13th CW RF, Sept 9, 2024

# Challenges and breakthroughs in recent RF Solid State PA design by Radial Combiner design with Initiatives for SDGs

Presented by Riichiro Kobana
R&K Company Limited

# Overview

Abstract

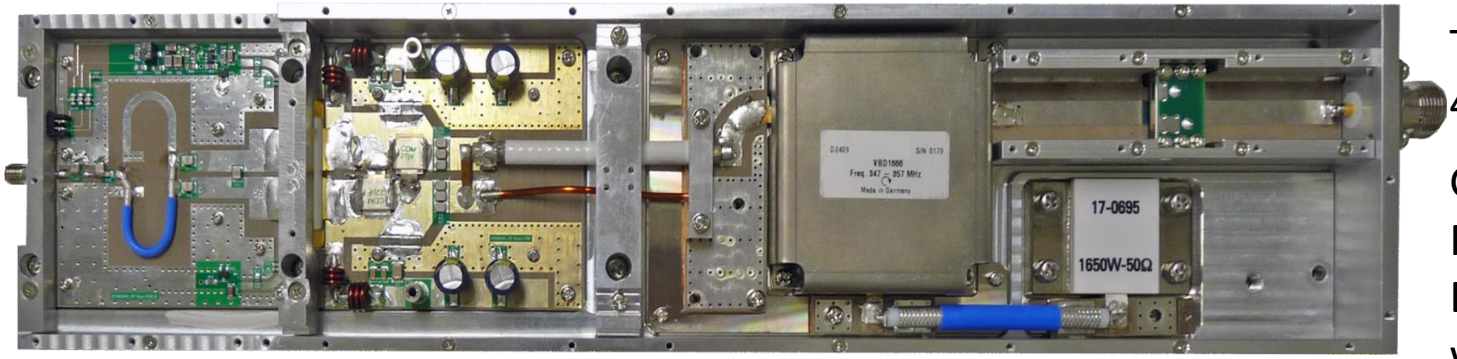
R&K, an independent company, has achieved production of 2.3 million 1.9GHz microwave power amplifiers for mobile-comm's-base-stations and then also supplies wideband power amplifiers for automobile EMC testing for domestic automobile industries. Then 16 years ago, we started designing and producing some hundreds kW RF SSA for accelerator applications as alternatives to Klystron / tube.

The measure characteristics of SSA is a possibility to design a band in a very wide frequency range available from few MHz to 14 GHz, and its upgradability of max-power in few kW to few MW design even after system completed. Recently, SSA is being recognized the significant advantages over vacuum tubes in terms of size, low power consumption, higher efficiency, low cost, and adaptive power design. In addition to these, we have learnt that SSA has very low phase noise and low envelope noise that cannot be achieved with vacuum tubes.

All these advantages are transforming SSAs into the first-chosen RF power source even for particle accelerators. There is no doubt that all these improved performances of SSA will minimize overall resource utilization, and well match with sustainable industry and society.

# SSA RF Module

## 352MHz > 1kW・CW・PA Module

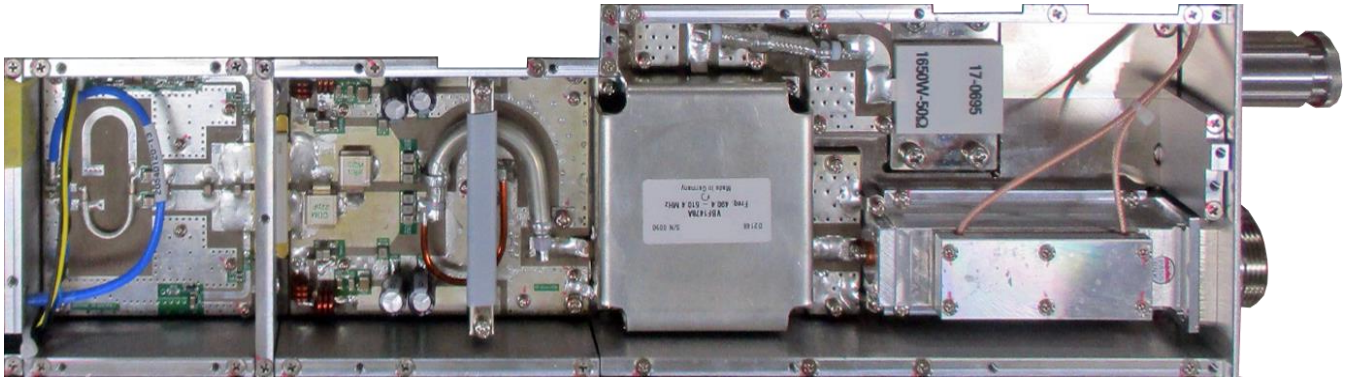



Final SSA Module “ SIZE-A”.

Typ. size for VHF SSA Module
400(L) x 92(W) x 30(H)mm,

G>+23dB, P-1dB>800W, and
Psat>1.2kW at class AB biasing
Efficiency DC-RF >76% @+50V
with output Circulator protect.

## 500MHz > 1kW・CW・PA Module




Final SSA Module “ SIZE-B”.

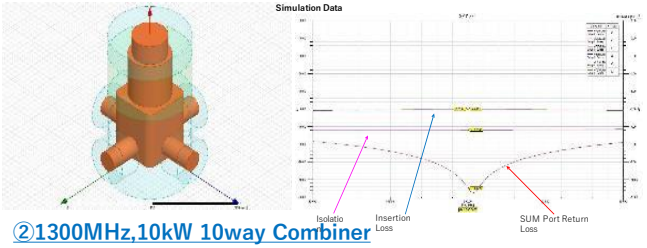
Typ. size for UHF SSA Module
350(L) x 88(W) x 33(H)mm,

G>+22dB, P-1dB>750W, and
Psat>1kW at class AB biasing
Efficiency DC-RF >72% @+50V
with output Circulator protect.

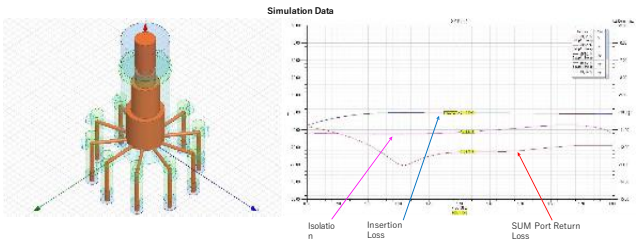
R&K Company Limited
721-1 Maeda,Fuji-City,Shizuoka-Pref.416-8577 Japan
Tel : +81-545-31-2600 E-mail : info@rkco.jp
Fax : +81-545-31-1600 URL : http://rk-microwave.com

# Various kind of design for very high power Radial Combiners

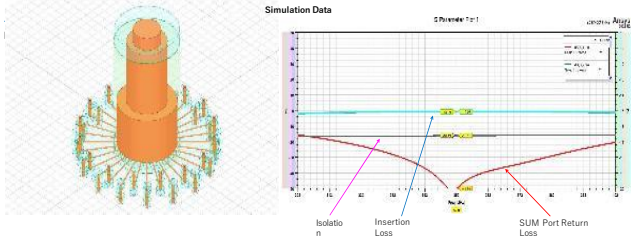
①500MHz,350kW(Pulse) 4way



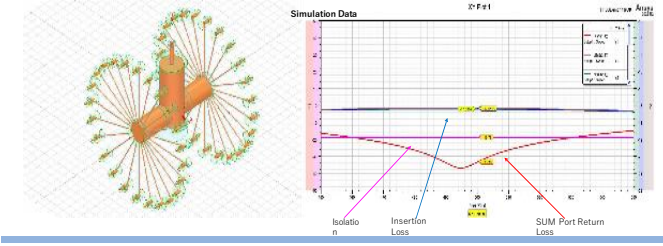

②1300MHz,10kW 10way Combiner



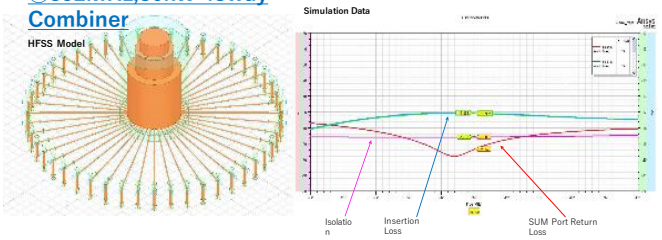

③352MHz,80kW 32way



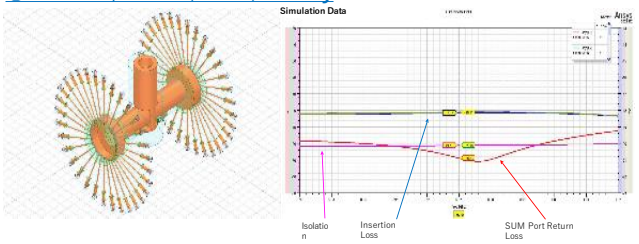

④500MHz,20kW 48way



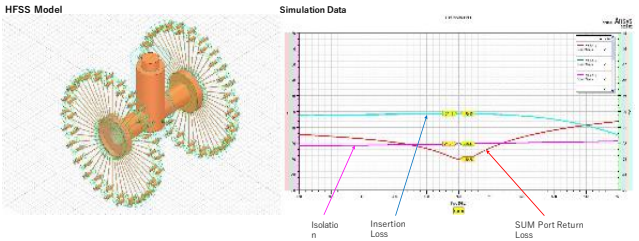

⑤352MHz,80kW 48way Combiner



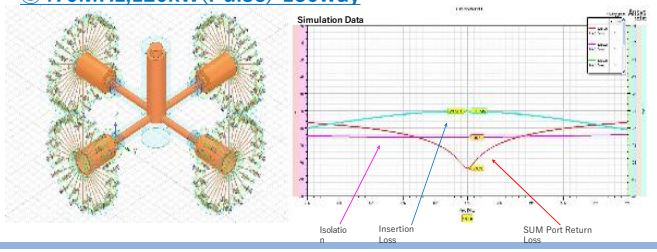

⑥972MHz,240kW(Pulse) 64way




⑦500MHz,70kW 96way Combiner




⑧476MHz,120kW(Pulse) 136way




※ Low power consumption,
※ high efficiency
※ low cost,

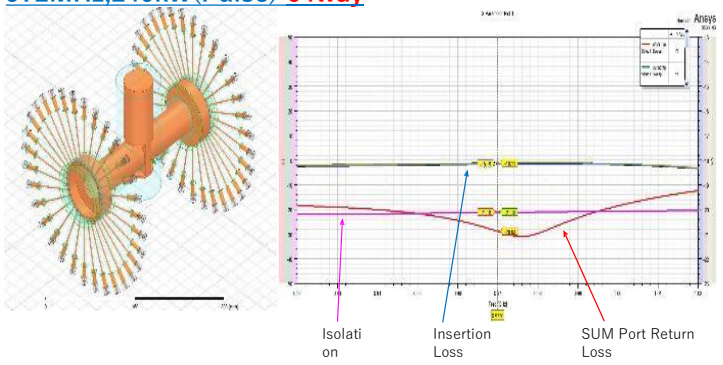
are all realized with following rugged radial power combiner circuits by HFSS and COMSOL simulation design.

◎ Odd, Even, and Prime ports design are all available.
◎ Max power is only limited up to the connector design.
◎ Isolation to adjacent ports are achieved by the number of branches.
◎ Max. insertion loss is only -0.05dB to -0.15dB max. with very broadband.
◎ RF Power Combiner using cavity resonators have high Q and low loss, but this method has a very low Q, so the temperature characteristics are very stable and the loss is relatively low.
In particular, most RF losses are caused by coax-cables, so the power combining method of the future will likely shift “coax with waveguide cascaded combiners”.

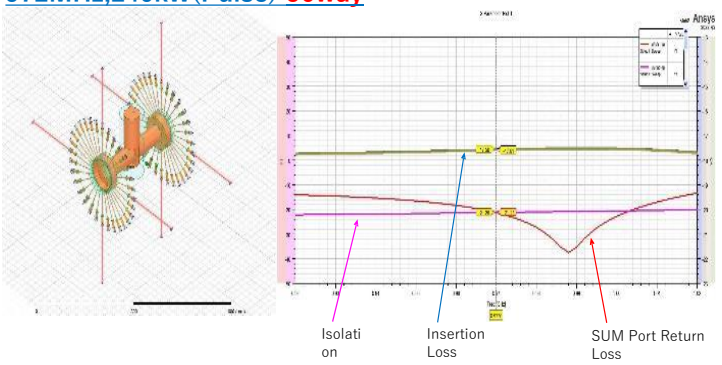

R&K Company Limited
721-1 Maeda,Fuji-City,Shizuoka-Pref.416-8577 Japan
Tel : +81-545-31-2600 E-mail : info@rkco.jp
Fax : +81-545-31-1600 URL : http://rk-microwave.com

# Adaptive Power Amplifier Design

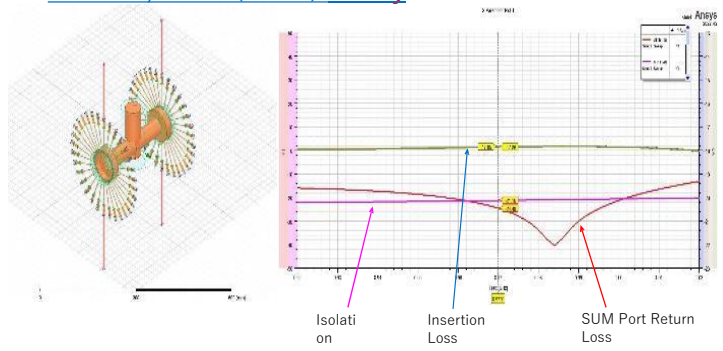
972MHz,240kW(Pulse) 64way



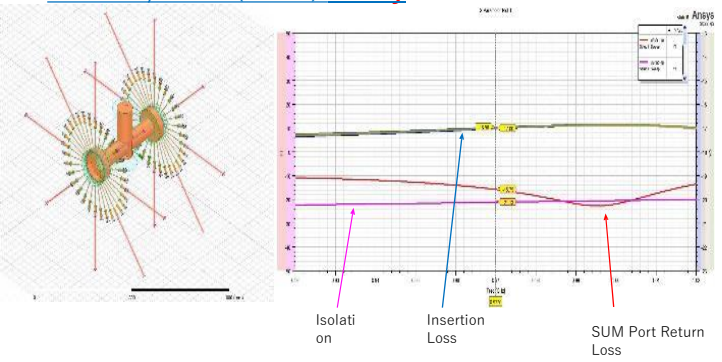

972MHz,240kW(Pulse) 56way




972MHz,240kW(Pulse) 60way




972MHz,240kW(Pulse) 48way



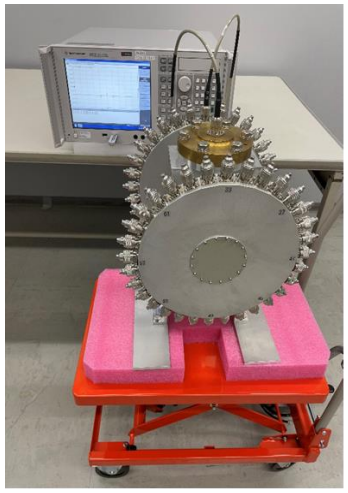
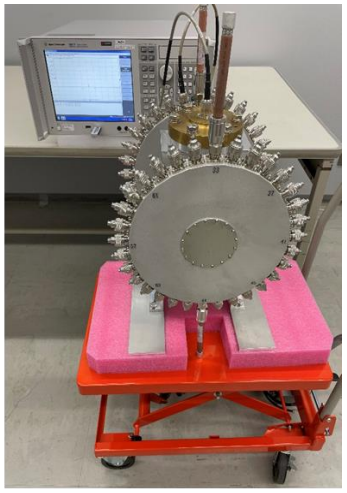
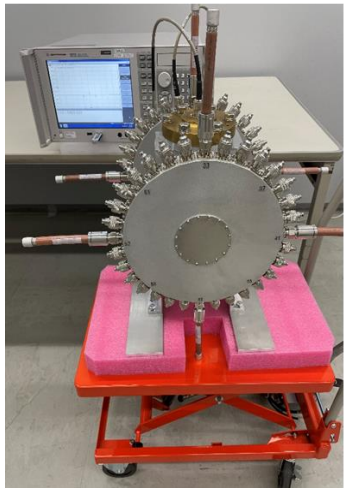
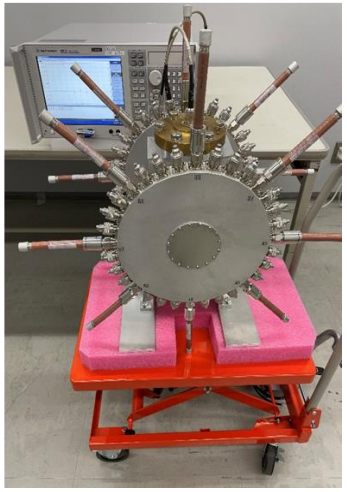

The fixed combiner device, but various branches make the Adaptive Functions.

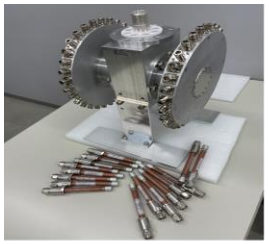
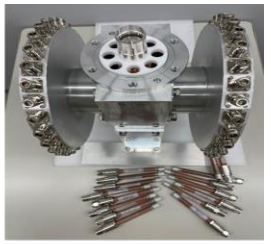
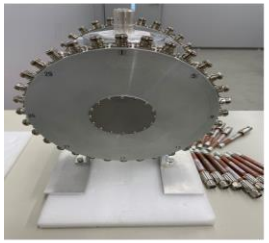
With quarter wave “Short” Can change 64way, 60way, 56way, 48way Radial Power Combiner Functions.

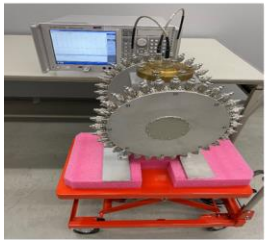
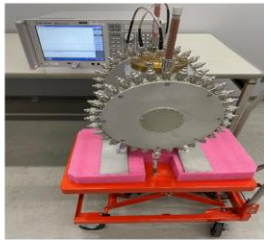
Start with a small budget and scale to your maximum possible potential.

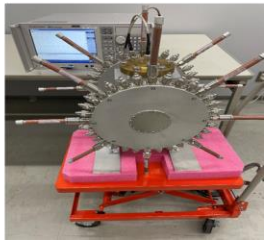
R&K Company Limited
721-1 Maeda,Fuji-City,Shizuoka-Pref.416-8577 Japan
Tel : +81-545-31-2600 E-mail : info@rkco.jp
Fax : +81-545-31-1600 URL : http://rk-microwave.com

# Single structure, but Multiple ports RF Power Combiner
## 972MHz > 240kW, Pulse RF, 64/60/56/48way design

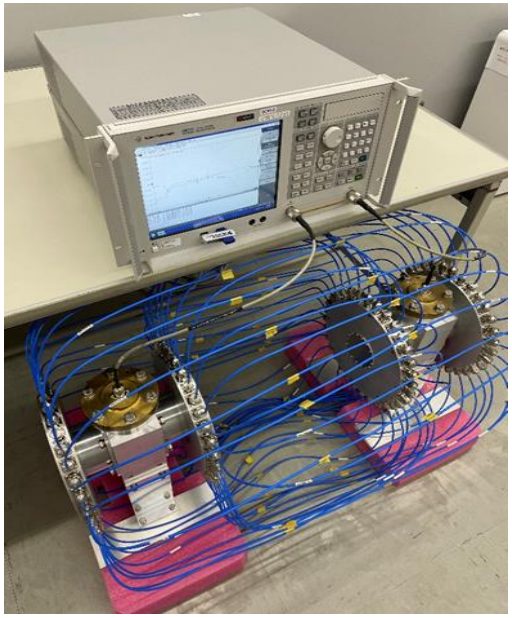





Adaptive
64 way Combiner
and
Quadrature Short

64/60/56/48 way

----Measurement----



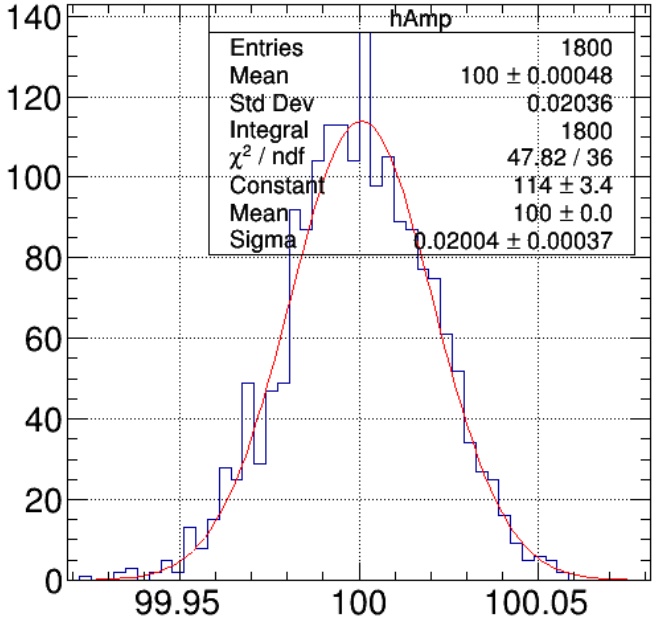
**R&K Company Limited**
721-1 Maeda,Fuji-City,Shizuoka-Pref.416-8577 Japan
Tel : +81-545-31-2600 E-mail : info@rkco.jp
Fax : +81-545-31-1600 URL : http://rk-microwave.com

# R&K 476MHz SSA for SACLA - pulse by pulse stability

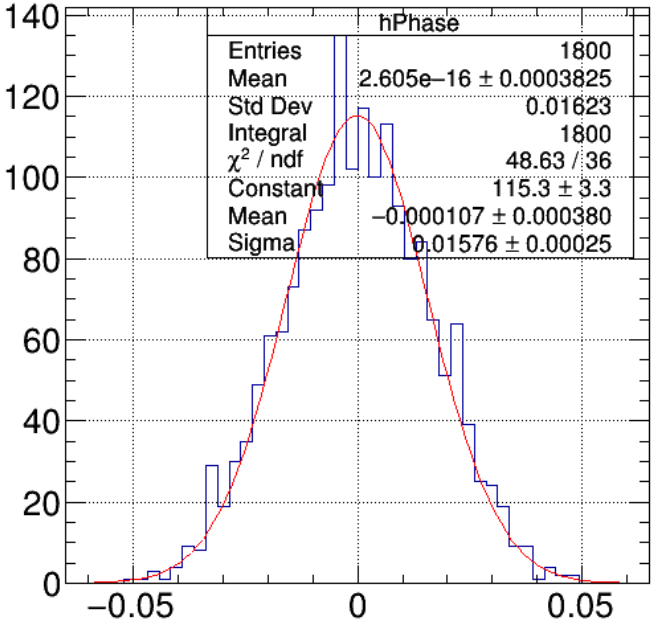
## Stability (short term)

- RF-out @ 100kW @476MHz
  0.020% , 0.016deg (sigma)

I would like to express my sincere gratitude to the RIKEN team for giving us the opportunity to collect "phase and level stability data under free-running conditions of RF over 100kW".
For a long time, cost, reliability, and power efficiency came first, and it has been difficult for us to obtain such fulfilling stability data.
Conventional vacuum tube amplifiers always have an electron transit time, and they are extremely sensitive to the thermal noise. They are noise source.
However, as shown here, solid-state amplifier is now possible to achieve this level of stability even without locking the signal by LLRF.




Level vector stability σ A/A [%]

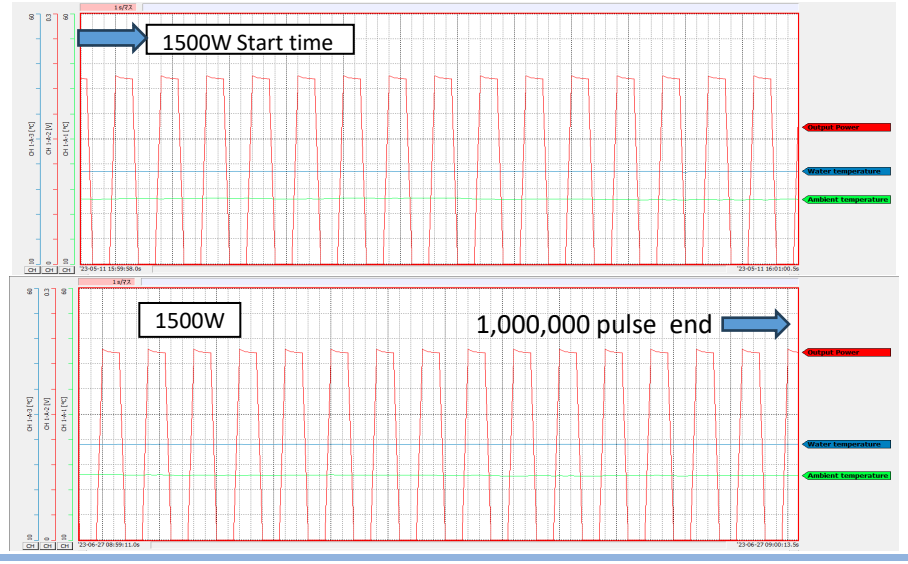



Phase vector stability σ phase [deg]

JASRI/RIKEN Eito Iwai, 2024, Private Communication

# Really scary metal vaporization in RF plasma sparks and soldering fatigue.

You can immediately spot a big problem with the familiar 7/16" DIN connector. That's right. You can not see the thick center conductor. This is because the center conductor has evaporated due to plasma discharge caused by RF sparks.
If you don't pay attention to it just because it's a low frequency, the brass metal will evaporate easily. This phenomenon is caused by a ground discontinuity between the internal ground plane of the DIN connector and the ground portion of the PCB board. It is always important to remember when two planes face each other there is a possibility of a gap. It was only 800W to 1000W at 186MHz.




Currently, SS devices need to be fixed mechanically, thermally and RF, but special care is required because silicone grease evaporates in 8-10 years and soldering leads to adhesion failure (especially due to the RoHS directive) and soldering fatigue.
For a 1.5kW-RF with 62% DC to RF efficiency and water cooling with a copper heat sink on the floor, the max. temperature deviation occurs when the device is powered on and off for about 2 seconds each time. This temperature change causes mechanical stress that would normally cause the device to peel off in about 6 months to a year, but if special measures are taken, the maximum stress can be applied more than 1 million times without any effect today.

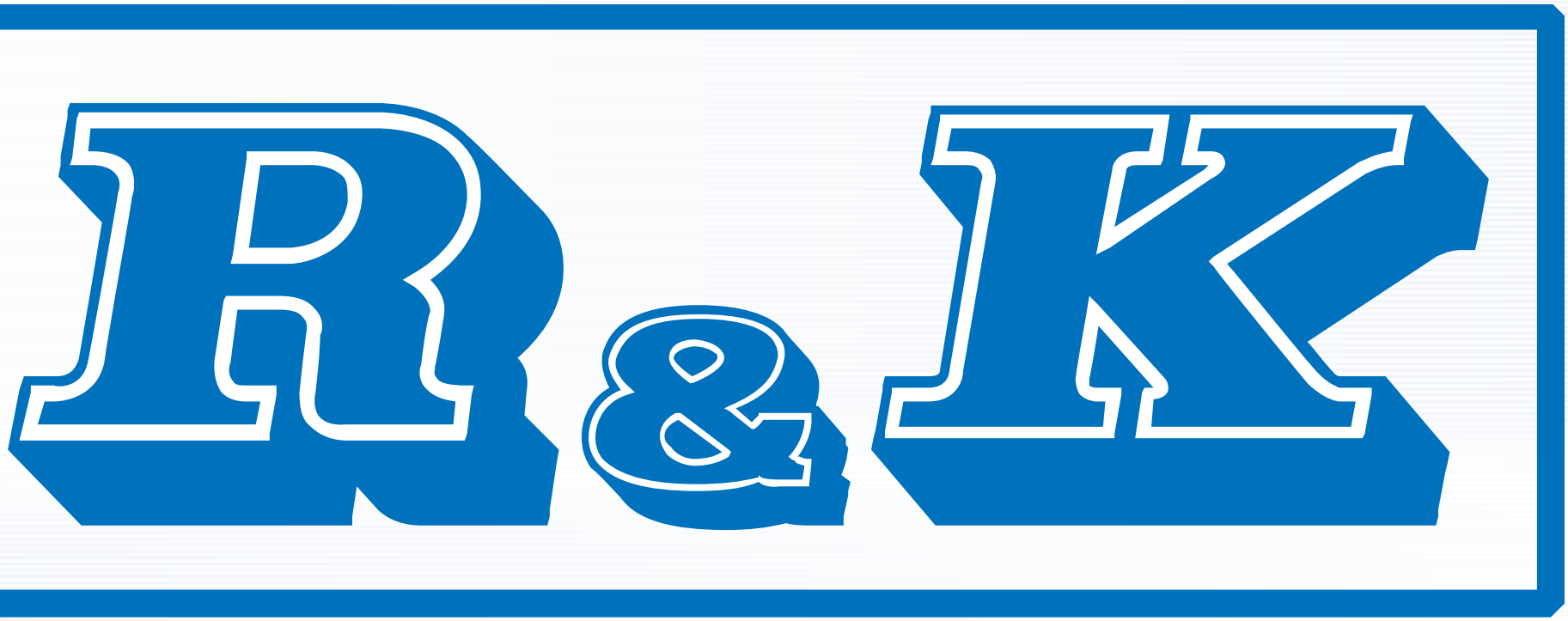

R&K Company Limited
721-1 Maeda,Fuji-City,Shizuoka-Pref.416-8577 Japan
Tel : +81-545-31-2600 E-mail : info@rkco.jp
Fax : +81-545-31-1600 URL : http://rk-microwave.com

So far, we have covered the important aspects of the SDGs, such as SSA size, low power consumption, high efficiency, low cost, adaptive combiner design, very low phase noise and low envelope noise.

However, we will now move on to the most important topic of latest RF GaN products, where we will discuss the most important aspects of the SDGs, such as the outlook for GaN RF-Device power efficiency for the near future.

In the 1300 MHz band, the current LD-MOS efficiency is 58% for DC-RF, but R&K has already achieved a DC-RF efficiency of 70% with GaN device.
Also, in the 1500 MHz band, the current LD-MOS efficiency is 49% for DC-RF, but R&K has already achieved a DC-RF efficiency of 70% with GaN device.

Regrettably, I am very sorry to say that as a result of discussions with the manufacturer, due to the NDA agreement, we are unable to disclose the detailed timeline of the semiconductor devices at this time. We are very sorry, but we will make an announcement at a later date, so I appreciate your understanding.




# R&K Company Limited

## RF/Microwave Power Amplifiers and Components

**www.rk-microwave.com**