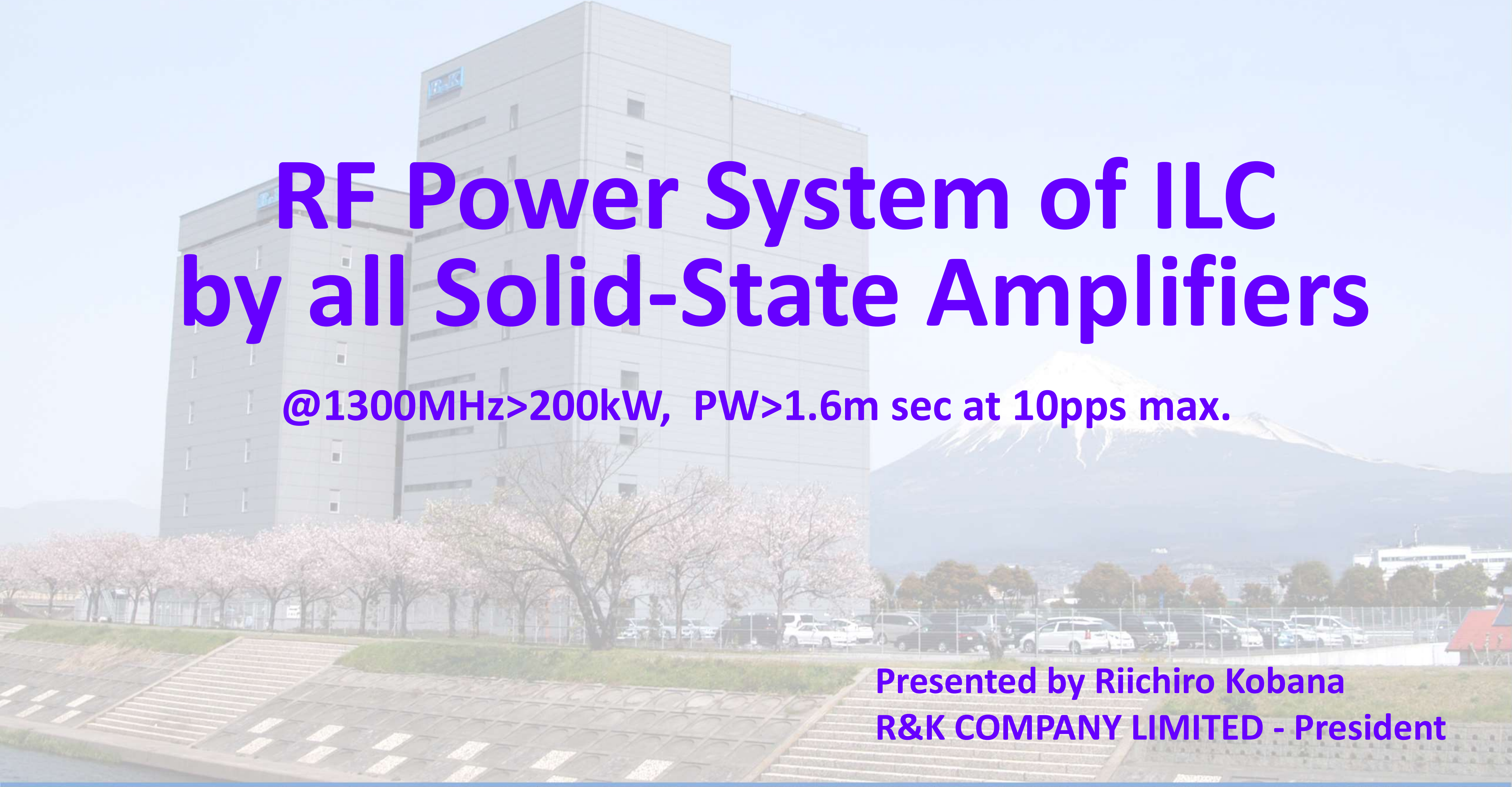
ILCX2021, Oct 2021



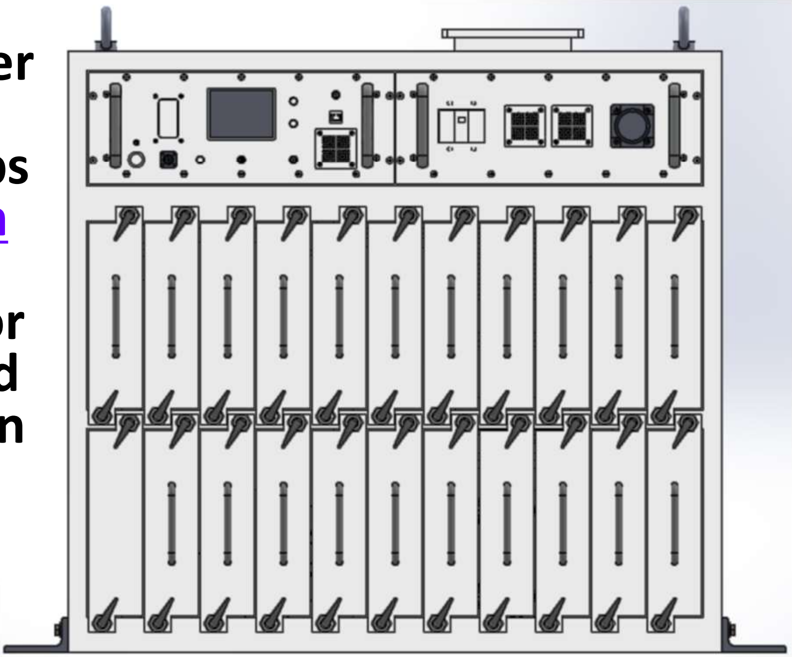
RF Power System of ILC by all Solid-State Amplifiers

@1300MHz>200kW, PW>1.6m sec at 10pps max.

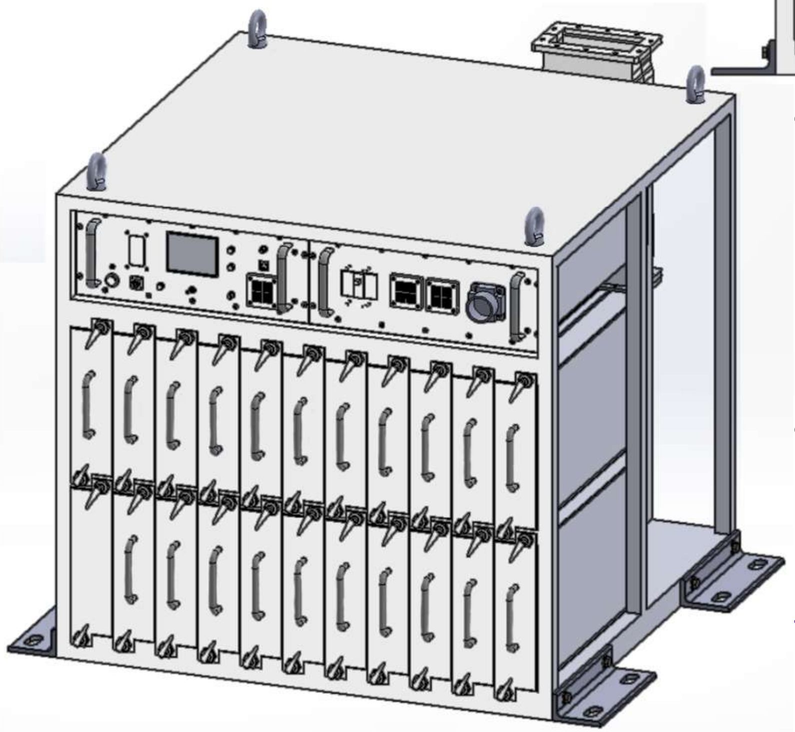
Presented by Riichiro Kobana
R&K COMPANY LIMITED - President

Overall Construction

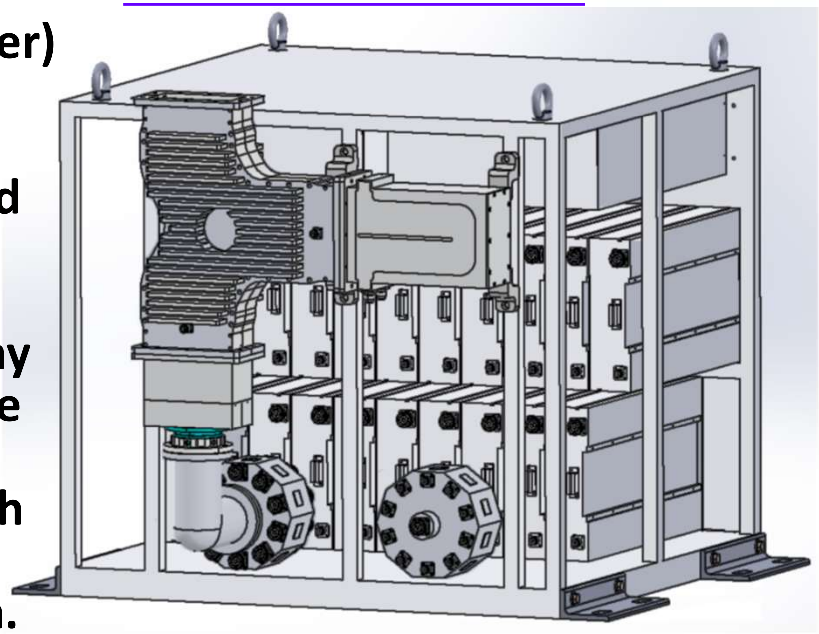
1300MHz Solid State Amplifier that can provide 200kW of 1.6m sec pulse width at 10pps max becomes available with reasonable cost. The latest LDMOS silicon semiconductor devices, NXP's 800W-CW and 1600W-Pk devices, have been implemented and tested successfully.



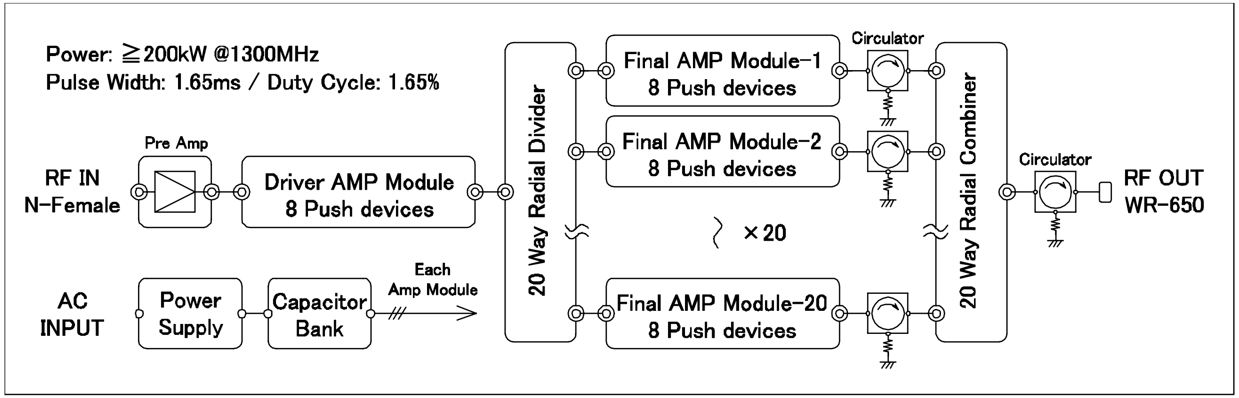
As to the initial cost, while the price of the pulsed RF amplifier about 6 years ago started from @US$3.60/W(≒@¥410/W), the current mass production price of this RF-SSA is estimated @US$0.28/W(≒@¥31.9/W).
----These are for LDMOS design.
The power efficiency of the system from the wall plug is expected to be more than 41%(during RFon) with LDMOS, but 55% can be achieved with latest GaN transistors.



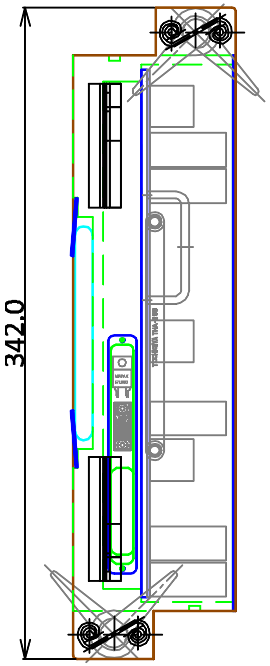
The SSA(Solid State Amplifier) can feed each cavity, which eliminates the complex RF distribution system required for high power Klystrons – Multi Beam Klystrons. Though the LLRF system may become a little complex, the adjustments for cavities become independent, which will add a variety of flexibilities in the operation.

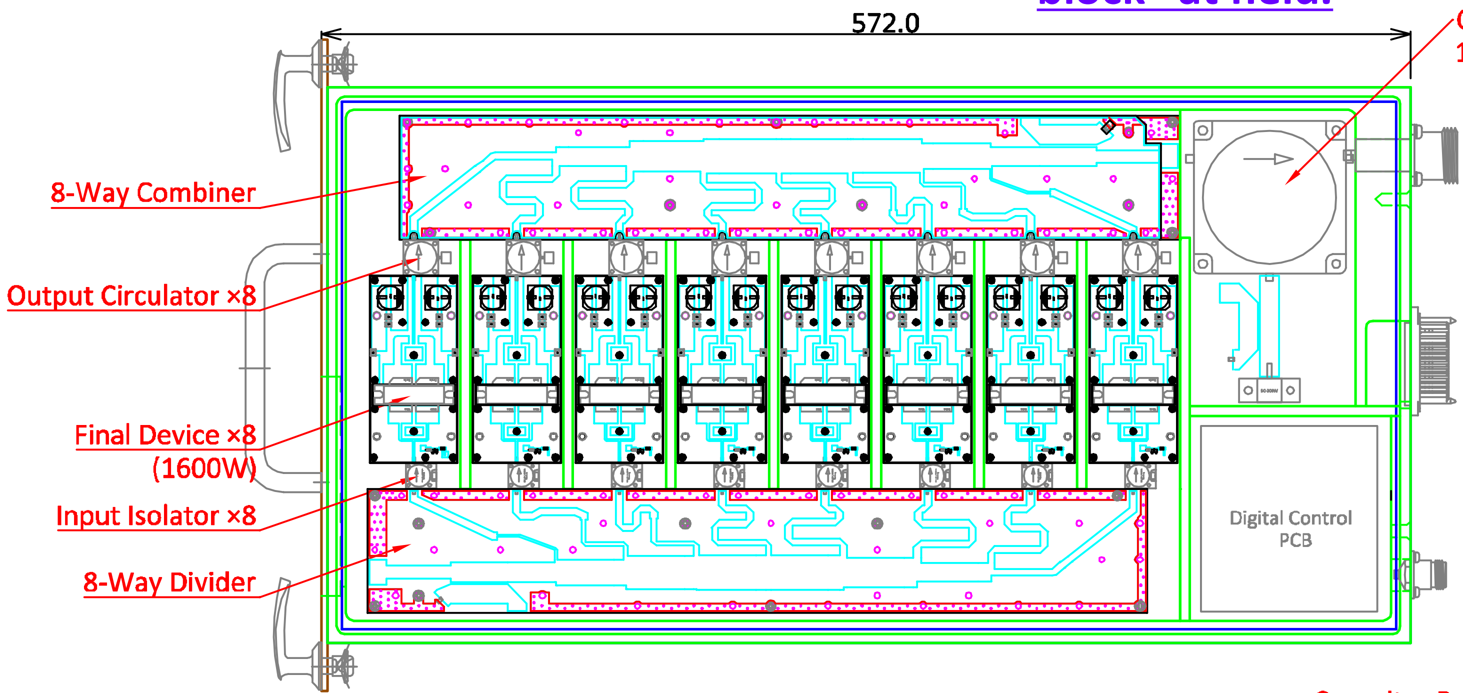


Amplifier Module (x20)



In addition to the electricity cost, maintenance costs will also be reduced due to the longer MTBF or MTTR ("Mean Time Between Failure" or "Mean Time To Repair") compared with vacuum tubes MBK that require high voltages. These features help protect the environment. Such a system will be presented briefly. The expected life time will be <u>over 40 years by replacing "retrofit-block" at field.</u>

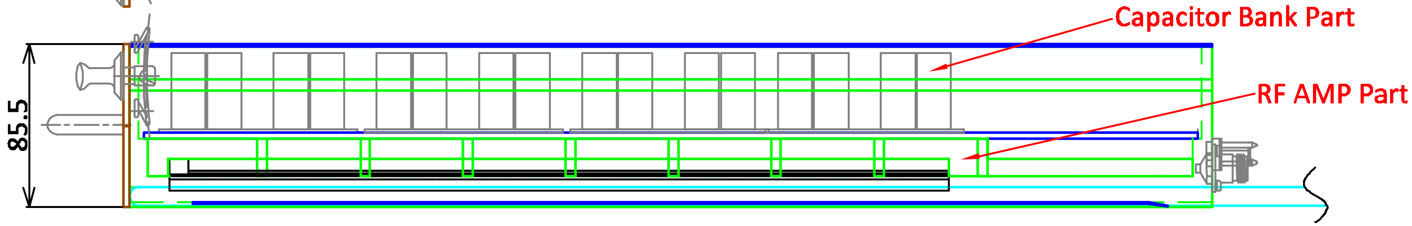




<u>Reason for</u>
<u>Green & SDGs are,</u>

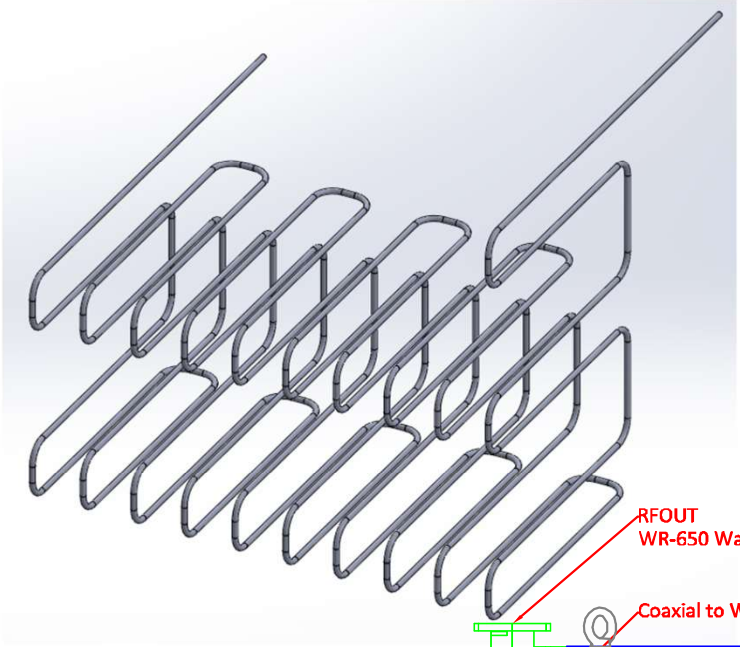
- ⇒No MBKs (no Tube)
- ⇒No W/G Assembly
- ⇒No Heater >400W
- ⇒No Solenoid>4kW
- ⇒No Marx Generator
- ⇒No Sudden Death
- ⇒No Gigantic Space
- ⇒Adjacent Installation
- ⇒1m(H)X1mX1m

<u>Independent Engine</u>

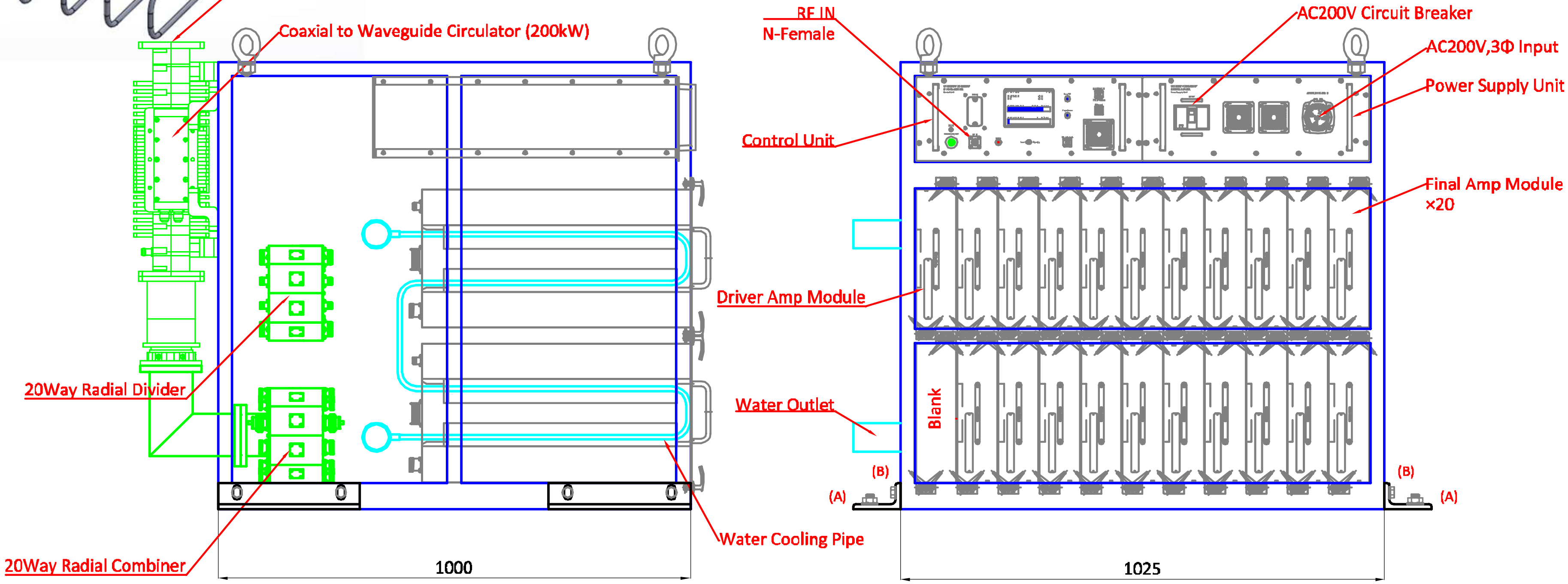


A very simple, and reliable stainless steel water pipe-cooling system.

Water Cooling System



Entire modules are cooled down with a reasonable and reliable cooling water pipe. A single SSA system is expected to raise the water temperature by about +4℃.
Basically, 20 Final SSA Modules and 1 Drive Amplifier Module operate all together, and HOT-SWAP is possible (with LLRF backup) in the event of single unit failure. The power supply is also Hot-Swappable by the HAPS technology (High Availability Power Supply) circuit method. However, further discussion should take place regarding the redundancy design of the margin-% in case of failure, depending on the budget. (Design margin vs Cost impact.)

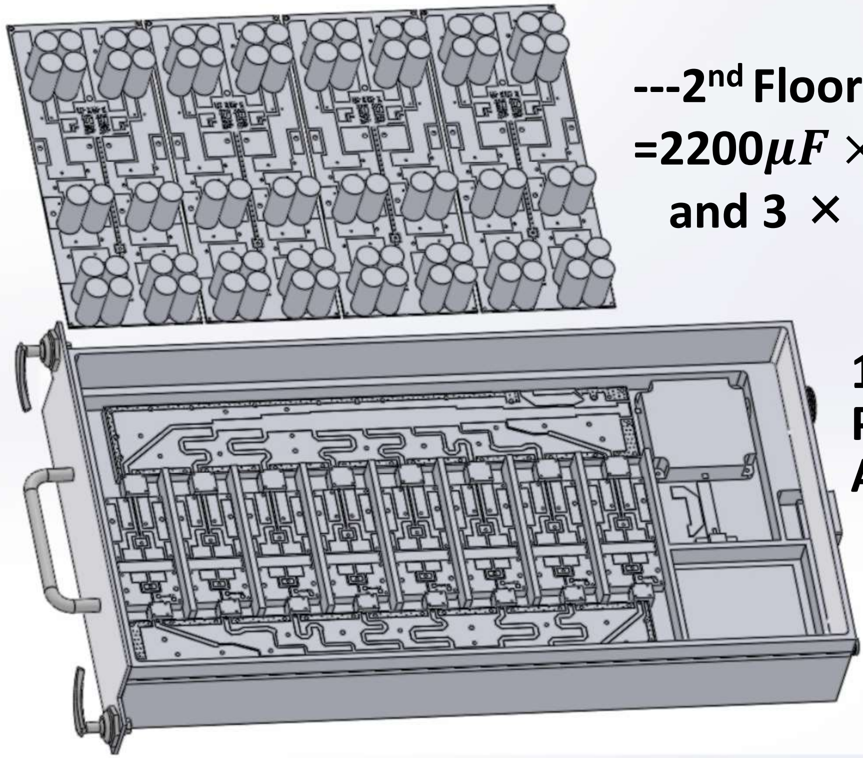


(Left Side View) (Front View)

What is a series-distributed RF power combiner using PTFE board? How about Wilkinson?
Each port isolation is performed by Circulator.

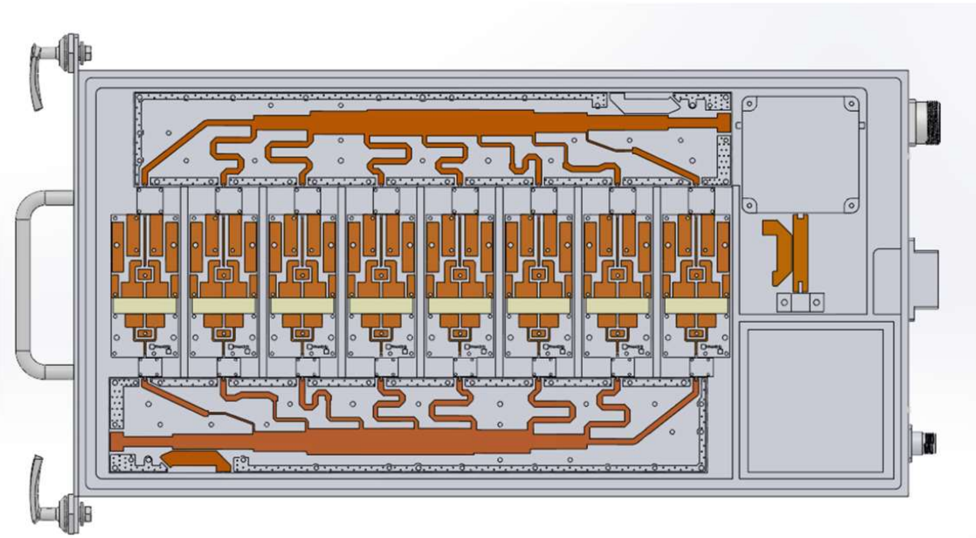
What is a pulse-forming network circuit?
How can we change 394A (peak) demands to 6.5A (CW)? This module require just only +65V, 6.5A (CW) to get 12kW RF pulse output.

Devices are all protected with circulators at the input, the output, and before/after the WILKINSON combiner.

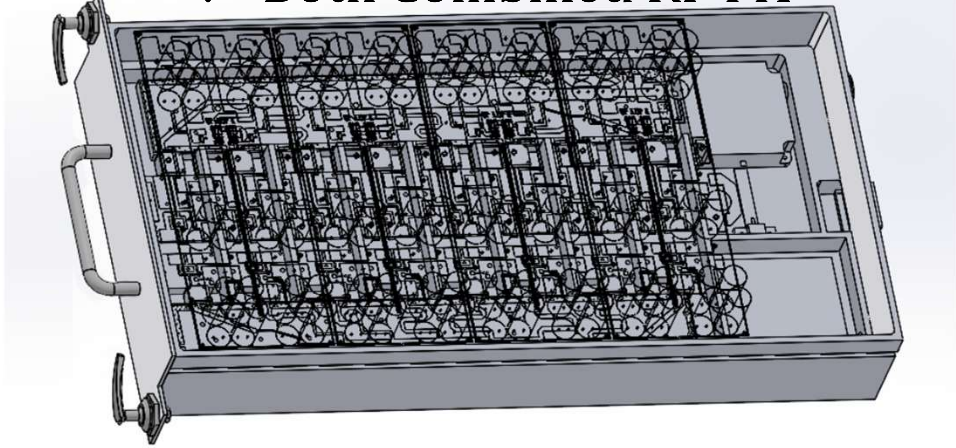


---2nd Floor PCB Ckt $=2200\mu F \times 10 \times 8$ and 3 × 8 Coils.

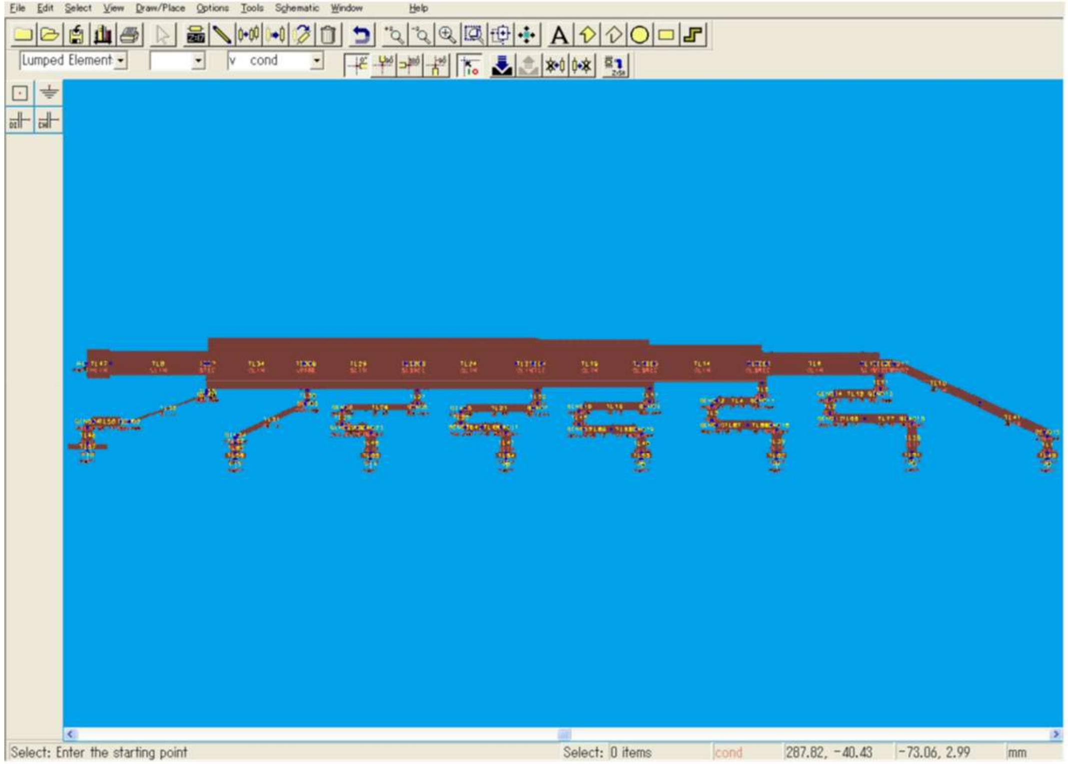
1st Floor PCB Ckt All RF PA

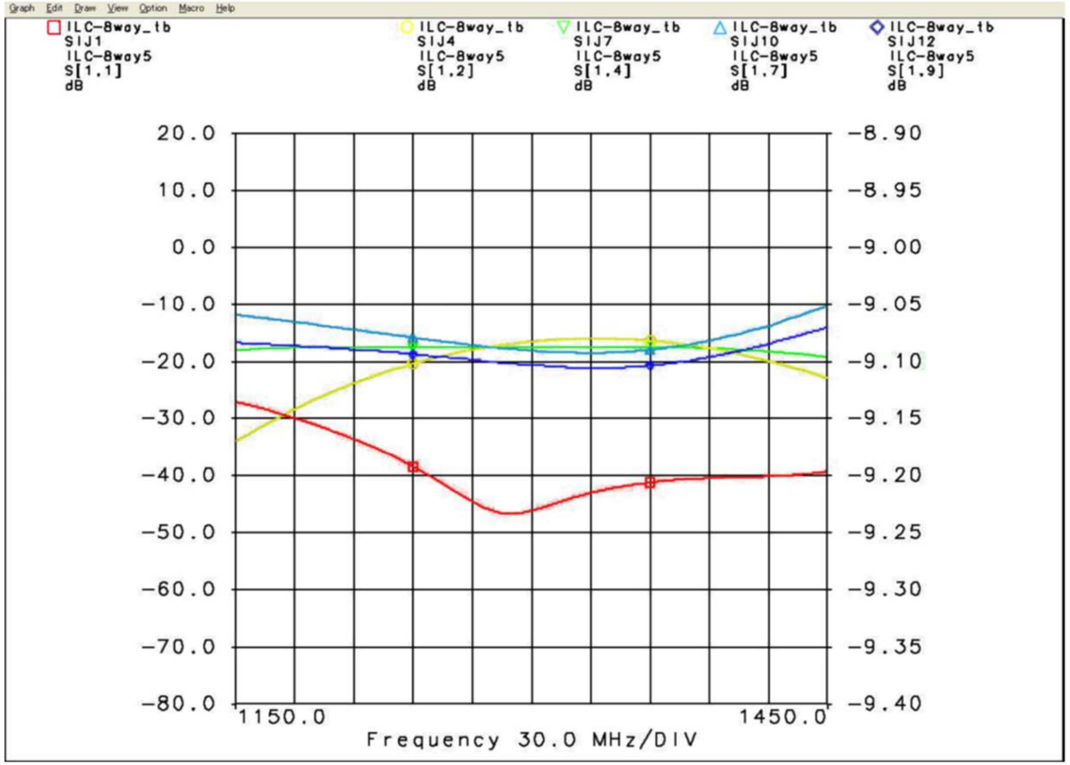


↓ Both Combined RF PA



Series-Distributed Power Combiner





Why choose "series-distributed" power combiner design with PTFE board?

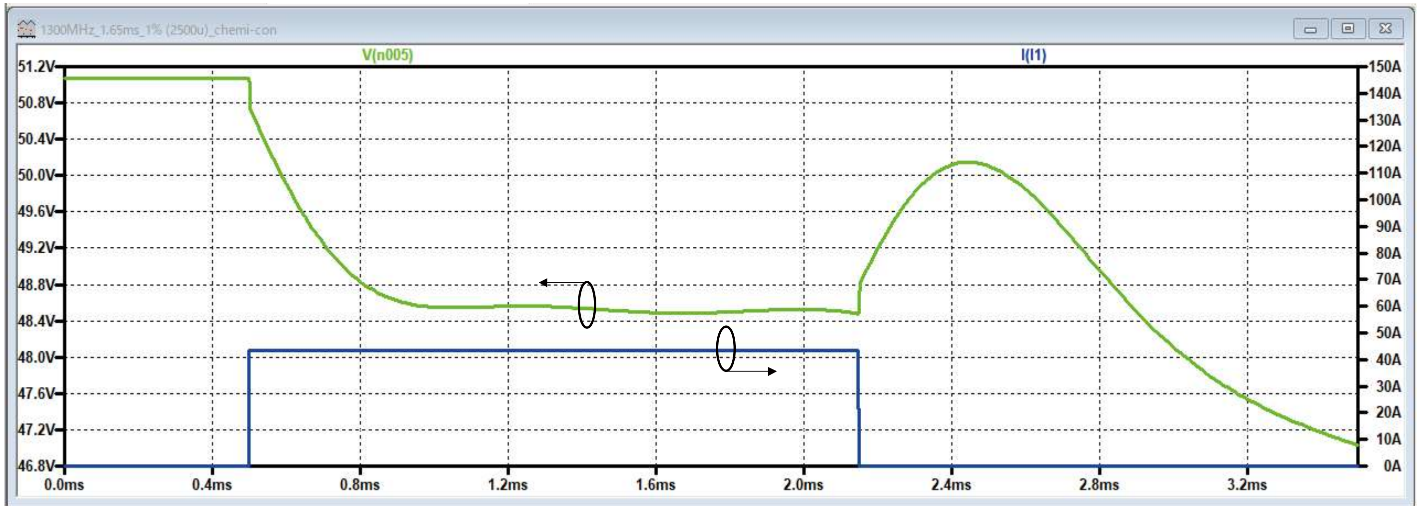
First of all, R&K has a tremendous track record in the production of high power SSA units for mobile communications base station. This straight design plays an important role. The design is the key factor of the perfect fit.

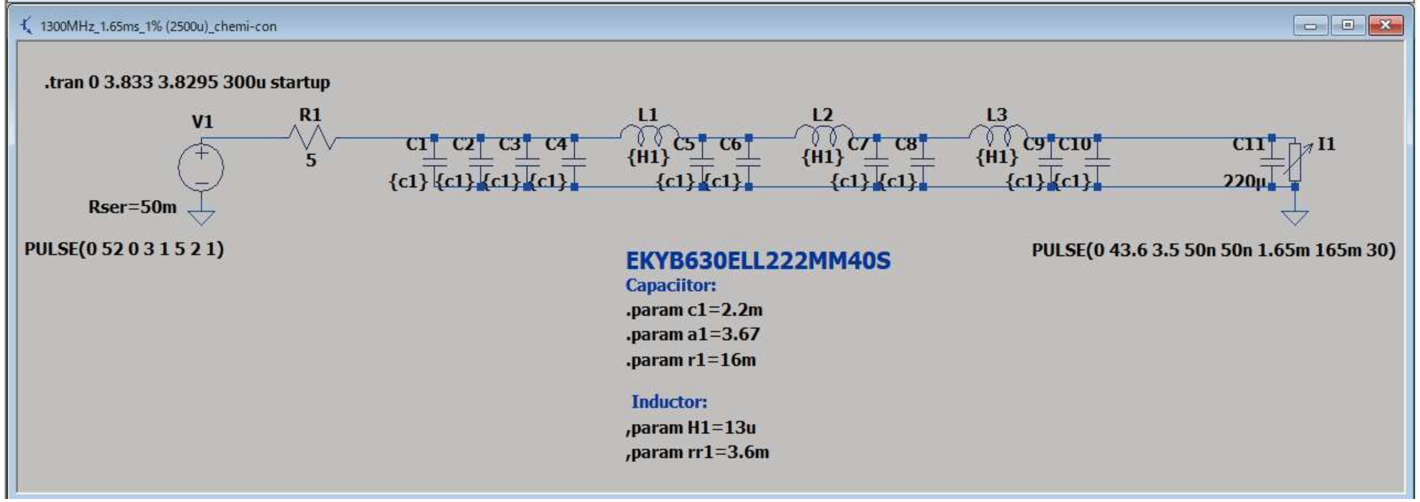
RF Performance by 2D Simulation Series-Distributed RF power combiner using PTFE board (8 way, 12kW peak)

Frequency: 1300MHz + / - 50MHz
Insertion Loss: -0.3dB max. (Except-9.03dB)
Isolation: 22dB min. (with Circulator)
PCB Thickness: 1.6mm PTFE
Copper Thick: 0.032mm t

Pulse Power Charging Network

Capacitor Bank Calculation





Specificat on

1) Device: 1500W Device
2) Eff(DC-RF @Po=1500W): 71%
3) Power Consumption: 2113W
4) Drain Voltage: +48.4V
5) Drain Current: 43.6A

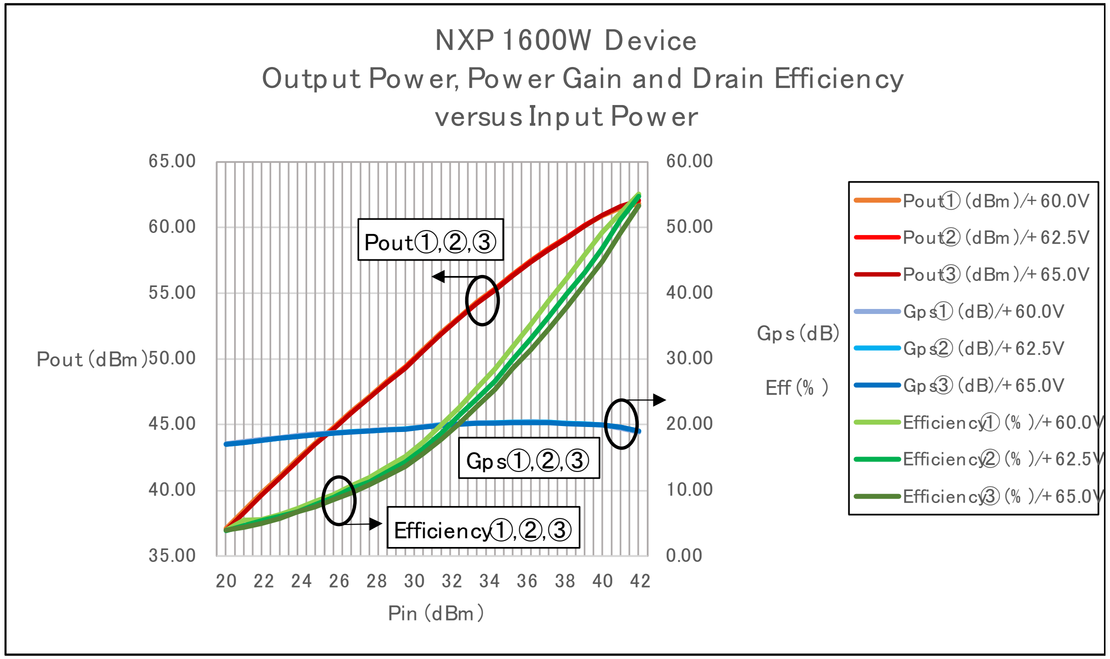
Pulse Condition

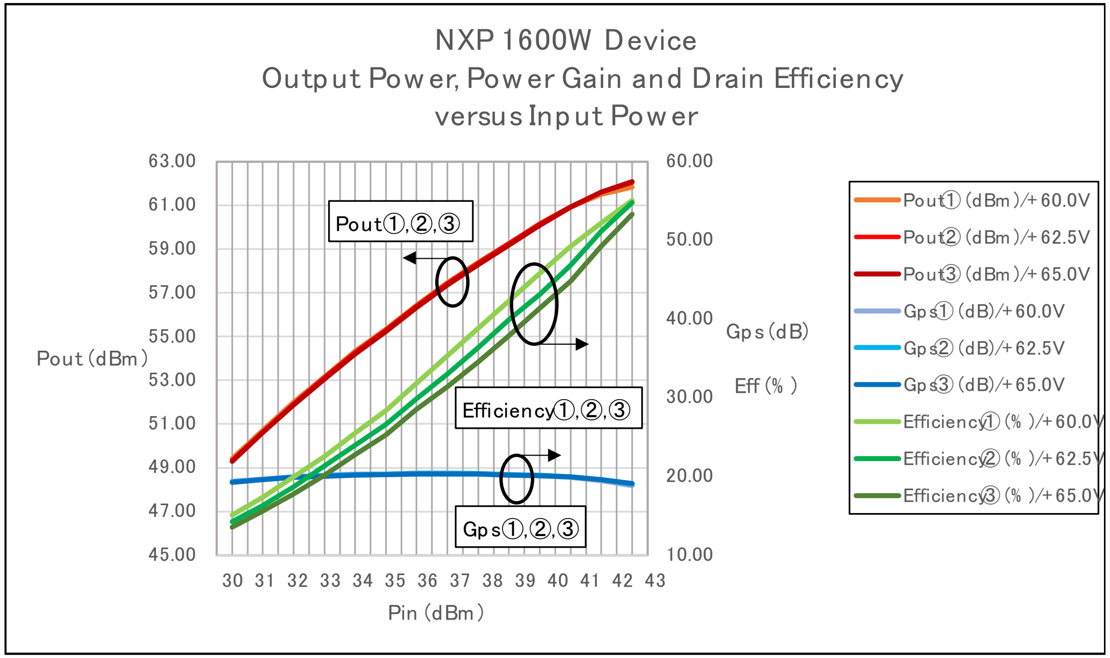
1) Pulse Widtl 1.65ms
2) Duty: 1%

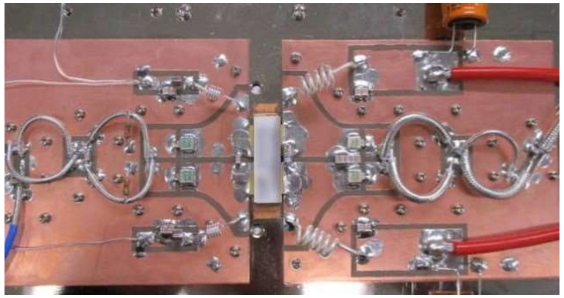
This circuit is a pulse waveform shaping circuit, which takes out a beautiful pulse constant current whose input drops by only -2.5V from a voltage of +51V.
This circuit is connected in series with RF power device, and input current limiting resistor protects each device independently.
Because of this circuit, there is almost no device damage when used for R&K pulse power SSAs.

This circuit consists of 1 input current limiting resistor, 3 inductors, and 10 electrolytic capacitors. Capacitor itself has 10 to 15 years of life time on average. As the capacitor is designed as a block for easy replacement at field, the product life of the amplifier can be secured for more than 40 years.

LD-MOS Device



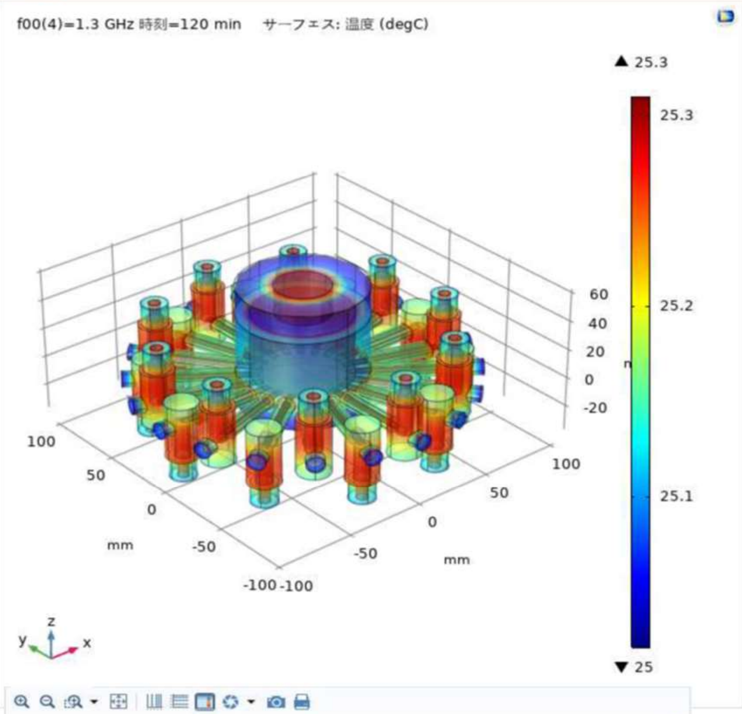


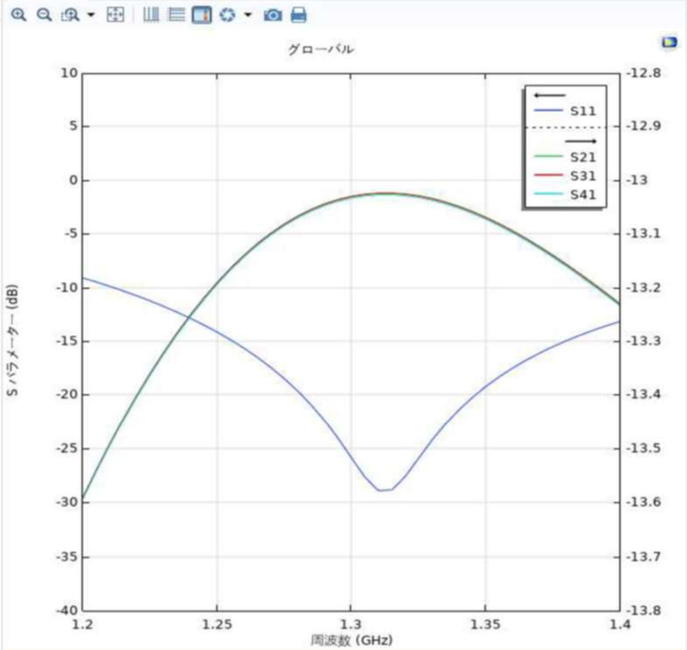


Experimental results of NXP's latest device (high voltage 1.3GHz, 1600W pulse LD-MOS)

Up to 55% DC efficiency and good frequency data are confirmed with reasonable pulsed RF sag power at 1600W per single device. We are familiar with the RF performance of NXP 750W devices from the experience of production and delivery for more than 1000 units by 2020. But this is >1600W.

In addition to NXP, other vendors such as Ampleon, Wolfspeed, Qorvo, and Integra have similar devices in their product lineup. Regardless of the vendor selection, GaN or LD-MOS, +65V device will be the best choice in terms of cost and performance in the current market.

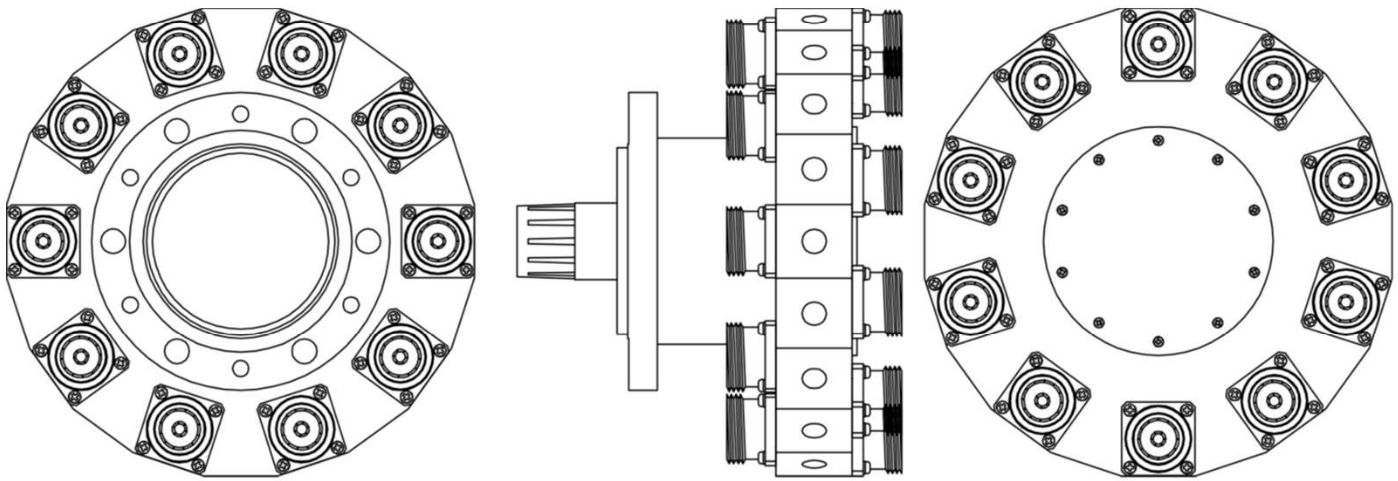




Everyone involved in this project is familiar with the WILKINSON type divider/combiner, so I assume that no detailed explanation be necessary for the part itself. However, I would like to decidedly mention that we have put the utmost effort when designing this in order to minimize the size and cost.

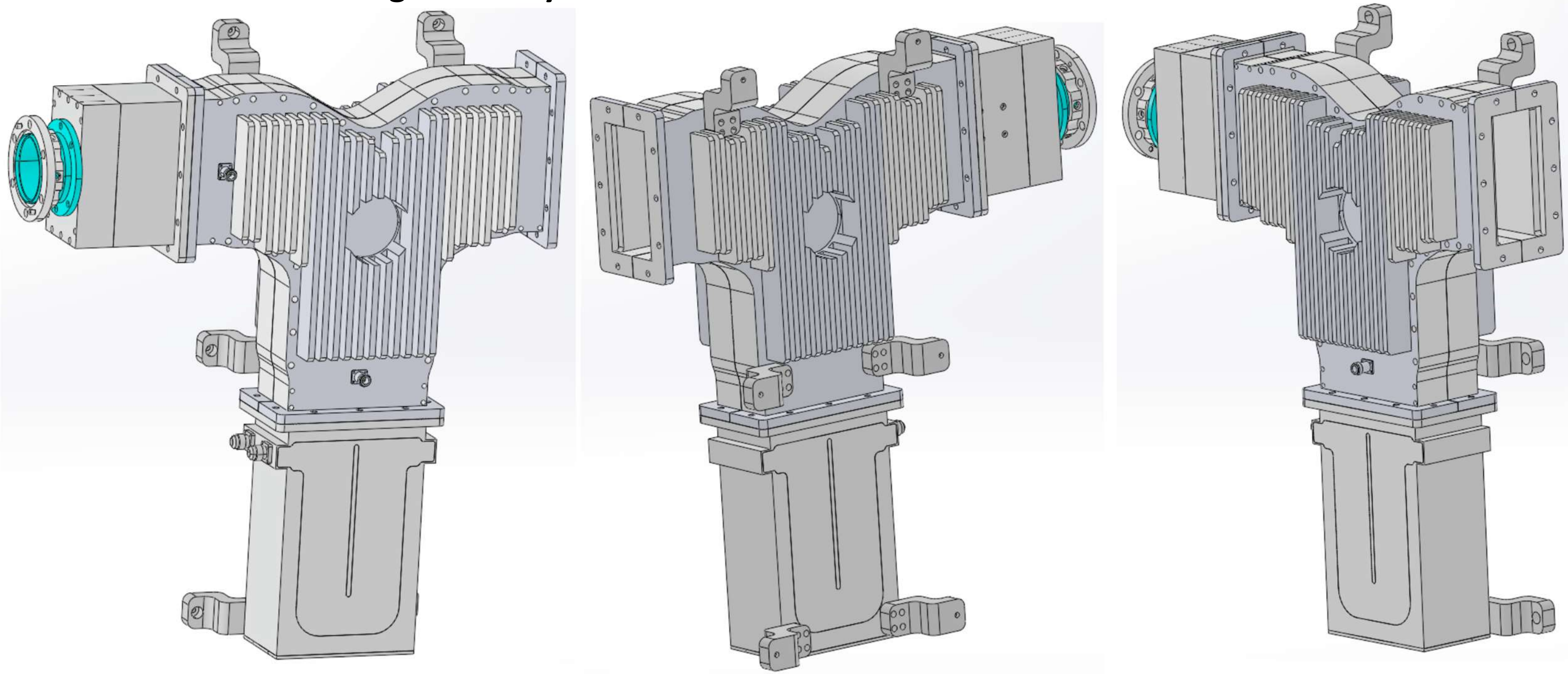
Simply put, if isolation performance needs to achieve with a WILKINSON design, the size becomes larger because it contains λ/4 branches. In other words, the size can be minimized if isolation performance is not required. But in this case, if the reflected power from the output is large and even a part of the branch SSA fails, PAY-BACK reflection will destroy with the avalanche phenomenon.

In this design, ferrite circulators are used everywhere as the preventive measure while keeping the size small.



Multi-Purpose Output Assembly called Circulator

This part has a coaxial 3-1/8" EIA input, and the output port has a waveguide WR650. It has a circulator and a directional coupler for both FWD/REF monitors outputs in between. Needless to say, it is equipped against full power reflection with integral 50 ohms resistor. And this terminating resistor exchanges heat without directly touching the cooling water, and has extremely long life characteristics. By employing all these structures, the total cost was well considered and reduced with holding reliability and life.



Thank you for listening.