APPLICATION NOTE

# A wideband power amplifier (25 – 110 MHz) with the MOS transistor BLF245

NCO8602

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**Application Note NCO8602**

**CONTENTS**

## 1 SUMMARY

For military communication purposes a wideband class-AB power amplifier has been designed around the BLF 245 with the frequency range 25 to 110 MHz.

The DC-setting is $V_D$ = 28 V and $I_{DQ}$ = 200 mA.

In the input and output matching networks asymmetrical 1 : 4 transformers on 4C6 ferrite core material have been applied.

**Table 1** The main properties are:

| | | UNIT |
|---|---|---|
| gain at $P_O$ | 17.7 ± 0.5 | dB |
| bandwidth | 25 – 110 | MHz |
| $V_D$ | 28 | V |
| $I_{DQ}$ | 200 | mA |
| efficiency | 55 – 67 | % |
| input VSWR | ≤1.6 | |

## 2 INTRODUCTION

The BLF245 is an RF power MOS transistor for the VHF frequency range in a SOT123 encapsulation.

For application in military communication equipment a wideband power amplifier has been developed with a frequency range from 25 to 110 MHz. The transistor operates in class-AB at $V_{DS}$ = 28 V and a quiescent current $I_{DQ}$ = 200 mA. The useful output power is in the range of 25 – 30 W.

## 3 DESIGN OF THE AMPLIFIER

### 3.1 General remarks

The amplifier has been developed with 1 : 4 impedance transformers in the input as well as in the output circuit. These transformers of the transmission line type with a ferrite core transform the 50 Ω system impedance at the input and output to about 12.5 Ω. An LC compensation circuit has been applied to transform this 12.5 Ω to the optimum load impedance of the transistor. At the input a circuit matches the 12.5 Ω to the gate impedance of the transistor and also takes care of a flat gain over the whole bandwidth.

### 3.2 Output circuit

For an optimum alignment of the output circuit the transistor has been replaced by a dummy. This dummy consists of a resistor of 12 Ω parallel with a capacitor of 82 pF. The real part of the dummy has been determined by the available drain voltage and the required output power.

$$R_L = \frac{V_D^2}{2P_O} \rightarrow R_L = \frac{28^2}{2.30} = 13.1\ \Omega$$

This is near to the value of 12.5 Ω mentioned in Section 3.1. The capacitor is about 15% higher than the output capacitance of the transistor. The RF choke at the drain side must have a sufficient high reactance at the lower end of the frequency range. Choosing this reactance appr. a factor 5 higher than the transistor loadresistance we get an inductance of 455 nH for $L_4$.

The output capacitance of the transistor can be compensated according to the Appendix. The result is: $L_6$ = 18.6 nH and $C_{11}$ = 82 pF. To transform the achieved 12.5 Ω to the 50 Ω system impedance an asymmetrical 1 : 4 transformer has been used. Information about this kind of transformation can be found in Refs 1 and 2. For the transformer a toroid of 4C6 material has been used. Dimensions: 23 × 14 × 7 mm. On this toroid 5 turns of two 0.7 mm twisted enamelled Cu-wires are uniformly distributed and connected as shown in Fig.1.

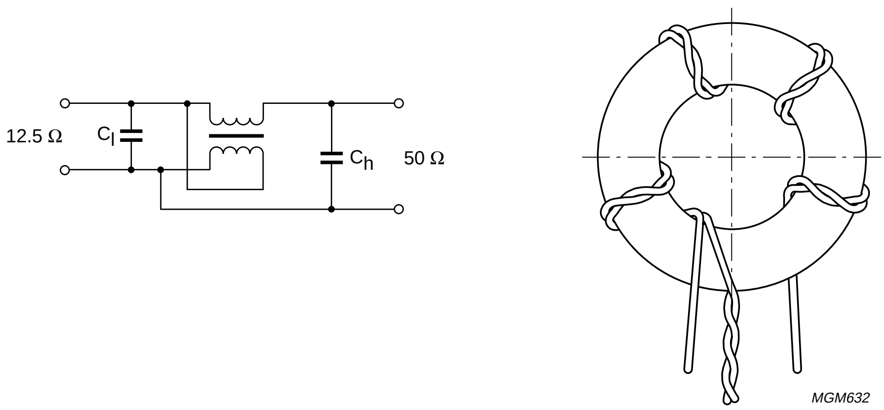


Fig.1 Output transformer.

With the aid of a network analyser the transformer has been corrected for higher frequencies. With $C_l$ = 68 pF and $C_h$ = 12 pF the return losses in the range 20 – 140 MHz are better than –30 dB (VSWR < 1.07). Optimization of the complete output circuit has been carried out by measuring the return losses at the output with the network analyser under swept condition (see Fig.2).

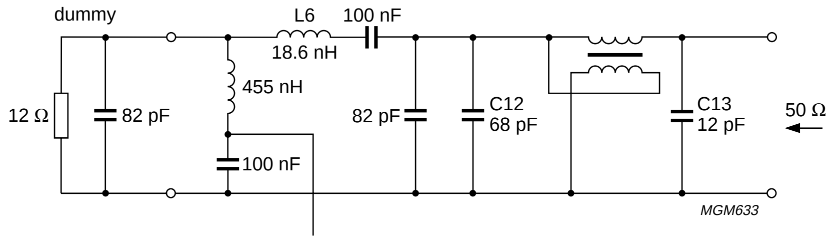


Fig.2 Output circuit before optimization.

Figure 4 shows the return losses of the output circuit before and after practical optimization. By decreasing $L_6$ to 10 nH and $C_{12}$ to 43 pF the return losses improved about 10 dB in the frequency range 20 to 140 MHz to –20 dB (VSWR = 1.22).

### 3.3 Input circuit

As mentioned in Section 3.1 a special circuit matches the input impedance of the transistor to 12.5 Ω and also takes care of a sufficient flat gain over the whole bandwidth. To determine the gate-source impedance and the gain of the transistor in combination with the output circuit described in Section 3.2, narrow band input circuits have been used at several frequencies. By tuning such an auxiliary input circuit the gain of the transistor in combination with the output circuit can be measured directly. In case the input circuit has been tuned the output impedance of this circuit is the conjugate complex of the input impedance of the transistor.

Figs 5 to 7 give the input impedance and the gain of the transistor in combination with the output circuit. The matching network chosen at the input of the transistor is depicted in Fig.3.

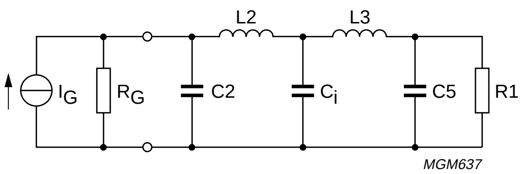


Fig.3 Input matching circuit.

$C_i$ represents the input capacitance of the BLF245 which is appr. 220 pF (see Fig.6). Across this capacitor a constant voltage versus frequency from 25 up to 110 MHz has to be developed. Provided Ci is an ideal capacitance the optimum dimensioning of this network is as follows:

$R_G = R_1 = 1.6/(\omega_c \times C_i) = 10.5\ \Omega$

$C_2 = C_5 = 0.386\ C_i = 85$ pF

$L_2 = L_3 = 0.997\ R_1/\omega_c = 15.1$ nH.

in which $\omega_c$ is the maximum angular frequency. The calculated voltage variation across $C_i$ is ±0.36 dB and the maximum VSWR seen by the generator is 1.36. Deviating from this calculation, for the ease of transformation, $R_G$ and $R_1$ have been chosen 12.5 Ω. Further the resistive component of $C_i$ is substantial especially at higher frequencies.

Therefore the values of the components have been changed in a computer optimization program for a maximally flat gain and a low input VSWR. This optimization results in a gain of 17.5 dB with a variation of ±0.17 dB and a maximum VSWR = 1.177. These results have been achieved by changing the components of Fig.3:

$C_2 = 97$ pF, $C_5 = 102$ pF, $L_2 = 17.6$ nH, $L_3 = 29$ nH and $R_1 = 12\ \Omega$.

The remaining part of the transformation from 12.5 Ω to the 50 Ω system impedance has been accomplished with a transformer similar to the output transformer. However the input transformer has been wound on a core consisting of 2 small toroids of 4C6 material (6 × 4 × 2 mm).

On this core 6 turns of two 0.25 mm twisted enamelled Cu-wires are uniformly distributed similar to the output transformer described in Section 3.2. (see Fig.1). With correction capacitors at the high ohmic and the low ohmic side of respectively 8.2 and 47 pF the return losses in the range 20 – 140 MHz are better than –27 dB (VSWR ≤ 1.1).

For the practical optimization of the complete inputcircuit the transistor has been adjusted at $V_D$ = 28 V and a quiescent current $I_{DQ}$ = 200 mA. The gain and input return losses have been measured in the frequency range of 20 up to 110 MHz.

The best results have been achieved by changing the correction capacitor $C_3$ from 47 to 62 pF and by executing $R_1$ as a parallel connection of 5 resistors of 61.9 Ω.

Figure 8 gives the complete circuit diagram of the BLF245 wideband amplifier and Table 3 gives the corresponding parts list.

## 4 MEASURED PERFORMANCE

### 4.1 Constant input power

Figs 9 to 11 give the gain, efficiency and output power versus the frequency at a constant input power ($P_i$ = 0.5 W).

In the frequency range of 25 to 110 MHz the gain is 17.2 to 17.9 dB, the efficiency 55 to 70% and the output power 26.5 to 30.5 W.

### 4.2 Constant output power

Figs 12 and 13 give the gain and efficiency versus the frequency at a constant power ($P_O$ = 27.5 W) and heatsink temperatures of 25 and 70 °C.

Figs 14 and 15 give the input return losses and the 2e and 3e harmonics of the output signal also versus the frequency. The return losses have been measured at a heatsink temperature of 25 and 70 °C. The harmonics have been measured at 25 °C. By increasing the heatsink temperature from 25 to 70 °C the gain decreases about 1.2 dB. The heatsink temperature has no influence on efficiency and return losses. At 25 °C the gain of the amplifier varies from 17.2 to 18.2 dB, the efficiency from 55 to 67% and the return losses at the input are at least –14 dB (VSWR ≤ 1.6). Also the 2e and 3e harmonics are at least 14 dB down.

### 4.3 Constant frequency

Figs 16 to 18 give the output power versus input power and the gain and efficiency versus power at 4 frequencies.

### 4.4 Stability

Applying an R&S PTU low pass filter at the output of the amplifier stability measurements have been carried out. Choosing a low pass frequency as close as possible above the measuring frequency the amplifier was stable through the whole frequency range of 25 to 110 MHz.

### 4.5 Mismatch

The amplifier has been tested for load mismatch at all phase angles. Up to VSWR = 10 : 1 the amplifier is stable. At VSWR = 20 : 1 the amplifier is only stable below 70 MHz. However also at higher frequencies degradation of the RF performance did not occur.

## 5 CONCLUSIONS

Based on the results presented in this report it may be concluded that it is quite possible to design a wideband amplifier from 25 to 110 MHz with a very good performance using the MOS transistor BLF 245.

**Table 2** The main properties are:

| | | UNIT |
|---|---|---|
| Bandwidth | 25 – 110 | MHz |
| $V_D$ | 28 | V |
| $I_{DQ}$ | 200 | mA |
| Gain ($P_O$ = 27.5 W) | 17.7 ± 0.5 | dB |
| Efficiency | 55 – 67 | % |
| Input VSWR | ≤1.6 | |

## 6 REFERENCES

Ref.1.
A.H. Hilbers
Application report ECO6907: Design of HF wideband Power Transformers.

Ref.2.
A.H. Hilbers
Application report ECO7703: Power Transformers for the Frequency Range 30 – 80 MHz

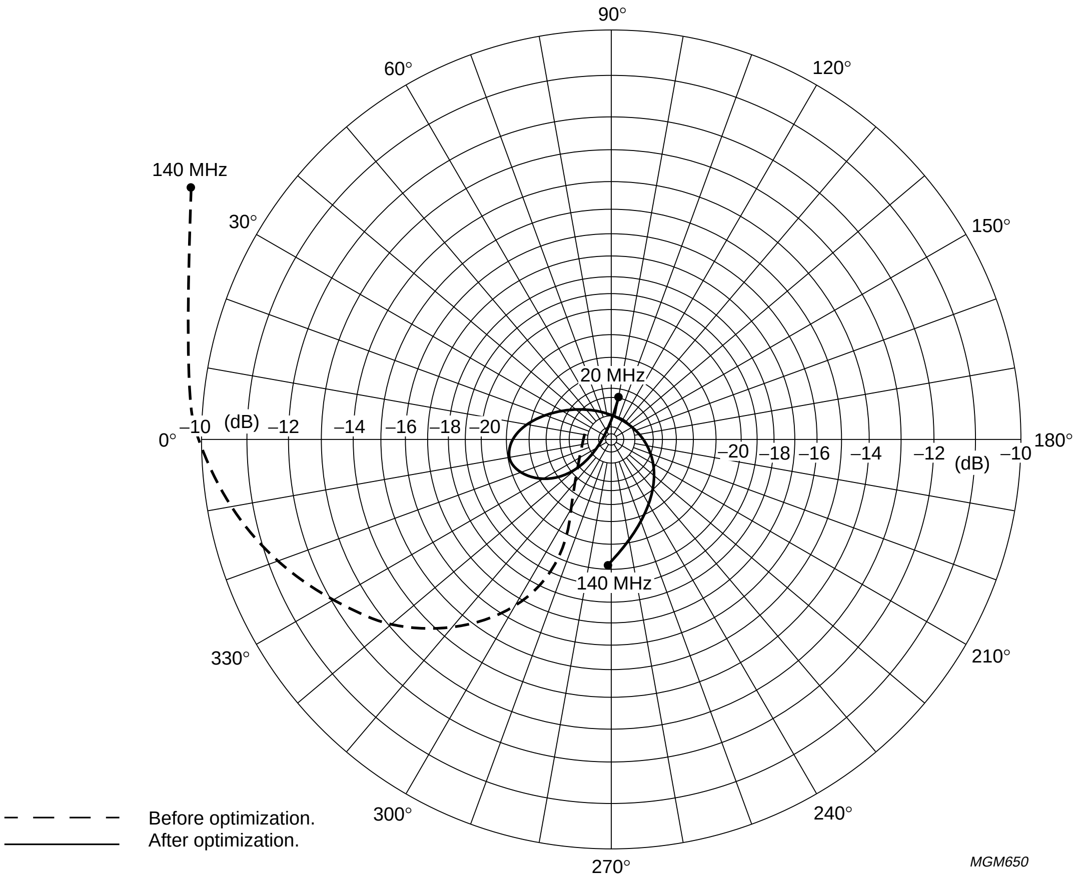


Fig.4 Return losses output circuit.

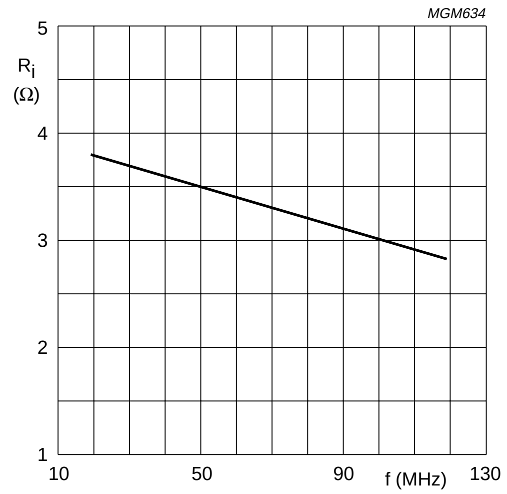


Fig.5 Real part of input impedance of loaded transistor.

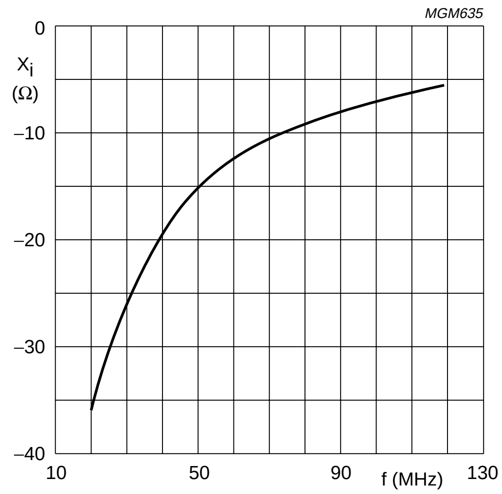


Fig.6 Imaginary part of input impedance of loaded transistor.

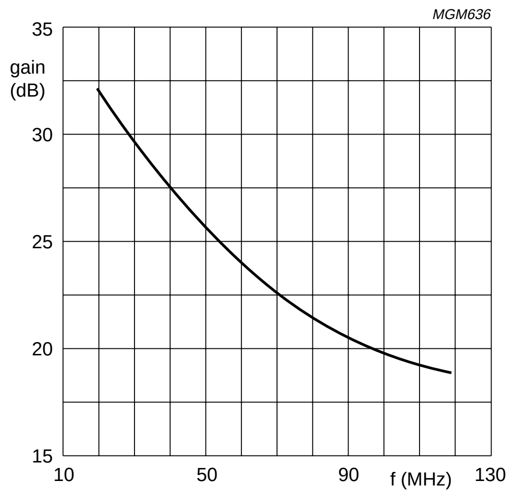


Fig.7 Gain of loaded transistor.

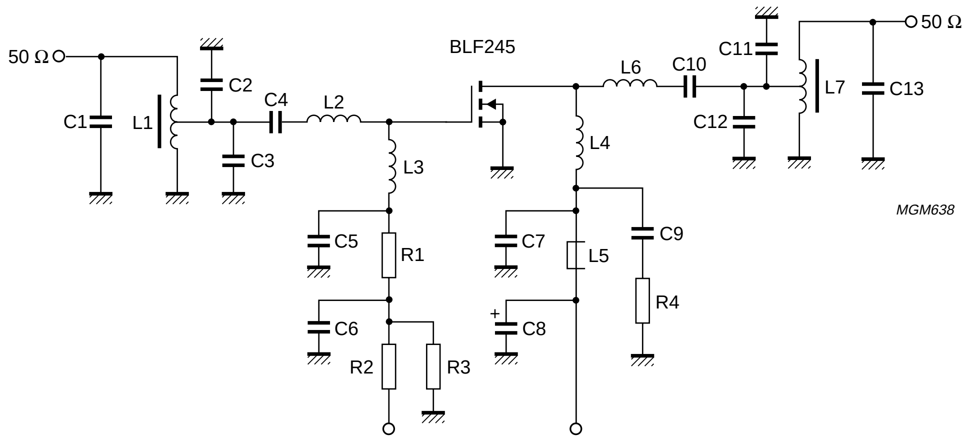


Fig.8 Circuit diagram of the BLF245 wideband amplifier.

**Table 3** Parts list of the BLF245 wideband amplifier

| WIDEBAND POWER AMPLIFIER WITH BLF245 (f = 25 – 110 MHz) | |
|---|---|
| C1 = 8.2 pF multilayer ceramic chip capacitor; note 1 | |
| C2 – C5 = 100 pF multilayer ceramic chip capacitor; note 1 | |
| C3 = 62 pF multilayer ceramic chip capacitor; note 1 | |
| C4 = C10 = 10 nF multilayer ceramic chip capacitor | cat. no. 2222 852 47103 |
| C6 = C7 = 100 nF multilayer ceramic chip capacitor | cat. no. 2222 852 47104 |
| C8 = 2.2 uF electrolytic capacitor | |
| C9 = 3 × 100 nF multilayer ceramic chip capacitor | cat. no. 2222 852 47104 |
| C11 = 82 pF multilayer ceramic chip capacitor; note 1 | |
| C12 = 43 pF multilayer ceramic chip capacitor; note 1 | |
| C13 = 12 pF multilayer ceramic chip capacitor; note 1 | |
| L1 = 2 Ferroxcube toroids, grade 4C6 (6 × 4 × 2 mm) with 6 turns of 2 × 0.25 mm twisted enamelled Cu-wire (see Fig.1) | cat. no. 4322 020 97160 |
| L2 = 17.6 nH, 2 turns enamelled Cu-wire (0.6 mm) int.dia.: 3 mm, length 2.5 mm, leads 2 × 5 mm | |
| L3 = 28.8 nH, 3 turns enamelled Cu-wire (0,6 mm) int.dia.: 3 mm, length 3.2 mm, leads 2 × 5mm | |
| L4 = 455 nH, 12 turns enamelled Cu-wire (1 mm) int.dia.: 7 mm, length 16.5 mm, leads 2 × 5 mm | |
| L5 = Ferroxcube h.f.choke, grade 3B | cat. no. 4312 020 36642 |
| L6 = 10 nH, 1 turn enamelled Cu-wire (1 mm) int.dia.: 3 mm leads 2 × 3 mm | |
| L7 = Ferroxcube toroid, grade 4C6 (23 × 14 × 7 mm) with 5 turns of 2 × 0.7 mm twisted enamelled Cu-wire (see Fig.1) | cat. no. 4322 020 97190 |
| R1 = 12.4 Ω, parallel connection of 5 metal film resistors 61.9 Ω | cat. no. 2322 151 76199 |
| R2 = 1 KΩ, metal film resistor | cat. no. 2322 151 71002 |
| R3 = 1 MΩ, metal film resistor | cat. no. 2322 151 71005 |
| R4 = 10 Ω, metal film resistor | cat. no. 2322 153 51009 |
| Printed-circuit board: double Cu-clad, 1.6 mm epoxy fibre-glass ($\varepsilon_r$ = 4.5) | |

**Note**

1. American Technical Ceramics type 100B or capacitor of same quality.

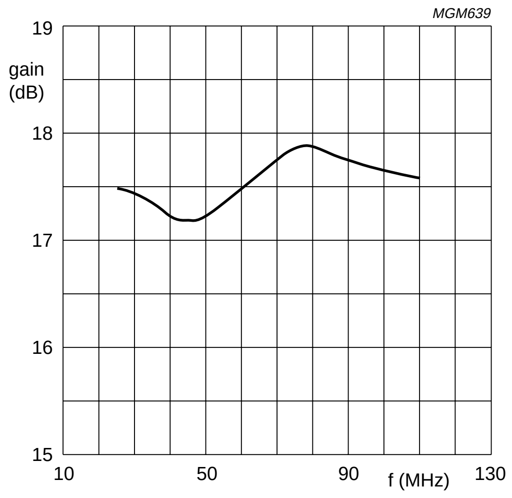


Fig.9 Gain at $P_i$ = 0.5 W.

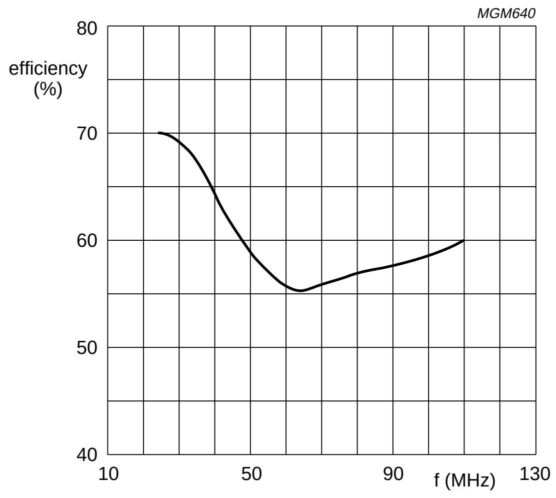


Fig.10 Efficiency at $P_i$ = 0.5 W.

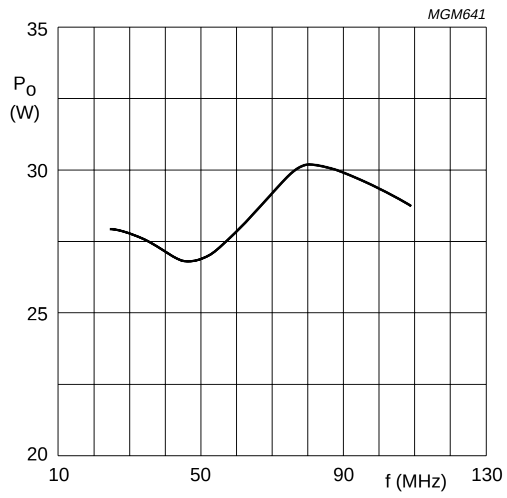


Fig.11 Output power at $P_i$ = 0.5 W.

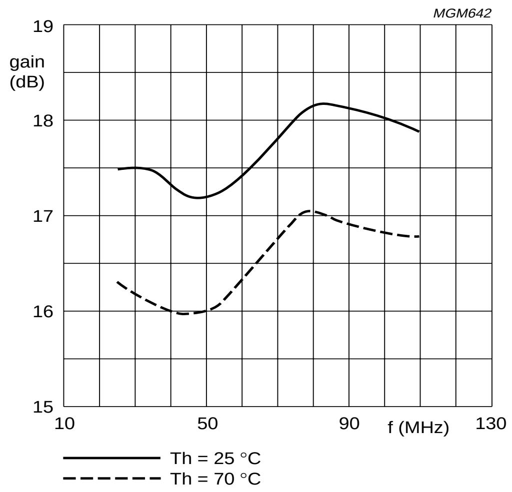


Fig.12 Gain at $P_O$ = 27.5 W.

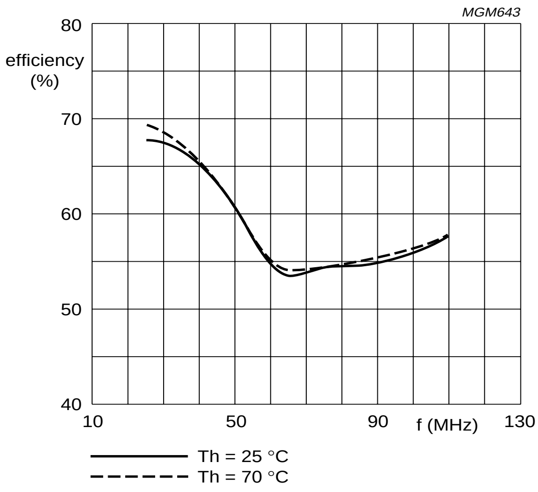


Fig.13 Efficiency at $P_O$ = 27.5 W.

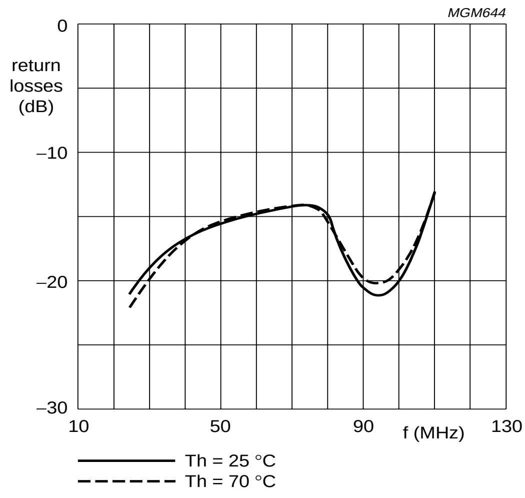


Fig.14 Input return losses at $P_O$ = 27.5 W.

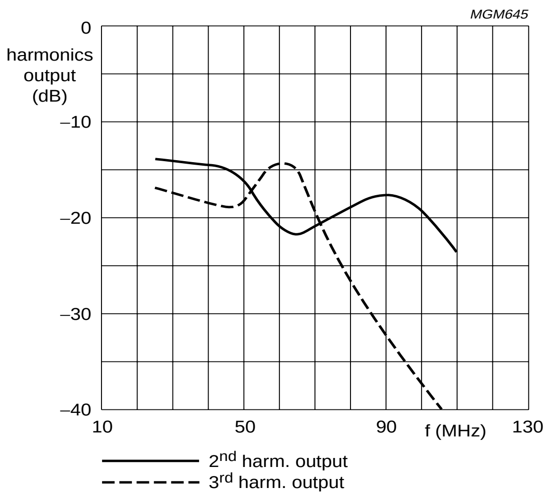


Fig.15 Output harmonics at $P_O$ = 27.5 W.

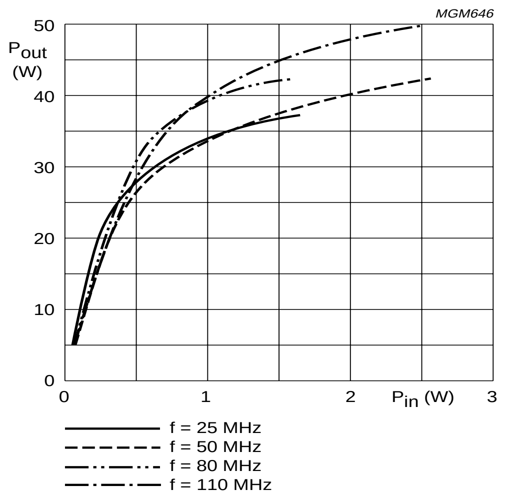


Fig.16 Output power versus input power.

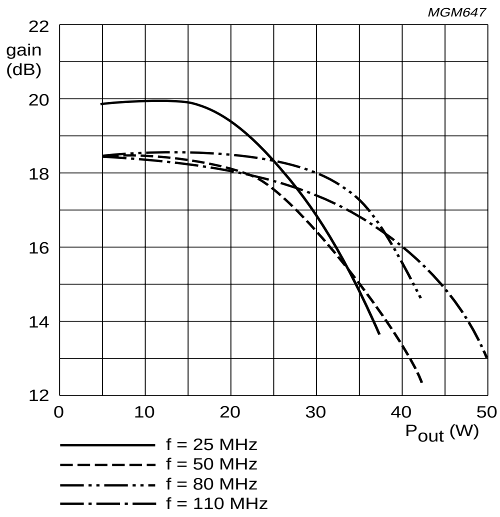


Fig.17  Gain versus output power.

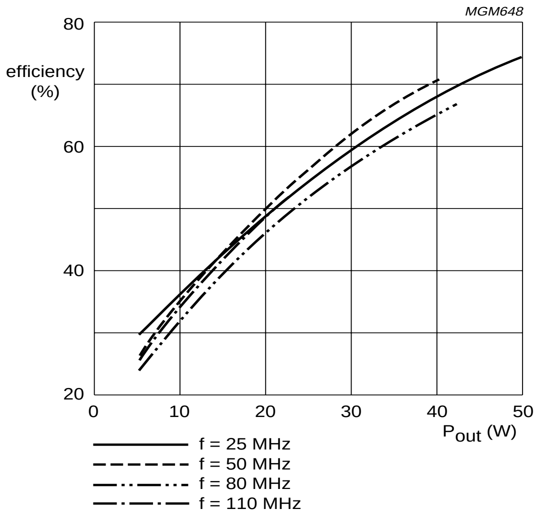


Fig.18  Efficiency versus output power.

## 7 APPENDIX

The output capacitance of a transistor can be compensated over a certain bandwidth by absorbing it in a low-pass Chebyshew $\pi$-section.

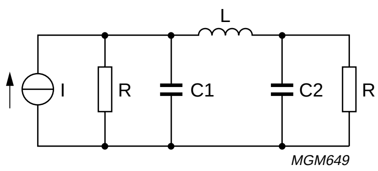


Fig.19

If C1 is the transistor output capacitance the components L and C2 must be added.
C2 = C1 = C

The normalized value of C is: $A = \omega_m CR$
In which $\omega_m = 2\pi f_{max}$

Now we can calculate the normalized value of L with:
$B = 8A/(3A^2 + 4)$
where $B = \omega_m L/R$

The maximum VSWR of this network can be calculated with the following procedure.

1. Determine $\gamma = \frac{1}{A}$
2. $X = \gamma + \sqrt{\gamma^2 + 1}$
3. $\mathrm{VSWR} = \left\{\frac{X^3 + 1}{X^3 - 1}\right\}^2$

In our amplifier:
R = 12.5 $\Omega$
C = 82 pF

This gives:
A = 0.784
B = 1.029
L = 18.62 nH
$\gamma$ = 1.412
X = 3.142
VSWR = 1.138

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**Australia:** 34 Waterloo Road, NORTH RYDE, NSW 2113, Tel. +61 2 9805 4455, Fax. +61 2 9805 4466

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**Indonesia:** see Singapore

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**Israel:** RAPAC Electronics, 7 Kehilat Saloniki St, PO Box 18053, TEL AVIV 61180, Tel. +972 3 645 0444, Fax. +972 3 649 1007

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**Korea:** Philips House, 260-199 Itaewon-dong, Yongsan-ku, SEOUL, Tel. +82 2 709 1412, Fax. +82 2 709 1415

**Malaysia:** No. 76 Jalan Universiti, 46200 PETALING JAYA, SELANGOR, Tel. +60 3 750 5214, Fax. +60 3 757 4880

**Mexico:** 5900 Gateway East, Suite 200, EL PASO, TEXAS 79905, Tel. +9-5 800 234 7381

**Middle East:** see Italy

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**New Zealand:** 2 Wagener Place, C.P.O. Box 1041, AUCKLAND, Tel. +64 9 849 4160, Fax. +64 9 849 7811

**Norway:** Box 1, Manglerud 0612, OSLO, Tel. +47 22 74 8000, Fax. +47 22 74 8341

**Philippines:** Philips Semiconductors Philippines Inc., 106 Valero St. Salcedo Village, P.O. Box 2108 MCC, MAKATI, Metro MANILA, Tel. +63 2 816 6380, Fax. +63 2 817 3474

**Poland:** Ul. Lukiska 10, PL 04-123 WARSZAWA, Tel. +48 22 612 2831, Fax. +48 22 612 2327

**Portugal:** see Spain

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**Russia:** Philips Russia, Ul. Usatcheva 35A, 119048 MOSCOW, Tel. +7 095 755 6918, Fax. +7 095 755 6919

**Singapore:** Lorong 1, Toa Payoh, SINGAPORE 1231, Tel. +65 350 2538, Fax. +65 251 6500

**Slovakia:** see Austria

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**South America:** Al. Vicente Pinzon, 173, 6th floor, 04547-130 SÃO PAULO, SP, Brazil, Tel. +55 11 821 2333, Fax. +55 11 821 2382

**Spain:** Balmes 22, 08007 BARCELONA, Tel. +34 3 301 6312, Fax. +34 3 301 4107

**Sweden:** Kottbygatan 7, Akalla, S-16485 STOCKHOLM, Tel. +46 8 632 2000, Fax. +46 8 632 2745

**Switzerland:** Allmendstrasse 140, CH-8027 ZÜRICH, Tel. +41 1 488 2686, Fax. +41 1 488 3263

**Taiwan:** Philips Semiconductors, 6F, No. 96, Chien Kuo N. Rd., Sec. 1, TAIPEI, Taiwan Tel. +886 2 2134 2865, Fax. +886 2 2134 2874

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**Turkey:** Talatpasa Cad. No. 5, 80640 GÜLTEPE/ISTANBUL, Tel. +90 212 279 2770, Fax. +90 212 282 6707

**Ukraine**: PHILIPS UKRAINE, 4 Patrice Lumumba str., Building B, Floor 7, 252042 KIEV, Tel. +380 44 264 2776, Fax. +380 44 268 0461

**United Kingdom:** Philips Semiconductors Ltd., 276 Bath Road, Hayes, MIDDLESEX UB3 5BX, Tel. +44 181 730 5000, Fax. +44 181 754 8421

**United States:** 811 East Arques Avenue, SUNNYVALE, CA 94088-3409, Tel. +1 800 234 7381

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