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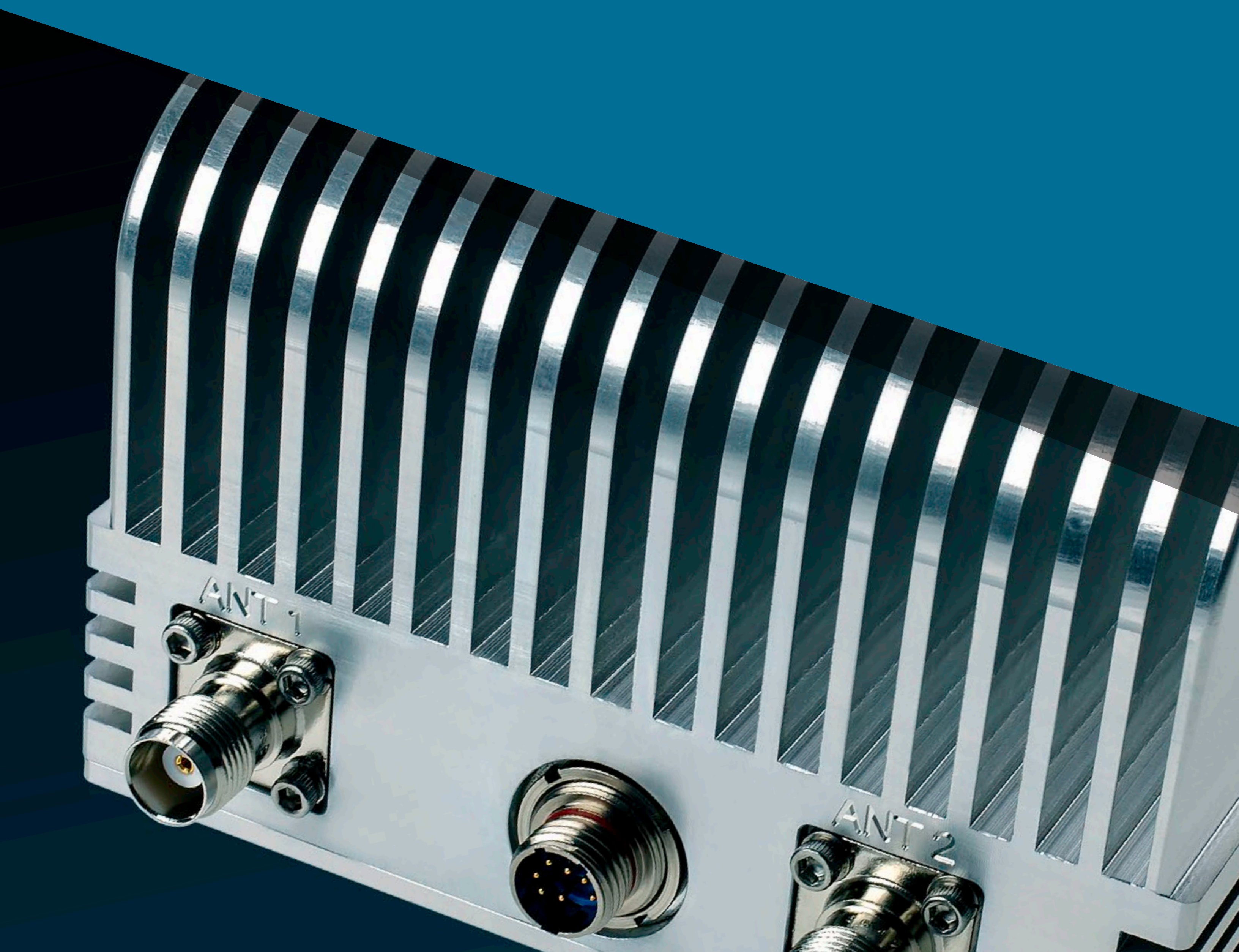
TECH BRIEF

Key Considerations for a Successful Custom RF Amplifier Design



INTRODUCTION

An RF amplifier is a type of electronic amplifier that converts a low-power radio-frequency signal into a higher power signal. It does not change the signal or the data therein, but amplifies it for transmission in ultra-critical long-range applications.

A customized RF amplifier is often required to suit a specific set of long distance radio system criteria. The ability to think beyond standard commercial off-the shelf (COTs) solutions allows a radio system designer to account for any number of specified requirements for the individual application. Frequent criteria for RF amplifiers include:

- **Gain:** A measure of the ability of an amplifier to increase the power or amplitude of a signal from the input to the output port by adding energy converted from a power supply
- **Bandwidth:** the operational range of frequencies within a given band
- **Power Efficiency:** the ratio of the output power divided by the input power
- **VSWR:** A measure of efficiency regarding how power is transmitted into a given load
- **Thermal Management/Heat Dissipation:** The process by which the heat generated by a function is cooled or redirected
- **Number of Channels:** With the recent pervasiveness of MIMO radios it's important that a single amplifier can be used to amplify multiple chains of RF

Figure 1

Custom MIMO RF Amplifier for UxV Systems

KEY CRITERIA

Custom RF amplifiers can be constructed to fit any number of these or other criteria, but before the design process begins, it's important to have some key information at hand. You'll need to know the application and environment of the RF amplifier in question, the band(s) within which it will be operating, its power requirements (input DC Power and output RF power), any size, weight or power (SWaP) constraints, and any other special feature or functionality which need to be accounted for.

Other examples of custom RF amplifier criteria include:

- Bi-directional operation (Tx and Rx)
- Multi-channel MIMO amplification
- Software or Hardware custom controls
- Fast Tx/Rx Switching
- Wide DC Power Operation
- MIL-STD compliance
- Specific GaN, GaAs & LDMOS Transistors technology requirements
- Amplifier Bypass Functionality
- Over/Under/Reverse Voltage Protection
- Automatic Level or Gain Control (ALC/AGC)
- Forward and reflected power monitoring
- Linearization
- Thermal management integration
- RF Distribution

APPLICATIONS

Figure 2

Custom CubeSat Amplifier

Common applications that receive the best return on investment (ROI) from a custom vs. standard amplifier include, but are not limited to:

- **UxVs** conducting ISR missions, or serving as comms relays at great distances
- **Naval vessels** traveling far distances and dealing with varying environmental conditions
- **Soldiers** on the battlefield using booster amplifiers to extend their operating range
- **Dispersed vehicles** (military or police) using radio networks to stay in touch
- **Counter UAS systems** using amplified RF to react to threats from drones
- **CubeSat platforms** needing a boost to close their RF link from Low Earth Orbit (LEO) to the ground

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INFORMATION GATHERING

There are a number of crucial pieces of information that need to be considered before detailing the requirements of your custom engineered RF power amplifier, and it's understandable that as a total system designer, you may be overwhelmed as you try and compile these criteria. As always, the more information you have on hand, the more thorough your amplifier supplier can be for you at this stage.

First, detail the specific function(s) of the device, as well as the system conditions in which it is to be used. Second, identify factors such as the intended frequency band and any size, weight, or power (SWaP) constraints which might affect functionality and design. And lastly, any special features should be identified.

- Application
    - High Data Rate Video Downlink
    - MANET/MESH Radio Network
    - Electronic Warfare (EW)
    - LEO Satellite Communications Link
- Amplifier Type
    - CW, Pulsed, Linear
    - Transmit Power Amplifier, Bi-directional Amplifier
- Band
    - HF through K Band, or higher
- Size, Weight, and Power (SWaP) Constraints
- Any special features

Figure 3

Custom Wideband EW Amplifier

TYPICAL DESIGN PROCESS

Once your amplifier partner is equipped with the information above, they can start designing your custom RF amplifier. This design process, or flow, is typically broken up into 3 main stages, each of which is comprised of smaller multi-step stages.

Figure 4

Computer Simulation and Modeling Software

1. Research and Planning

- Suitable parts search
- Architecture selection
    - Single Device, Hybrid Combined, Doherty, etc.
- Simulation
- Pallet Testing
- Cascade Design and Analysis
- Prototyping

Given the customer requirements for frequency, gain, and power, or more application specific requirements such as radio type, range and data rate, the amplifier designer can determine the devices available on the market to base a design off of.

Once available devices have been identified, the designer will begin to establish the architecture required to meet the given requirements. This can range from a single device meeting the requirements, to a more complex hybrid or Doherty combined design being utilized if multiple final stage devices are required to meet the requirements.

Once the architecture is established, computer modeling can be utilized to perform a software simulation of the amplifiers potential performance. This requires entering in the design characteristics of the chosen devices in a simulation and modeling software package. The output of this exercise is the physical layout required to maximize the transfer of energy of the input and output matching networks of the amplifier, as well as estimates of performance.

In conjunction with the computer modeling, pallet testing of the actual devices is performed to verify the published specifications of the devices. Pallet testing occurs on a simple circuit board either provided by the device manufacturer or designed by the engineer themselves. The pallet board presents the designer an opportunity to characterize their chosen devices in real-world conditions. This is an important step in the amplifier design as any variance in published vs. real-world performance of the devices can greatly impact the final design. Ideally, a customer supplied waveform will be used to test the devices as this stage.

Now that the final stage, high power amplification has been designed and analyzed, a cascade analysis can be performed. A cascade analysis is required to determine if the customer's input signal needs to be attenuated or more likely if pre-amplification is required, prior to the final stage amplification stage. For instance, if the final stage device cannot provide the required gain to amplify the low level input signal, multiple driver amplification stages may be added to the design prior to the final stage. This step weighs heavy in determining both the required DC power from the multiple amplification stages, as well as identifying the key heat generation points within the amplifier.

Figure 5

Mechanical Enclosure Design

2. Design, Simulation, and Manufacturing

- Schematic Layout
- PCB layout
- Manufacturing

Once the main RF components of the amplifier have been established, a designer will then set upon the DC power and control design. This task can range from very simple in the case of a basic power amplifier, to a very complicated design task taking into account custom requirements levied by the end user. This is all performed in a schematic entry tool, and the output is the final design schematic.

The final schematic is then transferred into a printed circuit board (PCB) design layout. This represents the physical layout of components on the final circuit board. This stage requires great care, as simple traces on a circuit card can become antennas both radiating and receiving potentially harmful interference which can interrupt, overwhelm, or create oscillations in other parts of the circuit. Impedance matching is also designed at this stage, using the output of the prior computer modeling to ensure that the circuit layout is designed in such a way that as little energy as possible is lost through the various amplification stages. PCB layout provides you with the physical dimensions of the final product, as well as connector locations.

The designer is now ready to work with a mechanical engineer to design an enclosure for the end product. A metal enclosure is typically required to provide isolation between various sections of the circuitry, in the case of a bi-directional amplifier for instance, the enclosure must be designed to provide isolation between the transmit and receive sections. Just as importantly, the enclosure design must provide a heat management solution for the amplifier. This can range from simply identifying the "hot spots" of the enclosure for an integrator to manage, all the way to a fully integrated heat sink and fanned design. Thermal analysis is performed on the design to ensure that the amplifier can stand up to the intended use.

Once this work has been performed, a designer will have a contract manufacturer produce a prototype amplifier design for lab testing and evaluation. This step ensures the performance of the final product prior to a larger quantity build of products. Mechanical fitment, DC power and control, and RF performance are all checked and double checked prior to approving a design.

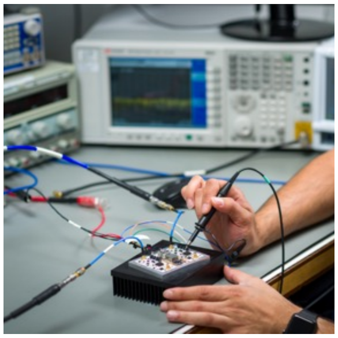


Figure 6

Testing and Tuning of a Custom RF Amplifier

3. Test, Tune, Repeat...

Once a final design is received in-house, the design engineer has one more job prior to handing it over to production. This is to test the unit, characterize its performance, and modify or tune the design as required to optimize its performance.

Prior to making any changes, the design engineer will test the unit to establish its baseline performance. Once this is done, there may be any number of changes made to the design to improve upon this baseline. Component parts modification may be made to increase or lower component values. Firmware may be updated to change sequencing, timing or biasing of certain components. Lastly, manual tuning of the RF circuitry may be performed by painting on a conductive silver compound to change the RF properties of the amplifier.

Once these changes have been made and optimal performance achieved, the design engineer will capture all of these changes, as well as document any manual tuning that may be required on follow-on production units.

RF DESIGN CHALLENGES

As you might expect, custom RF amplifier design is subject to an array of challenges at each step of the design process. Customer requirements, technology limitations, and the never ending challenge of balancing performance, efficiency, and size and weight are just the start.

Even when provided with clear customer requirements, the job of a RF design engineer is still full of market surveys, trade studies, and design decisions. No two RF engineers will design a custom RF amplifier the same way. There are a lot of design challenges that play into the design of a final product.

Technology limitations: A RF design engineer can choose from various FET technologies to base the design around. Newer Galium Nitride(GaN) technology provide more efficient designs in smaller packages, however, they can also be more finicky to design around. Older technologies such as LDMOS and Gallium Arsenide (GaAs) provide more predictable performance, but at the cost of size and efficiency.

Figure 7

Miniaturized S-Band Amplifier

Size, Weight, and Power (SWaP): The final size of an amplifier will likely play into the design of the final product in a major way. The size requirements usually dictate the size of the canvas, or circuit card, the RF engineer has to work with. When constrained, this can have a large impact on how the design is laid out. A RF amplifier line-up typically requires a set amount of space for impedance matching, therefore, the other circuitry required for power and control can be impacted.

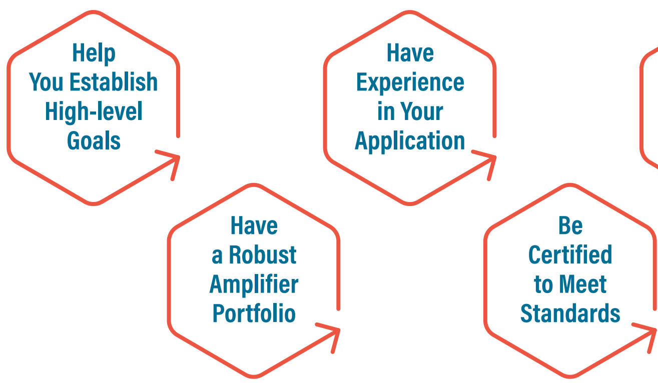
Environmental Requirements: The ultimate environment that the amplifier will operate in will also come into play as the engineer moves forward with a design. Some amplifiers will operate in fairly benign environments, such as in a test lab, or in a racked environment where power and cooling are not typically constrained, nor are the environmental surroundings impacting the operation of the amplifier. On the other hand, some amplifiers are required to operate on small platforms in the vacuum of space, not allowing for a high power budget, or traditional cooling methods to keep the design cool. These environments can greatly impact the design of the amplifier and always pose a major challenge.

Customer Requirements: Customer requirements are the driving force behind custom RF amplifier design, and can create design challenges from the outset. Conflicting or unclear requirements can stop a design before it's even started. It's important to have engineering involved in the design as early as possible, including during the requirements derivation stage. This can allow the tradeoffs of design decisions to be communicated clearly and early to the customer, so they can understand the impact of certain constraints being placed on the design.

CHOOSING A SUPPLIER

When looking for a partner to craft a custom RF amplifier, there are a few important factors to take into consideration.

A Good Custom RF Amplifier Supplier will:



Firstly, you should look for a partner that will work with you from the outset to establish your high level goals for the amplifier. They should be asking questions like:

- "What will you be using the amplifier for?"
- "What are your high level goals for the amplifier?"
- "Is the amplifier part of a larger system, if so, can we understand more about it?"
- "What environment will the amplifier be operating in?"
- "What are your criteria for success?"

Someone simply asking for a list of requirements to quote against is unlikely to understand the bigger picture of how the amplifier will ultimately be used and what will cause the design to ultimately add value to a larger system.

A partner should also be able to demonstrate a breadth of experience in the field of interest. For instance, has the supplier performed RF amplifier design for the space environment before? Have they supplied amplifiers specifically for use within UxV, unmanned systems?

A good partner should be able to communicate to you their experiences in designing for your specific environment, including the challenges that come with it. They should be able to provide examples of frequently meeting the following custom RF amplifier design challenges:

- Balancing power output, DC power input and efficiency
- Size and Weight challenges
- Meeting various characteristic requirements like
    - Spurious
    - Harmonics
    - ACPR
    - Spectral Mask
- Major component lead times and mitigation strategies
- Managing challenges between simulation and real life performance of parts, especially the higher in frequency that's required

Figure 8

RF Amplifier Tested for Harsh Conditions

In addition, your supplier should be able to display that their connectorized RF and microwave power amplifiers are built to promote easy integration and reliable operation in even the harshest system conditions. These include the best protection against over, under, and reverse voltage conditions. Additionally, modules should be available with internal wide input range DC-DC conversion sections, if required.

Their high-power amplifier portfolio should also include advanced built-in PA monitoring and control sections that are directed by microprocessor, FPGA, CPLD, or a combination of these devices. Functions should include forward and reflected RF power measurement, temperature logging, DC monitoring to the device level, transmit/receive switching, and gain / power control across frequency, temperature, and adverse VSWR conditions. Many other configurable alarms and warnings can be tailored to your system's requirements.

If your system is headed for harsh environments your supplier should also be able to demonstrate their amplifiers have been proven to withstand the most demanding shock, vibration, and temperature cycle profiles contained in MIL-STD-810 requirements. Experience in meeting EMI and EMC considerations of MIL-STD-461 are also key. It takes years of expertise to push the boundaries of linearizing RF Solid State Power Amplifiers (SSPAs) while maintaining a price structure that allows RF amplifier solutions to meet cost targets. So, due diligence is crucial. Certifications such as AS-9100 go a long way to giving you confidence that the supplier you've chosen can perform the quality work you require.

CONCLUSION

As you can see, custom amplifier design can be a challenging process. It's important to understand the process of custom amplifier design prior to engaging with potential design partners. We've seen that the information gathering stage is key to a successful outcome. It's important to go beyond a specification and allow your partner to understand the application, and larger system architecture the amplifier will be operating in. Additionally, by highlighting the design process and common challenges provides better insight into some of the potential pitfalls along the way. Hopefully this paper has increased your knowledge base regarding what information is required, the design process, the common challenges, and how to best choose a partner to design your custom amplifier.

NEXT STEPS

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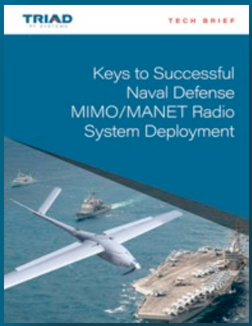

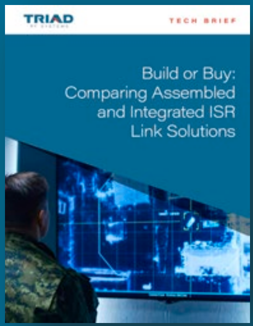

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About Triad RF

Triad RF is an AS-9100 certified aerospace manufacturer and offers full MIL-STD solutions. Our solutions are designed with the larger system operation in mind. This includes options for remote control and monitoring by maritime Communication Control and Monitoring Systems (CCMS.) We offer solutions in various physical sizes and configurations, including solutions intended to be exposed to the harshest of elements. We also offer varying power solutions to accommodate for our users SWaP limitations. This includes systems that can transmit up to 200 Watts for large ships all the way down to 10 Watts for UxVs

About the Author

Patrick Sherlock has bachelor's degrees in Electrical and Computer Engineering and a Master's degree in Engineering Management. Pat has spent over 20 years working on designing, integrating, and implementing naval communication systems within the United States and internationally, including Canada, Australia, New Zealand, Turkey, South Africa, South Korea, as well as many others. Pat has received numerous awards for his work including a Deepwater Award for Excellence from the United States Coast Guard for his "exemplary performance of duty while assigned to the Integrated Deepwater System (IDS) Program." Pat has most recently joined Triad RF Systems, Inc. as their Vice President of Business Development, focusing on MIMO/MANET radios and amplified radio systems.