Spatium® Amplifier Modules (QPB series)

Introduction

This document provides application assistance for the Qorvo Spatium® power amplifier modules to assist users in integrating the modules in to their designs. Included is a functional description, application schematic, grounding recommendations (prime power current return), thermal management recommendations, bias application, fault indication and troubleshooting.

This application note is *not* model specific, but makes general recommendations applicable to most Spatium amplifier modules.

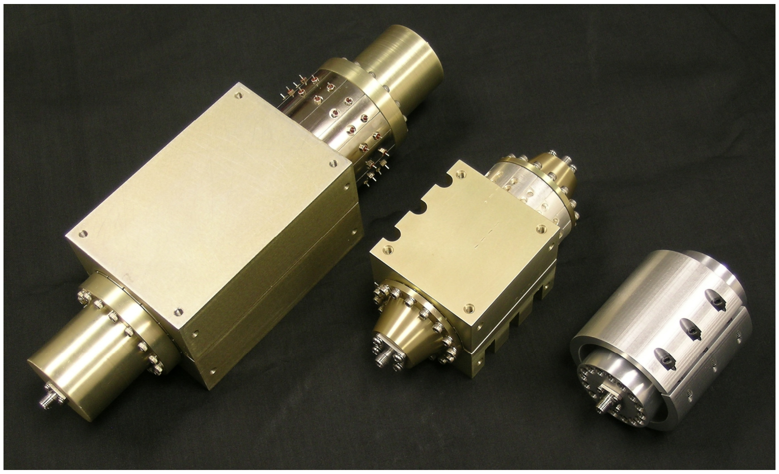

Figure 1 Various Spatium Solid-State Power Amplifiers

Description, Operation, and Control

Spatium® is Qorvo's trademark for its high power, spatially combined amplifier technology.

Basic Theory of Operation

The Spatium amplifier enables high power amplification to be achieved through the nearly lossless combination of multiple MMIC power amplifiers. A simplified schematic of the Spatium power amplifier is shown in Figure 2. A tapered coaxial transmission line transitions from the user interface (RF Input) to an oversized coaxial waveguide. Contained within the waveguide are multiple broadband end–fire radiation elements, each accepting an equal portion of the signal from the coaxial waveguide. The radiation elements rotate and transform the split signals onto separate microstrip transmission lines which, in turn, feed MMIC power amplifiers. The amplified output from the MMIC power amplifiers launches onto output microstrip lines which feed the output radiation elements. The signals launch from the radiation elements into and combine within an output coaxial waveguide, and the combined signal travels along an output tapered coaxial transmission line to the amplifier output, at which point the high power amplified signal is available to the user.

A positive drain supply voltage and a negative gate supply voltage are supplied to each MMIC, provided via a flexible circuit card assembly from a separate Bias Card assembly. The Bias Card assembly generates the negative gate supply voltage from a user applied positive voltage input. The card properly sequences the drain and gate voltages applied to the MMICs to prevent damage.

The return current path from the Spatium amplifier back to the prime power supply is via properly sized wire leads that are connected to the Spatium amplifier "cylinder". *Note that the mechanical thermal clamp that supports and confines the Spatium amplifier IS NOT an appropriate current return path*, due to the thermally efficient compliant material that resides between the Spatium amplifier cylinder and the thermal clamp.

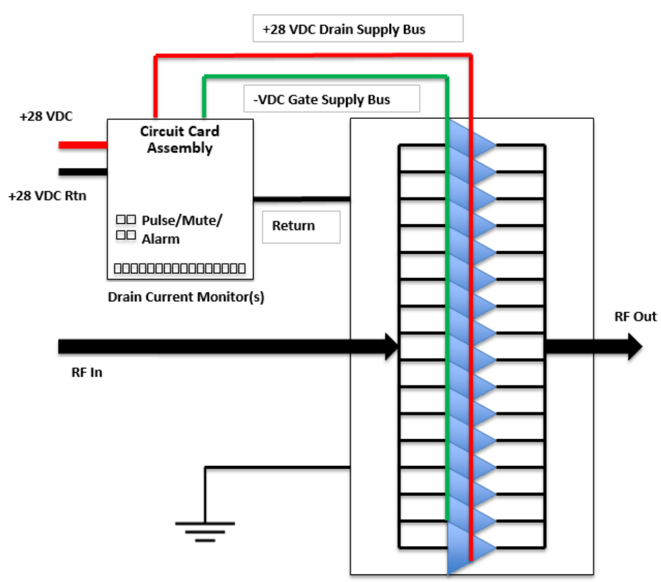

Figure 2 Functional Block Diagram of Spatium Amplifier and Bias Card Assembly

Overview

As with most high power microwave assemblies, several of the important usage considerations are interrelated. Mechanical attachment, high supply current management, and thermal management must be considered in aggregate. The high impedance, low current gate bias signals may be impacted by the overall high current levels, and their variation with time, temperature and RF power level. Asymmetric thermal management may result in less than optimal power combining. Use in a dynamic bias environment (pulsed or otherwise) will likely require special consideration.

This application note assumes that the user has a working knowledge of high power amplifier measurement techniques and equipment. Although the DC voltages involved are generally low and insufficient to cause injury, high levels of DC current, DC power, RF power, and heat may be present; suitable caution needs to be employed in these areas.

Mechanical Mounting

The Bias Card assembly and the Spatium amplifier are mounted separately, but are interconnected with a flexible multi-conductor interconnect (flexline) and several current return wires (ground). The Bias Card assembly and Spatium amplifier should be located such that the flexline can be easily mated to the header connectors on the Bias Card assembly. The orientation of the Bias Card assembly is independent of the Spatium amplifier and may be mounted on any convenient surface, as long as the appropriate interconnections can be achieved.

The flexline should not be subjected to sharp bends which would result in permanent deformation of the flexible circuit.

The Spatium amplifier may be mounted using any of the mounting point locations in any desired orientation, so long as the other criteria are met.

Refer to the specific product data sheet for product specific fastener sizes and recommended mounting patterns.

Supply Voltage and Grounding (Return Current Path)

MMIC drain voltage and gate voltage are provided to the Spatium amplifier from the Bias Card assembly to the Spatium amplifier via the flexline assembly. (Further detail is provided in the Power Supply and Bias Control Section). The return current path must be provided by the appropriate supplied “ground” wires attached to the face of the Spatium amplifier cylinder. The opposite end of the “ground” wires must be connected in one of two ways. They may be connected to the Bias Card assembly “ground” typically using a mechanical fastener to secure the ring lugs to one of the Bias Card mounting locations. Alternatively, the “ground” wires may be attached to the DC Voltage supply common or return (preferred). The DC supply common should also be connected to the system chassis ground (earth).

Although the thermal clamp surrounding the Spatium amplifier cylinder is nominally electrically common with the Spatium amplifier cylinder, there is a layer of thermally conductive, compliant pyrolytic carbon between the cylinder and the thermal clamp. This layer is significantly more resistive than the surrounding metal conductors. If the thermal clamp is relied upon for the sole path of current return, it can result in the Spatium amplifier cylinder reference potential being elevated at an unknown level relative to chassis ground and, perhaps more importantly, relative to the set gate voltage potential. Furthermore, this elevated potential will vary depending upon the overall current level at which the Spatium amplifier is operating, meaning that it may change with temperature, RF drive level, load impedance, etc. This will likely result in otherwise unexplained dynamic and erratic changes in amplifier performance.

In some cases, particularly when the Spatium amplifier is drawing multiple tens of amps of current, multiple separate conductors are warranted for management of the return current. In these cases, the conductors should be attached to the Spatium amplifier at roughly equal distances to maintain (approximately) the same relative potential at each blade of the Spatium amplifier (Figure 3). The current return conductors should be appropriately sized to handle the same amount of current as the supply wires with minimal voltage drop across from the Spatium amplifier to the common return point.

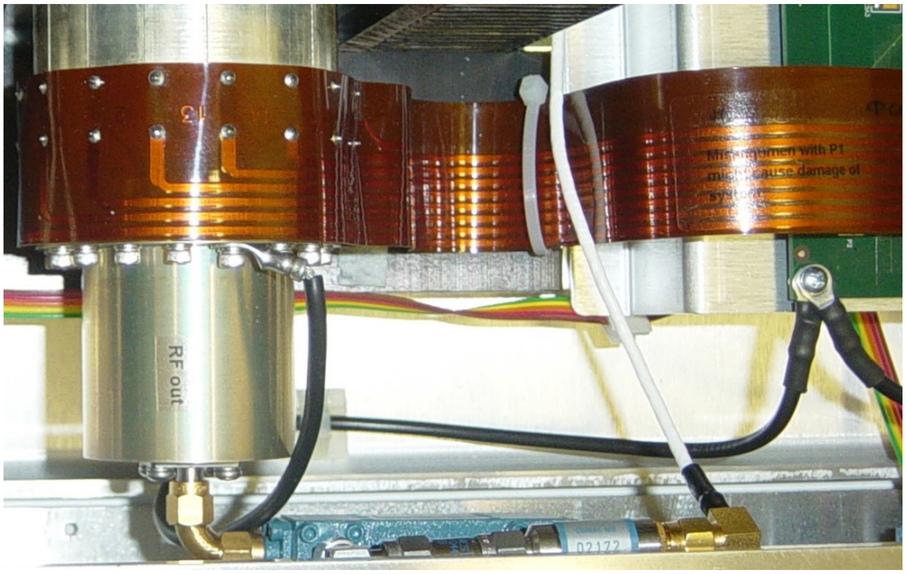

Figure 3 Typical installation showing return current path attached to Bias Card Assembly

Thermal Management

The Spatium amplifier will, under most bias and operating conditions, generate substantial amounts of heat that must be suitably removed to achieve maximum lifetime and reliability. The Bias Card assembly generally dissipates only about 10 Watts and is of significantly lesser concern in thermal management situations, unless its temperature is significantly impacted by the Spatium amplifier itself.

Removal of heat from the amplifier can be achieved using any of several conventional means including: forced air convection; conduction to a chill plate; liquid cooling; heat pipes; other phase change material. More exotic methods, including conduction through thermal pyrolytic graphite, and evaporative spray cooling have been performed. For extreme dissipation, immersion in a fluid such as Fluorinert has been examined.

Although not required, optimum combining efficiency is achieved when heat is removed equally from each of the rectangular clamp surface areas. This can be achieved relatively simply in forced air convection systems by attaching finned heatsinks to all four surfaces.

Detailed thermal modeling can validate a thermal management plan and highlight areas for improvement (Figures 4 – 6). Basic solid models can help estimate the overall thermal performance and identify potential hot spots that may exist. Airflow, back pressure, and fin surface area all affect overall performance in a convection environment. Thermal simulation and modeling, verified with a thermal survey of the proposed implementation, enables successful generation of a robust thermal solution.

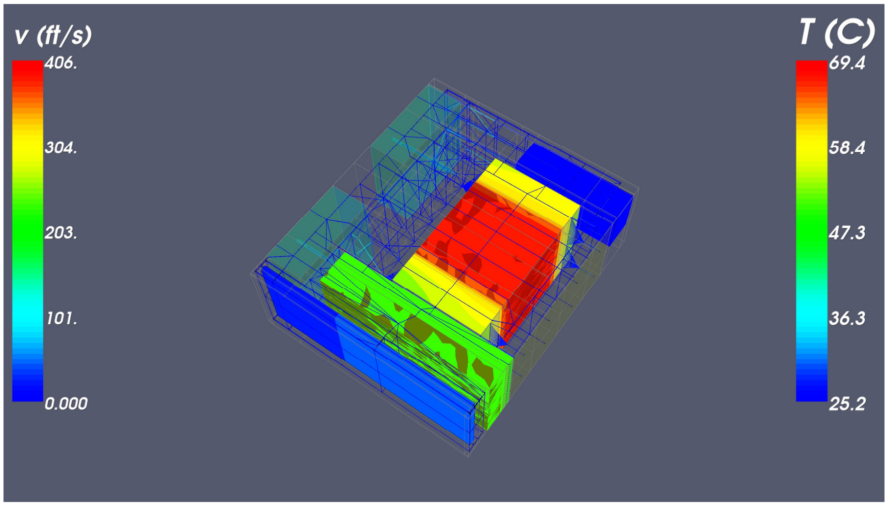

Figure 4 Fluid analysis methods can be used to effectively predict and optimize airflow and cooling (results from Qfin simulation software)

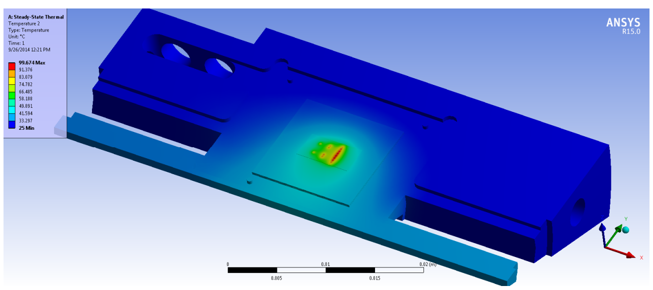

Figure 5 Solid Modeling can support aggregate thermal Performance

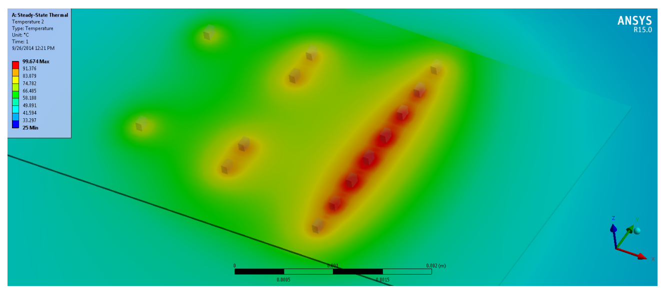

Figure 6 Solid Modeling can illustrate thermal perfromance at the device geometry level

Thermal Interface Material

In most cases, some type of thermal interface material must be used between the Spatium amplifier surface and the heat removal surface. The material can be a thermal grease (messy, but effective), or a compliant material such as a thermal pad or graphite sheet. The thermal impedance of the interface material must also be accounted for in the calculation of the overall thermal performance of the system.

Thermal Self Protect

The Spatium amplifier is strictly an amplifier. In most cases, it does not include temperature compensation of any type, nor does it include any over or under temperature protection. The amplifiers do include permanent change temperature indicators (inaccessible to the user) which indicate the maximum temperature to which the amplifier has been operated or exposed. The user is responsible for maintaining (and monitoring, if so desired) the temperature of the amplifier to assure reliable operation with specified performance.

Thermal Management Examples

Figures 7 -11 illustrate some of the thermal management solutions that have been implemented. Each solution is unique and dependent upon the power dissipation, cooling method, and space available, as well as operational and lifetime requirements.

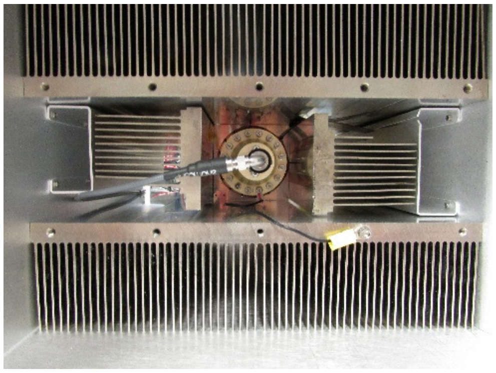

Figure 7 Finned heatsinks in a forced air system dissipates 1500 Watts

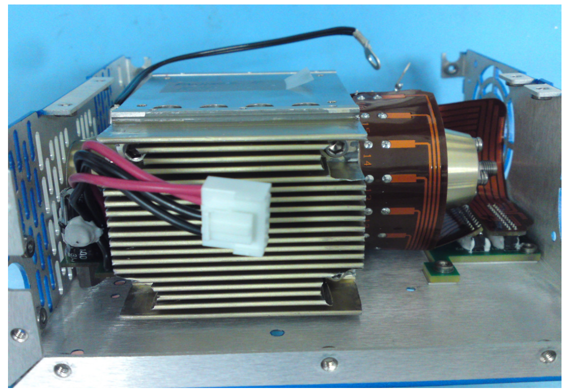

Figure 8 A compact assembly using bonded folded fins

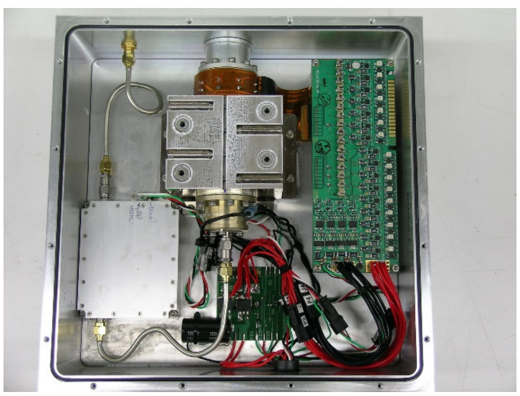

Figure 9 Configured with Driver in an O-Ring Sealed Housing with Passive Convection for Outdoor Use

Figure 10 Exterior View of Passive Convection O-Ring Sealed Housing

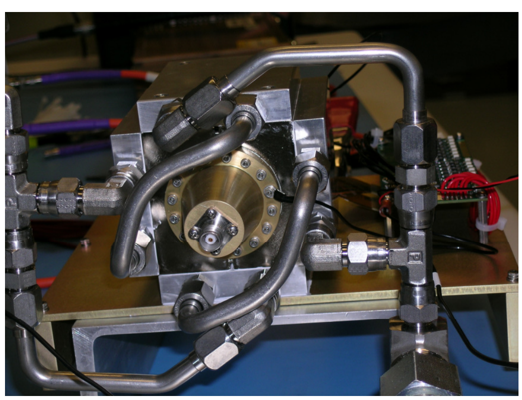

Figure 11 Liquid Cooled with bolt on Cold Plates

Power Supply, Bias Control, Command, Control and Monitoring

The Bias Card assembly (Figures 12 – 13) performs several functions, including:

- Negative gate voltage generation from the supplied positive voltage
- Regulation of negative gate voltage
- Enables factory adjustment of negative gate voltage for appropriate MMIC bias current
- Sequences application of the negative gate bias prior to and after removal of the drain voltage to the MMIC
- Monitors drain current and compares with preset thresholds
    - Provides a voltage proportional to each individual drain current (available to customer)
    - Provides visual indication if MMIC(s) current is outside the preset window
    - Provides a summary fault indication (TTL) if one or more MMIC(s) current is outside the preset window
- *THE BIAS CARD DOES NOT INCORPORATE A CURRENT RETURN PATH FOR THE SPATIUM AMPLIFIER*

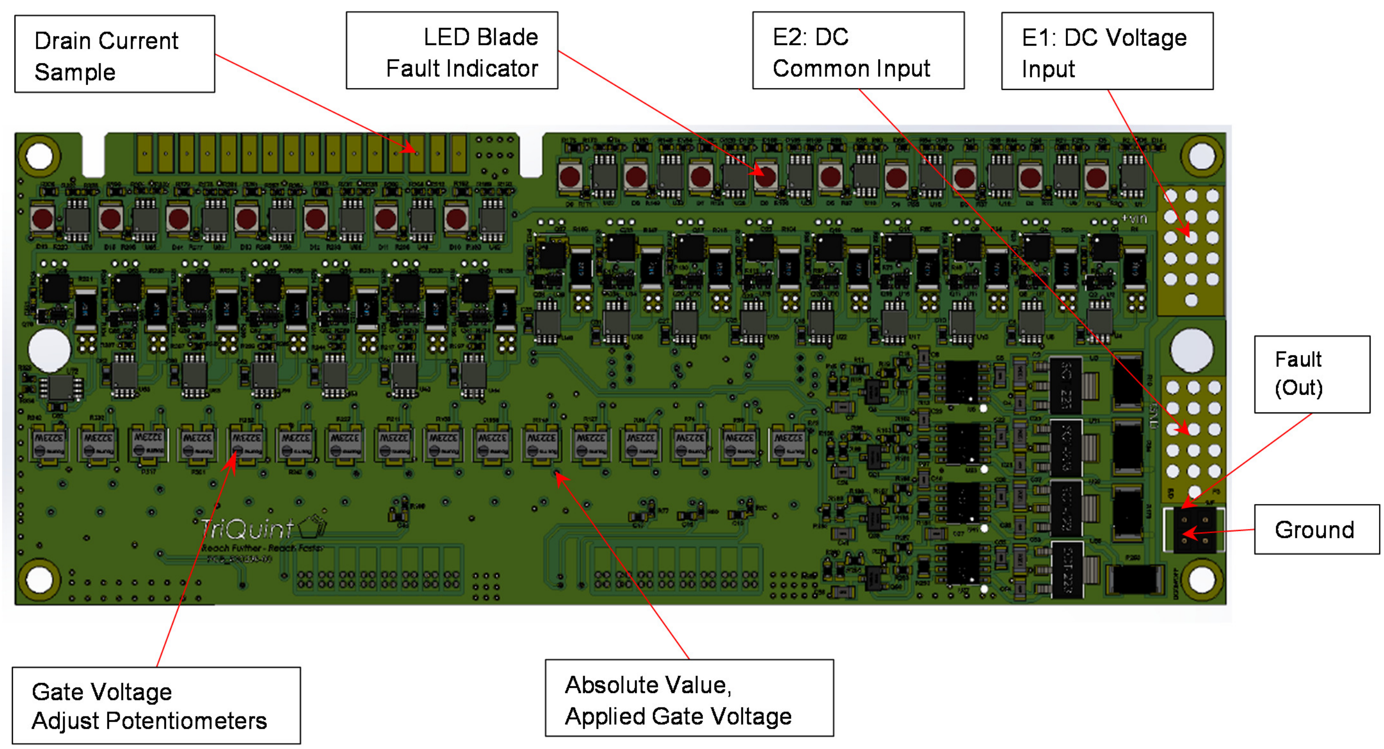

Figure 12 Bias Card Assembly Top View

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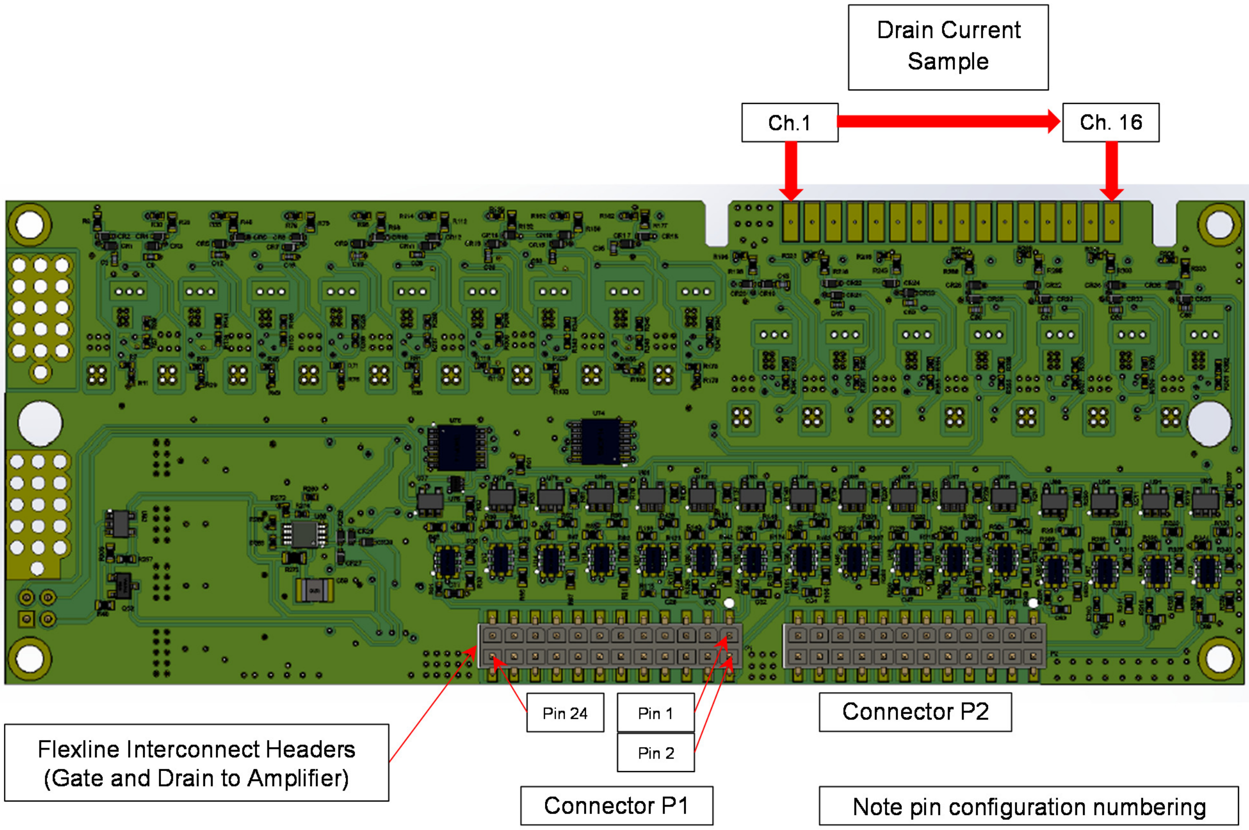


Figure 13 Bias Card Assembly Bottom View

Bias Card Interface Definition

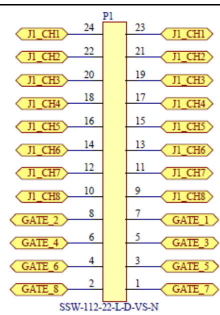
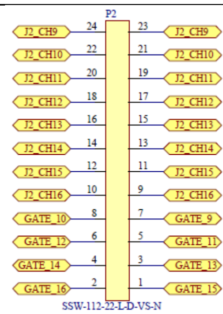
Description	Connector Designator		Bias Card Assembly	Customer Connector	Comments
Drain Current Monitor			16 Pin Edge Connector		Contact Factory for scale factor.
Flexline Interconnect	P1		Samtek SSW-112-22-L-D-VS-N	Samtek HTSS-112-01-L-D	0.25" Minimum bend radius on Flex-line. Flex-line mating connector usually supplied with amplifier.
Flexline Interconnect	P2		Samtek SSW-112-22-L-D-VS-N	Samtek HTSS-112-01-L-D	0.25" Minimum bend radius on Flexline. Flexline mating connector usually supplied with amplifier.
Prime Input Voltage +DC	E1		Flying Lead with Ring Lug Qty 4 #8 Barrel P/N P8-8RN-Q terminated 16 Ga Red Wire. Wire length is 9.5".	#8 Stud or Screw Threaded fastener	
Prime Input Voltage Common	E2		Flying Lead with Ring Lug Qty 4 #8 Barrel P/N P8-8RN-Q terminated 16 Ga Black Wire. Wire length is 9.5".	#8 Stud or Screw Threaded fastener	Recommended to be connected to same point as Spatium amplifier current return connections.

Table 1

Signal Definitions	I/O	Connector-Pin	Signal Value	Comments
Gate Voltage	O	P1-1 through P1-8 P2-1 through P2-8	Analog, varies between approximately -3 to -5 volts at pinch off to -1.5 to -3 volts at quiescent bias	Gate quiescent voltage is set by potentiometers. Absolute value of applied gate voltage may be measured at center tap of potentiometer R43 (Gate 1), R59, R74, R84, R127, R143, R158, R168, R211, R227, R242, R252, R301, R317, R332, R342 (Gate 16)
Drain Supply	O	P1-9 through P1-24 P2-9 through P2-24	Drain voltage. 0 or V_{DD}, depending on whether fault was detected.	0 volts on a drain pin should correspond to an illuminated LED fault indicator unless DC On/Off=TTL Low
Summary Fault	O	P3-2	TTL High on Fault TTL Low on $\overline{\text{Fault}}$	Summary Fault indicates presence of any fault condition. Fault condition can only be reset by correcting fault cause and cycling $+V_D$ input voltage
Channel Fault	O	LED	Illuminated on Fault Condition	Properly functioning amplifier should have no illuminated fault indicators
Signal Common	I/O	P3-1	Common reference for signal I/O	
Drain Current Monitor	O	Card Edge Ch.1 – Ch. 16	Analog voltage proportional to MMIC Drain Current	Scale Factor varies by product. Contact factory for scale factor.

Table 2

MMIC bias conditions are set and recorded at the factory for optimum performance using the potentiometers. In general, MMICs are adjusted such that the applied gate voltage results in approximately equal device quiescent currents. This may result in the gate voltages having differing set points. *The potentiometers should not be adjusted in the field.* Damage and/or destruction of the MMICs in the Spatium amplifier may occur if the potentiometer settings are changed. *Damage caused by field adjustment to any part of the product is not covered by product warranty.*

MMIC Bias Current windows are preset with fixed resistors at the factory. The window settings support operation from zero RF power (I_{DQ}) to full saturation over the specified operating temperature range, along with a safety margin.

The negative voltage required for gate bias is generated on the Bias Card assembly using DC-DC conversion techniques.

The Bias Card also delays the application of positive drain bias voltage to the MMICs by a preset time, enabling the negative voltage generation to occur, stabilize, and be applied appropriately to the MMIC gates. If a slow ramping DC voltage supply (typically greater than 2 seconds from zero to full voltage) is used to power up the Bias Card, timing conflicts can result in the appearance of fault indications and the resultant shutdown of one or more MMICs. A fast ramping supply must be used to apply voltage to the Bias Card.

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Faults

The summary fault signal will indicate a TTL high level if one or more MMICs has been detected to have a current outside its allowable set points. A corresponding illuminated LED will indicate which of the MMICs have failed operation. False fault indications can occur due to operation at low voltage, or due to slow ramp of DC power supplies. False faults may be cleared, but only by cycling DC power to the Bias Card.

Bias Card Common Issues

	Poor Current Return Path (ground)	Supply Voltage Out of Range	Poor Flexline to Bias card mating	Slow Power Supply Ramp	MMICs have failed	Insufficient Heatsinking	Oscillation	No Input Signal	High Load VSWR
Fault Indicators flashing erratically	X	Low	X				X		
No Power					X			X	
One or several indicator lights on	X	Low	X	X	X				X
All indicator lights on		X					X		X
Indicator lights come on during power up, intermittently				X			X		
Amplifier excessively hot		High				X			X
Action	Verify that Ground potential of all locations relative to power supply return is no more than a few millivolts. Verify Amplifier ground current return cables are connected to power supply common.	Check Supply Voltage	Verify connections are secure and fully mated May result in MMICs having no gate voltage applied and devices operating at IDSS. Extended operation may cause permanent damage.	Validate Supply Voltage Ramp Speed. Use DC On/Off Control	Contact Factory	Improve Connection to heatsink, Improve cooling	Check DC inputs to Spatium amplifier with an oscilloscope. Check output of amplifier (after high power attenuator) with spectrum analyzer.	Check Input signal level and frequency	Check Load VSWR

It is impossible for a simplified table to capture all opportunities resulting in unanticipated performance. The above table describes some of the more common situations and possible remedies.

If the above options do not describe or remedy the particular issue, please contact the factory. For optimum support, please record in as much detail as possible, the sequence of events, test equipment and test set up. Pictures are always helpful.

Contact Information

For the latest specifications, additional product information, worldwide sales and distribution locations:
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