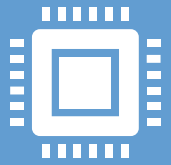
Mini-Circuits®

ISM RF & MW Energy

MAY, 2024

Solid State
is a smart alternative
to Magnetrons

- Solid state amplifiers are a realistic alternative to the Magnetron
- Solid State puts unlimited power control at your finger-tips
- It provides accurate frequency control
- And the capability to actively adapt to variable dielectric constants
- While being modular and easy to scale to higher power levels



Integrated solid state PA solutions offer potentially revolutionary capabilities to RF & MW Energy users

Mini-Circuits is extending their product offering to support solid-state RF & MW Energy solutions for Industrial, Scientific and Medical applications

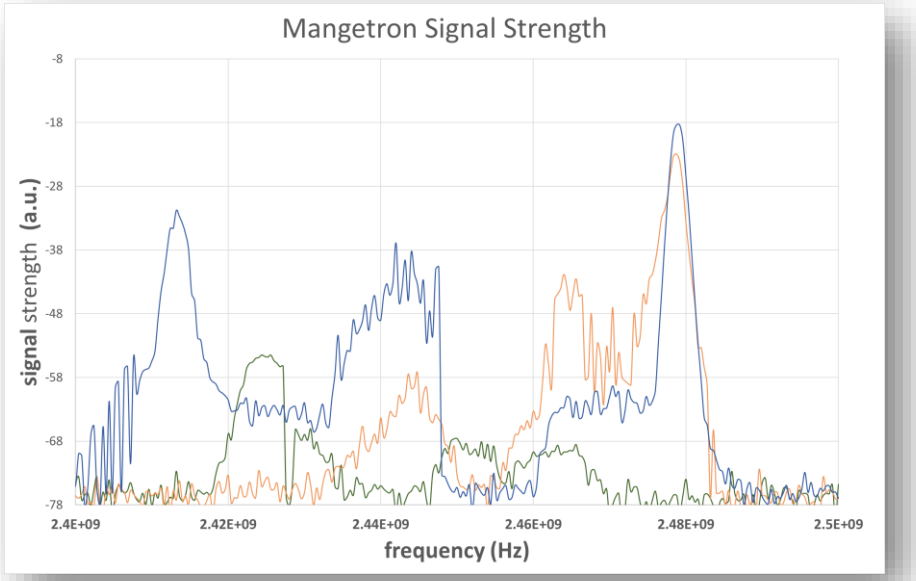
Products are available on our catalog and prototypes of our newest models are available. Just let us know your requirements.

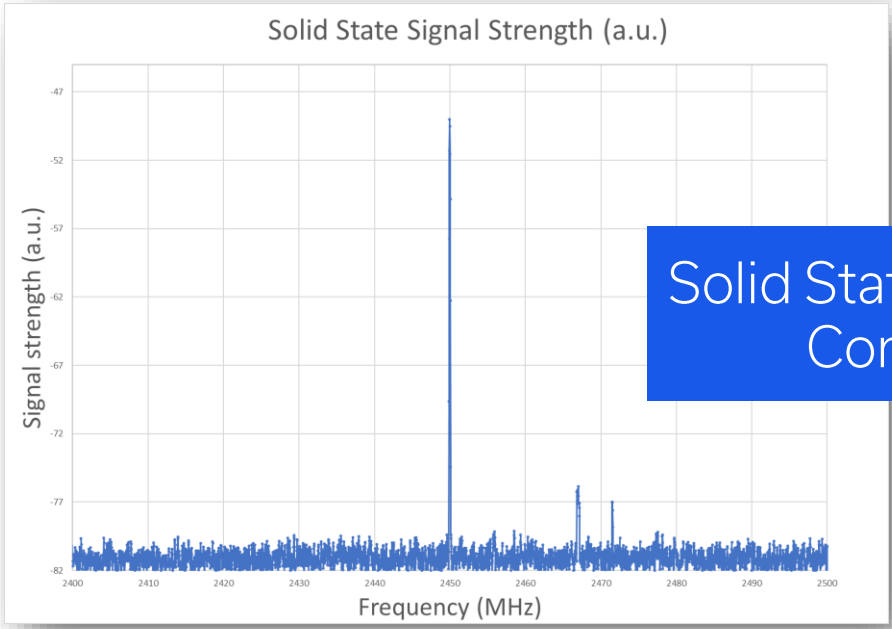
Our experienced RF Power design and application support teams are here to support you. We would be happy to answer any questions you may have about our product portfolio.

The Benefits of Solid State

Magnetron/Tube = brute force

Solid-State = provides control & finesse



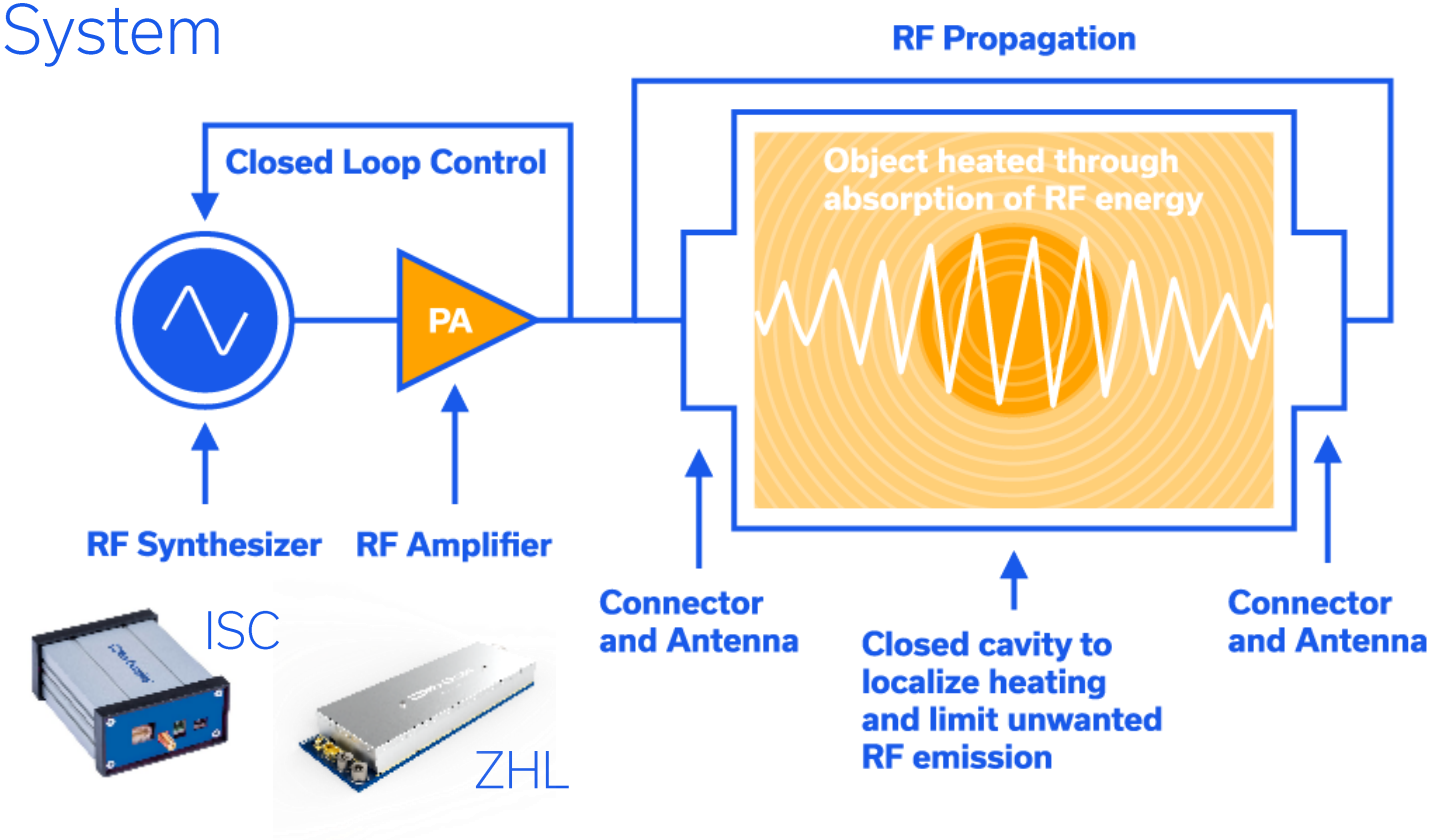


Solid State Enables Control!

A Solid-State System

Modular

Small, Easy to Integrate



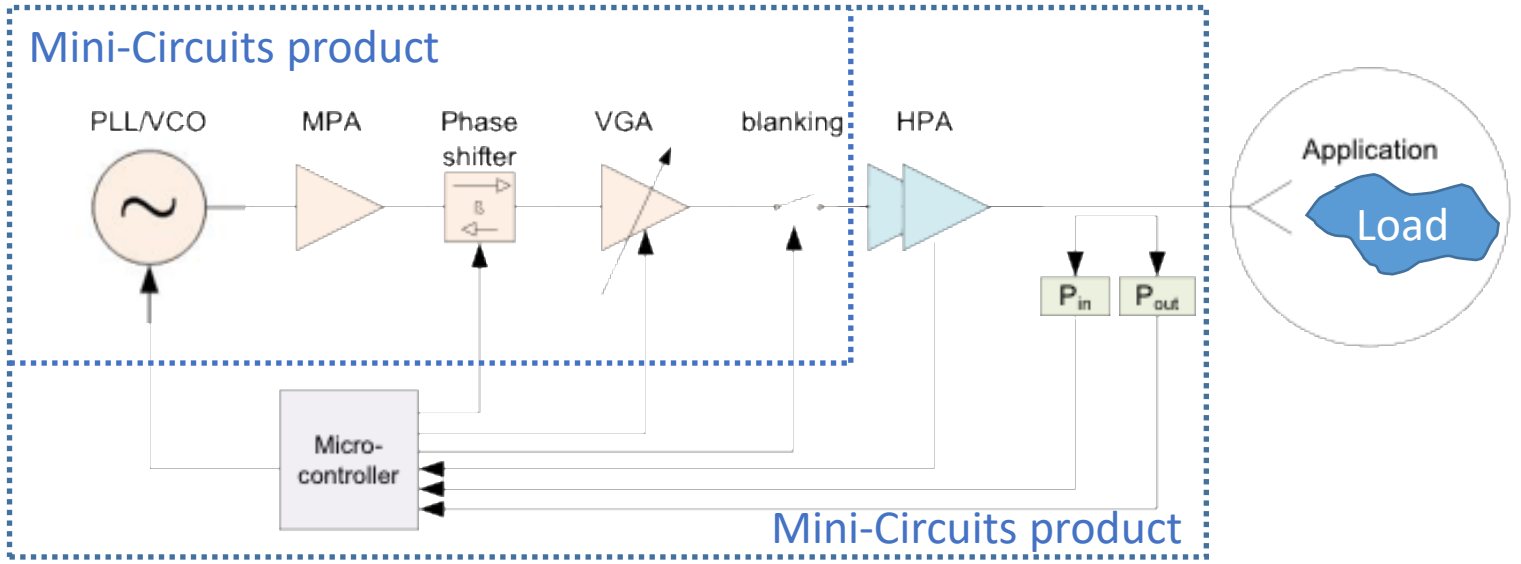
Better Process Yield

Lower Cost of Ownership — 24/7 Operation

Unlimited power control and capability to adapt to variable dielectric constants

1. **Unprecedented control** over RF signal via feedback of power and energy levels, enabling real reproducibility
2. **Feedback to the process**, effective, and fast reaction to (changing) load conditions
3. **Efficient** energy delivery
4. **Fast** shutdown
5. **Low-voltage** electronics Vs tubes
6. **Small form factors** enabling flexible hardware partitioning
7. **Reliability** solid state semiconductor-based reliability

Solid State ISM RF & MW Energy Application Diagram:
=> It's all about precision energy delivery

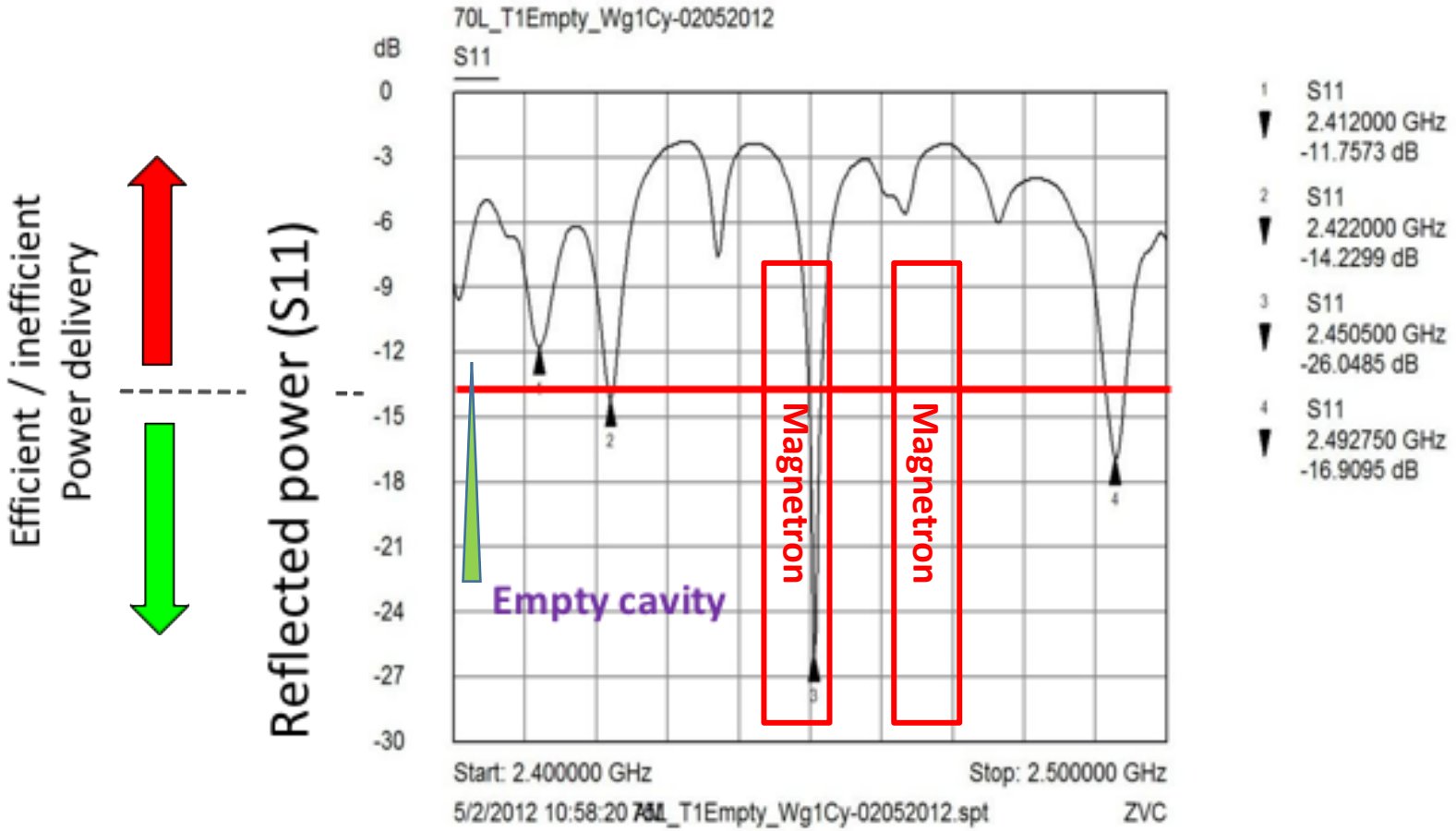


- Plasma generation
- Dielectric heating
- Industrial heating
- Industrial drying
- Medical treatment
- And many more……

- The right amount of power/energy
- Into the applicator (the active application/volume)
- Into the load/process
- With active feedback

Solid State Enables : Efficient RF & MW Energy Delivery

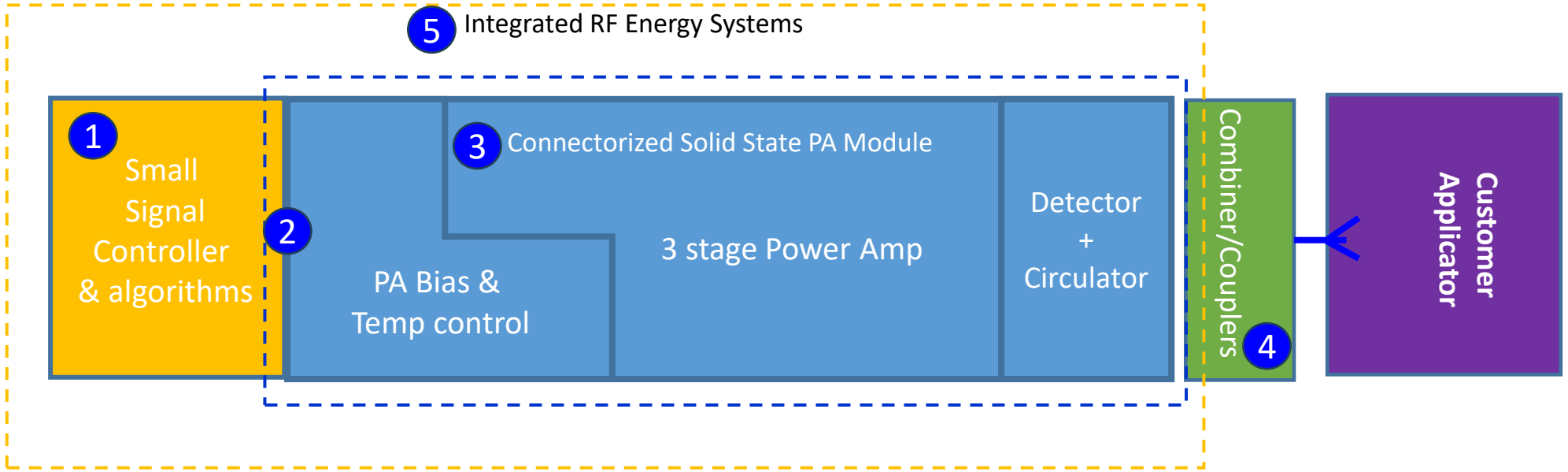
- Take control
- Use frequencies with minimum reflected power!



RF & MW Energy

Products

Mini-Circuits Products



1. Controllers
2. Splitters
3. Amplifiers => **PA Bias/Control + Power Amp + Detector + circulator**
4. High Power Combiners & Power Couplers
5. Rack Mounted Systems

Mini-Circuits ISM - RF & Microwave Energy Portfolio

- Mini-Circuits provides High Power Amplifiers for ISM, RF & MW Energy Systems
- Covering most of the ISM bands <6GHz
- From 10W to >25kW

ISM: High-Power RF & MW Energy Products EASY TO USE Building Blocks- Fast TTM

ZHL-XX-XX
RFE-XX-XX
RFS-XX-XX
COM-XX-XX
SPL-XX-XX
ISC-XX-XX

RFE-XX-XX
RFS-XX-X

RFS-XX-XX

10W to 1.8kW

1kW to 3kW
(2U – 3U)

4kW to 25kW
(6U – 24U)

ZHL & RFE => amplifier module/generator **without** signal source
RFS=> amplifier module/generator **with** signal source
ISC => signal generator & controller

SPL => splitter/phase/mag module
COM => combiner

2.45GHz Building Block Video

https://youtu.be/0ABleW4hAlo

Products Hi-lights

View on https://www.mcdi-ltd.com/rf-mw-energy-solutions/

2.45GHz

2.45GHz Building Blocks

Available 2.45GHz building blocks

Available

SPL-2G42G50W4+
4 Ways Active Power Splitter

SPL

Available

ISC-2425-25+
Signal generator and controller

ISC

Available

ZHL-2425-250X+
50Ω 250W 2.4 to 2.5 GHz

SSPA

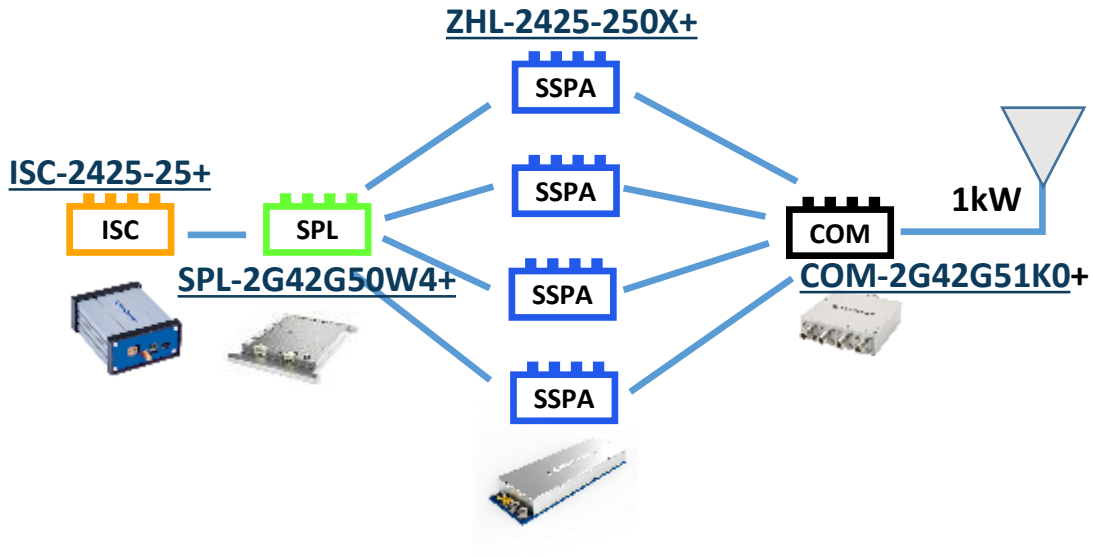
Available

COM-2G42G51K0+
2.3 – 2.7 GHZ, 1.2KW

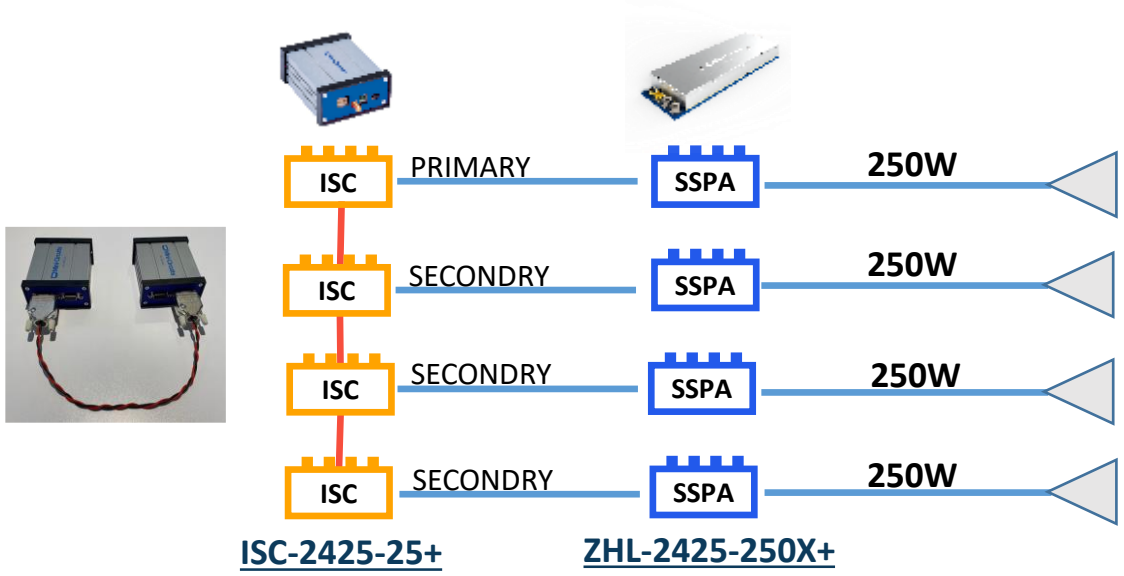
COM

EASY TO USE BUILDING BLOCKS

Flexibly to build a solution that fits your application requirements in a way that makes best sense to you



2.45GHz, 1kW
RFS-2G42G51K0+



2.45GHz, 4 x250W
RFS-2G42G51K0X4

SSPA

ZHL-2425-250X+

50Ω 250W 2.4 to 2.5 GHz

Available

The Big Deal

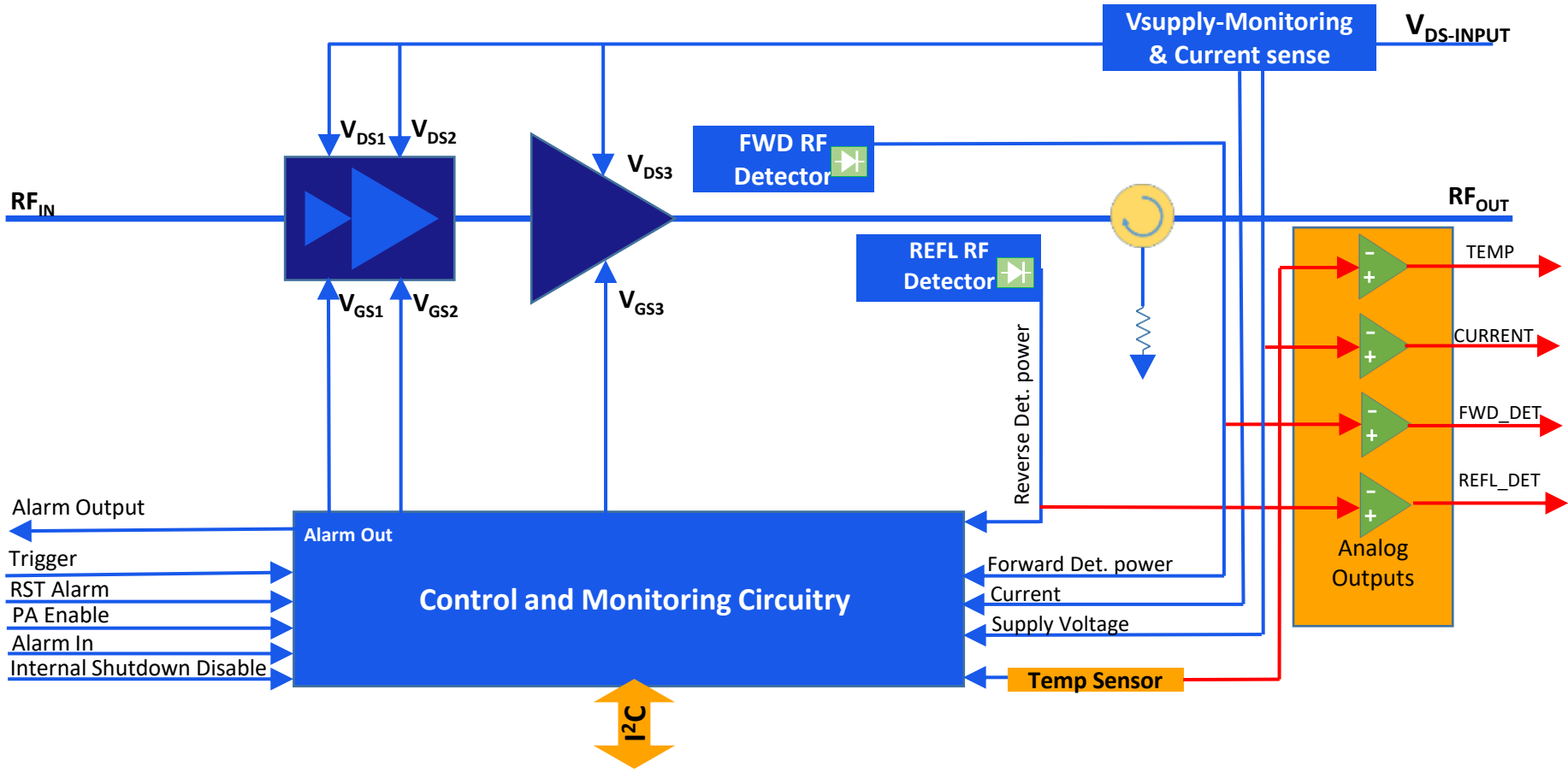
- High output power, 300W
- 2.4 to 2.5GHz ISM band
- Suitable for CW and pulsed signals
- High gain, 40 dB typical
- High efficiency, 60%
- High ruggedness
- Built-in monitoring and protection for temperature, current forward and reflected power
- User friendly I2C control interface

SSPA

ZHL-2425-250X+

50Ω 250W 2.4 to 2.5 GHz

Block Diagram



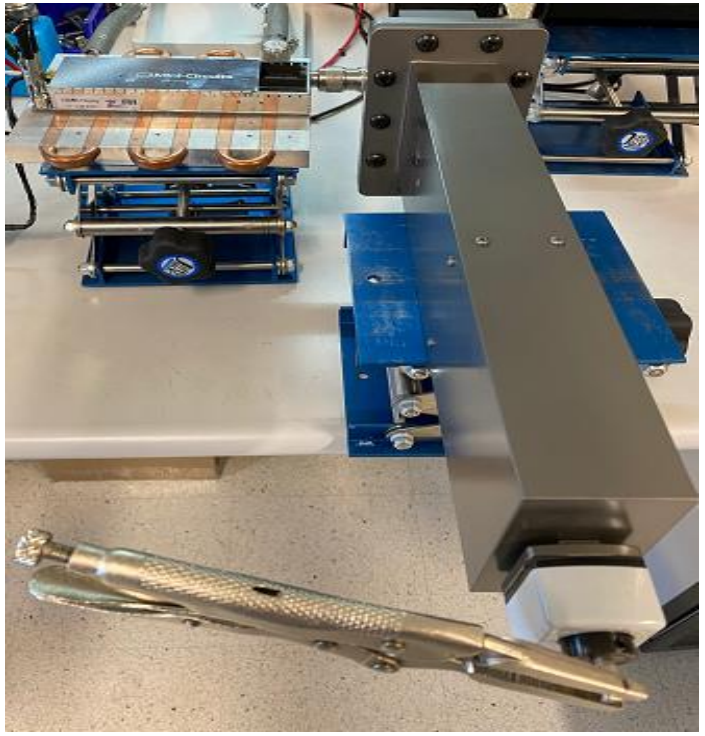
SSPA

ZHL-2425-250X+

50Ω | 300W CW | 2.4 - 2.5GHz

RUGGEDNESS & RELIABILITY

- ZHL-2425-250X+ tested at 250W CW output power into a sliding short
- >80:1 Mismatch thru all phases
- Built-in monitoring and protection for temperature, current, forward power, reverse power, and internal shutdown circuitry for added reliability under difficult operating conditions



ISC

ISC-2425-25+ Signal generator and controller

50Ω 25dBm 2.4 - 2.5GHz

Available

The Big Deal

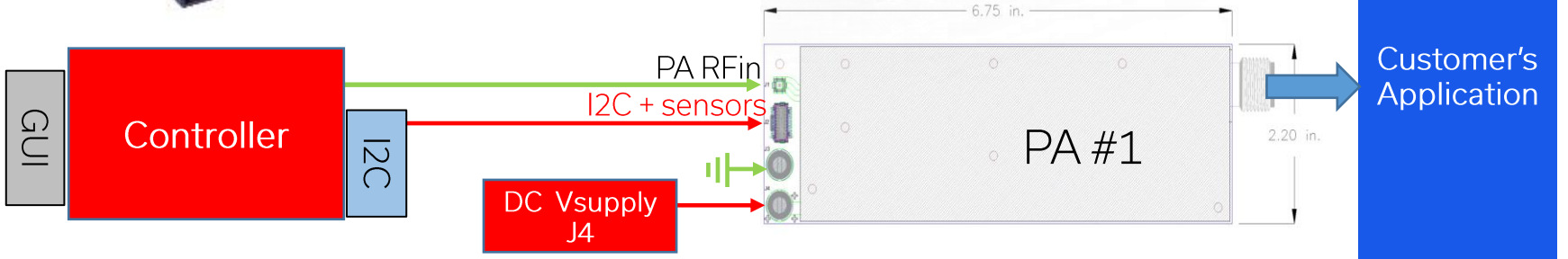
- Turnkey ISM-RF Energy signal generator and system controller
- High resolution and control range of key RF signal parameters
- Output power up to 25dBm
- Support by a comprehensive command language
- Powerful embedded functionalities to support end users applications
- Supports stand-alone or multichannel operation (in either coherent or in-coherent modes)
- Easy integration with most industrial systems supporting control protocols such as RS422, RS485
- Works seamlessly with Mini-Circuits connectorized RF Energy amplifiers

Easy To USE

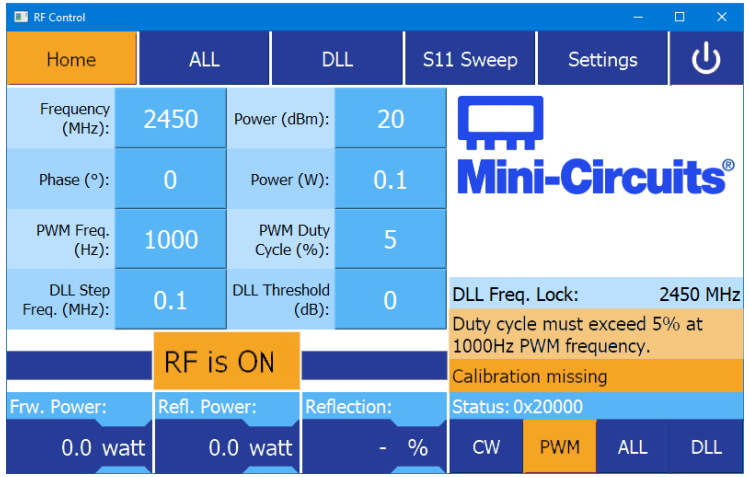
ISC

ISC-2425-25+
Signal generator and controller

50Ω 25dBm 2.4-2.5GHz

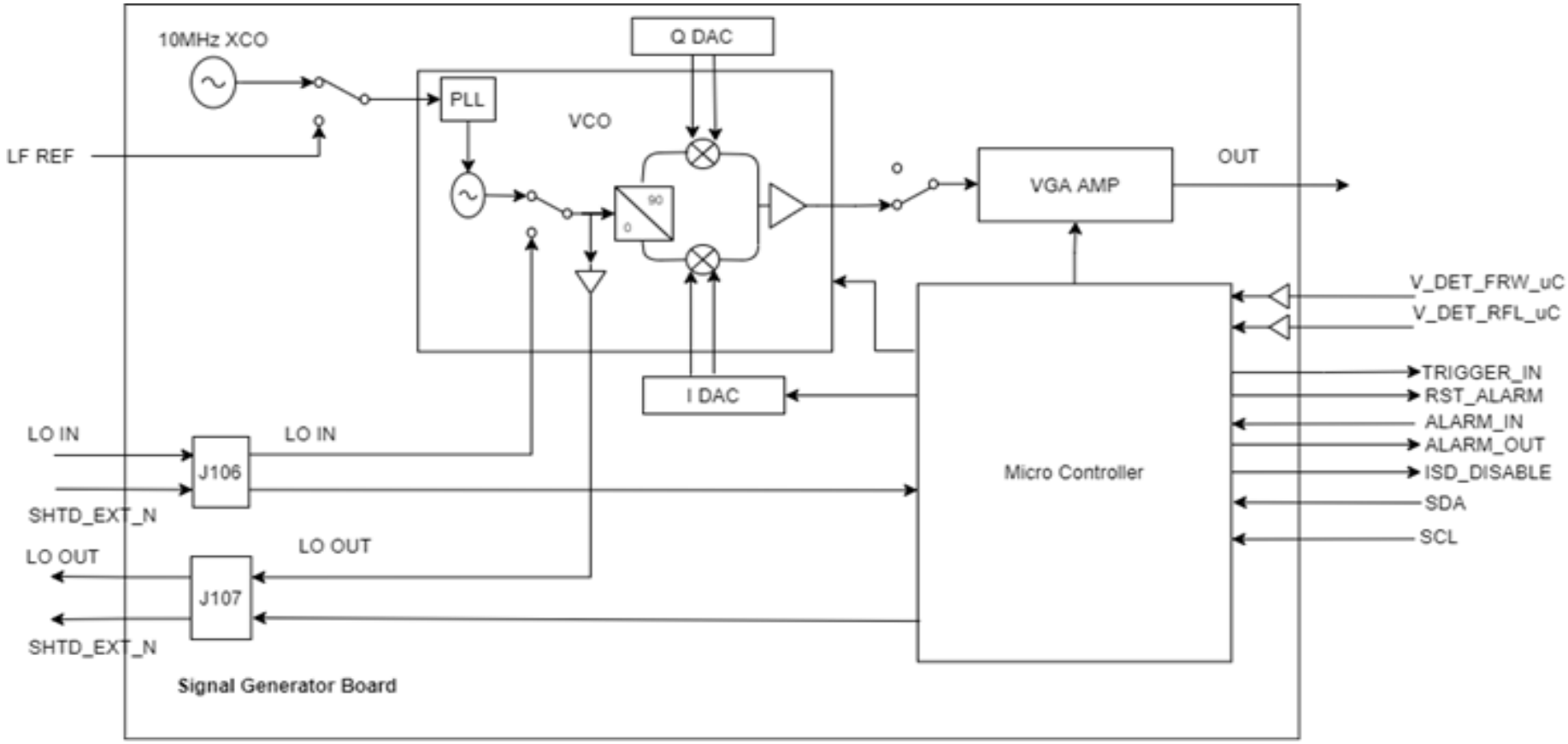


GUI



ISC-2425-25+

(50Ω 25dBm 2.4 - 2.5GHz)



COM

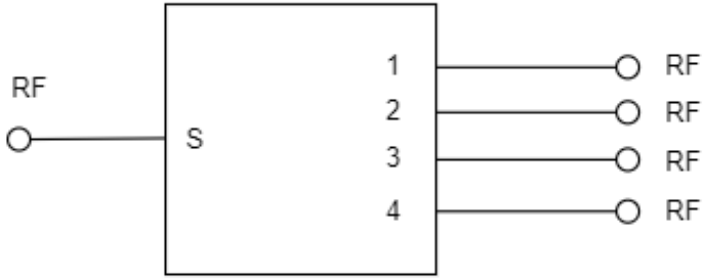
COM-2G42G51K0+
2.3 – 2.7 GHZ

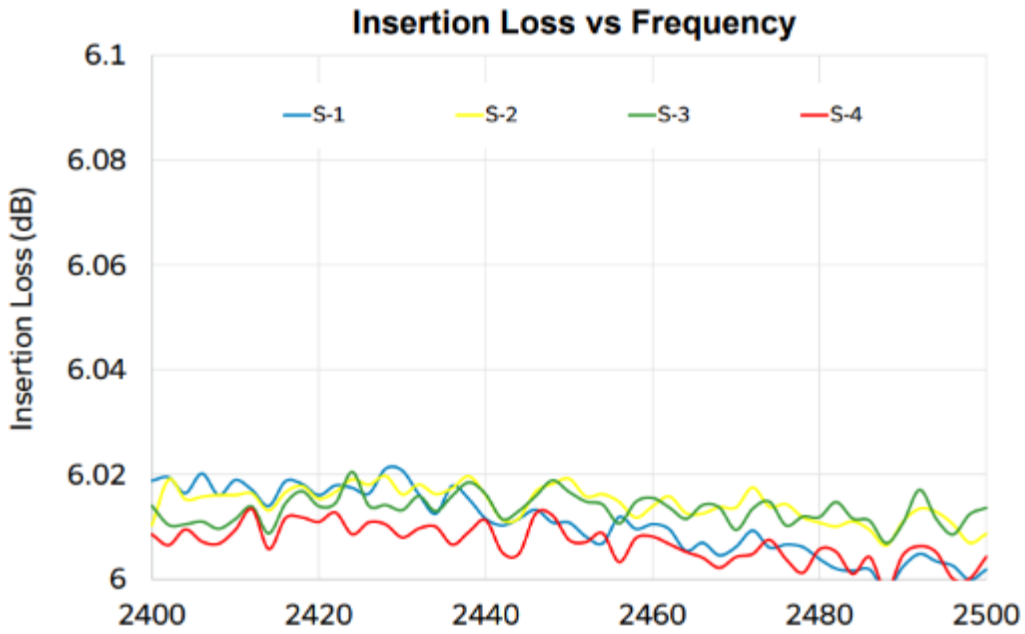
4-way 0° non-isolating combiner
providing very high- power handling and exceptionally low insertion loss across 2400 to 2500 MHz.

Available

FUNCTIONAL SCHEMATIC

COAXIAL CONNECTIONS	
Input (Port 1,2,3,4)	N Type Female
Output (Port S)	7/16 DIN Female





THE BIG DEAL:

Very high-power handling, up to 1200W CW
Exceptionally low insertion loss, 0.1dB typ.
Low amplitude (0.15dB typ.) and phase unbalance (1deg typ.)

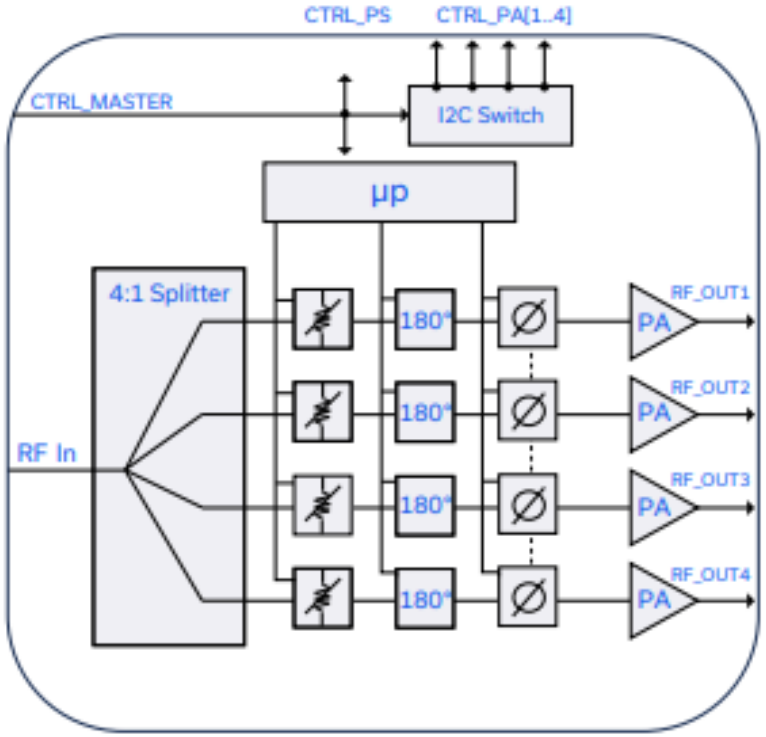
SPL

SPL-2G42G50W4+
2.4 – 2.5 GHZ

4 Ways Active Power Splitter
2.4 - 2.5 GHz, 50Ω
Connector Type: MCX

Available

FUNCTIONAL DIAGRAM

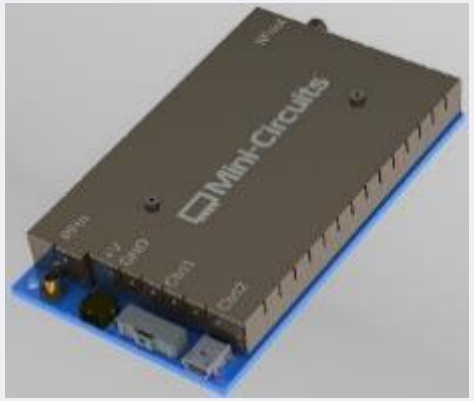


THE BIG DEAL:

- 2.4 to 2.5 GHz ISM band
- 30 dB attenuation range
- 360° phase shift range
- Suitable for CW and pulsed signals
- Easy integration with ZHL-2425-250X+ and ISC-2425-25+
- I2C control interface
- Isolated Paths

ISC → SSPA

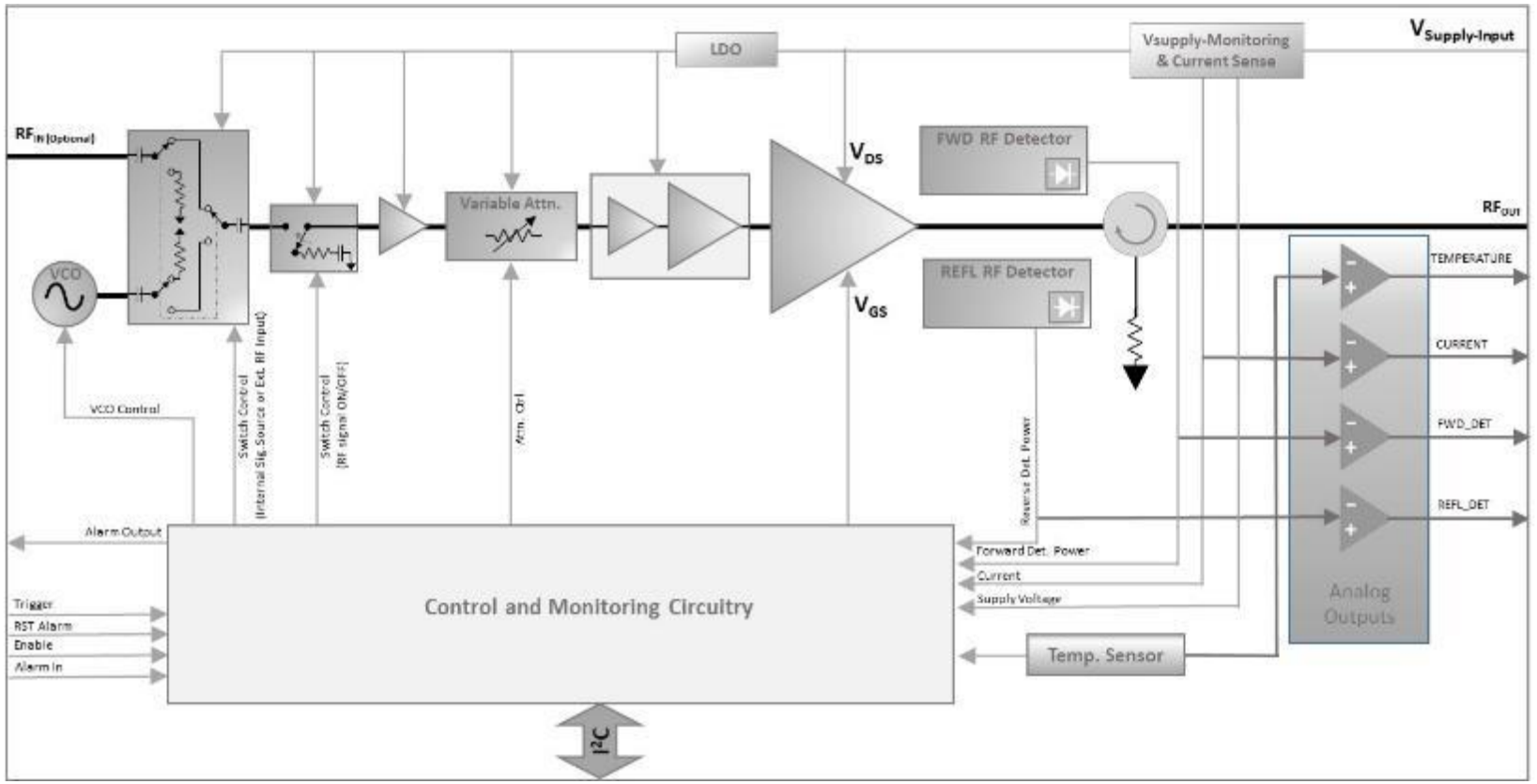
RFS-2G42G5050X+



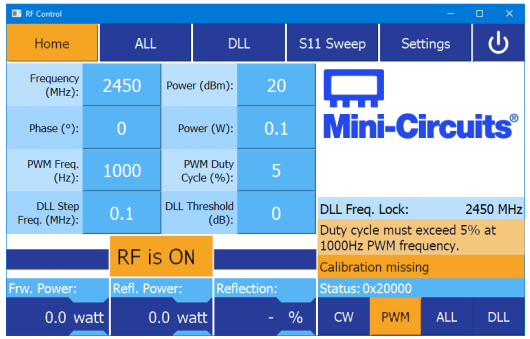
50Ω 50W 2.4 to 2.5 GHz Signal generator integrated. (can also be used as a stand-alone amplifier).

Available

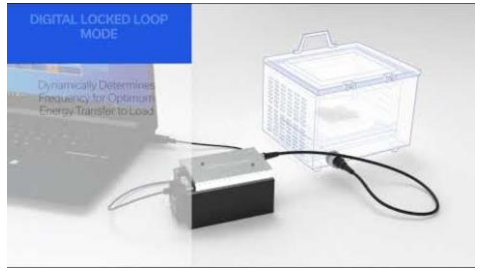
Block Diagram



GUI



Video



https://youtu.be/E6lFZ2qvp00

RFS-2G42G51K0+

Easy to use LAB Amplifier

50Ω 1000W (2U) 2.4 to 2.5 GHz

Available

Front Side

Back Side

GUI

Video

https://youtu.be/3H5wXV5bcEE

ISC & ZHL Evaluation Kit & Support Environment

Coming Soon

"Out of the box" evaluation kit, Includes the following:

- ZHL-2425-250+ (inc. Heat Sink w/ Fan)
- ISC-2425-25+ Signal Source and Controller (Included DC Power Connector, USB Cable, and 20-Pin Control Cable)
- 12" MCX-SMA Cable
- 3FT 12AWG Hookup Wire Red & Black with terminal mounting hardware
- High Power RF Cable 300W N-Connector
- 12V Power Supply for DC fan

Optional Accessories:

- High Power Termination (250W)
- High Power Attenuator (250W)
- 32V Power Supply for Amplifier
- 5V Power Supply for ISC
- High Power Attenuator (300W)

27MHz

Coming Soon

RFE-24M30M1K7+

50Ω 1700W 27MHz

The Big Deal

- High output power, 1700W
- 27MHz ISM band
- Suitable for CW and pulsed signals
- High gain, 26 dB typical
- High efficiency, 80%
- High ruggedness
- Built-in monitoring for temperature and current
- Built-in emergency switch-off

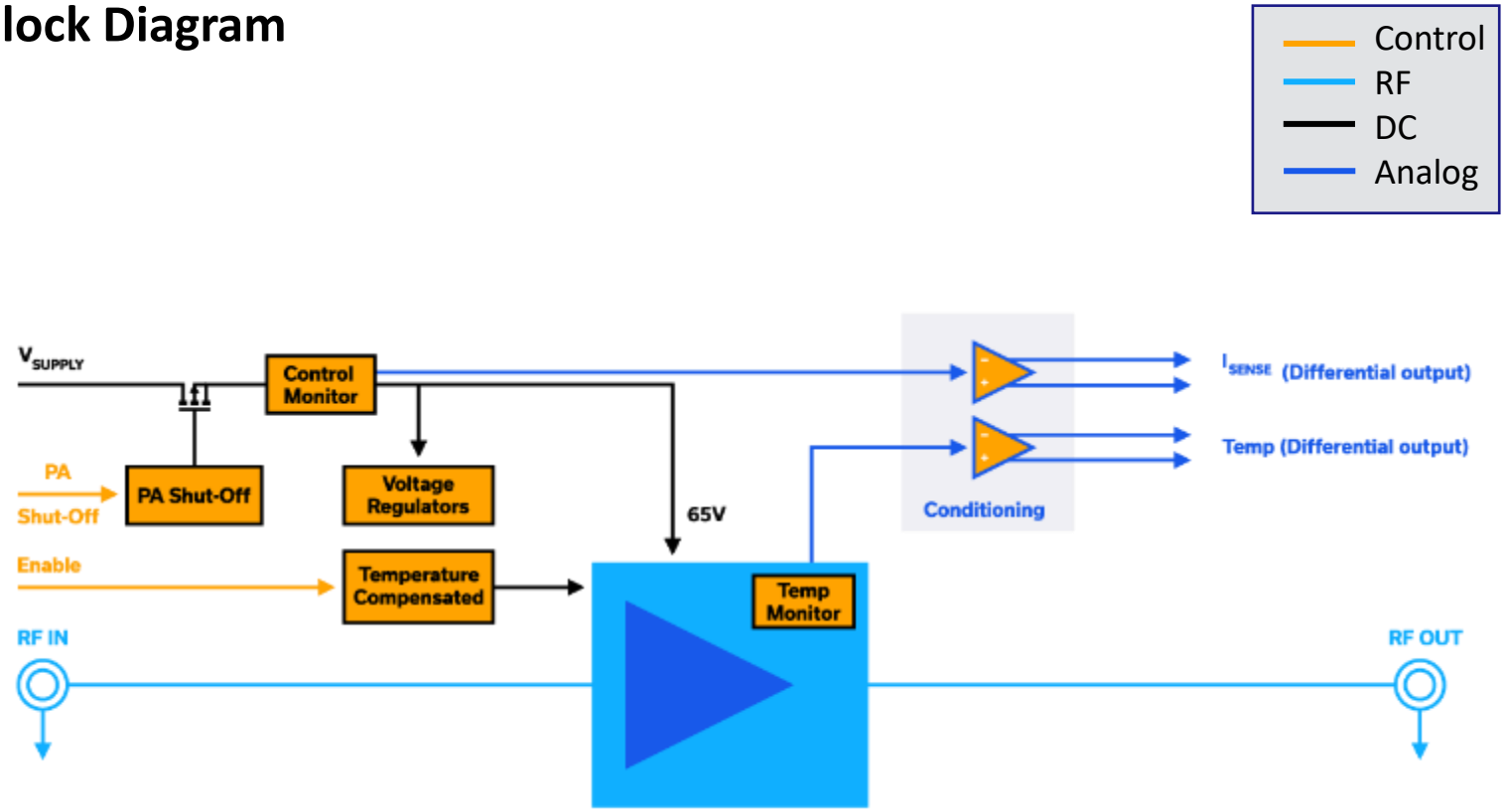
Coming Soon

RFE-24M30M1K7+

50Ω 1700W 27MHz

Availability	
Customer Sample	Now

Block Diagram



RFE-24M30M075X+

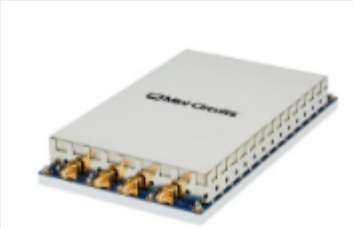
50Ω 75W 27MHz

Available

The Big Deal

- One input, four 19W outputs
- 27MHz ISM band
- Suitable for CW and pulsed signals
- High gain, 16 dB typical at P3dB
- 55% typical efficiency
- Integrated harmonic suppression
- Temperature compensated gate bias

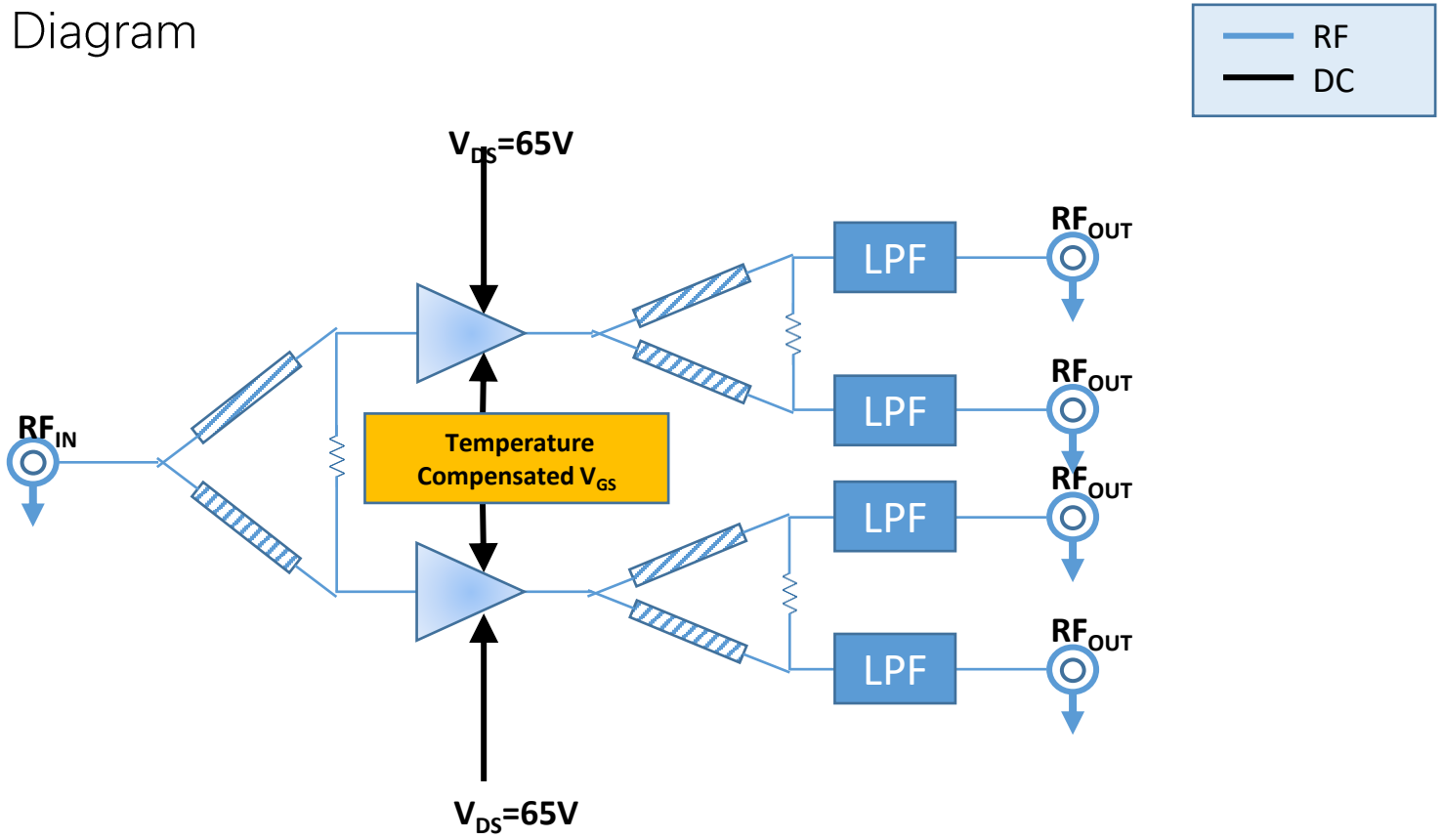
RFE-24M30M075X+



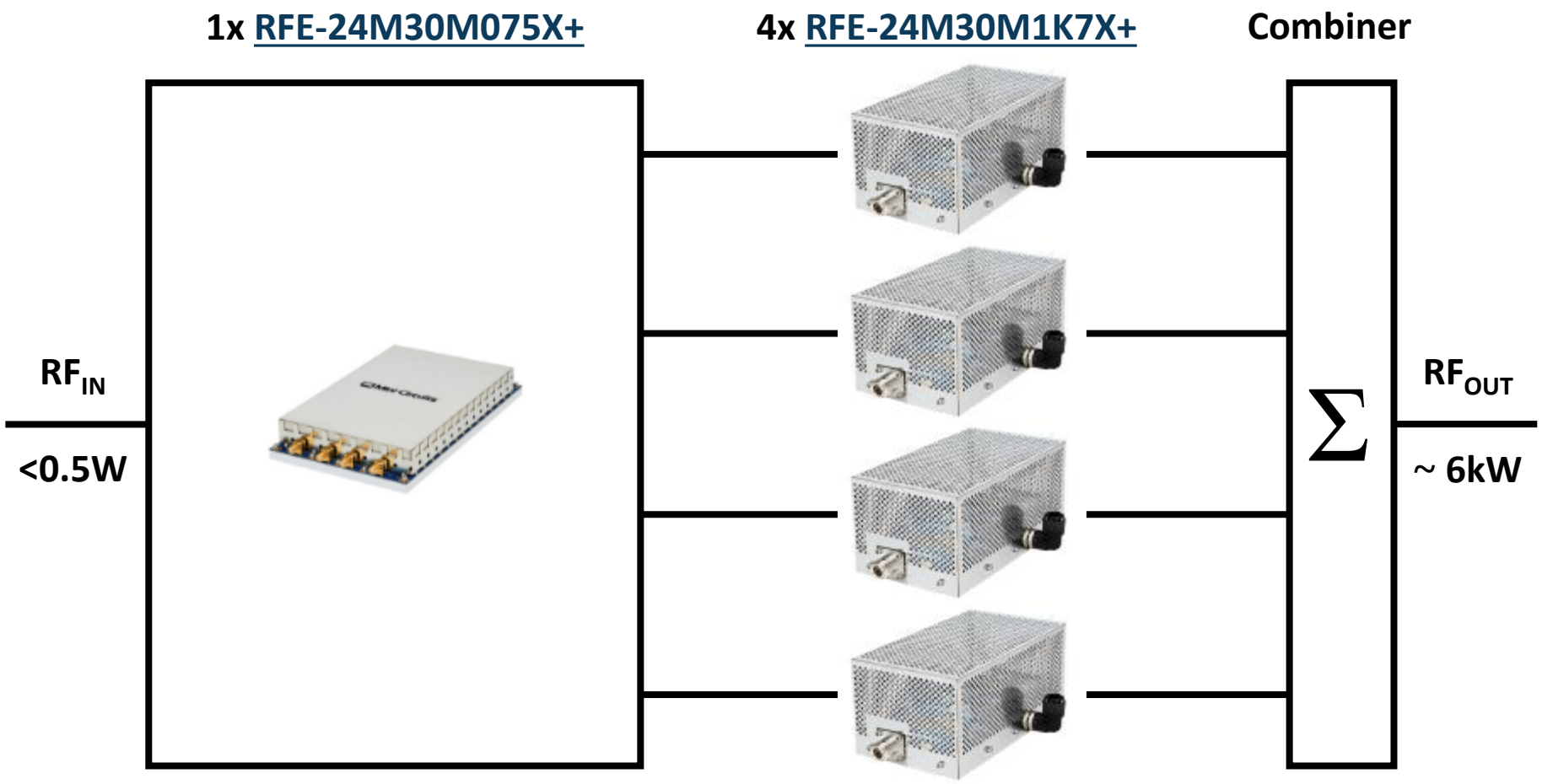
50Ω 75W 27MHz

Available

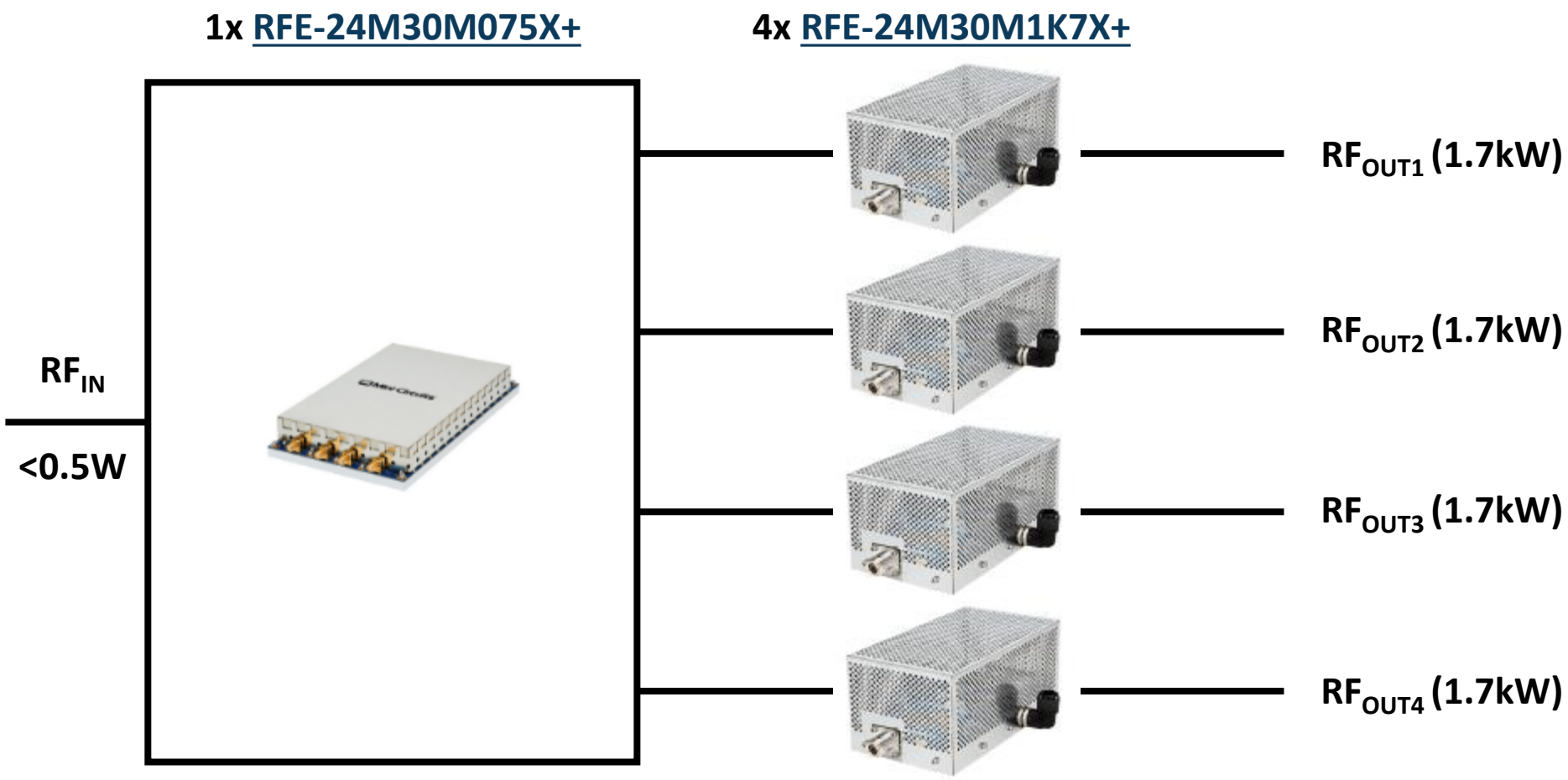
Block Diagram



6kW Line-Up at 27MHz



Four equal individual 1.7kW outputs at 27MHz



Combiners

> 1kW

Combiner Designs for 2.45GHz & 915MHz

COM-2G42G51K0+

4 Ways Power Splitter
2.4 - 2.5 GHz, 50Ω

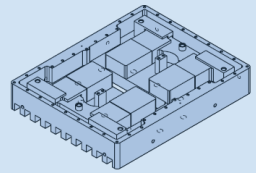
- Very high-power handling, up to 1200W CW
- Exceptionally low insertion loss, 0.1dB typ.
- Low amplitude (0.15dB typ.) and phase unbalance (1° typ.)
- Patent Pending

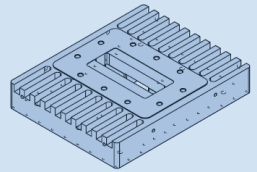
SPL-2G42G50W4+

4 Ways Active Power Splitter

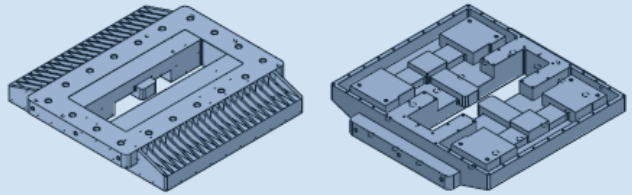
2.4 - 2.5 GHz, 50Ω

- 2.4 to 2.5 GHz ISM band
- 30 dB attenuation range
- 360° phase shift range
- Suitable for CW and pulsed signals
- Easy integration with ZHL-2425-250X+ and ISC-2425-25+
- I2C control interface
- Isolated Paths





6kW & 8kW,
2.45GHz
6/8 x 7/16” IN,
WR-340 OUT

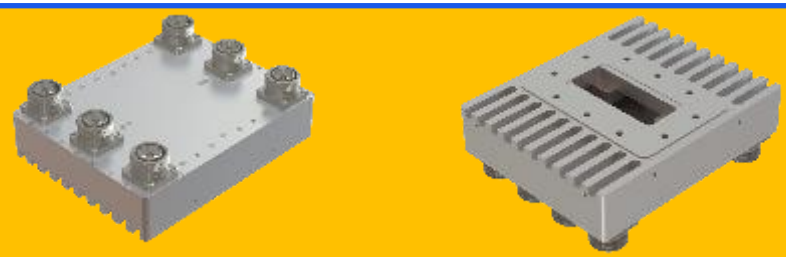


5kW & 20kW,
915MHz
8x 7/16” IN,
WR-975 OUT

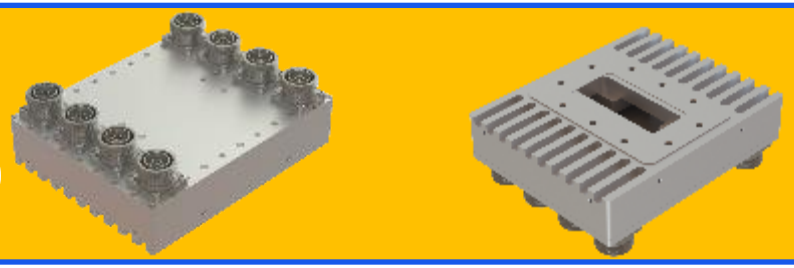
All Designs Covered by Mini Circuits Patent

High Power Combiners 2.45GHz and 915MHz (patent pending)

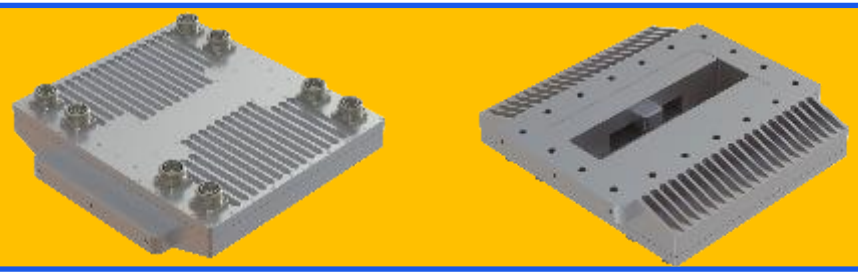
2.4 - 2.7 GHz
COM-2G42G56K0+
6kW - 8kW, 6-way 0˚ non-isolating differential combiner, WR340



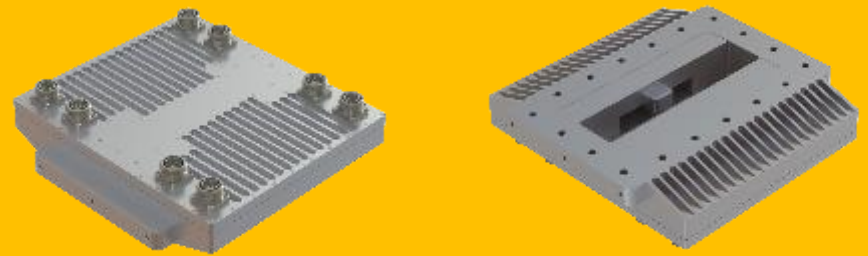
2.4 - 2.7 GHz
COM-2G42G58K0+
8kW - 10kW, 8-way 0˚ non-isolating differential combiner, WR340



902 - 928 MHz
COM-G90G935K0+
5kW, 8-way 0˚ non-isolating differential combiner, WR975

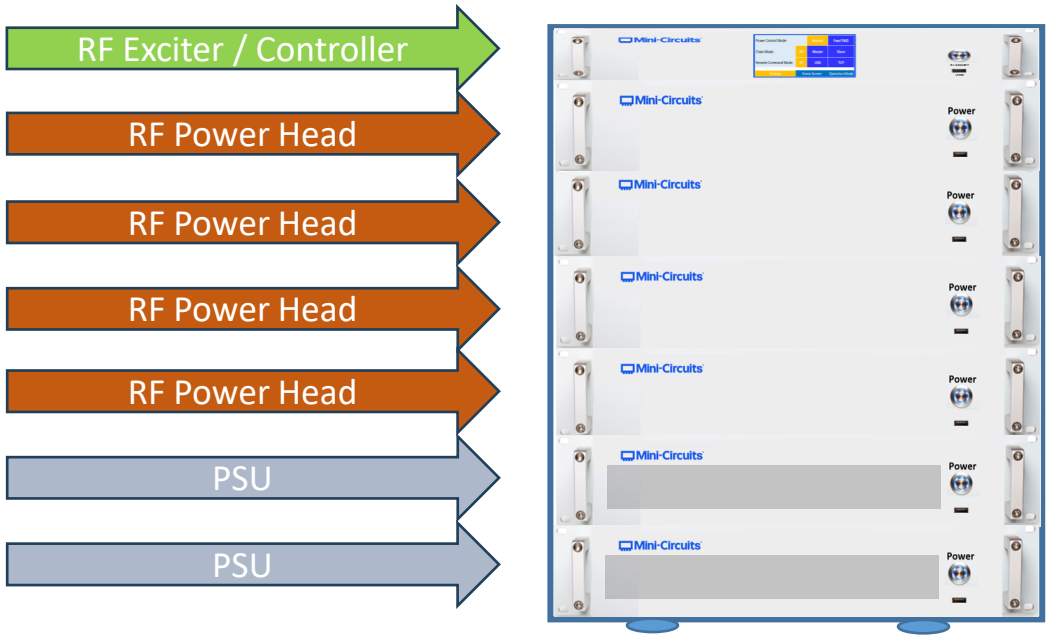


902 - 928 MHz
COM-G90G9320K+
20kW, 8-way 0˚ non-isolating differential combiner, WR975



Upcoming Products

Rackmount High Power Systems



- Simple, low weight and cost-effective designs
- Easy and fast scalability
- Custom designs possible

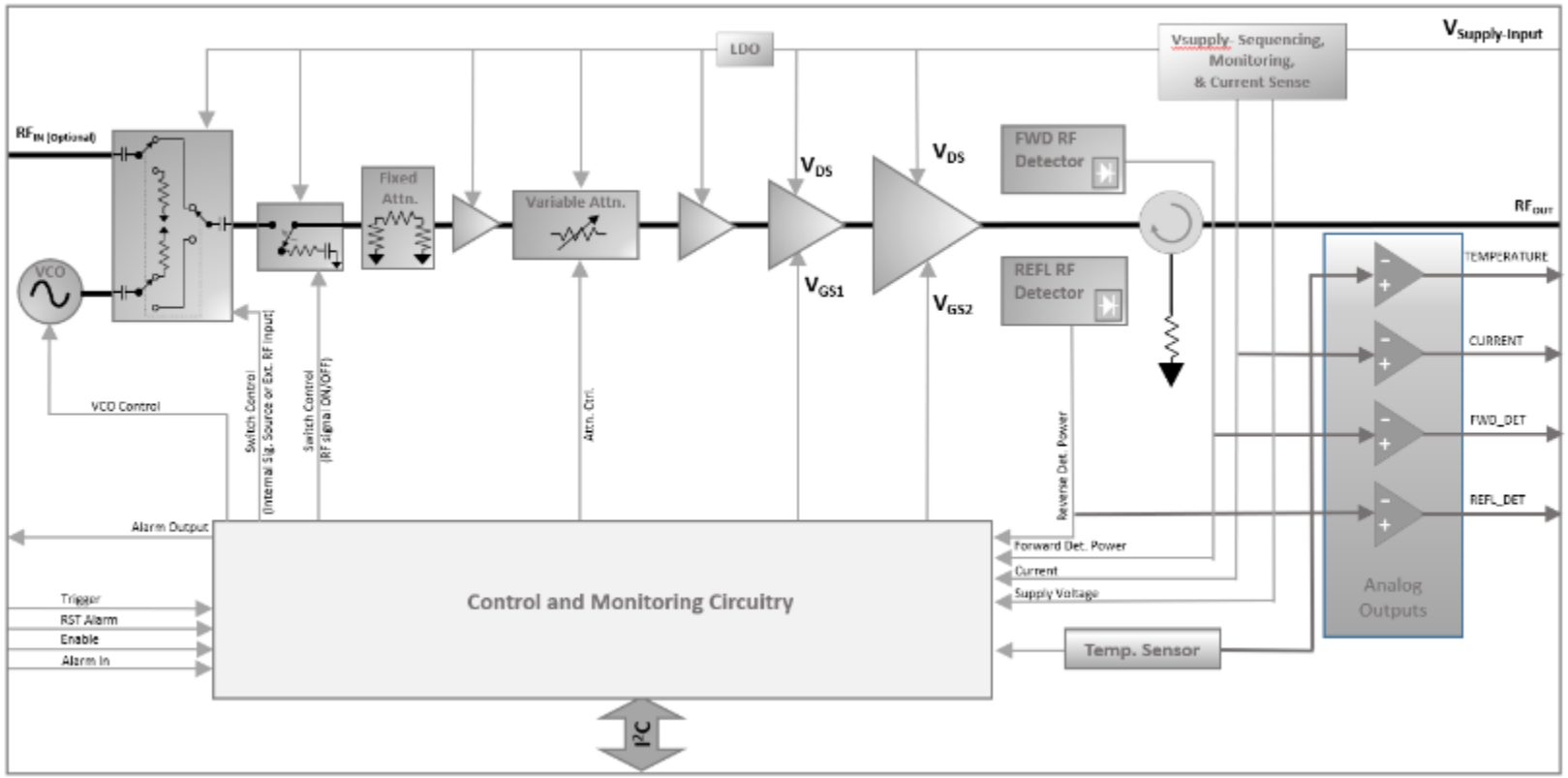
RFS-G90G93750X+

ISC → SSPA

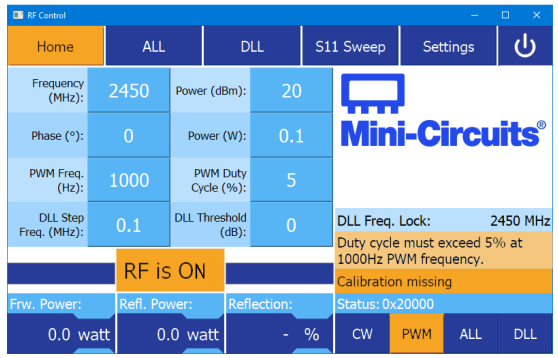
RFS-G90G93750X+ 915MHZ

50Ω 750W 900 to 930 MHz Signal generator integrated (Can also be used as a stand alone amplifier)

Block Diagram



GUI



Availability	
Customer Sample	APRIL 2024

RFS-G90G93750X+ Overview:

- This amplifier is a new generation solid state connectorized high-power signal source module which can be used in a wide range of industrial, scientific, and medical applications in the 902-928 MHz ISM band.
- This high power amplifier is capable of providing signals (CW & pulsed) from 1W to 750W output power with built-in monitoring and protection for temperature (final stage transistor and high power load), current, supply voltage, forward power, and reverse power.
- It includes control, monitoring, protection features, a signal generator and a phase shifter that can be adapted by the end user to support different types of applications.
- It can be controlled externally through a user-friendly USB interface to monitor forward and reflected power to support dynamic load analysis, temperature monitoring, current monitoring, shutdown alarms, enable/disable the signal source/amplifier, controlling the RF frequency and power and for resetting protection alarms.

RFS-G90G93750X+:

RFS-G90G93750X+ Performance Summary (Signal Source Mode)

HIGH POWER SIGNAL SOURCE ELECTRICAL SPECIFICATIONS AT +25°C, 50V, 50Ω SYSTEM, 3.3V LOGIC LEVELS

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Frequency Range	f		902	—	928	MHz
Frequency Resolution	f_{RES}	f=902 MHz to 928 MHz	0.5	—	—	MHz
Output Power Setting	P_{OUT}	f=902 MHz to 928 MHz	4	—	750	Watts
			36	—	58.75	dBm
Output Power Control Range	P_{OUT_CTRL}	f=902 MHz to 928 MHz	23	—	—	dB
Output Power Control Resolution	P_{OUT_RES}	f=902 MHz to 928 MHz	—	0.25	—	dB
Output Power Meas. Resolution	$P_{OUT\_MEAS\_RES}$	f=902 MHz to 928 MHz, @58.75dBm P_{OUT}	—	—	0.1	dB
PWM Duty Cycle [1]	PWM-DC	f=902 MHz to 928 MHz	5	—	99	%
PWM Frequency [1]	PWM-Freq	f=902 MHz to 928 MHz	1	—	19.8	kHz
Efficiency	η	f=902 MHz to 928 MHz, @58.75dBm P_{OUT}	58	62	—	%
Operating Voltage	V_{DC}	f=902 MHz to 928 MHz	48	50	52	V
Supply Current	I_{DC}	f=902 MHz to 928 MHz, @58.75dBm P_{OUT}	—	24.0	26.0	A
Temperature Sense [4,5] (Based on analog output)	T_{SENSE}	T_{SENSE}= (-72 x TEMP_AOUT) +186.5 (TEMP_AOUT is the analog voltage on pin 10 of the 30 Pin conn., Ctrl1. Temperature can also be read thru USB)				˚C
Supply Current Measured (Based on analog output)	$I_{CURRENT}$	$I_{CURRENT}$ = (10.03 x ISENSE_AOUT) (ISENSE_AOUT is the analog voltage on pin 8 of the 30-pin connector, Ctrl1. Current can also be read thru USB)				A
Signal Source On / Off	–	Enable (TTL low, default) / Disable (TTL high) on Pin 7 of the 30-pin connector, Ctrl1.				

RFS-G90G93750X+ Performance Summary (Power Amplifier Mode)

STAND-ALONE HIGH POWER AMPLIFIER ELECTRICAL SPECIFICATIONS AT +25°C, 50V, 50Ω SYSTEM, 3.3V LOGIC LEVELS

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units
Frequency Range	f		902		928	MHz
Input Power	P_{IN}	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	—	-6	-2	dBm
Output Power	P_{OUT}	f=902 MHz to 928 MHz @0dB Atten setting	750	—	See Notes 2 & 3	Watts
			58.75	—	See Notes 2 & 3	dBm
Power Gain	G_P	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	60	62.5	—	dB
Power Gain Flatness	G_{FLAT}	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	—	1.0	2.0	dB
Efficiency	η	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	58	62	—	
Input VSWR	I_{VSWR}	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	—	1.2	1.35	
Operating Voltage	V_{DC}	f=902 MHz to 928 MHz	48	50	52	V
Supply Current	I_{DC}	f=902 MHz to 928 MHz @0dB Atten. setting and 58.75dBm P_{OUT}	—	24.0	26.0	A

SAFE OPERERATING AREAS and PROTECTION LIMITS[2]

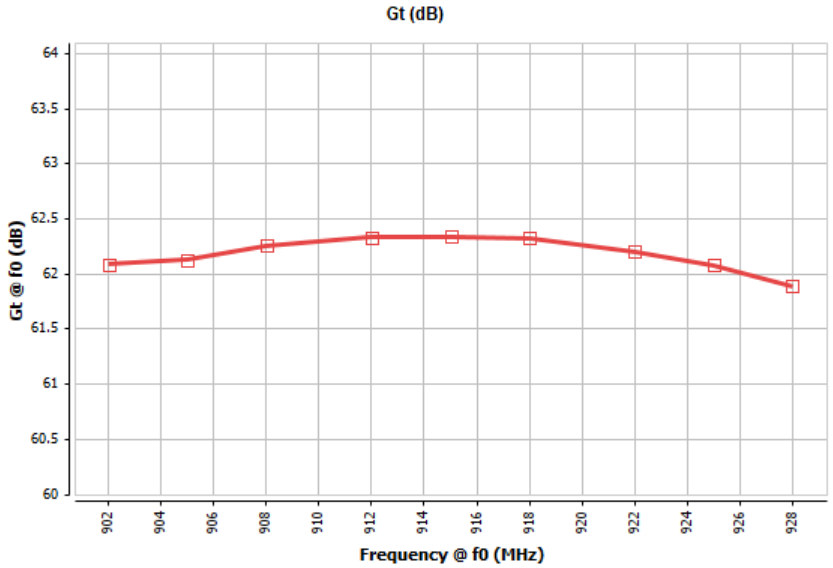
Parameter	Warning Limits		Shutdown Limits		Units
	Low	High	Low	High	
Temperature Sense [4,5]	5	65	0	75	°C
Forward Power	—	770	—	800	Watts
	—	58.86	—	59.03	dBm
Reverse Power	—	750	—	780	Watts
	—	58.75	—	58.92	dBm
Voltage Supply	48	52	46	54	V
Current Supply	—	26.5	—	27	A

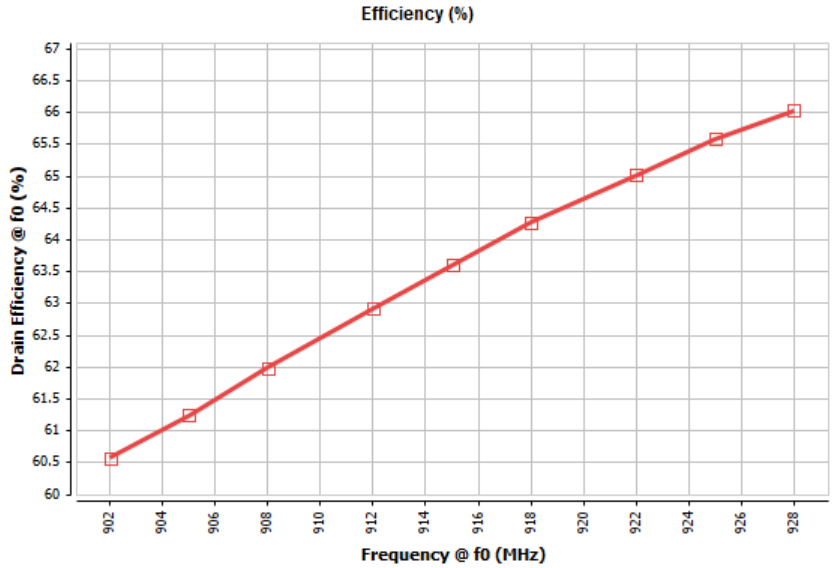
MAXIMUM RATINGS[3]

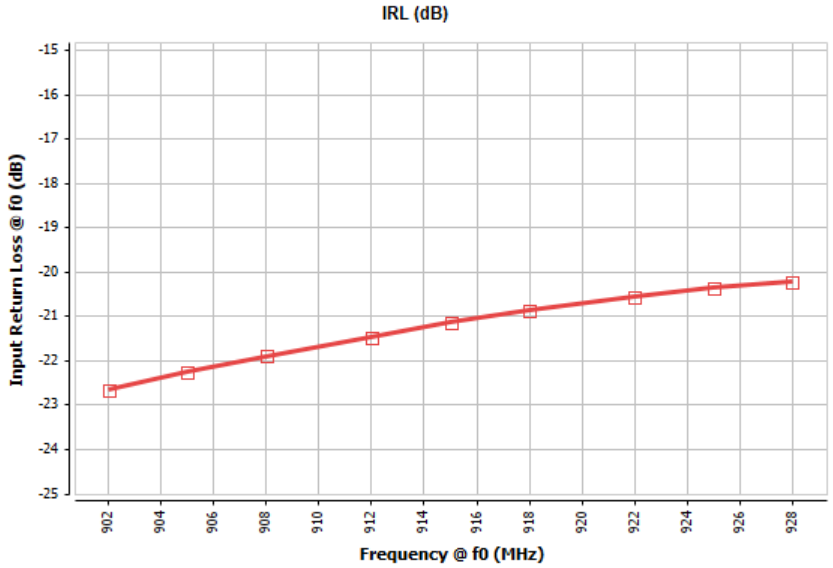
Parameter	Ratings
Operating Temperature [4]	0°C to +55°C
Storage Temperature	-20°C to +85°C
DC Voltage	55V
Input RF Power	2 dBm
Forward Output Power	800W
Power into the RF output connector	780W
Current Supply	27 A

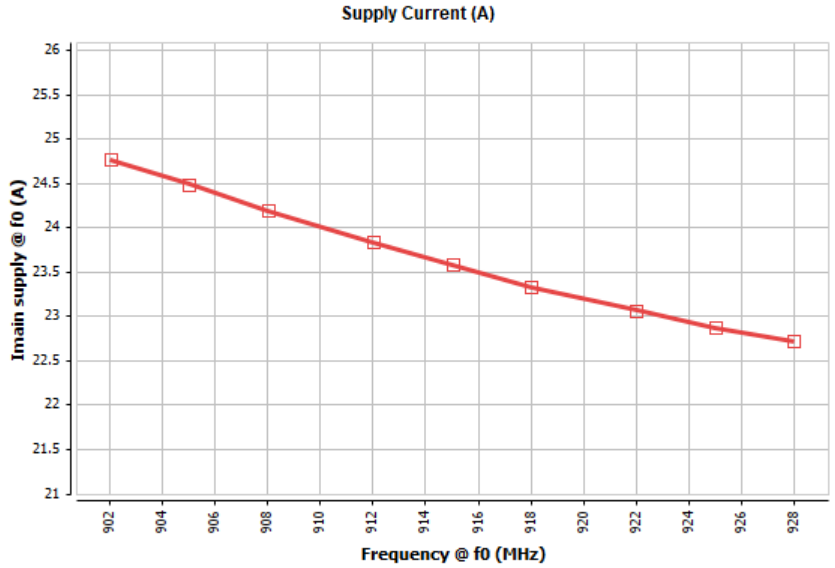
1. To ensure accurate power readings (and therefore accurate power output), the minimum value of the duty cycle changes along with the PWM frequency. See the PWM section for more detail.
2. There are two reactions to excessive operation depending on severity. If the parameter reaches a level that is high but still tolerable a warning error will be raised. If the parameter is dangerously high and exceeds the prestored limits the module will be shut down and remain disabled until a reset command is sent thru the USB interface or by applying a logic high level to pin 5 of the multi-pin connector, Ctrl1.
3. RFS-G90G93750X+ may operate up to these maximum ratings with no damage, permanent damage may occur if any of these limits are exceeded.
4. This is the sensed operating temperature calculated from the analog output, TEMP_AOUT, or read thru USB from the RFS-G90G93750X+.
5. There is an offset from the temperature measured at the temp. sense location to the module pallet base of approximately +5 to 10°C. I.e. When the internal sensed temperature read from the module is +55°C then the temperature at the base of the pallet is approximately +80-85°C.

RFS-G90G93750X+ Performance Summary (Power Amplifier Mode)

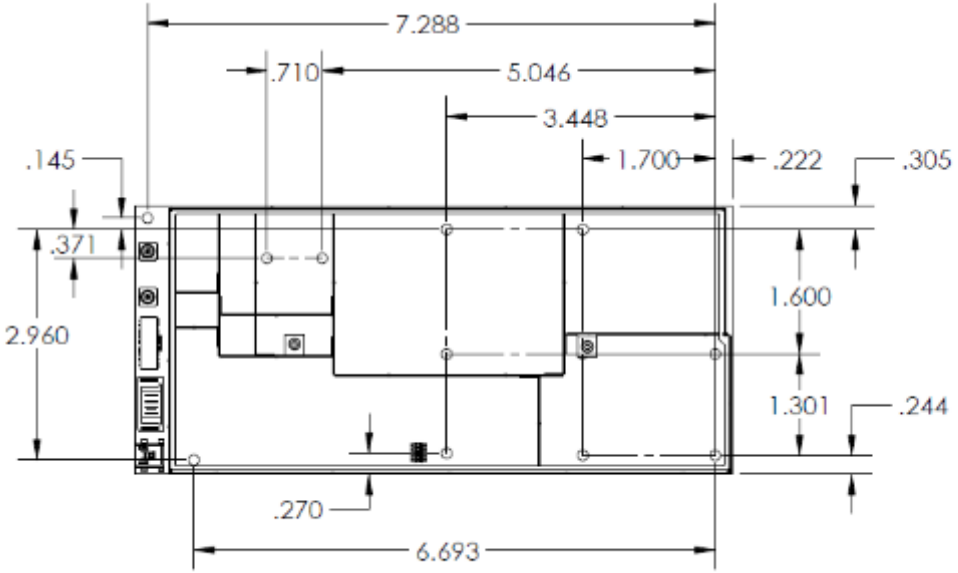


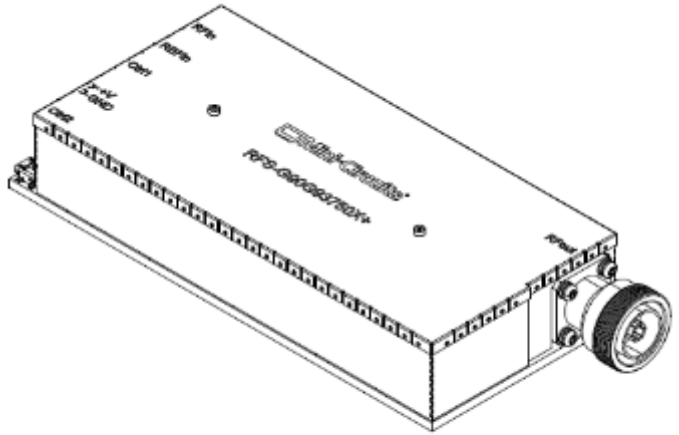


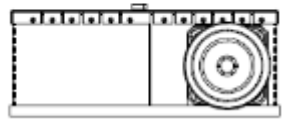




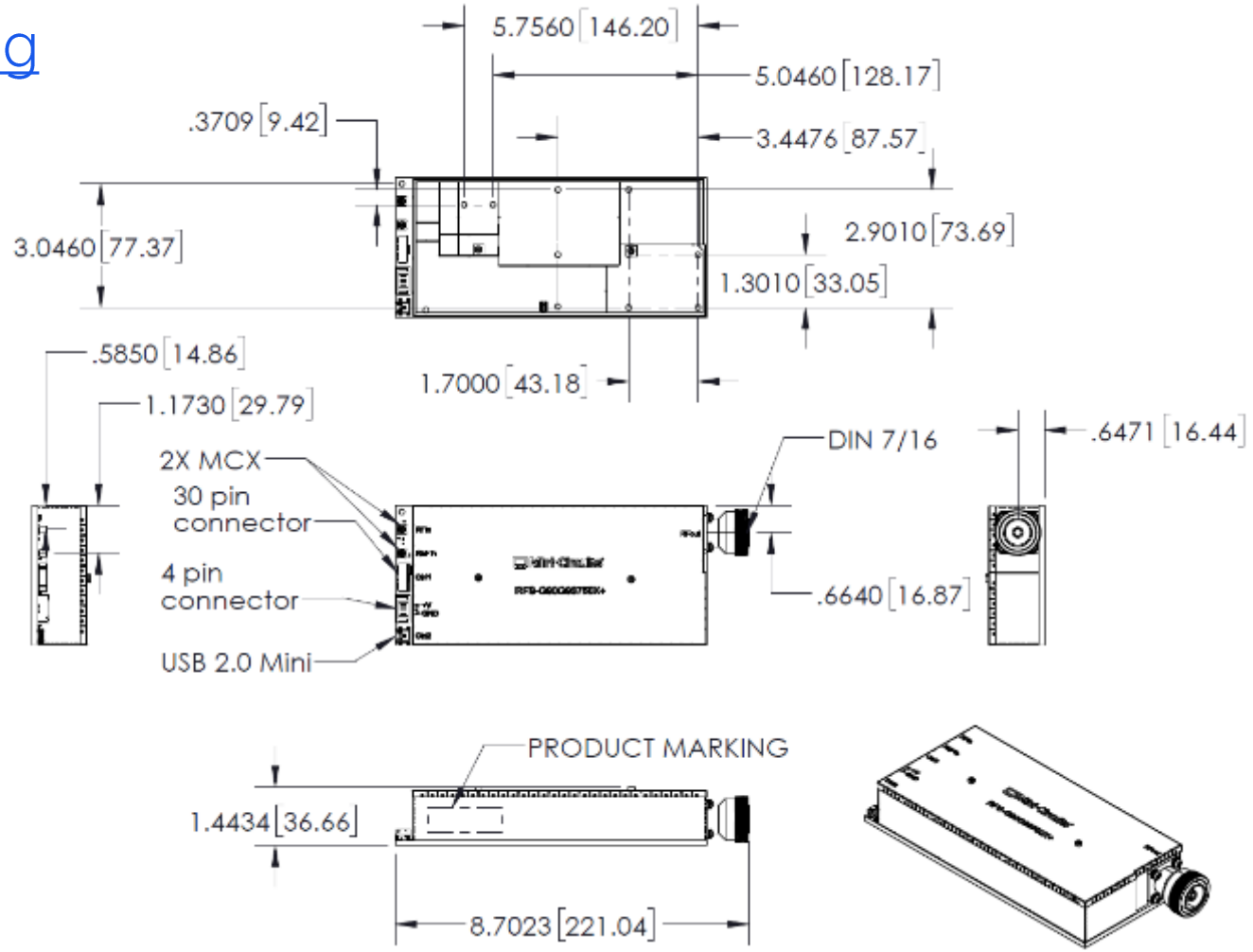
Outline Drawing







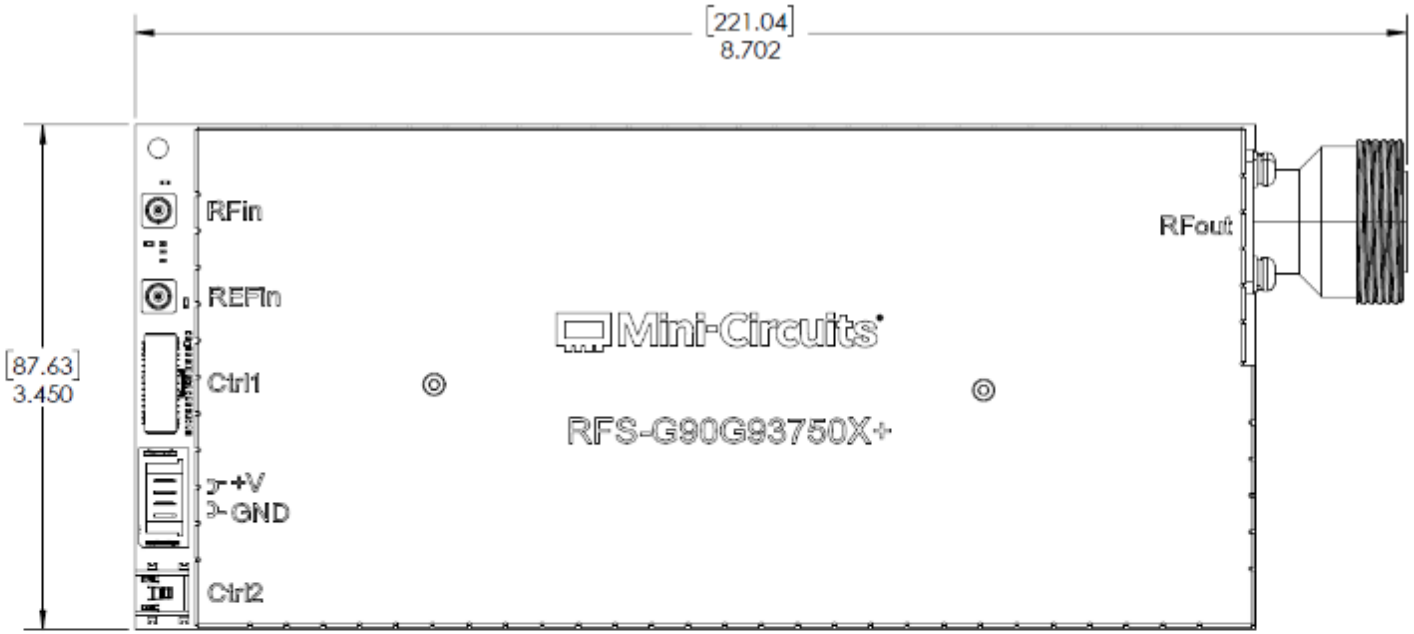
Case Style Drawing

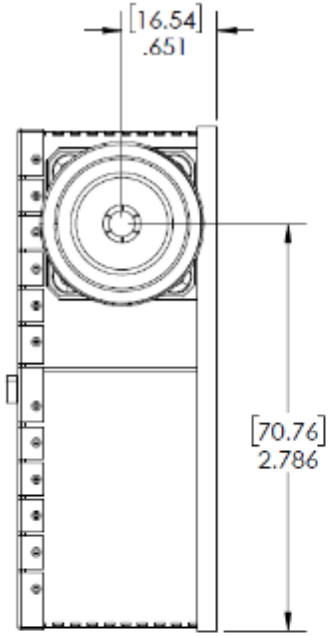


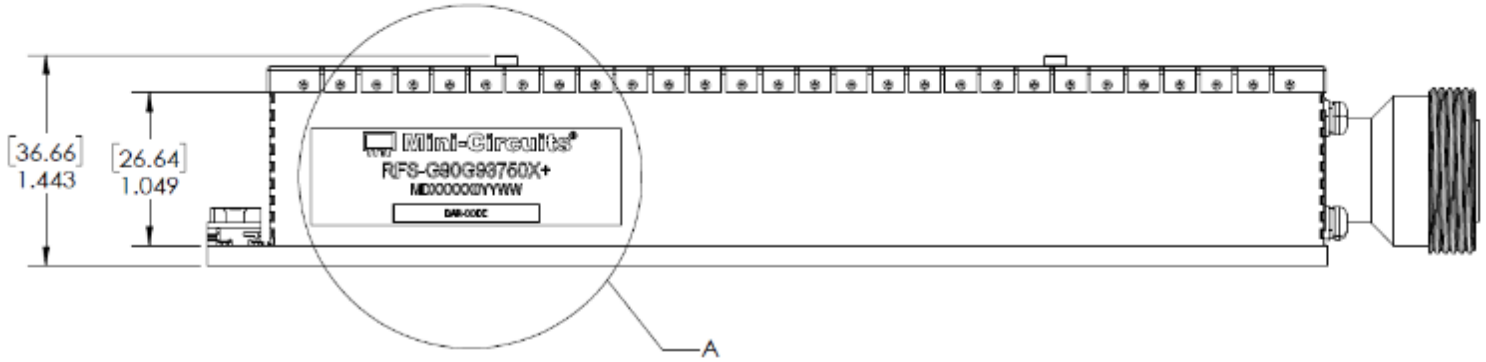
Dimensions are in inches [mm]. Tolerances: 2 Pl. ±0.03 inch; 3 Pl. ±0.015 inch

Notes:
1. Case Material/Finish: Nickel silver Shield and Cover. ENIG finish on bottom of PCB
2. Shield cover requires temporary removal to install mounting screws
3. M3 SHCS(DIN 912, ISO 21269) screws recomended for mounting.
4. 1.5NM (13lbf) Max. torque recommended for mounting screws.l
5. Weight: 200 grams

Final Inspection Drawing







MD = Connector type: MCX & Din
XXXX = Serial Number (can repeat with diff. date codes)
0 = Test Facility: MCL
YY = Last 2 digitd of year
WW = Week number

DETAIL A
SCALE 2 : 1

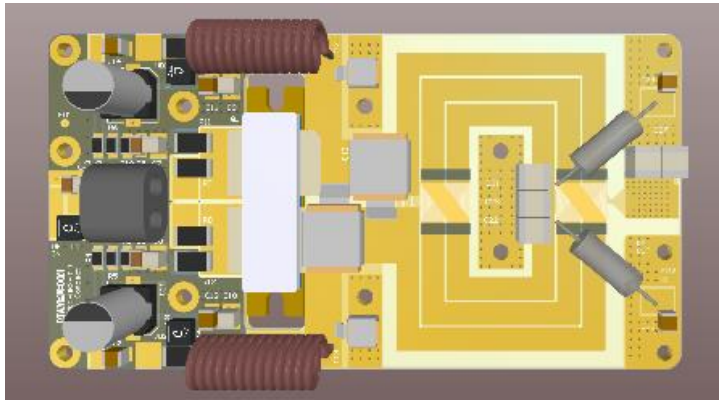
Low Frequency Platform

Products from 2MHz – 128MHz

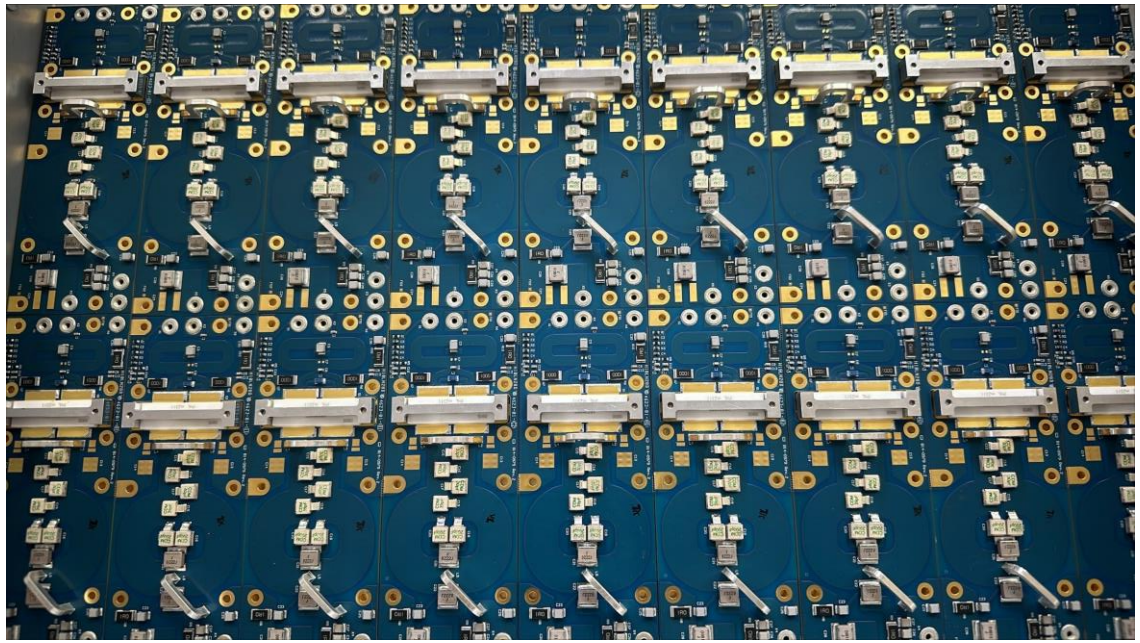
RFE-XXXX1K0X+

Low Frequency Platform Covers Products from 2MHz up to 128MHz

- Description:
  - Power levels from: 1.0kW – 1.7KW,
  - High Efficiency e.g. Class EF2
- Features:
  - Standard SMD
  - Multi-Layer PCB
  - Transformers Embedded in PCB
  - No Core & Wire
  - Best in class repeatability
- Volume Manufacturing:

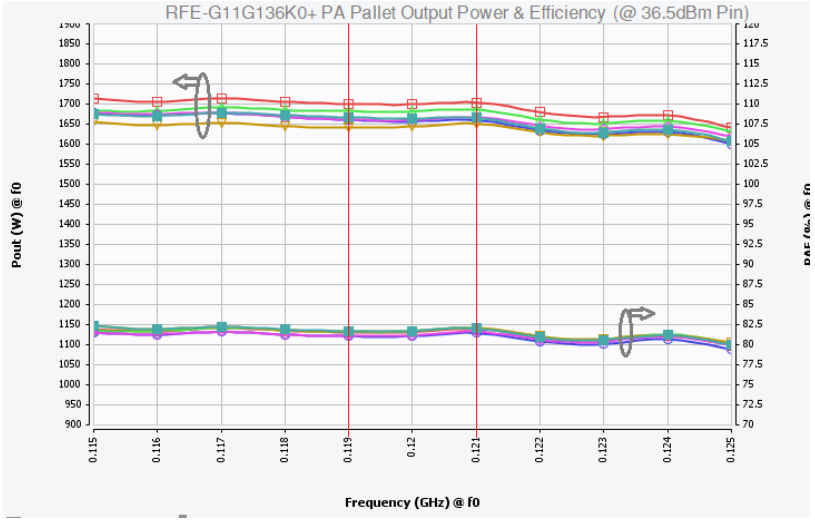


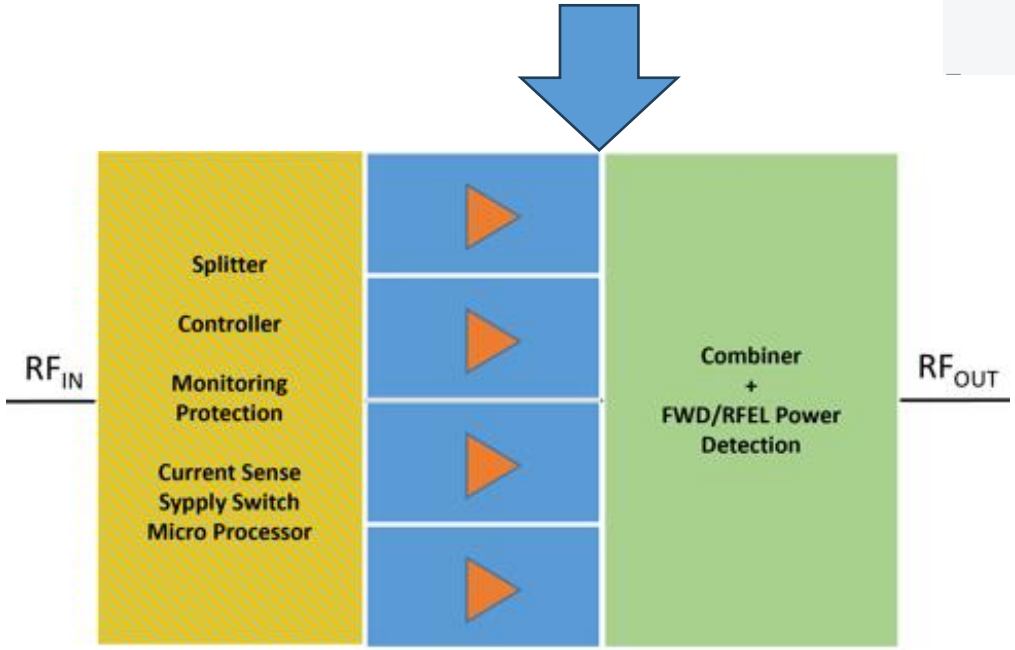
13MHz class EF2 reference PCB design
(Pout = 1.0kW CW / Eff = 90%)



120MHz building block

1.7kW, 120MHz
PA Pallet

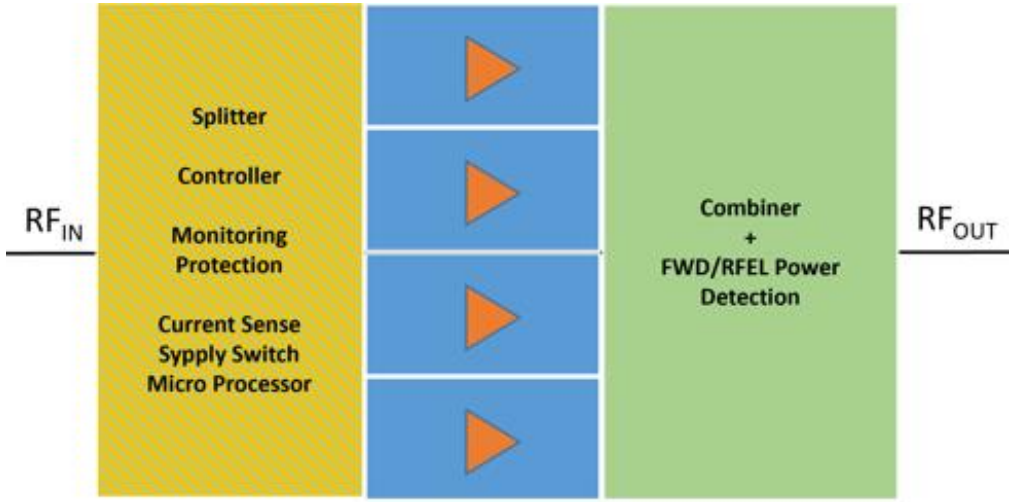




6kW, 120MHz
Module (20 x 40 cm)

Low Frequency Platform

Targeted Applications:
- Particle Accelerators
- MRI
-Energy



1kW -> 6kW, 120MHz Module
Covering: 2MHZ - > 352MHz

This Platform Supports The Following Applications

Application	Frequency	Power Options Available
MRI	64MHz 128MHz	1kW – 6kW
Industrial Heating	60MHz	1kW – 6kW
Laser	80 – 108MHz	1kW – 6kW
Wireless Charging	6MHz 13Mhz 41MHz	1kW – 6kW
ISM Applications	2MHZ 6MHZ 13MHz 27MHz 40MHz	1kW – 6kW
Particle Accelerators	120MHz 176MHz 325MHz 352MHZ 500MHz (other frequencies can be discussed 70MHz, 915MHz, 1300MHz, 2998MHz, 5800MHz)	1kW – 6kW

Availability	
Customer Samples	Call us to discuss your requirements

Plasma Application Examples

Ease of use

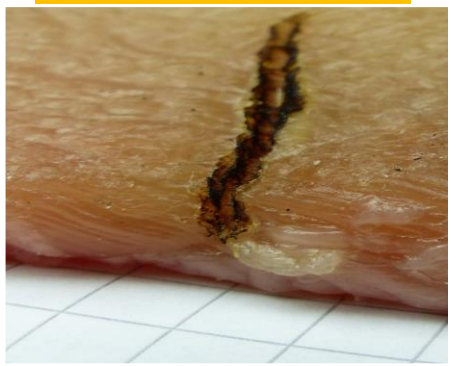
Examples of where our products are used in Solid-State Plasma Applications:

- Arc plasma
- Plasma jets
- Surface activation
- 3-D printing
- Sterilization
- Cutting
- Exhaust cleaning
- etc.

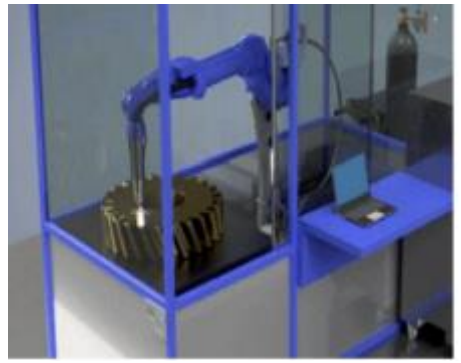
Recommend Product:
RFS-2G42G5050X+

Mini plasma jet with **10W** for cosmetic applications

Recommend Product:
RFS-2G42G5050X+

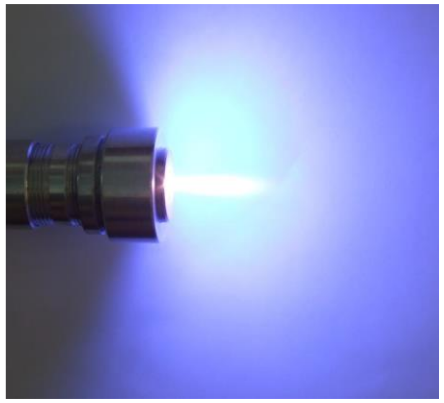


50W plasma scalpel cut in pork meat (comparable to human tissue)



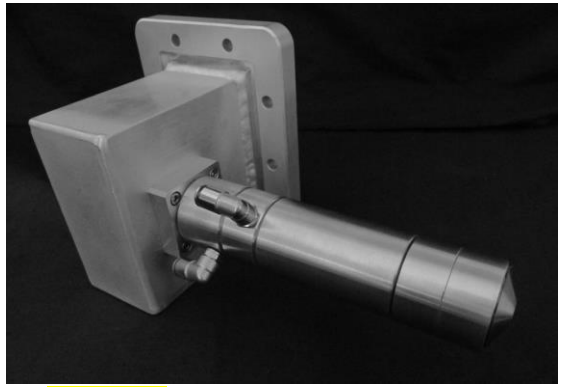
500W Plasma jet driven for 3-D printing

Recommend Product:
2 x ZHL-2425-250X+

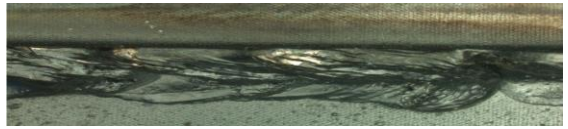


800W plasma Jet for air cleaning, activation and more

Recommend Product:
RFS-2G42G51K0+



6000W MW welder for steel, aluminum etc.



Need to build a Test Setup for your evaluation ?

Every Block Covered

Need to build a test setup ?

We probably have everything you need

SYNTHESIZER SIGNAL GENERATORS	Digital Step Attenuators, 50Ω	ISM-RF & MW Energy POWER AMPS, 50Ω
		
Low Noise AMPS, 50Ω	**CABLES**	**Check out our website**
		

Thank you

Every Block Covered