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

Antonio Caruso
INFN-LNS
Talking points

• Overview of the block diagram and RF amplification stages

• Main reasons to modify the existing amplifiers;

• Solid state vs tube amplifier as 1\textsuperscript{st} stage;

• Matching between the new 1\textsuperscript{st} stage and the existing 2\textsuperscript{nd} “tube” stage;

• Test, measurements and operation with our cyclotron;

• Conclusion;

• References and discussion.
The general RF system block diagram
The general RF system block diagram

Let’s see inside the RF amplifiers block
15-50 MHz RF power amplifier (Ampegon ex BBC)

- Gain 50-55 dB
- Wide bandwidth
- "DRIVER AMPLIFIER"

- Standard solid state
  100-200 Watt
  Gain 50-55 dB
  Wide bandwidth
  "DRIVER AMPLIFIER"

- RF Generator 15-50 MHz

- -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)
  $P_{\text{max}}$, 90 kW CW, nominal 75 kW (~1981)
  Frequency range 15-50 MHz

- Cavity 1
  +78.75dBm (75 kW)
  +74.7dBm (30 kW)
  +73dBm (20 kW)

- Cav2
  +45.7dBm (37 W)
  +44dBm (25 W)

- Cavity 3
  +73dBm (20 kW)

- Courtesy of L. Piazza
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.

\[ P_{\text{OUT}} \] 5 kW

T1 THALES RS1054L
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\textsubscript{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
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.

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.

Class AB.
Forced air cooled.
$P_{OUT}$ 5 kW
T1 THALES RS1054L
Power amplifier

The 1\(^{st}\) 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.

\[ P_{\text{OUT}} = 5 \text{ kW} \]

T1 THALES RS1054L

Input filter stage:
- wide band
- adapts from tetrode and Driver impedance
- The RF power is dissipated on 50\(\Omega\).
- No tuning is required

The 2\(^{nd}\) stage (T2=4CW100000): common-grid configuration, high isolation between the in/out sections. Filament input. Water cooled. The load is a \(\frac{1}{4} \lambda\) cavity plus a capacity.
The 2nd stage (T2=4CW100000): common-grid configuration, high isolation between the in/out sections. Filament input. Water cooled. The load is a $\frac{1}{4}\lambda$ cavity plus a capacity.

Forced air cooled.

Class AB.

Power amplifier 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.

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.

Forced air cooled.

$P_{OUT} 5$ kW

T1 THALES RS1054L

T2 1st stage (THALES RS1054LSC)

2nd stage (CPI-4CW100000E)
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 1054 SKSC | TH 363 SC |
| RS 1054 LCS | TH 382 SC |
| RS 2026 CLSC | TH 571 A |
| RS 2056 CLSC | 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 Velizy cedex – France
E-mail : stephane.bethuys@thalesgroup.com, jean-charles.cherp@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
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Science Marketing Manager

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

June 22th, 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 22nd, 2010.

Stéphane Bethuys
Science Marketing Mng

Sergio Brunetti
THALES Microwave Area Mng
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Dear Mister Caruso,

On May 18th, 2010 TED received a tube ref. RS1054LSC in the market and offered it for order (LBO) procedure to close at receipt of funds totaling ~60k€, not on SALE.

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 S...
The final stage

RF Generator
15-50 MHz
Wide band stage 15-50 MHz
Gain ~ 65-70 dB

The final stage

MUST BE CHANGED

RF Generator
15-50 MHz
<table>
<thead>
<tr>
<th>Reference</th>
<th>General characteristics</th>
<th>Heather power supply</th>
<th>Maximum ratings</th>
<th>Dimensions</th>
<th>Cooling</th>
<th>Cavity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Output power</td>
<td>Gain</td>
<td>Anode voltage</td>
<td>Screen grid</td>
<td>Voltage</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>kW</td>
<td>dB</td>
<td>kV</td>
<td>V</td>
<td>A</td>
<td>kW</td>
</tr>
<tr>
<td>YL 1067</td>
<td>1.1</td>
<td>17.5</td>
<td>3.4</td>
<td>600</td>
<td>0.75</td>
<td>3.8</td>
</tr>
<tr>
<td>TH 347</td>
<td>2.2</td>
<td>15</td>
<td>4.5</td>
<td>400</td>
<td>1.15</td>
<td>5.8</td>
</tr>
<tr>
<td>TH 393</td>
<td>2.5</td>
<td>15.5</td>
<td>5.5</td>
<td>600</td>
<td>1.6</td>
<td>6</td>
</tr>
<tr>
<td>RS 1054 L</td>
<td>2.6</td>
<td>16</td>
<td>4.6</td>
<td>800</td>
<td>1.5</td>
<td>2.8</td>
</tr>
<tr>
<td>RS 1054 SK</td>
<td>2.6</td>
<td>16</td>
<td>4.6</td>
<td>800</td>
<td>1.5</td>
<td>2.8</td>
</tr>
<tr>
<td>TH 382</td>
<td>5.25</td>
<td>15.5</td>
<td>5.5</td>
<td>600</td>
<td>2.7</td>
<td>4.2</td>
</tr>
<tr>
<td>RS 1034 L</td>
<td>6.3</td>
<td>16</td>
<td>5.1</td>
<td>800</td>
<td>2.8</td>
<td>4.5</td>
</tr>
<tr>
<td>TH 582</td>
<td>10.5</td>
<td>15</td>
<td>5.5</td>
<td>600</td>
<td>3.45</td>
<td>4.2</td>
</tr>
<tr>
<td>RS 1036 L</td>
<td>11.5</td>
<td>15</td>
<td>6</td>
<td>800</td>
<td>3.7</td>
<td>4.5</td>
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<tr>
<td>RS 1034 SK</td>
<td>12.6</td>
<td>15</td>
<td>6.3</td>
<td>800</td>
<td>3.9</td>
<td>4.5</td>
</tr>
<tr>
<td>TH 563</td>
<td>31.5</td>
<td>14.5</td>
<td>8.5</td>
<td>800</td>
<td>6.45</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(1) Common amplification

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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
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.

make a virtue out of necessity

ENOUGH SPARE PARTS

SOME IN-HOUSE SOLID STATE AMPLIFIERS
Frequency & Power range of tetrodes

In the meanwhile further news coming from the market …

Tetrodes & Diacrodes available from industry

Power kW per single tube vs Frequency MHz

- LDMOS Transistor
  - >1 kW, 2-600 MHz

Courtesy of Eric Montesinos, CERN-RF
Frequency & Power range of tetrodes

In the meanwhile further news coming from the market …

Tetrodes & Diacrodies available from industry

WE THOUGHT OF TRYING AN APPROACH WITH A SOLID STATE STAGE (useful collaboration with Warsaw University)

LDMOS Transistor
>1 kW, 2-600 MHz

Courtesy of Eric Montesinos, CERN-RF
CHANGE THE TUBE 1\textsuperscript{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

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**ELECTRICAL**

Filament: Thoriated Tungsten

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>15.5 ± 0.75 V</td>
</tr>
<tr>
<td>Current @ 15.5 V</td>
<td>215 A</td>
</tr>
</tbody>
</table>

Direct Interelectrode Capacitances (grounded cathode)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cin</td>
<td>370 pF</td>
</tr>
<tr>
<td>Cout</td>
<td>60 pF</td>
</tr>
<tr>
<td>Cgp</td>
<td>1.0 pF</td>
</tr>
</tbody>
</table>

Direct Interelectrode Capacitances (grounded grid)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cin</td>
<td>175 pF</td>
</tr>
<tr>
<td>Cout</td>
<td>60 pF</td>
</tr>
<tr>
<td>Cpk</td>
<td>0.35 pF</td>
</tr>
</tbody>
</table>

Frequency of Maximum Rating, CW 108 MHz
High power water cooled tetrode EIMAC 4CW100000, maximum and minimum rated values

**RANGE VALUES FOR EQUIPMENT DESIGN**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filament: Current @ 15.5 volts</td>
<td>200</td>
<td>230 A</td>
</tr>
<tr>
<td>Cutoff Bias, at $E_b = 25 \text{ kVdc}$, $E_{c2} = 1500 \text{ Vdc}$, $I_b = 10 \text{ mA}_{dc}$</td>
<td>---</td>
<td>-625 Vdc</td>
</tr>
<tr>
<td>Interelectrode Capacitances (grounded cathode)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{in}$</td>
<td>350</td>
<td>390 pF</td>
</tr>
<tr>
<td>$C_{out}$</td>
<td>55</td>
<td>65 pF</td>
</tr>
<tr>
<td>$C_{gp}$</td>
<td>---</td>
<td>1.2 pF</td>
</tr>
<tr>
<td>Interelectrode Capacitances (grounded grid)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{in}$</td>
<td>160</td>
<td>190 pF</td>
</tr>
<tr>
<td>$C_{out}$</td>
<td>55</td>
<td>65 pF</td>
</tr>
<tr>
<td>$C_{pk}$</td>
<td>---</td>
<td>0.5 pF</td>
</tr>
</tbody>
</table>
Matching the new solid state driver with the 2\textsuperscript{nd} stage

\[ Z_{in} = R \pm jX \]

50\,\Omega

The final stage

RF Generator
15-50 MHz
We need a matching network as impedance transformer from $Z_0$ to cathode impedance $Z_{\text{cathode}}$. The real part of the load to be matched $R_L$ ($Z_{\text{cathode}}$) is much lower than $Z_0$ (50Ω). In this case we may use the simple $\Gamma$-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 $Z_o$. In this case we may use the simple $\Gamma$-matching network.

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

$$L_S = 0.2 - 1.1 \text{ } \mu\text{H} \text{ (existing)}$$

$$C_{bbc1} = 470 \text{ pF} \text{ (existing)}$$

$$C_{bbc2} = 5-100 \text{ pF} \text{ (recycled)}$$
\[ Y_{in} = \frac{1}{Z_{C1}} + \frac{1}{Z_{C2} + Z_L + Z_{cathode}} \]

\[ Z_{in} = \frac{1}{Y_{in}} \]

\[ Z_{in} = 50\Omega \]
$Z_{in} = R ± jX$
Inside the amplifier instead of 1\textsuperscript{st} stage
The matching box already installed instead of the 1\textsuperscript{st} stage RS1054LSC in one of the 3 amplifiers.
V1: THALES RS 1054 LSC

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\textsuperscript{st} stage RS1054LSC in one of the 3 amplifiers.
Matching measurements

VSWR = 1.024

31.87 MHz

~ 50Ω
Matching measurements

VSWR = 1.024

~50Ω

16.35 MHz

VSWR = 1.0137
Matching measurements

VSWR = 1.0137

43.61 MHz

~50Ω
SSA driver test bench block diagram

RF Generator 15-50 MHz

FAST RF SWITCH → SSA → DIRECTIONAL COUPLER

FORWARD REFLECTED

MATCHING BOX

FINAL STAGE AMP

50 Ω DUMMY LOAD

STOP THE RF INPUT IN CASE OF FINAL STAGE FAILURE

16 – 43 MHz

P_{IN} \sim 200 \mu V

From LLRF

SSA

P_{SSA} \sim 500W

Gain \sim 16 \text{ dB}

P_{OUT} \sim 20kW

AR 2500A225 Amplifier Research
2500W, 10 kHz–100 MHz
2500–1900W, 100 MHz–225 MHz
Gain 64 dB min
Beams delivered with SSA as permanent driver of Cavity 3

36.8534 MHz
\( P_{IN} \approx 158 \mu V \)

From LLRF

AR 2500A225 Amplifier Research
2500W, 10 kHz–100 MHz
2500–1900W, 100 MHz–225 MHz
Gain 64 dB min
CLASS A - AB

16.35 MHz
\( P_{IN} \approx 400 \mu V \)

From LLRF

2071 EM POWER
300 W, 1 MHz–100 MHz
Gain 56 dB
CLASS AB
Beams delivered with SSA as permanent driver of Cavity 3

39.3112 MHz
P_{IN} \sim 0 \text{ dBm}

From LLRF

HERFURTH
500 W, 10 - 100 MHz
Gain 58 dB (average)
CLASS AB

P_{SSA} \sim 500 \text{ W} (~57 \text{ dBm})

Gain \sim 16 \text{ dB}

P_{OUT} \sim 20 \text{ kW}

62 \text{ MeV/amu}
Beams delivered with SSA as permanent driver of Cavity 3

39.3112 MHz
$P_{IN} \sim 0 \text{ dBm}$

From LLRF

HERFURTH
500 W, 10 - 100 MHz
Gain 58 dB (average)
CLASS AB

$P_{SSA} \sim 500W$
($\sim 57 \text{ dBm}$)

Gain $\sim 16 \text{ dB}$

$P_{OUT} \sim 20kW$

62 MeV/amu
SSA as driver amplifier (preliminary test on Cavity 2)

22.9 MHz
P_{IN} \sim 2.9\text{dBm}

From LLRF

KALMUS LA1000H
1000 W, 2 - 32 MHz
Gain 58 dB (average)
CLASS AB

SSA

P_{SSA} \sim 650\text{W}
(~58 \text{dBm})

Gain \sim 16-18 \text{dB}
P_{OUT} \sim 30\text{kW}

Not only tested on cavity 3…

31.87 MHz
P_{IN} \sim 2.9\text{dBm}

From LLRF

KALMUS LA1000H
1000 W, 2 - 32 MHz
Gain 58 dB (average)
CLASS AB

SSA

P_{SSA} \sim 670\text{W}
(~58 \text{dBm})

Gain \sim 16-18 \text{dB}
P_{OUT} \sim 30\text{kW}
DRIVER BASED ON NEW LDMOS FREESCALE

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

39.3112 MHz
P\textsubscript{IN} \sim 0 \text{ dBm}

From LLRF

1W

(\sim +30 \text{ dBm})

FREESCALE OR NXP

P\textsubscript{SSA} \sim 500W

(\sim +57 \text{ dBm})

Gain \sim 16 \text{ dB}

Output Power \geq 1\text{ kW}

Flatness \pm 1.5 \text{ dB}

Gain \sim 27 \text{ dB}

Mismatch max tested 2:1

Frequency range 1.8 - 54 MHz

MRFE6VP61K25HR6 (FREESCALE)
DRIVER BASED ON NEW LDMOS FREESCALE

33.74 MHz
29.835 MHz
16.35 MHz
39.3112 MHz

\( P_{\text{IN}} \approx 0 \text{ dBm} \)

From LLRF

1W

\( (\approx +30 \text{ dBm}) \)

FREESCALE OR NXP

LDMOS Transistor

\( >1 \text{ kW, 2-600 MHz} \)

\( P_{\text{SSA}} \approx 500 \text{W} \)

\( (\approx +57 \text{ dBm}) \)

Gain \( \approx 16 \text{ dB} \)

\( P_{\text{OUT}} \approx 20 \text{ kW} \)

 INFN/LNS prototype
1 kW, 1.8 - 54 MHz
Gain 27 dB (average)

Output Power \( \geq 1 \text{ kW} \)
Flatness \( \pm 1.5 \text{ dB} \)
Gain \( \approx 27 \text{ dB} \)
Mismatch max tested 2:1
Frequency range 1.8 - 54 MHz
MRFE6VP61K25HR6 (FREESCALE)

We got a pre assembled board and made a driver amplifier…
DRIVER BASED ON NEW LDMOS FREESCALE

33.74 MHz
29.835 MHz
16.35 MHz
39.3112 MHz

P_{IN} \sim 0 \text{ dBm}

From LLRF

1 \text{ W}

\text{FREESCALE OR NXP}

\text{P_{SSA}} \sim 500 \text{W}

\text{\sim +57 dBm)

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

LDMOS Transistor

>1 \text{kW, 2-600 MHz}

Gain \sim 27 \text{dB}

Mismatch max tested 2:1

Frequency range 1.8 - 54 MHz

MRFE6VP61K25HR6 (FREESCALE)

Output Power \geq 1 \text{kW}

Flatness \pm 1.5 \text{ dB}

Gain \sim 27 \text{ dB}

Mismatch max tested 2:1

Frequency range 1.8 - 54 MHz

MRFE6VP61K25HR6 (FREESCALE)
Test bench LDMOS TEST

~+59 dBm
~800 W
COMPONENTS

RF Power LDMOS Transistors
High Ruggedness N-Channel Enhancement-Mode Lateral MOSFETs

These high ruggedness devices are designed for use in high VSWR industries (including laser and plasma excitors), broadcast (analog and digital), aerospace and railway mobile applications. They are unmatched input and output designs allowing wide frequency range utilization between 1.5 and 600 MHz.

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

<table>
<thead>
<tr>
<th>Signal Type</th>
<th>$P_{out}$ (W)</th>
<th>$f$ (MHz)</th>
<th>$G_{sat}$ (dB)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse</td>
<td>1250 Peak</td>
<td>230</td>
<td>24.0</td>
<td>74.0</td>
</tr>
<tr>
<td>CW</td>
<td>1500 CW</td>
<td>230</td>
<td>22.9</td>
<td>74.8</td>
</tr>
</tbody>
</table>

Application Circuits — Typical Performance

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Signal Type</th>
<th>$P_{out}$ (W)</th>
<th>$G_{sat}$ (dB)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>CW</td>
<td>1300</td>
<td>27</td>
<td>81</td>
</tr>
<tr>
<td>40</td>
<td>CW</td>
<td>1300</td>
<td>26</td>
<td>85</td>
</tr>
<tr>
<td>81.5-108</td>
<td>CW</td>
<td>1250</td>
<td>30</td>
<td>84</td>
</tr>
<tr>
<td>144-148</td>
<td>CW</td>
<td>1250</td>
<td>25</td>
<td>78</td>
</tr>
<tr>
<td>120-250</td>
<td>DvB-T</td>
<td>225</td>
<td>25</td>
<td>90</td>
</tr>
<tr>
<td>352</td>
<td>Pulse (200usahaan, 20% Duty Cycle)</td>
<td>1290</td>
<td>21.5</td>
<td>66</td>
</tr>
<tr>
<td>352</td>
<td>CW</td>
<td>1150</td>
<td>20.5</td>
<td>68</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Signal Type</th>
<th>VSWR</th>
<th>$P_{max}$ (W)</th>
<th>Test Voltage</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>220</td>
<td>Pulse (100usahaan, 20% Duty Cycle)</td>
<td>0.5-1 at 0.5</td>
<td>1500 Peak</td>
<td>50</td>
<td>No Device Degradation</td>
</tr>
</tbody>
</table>

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 Insulation Parameters
- In Tape and Reel. P6 Suffix = 150 Units, 56mm Tape Width, 13-Inch Reel. R5 Suffix = 50 Units, 56mm Tape Width, 13-Inch Reel.

Figure 1. Pin Connections

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

<table>
<thead>
<tr>
<th>Test signal</th>
<th>f (MHz)</th>
<th>$V_{DD}$ (V)</th>
<th>$P_{L}$ (W)</th>
<th>$G_{sat}$ (dB)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CW</td>
<td>2-30</td>
<td>50</td>
<td>1270</td>
<td>29.0</td>
<td>75</td>
</tr>
<tr>
<td>27</td>
<td>50</td>
<td>1400</td>
<td>23.7</td>
<td>73</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>50</td>
<td>1200</td>
<td>22.0</td>
<td>82</td>
<td></td>
</tr>
<tr>
<td>69</td>
<td>45</td>
<td>1240</td>
<td>22.0</td>
<td>77</td>
<td></td>
</tr>
<tr>
<td>72.5</td>
<td>50</td>
<td>1350</td>
<td>23.1</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>81.4</td>
<td>50</td>
<td>1200</td>
<td>27.1</td>
<td>77.8</td>
<td></td>
</tr>
<tr>
<td>88 to 106</td>
<td>50</td>
<td>1320</td>
<td>22.5</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>50</td>
<td>1280</td>
<td>26.5</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>50</td>
<td>1288</td>
<td>19.3</td>
<td>68.3</td>
<td></td>
</tr>
</tbody>
</table>

Pulsed RF

<table>
<thead>
<tr>
<th>Test signal</th>
<th>f (MHz)</th>
<th>$V_{DD}$ (V)</th>
<th>$P_{L}$ (W)</th>
<th>$G_{sat}$ (dB)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>81.4</td>
<td>50</td>
<td>1200</td>
<td>25.8</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>81.4</td>
<td>50</td>
<td>1400</td>
<td>25.4</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>50</td>
<td>1400</td>
<td>24.0</td>
<td>73</td>
<td></td>
</tr>
</tbody>
</table>

DvB-T

<table>
<thead>
<tr>
<th>Test signal</th>
<th>f (MHz)</th>
<th>$V_{DD}$ (V)</th>
<th>$P_{L}$ (W)</th>
<th>$G_{sat}$ (dB)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>174 to 230</td>
<td>50</td>
<td>225</td>
<td>23.8</td>
<td>29</td>
<td></td>
</tr>
</tbody>
</table>

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
Cyclotron cavity

The final stage

\[ Z_{in} = R \pm jX \]
\[ Z_{in} = R \pm jX \]
\[ Z_{in} = R \pm jX \]
\[ Z_{in} = R \pm jX \]
RF_{in} \rightarrow 50\Omega \rightarrow Z_{in} = R \pm jX \rightarrow 50\Omega \rightarrow \text{Cyclotron cavity}
$Z_{in} = R \pm jX$

The final stage
RF_{in} \rightarrow 50\Omega \rightarrow Z_{in} = R \pm jX \rightarrow \text{Cyclotron cavity}

\text{The final stage}
$Z_{in} = R \pm jX$

Cyclotron cavity

The final stage
RF$_{in}$ to 50Ω through a matching box.

\[ Z_{in} = R \pm jX \]
From January 2015

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

Cyclotron beams developed to date

<table>
<thead>
<tr>
<th>Element</th>
<th>Frequency [MHz]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^4$He</td>
<td>80</td>
</tr>
<tr>
<td>$^{112}$Sn</td>
<td>43.5</td>
</tr>
</tbody>
</table>
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 1\textsuperscript{st} stage solid state matching operation, was:

Gain lot of know-how, useful in the next phase, to prepare the line guide for a proper 1\textsuperscript{st} 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 1\textsuperscript{st} 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 1\textsuperscript{st} stage solid state matching operation, was:

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

<table>
<thead>
<tr>
<th><strong>Frequency range</strong></th>
<th>15-50 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output Power</strong></td>
<td>1.5 kW</td>
</tr>
<tr>
<td><strong>Input impedance</strong></td>
<td>50 Ω</td>
</tr>
<tr>
<td><strong>Output impedance</strong></td>
<td>50 Ω</td>
</tr>
<tr>
<td><strong>Class</strong></td>
<td>A - AB</td>
</tr>
<tr>
<td><strong>Gain</strong></td>
<td>63 dB</td>
</tr>
<tr>
<td><strong>Flatness</strong></td>
<td>± 1.5 dB</td>
</tr>
<tr>
<td><strong>Harmonic distortion</strong></td>
<td>≤14dBc</td>
</tr>
<tr>
<td><strong>Spurious</strong></td>
<td>≤70dBc</td>
</tr>
<tr>
<td><strong>VSWR</strong></td>
<td>100% rated power</td>
</tr>
</tbody>
</table>

Based on MOSFET MRF151G
Thank you for your kind attention

Working Group

A. Caruso\textsuperscript{1}, J. Sura\textsuperscript{2}, A. Longhitano\textsuperscript{1},

A. Spartà\textsuperscript{1}, G. Primadei\textsuperscript{3}, G. F. Caruso\textsuperscript{1}

1. INFN-LNS – Catania, Italy

2. Warsaw University, Warsaw, Poland

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.