First Experience at ELBE with the new 1.3 GHz CW RF-System based on 10 kW Solid State Amplifiers

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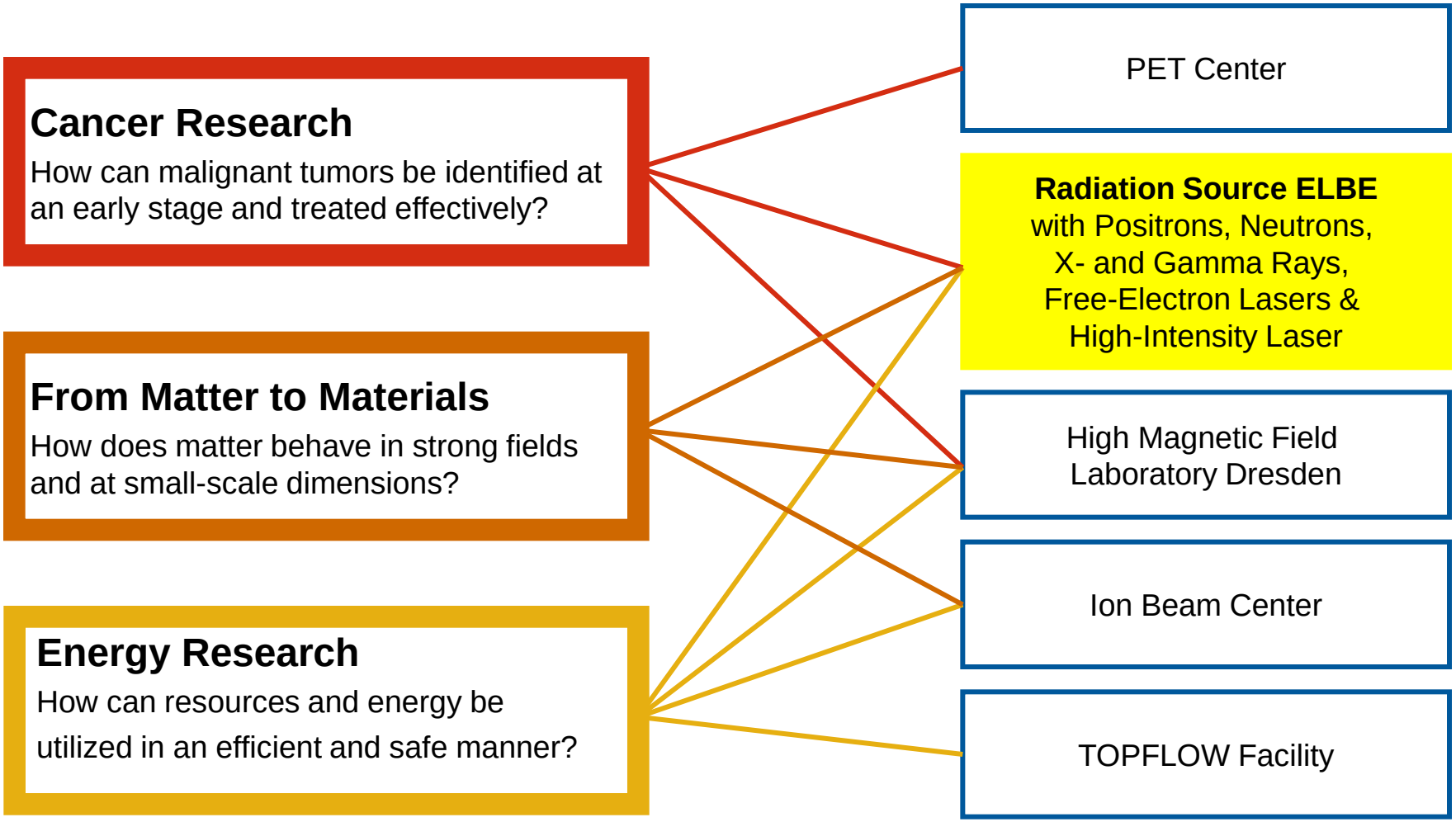
TOPICS

- 1: Short Remarks on ELBE upgrade
- 4: 10kW@1300MHz SOLID STATE PA
- 5: 20 kW (Combination of two SSPA)
- 6: Operation of the new ELBE RF-System

To remember where ELBE is

HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF



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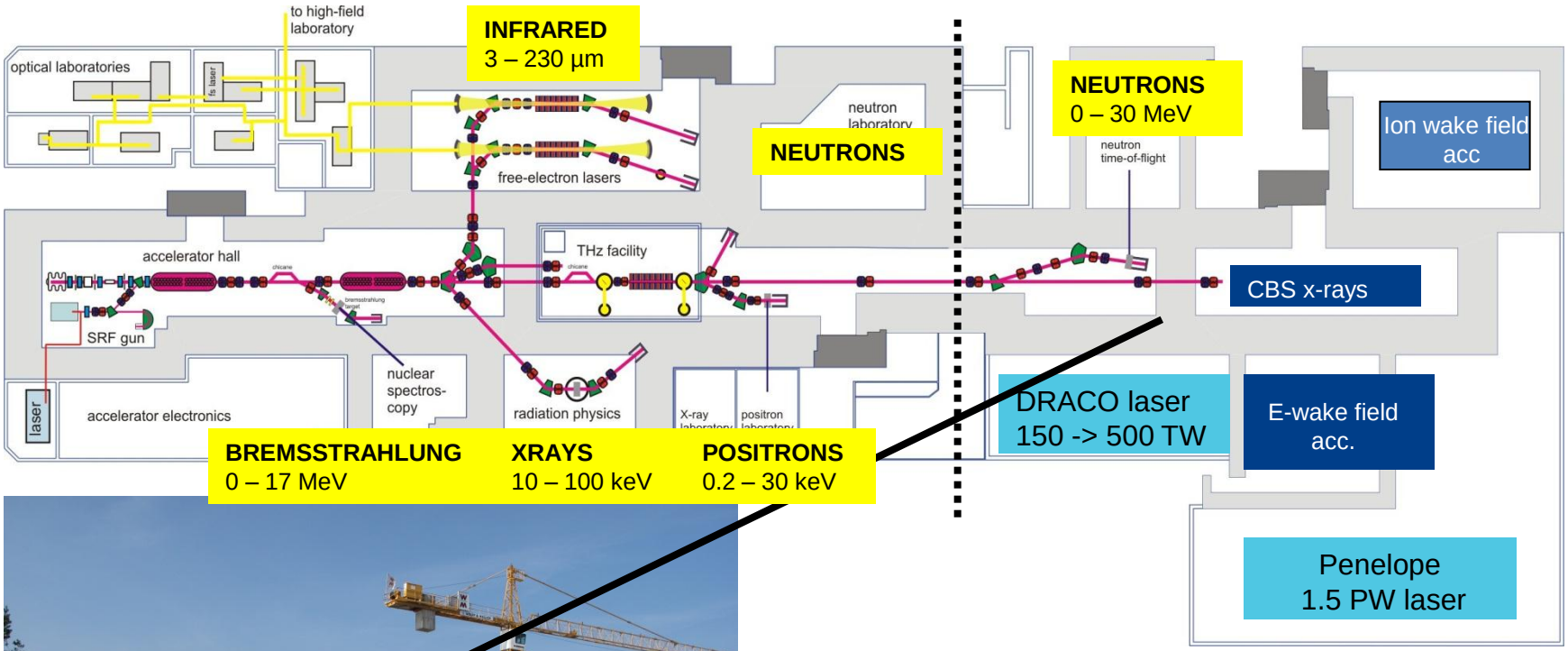
ELBE –UPGRADE Status 3/2012



APRIL 2012

3

UPGRADE to HSQ

- ELBE: FUTURE CENTER OF HIGH POWER RADIATION SOURCES (HSQ)
- ELBE UPGRADE AFTER 10 YEARS OF OPERATION (MANY ACTIVITIES)
- ONE TOPIC IS: DOUBLING THE RF POWER

- Has an impact on:
- RF power amplifiers, RF - couplers, WG-windows; diagnostics, beam dumps, water cooling, mains power…

ELBE SC-LINAC Beam Parameters

	Thermionic Gun	SRF Photo Gun
Maximum permitted Energy	40 MeV (CW)	40 MeV (CW)
Bunch Charge	77 pC > 150 pC	77pc / 2.5 nC
Beam Current CW	0.85 mA >1.6 mA	1 mA
Bunch Length (rms)	1 – 10 ps	4 / 20 ps
Transv. Emittance	2/10 mm mrad (rms)	0.5 / 2.5 mm mrad
Max. Rep.Rate	260MHz@0.77pC 13 MHz@ 77pC	13 MHz
Energy Spread	35 keV /55 keV	40 keV

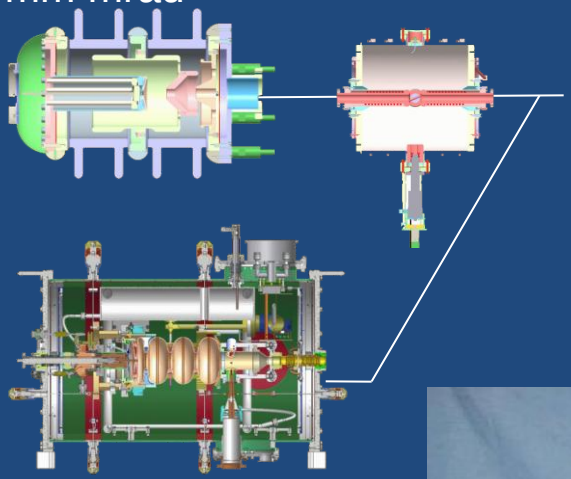
2

Thermionic
DC Gun
250 kV
<= 260 MHz
77
pC(1mA*13MHz)
~ 500ps
~10 mm mrad

RF Bunchers
260 MHz
+1,3GHz
compr. ~ 100:1

Linac
1,3 GHz
~20MeV@10 MeV/m
<1mA CW

Linac
1,3 GHz
~20 MeV@10MV/m
<1mA CW



SRF photo gun
9.5 MeV
<= 13 MHz
80pC / 1nC / 2.5 nC
~ 5-20 ps
~ 1.5-3 mm mrad

4 x 10kW CW - VKL7811St

8 x 10kW CW-SSPA

2

2001 - 2011

Since Feb.2012

ELBE-UPGRADE:
RF RELATED ACTIVITIES

- RESONANT RING (CWRF-2008):

- Conditioning of RF couplers, WG-windows,

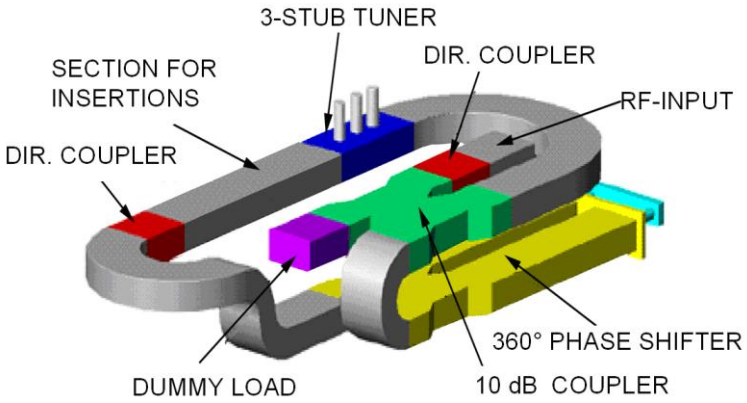
- (NIM A 612 (2010) 427 – 437)

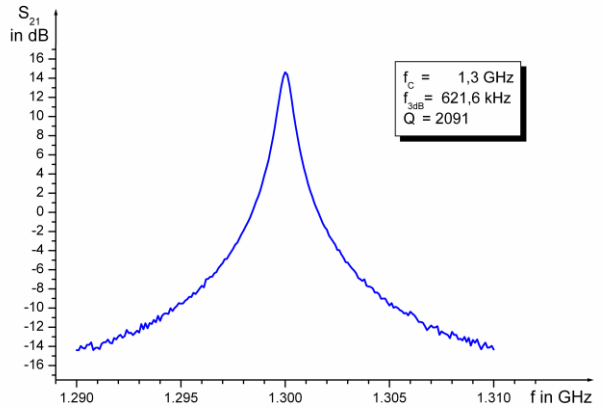
- DOUBLING THE RF – POWER:

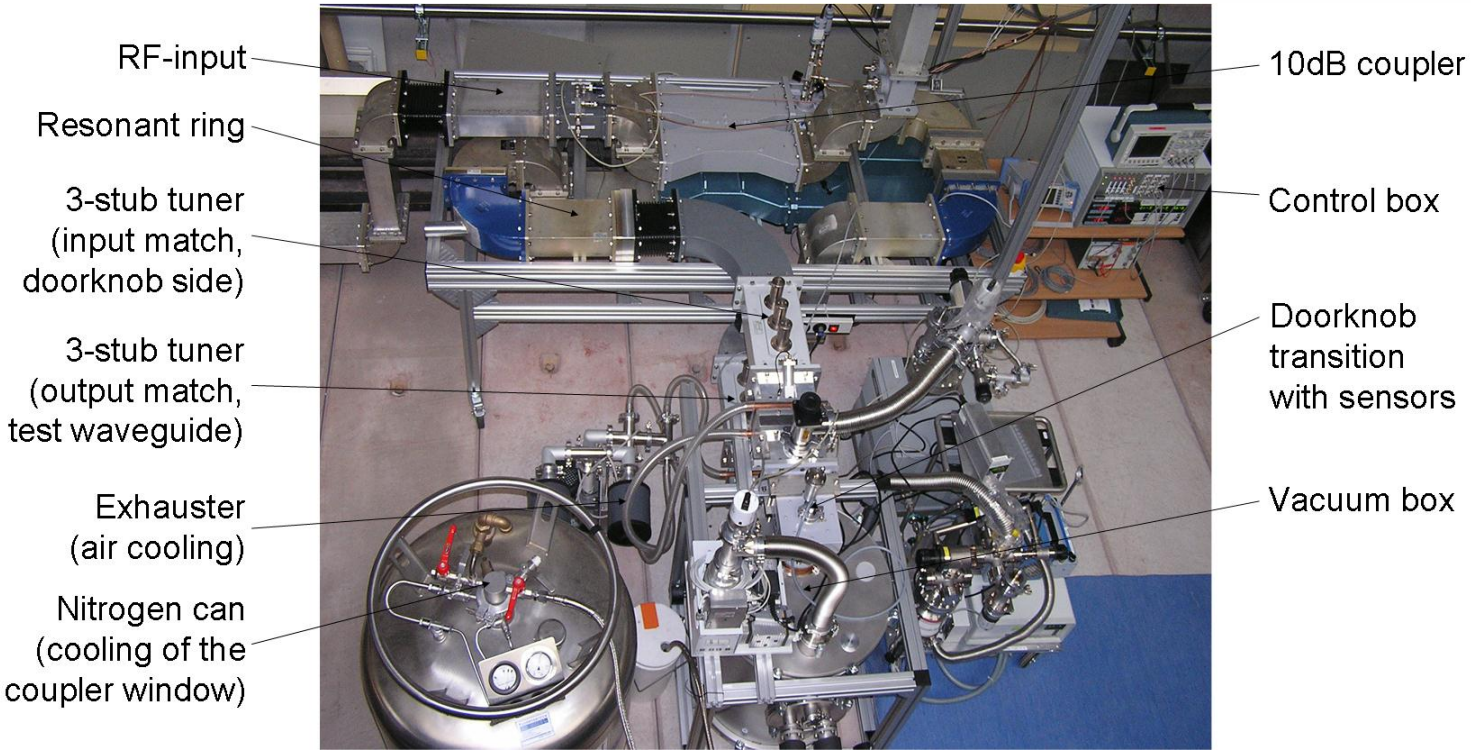
-Test of a 16 kW IOT at a SC-Cavity (2008),
(Good cooperation with Bruker BioSpin+CPI)

-(SRF 2009, TUPP026)

-Test of a 10 kW BRUKER SSPA (CWRF-2010)


3-STUB TUNER
DIR. COUPLER
SECTION FOR INSERTIONS
RF-INPUT
DIR. COUPLER
360° PHASE SHIFTER
DUMMY LOAD
10 dB COUPLER


S21 in dB
fC = 1,3 GHz
f3dB = 621,6 kHz
Q = 2091
f in GHz

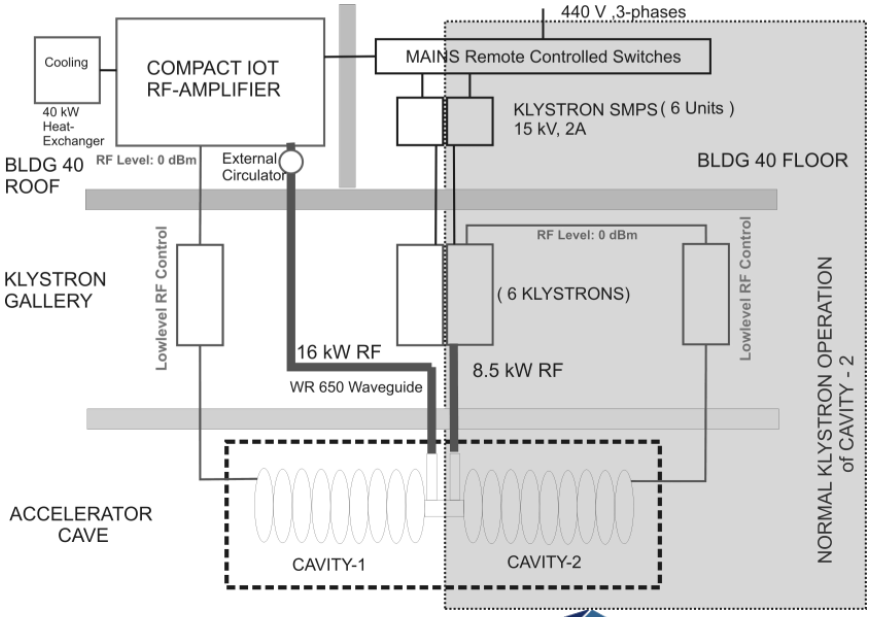

RF-input
Resonant ring
3-stub tuner (input match, doorknob side)
3-stub tuner (output match, test waveguide)
Exhauster (air cooling)
Nitrogen can (cooling of the coupler window)
10dB coupler
Control box
Doorknob transition with sensors
Vacuum box

What kind of RF-Power Amplifier for 20 kW CW@1.3GHz?

- 2 Klystrons ? (1998: VKL7811St (CPI) 38 000 USD/piece)
  (2008: 122 000 USD/piece)

  Answer: NO
- IOT ? eventually

Year 2008: Start of cooperation with BRUKER BioSpin !



Remarks on 16kW - IOT

- Test in 2008 with beam in principle ok
- Compared with a 10kW VKL7811St Klystron (permanent magnet system) IOT is more exp.
- Solid state technology becomes more and more competitive.
- (costs: 10…12 €/W@1.3GHz)
- The „border line between tube- and SSA-technology“ may be in the range of 30 kW at present, but moving up quickly

SOLID STATE AMPLIFIER (SSA)

- ELBE was focused on IOT but not happy.
- INSPIRATION TO SSA-Technology by:

- BRUKER EXP. (Big SSA for Orsay)
- BRUKER 1kW@1.3GHz CW IOT-drivers
- CWRF 2008 GENEVA
- The trend to solid state technology was clear !

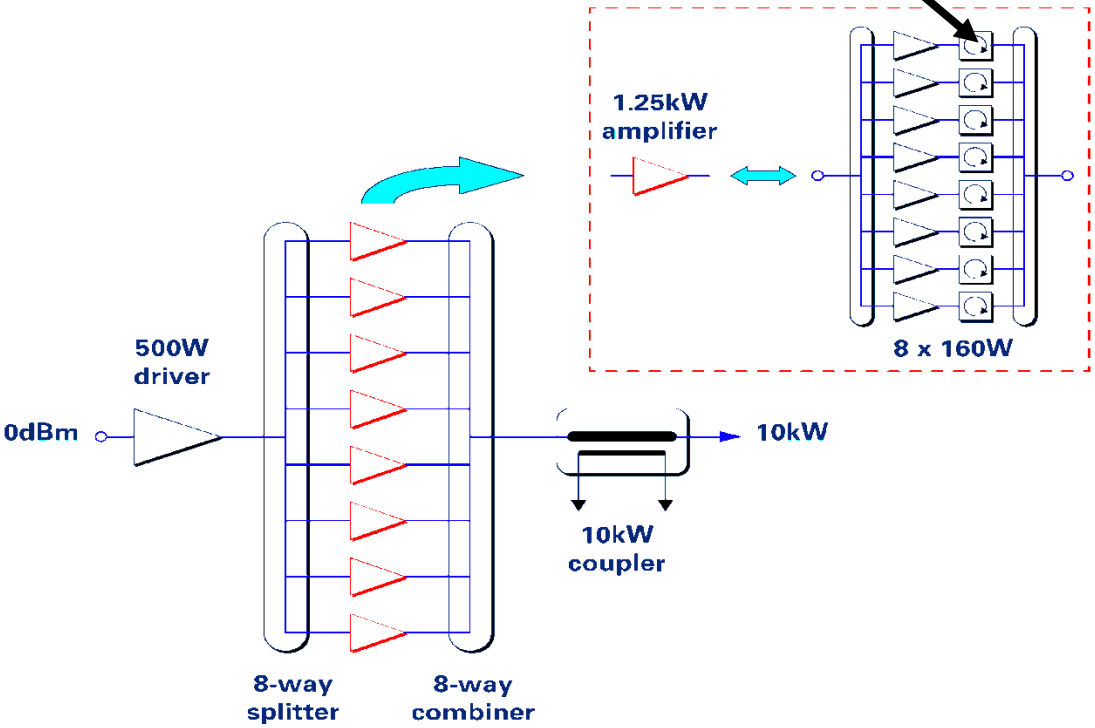
10kW transmitter presented at SRF Berlin October 2009

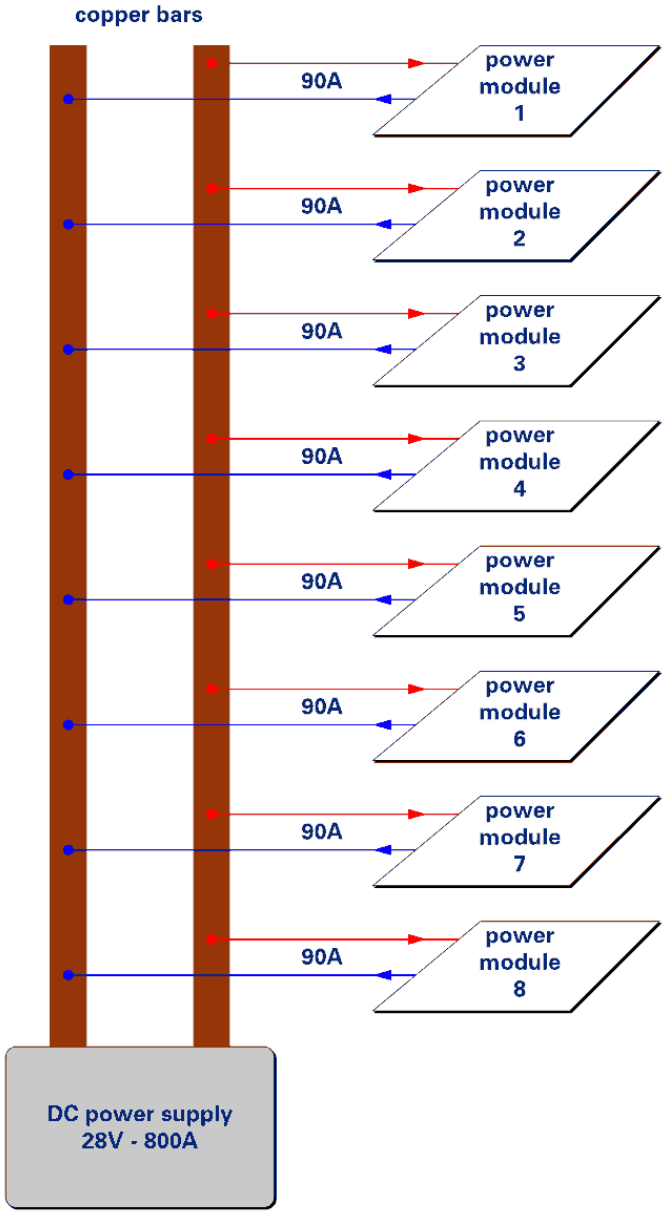
- 42U cabinet
- WR650 waveguide output on top

- water cooled power modules
- water cooled driver
- built in 24kW 28V power supply

Start Development 1/2009; Prototype 9/2009

Each single transistor is protected by a drop-in circulator





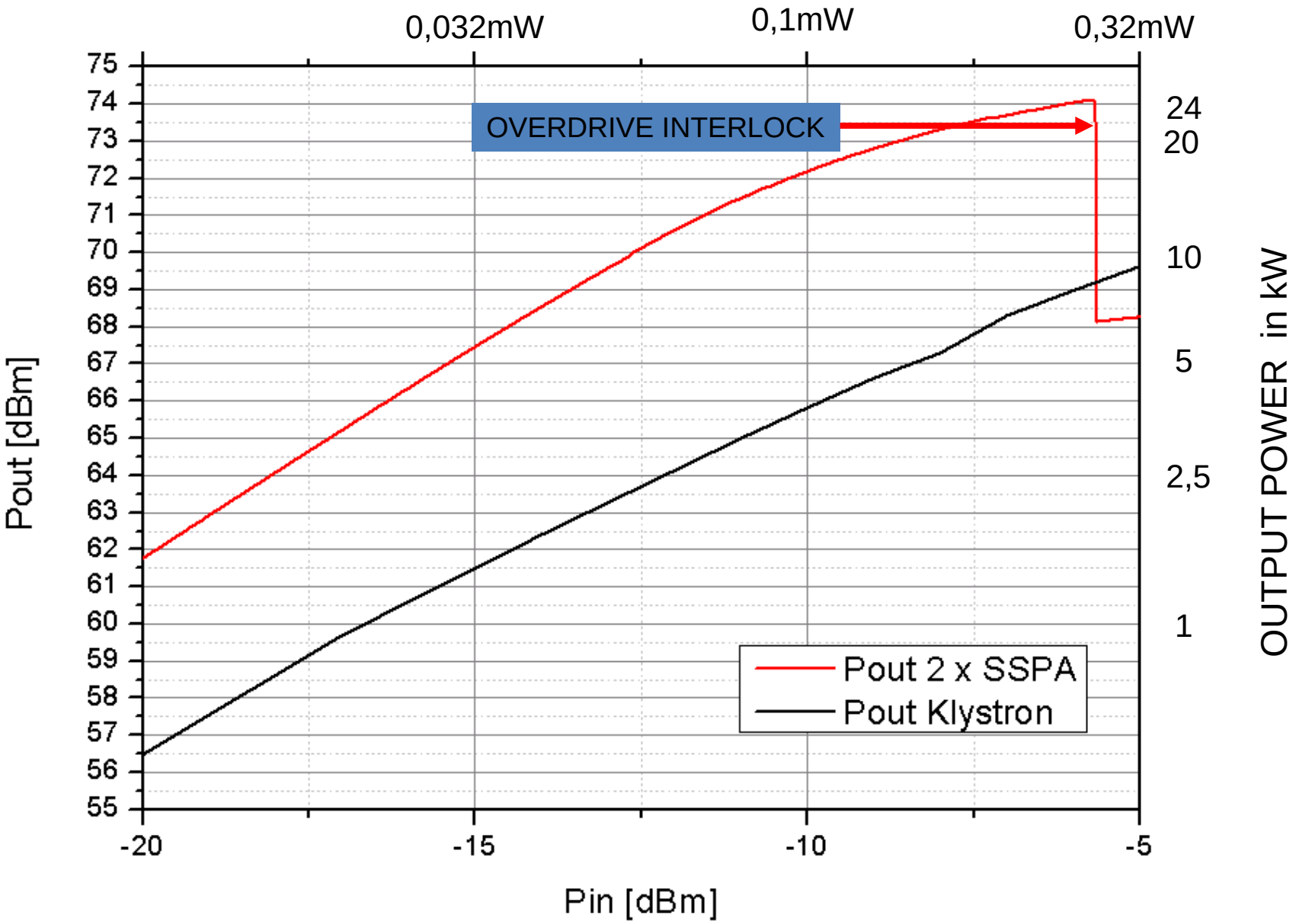
Prototype . 8 x 8 Transistors
Now: 9 x 8 Transistors

GAIN and PHASE CHANGE vs POWER SUPPLY VOLTAGE

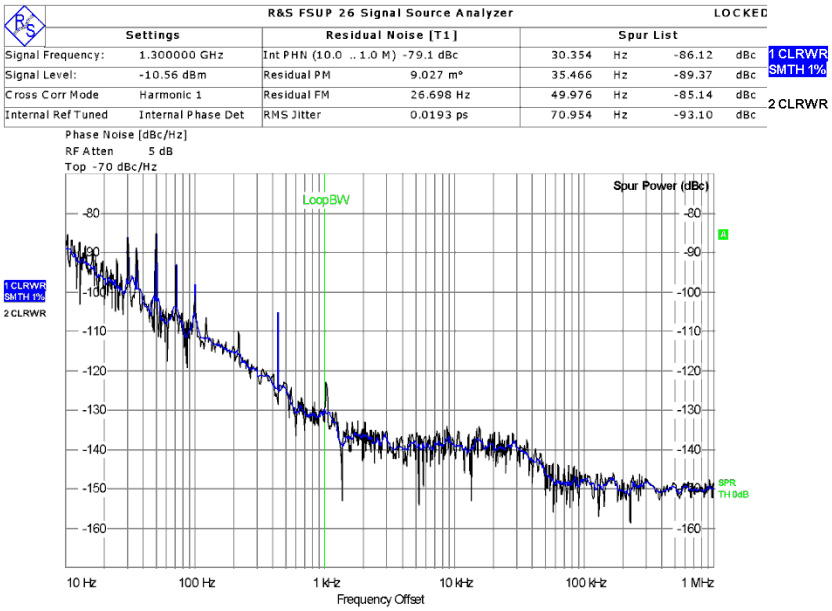
sensitivity to voltage changes measured at different power levels

	2kW	4.6kW	8.5kW	9.1kW
∆gain/∆V	0.01dB/V	0.01dB/V	0.08dB/V	0.06dB/V
∆phase/∆V	0.08°/V	0.25°/V	1°/V	0.6°/V

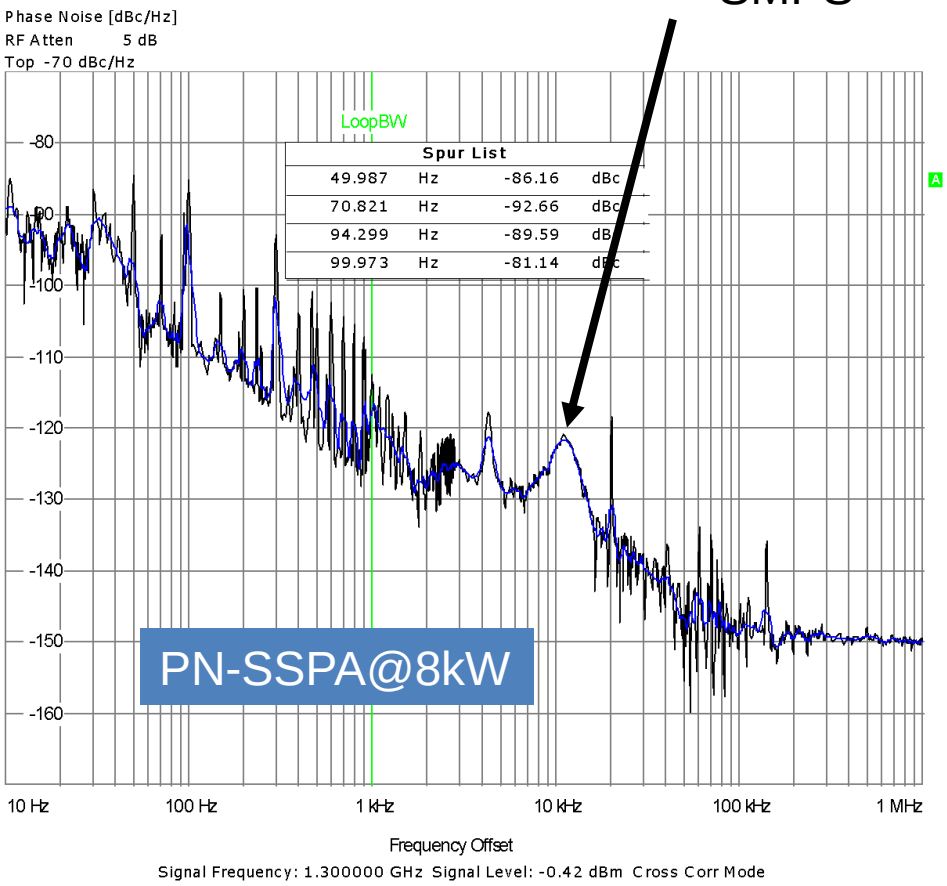
INPUT POWER


0,032mW
0,1mW
0,32mW
OVERDRIVE INTERLOCK
Pout [dBm]
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
-20
-15
-10
-5
Pin [dBm]
24
20
10
5
2,5
1
OUTPUT POWER in kW
Pout 2 x SSPA
Pout Klystron

PN-SOURCE



SMPS



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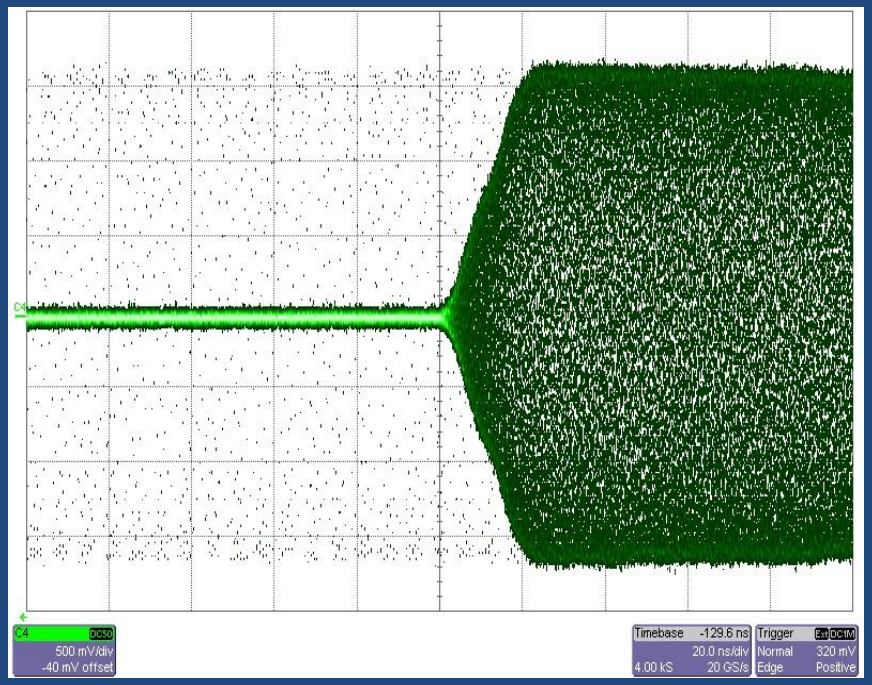
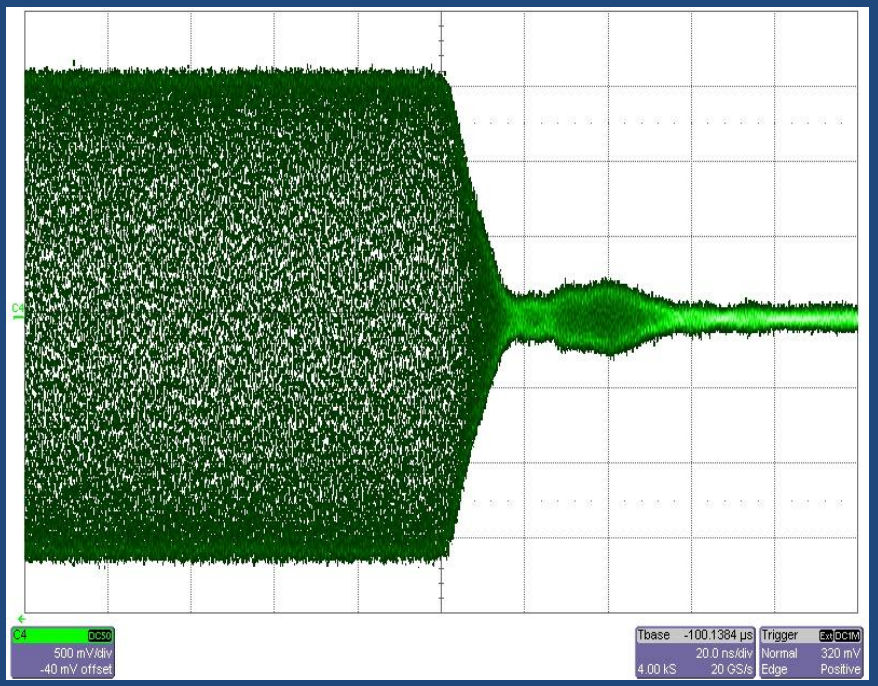
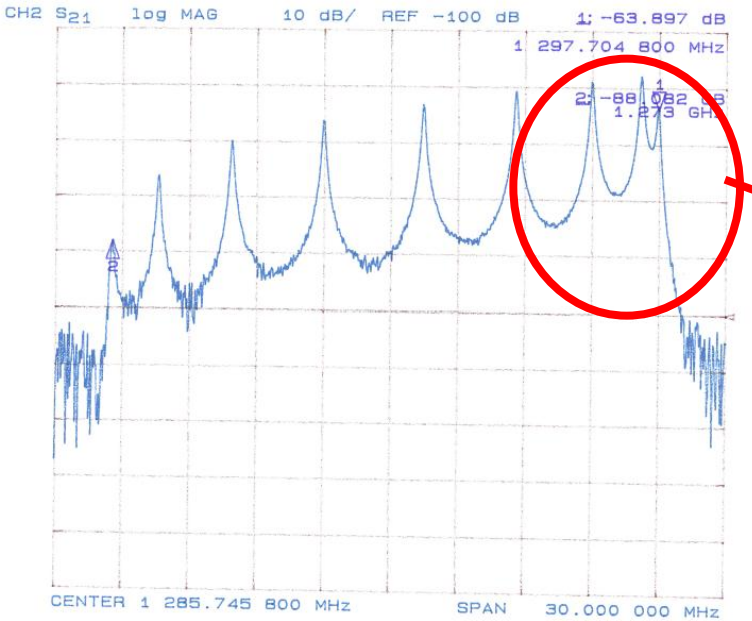
RAISE TIME and FALL TIME



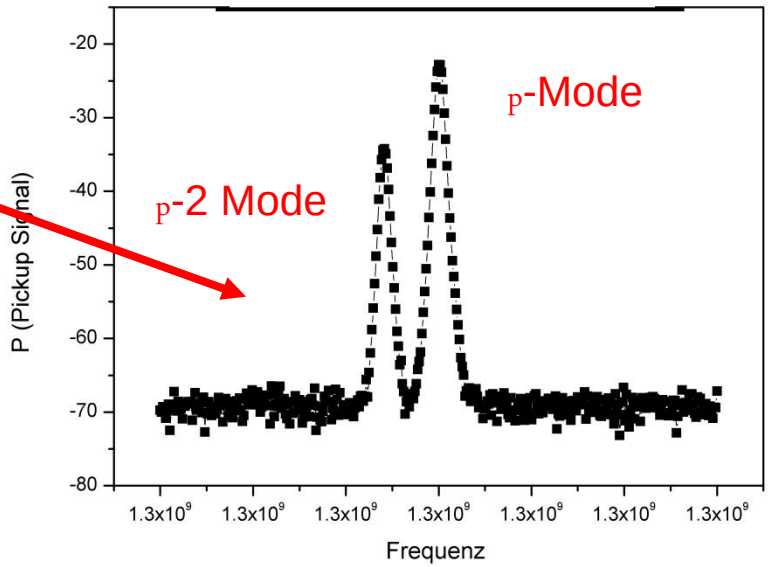


measured at 8kW output power
rise time ≈20ns fall time ≈ 60ns

Observation when the Klystron was replaced by a Solid State PA (SSA):

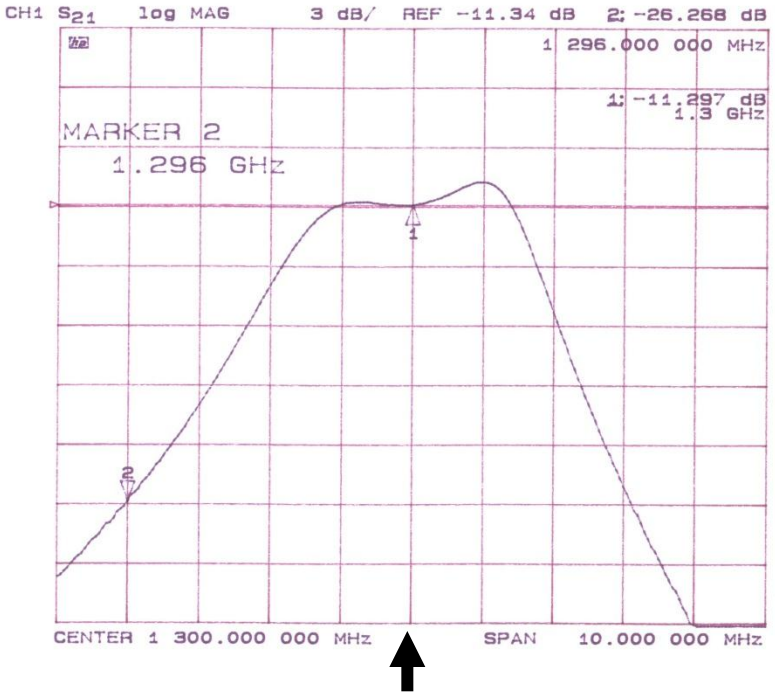


Passband of a 9-cell cavity

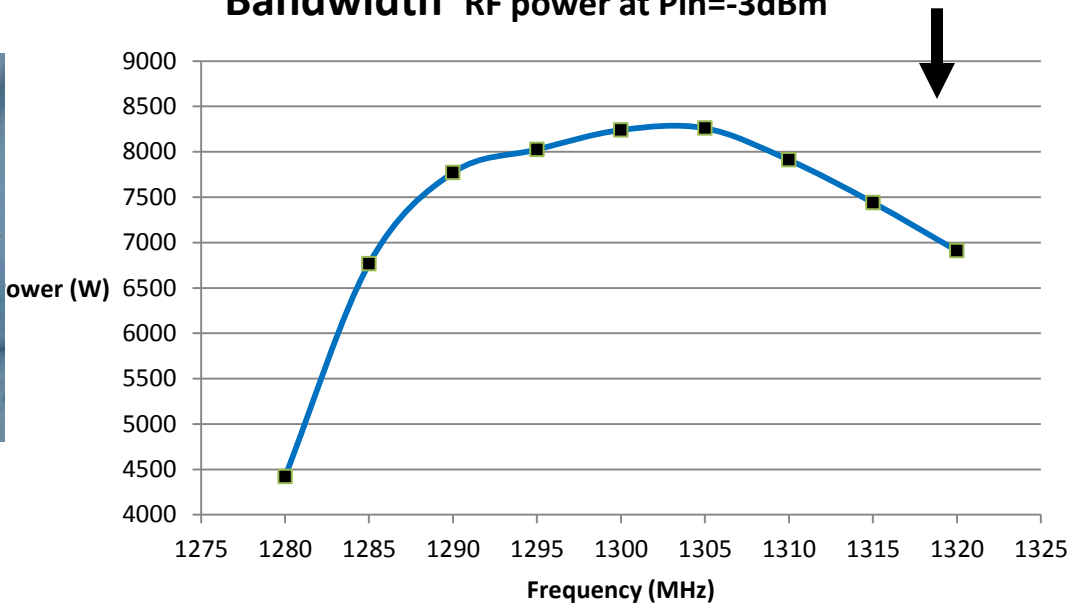


Pickup Signal at Cavity C4

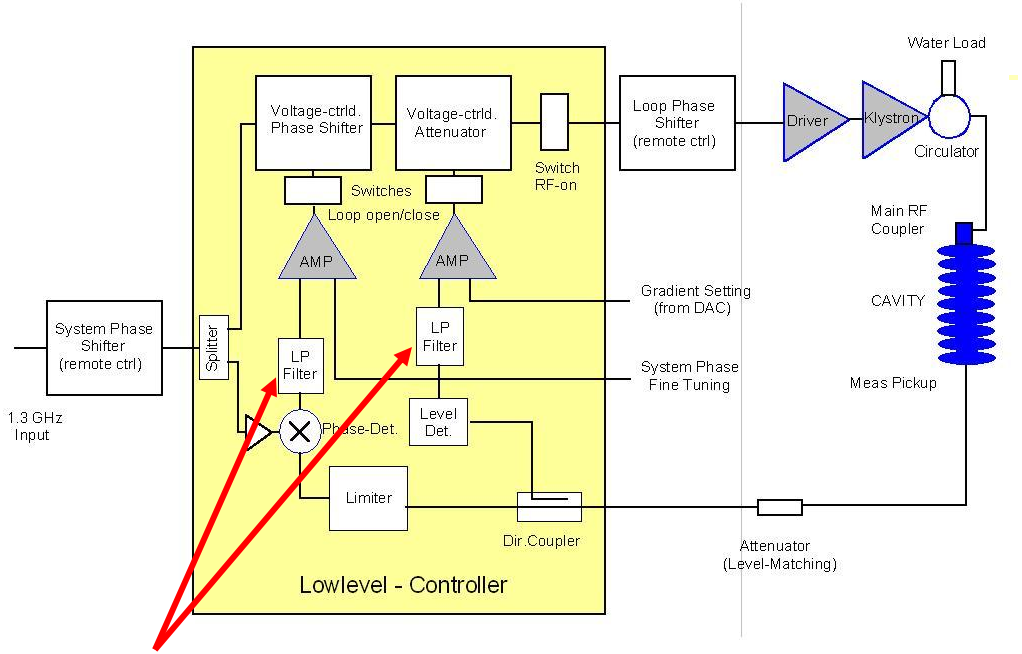
Due to a 10 times higher RF- bandwidth of the SSA at certain circumstances (e.g. detuned cavities, high loop gain) the LLRF controller locked not only on the Pi-mode but also on (Pi-1) or / and (Pi-2). The system became instable.

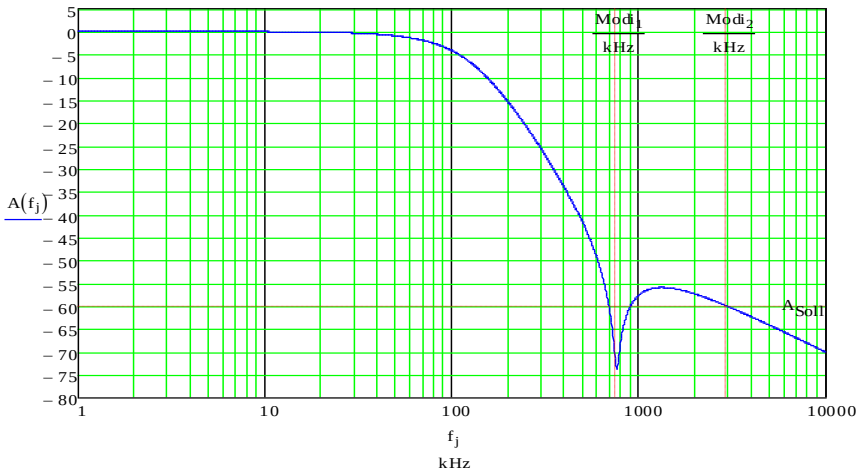


Bandwidth RF power at Pin=-3dBm



Solution: Improved LLRF Controller





Attenuation >-70dB at Pi-1; -60dB at Pi-2

- Redesign of the LLRF-Controller
- Loop filters with notches in both loops (amplitude, phase)
- Loop gain is now adjustable independently from the transfere function of the loop filters

  Result: absolutely stable operation at all circumstances

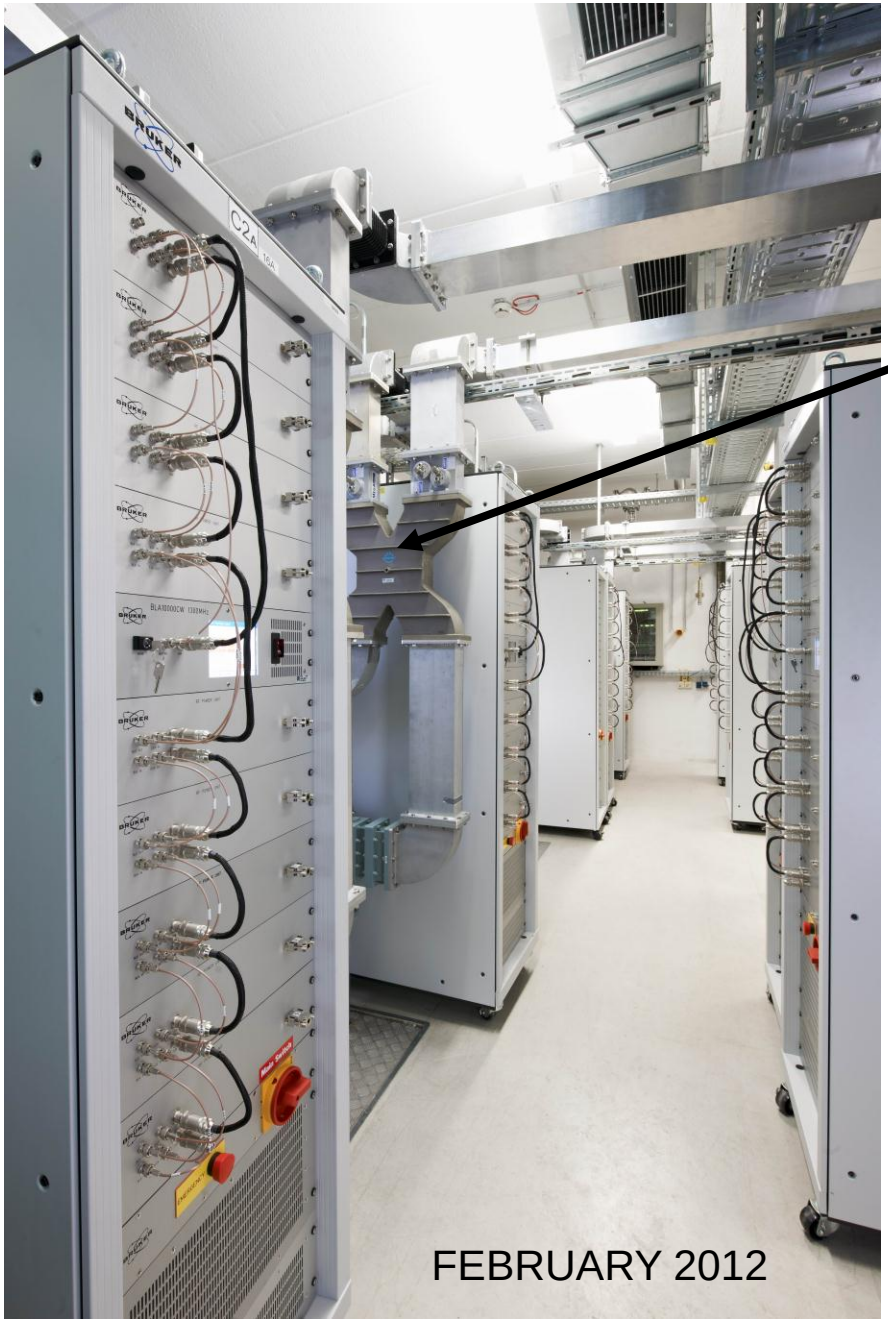
TEST OPERATION AT ELBE

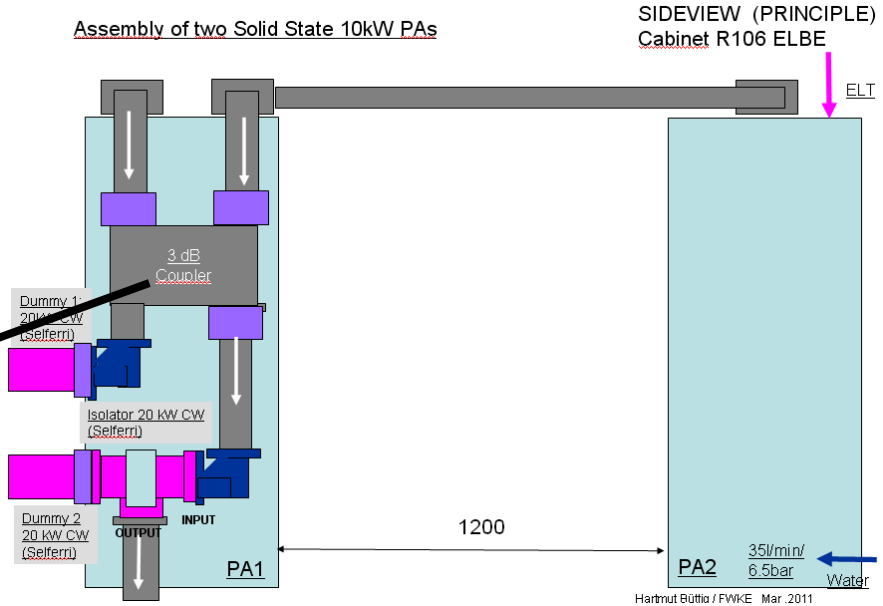
- Routine OP : 08.Feb. 2010 to 17.Dez.2011
- No failures, much smoother than klystron op
- Regimes of operation:

- CW (FEL, Cavity C4: 8MV/m/ 0.7 mA)
- Raise-/Fall time sufficient to run macropulse mode (0.1ms/40ms)
- Ok for single pulse mode
- Pulse Mode (cavity training)

TIME TABLE (RF-UPGADE)

- Feb. 2010: Test-Operation at ELBE (one klystron replaced)
- Decision in May 2010:
  we keep the replacement, SSPA is more stable than klystron,
- Dec.2010: Order of another 9 Bruker SSPA
- ELBE shutdown 2010/2011: Reconstruction of coolingsystem
- Sep.2011 to Dec.2011: Delivery of 9 SSPA
- 17.Dec.2011: Begin ELBE shutdown, all klystrons removed,
- Jan. 2012: complete new installation of the power RF system
- 1-st week in Feb.2012: test with dummy load, matching
- 4-th week in Feb.2011. start routine OP of ELBE with SSPA



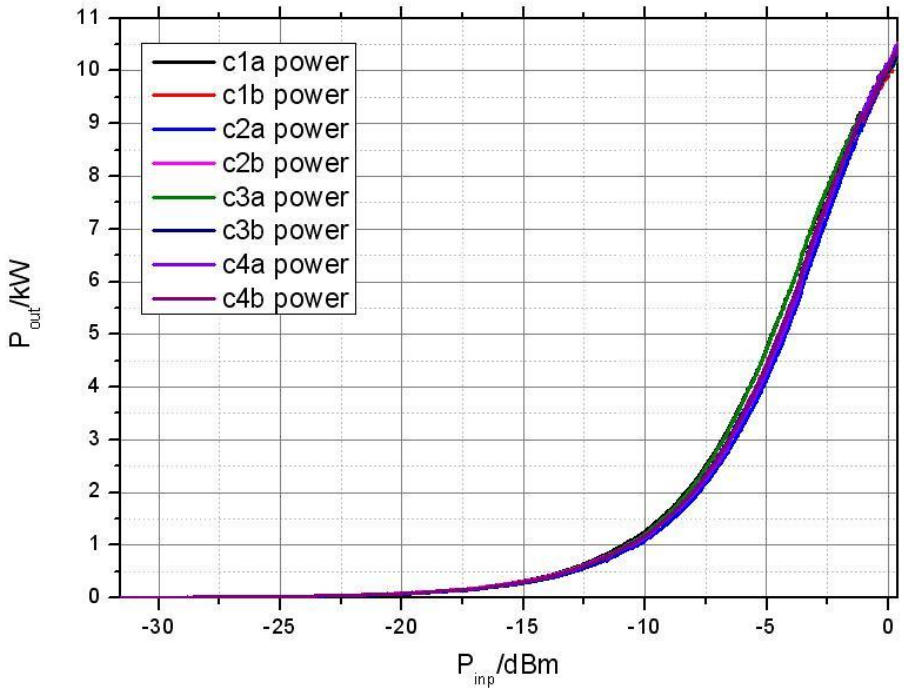


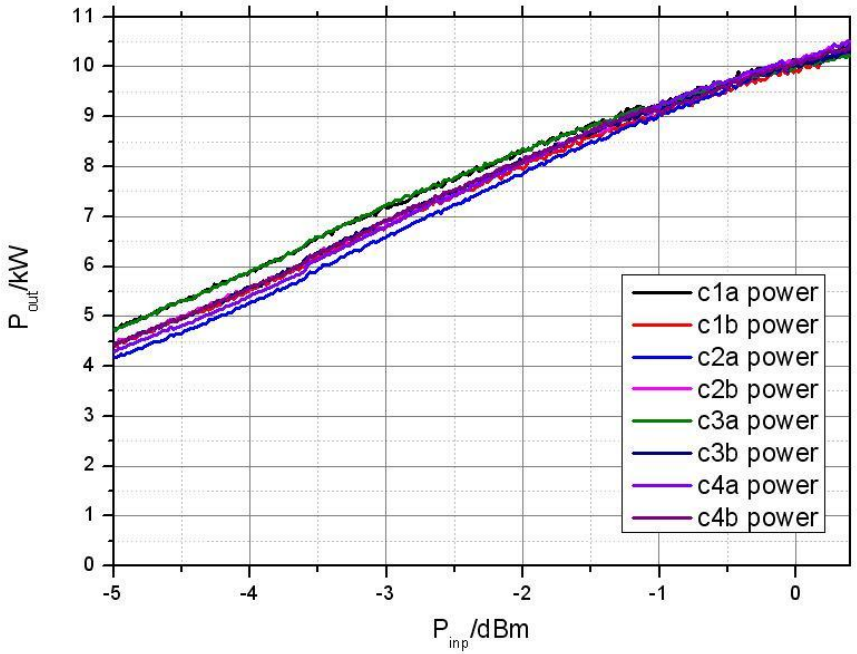
CAVITIES 1 – 4
DRIVEN BY
A PAIR OF 10kW
BRUKER SSPA

SRF-GUN with
one 10 kW SSPA

DRESDEN concept

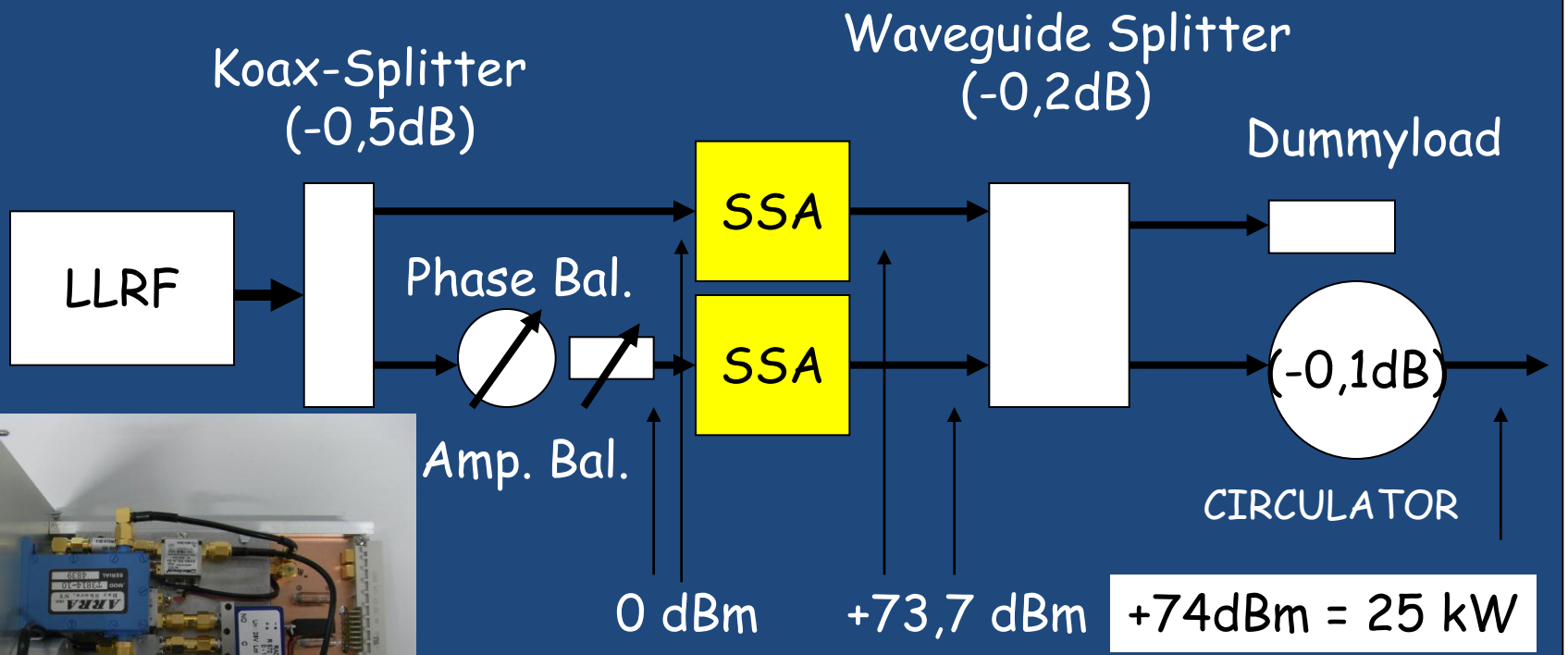
HZDR


c1a power
c1b power
c2a power
c2b power
c3a power
c3b power
c4a power
c4b power
P_out/kW
P_inp/dBm
11
10
9
8
7
6
5
4
3
2
1
0
-30
-25
-20
-15
-10
-5
0


c1a power
c1b power
c2a power
c2b power
c3a power
c3b power
c4a power
c4b power
P_out/kW
P_inp/dBm
11
10
9
8
7
6
5
4
3
2
1
0
-5
-4
-3
-2
-1
0

Block Diagram

RF-POWER (1dB reserve below -1dB comp.: +71 dBm = 12,6 kW
(LIMIT: (each amp.8,5 kW): 72,3dBm-0,3dB= 15,58 kW



MATCHING PROCEDURE IS SIMPEL !

Summary

- 20 kW @1,3 GHz CW RF System with SSPA:
- Compact system (turn-key solution)
- High redundancy ! If the klystron fails, the accelerator stops, if a transistor fails, tjhere is no problem to continue operation !
- SSPA technology is developing fast , there is no vacuum device, no time-limiting cathod,
- For ELBE UPGRADE: we saved about 40 % costs against tubes


IPAC 2014
DRESDEN