of those end applications.

Advanced Energy Power Supplies

Advanced Energy power supplies are used in RANs and other 'last-mile' solutions. Our industry standard telecom brick DC-DC converters provide output power capabilities from 35 to 600 W with form factors of sixteenth-, eighth-, quarter-, and half-brick. These solutions also offer a wide choice of voltages and form factors for surface-mount or through-hole terminations. The open-frame designs are able to be fitted with an optional baseplate for enhanced thermal performance. Flat efficiencies of greater than 95% are essential for RAN and Advanced Energy Artesyn products meet or exceed this performance.

Advanced Energy's Artesyn ADH700 series has fold-back overload protection that will not switch off completely, so it will not lose subscriber connections in the event of an overload condition or a fast transient. This half-brick, isolated DC-DC series is excellent for RRH applications, as well as macro, micro, and pico base stations and femto cells.

Other Advanced Energy solutions that are appropriate for 5G RAN are eighth- half-, and full-brick isolated DC-DC converters with the capability of low noise, regulated DC supply that RF power amplifiers require. Power outputs range from 100 to 800 W and are capable of covering all power levels needed by pico- up to macro-base stations to power LDMOS power amplifiers.

It is no anomaly that telecom companies are embracing Open Compute Project (OCP) hardware with the impending arrival of 5G wireless technology, which may change the infrastructure landscape for telecom companies, as well as the next-gen services enabled by 5G. Advanced Energy is working closely with OCP-compliant telecommunications companies to develop power supply units, rectifiers and power distribution units for OCP telecommunications deployments.

Appendix

Power bricks

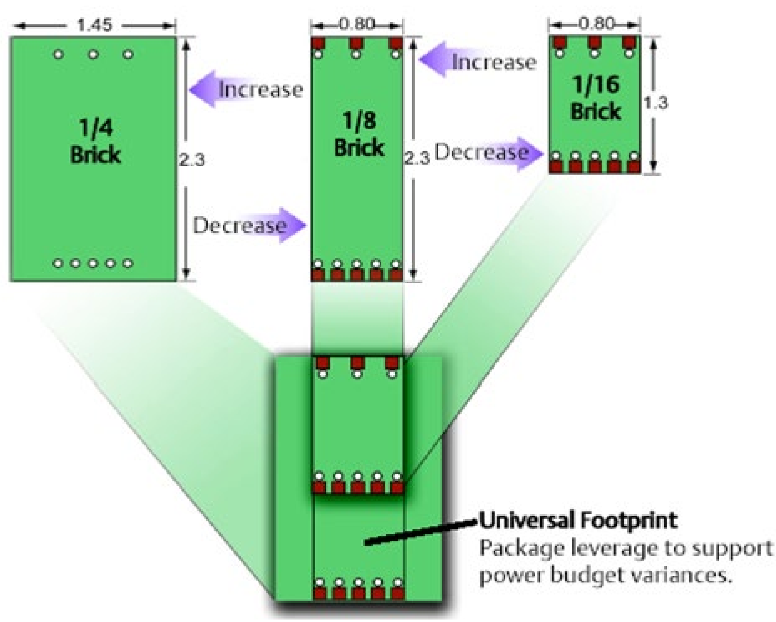
The term power brick is most often used in the context of an AC-DC switching power supply that is similar in size, shape, and weight to a brick, which plugs into the device via a cord, and to the main supply by another cord. However, in board-mounted DC-DC converters, bricks have been defined by the Distributed-power Open Systems Alliance (DOSA).

Standard brick definitions include characteristics such as footprints and pinouts, which means the designer knows in advance how much space to allocate and how to connect the brick to the rest of the circuit. A designer can add a high-power compact brick to their board without requiring in-depth knowledge of power supply design. The creation of a standard specification also allows for alternative sourcing, embedding reliability into the supply chain and driving down cost through innovation, competition and economies of scale.

A DC-DC isolated converter in a fractional brick format is a self-contained, isolated supply module suitable for on-board use. The brick typically comprises all the components (apart from filter circuits) required for a switching power supply including MOSFET switches, energy storage components, and switching controller.

The six standard brick sizes:

1. Full brick – 4.6 x 2.4 x 0.5 in
2. Half brick – 2.3 x 2.4 x 0.35 in
3. Quarter brick – 2.3 x 1.45 x 0.35 in
4. 8th brick – 1/8
5. 16th brick – 1/16
6. 32nd brick – 1/32



ABOUT ADVANCED ENERGY

Advanced Energy (AE) has devoted more than three decades to perfecting power for its global customers. We design and manufacture highly engineered, precision power conversion, measurement and control solutions for mission-critical applications and processes.

Our products enable customer innovation in complex applications for a wide range of industries including semiconductor equipment, industrial, manufacturing, telecommunications, data center computing, and medical. With deep applications know-how and responsive service and support across the globe, we build collaborative partnerships to meet rapid technological developments, propel growth for our customers, and innovate the future of power.

PRECISION | POWER | PERFORMANCE

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