HYBRID CONFIGURATION, SOLID STATE – TUBE, REVAMPS AN OBSOLETE FULL TUBE AMPLIFIER FOR THE INFN K-800 SUPERCONDUCTING CYCLOTRON

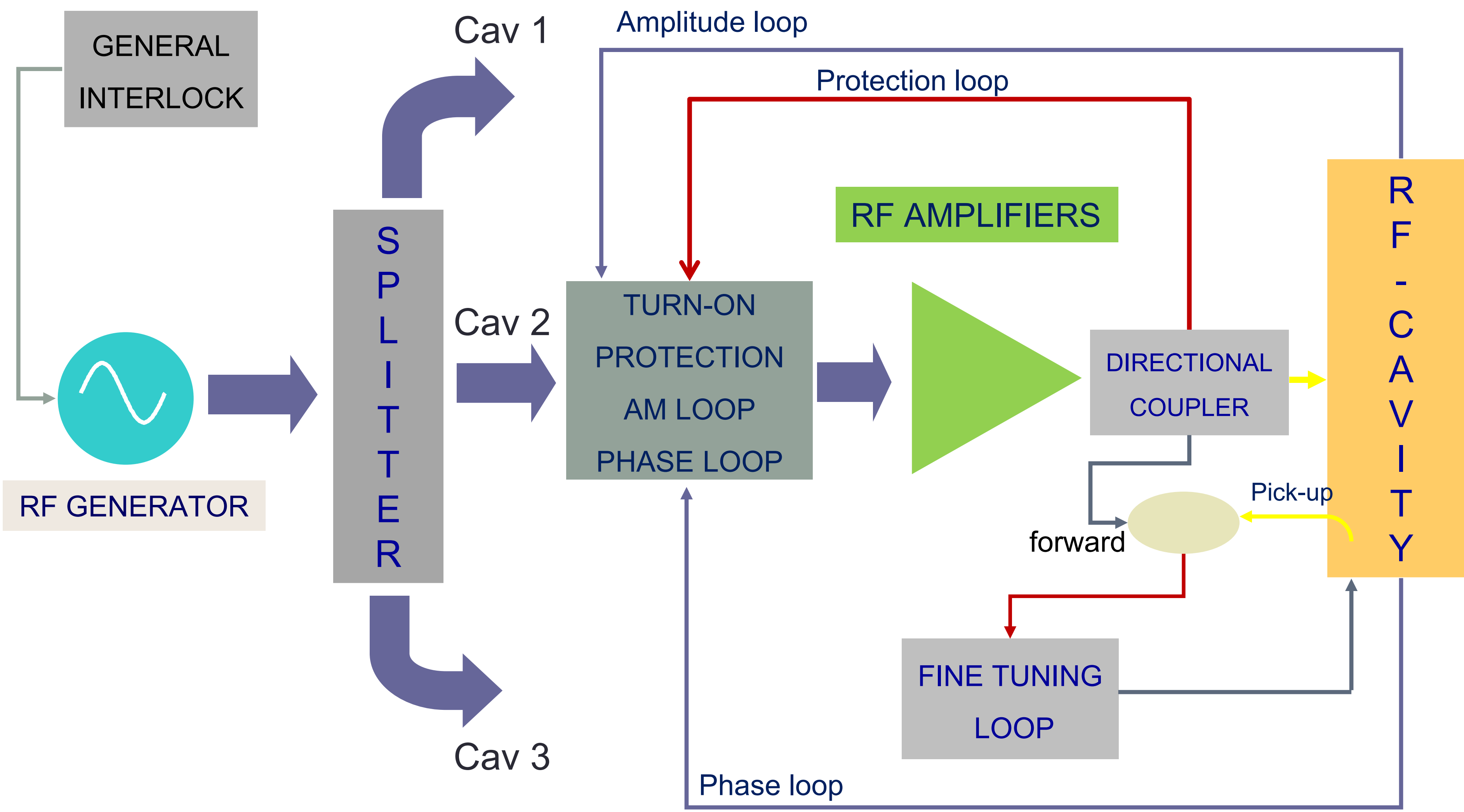
Antonio Caruso
INFN-LNS

INFN Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Sud

Talking points

- **Overview of the block diagram and RF amplification stages**
- **Main reasons to modify the existing amplifiers;**
- **Solid state vs tube amplifier as 1st stage;**
- **Matching between the new 1st stage and the existing 2nd "tube" stage;**
- **Test, measurements and operation with our cyclotron;**
- **Conclusion;**
- **References and discussion.**

The general RF system block diagram



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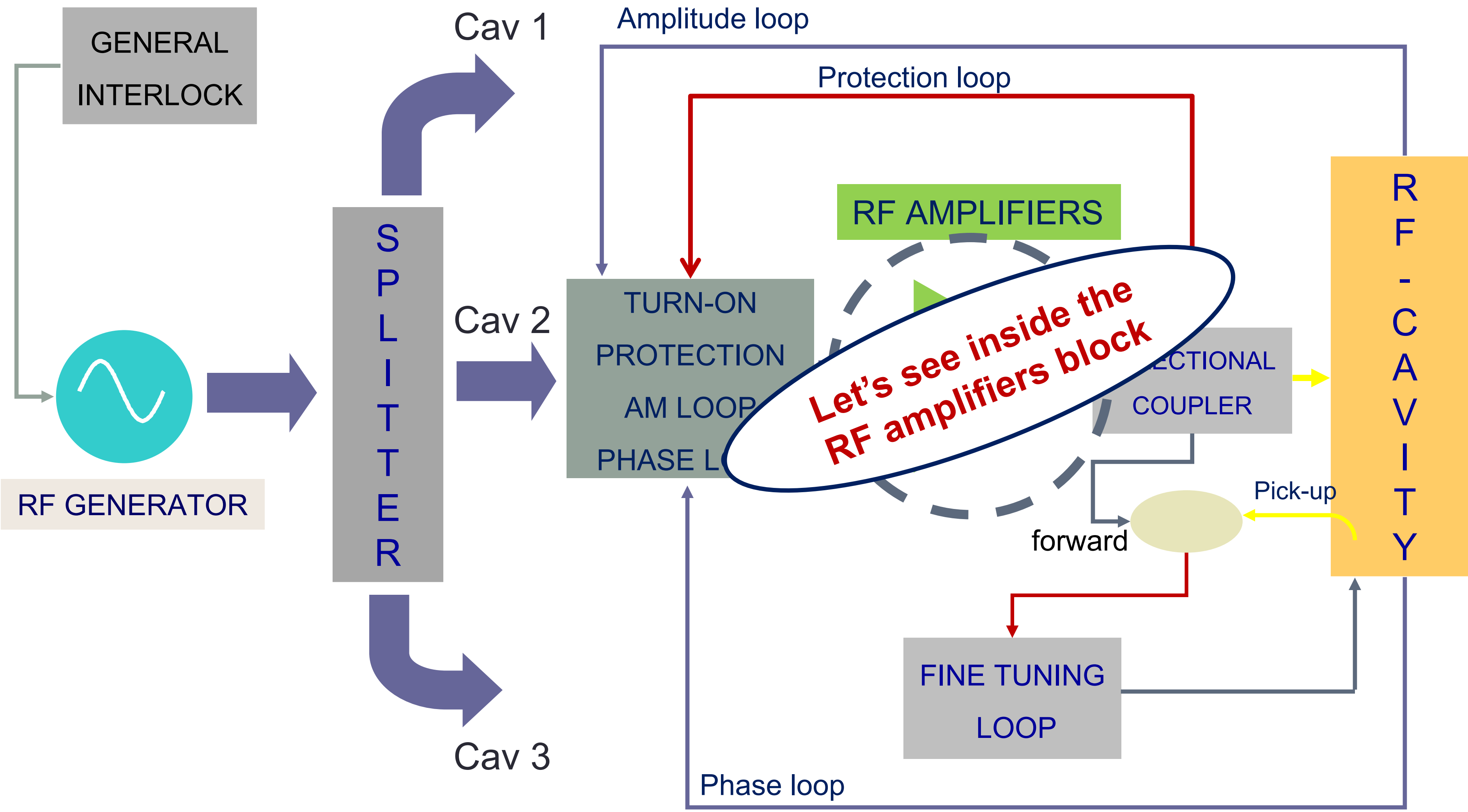
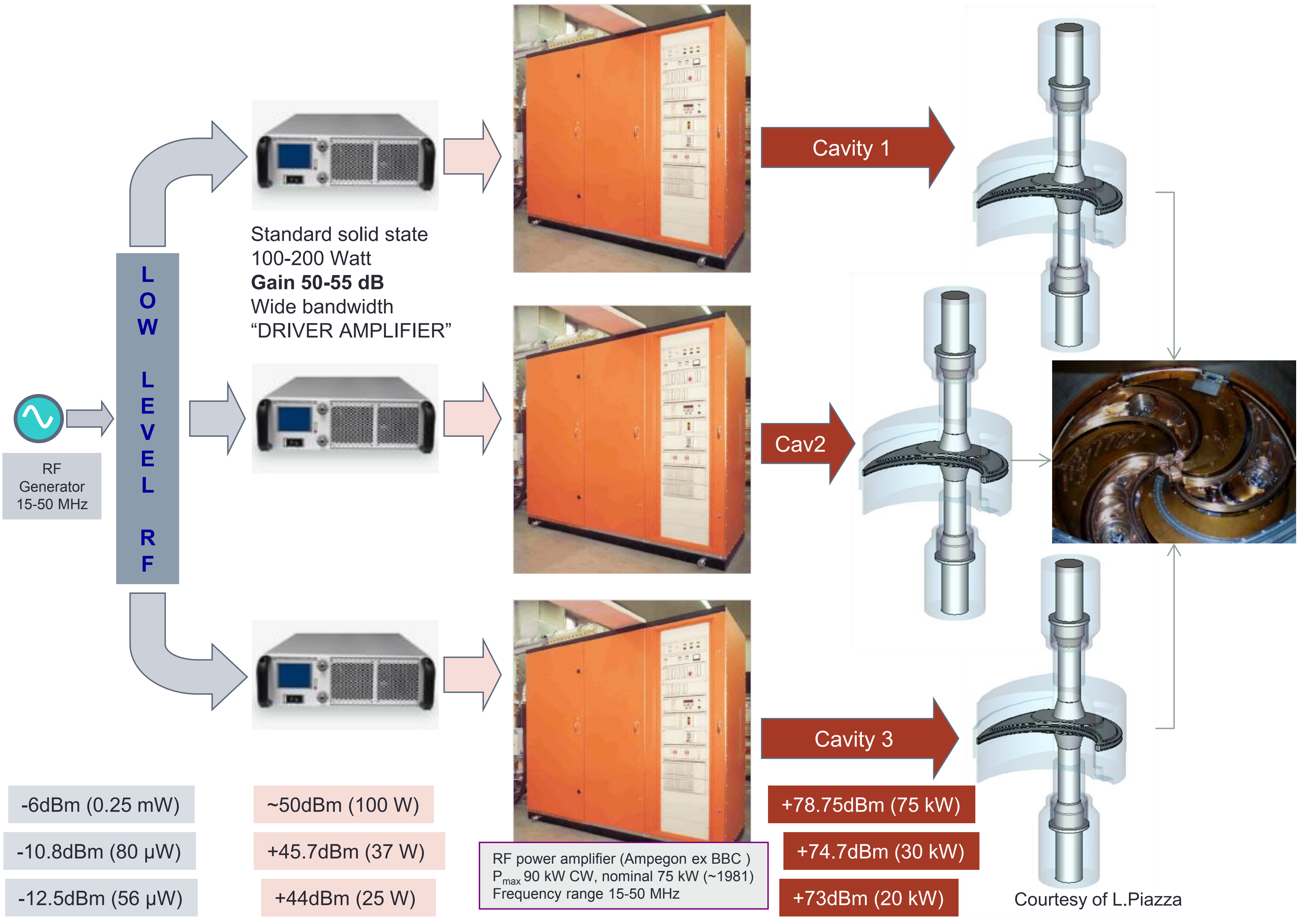
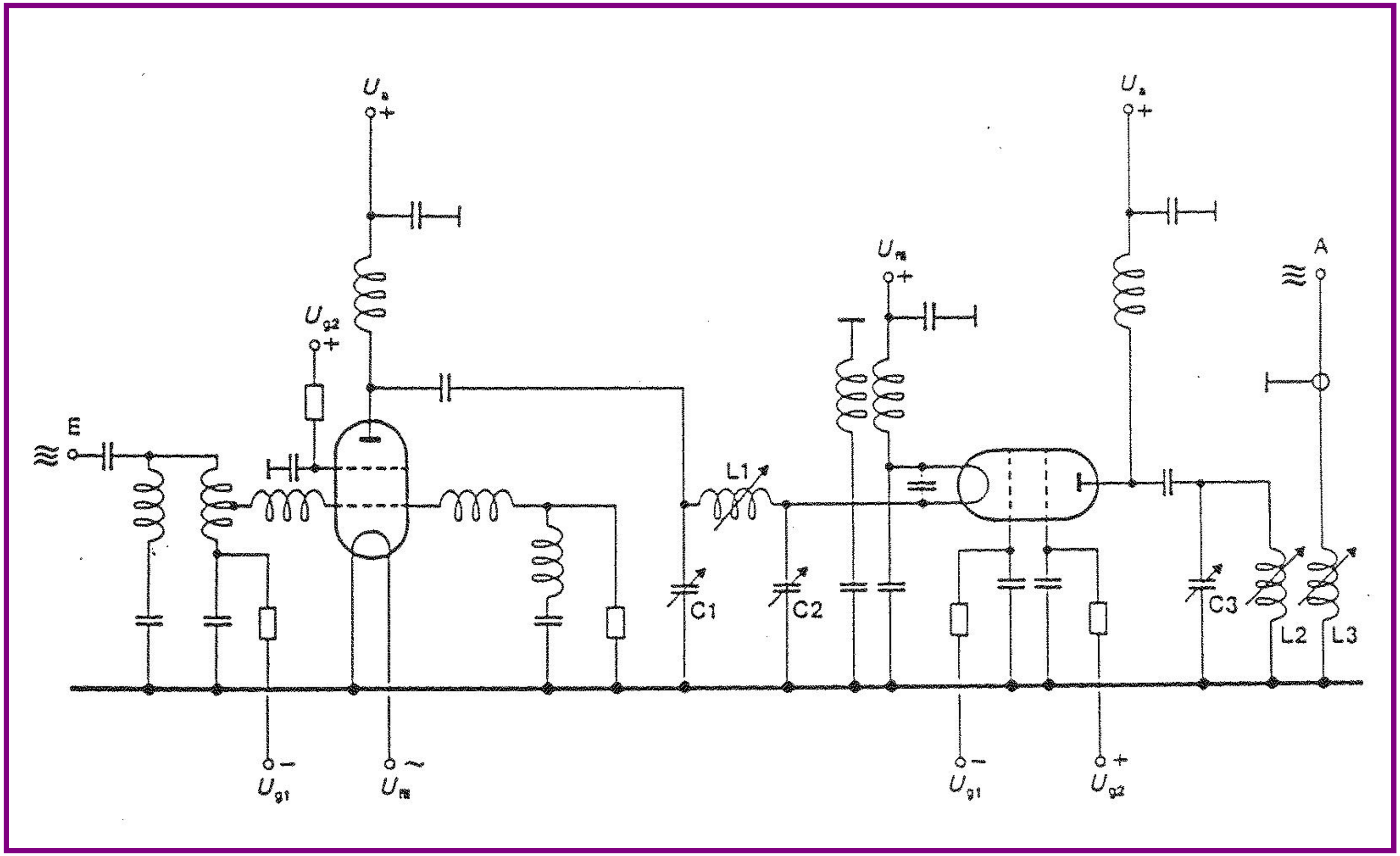


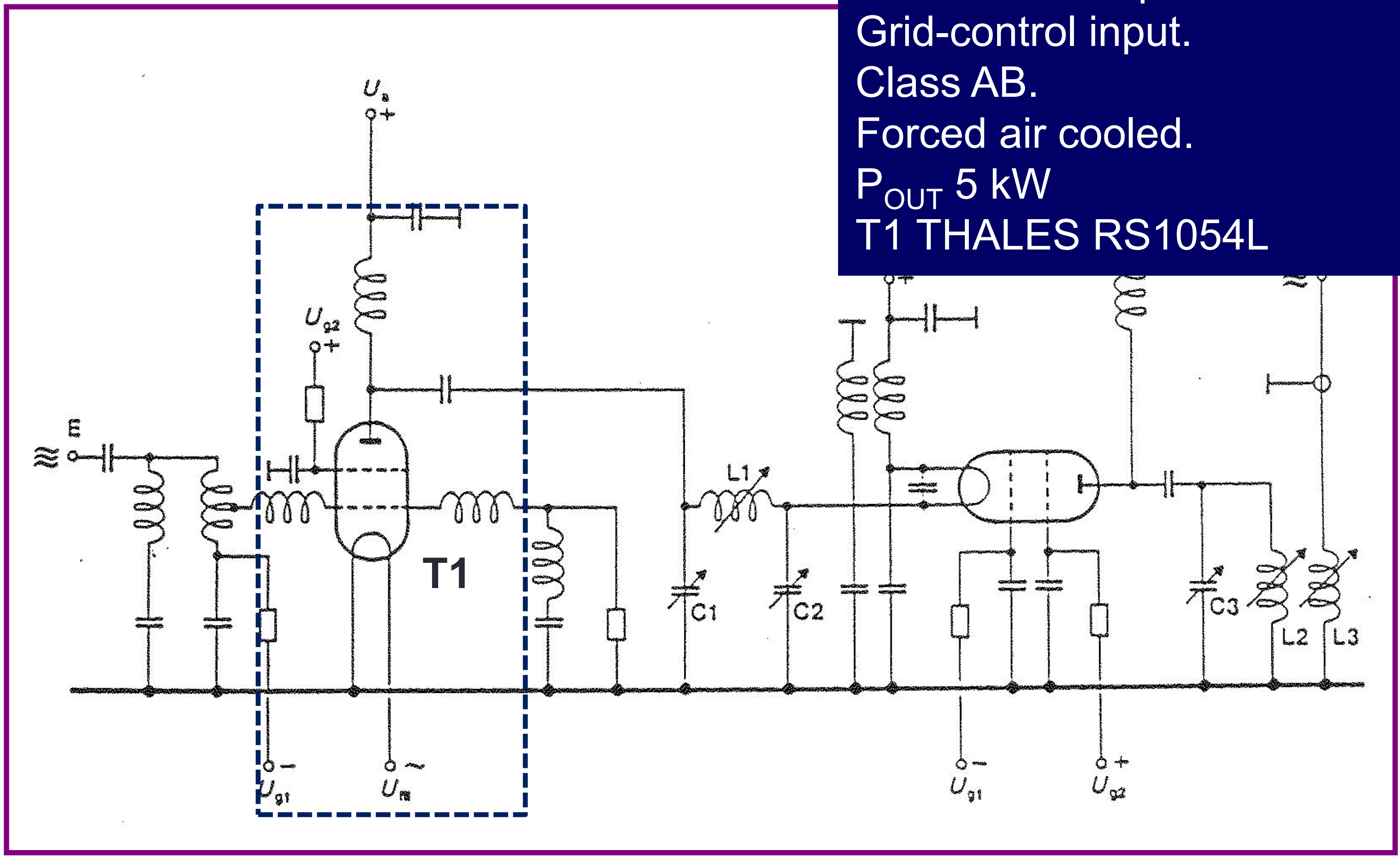

RF Generator 15-50 MHz
LOW LEVEL RF
Standard solid state
100-200 Watt
Gain 50-55 dB
Wide bandwidth
"DRIVER AMPLIFIER"
Cavity 1
Cav2
Cavity 3
-6dBm (0.25 mW)
-10.8dBm (80 μW)
-12.5dBm (56 μW)
~50dBm (100 W)
+45.7dBm (37 W)
+44dBm (25 W)
RF power amplifier (Ampegon ex BBC)
Pmax 90 kW CW, nominal 75 kW (~1981)
Frequency range 15-50 MHz
+78.75dBm (75 kW)
+74.7dBm (30 kW)
+73dBm (20 kW)
Courtesy of L.Piazza

Power amplifier



Power amplifier

The 1st stage is a **ground-cathode** configuration. In general this configuration is very reliable, shows very few technical problems and a considerably low number of components.
Grid-control input.
Class AB.
Forced air cooled.
P_{OUT} 5 kW
T1 THALES RS1054L



Input filter stage:
- wide band
- adapts from 25 to 50Ω between tetrode and Driver impedance
- The RF power of Driver is dissipated on the parallel 50Ω.
- No tuning is required

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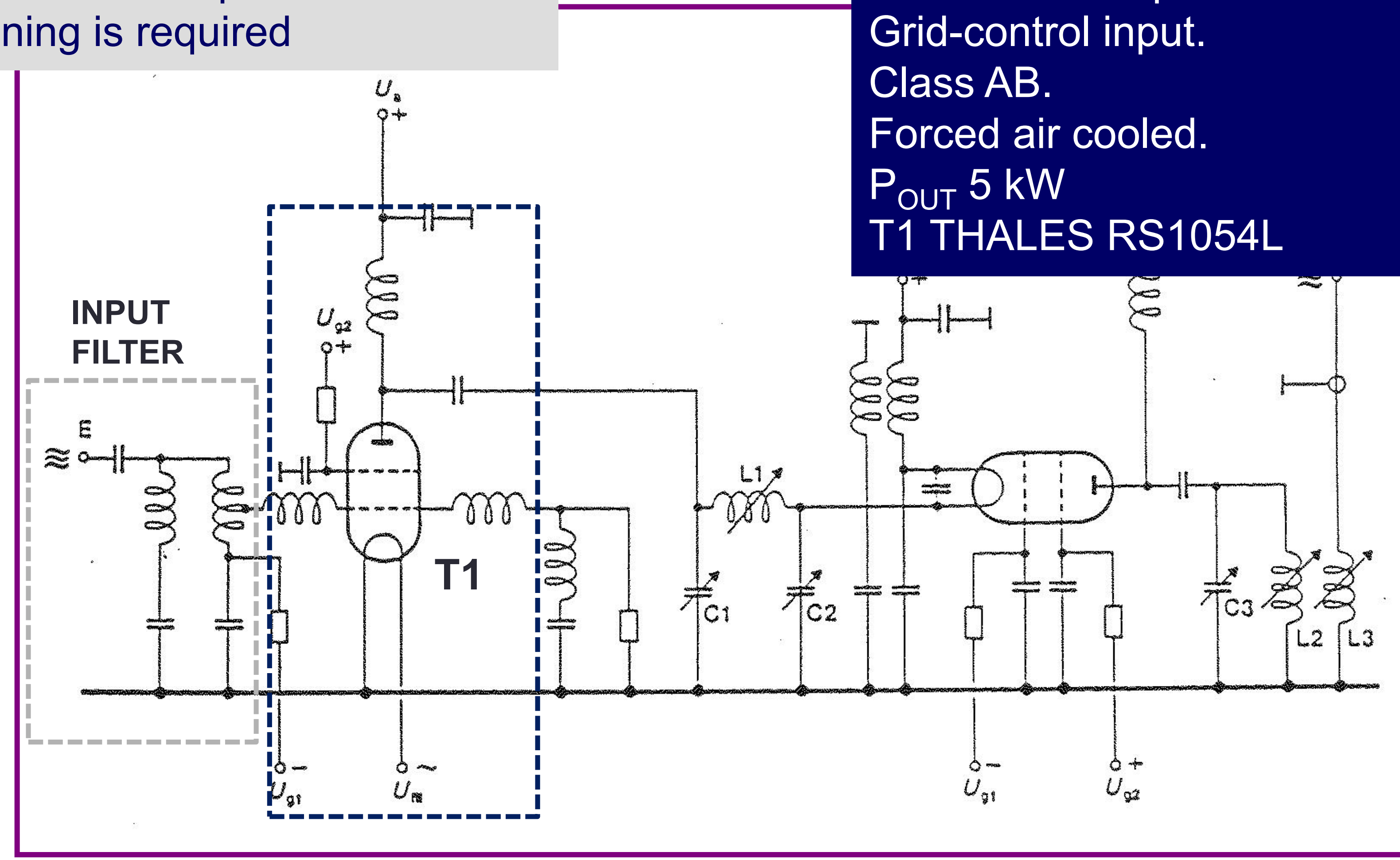

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- adapts from 25 to 50Ω
tetrode and Driver impe

•The RF power of Drive
dissipated on the parall

•No tuning is required

The Π filter between the two stages is the resonant load for the 1st stage and it adapts the input impedance of the 2nd stage at the same time. All the components, inductive and capacitive are variable.

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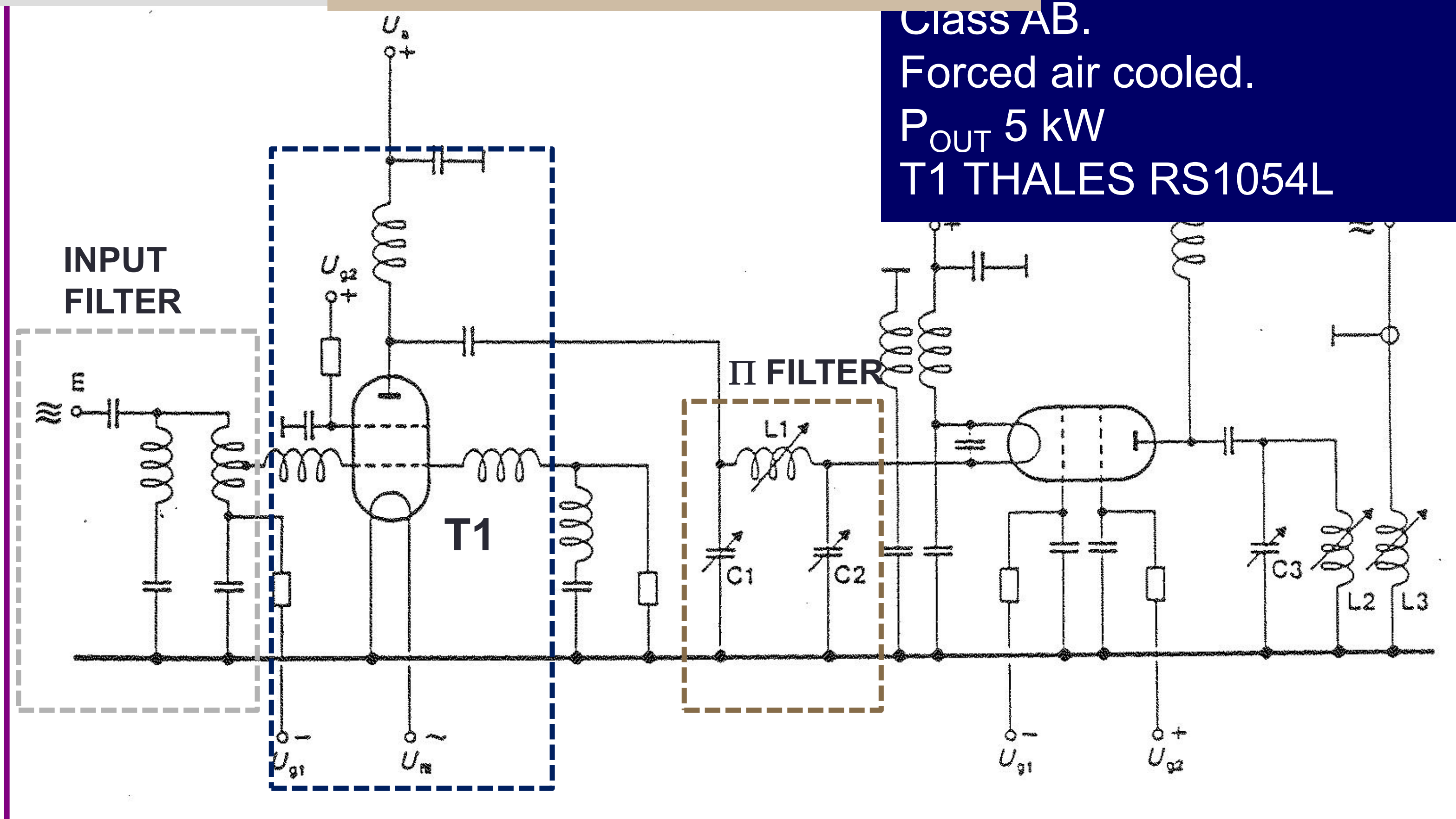

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tetrode and D
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The 2[nd] stage (T2=4CW100000): **common-grid configuration**, high isolation between the in/out sections. Filament input. Water cooled. The load is a ¼ λ cavity plus a capacity.

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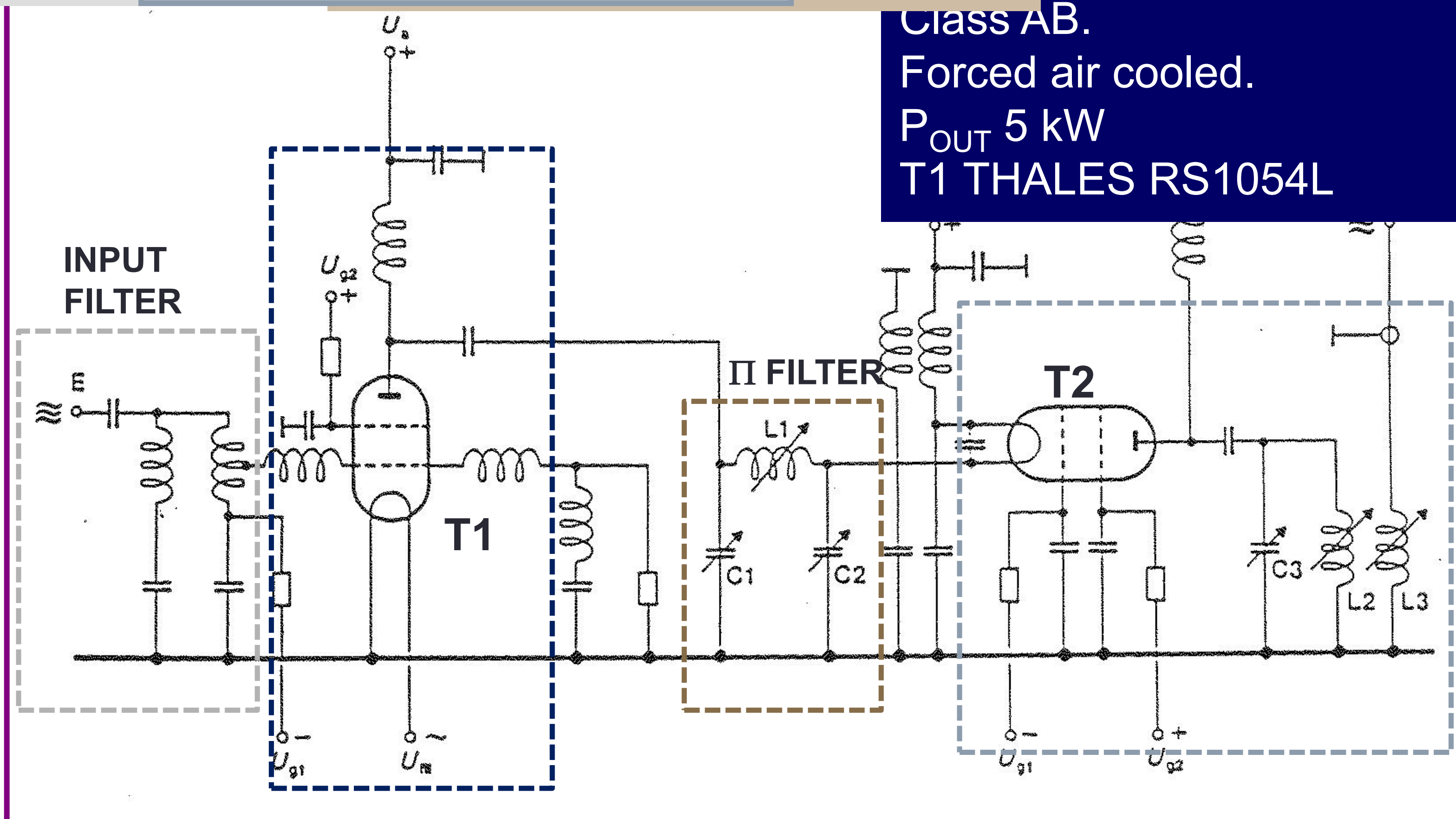

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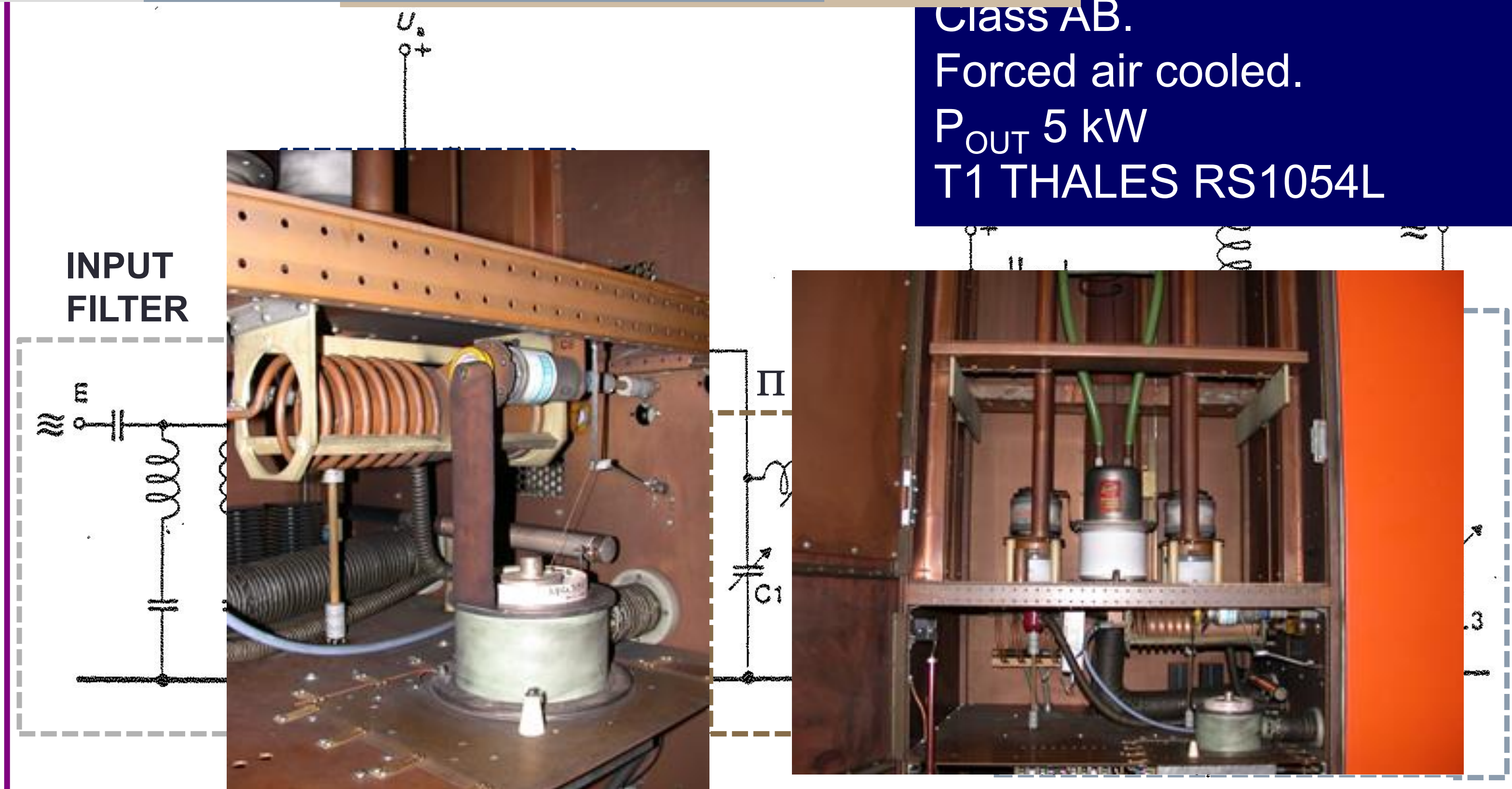

1st stage (THALES RS1054LSC)

2nd stage (CPI-4CW100000E)

THALES

Microwave & Imaging Sub-Systems
2, rue Marcel Dassault - BP 23
78141 Vélizy-Villacoublay Cedex
France
Tél : + 33 (0) 1 30 70 35 00
Fax : + 33 (0) 1 30 70 35 35
www.thalesgroup.com

May 05th, 2010

Subject : End of production – Ceramic tubes for Scientific applications

For the attention of the Purchasing Manager / INFN Catania.

Dear Madam, Sir,

Thales Electron Devices (formerly Thomson Tubes Electroniques) offers the largest choice of high power tubes for scientific applications (Fusion and Particle accelerators). Thales continuously works on offering the best level of performance and service with dedicated teams in charge of the technical support.

However, as the demand for ceramic tubes keeps decreasing globally, we are obliged to adapt our product portfolio to this market trend, in order to ensure a continuous service for our best seller tubes.

Consequently, we intend to stop producing and selling the below mentioned references:

RS 1034 SKSC
RS 1054 LSC
RS 1054 SKSC
RS 2026 CLSC
RS 2068 CLSC

TH 361 SC
TH 382 SC
TH 571 A
TH 610 SC

Based on this information we suggest you review your possible needs for these references and invite you to organise with us your procurement plan by June 30th 2010. You can also send such information to our Headquarters:

Thales Electron Devices – 2 rue Marcel Dassault – 78941 Vélizy cedex – France
E-mail : stephane.bethuys@thalesgroup.com; jean-charles.chen@thalesgroup.com

The last order for the above mentioned tubes will have to be placed before September 30th, 2010 at the very latest.

Should you have any questions, please do not hesitate to get in touch with us.
Be sure that we are fully aware of the inconvenience this decision may cause to you.

Best regards

Stéphane Bethuys
Science Marketing Manager

Sergio Brunetti
Sales Manager

THALES

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To the attention of M. Caruso
Istituto Nazionale Di Fisica Nucleare
Laboratori Nazionali del Sud
Via S. Sofia 62
95123 CATANIA – Italy

June 22st, 2010

Subject : End of production – Electron tubes for Scientific applications

Dear Mister Caruso,

On May 18th, 2010 Thales Electron Devices (TED) announced the end of electron tube ref. RS1054LSC production due to decreasing demand in the worldwide market and offered you to cover your final remaining needs through an Last-buy order (LBO) procedure.

Leading to a Last Production Run by end of 2010, this LBO procedure is planned to close at receipt of your LBO by September 30th, 2010.

However, considering our very good business relationships with INFN Catania over the past years, TED agrees to postpone the above deadline for the electron tube RS1054LSC and kindly accepts to receive your last order for this very reference by **January 31st, 2011** according to our offer STB/4.3724 dated on June 22th, 2010.

Stéphane Bethuys
Science Marketing Mng

Sergio Brunetti
THALES Microwave Area Mng

THALES

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Subject : End of production – Ceramic tubes for Scientific applications

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Subject : End of production – Ceramic tubes for

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Dear Mister Caruso,

On May 18th, 2010 T... ...e end of electron tube ref. RS1054LS... ...in the worldwide market and offered ... ...ough an Last-buy order (LBO) procedu...

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8. LUG. 2010 13:34 I. N. F. N. - L. N. S. CT NR. 626 P. 2/10

INFN Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Sud

Istituto Nazionale di Fisica Nucleare
AOO: Laboratori Nazionali del Sud
Partenza
Prot.N. 0002462 - 08/07/2010 - Tit. 9.3
Dest. Princ. THALES ELECTRON DEVICES
Dest. CC.

SPETT.LE
Thales Electron Devices SA
2, Rue Marcel Dassault – BP 23
78141 Velizy – Villacoublay Cedex
France

~60k€, not on SALE…

Oggetto: PROCEDURA NEGOZIATA PER LA FORNITURA DI N. 3 TETRODI RS1054L COME RICAMBI DEGLI AMPLIFICATORI DI POTENZA RF DEL CICLOTRONE.
(IMPORTO ... € 47.000,00 ... IVA+ONERI) COD.CIG. 0503991287.

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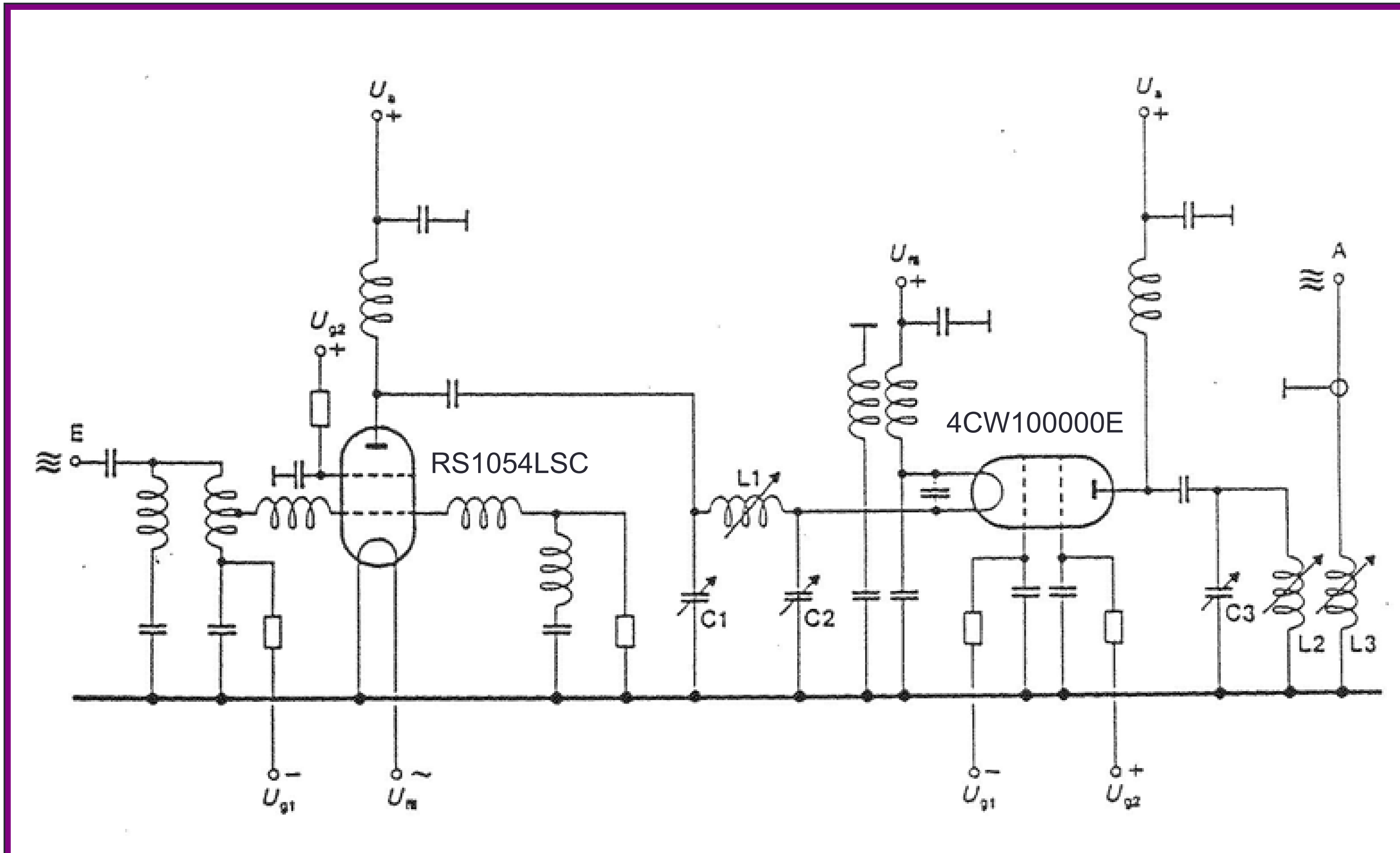
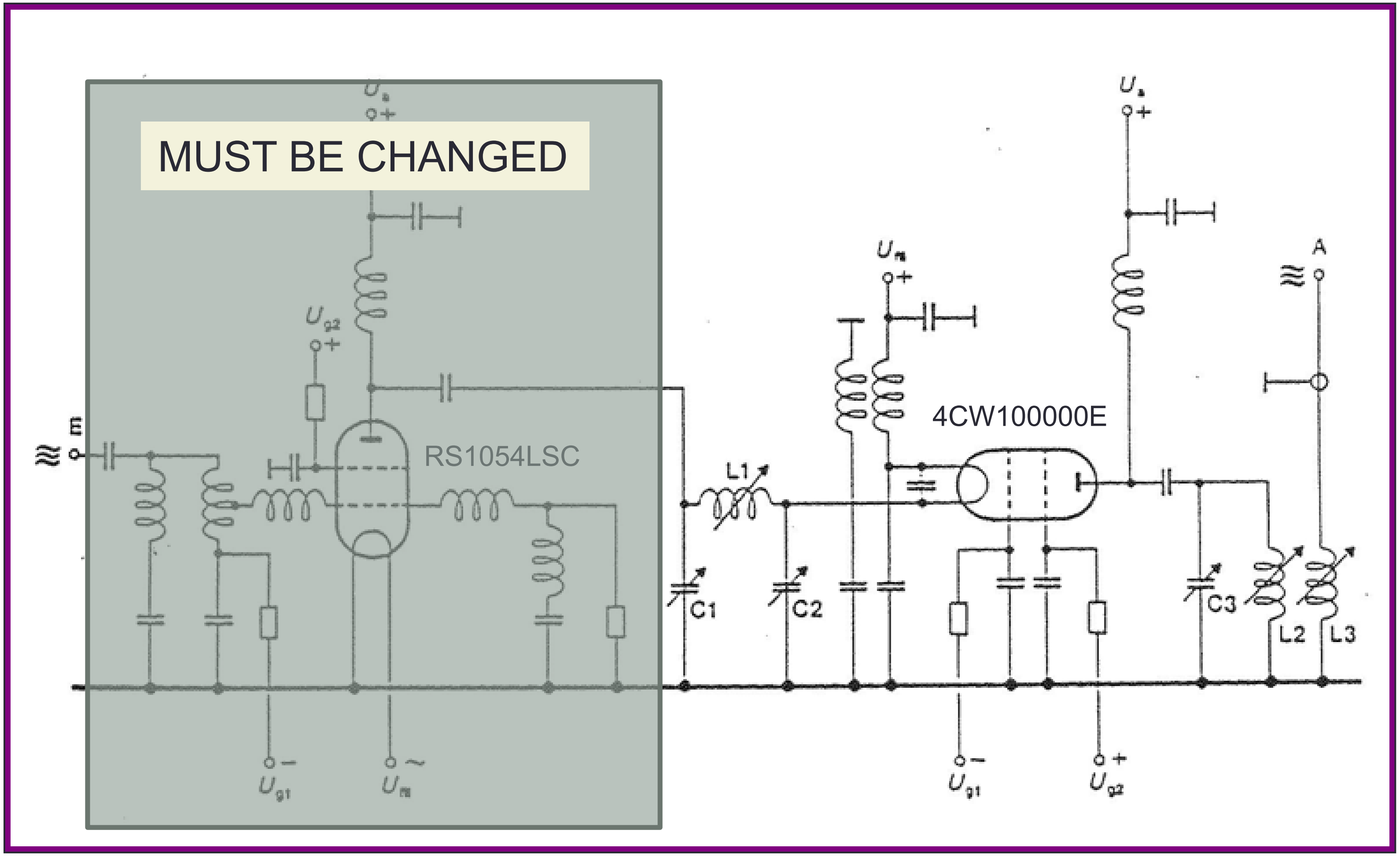
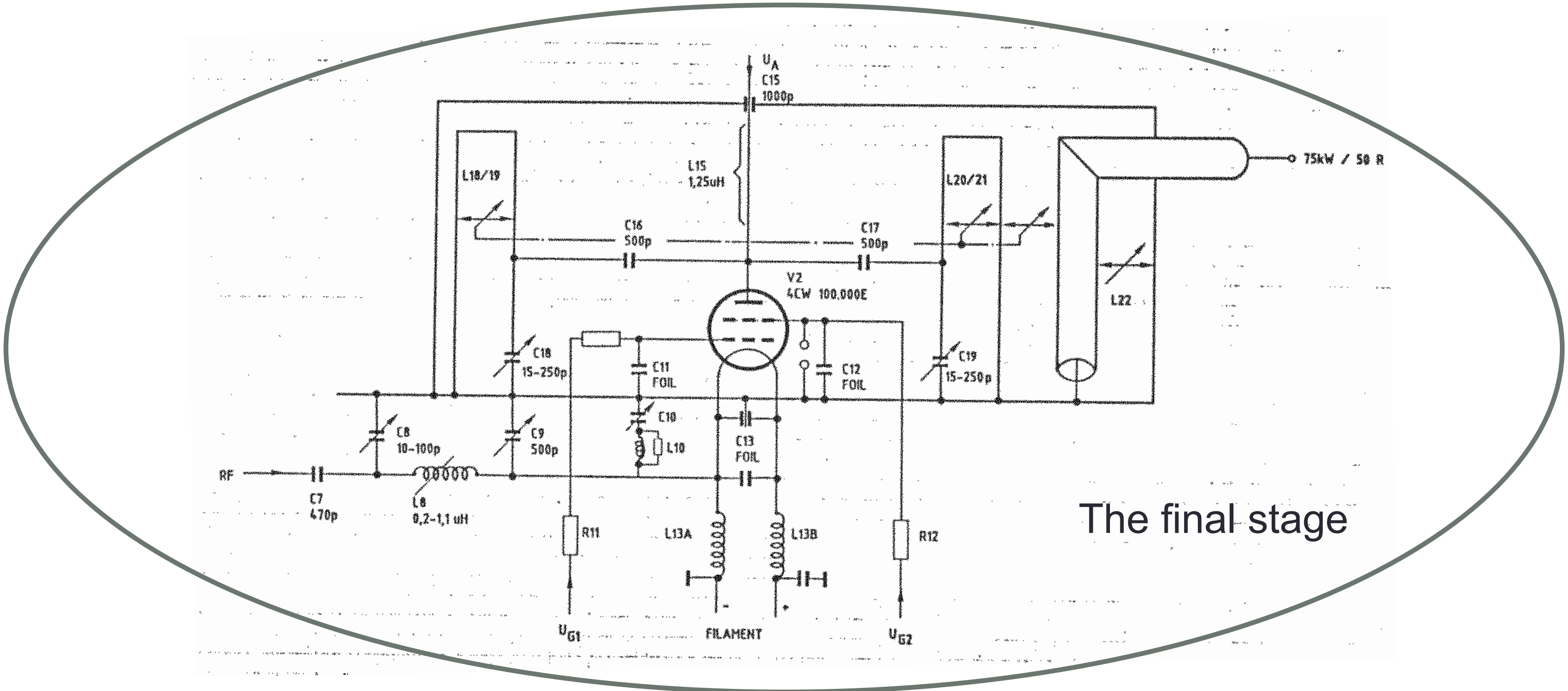
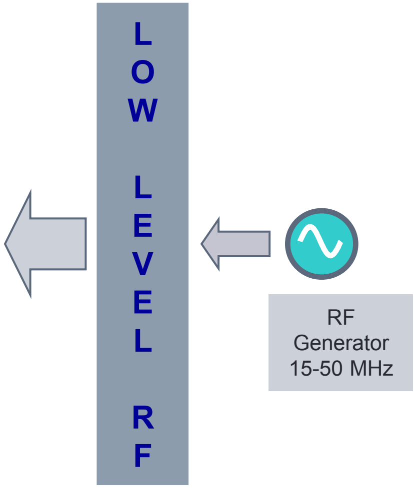
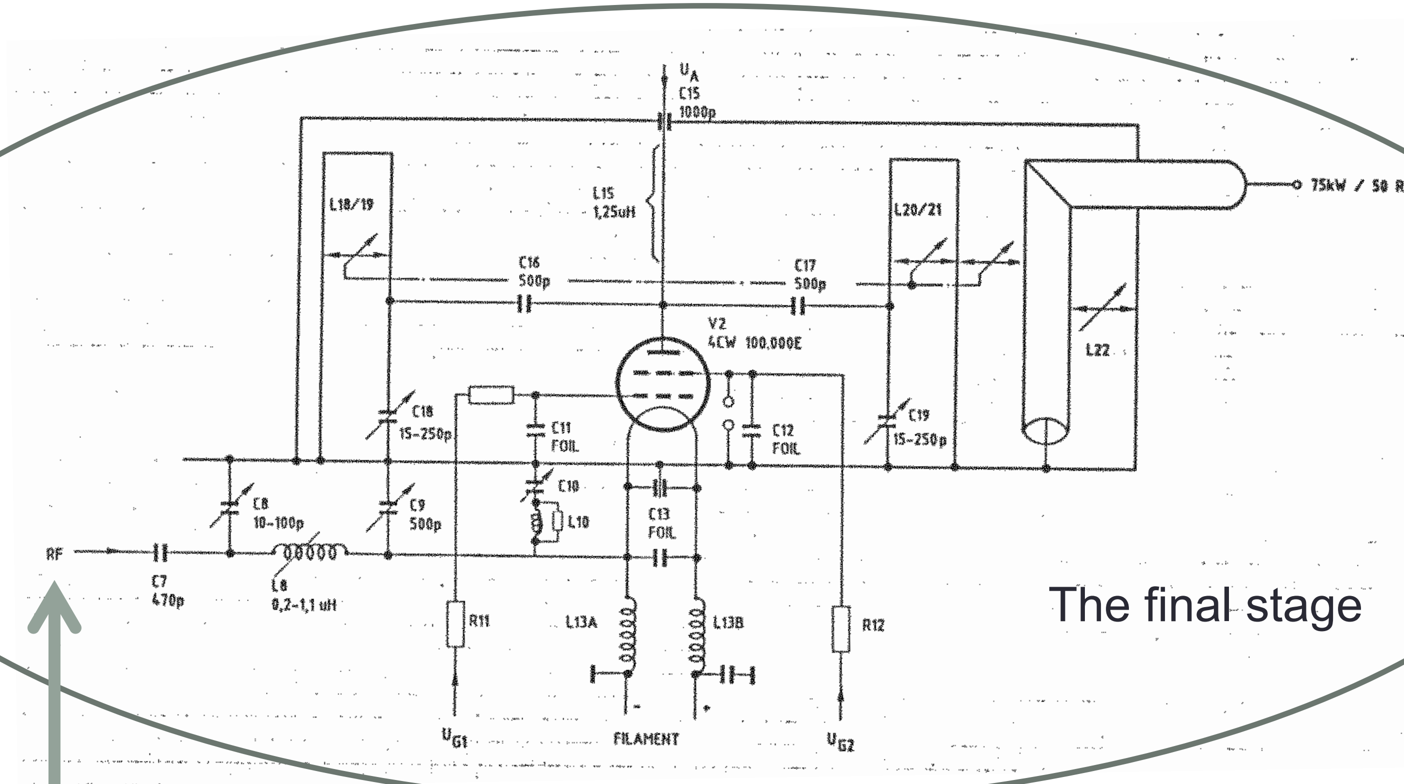

E
A
RS1054LSC
4CW100000E
L1
C1
C2
C3
L2
L3

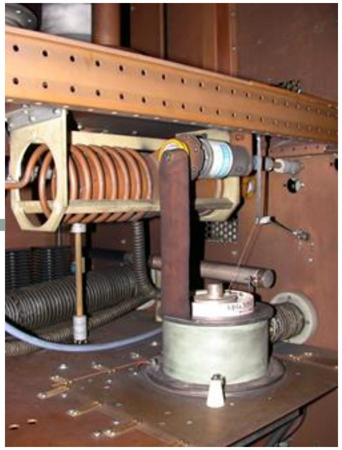

MUST BE CHANGED
RS1054LSC
4CW100000E
E
A
L1
C1
C2
C3
L2
L3


U A
C15
1000p
L15
1,25uH
L18/19
C16
500p
C17
500p
L20/21
75kW / 50 R
V2
4CW 100,000E
L22
C18
15-250p
C11
FOIL
C12
FOIL
C19
15-250p
C8
10-100p
C9
500p
C10
L10
C13
FOIL
RF
C7
470p
L8
0,2-1,1 uH
R11
L13A
L13B
R12
U G1
FILAMENT
U G2
The final stage


LOW LEVEL RF
RF Generator 15-50 MHz



The final stage



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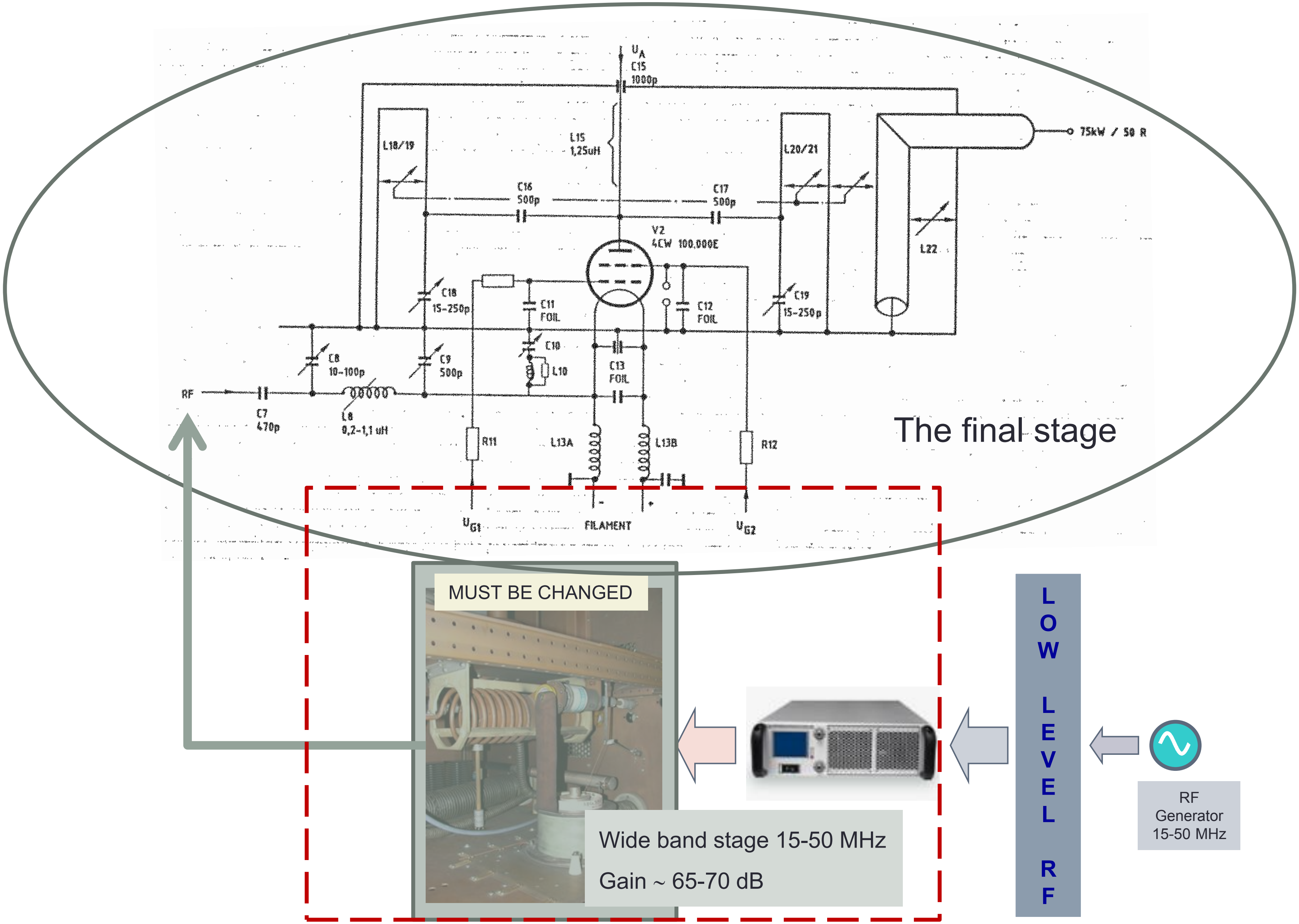


UA
C15
1000p
L15
1,25uH
L18/19
L20/21
75kW / 50 Ω
C16
500p
C17
500p
V2
4CW 100,000E
L22
C18
15-250p
C11
FOIL
C12
FOIL
C19
15-250p
C8
10-100p
C9
500p
C10
L10
C13
FOIL
RF
C7
470p
L8
0,2-1,1 uH
R11
L13A
L13B
R12
UG1
FILAMENT
UG2
The final stage
MUST BE CHANGED
Wide band stage 15-50 MHz
Gain ~ 65-70 dB
LOW LEVEL RF
RF Generator 15-50 MHz

Tetrodes

Reference	General characteristics					Heather power supply		Maximum ratings			Dimensions			Cooling	Cavity
									Power dissipation						
	Output power	Gain	Anode voltage	Screen grid voltage	Anode current	Filament voltage (2)	Filament current	Anode voltage	Anode	Screen grid	Diameter	Height	Weight		
	kW	dB	kV	V	A	V	A	kV	kW	W	mm	mm	kg		
YL 1057	1.1	17.5	3.4	600	0.75	3.8	20	3.8	2.2	30	95	110	1.1	forced air	-
TH 347	2.2	15	4.5	400	1.15	5.8	34	5	4.5	25	110	135	2.3	forced air	TH 18363
TH 393	2.5	15.5	5.5	600	1.6	6	65	6	7.5	75	135	145	3.6	forced air	TH 18665
RS 1054 L	2.6	16	4.6	800	1.5	2.8	135	5	5	80	120	117	1.9	forced air	-
RS 1054 SK	2.6	16	4.6	800	1.5	2.8	135	5	5	80	98	141	1.9	water (4)	-
TH 382	5.25	15.5	5.5	600	2.7	4.2	125	6.5	12.5	120	170	158	7	forced air	TH 18482
RS 1034 L	6.3	16	5.1	800	2.8	4.5	200	5.5	13	180	160	154	5.3	forced air	-
TH 582	10.5	15	5.5	600	3.45	4.2	146	7.5	25	120	128	166	4.1	water (4)	TH 18582
RS 1036 L	11.5	15	6	800	3.7	4.5	200	7	20	180	200	152	7.8	forced air	-
RS 1034 SK	12.6	15.5	6.3	800	3.9	4.5	200	7.5	25	180	160	152	7	water (4)	-
TH 563	31.5	14.5	8.5	800	6.45	4.2	210	9	42	200	126	190	6.5	water (3)	TH 18550

(1) Common amplification

Ref.	Output power	Typical operating conditions				Heater power supply		Maximum ratings			Dimensions			Cooling	Cavity	PDF
			Anode		Screen grid	Filament		Anode voltage	Anode	Screen grid	Diameter	Length	Weight			
		Gain	Voltage	Current	Voltage	Voltage	Current		Power dissipation							
	kW	db	kV	A	V	V	A	kV	kW	W	mm	mm	kg			
TH 298	3	23	5	0.8	400	6	50	5	5	60	104	140	2	Air	-	
TH 341	10	17	7	2	400	6.5	85	8	6	150	130	150	3.5	Air	TH 18108 G	

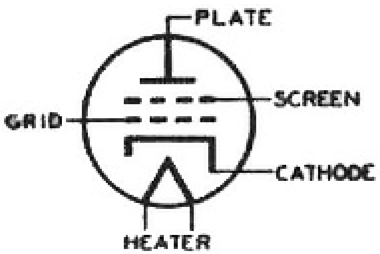
different different different

BUT TH298 COULD BE NEARLY OBSOLETE TOO…

Proposed solution by Eimac

As a possible **alternative** to the originally used RS1054L the **CPI tube 4CX3500A** has been selected. This tube is less powerful than the original one but was selected because we thought than the **final power of 30kW** was enough as regards normal cyclotron activity.

The most **critical parameter is the input capacitance of the 4CX3500A** as it influences the input circuit negatively. The existing wide band circuit has to be redesigned in order to cope with the higher tube capacitance:



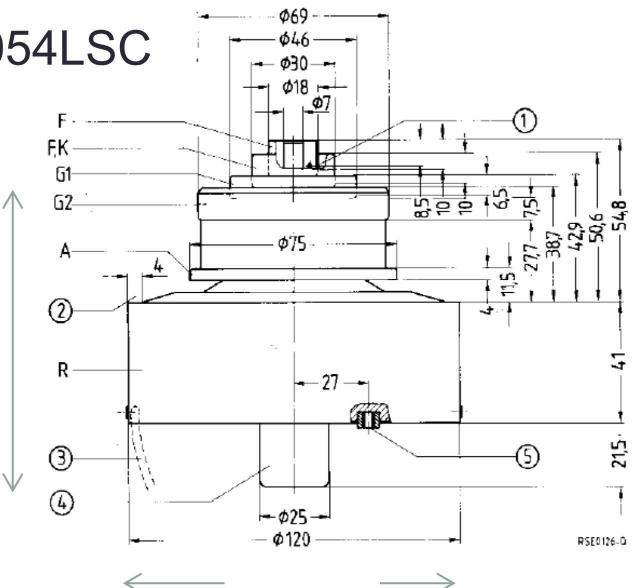
RS1054 Cin = 57 to 60 pF

4CX3500A Cin = 111 pf

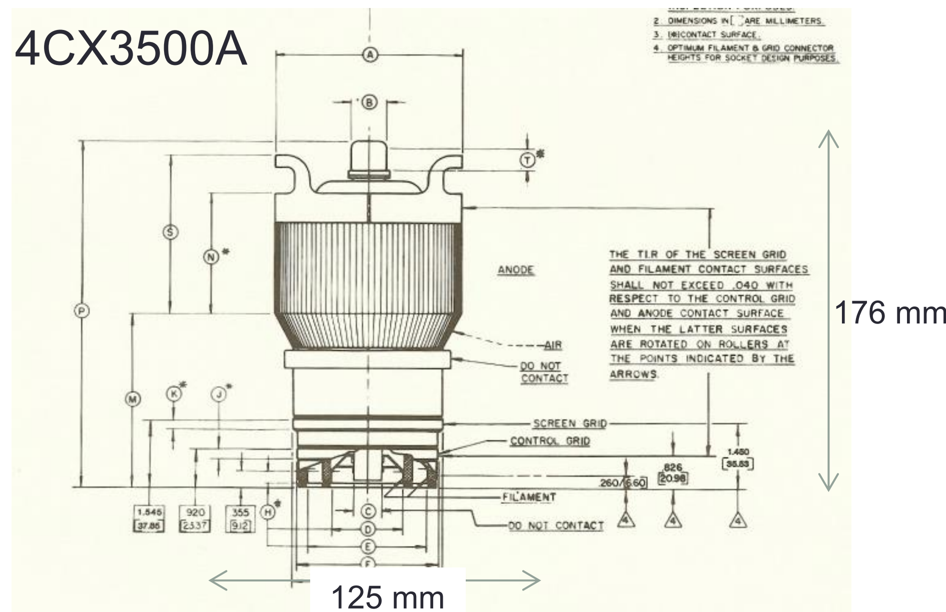
Main modifications for the installation of the 4CX3500A

- Most critical point, **input capacitance: redesign the input impedance circuit** and related board;
- The tube needs **a completely new socket** which ends up in a completely new design for the driver stage. The outline of the present module will be kept so that no major mechanical work is necessary;
- **New filament power supply;**
- Slight modification of control grid power supply (no need for screen grid);
- Insertion of new crowbar circuit in the anode power supply plus retuning of anode matching circuit

RS1054LSC



4CX3500A



Cost of the operation, to modify 3 amplifiers (including a single new tube), about 250 k€

Risks of the operation

- The tetrode manufacturer can notify the end of the production of this new tetrode in any moment. With a very short margin in terms of time, according to our experience;
- It is not possible to store a lot of spare parts, economic and vacuum tube technology;
- **The new solid state technology is going to cover the slice of market under a power of 100 kW and up to few hundred MHz of bandwidth (most important);**

Positive points

- 4CX3500 cost relatively low, high efficiency, high reliability, robustness;
- Apparently no end of production in the near future, according to the manufacture;
- Econco (CPI group), ensured us about the total assistance to rebuild the tube in case of failure (not necessary to buy a bright new tube all the time).

The total operation can be divided into two phases:

1. Design and manufacture the hardware during the cyclotron operation;
2. Installation of the new parts during a cyclotron long maintenance period .

Also the distribution of the total cost, after an agreement with the constructor, should be divided into two, or better for us, more phases…

But remain the financial problem of getting the whole budget.

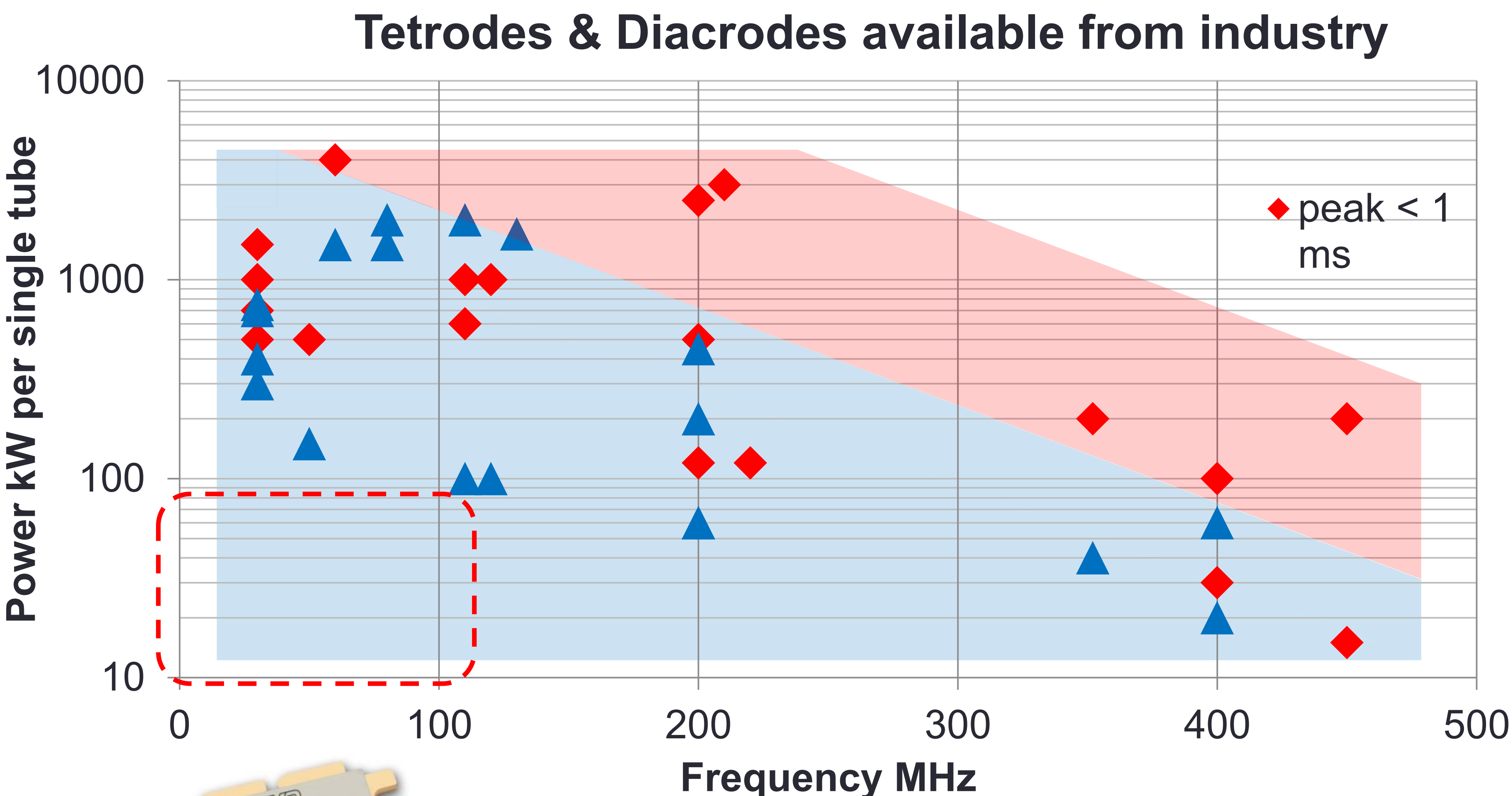
ENOUGH SPARE PARTS

make a virtue out of necessity

SOME IN-HOUSE SOLID STATE AMPLIFIERS

Frequency & Power range of tetrodes

In the meanwhile further news coming from the market …



LDMOS Transistor
>1 kW, 2-600 MHz

Courtesy of Eric Montesinos, CERN-RF

Frequency & Power range of tetrodes

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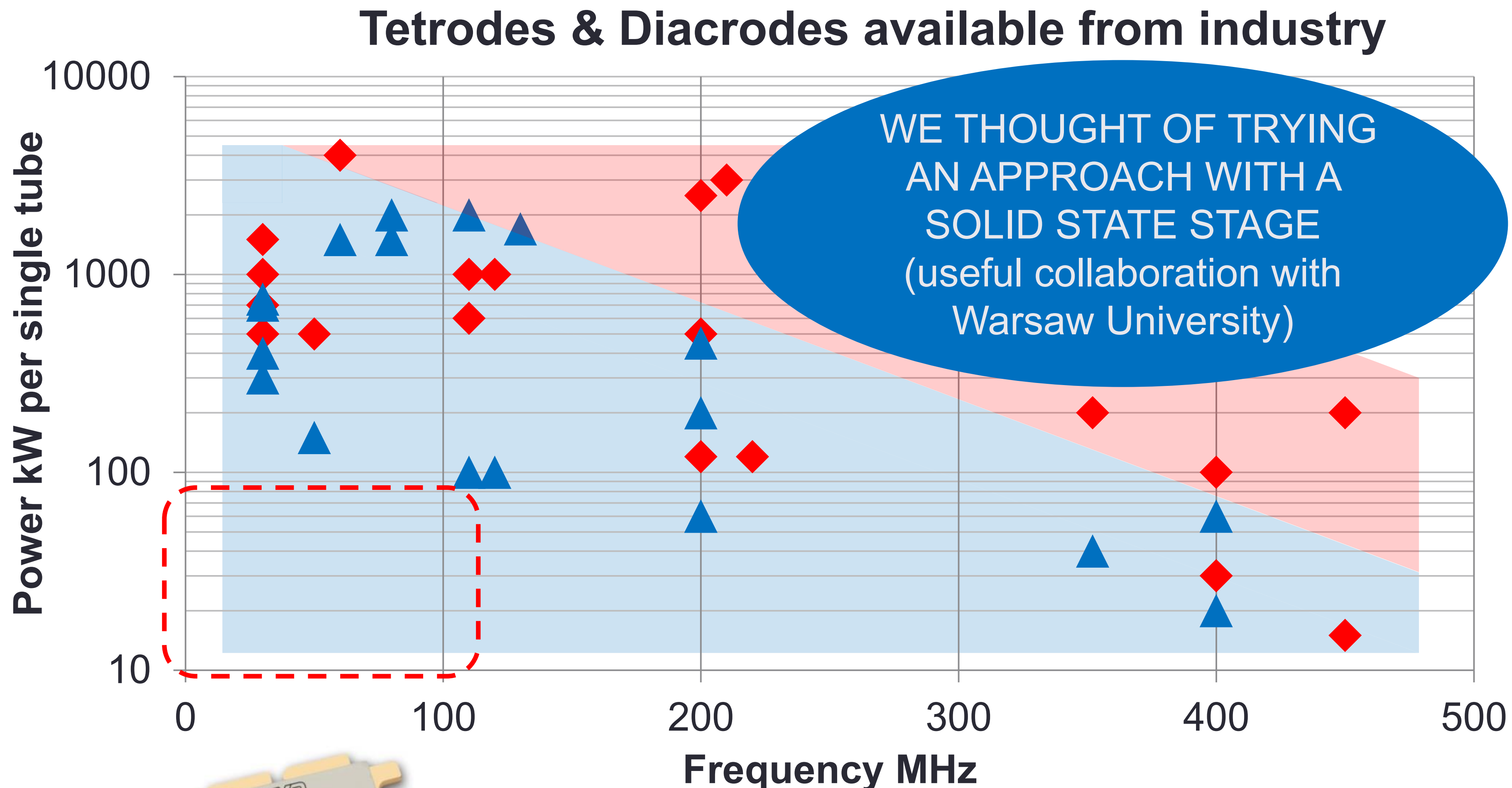


LDMOS Transistor
>1 kW, 2-600 MHz

Courtesy of Eric Montesinos, CERN-RF

RULES OF THUMB OF THE SOLID STATE OPERATION

CHANGE THE TUBE 1^{ST} STAGE WITH A SOLID STATE:

- MINIMIZE THE HARDWARE MODIFICATIONS, MAINLY IN THE SECOND STAGE OF THE AMPLIFIER;
- NEVER FORGET THE POSSIBILITY TO RE-INSTALL AGAIN THE OLD TUBE, IN CASE OF PROBLEMS IN A REASONABLY SHORT TIME;
- CONTAIN THE COST.

High power water cooled tetrode EIMAC 4CW100000 (final stage)

study the technical characteristics, mainly about the input circuit

4CW100,000E without SK-2100 Water Jacket

GENERAL CHARACTERISTICS[1]

ELECTRICAL

Filament: Thoriated Tungsten

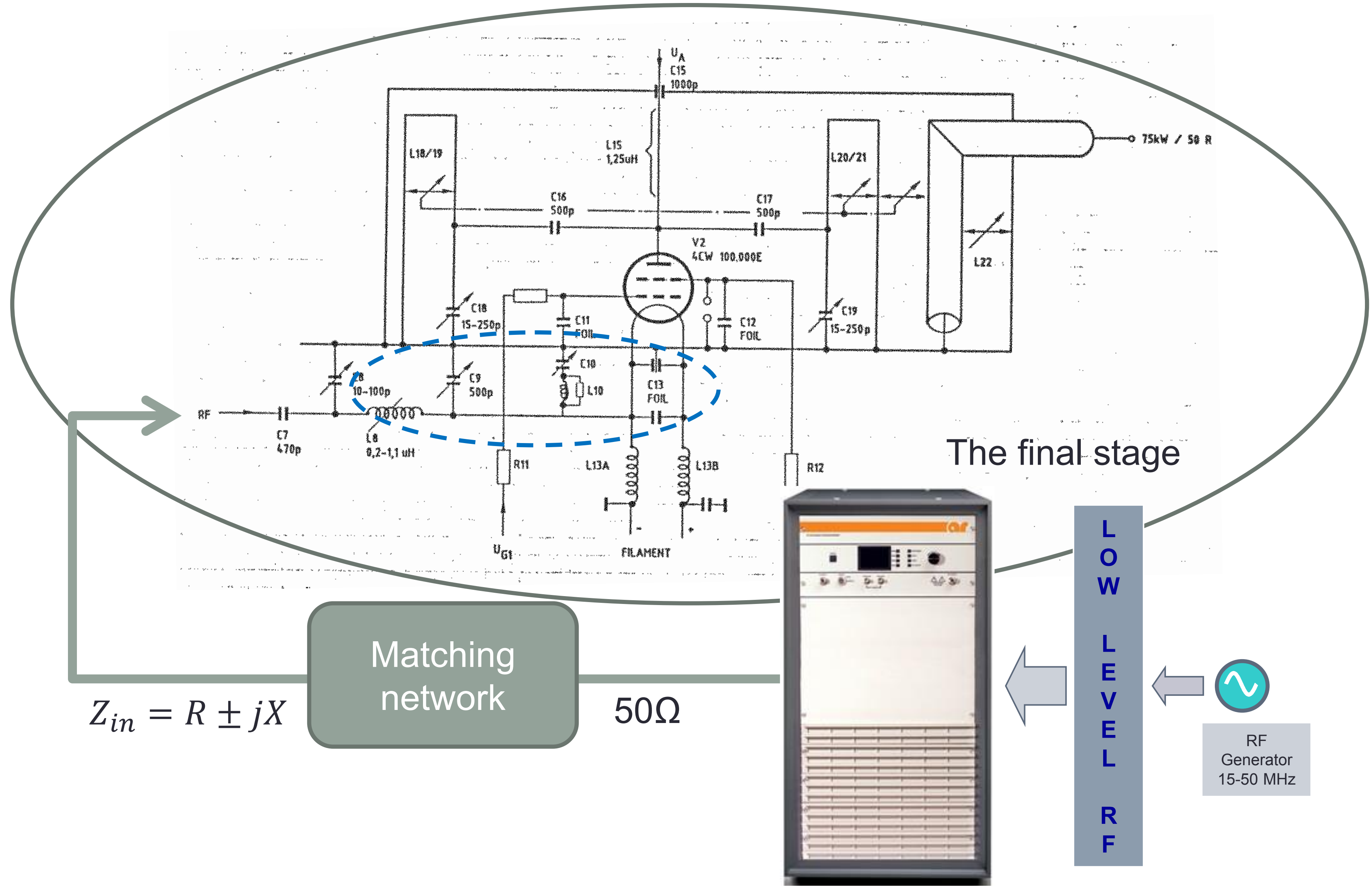
Voltage	15.5 ± 0.75	V
Current @ 15.5 V	215	A
Direct Interelectrode Capacitances (grounded cathode)		
Cin	370	pF
Cout	60	pF
Cgp	1.0	pF
Direct Interelectrode Capacitances (grounded grid)		
Cin	175	pF
Cout	60	pF
Cpk	0.35	pF
Frequency of Maximum Rating, CW	108	MHz

High power water cooled tetrode EIMAC 4CW100000, maximum and minimum rated values

RANGE VALUES FOR EQUIPMENT DESIGN

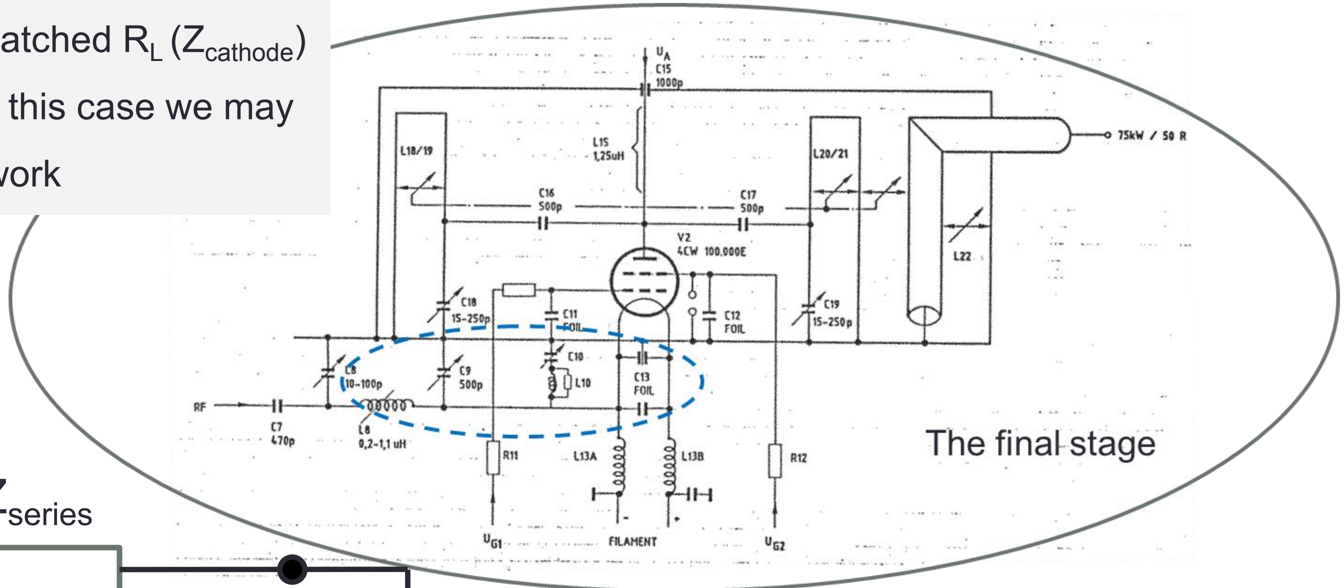
	Min.	Max.	
Filament: Current @ 15.5 volts	200	230	A
Cutoff Bias, at Eb = 25 kVdc, Ec2 = 1500 Vdc, Ib = 10 mAdc	---	-625	Vdc
Interelectrode Capacitances (grounded cathode)			
Cin	350	390	pF
Cout	55	65	pF
Cgp	---	1.2	pF
Interelectrode Capacitances (grounded grid)			
Cin	160	190	pF
Cout	55	65	pF
Cpk	---	0.5	pF

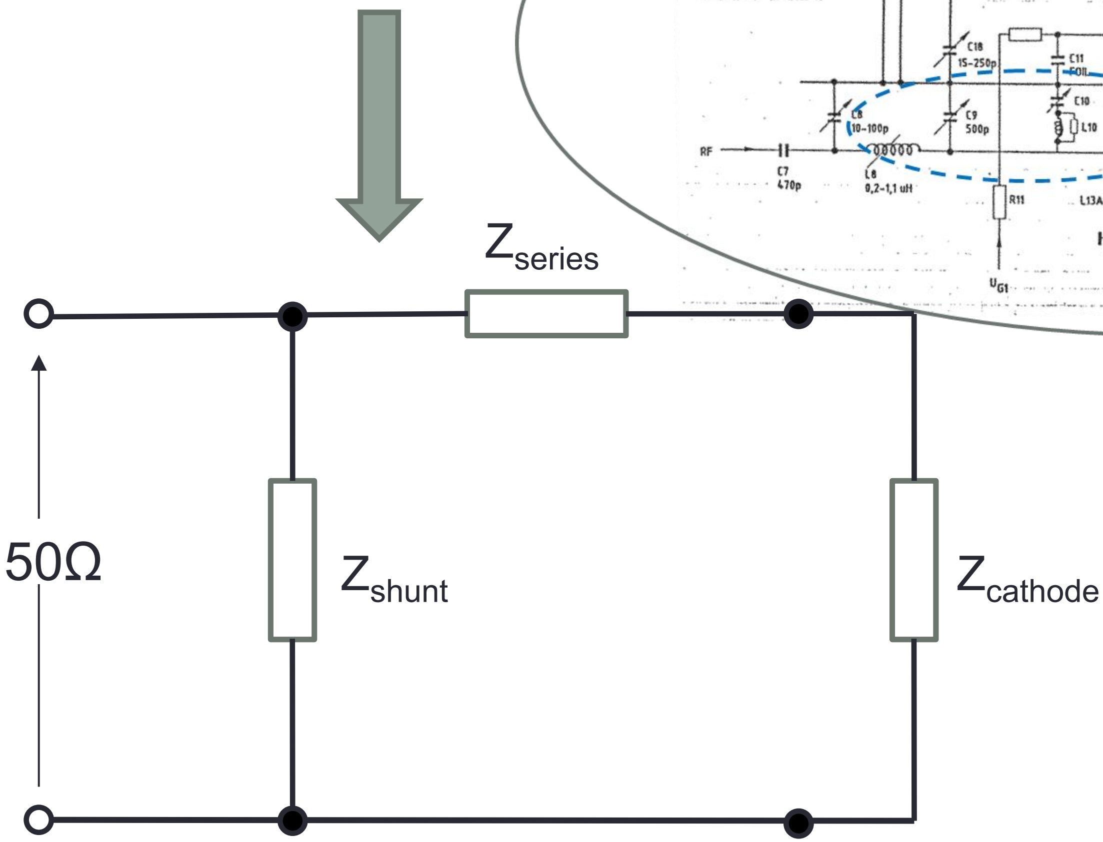
Matching the new solid state driver with the 2nd stage



We need a matching network as impedance transformer from Z_0 to cathode impedance Z_c

the real part of the load to be matched R_L ($Z_{cathode}$) is much lower than Z_0 (50Ω). In this case we may use the simple Γ-matching network





Impedance transformer from Z_0 to cathode impedance Z_c

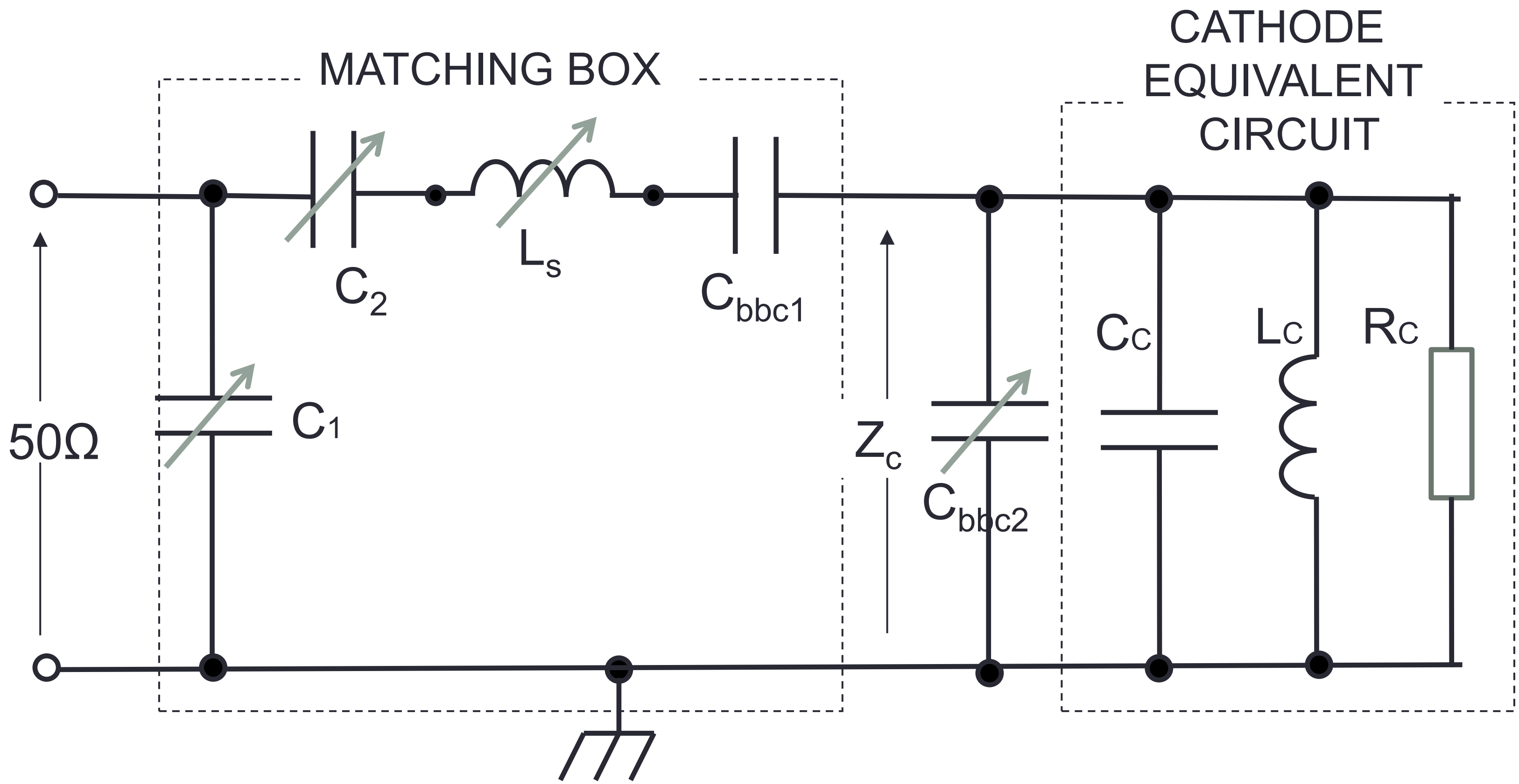
the real part of the load to be matched RL is much lower than Zo. In this case we may use the simple Γ-matching network

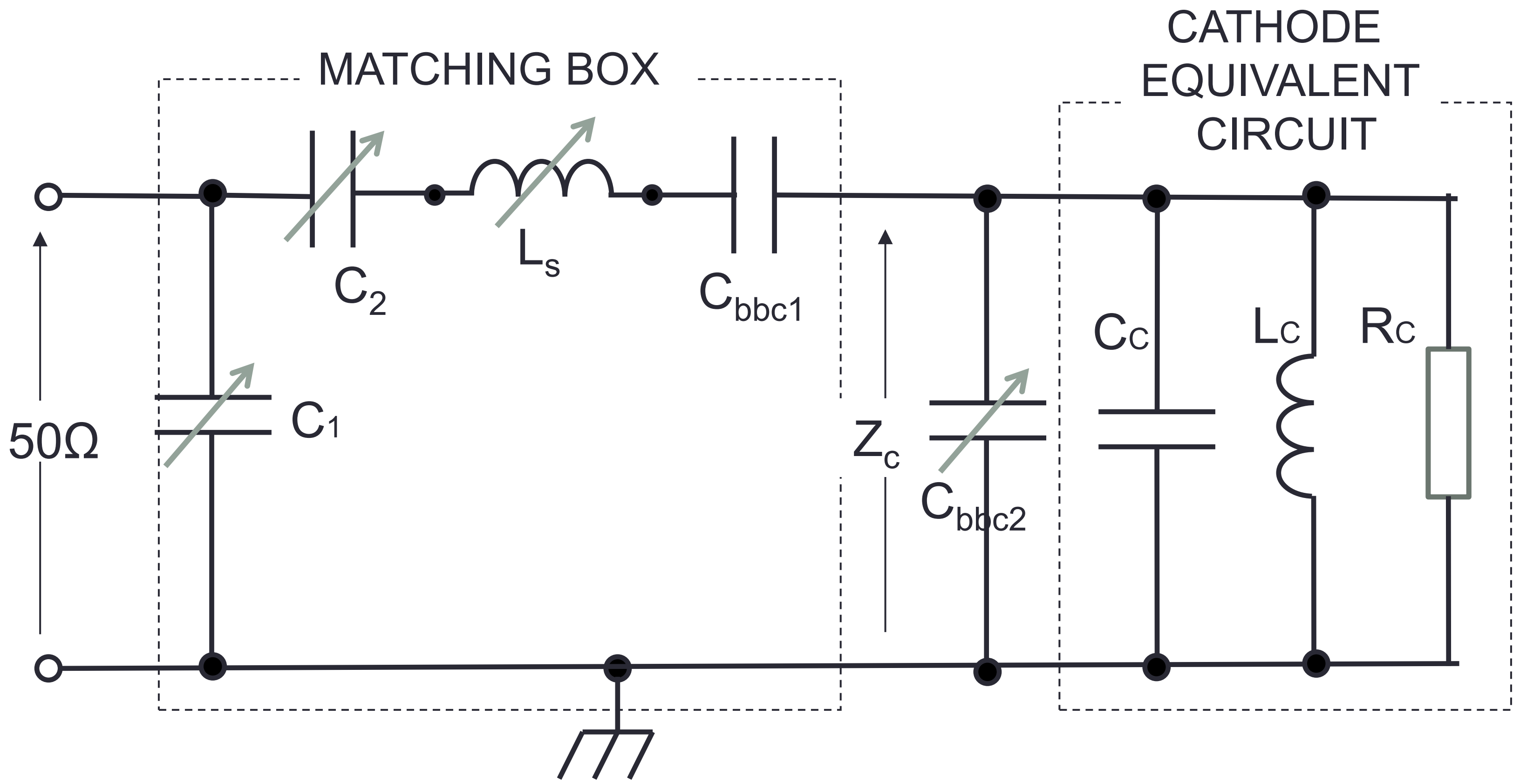
$C_1 = C_2 = 10\text{-}1000\ pF$

L_S = 0.2 – 1.1 μH (existing)

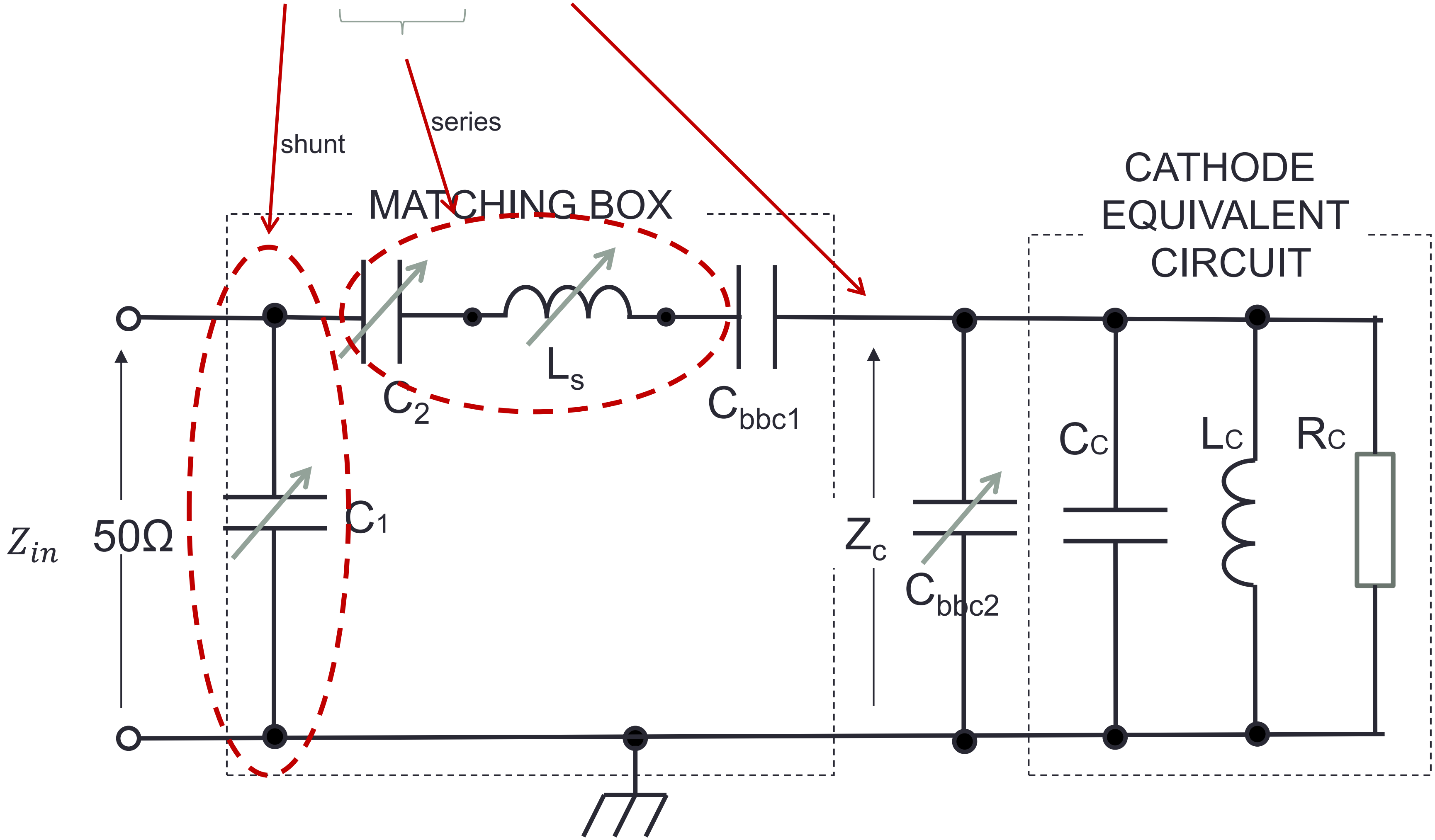
C_{bbc1} = 470 pF (existing)

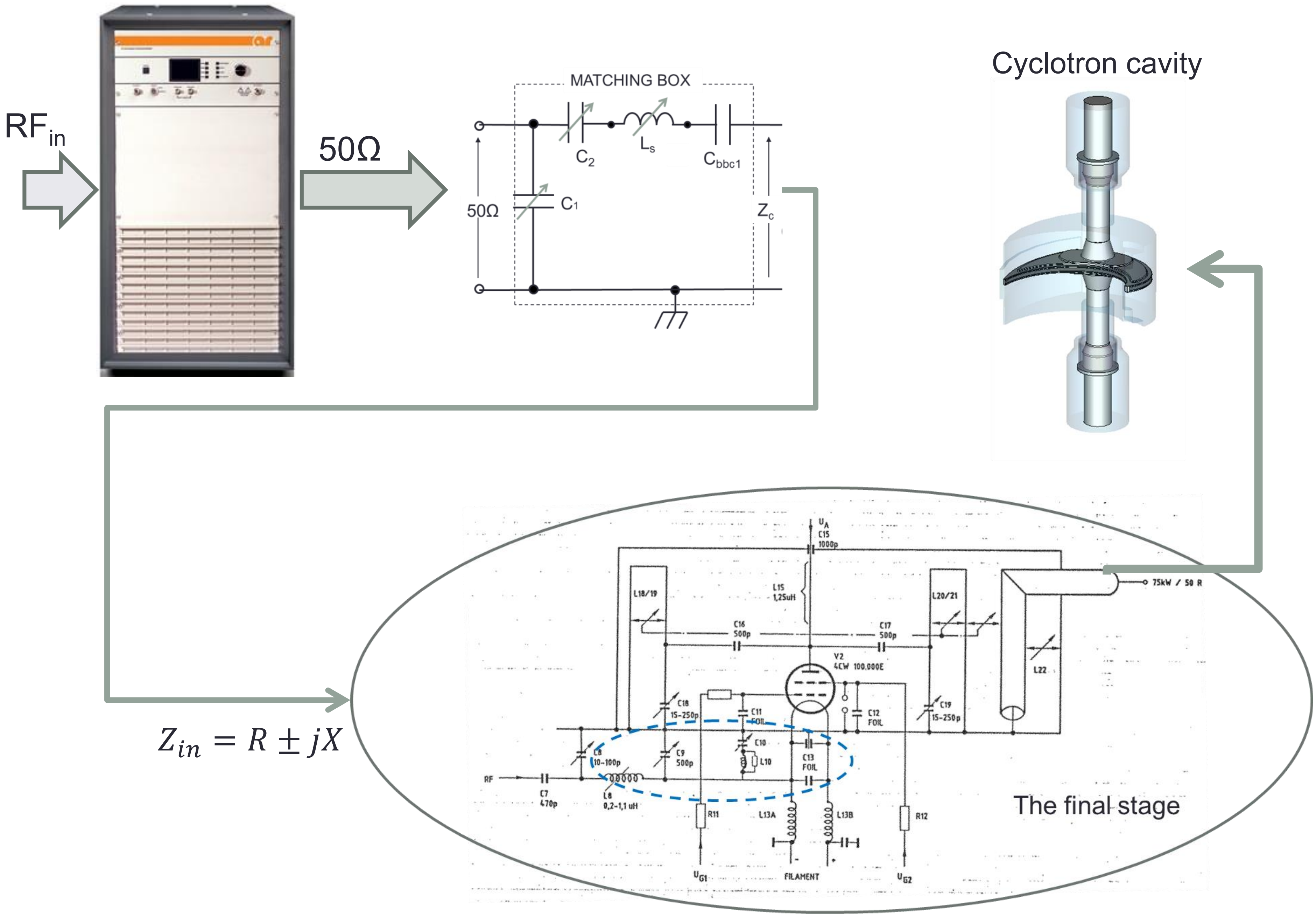
C_{bbc2} = 5-100 pF(recycled)



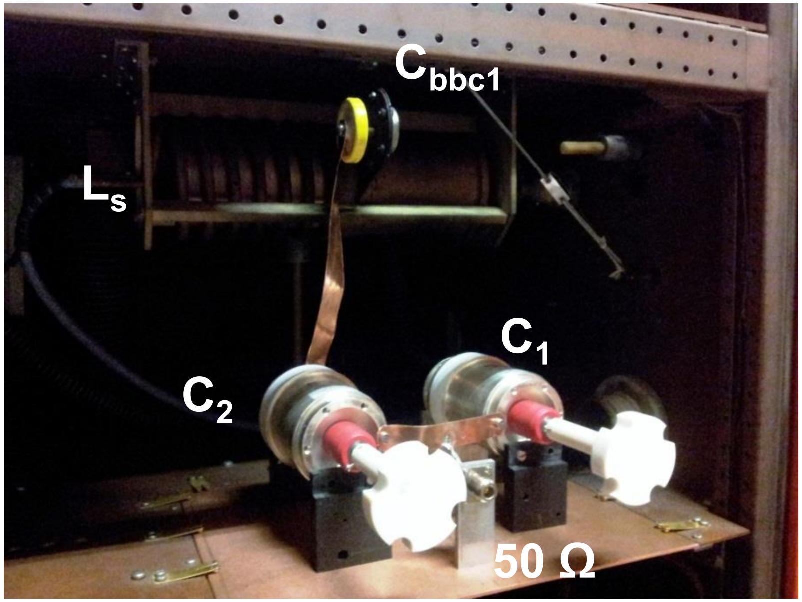

MATCHING BOX
CATHODE EQUIVALENT CIRCUIT
C2
Ls
Cbbc1
C1
50Ω
Zc
Cbbc2
CC
LC
RC

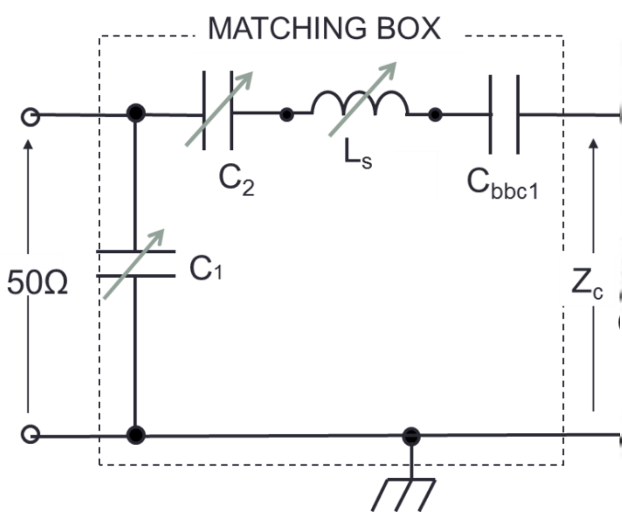
$$Y_{in} = \frac{1}{Z_{C1}} + \frac{1}{Z_{C2} + Z_L + Z_{cathode}} \qquad Z_{in} = \frac{1}{Y_{in}} \qquad Z_{in} = 50\Omega$$

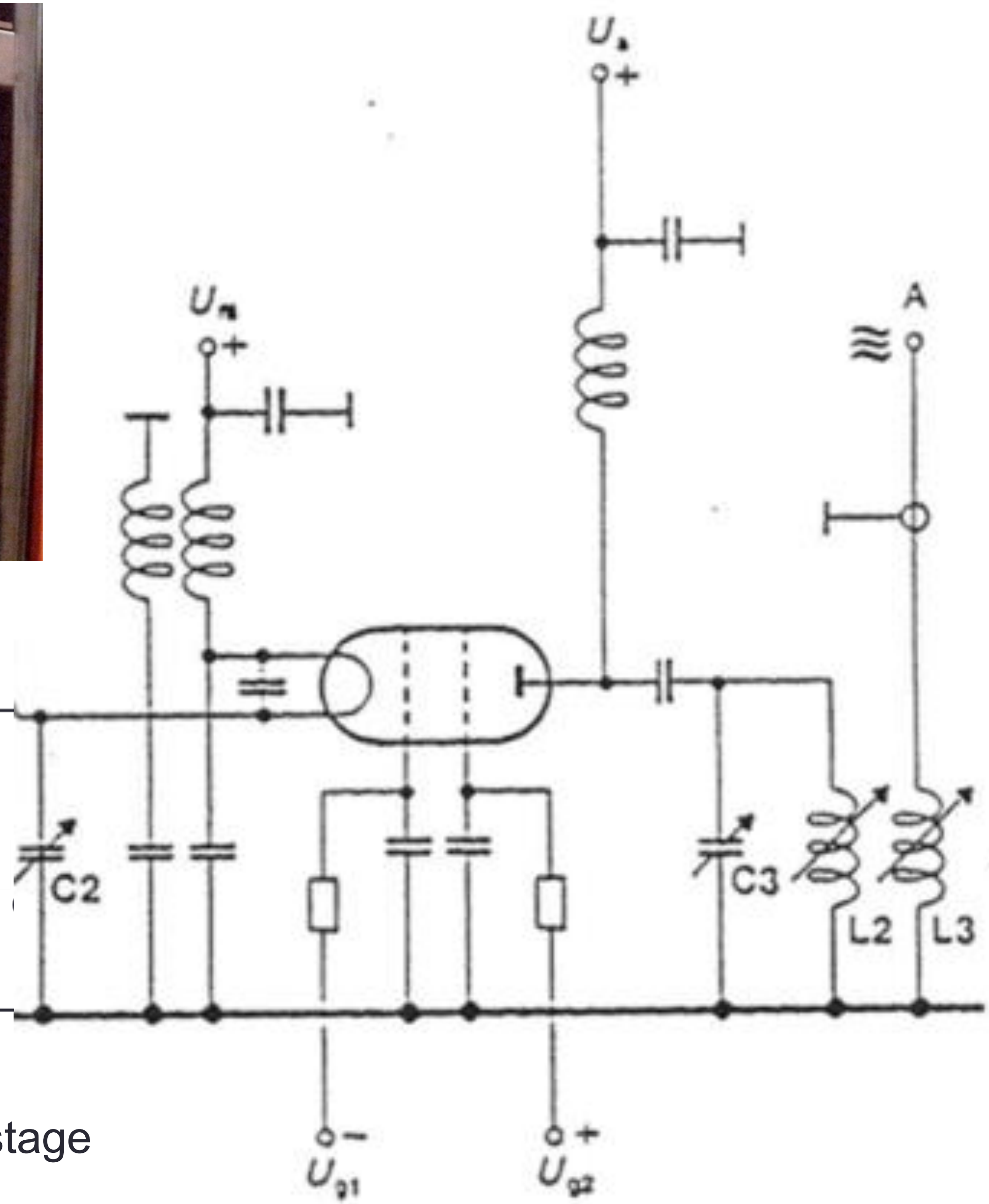




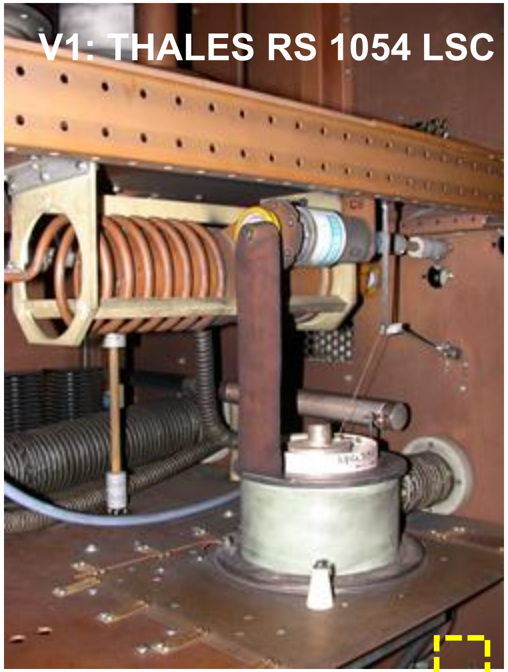
RF in
50Ω
MATCHING BOX
C2
Ls
Cbbc1
C1
50Ω
Zc
Cyclotron cavity
Z_in = R ± jX
The final stage
75kW / 50 R
RF
FILAMENT

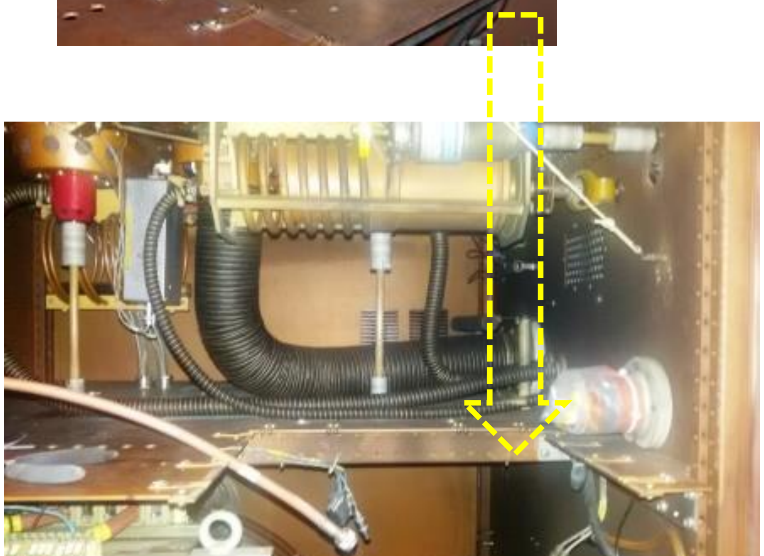




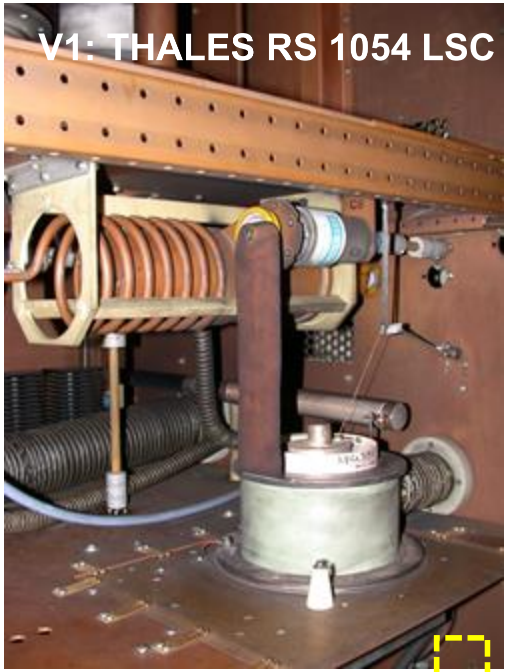


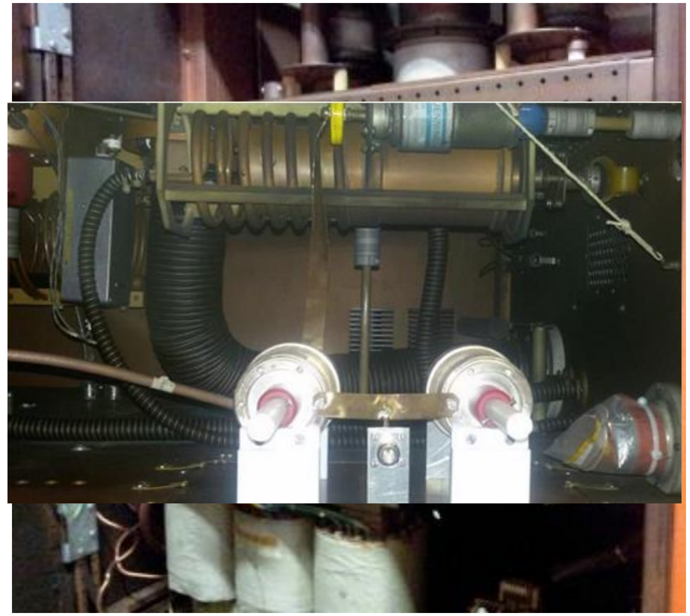
Inside the amplifier instead of 1st stage

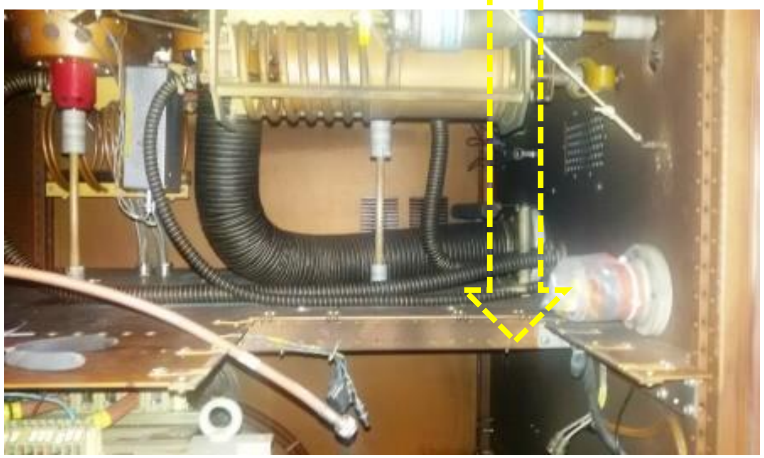




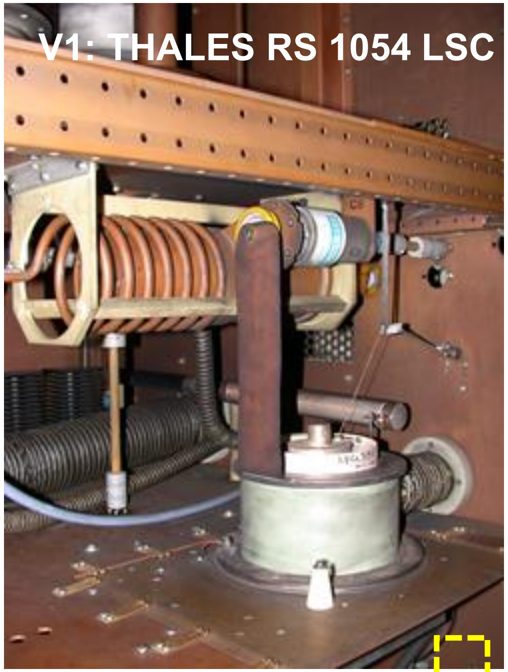
The matching box already installed instead of the 1st stage RS1054LSC in one of the 3 amplifiers

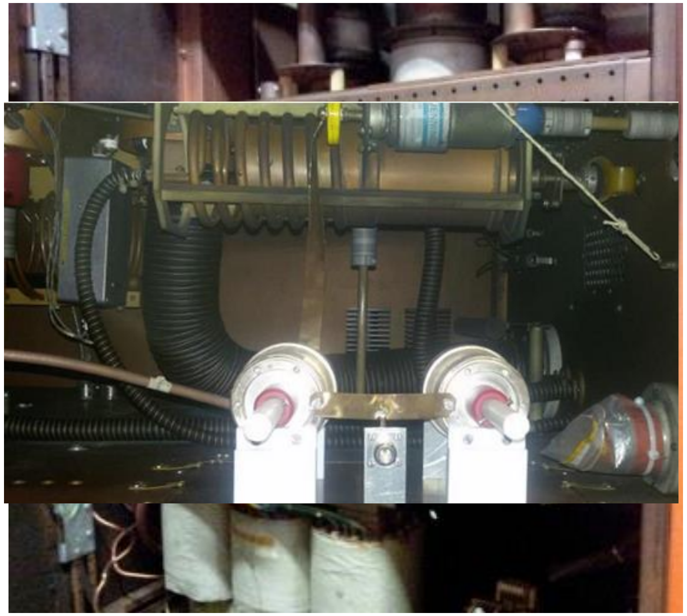


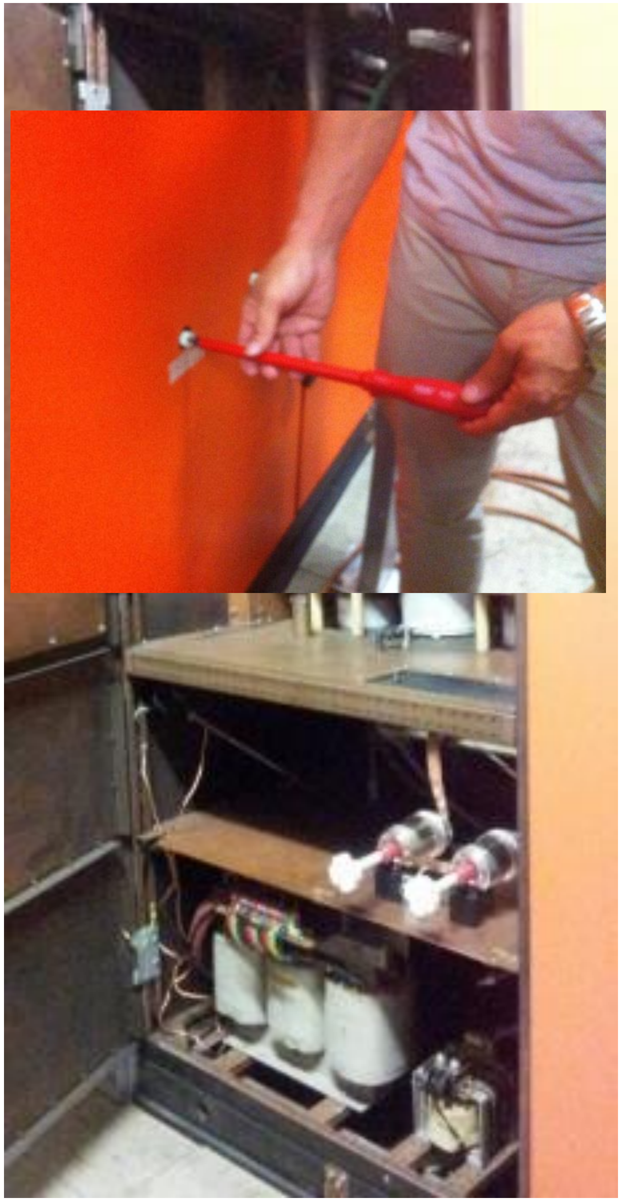


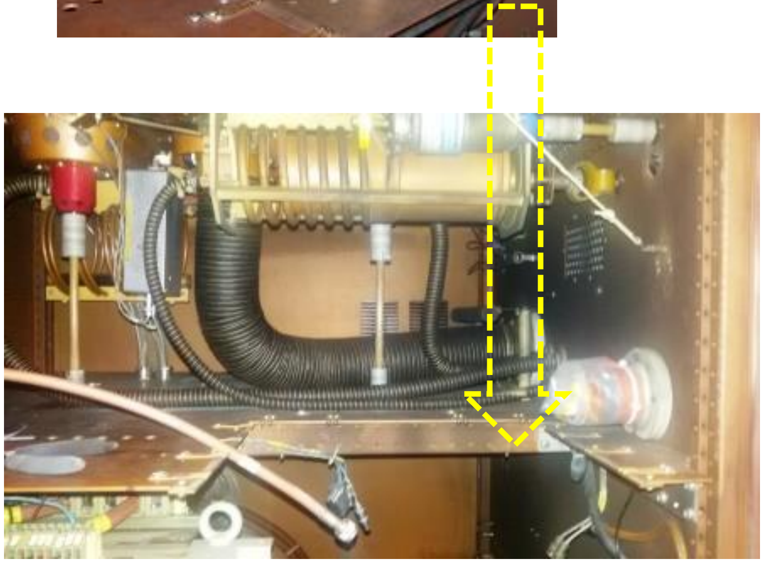


The matching box already installed instead of the 1^{st} stage RS1054LSC in one of the 3 amplifiers



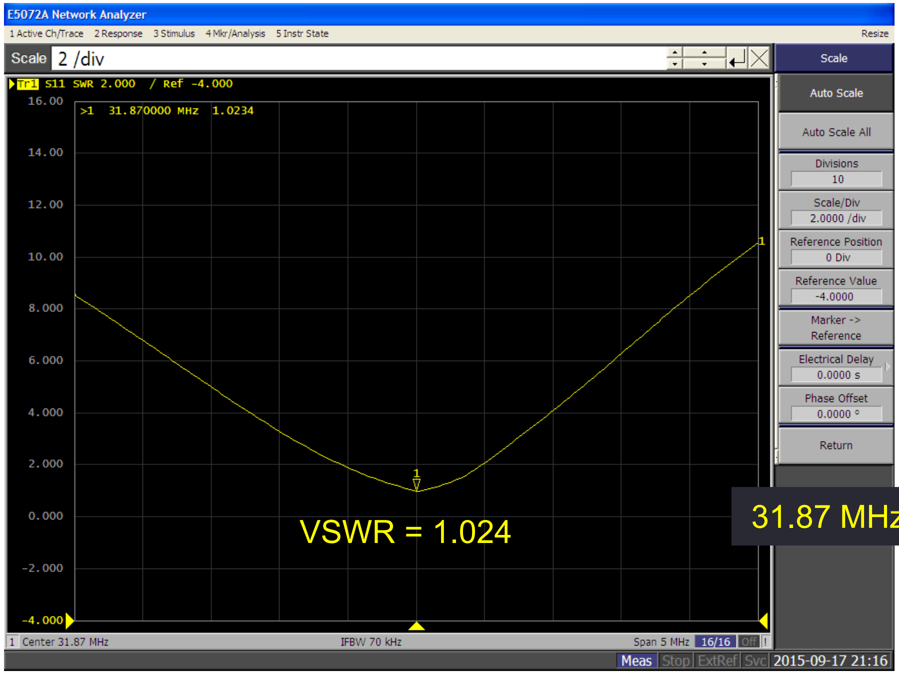




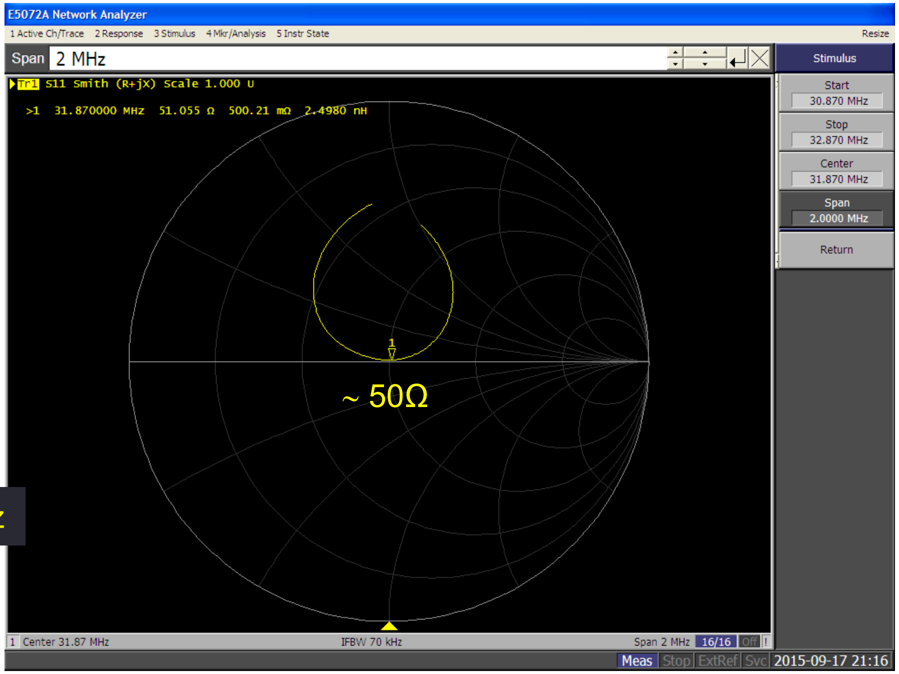


The matching box already installed instead of the 1st stage RS1054LSC in one of the 3 amplifiers

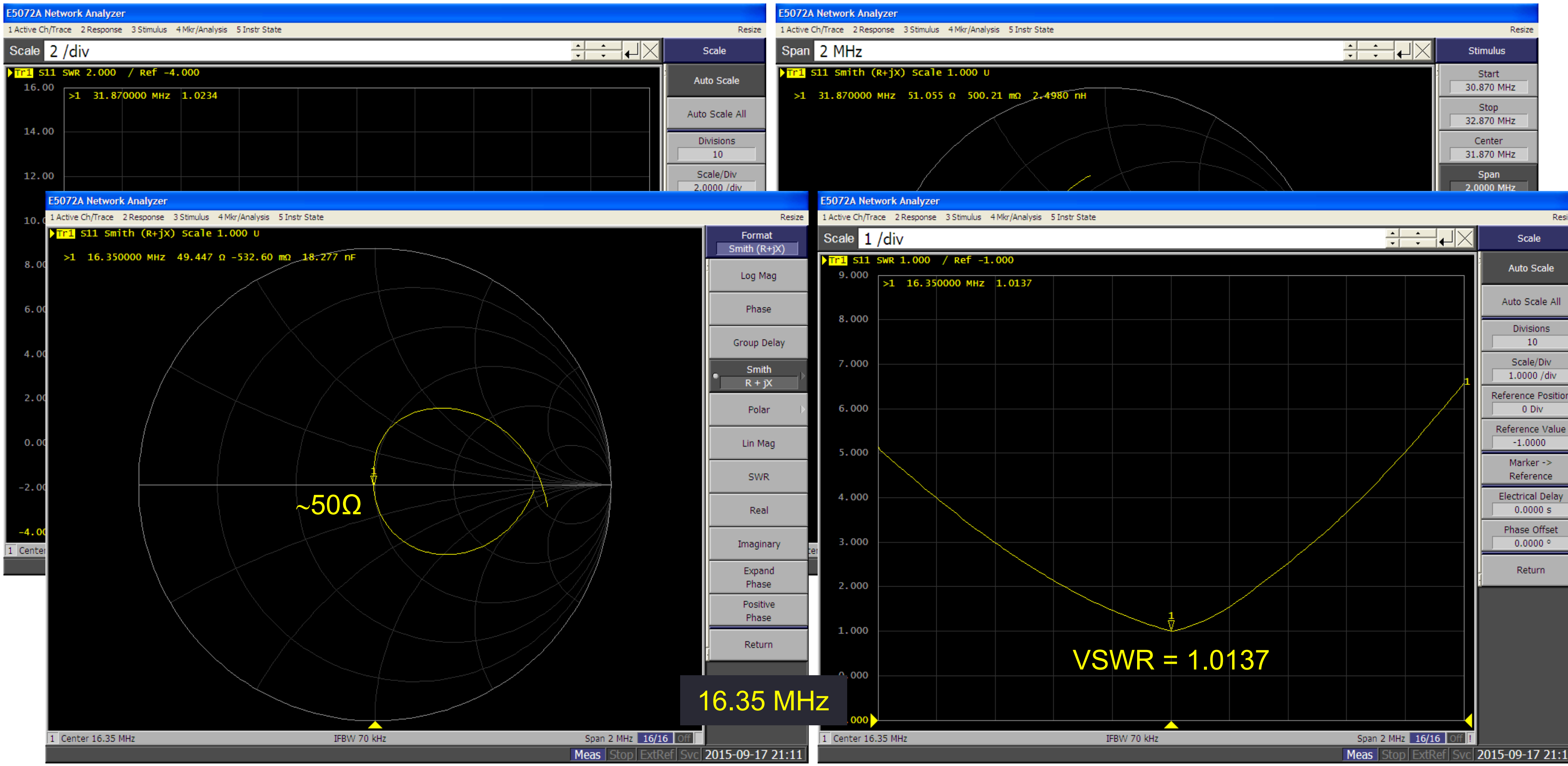
Matching measurements



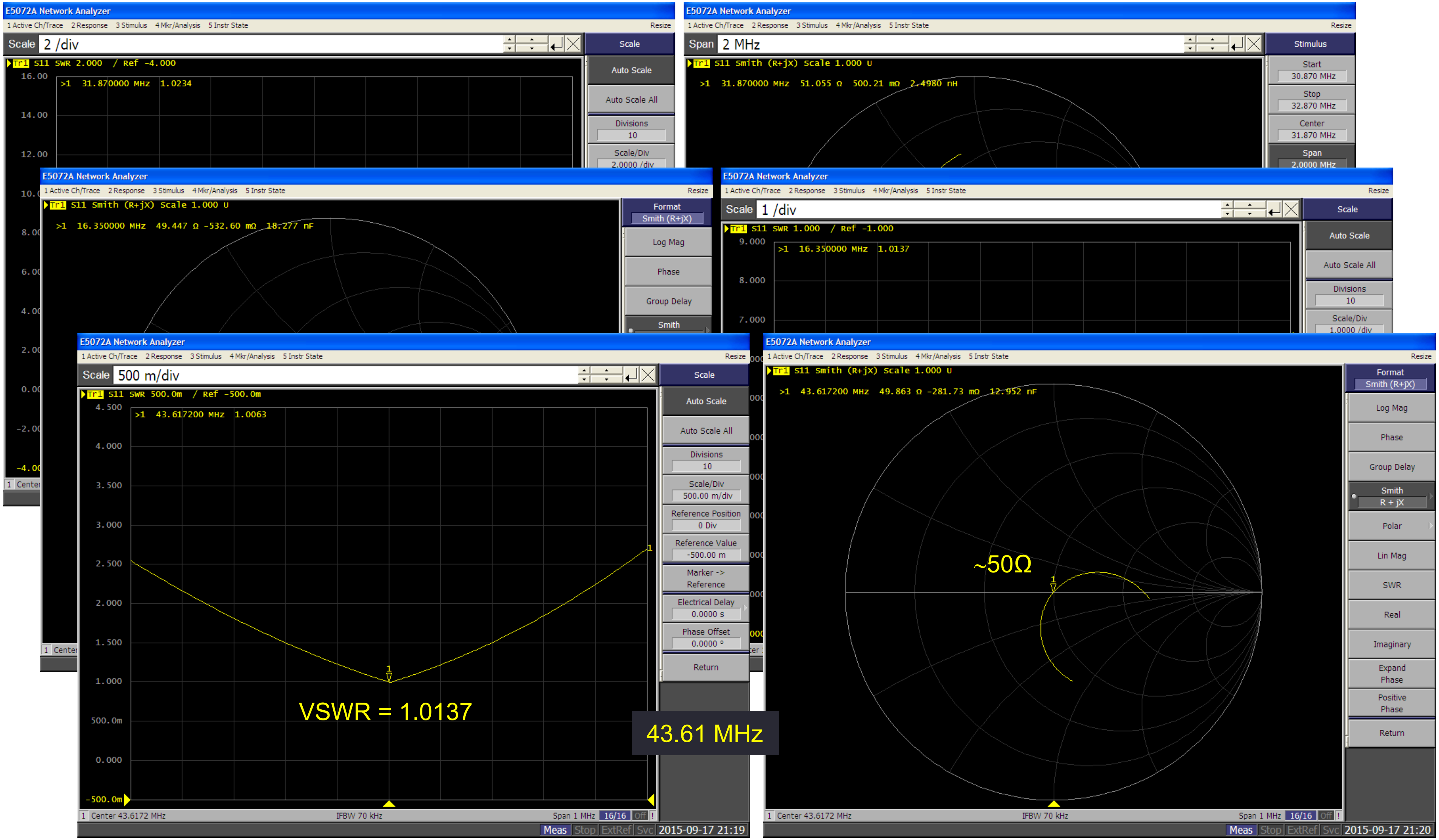
31.87 MHz



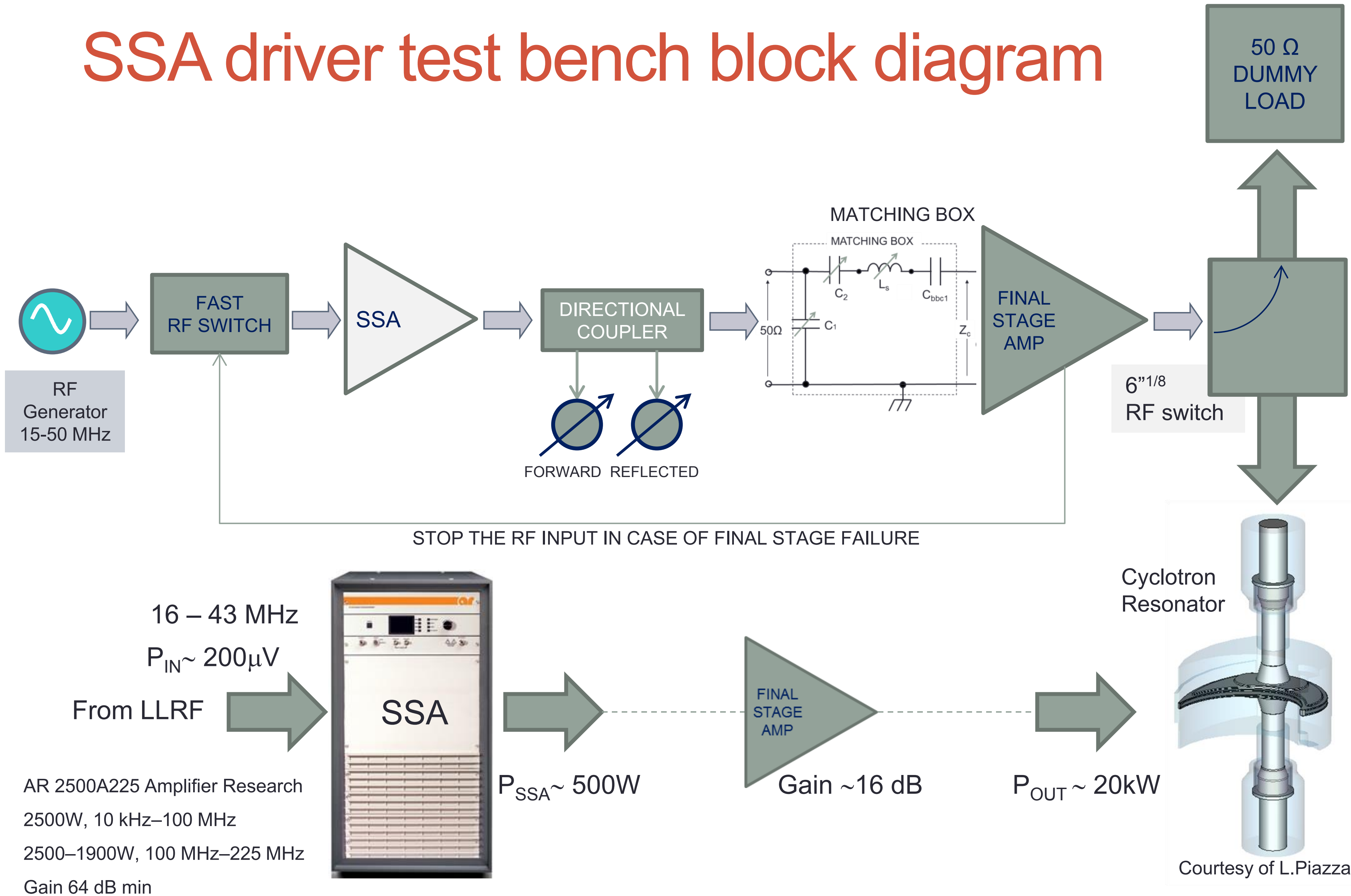
Matching measurements



Matching measurements



SSA driver test bench block diagram



Beams delivered with SSA as permanent driver of Cavity 3

36.8534 MHz

P_{IN}~ 158μV

From LLRF

SSA

AR 2500A225 Amplifier Research

2500W, 10 kHz–100 MHz

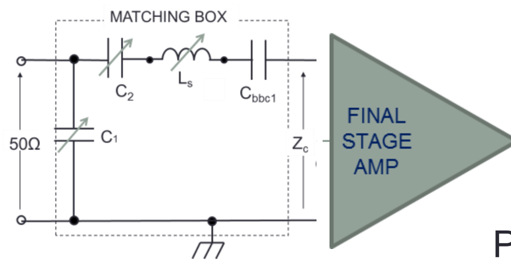
2500–1900W, 100 MHz–225 MHz

Gain 64 dB min

CLASS A - AB

P_{SSA}~ 400W

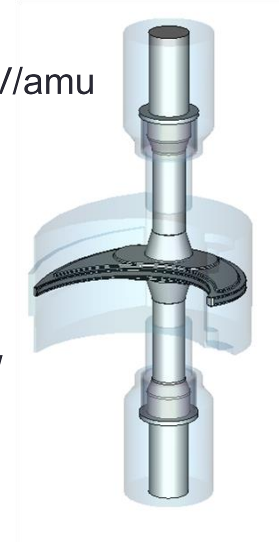
(~56 dBm)



Gain ~16 dB

P_{OUT} ~ 16kW

55 MeV/amu



16.35 MHz

P_{IN}~ 400μV

From LLRF

SSA

2071 EM POWER

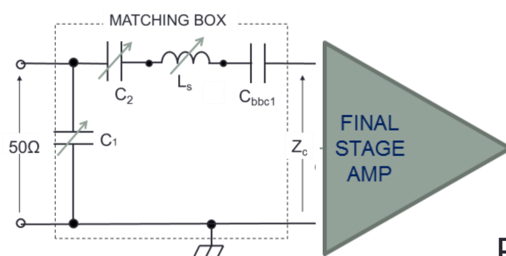
300 W, 1 MHz–100 MHz

Gain 56 dB

CLASS AB

P_{SSA}~ 160W

(~52 dBm)

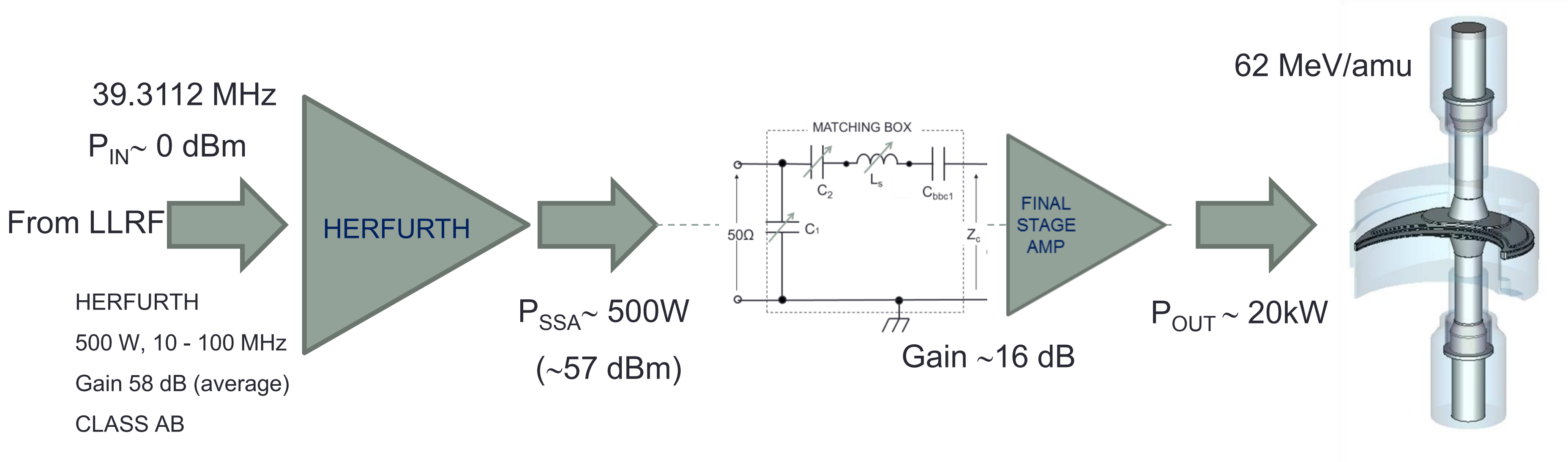


Gain ~16 dB

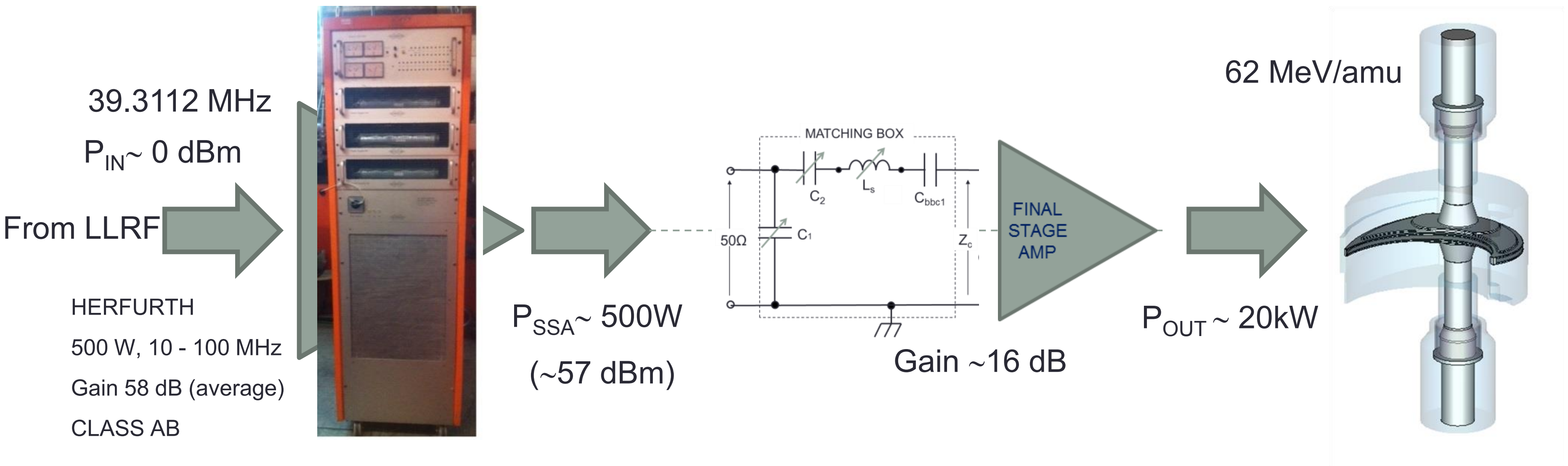
P_{OUT} ~ 7 kW

10 MeV/amu

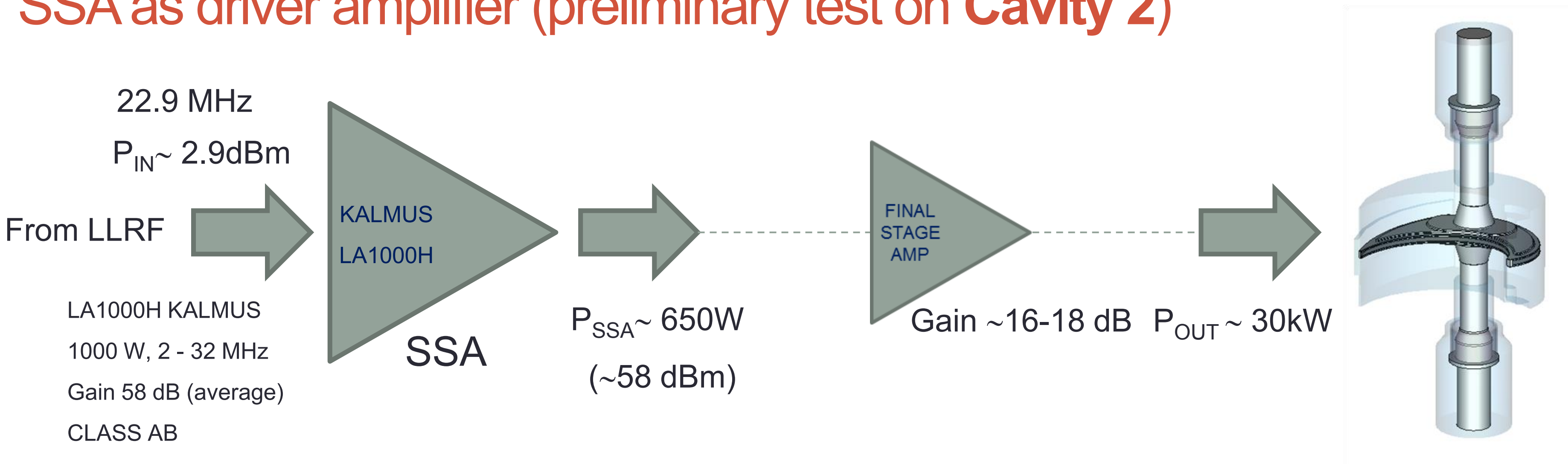
Beams delivered with SSA as permanent driver of Cavity 3



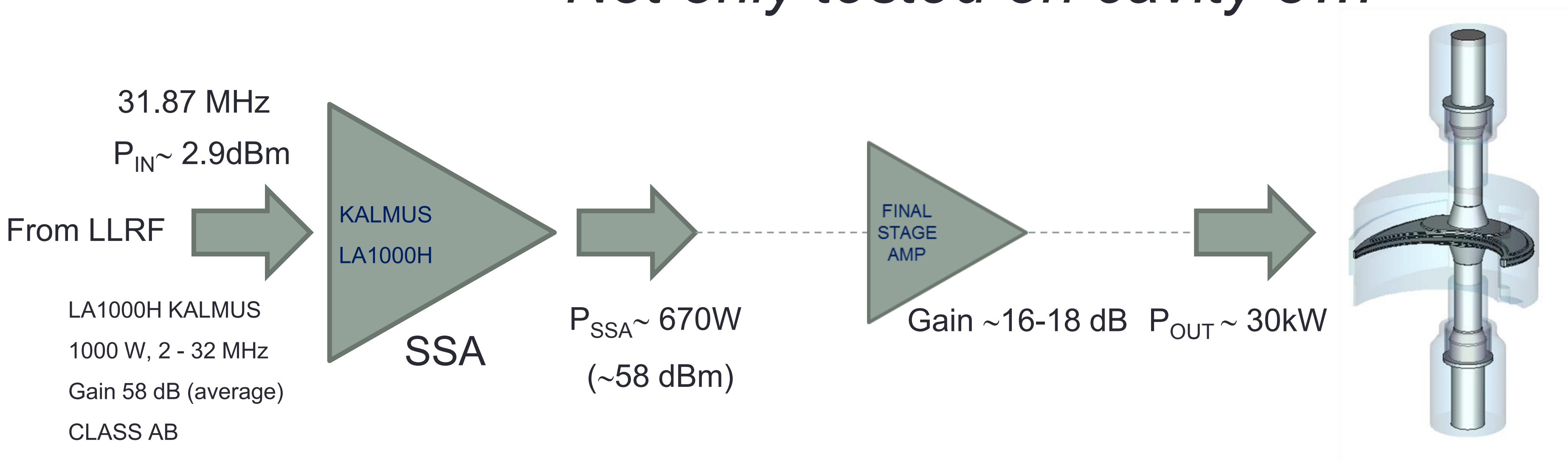
Beams delivered with SSA as permanent driver of Cavity 3



SSA as driver amplifier (preliminary test on **Cavity 2**)



Not only tested on cavity 3…



DRIVER BASED ON NEW LDMOS FREESCALE

We got a pre assembled board and made a driver amplifier…

39.3112 MHz

P_{IN}~ 0 dBm

From LLRF

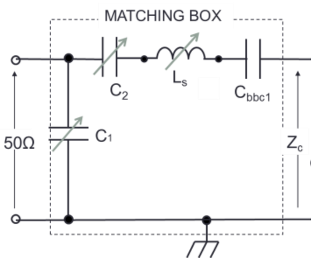
1W

(~+30 dBm)

FREESCALE OR NXP

P_{SSA}~ 500W

(~+57 dBm)



FINAL STAGE AMP

Gain ~16 dB

P_{OUT} ~ 20kW

DUMMY LOAD

INFN/LNS prototype

1 kW, 1.8 - 54 MHz

Gain 27 dB (average)

Output Power ≥ 1kW

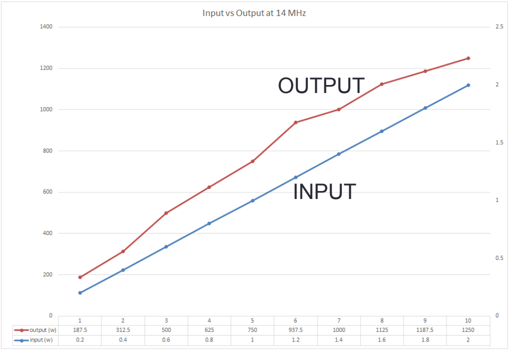
Flatness ± 1.5 dB

Gain ~ 27 dB

Mismatch max tested 2:1

Frequency range 1.8 - 54 MHz

MRFE6VP61K25HR6 (FREESCALE)



DRIVER BASED ON NEW LDMOS FREESCALE

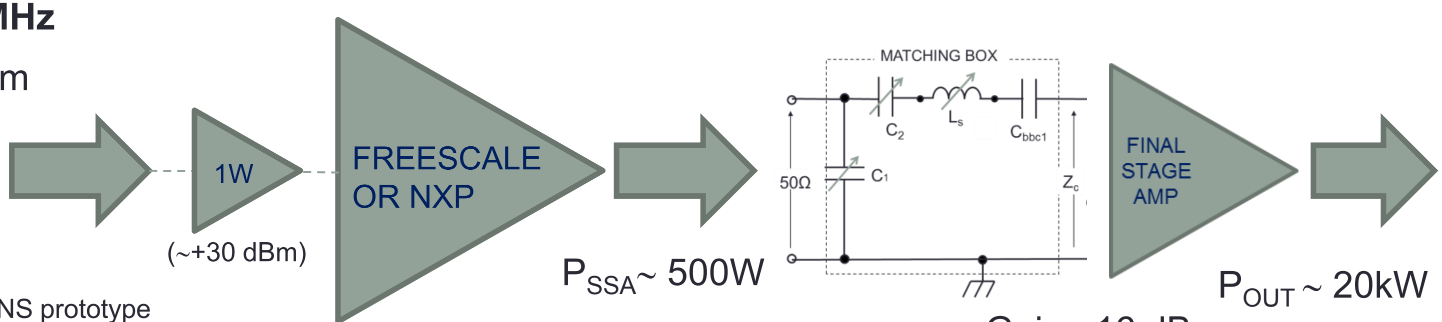
We got a pre assembled board and made a driver amplifier…

33.74 MHz
29.835 MHz
16.35 MHz
39.3112 MHz

LDMOS Transistor
>1 kW, 2-600 MHz

P_{IN}~ 0 dBm

From LLRF



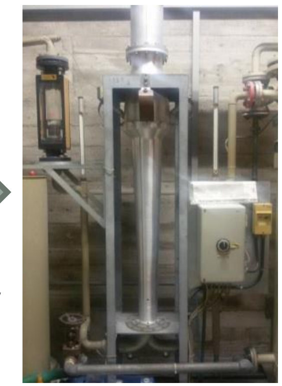
(~+30 dBm)

P_{SSA}~ 500W

(~+57 dBm)

Gain ~16 dB

P_{OUT} ~ 20kW



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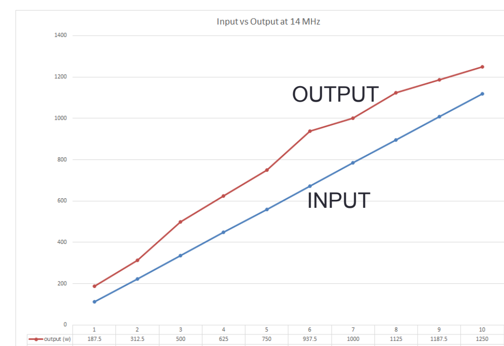


DRIVER BASED ON NEW LDMOS FREESCALE

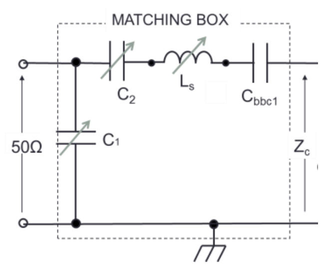
We got a pre assembled board and made a driver amplifier…

33.74 MHz
29.835 MHz
16.35 MHz
39.3112 MHz

LDMOS Transistor
>1 kW, 2-600 MHz

P_{IN}~ 0 dBm

From LLRF → 1W (~+30 dBm) → FREESCALE OR NXP → P_{SSA}~ 500W (~+57 dBm) → MATCHING BOX → FINAL STAGE AMP → P_{OUT} ~ 20kW → CAV3



Gain ~16 dB

INFN/LNS prototype

1 kW, 1.8 - 54 MHz

Gain 27 dB (average)

Output Power ≥ 1kW

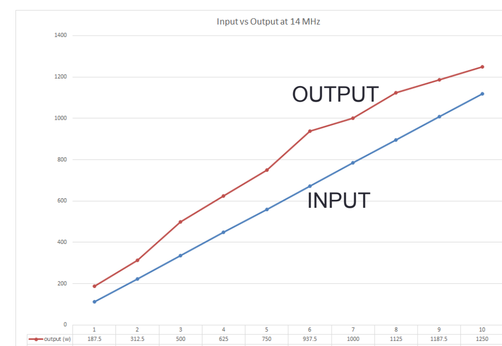
Flatness ± 1.5 dB

Gain ~ 27 dB

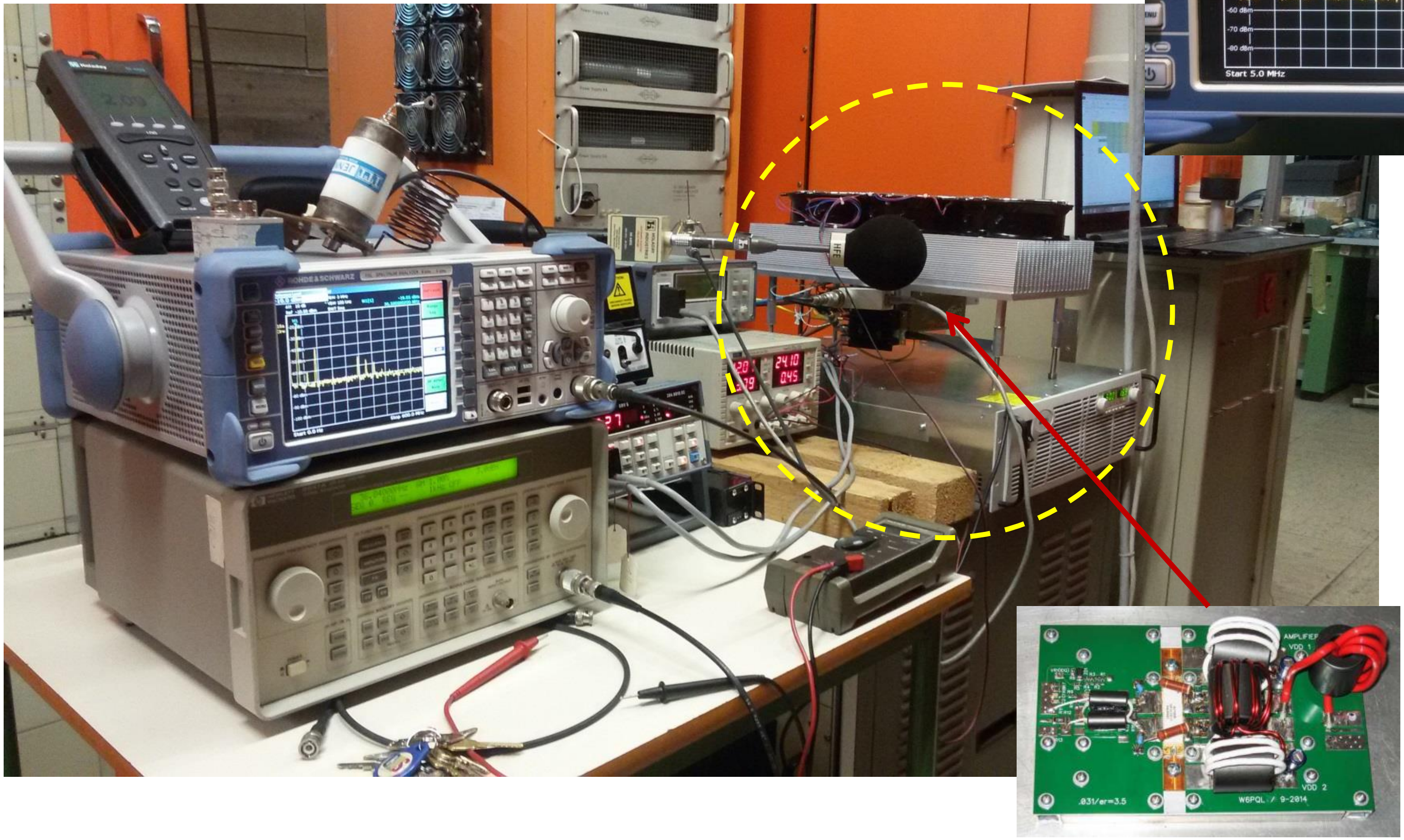
Mismatch max tested 2:1

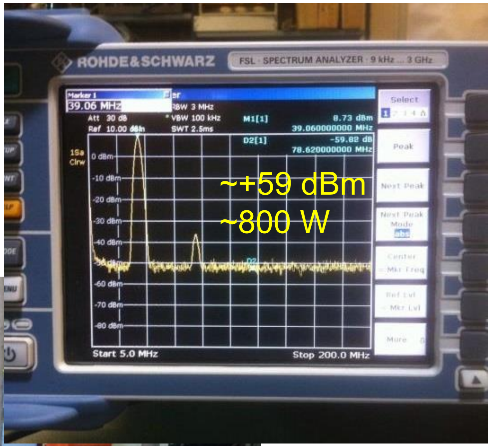
Frequency range 1.8 - 54 MHz

MRFE6VP61K25HR6 (FREESCALE)



Test bench LDMOS TEST





COMPONENTS

Freescale Semiconductor
Technical Data

Document Number: MRFE6VP61K25H
Rev. 4.1, 3/2014
√RoHS

RF Power LDMOS Transistors

High Ruggedness N-Channel
Enhancement-Mode Lateral MOSFETs

These high ruggedness devices are designed for use in high VSWR industrial (including laser and plasma exciters), broadcast (analog and digital), aerospace and radio/land mobile applications. They are unmatched input and output designs allowing wide frequency range utilization, between 1.8 and 600 MHz.

- Typical Performance: V_{DD} = 50 Volts, I_{DQ} = 100 mA

Signal Type	P_{out} (W)	f (MHz)	G_{ps} (dB)	η_D (%)
Pulse (100 μsec, 20% Duty Cycle)	1250 Peak	230	24.0	74.0
CW	1250 CW	230	22.9	74.6

Application Circuits (1) — Typical Performance

Frequency (MHz)	Signal Type	P_{out} (W)	G_{ps} (dB)	η_D (%)
27	CW	1300	27	81
40	CW	1300	26	85
81.36	CW	1250	27	84
87.5-108	CW	1100	24	80
144-148	CW	1250	26	78
170-230	DVB-T	225	25	30
352	Pulse (200 μsec, 20% Duty Cycle)	1250	21.5	66
352	CW	1150	20.5	68
500	CW	1000	18	58

1. Contact your local Freescale sales office for additional information on specific circuit designs.

Load Mismatch/Ruggedness

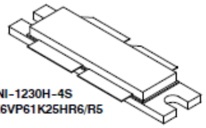
Frequency (MHz)	Signal Type	VSWR	P_{out} (W)	Test Voltage	Result
230	Pulse (100 μsec, 20% Duty Cycle)	> 65:1 at all Phase Angles	1500 Peak (3 dB Overdrive)	50	No Device Degradation

Features

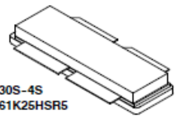
- Unmatched Input and Output Allowing Wide Frequency Range Utilization
- Device can be used Single-Ended or in a Push-Pull Configuration
- Qualified Up to a Maximum of 50 V_{DD} Operation
- Characterized from 30 V to 50 V for Extended Power Range
- Suitable for Linear Application with Appropriate Biasing
- Integrated ESD Protection with Greater Negative Gate-Source Voltage Range for Improved Class C Operation
- Characterized with Series Equivalent Large-Signal Impedance Parameters
- In Tape and Reel. R6 Suffix = 150 Units, 56 mm Tape Width, 13-inch Reel. R5 Suffix = 50 Units, 56 mm Tape Width, 13-inch Reel.

MRFE6VP61K25HR6
MRFE6VP61K25HR5
MRFE6VP61K25HSR5
MRFE6VP61K25GSR5

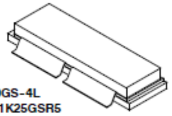
1.8-600 MHz, 1250 W CW, 50 V
WIDEBAND
RF POWER LDMOS TRANSISTORS



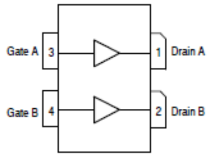
NI-1230H-4S
MRFE6VP61K25HR6/R5



NI-1230S-4S
MRFE6VP61K25HSR5



NI-1230GS-4L
MRFE6VP61K25GSR5



(Top View)

Note: The backside of the package is the source terminal for the transistors.

Figure 1. Pin Connections

freescale

BLF188XR; BLF188XRS

Power LDMOS transistor

Rev. 5 — 12 November 2013 **Product data sheet**

1. Product profile

1.1 General description

A 1400 W extremely rugged LDMOS power transistor for broadcast and industrial applications in the HF to 600 MHz band.

Table 1. Application information

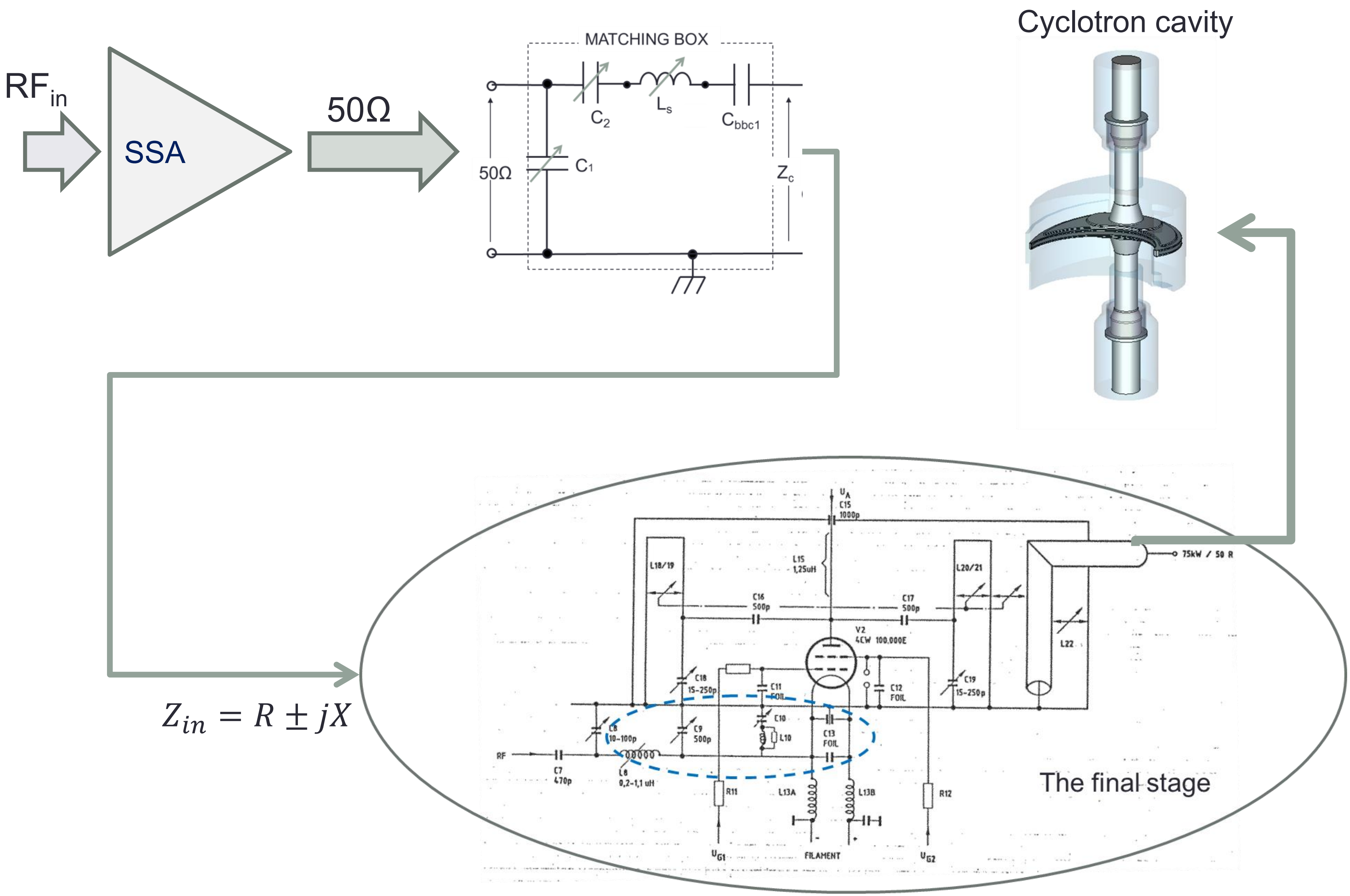
Test signal	f (MHz)	V_{DS} (V)	P_L (W)	G_p (dB)	η_D (%)
CW	2 to 30	50	1270	29.0	75
	27	50	1400	23.7	73
	41	50	1200	22.0	82
	60	48	1240	22.0	77
	72.5	50	1350	23.1	83
	81.4	50	1200	27.1	77.8
	88 to 108	50	1320	22.5	85
	108	50	1200	26.5	83
	200	50	1288	19.3	68.3
pulsed RF	81.4	50	1200	25.8	85
	81.4	50	1400	25.4	81
	108	50	1400	24.0	73
DVB-T	174 to 230	50	225	23.8	29

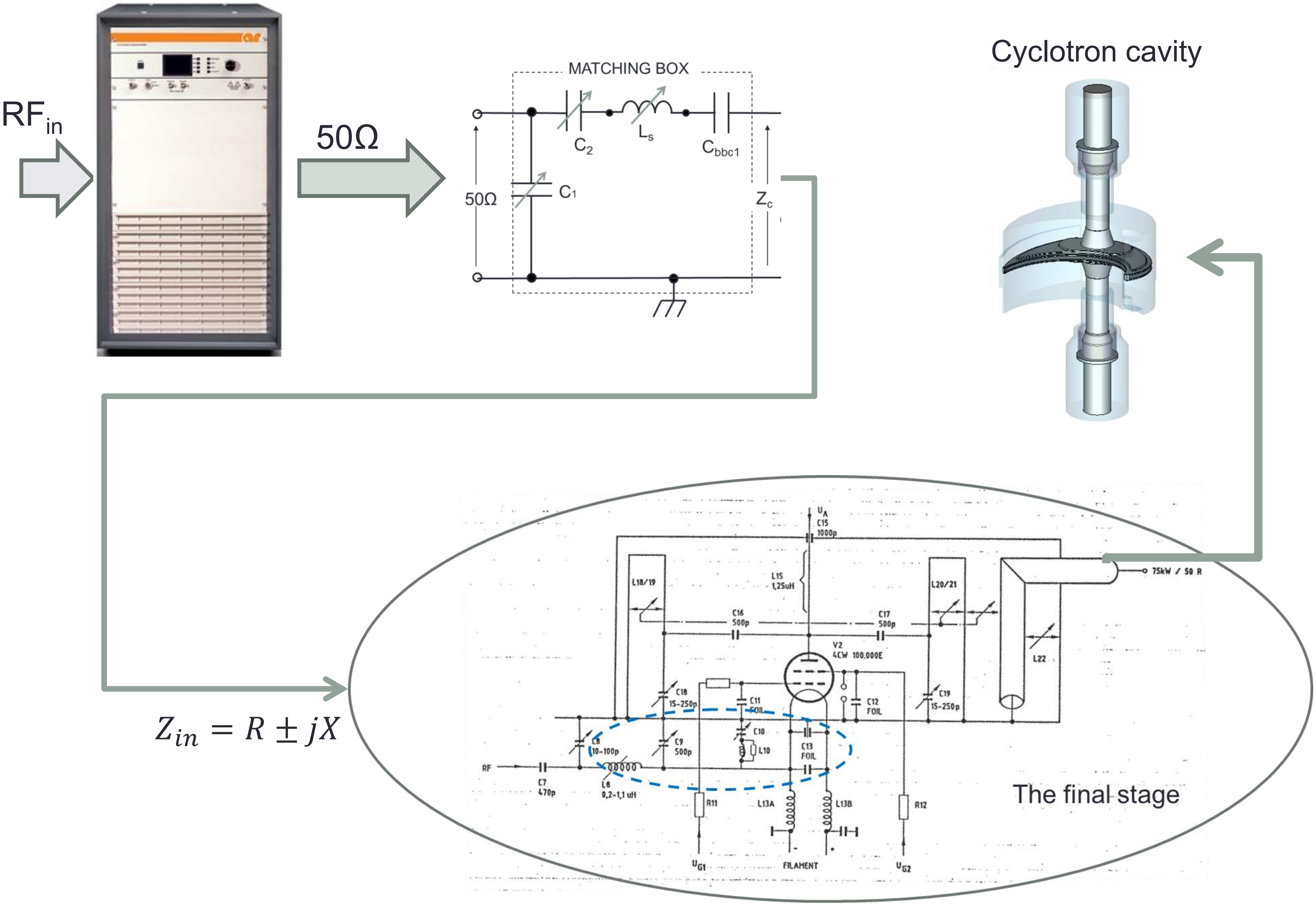
1.2 Features and benefits

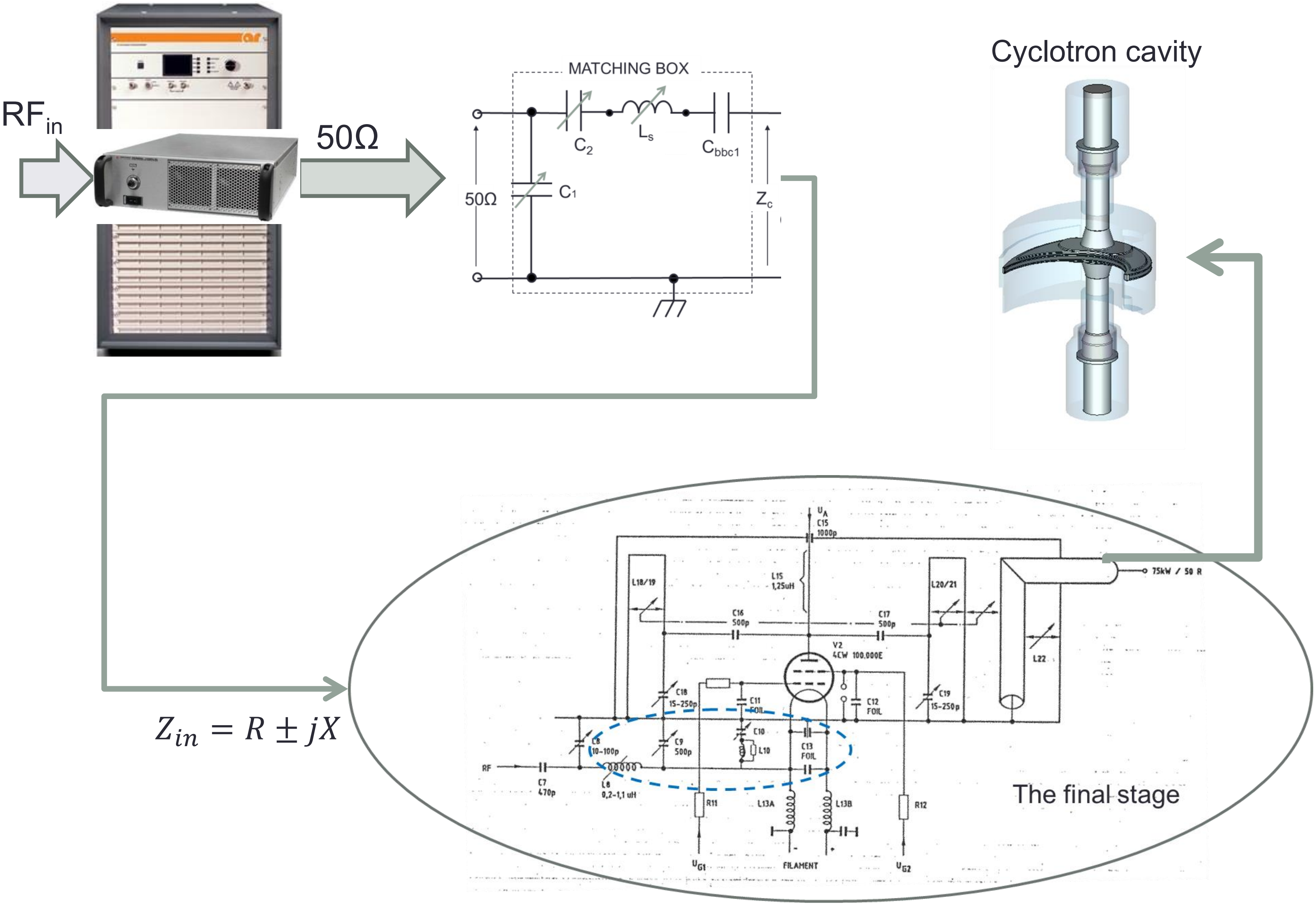
- Easy power control
- Integrated ESD protection
- Excellent ruggedness
- High efficiency
- Excellent thermal stability
- Designed for broadband operation (HF to 600 MHz)
- Compliant to Directive 2002/95/EC, regarding Restriction of Hazardous Substances (RoHS)

1.3 Applications

- Industrial, scientific and medical applications
- Broadcast transmitter applications


RFin
SSA
50Ω
MATCHING BOX
C2
Ls
Cbbc1
C1
50Ω
Zc
Cyclotron cavity
$Z_{in} = R \pm jX$
The final stage

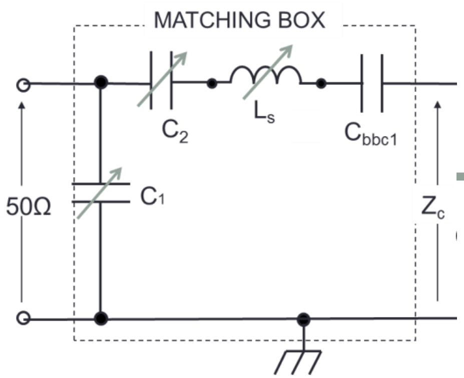

RF$_{in}$
50Ω
MATCHING BOX
C$_2$
L$_s$
C$_{bbc1}$
C$_1$
50Ω
Z$_c$
Cyclotron cavity
$Z_{in} = R \pm jX$
The final stage
75kW / 50 R
FILAMENT



RF$_{in}$
50Ω
MATCHING BOX
C$_2$
L$_s$
C$_{bbc1}$
C$_1$
50Ω
Z$_c$
Cyclotron cavity
$Z_{in} = R \pm jX$
U$_A$
C15 1000p
L15 1,25uH
L18/19
L20/21
C16 500p
C17 500p
V2 4CW 100.000E
75kW / 50 R
L22
C18 15-250p
C11 FOIL
C12 FOIL
C19 15-250p
C8 10-100p
C9 500p
C10
L10
C13 FOIL
RF
C7 470p
L8 0,2-1,1 uH
R11
L13A
L13B
R12
U$_{G1}$
FILAMENT
U$_{G2}$
The final stage

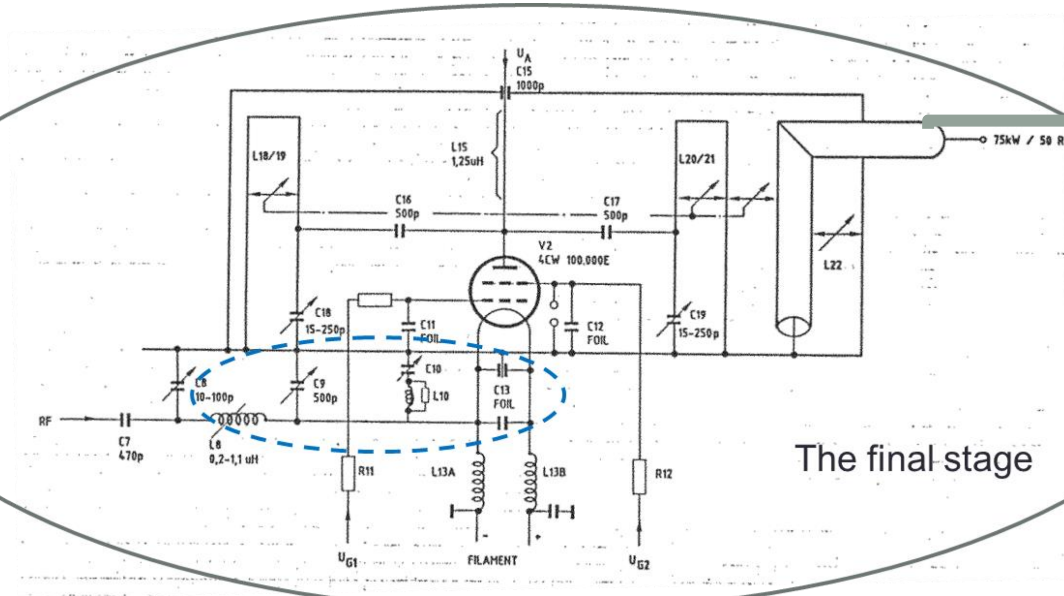
RF$_{in}$

50Ω

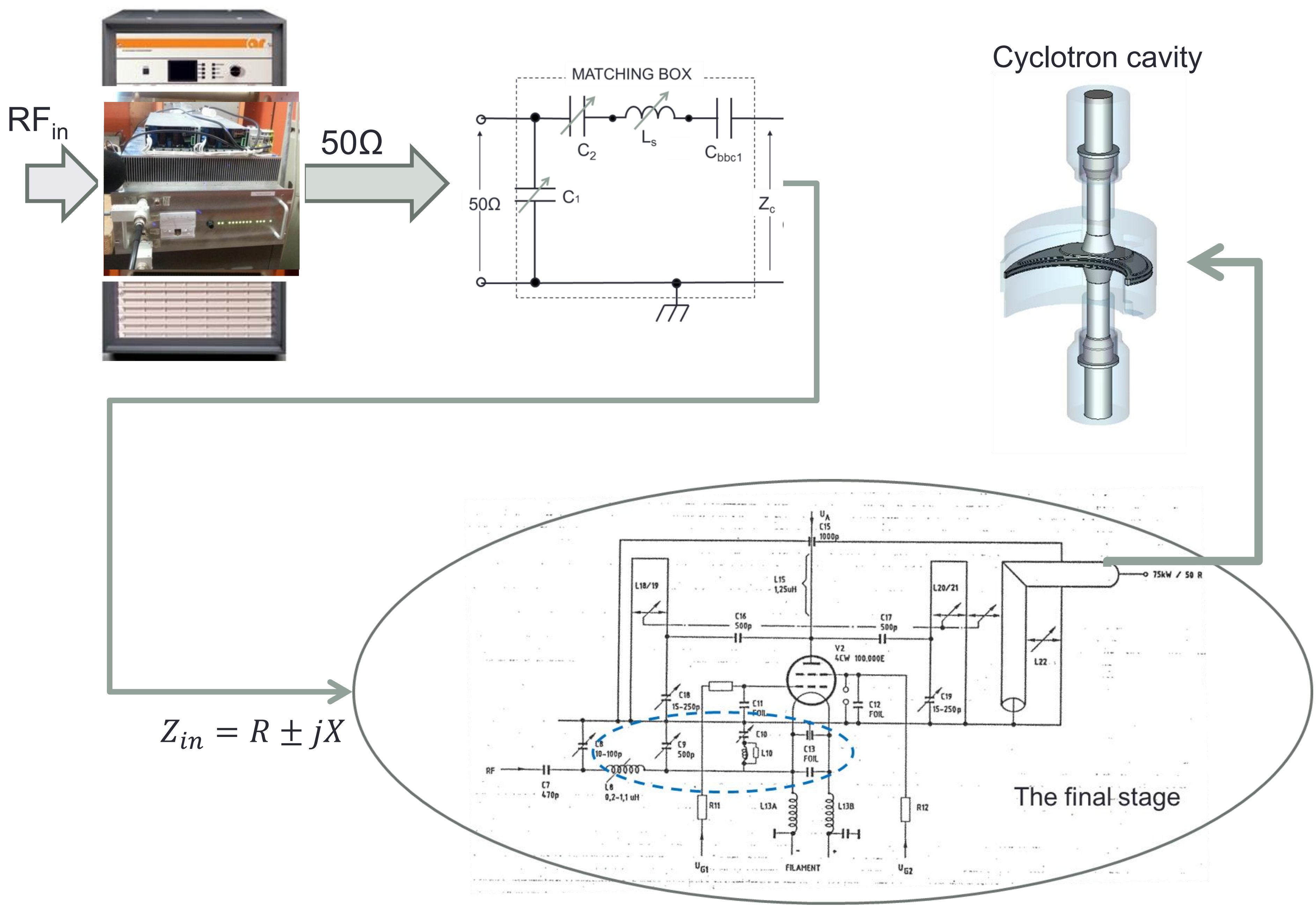


Cyclotron cavity

$$Z_{in} = R \pm jX$$



The final stage


RF in
50Ω
MATCHING BOX
C2
Ls
Cbbc1
C1
50Ω
Zc
Cyclotron cavity
Zin = R ± jX
UA
C15 1000p
L15 1,25uH
L18/19
L20/21
C16 500p
C17 500p
V2 4CW 100.000E
75kW / 50 R
L22
C18 15-250p
C11 FOIL
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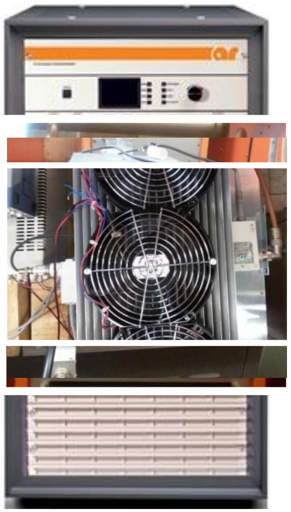
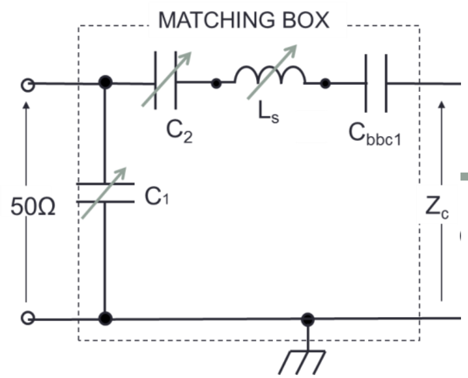
C8 10-100p
C9 500p
C10
L10
C13 FOIL
RF
C7 470p
L8 0,2-1,1 uH
R11
L13A
L13B
R12
UG1
FILAMENT
UG2
The final stage

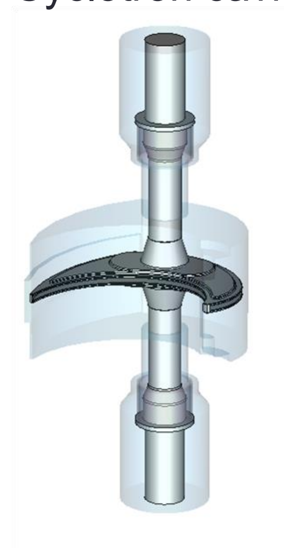
RF$_{in}$



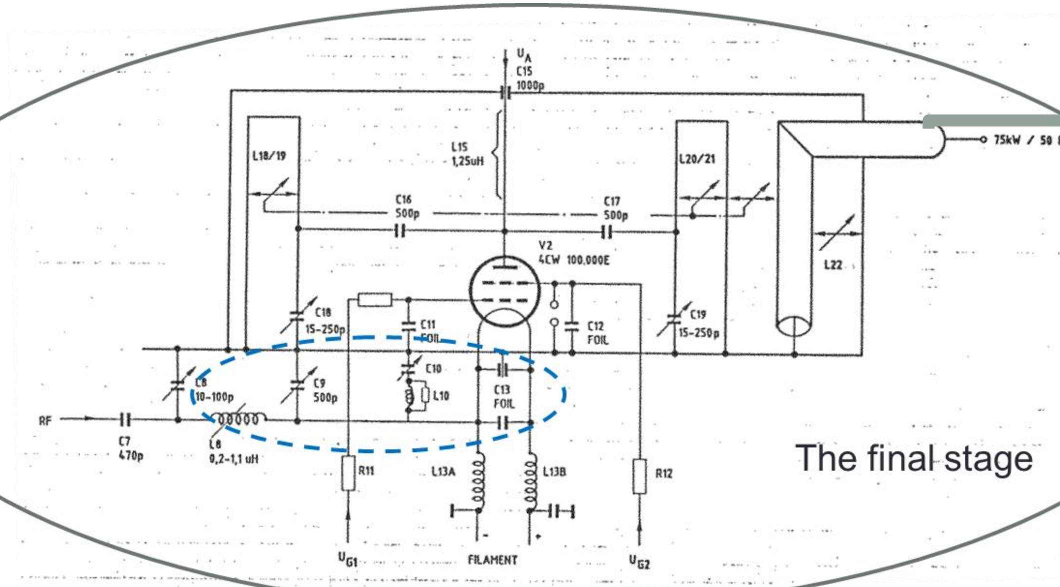
50Ω



Cyclotron cavity



$Z_{in} = R \pm jX$

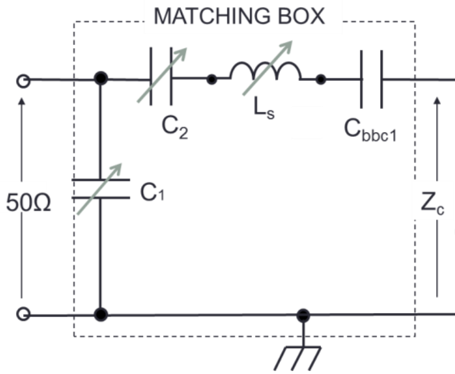


The final stage

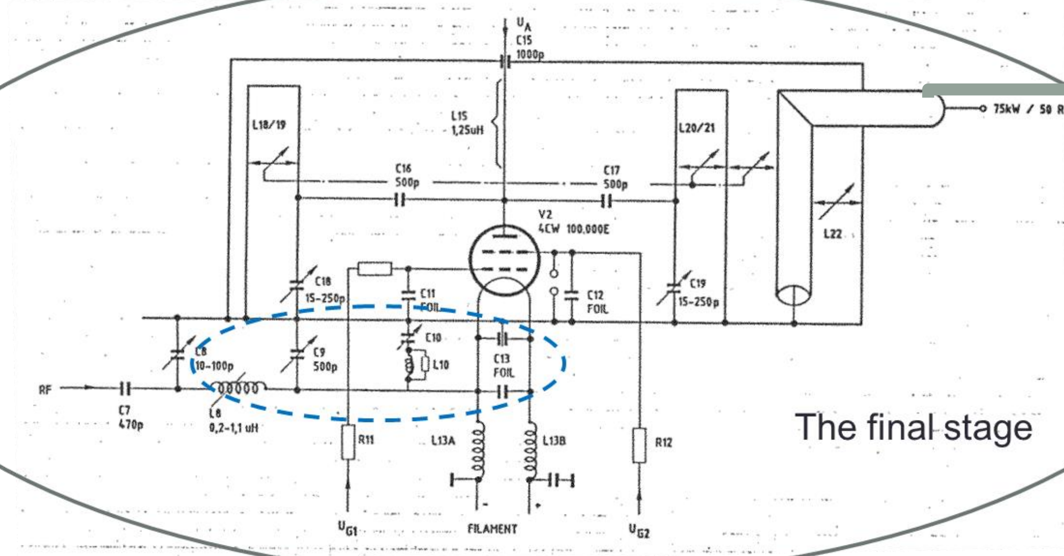
Cyclotron cavity

RF_{in}

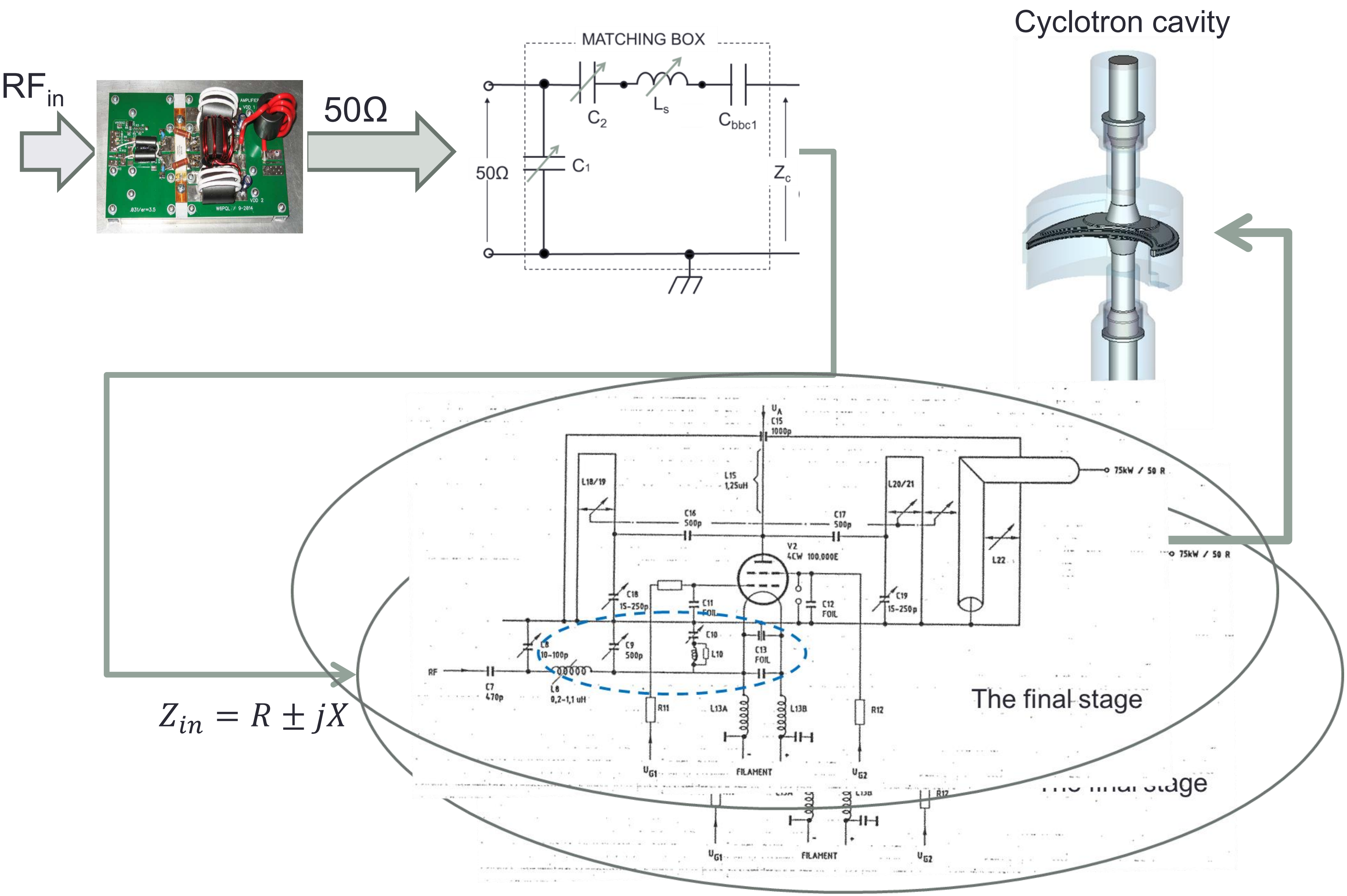
50Ω



$$Z_{in} = R \pm jX$$



The final stage


Cyclotron cavity
RFin
50Ω
MATCHING BOX
C2
Ls
Cbbc1
C1
50Ω
Zc
Zin = R ± jX
The final stage
UA
C15 1000p
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L18/19
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75kW / 50 R
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V2 4CW 100,000E
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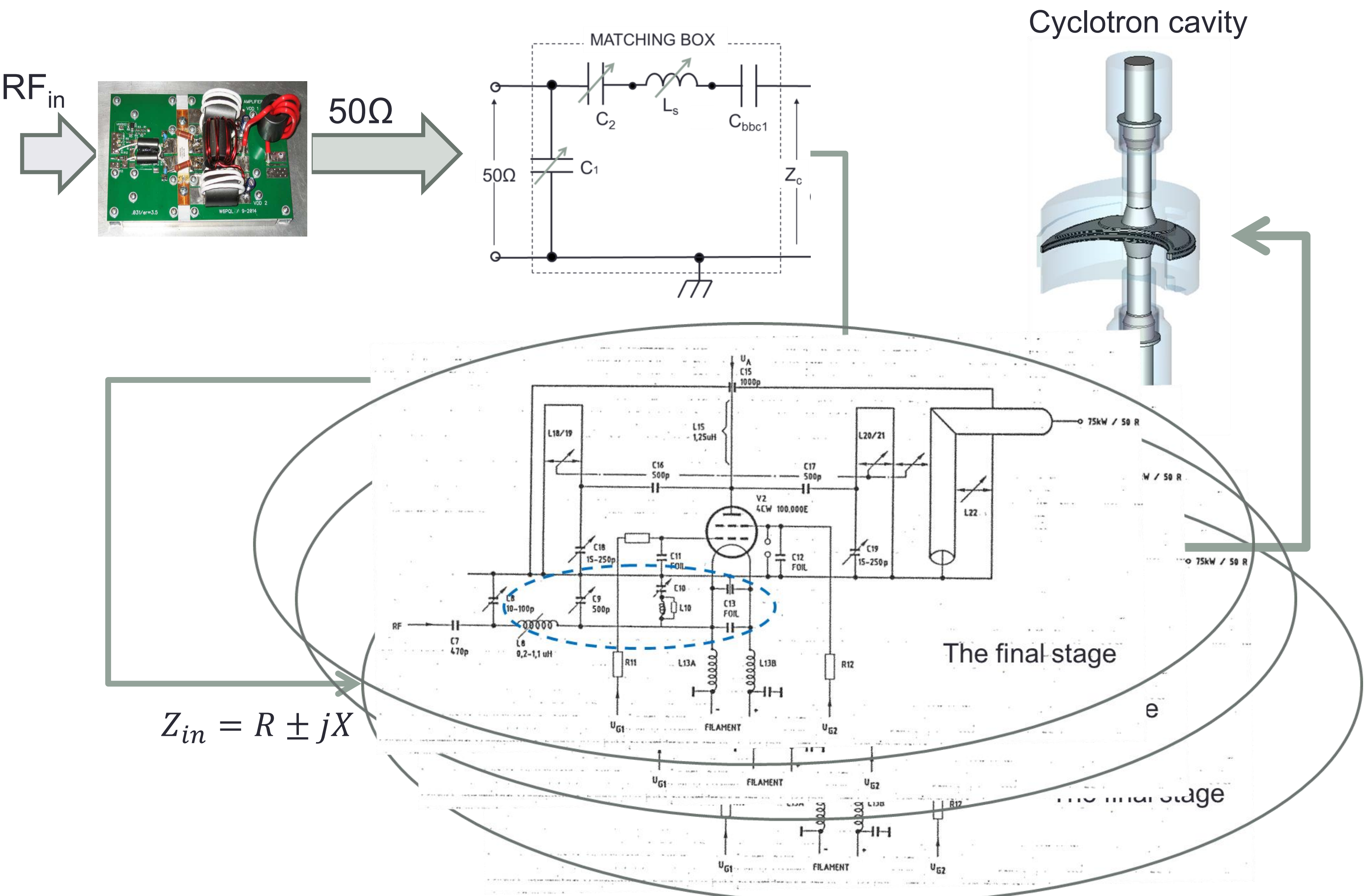
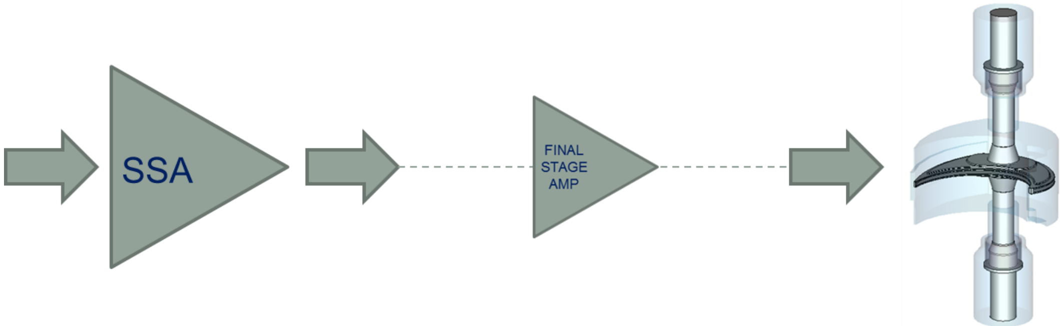
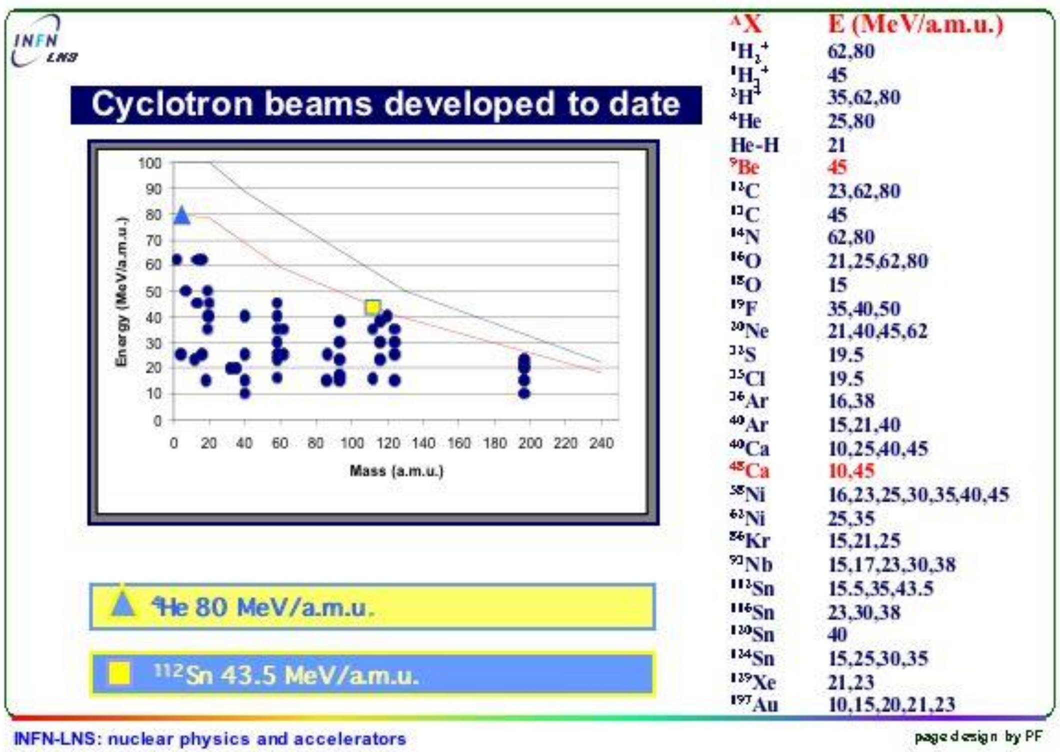
C8 10-100p
C9 500p
C10
L10
C13 FOIL
RF
C7 470p
L8 0,2-1,1 uH
R11
L13A
L13B
R12
UG1
FILAMENT
UG2


RFin
50Ω
MATCHING BOX
C2
Ls
Cbbc1
50Ω
C1
Zc
Cyclotron cavity
The final stage
Zin = R ± jX

From January 2015





Frequency [MHz]	Energy MeV/amu
16,350000	4,0
16,350000	10,0
18,671000	13,25
20,060000	15,0
21,390000	15,0
22,900200	20,0
23,919200	22,05
25,565700	25,0
28,630000	32,0
29,835000	35,0
31,870700	40,0
32,525000	42,0
33,741630	45,5
35,456800	50,0
36,853400	55,0
39,311200	62,0
42,388250	75,0
43,617200	80,0

Conclusions

- The frequency range 15-50 MHz was achieved;
- Mismatch up to 2.0:1 was tested too (30%);
- The system works very well with a lot of final 1st stage configuration (tetrode, mosfet, bjt, new LDMOS etc) of the SSA drivers, we used commercial ones, amplifier research, Kalmus, EMPower, ENI, dB_Science, in-house custom amplifier based on BLF188XR;
- Enough power, 20-30 kW, at the output of the final tetrode, was achieved in the cyclotron cavity;
- Automatic tuning of the matching network, in the near future.

One of the most important result in developing, designing, installing, testing, mostly in-house, the 1st stage solid state matching operation, was:

Gain lot of know-how, useful in the next phase, to prepare the line guide for a proper 1st stage (custom and/or commercial device).

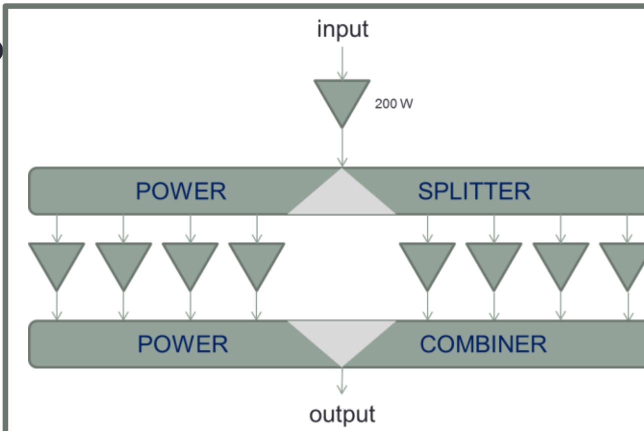
In the end, the solid state solution greatly reduces the cost of the revamp and the maintenance operations.

Only one amplifier is equipped with this new solution, the other 2 are still working with the tetrode 1st stage, until the last spare parts, related to the RS1054L, are used up.

One of the most important result in developing, designing, installing, testing, mostly in-house, the 1st stage solid state matching operation, was:

Gain lot of know-how, useful in the next phase, to prepare the line guide for a proper 1st stage (custom and/or commercial device).

Frequency range	**15-50 MHz**	
Output Power	1.5 kW	Linear P_{1dB}
Input impedance	50 Ω	N connector
Output impedance	50 Ω	7/16”
Class	A -AB	
Gain	63 dB	CW
Flatness	± 1.5 dB	
Harmonic distortion	≤14dBc	
Spurious	≤70dBc	
VSWR	100% rated power	



Based on MOSFET MRF151G

Thank you for your kind attention

Working Group

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3. CERN, Geneva, Switzerland

References:

- THALES RS1054LSC, data sheet;
- THALES TH298, data sheet;
- EIMAC 4CX3500, data sheet;
- MRFE6VP61K25HR6 (FREESCALE), data sheet;
- BLF188XR (NXP), data sheet;
- MRF151G MA-COM electronic solution corporation, data sheet;
- http://www.w6pql.com/ (James Klitzing – Custom Radio Equipment CA-USA)
- Integrated Electronic: analog and digital circuits and system, Millman-Halkias; Mc Graw-Hill (New York)
- Electronic and Radio Engineering, Terman, Mc Graw-Hill (New York);
- Manuale di elettronica e telecomunicazioni, Biondo – Sacchi, Hoepli.