Workshop at Globe, CERN, Sep. 2022

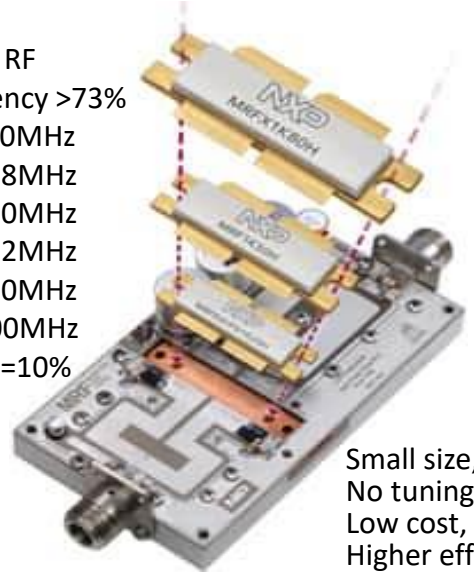
New Solid State Power Amplifier will be soon merge both Broadband & Large-power performance

When it's narrower-bandwidth,
much higher efficiency SSPA

Presented by Riichiro Kobana
R&K COMPANY LIMITED - ceo

Abstract;
R&K has achieved technological success in the fields of accelerators, mobile communications, plasma, EMC, and NMR/MRI. R&K's most differential feature is that it is a group of craftsmen and a manufacturing organization that values results obtained through actual trial and error.
By carefully adjusting the latest technology based on these experiences and achievements, R&K has been able to realize a newly designed solid-state power amplifier with both wide bandwidth and high output power, which will be released in the near future.
The control system, basic amplifier module, and power combiners, which are all the key components of these products, will be introduced.

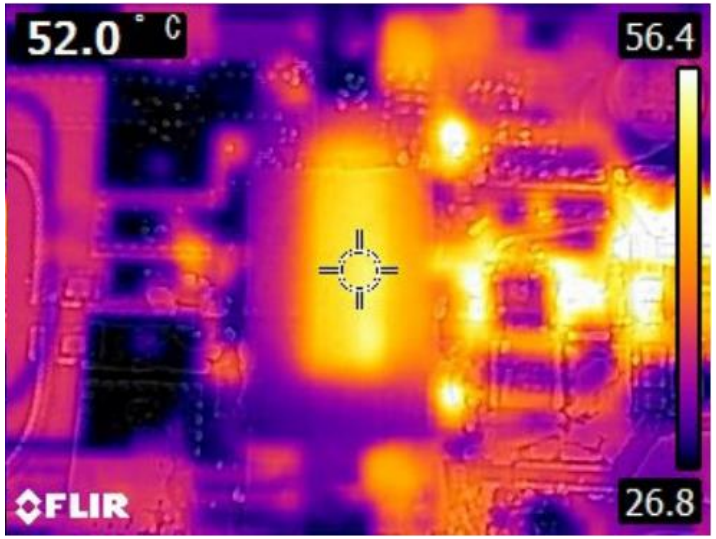
DC to RF
Efficiency >73%
@ 50MHz
@ 118MHz
@ 200MHz
@ 352MHz
@ 500MHz
@1300MHz
BW=10%



Small size, No loss,
No tuning, No adjust
Low cost, High MTBF
Higher efficiency !

courtesy of NXP semiconductor

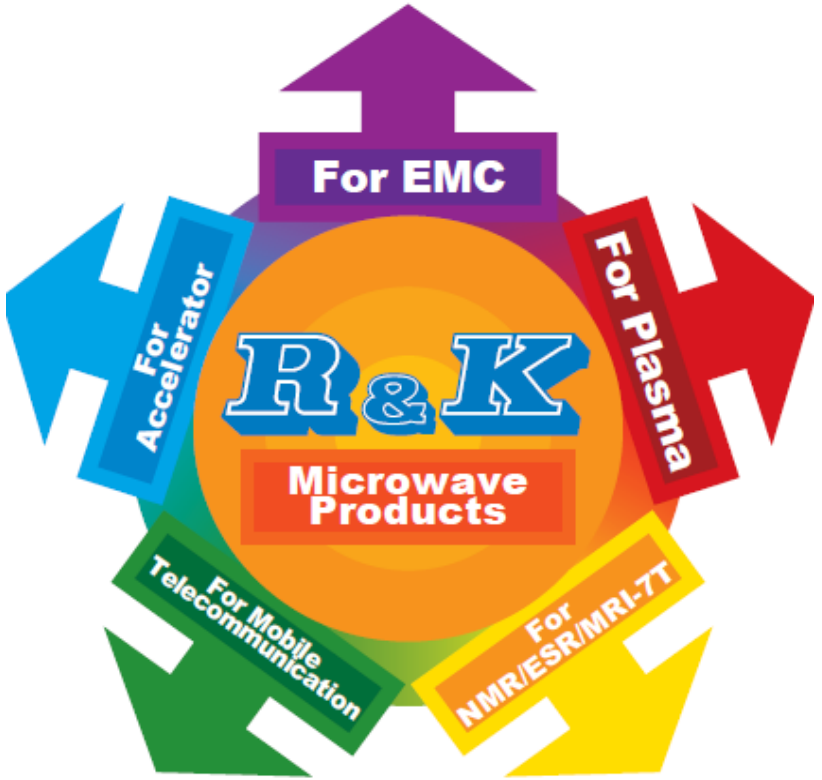
R&K 500MHz 96way, 100kW, WILKINSON



Proven to withstand >1,000,000 times even with thermal TC
to saturated Temp ON/OFF in 2 sec/2 sec pulse operation.

R&K's technological experience and footprints from the past Accelerators, Mobile Telecom, Plasma, EMC, and NMR/MRI. Our greatest feature is that we are a group of craftsmen and a manufacturing organization that values results through actual trial and error.

1. Quality manufacturing in Japan of exceptional products for 45 years. Founded private in 1977.
2. A globally connected company with direct purchasing in southeast Asia to control costs.
3. RF Power Amplifiers manufactured using unique radial combiner and ferrite combiner designs.
4. Product design optimized with proprietary 2D & 3D CAD software, HFSS, MDS and others.
5. Standard products are available from off-the-shelf, based on current price list. Easy design and easy actual evaluation are possible.

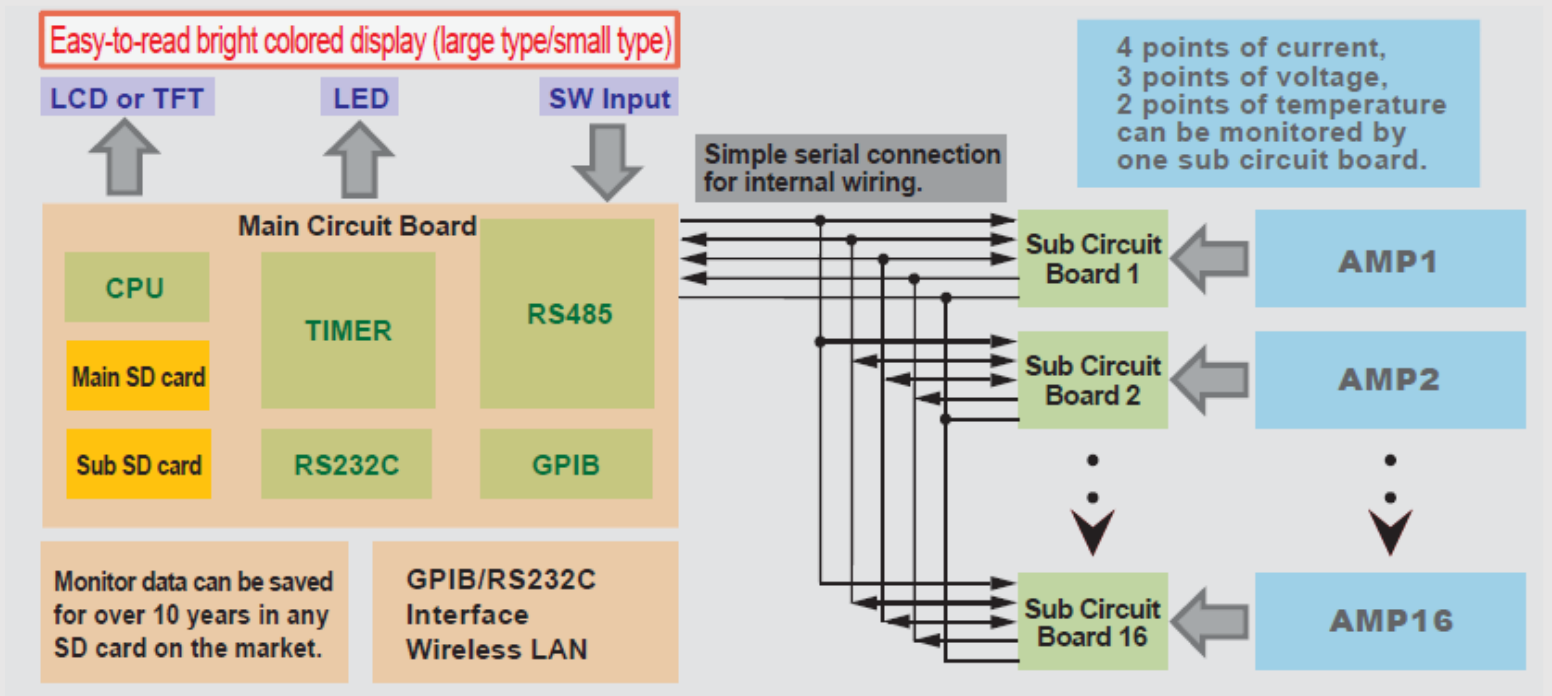


Feature one; R&K's Multi-Monitoring System

〔Photo〕Front Panel Display Sample

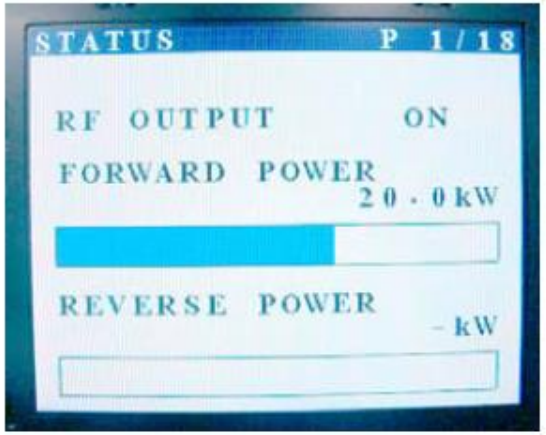
- Monitor data, such as current, voltage, temperature, forward power and reverse power, can be saved for more than 10 years on any type of SD memory card.
- Saved data can be viewed by LCD and/or TFT at anytime.
- R&K warrants amplifiers equipped with new display panel for a period of 3.5 years.
- Easy-to-read brightly-colored display with large or small font.
- GPIB/RS488 and other interface enables control by command input through computer for functions such as: ON/OFF and Band Switching.

R&K's Multi Monitoring System (Cont'd)

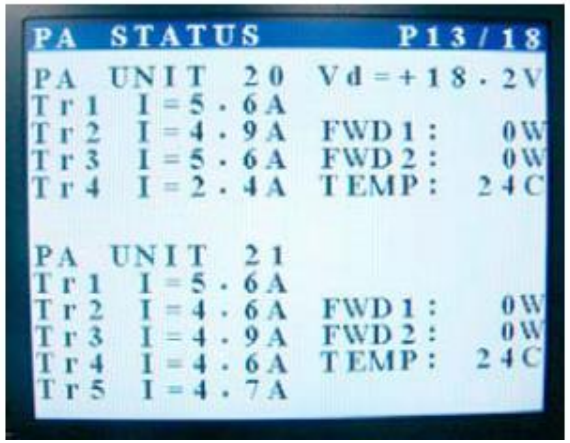


All details such as time the unit was powered on, value of forward power, reverse power, currents, voltages, temperature and TTL are recorded and saved. All data can be sent to R&K via email for diagnoses when necessary.

Feature two; R&K's Digital Panel Meter



Forward power/Reverse power



Detailed status

Compact LCD panel meter

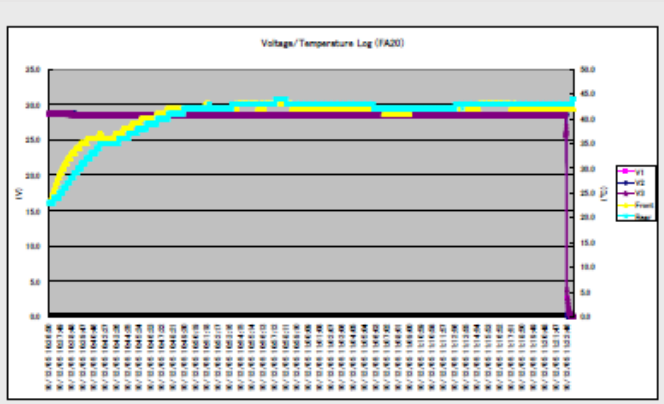
- ***REVIEWABLE*** Monitor data can be saved for over 10 years on USB flash drive
- ***MONITORABLE*** Data can be viewed by LCD or TFT at anytime
- ***PREDICTABLE*** Failures may be predicted through data analysis after long usage
- ***IDENTIFIABLE*** Easily identify errors if problems occur

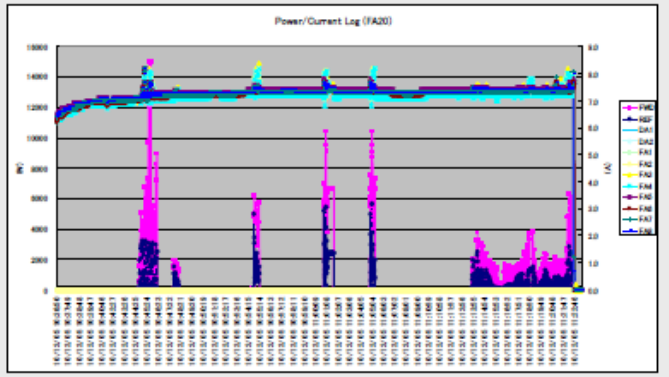
R&K's Digital Panel Meter (Cont'd)

Analysis – performance can be analyzed by the data taken into USB drive

- Data can be extracted in text format and graphs can be made after converted into Excel
- Degradation can be identified

Data Analysis 1





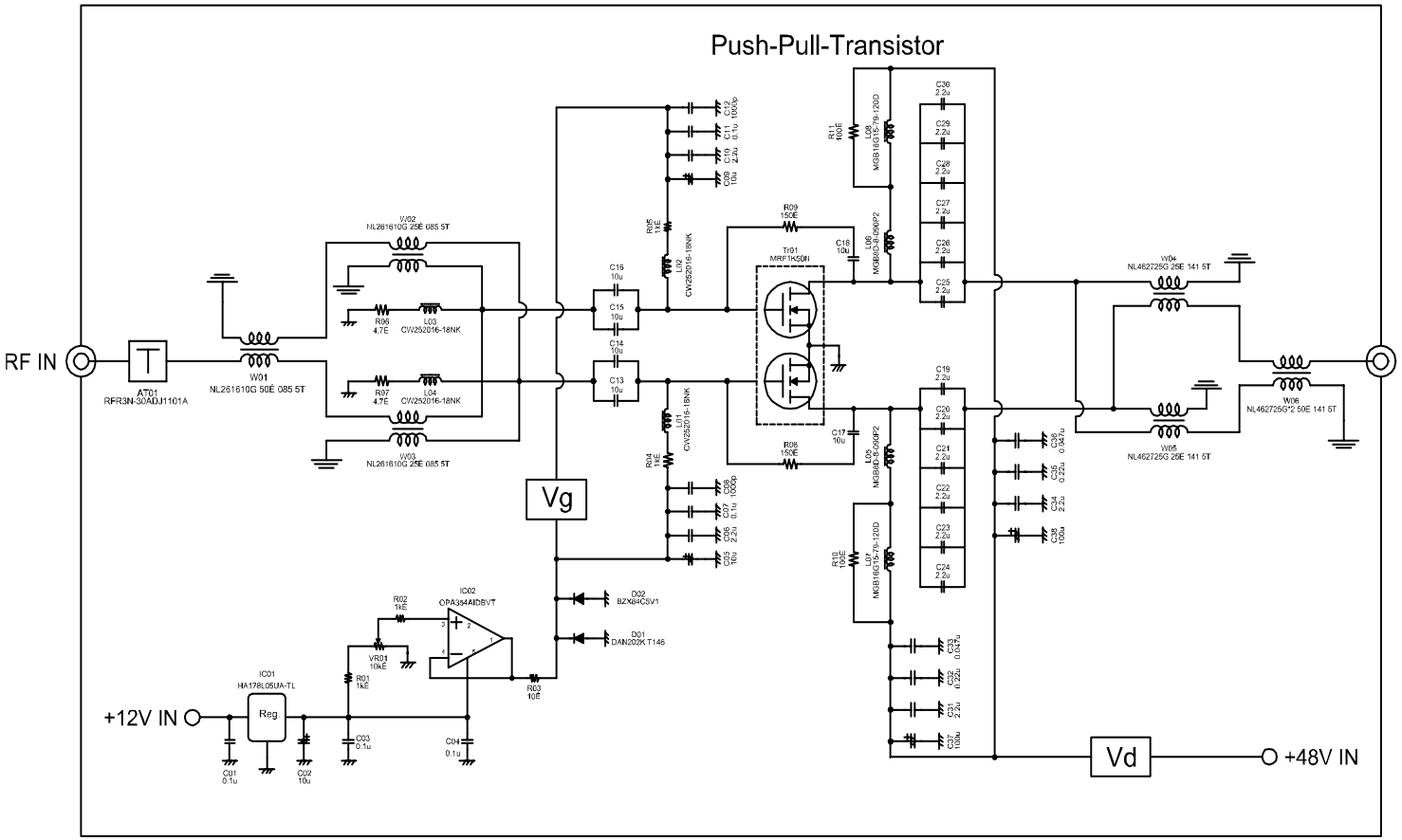
Data Analysis 2

Diagnosis – easily identify problems

- Easily identify problems if an amplifier is out of order as device current consumption and device voltage supply are always monitored and recorded

Feature three; Push-Pull-Transistor Circuit diagram

Typical Broadband (GaAs / MOS / GaN) FET Power Amplifier Test Circuit



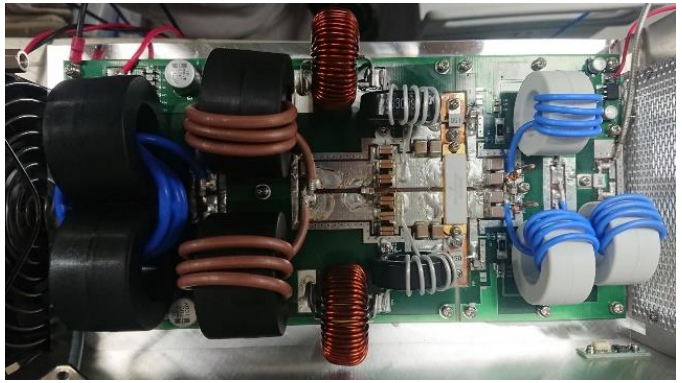
1) There are not so many circuits for the SSPA device itself, which is the basis of semiconductor power amplifiers.
For example, if the current semiconductor devices are LDMOS-FET, GaN-FET, and GaAsFET, there is only one circuit diagram of a simplified push-pull amplifier.

2) However, there is actually a more important problem than how to connect the circuit.
It will require specific performance and characteristics for each individual part, but it may be the difference by the external shape or the materials of the parts, so the experience from the past is much more important to prepare at first.

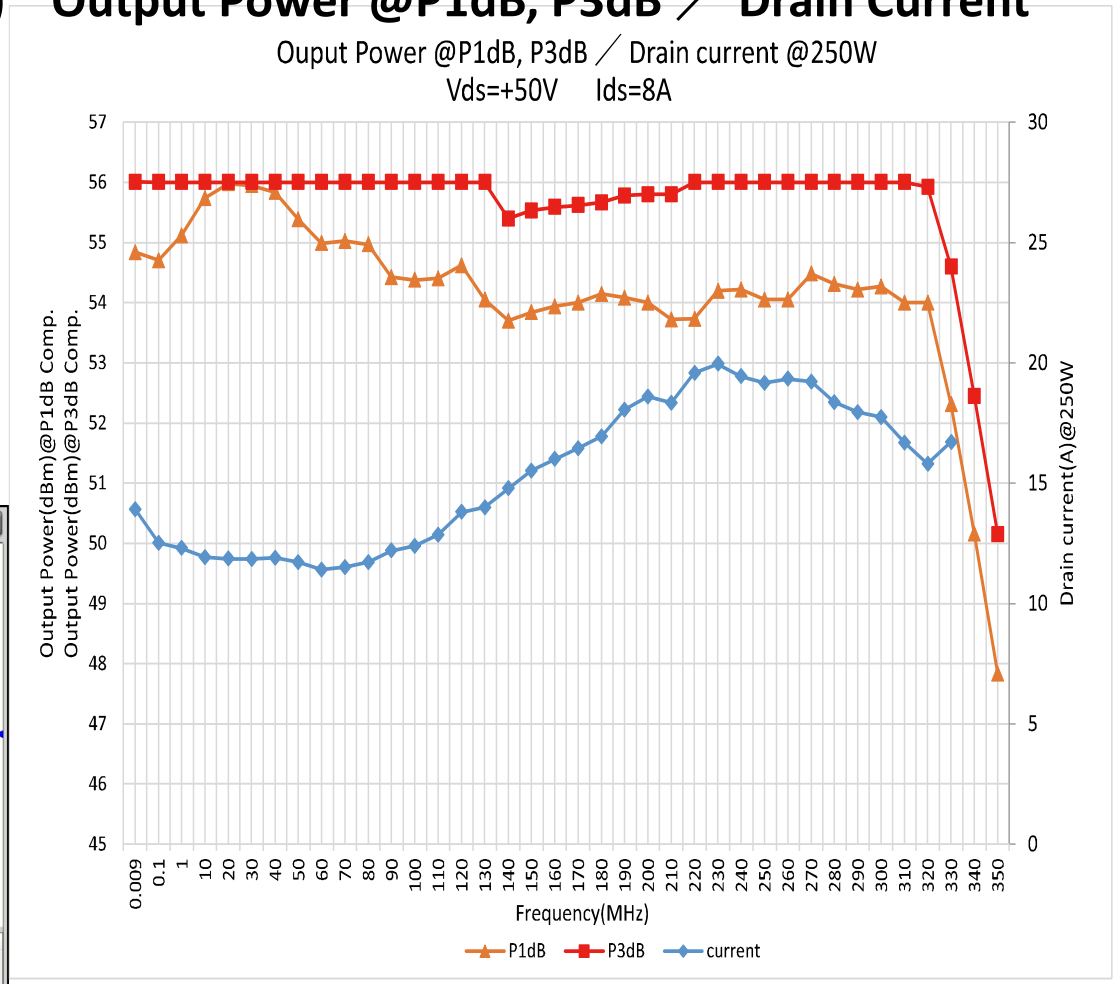
3) The most important thing in the basic design is that if you have the purpose of obtaining broadband characteristics, you may sacrifice other characte-ristics. We cannot be greedy for anything other than main purpose.

R&K PA-031 Module(NXP-MRFE6VP61K25H) Test Data

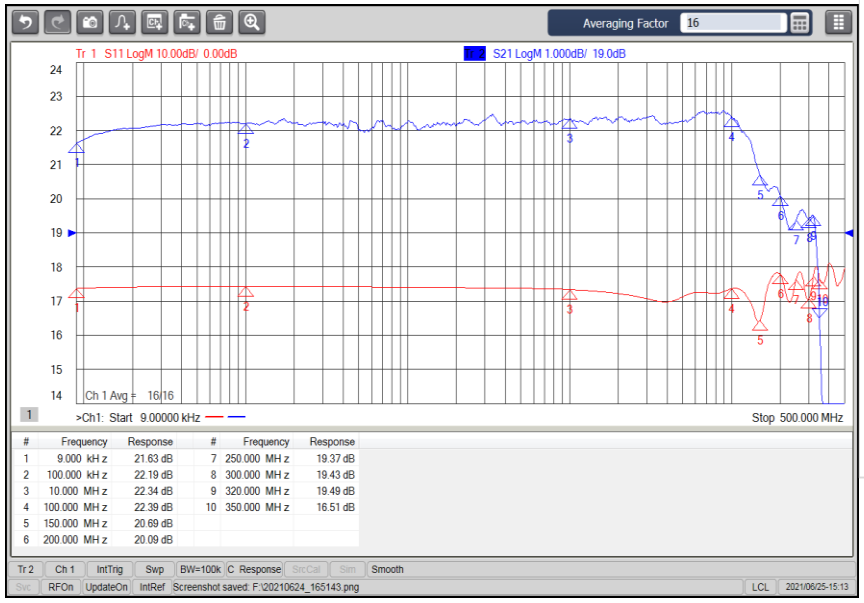
Module Pic(Actual 9kHz-320MHz>200W)



Output Power @P1dB, P3dB ／ Drain Current



Gain(9kHz～500MHz)

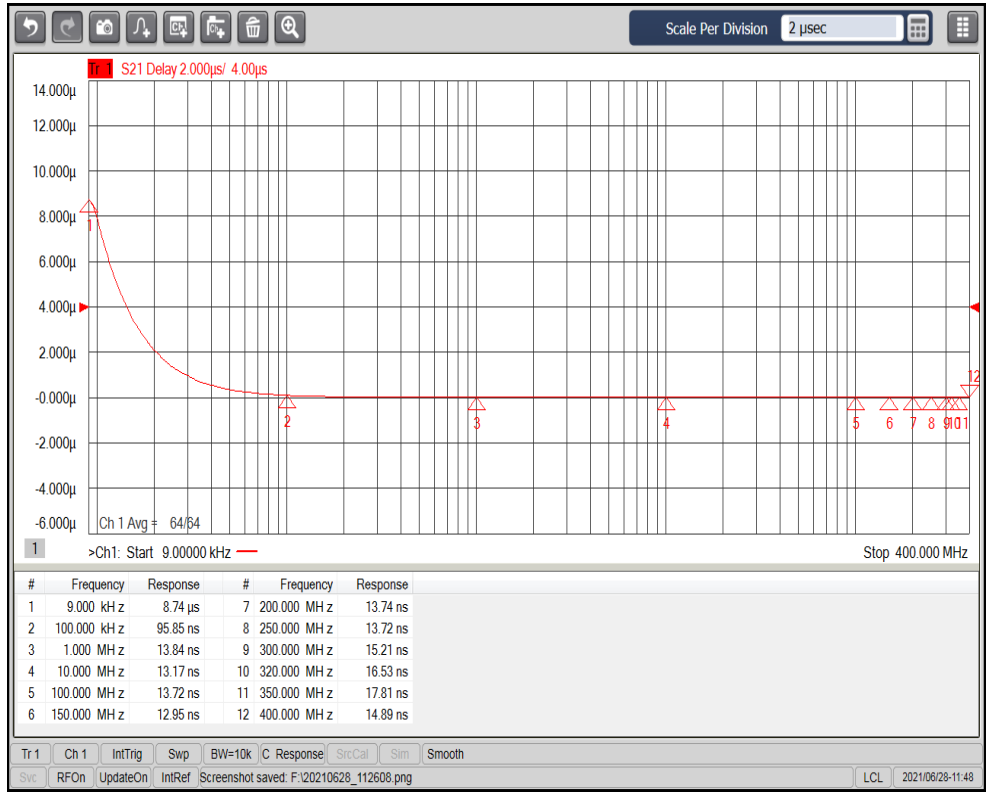


#	Frequency	Response	#	Frequency	Response
1	9.000 kHz	21.63 dB	7	250.000 MHz	19.37 dB
2	100.000 kHz	22.19 dB	8	300.000 MHz	19.43 dB
3	10.000 MHz	22.34 dB	9	320.000 MHz	19.49 dB
4	100.000 MHz	22.39 dB	10	350.000 MHz	16.51 dB
5	150.000 MHz	20.69 dB			
6	200.000 MHz	20.09 dB			

A basic transistor operates stably at frequencies from DC to 500MHz or more, and rather than how to increase performance and broaden the bandwidth, but how to reduce performance and broaden the bandwidth with reasonable total performance.

R&K PA-031 Module(MRFE6VP61K25H) Test Data

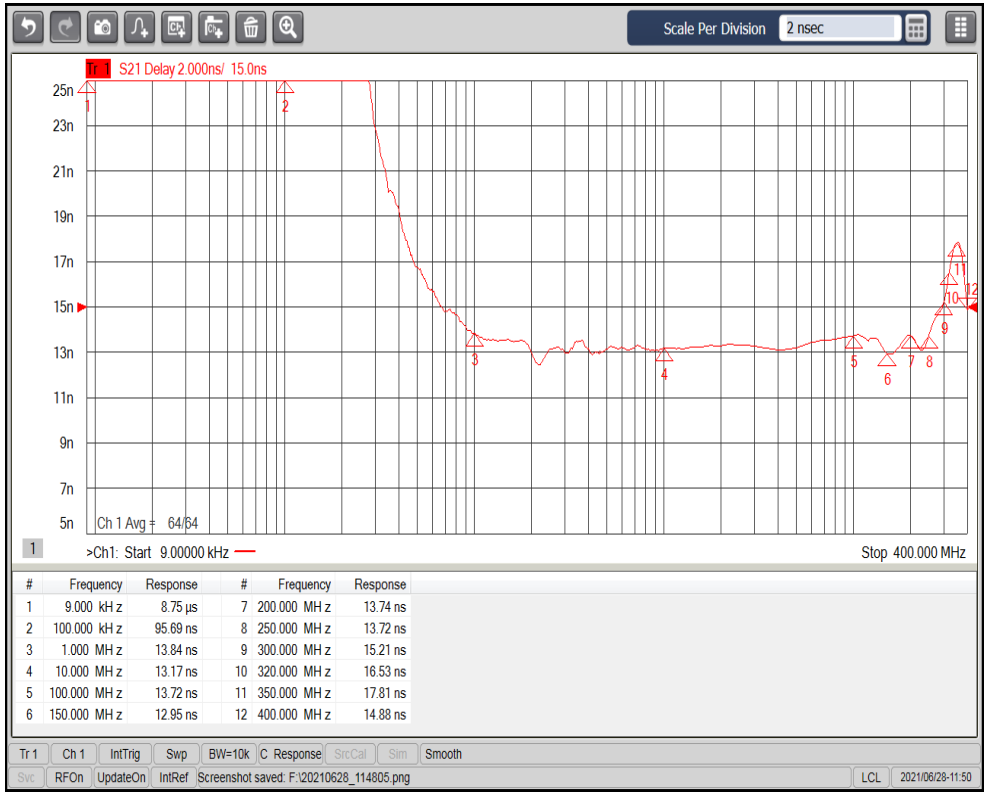
Group Delay (Scale=2µs)



9kHz to 400MHz broadband Group Delay data
P@-1dB gain compression was adjusted >200W

2µ sec / div. scale

Group Delay (Scale=2ns)

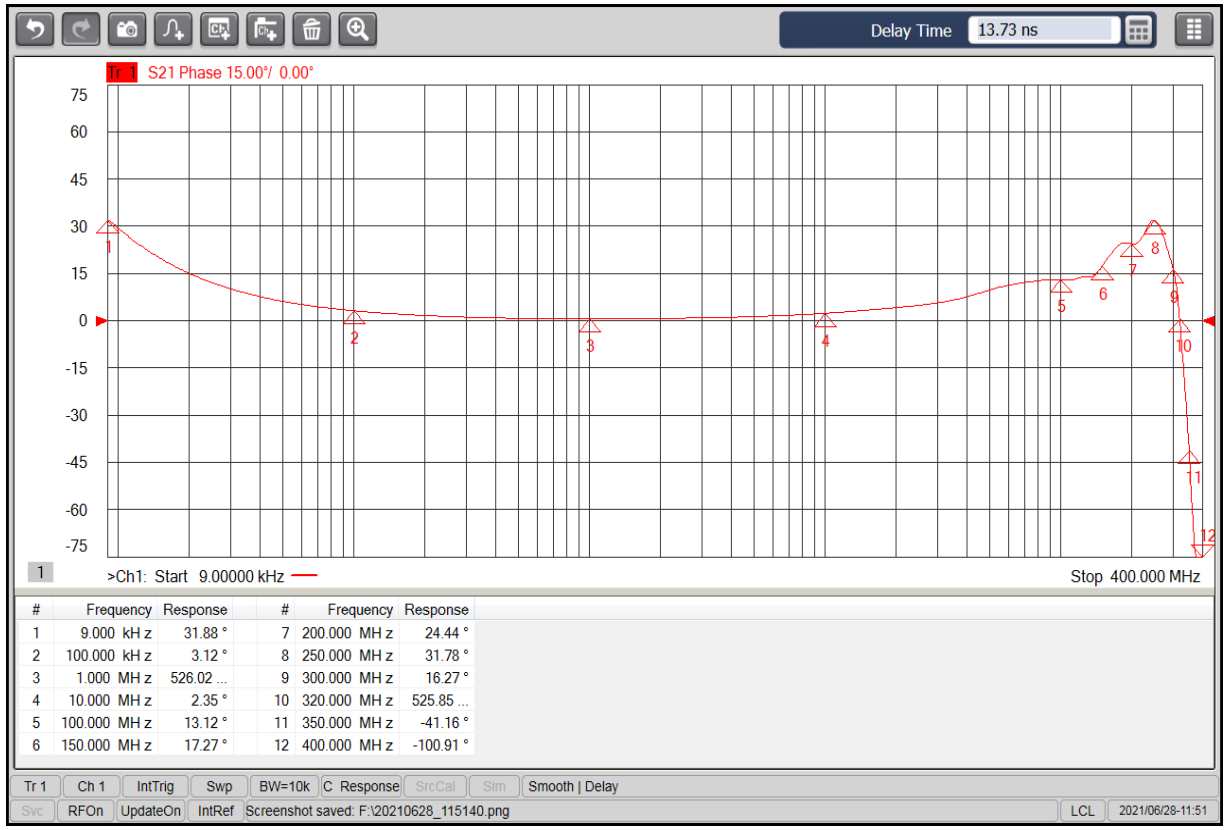


9kHz to 400MHz broadband Group Delay data
P@-1dB gain compression was adjusted >200W

2n sec / div. scale

R&K PA-031 Module(MRFE6VP61K25H) Test Data

Phase Flatness



Delay Time=13.73ns, Delay Distance=4.12ms, Phase Offset=0°

In the case of normal class AB or class A SSA circuits, the offset of the DC bias voltage on the gate side is super-imposed on the input signal waveform, so the bi-polar-pulse signal is distorted and can not be amplified directly.

However, this amplifier circuit has the characteristics of a circuit that specifically solves this problem, reduces the amount of group-delay as much as possible, and can drive the TEM stripline kicker.

＊SSA is phase invertered per device so we put phase inverter for each odd stage to amplify pulse at the same phase in any stage.

Ultimately, it became possible to put it into practical use in the next generation from 9 kHz to 500 MHz.

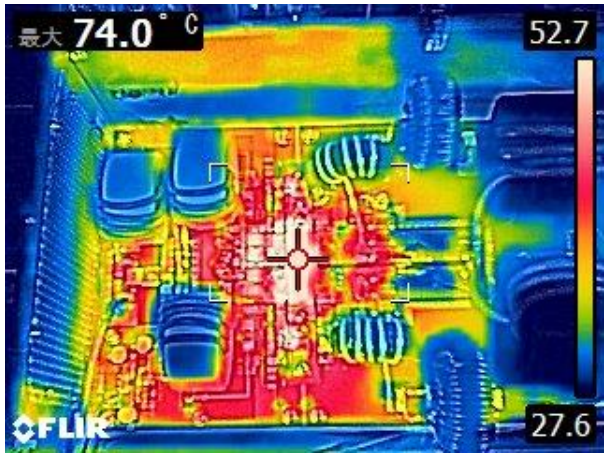
R&K PA-031 Module(MRFE6VP61K25H) Test Data

Module Thermal data

f=9kHz/Po=250W

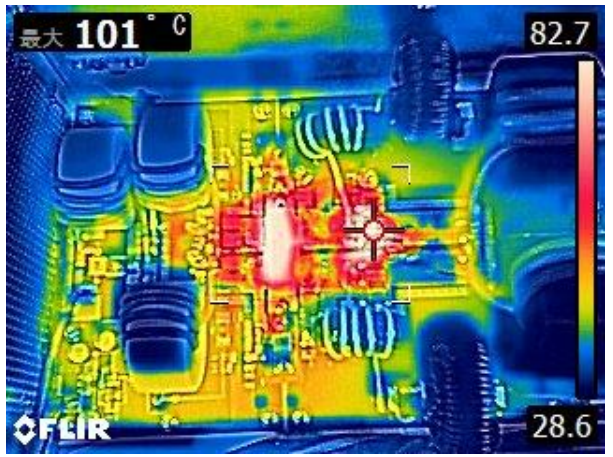
f=1MHz/Po=250W

f=10MHz/Po=250W



f=100MHz/Po=250W

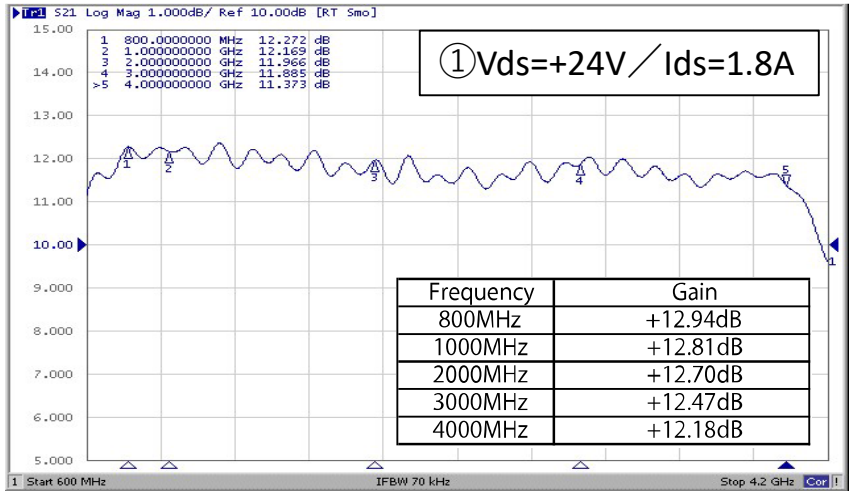
f=200MHz/Po=250W



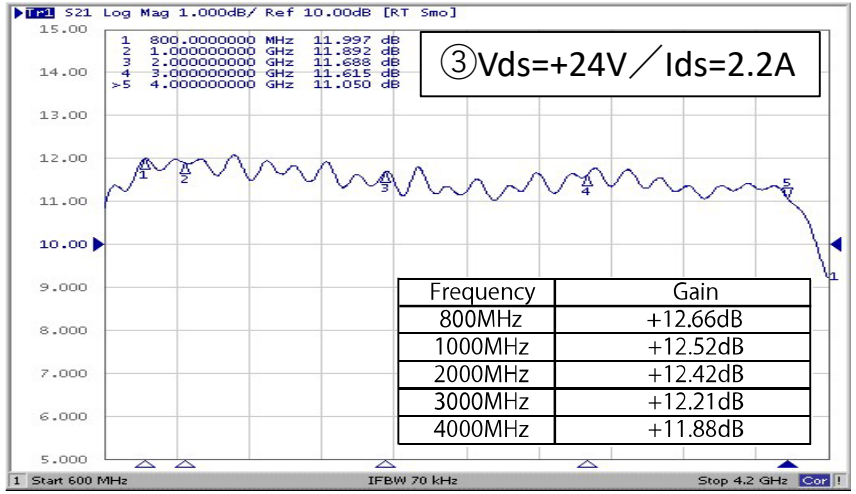
f=320MHz/Po=250W

Wolfspeed model CG2H40045 Test data by R&K

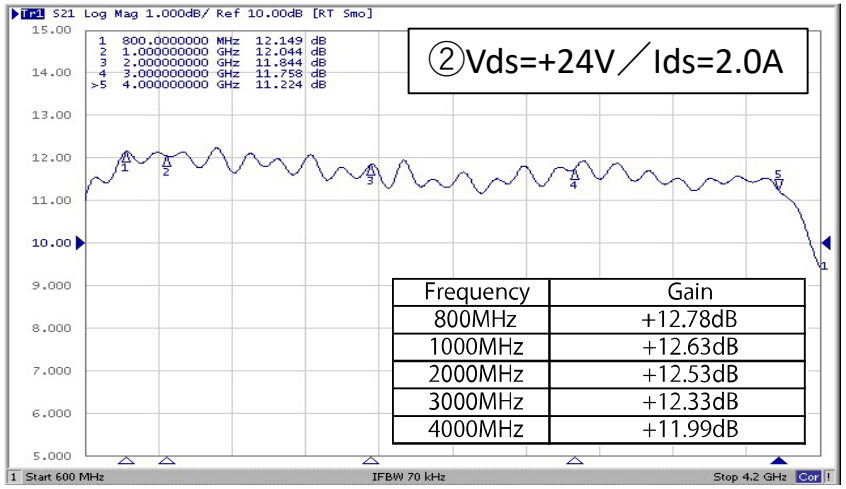
In-Band Gain Deviation



Frequency	Gain
800MHz	+12.94dB
1000MHz	+12.81dB
2000MHz	+12.70dB
3000MHz	+12.47dB
4000MHz	+12.18dB



Frequency	Gain
800MHz	+12.66dB
1000MHz	+12.52dB
2000MHz	+12.42dB
3000MHz	+12.21dB
4000MHz	+11.88dB



Frequency	Gain
800MHz	+12.78dB
1000MHz	+12.63dB
2000MHz	+12.53dB
3000MHz	+12.33dB
4000MHz	+11.99dB

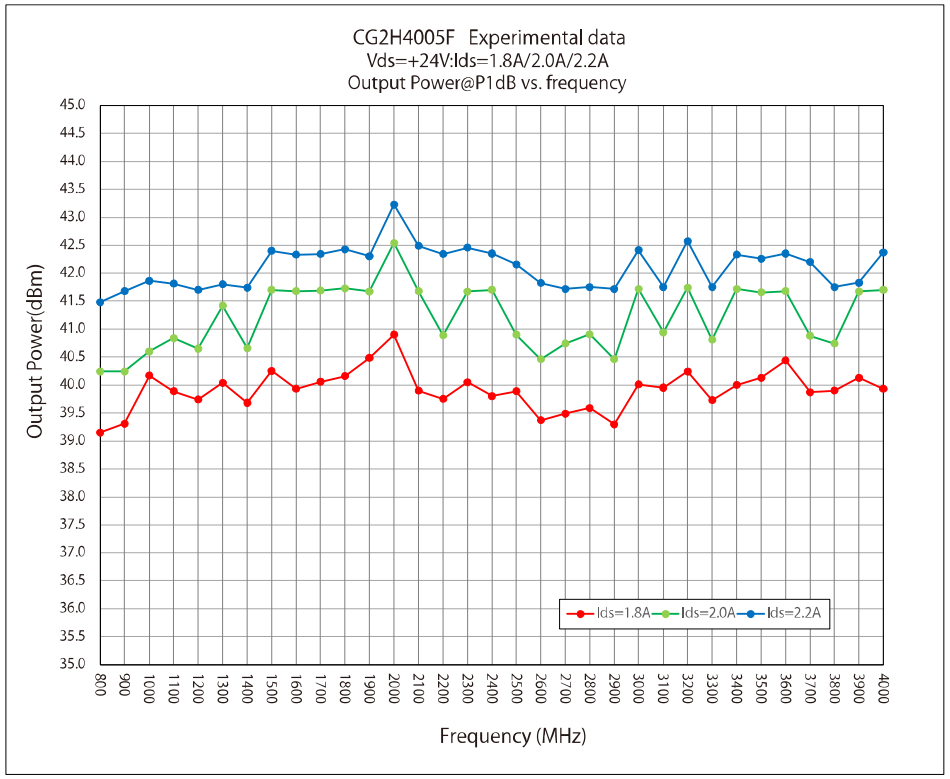
Now, this is a new device, Wolfspeed's "unmatched, single-ended" GaN device which is quad-hybrid combined structure performance. This is so simple circuits.

Note that there is no significant change in frequency response with adjustment of Idq, but there is a very large impact on linearity and maximum output power performance by Idq difference.

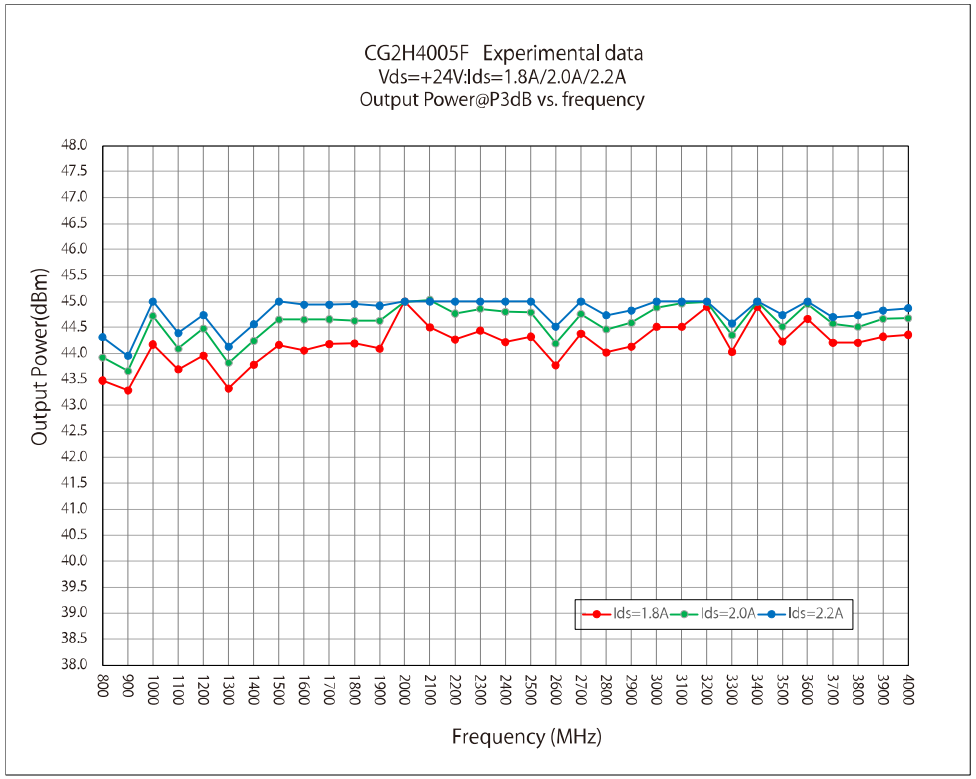
Wolfspeed model CG2H40045 Test data by R&K

Output Power P1dB＆P3dB

①P1dB (Vds=+24V／Ids=1.8A／2.0A／2.2A)



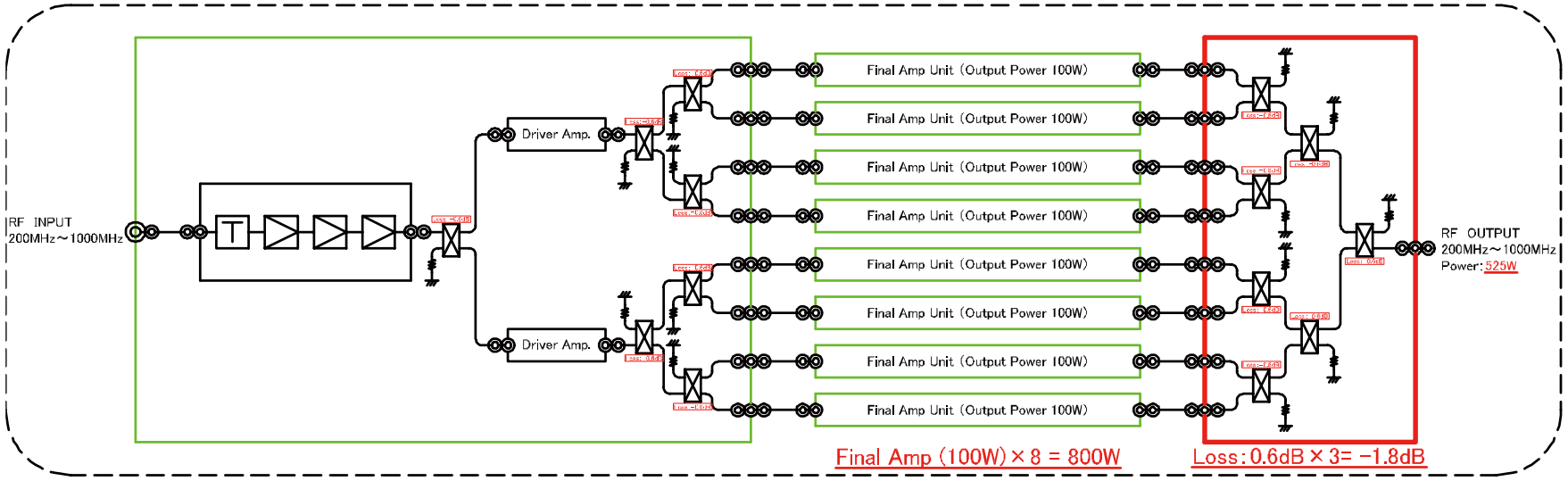
②P3dB (Vds=+24V／Ids=1.8A／2.0A／2.2A)



2 push-pull GaN in a module can get >20W@P-1dB for 800MHz to 4000MHz without MMIC.

R&K's Radial Combiners

(Conventional) 90 degree hybrid combiner



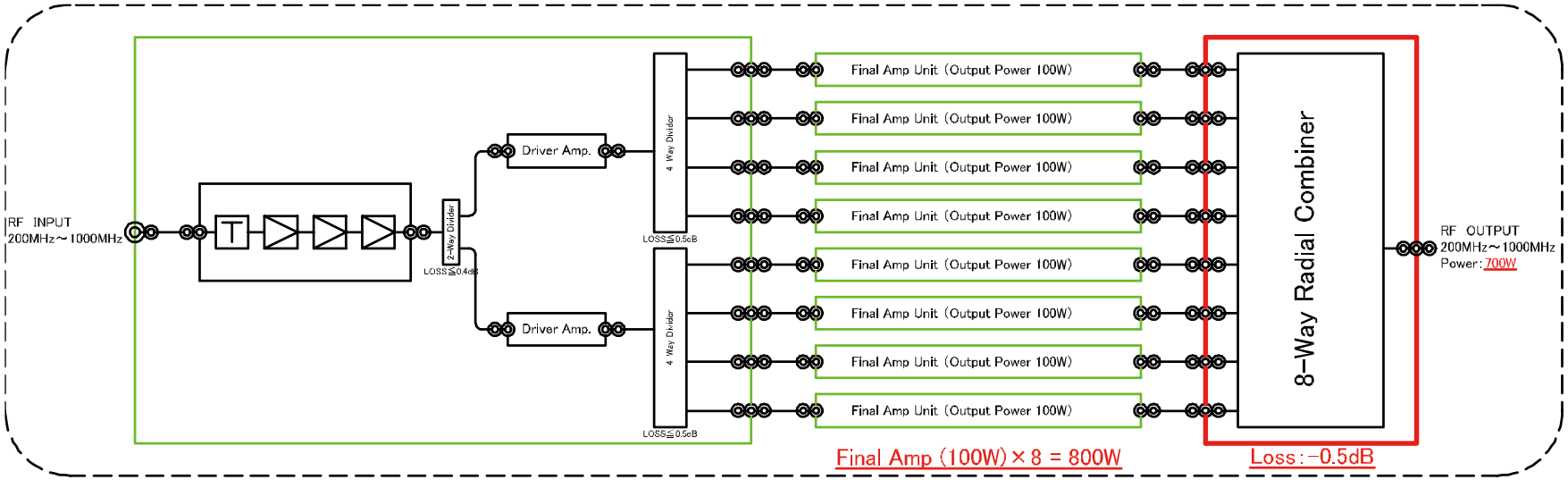
100W × 8 = 800W(+59.03dBm)
(+50dBm + 9.03dB(8WAY))
↓ Combiner loss = -1.8dB
+59.03dBm - 1.8dB = +57.2dBm(528W)

In this ancient method, there is significant loss in the output quadrature combiner but we only can get 528W, even the source is 100W x 8 = 800W originally.

Next page; 8-Way Radial Combiner has 180W larger power.

R&K's Radial Combiner (Cont'd)

8-Way Radial Combiner



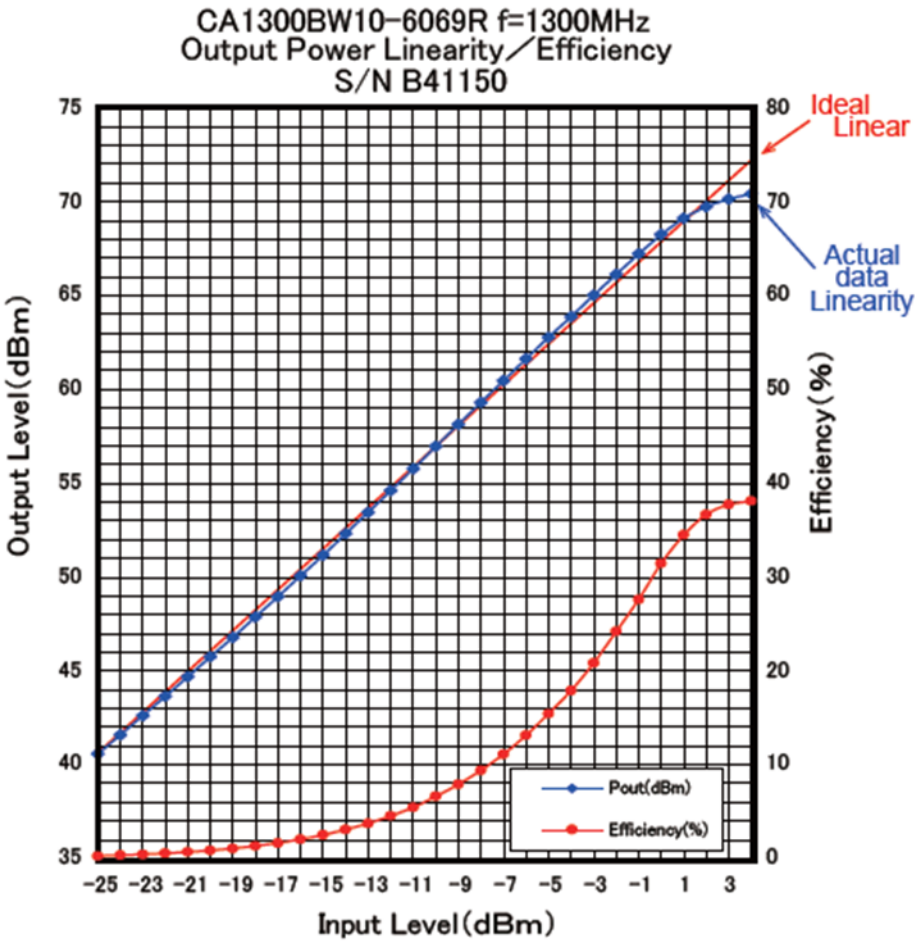
100W × 8 = 800W(+59.03dBm)
(+50dBm + 9.03dB(8WAY))
↓ Combiner loss = -0.5dB
+59.0dBm - 0.5dB = +58.5dBm(708W)

Even if one unit of Final Amp Unit (Power 100W) is reduced…(Fault)

⇒100W × 7 = 700W(+58.45dBm)
(+50dBm + 8.45dB(7WAY))
↓ One port at λ/4 short.
+58.45dBm - 0.5dB = +57.95dBm(623W)

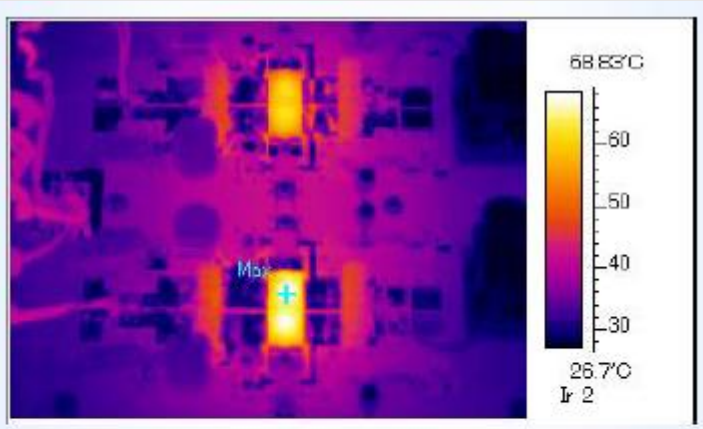
=> Radial combiner's output is larger than 90 degree hybrid combiner!

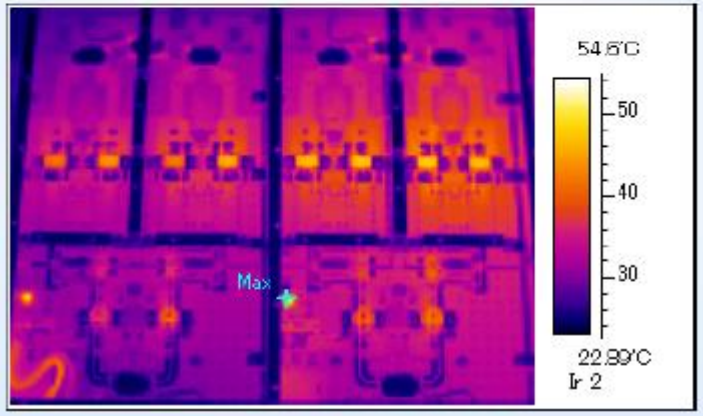
Linearity



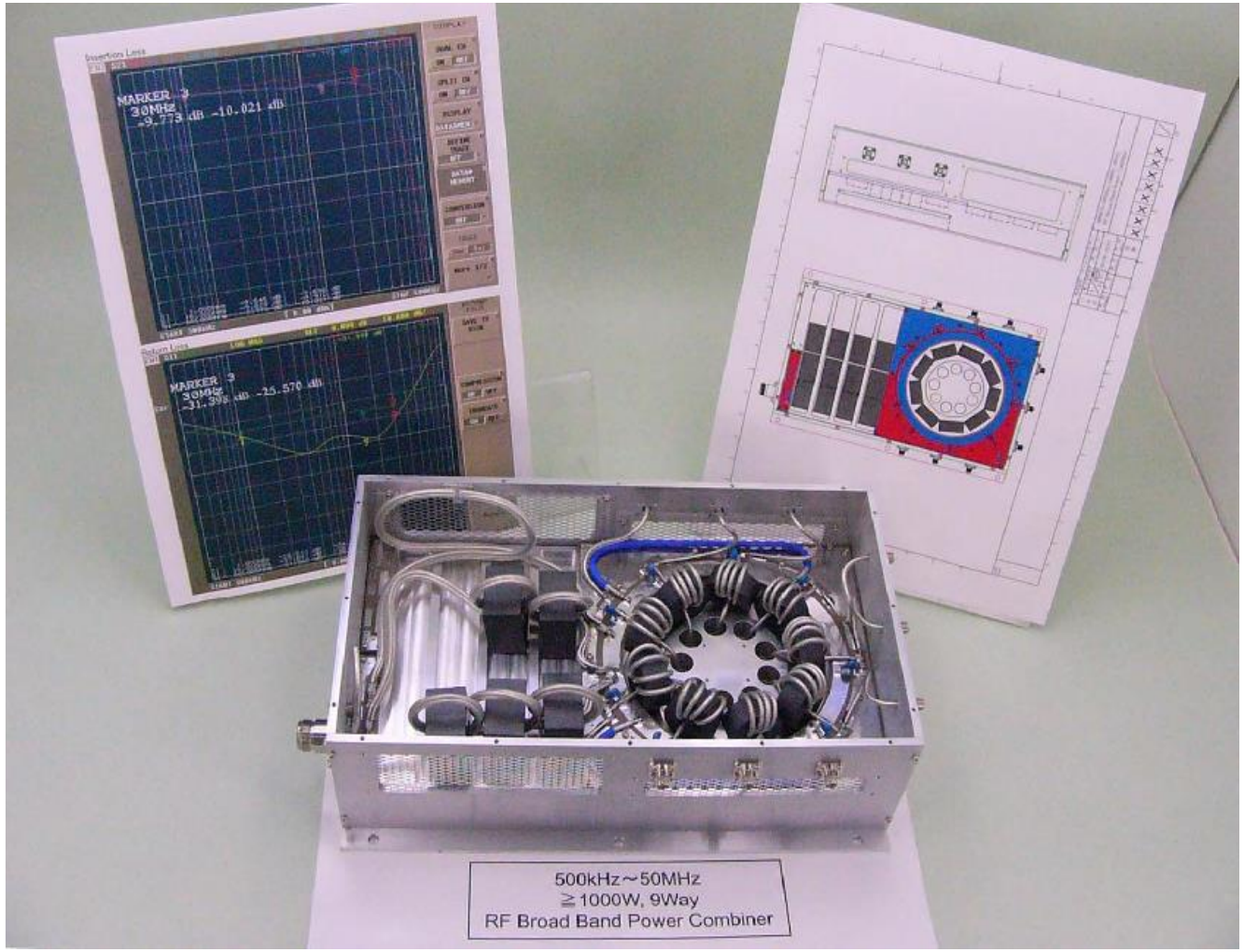
- Exact performance of R&K's RF power amplifiers with LDMOS solid state device.
- Ideal vs. Actual Linearity performance of class AB amplifier.
- Actual Linearity: within a dynamic range, Linearity = rolling and winding, unlike Ideal Linearity.
- R&K's RF power amplifiers with LDMOS solid state device are applicable to any applications that focus on Linearity.
- Even CW-55kW complete class AB can perform the phase stability less than zero to -14deg over 5kW to 55kW.

Pre-shipment Inspection



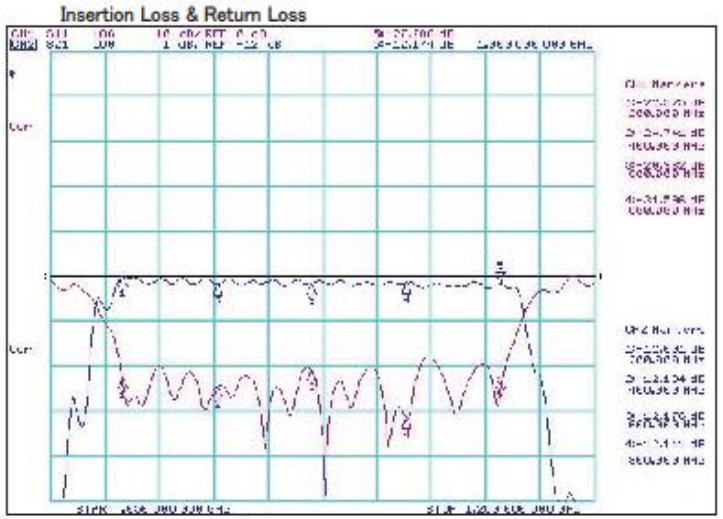


Prior to shipment, all R&K power amplifiers are inspected by infrared thermal cameras. The inspection data is saved and recorded as part of the quality control process.



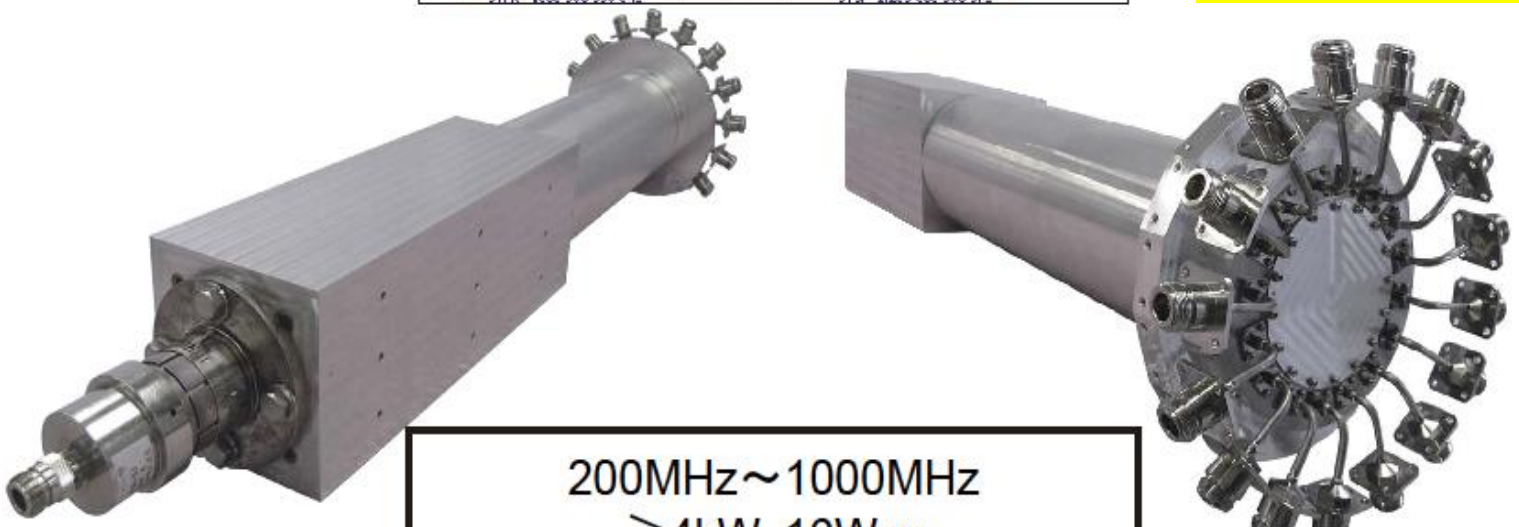
R&K manufactures various kind of RF power combiners, but in this case, for example, the WILKINSON method combining circuit goes through equally divided by multiple impedance transformers.

The biggest feature of this method is that it combines 1 kW of power, but distributed power is given to the transformer load, and both RF power and heat-temp will be distributed and loaded.
So, the input transformers are all small size but output impedance transformer is big enough to pass through 1kW.
500kHz-50MHz, >1000W, 9 way

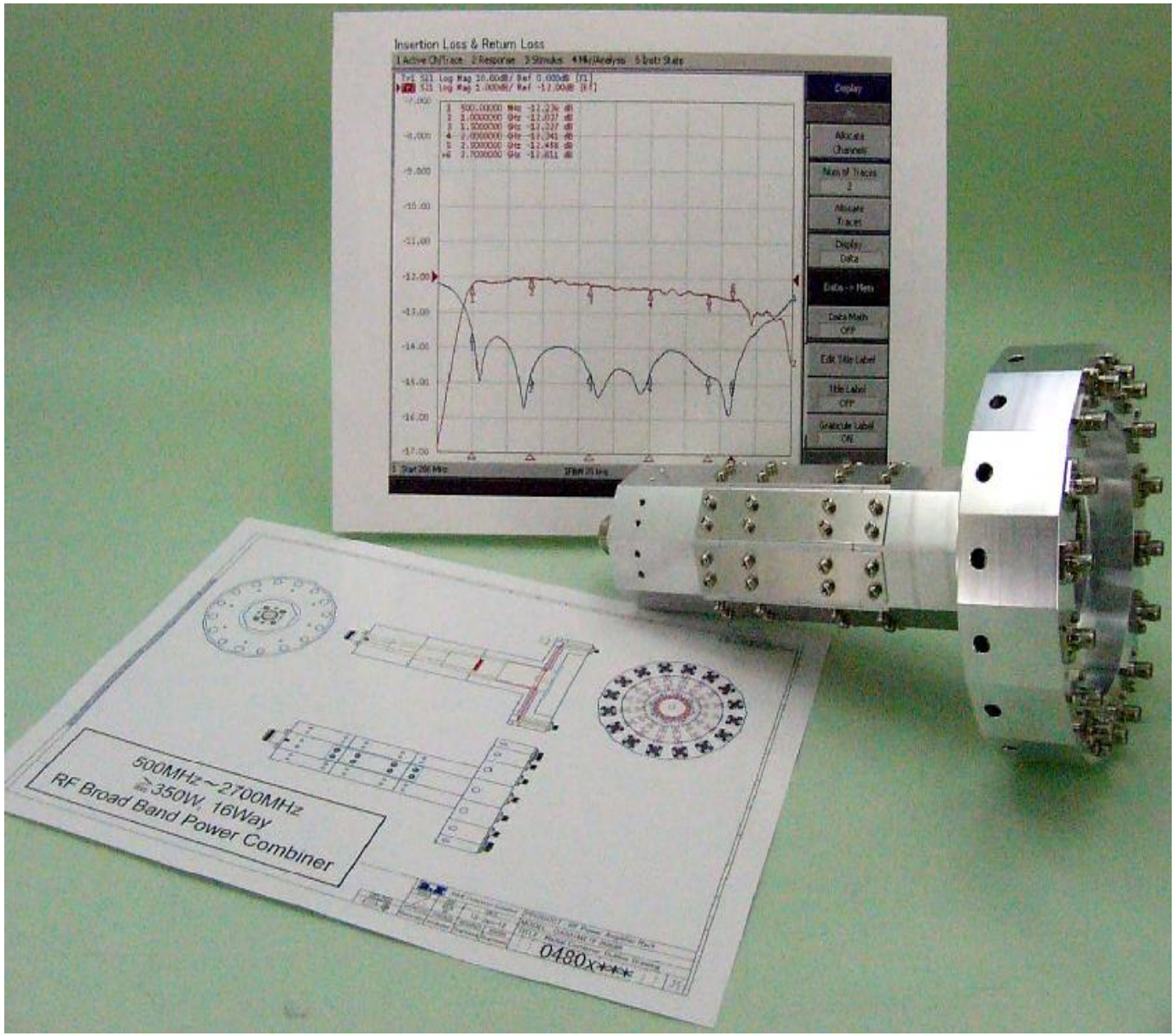


This Combiner is a traditional Wilkinson combiner, but all 200W chip resistors are placed between the input terminals and act as absorption resistors, resulting in excellent isolation performance. However, in the case of reflected power for a long periods, reasonably enough cooling is required, or RF must be shut down.

200MHz-1000MHz, >4000W, 16 way



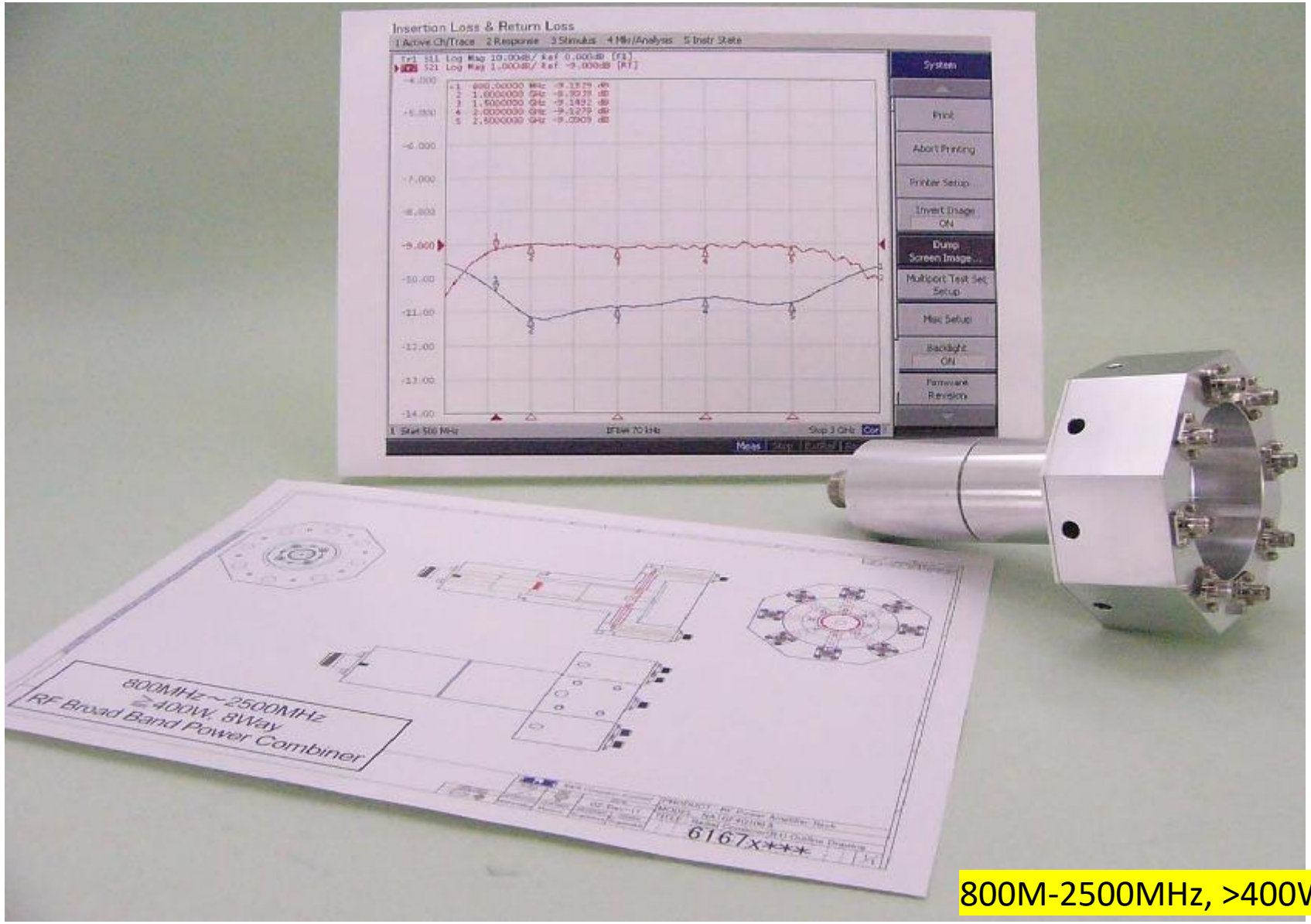
200MHz～1000MHz
≧4kW, 16Way
RF Broad Band Power Combiner



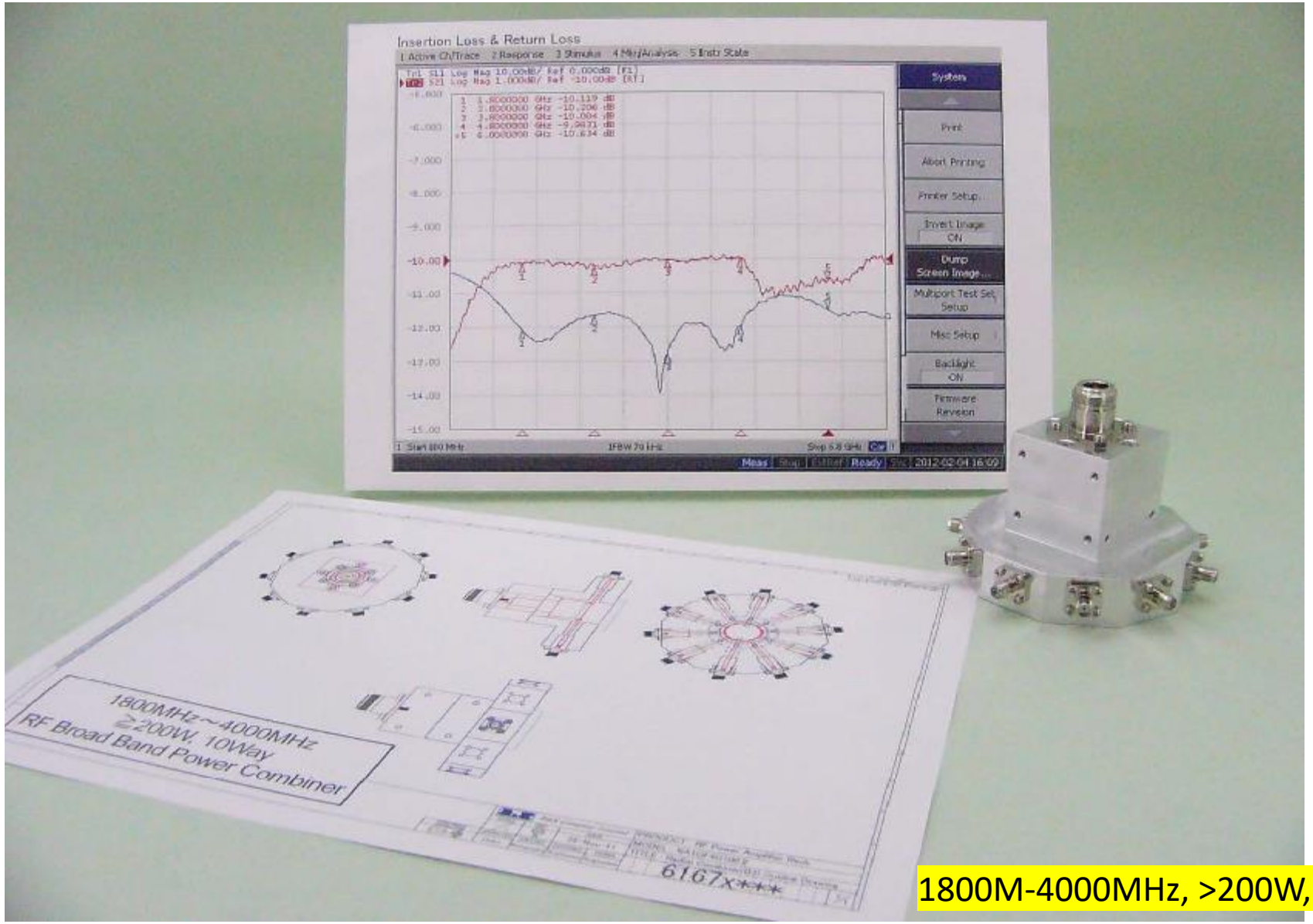
The method of this device is a typical circuit often called the WILKINSON-RADIAL combiner. The combined output has a multi stage broadband matching-shaft network circuit, and a radial structure on the low impedance side, which are multiple input terminals and all in-phase connected, so when all port have exactly same RF voltage, no RF current flows between neighbor ports.

If combining larger number of terminals, the larger isolation performance can be achievable between terminals. But kickback reflection is similar power as forward when input failure mode.

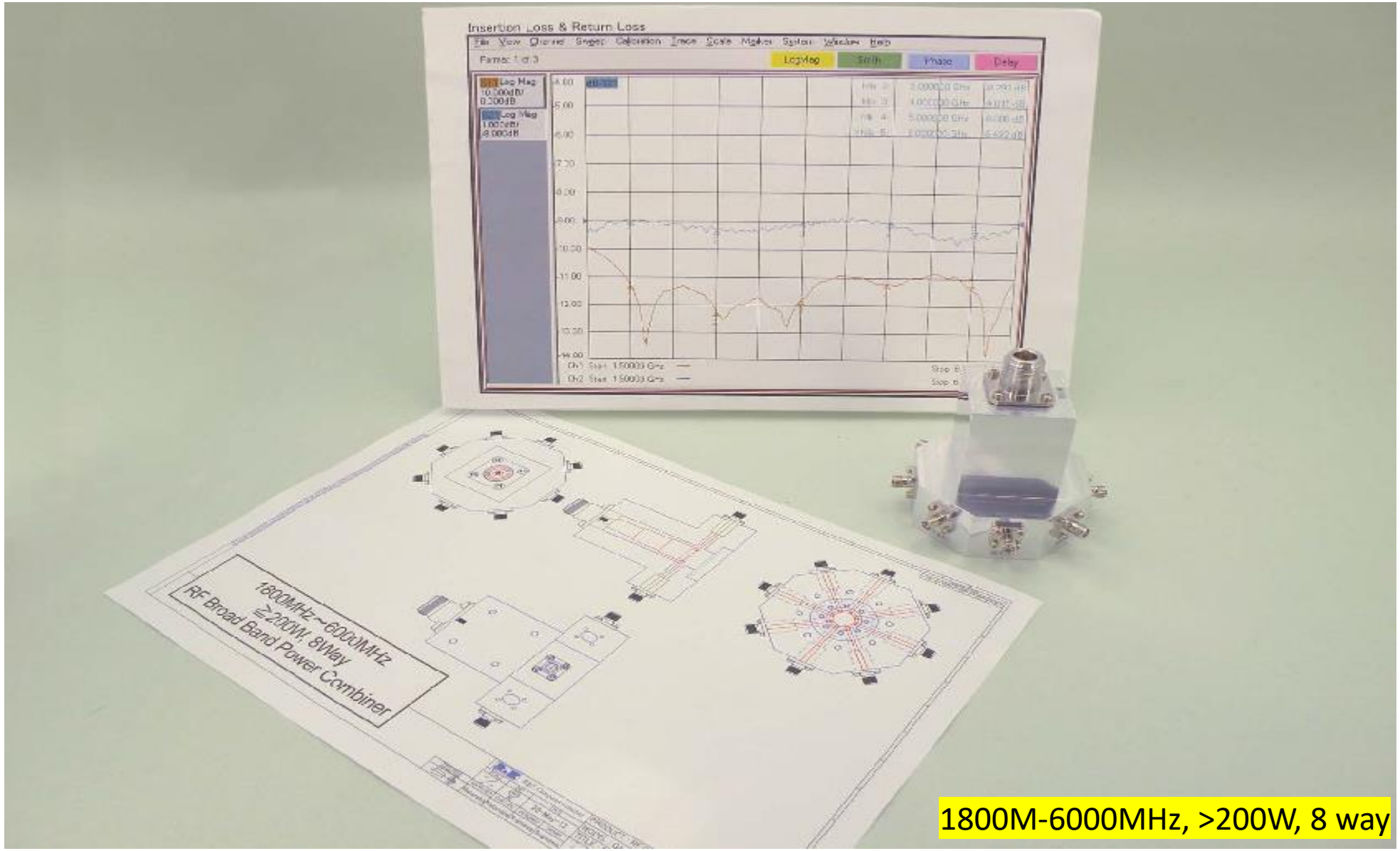
500M-2700MHz, >350W, 16 way



800M-2500MHz, >400W, 8 way



1800M-4000MHz, >200W, 10 way



1800M-6000MHz, >200W, 8 way

Thank you for listening.

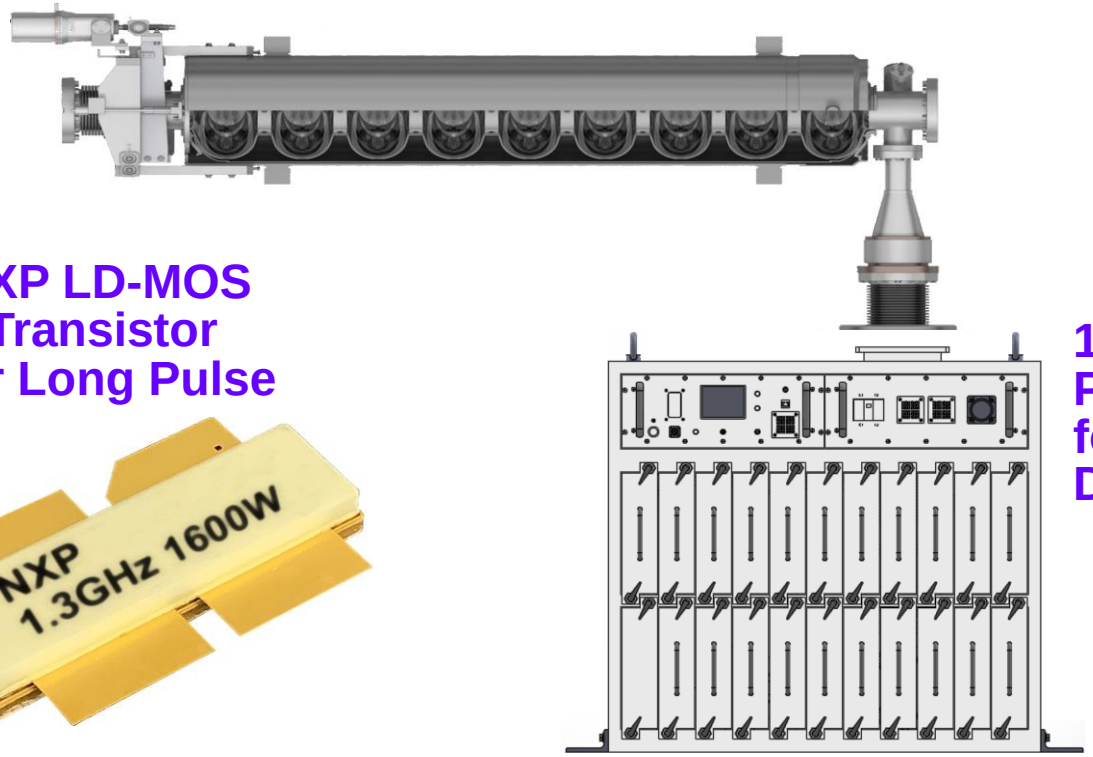
SRF controlled by “LLRF and SSPA”.

(SRF=Superconducting RF Cavity, LLRF=Low Level RF control, SSPA=Solid State Power Amplifier)

No need any additionals----------
Klystron(Heater & Solenoid Power), Marx Generator, complex Waveguide Assy, and their Adjustment,
Then,

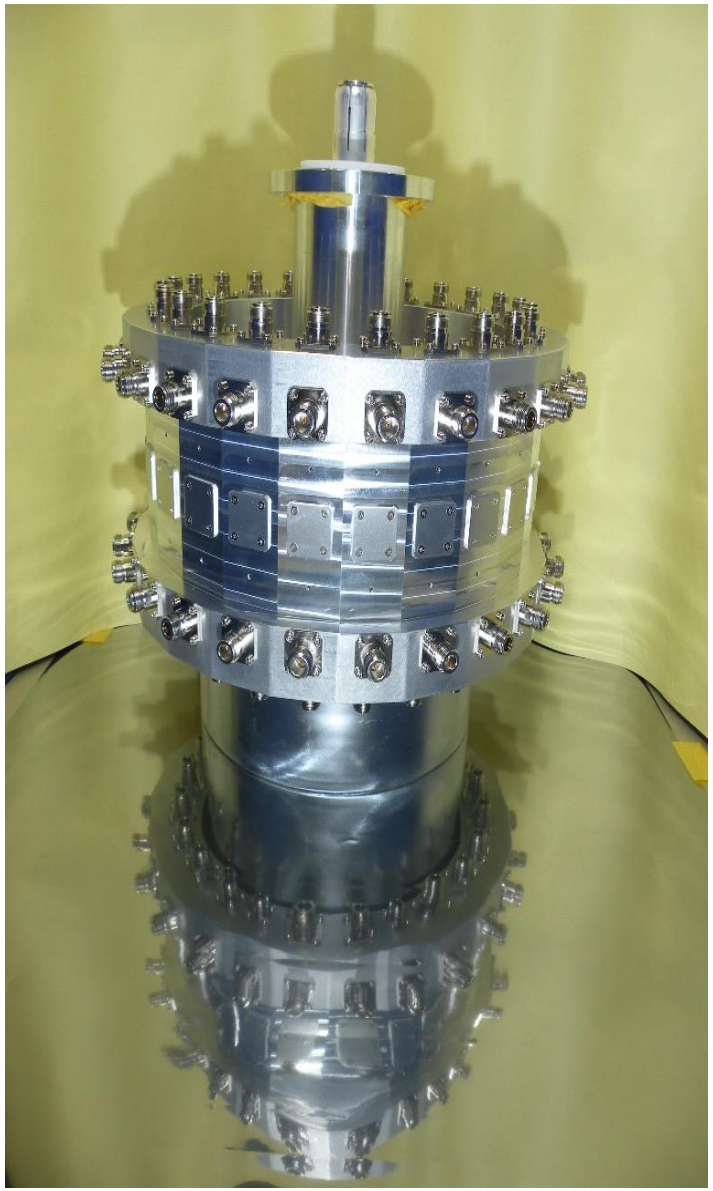
No Warm-up operation, (shorter time)
No High Voltage is Less dangerous, and get Longer MTBF and Shorter MTTR,
Statistically, there is no sudden breakdown of everything, and the reliability is high.
R&K already reached >73% DC to RF efficiency even at 1300MHz +/-10MHz. (>73%@280W)

Electrolytic capacitor in PCB-Bank quick exchangeable design-----Affordable Cost for P/S for SSA.



NXP LD-MOS Transistor For Long Pulse

1300MHz, 200kW Pulse RF SSA for 10pps 1.6m sec Designed for ILC



Typical 500MHz,
96 way Power Combiner
For 100kW Pulse Power
at no port-Isolation