APPLICATION NOTE

Wideband 300 W push-pull FM amplifier using BLV25 transistors

AN98031

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Wideband 300 W push-pull FM amplifier using BLV25 transistors

CONTENTS

SUMMARY

For transmitters and transposers for the FM broadcast band (87.5 – 108 MHz), a 300 W push-pull amplifier using two BLV25 transistors has been designed and built. The transistors operate in class-B from a 28 V supply. In addition, a suitable single-stage driver amplifier using a BLW86 transistor also operating in class-B from a 28 V supply has been designed and built.

Table 1 shows the main properties of each amplifier and of the driver/final-amplifier combination. The driver and final amplifier have been aligned at output powers of 45 W and 300 W respectively.

The 2× BLV25 amplifier has a heatsink with forced air cooling and a 10 mm copper plate heat-spreader.

Table 1 Amplifier performance overview; note 1

FM BAND 87.5 – 108 MHz	BLW86 DRIVER P_{OUT} = 45 W		2 × BLV25 FINAL AMPLIFIER P_{OUT} = 300 W		COMBINATION AMPLIFIER BLW86 AND 2 × BLV25 P_{OUT} = 300 W	
	MIN.	MAX.	MIN.	MAX.	MIN.	MAX.
Gain (dB)	12	13	10.4	11	22.6	25
Input VSWR	1.2	1.3	1.45	1.70	1.1	1.85
Efficiency (%)	69	72	70	71	63	66

Note

1. Circuit board: double copper-clad epoxy fibre glass (ε_r = 4.5), thickness $^1/_{16}$-inch.

1 INTRODUCTION

The BLV25 power transistor is intended for use in FM broadcast transmitters and transposers. This transistor which is in a 6-lead flanged package with $^1/_2$-inch ceramic cap (SOT119) can deliver 175 W output power at 108 MHz. This report describes the design and practical implementation of a 300 W wideband push-pull amplifier for the FM broadcast band using two BLV25 transistors operating in class-B from a 28 V supply voltage. In addition, a suitable driver amplifier is described. The driver is a single-stage amplifier designed for an output power of 45 W using a BLW86 transistor which also operates in class-B from a 28 V supply. The BLW86 is in a $^3/_8$-inch, 4-lead flanged package with a ceramic cap (SOT123).

2 AMPLIFIER DESIGN THEORY

First, consider the BLV25 transistor. Table 2 gives some of its characteristics at an output power of 160 W and a supply voltage of 28 V.

The output of a BLV25 can be accurately represented by the equivalent circuit of Fig.1. In Section 3.2, it will be explained how the information in Table 2 and Fig.1 are used to align the amplifier.

Figure 2 shows a schematic of the amplifier; Fig.3 shows the complete circuit.

Table 2 Some characteristics of the BLV25 at several frequencies in the FM broadcast band

Freq. f (MHz)	**POWER GAIN G (dB)**	**INPUT IMPEDANCE Z_i (Ω)**	**OPTIMUM LOAD IMPEDANCE Z_L (Ω)**
87.5	11.8	0.54 + j0.38	1.96 – j0.04
92.2	11.5	0.56 + j0.43	1.94 – j0.06
97.2	11.1	0.58 + j0.48	1.91 – j0.07
102.5	10.8	0.60 + j0.53	1.88 – j0.08
108.0	10.4	0.63 + j0.59	1.84 – j0.11

2.1 The output network

The output network consists of three parts:

1. The combination of L_9, L_{10} and C_8 which transforms the output impedance of the transistors to a resistance of 12.5 Ω (balanced).
2. The transmission lines L_{11} and L_{12} which are connected such that they perform a 1:4 impedance transformation, making the output impedance of this part 50 Ω (balanced).
3. The transmission lines L_{13} and L_{14} which function as a balanced-to-unbalanced transformer (balun), so their output impedance is 50 Ω (unbalanced).

Note on 1:
The matching section L_9, L_{10} and C_8 is rather conventional except that the inductors have been replaced by striplines.

Note on 2:
Lines L_{11} and L_{12} are transmission lines with a characteristic resistance of 25 Ω. They are soldered to a copper track on the p.c. board. This track is 2.8 mm wide, so its characteristic impedance with reference to the ground plane of the p.c. board is 50 Ω.

Theoretically, their lengths should be ¼ wavelength for the centre of the frequency band, namely 42 cm. As this is rather impractical, we must find a way to use shorter lines. Two possibilities exist:

Lines L_{11} and L_{12} are not soldered to tracks on the p.c. board but are surrounded by ferrite tubes of suitable dimensions and material. Finding the correct combination is however somewhat involved.

The lengths of lines L_{11} and L_{12} are reduced significantly and the parallel inductance introduced is compensated by increasing the value of C_8. As this method provides good results, it has been adopted.

Note on 3:
The line L_{14} is a transmission line with a characteristic resistance of 50 Ω. It is also soldered to a 2.8 mm wide track on the p.c. board. For the length of this line, the story is similar to that of the 1:4 impedance transformer. By making the line shorter than a ¼ wavelength, an inductance is introduced from point B (Fig.2) to ground. To restore the symmetry, an equal inductance must be introduced between point A and ground. This is done by means of line L_{13} which is a 2.8 mm wide track on the p.c. board of the same length as L_{14}. Finally, the parallel inductances (from point A to ground, and from point B to ground) are compensated by the series capacitors C_9 and C_{10}.

After initial calculation of the separate sections and their compensation, the network was optimized using a computer optimization program. The final dimensions of the components can be found in Fig.3.

The maximum VSWR of this network is <1.05.

A remark must be made about the reactive loading of C_8 which is nearly 900 VA at 108 MHz, so a high-quality capacitor must be used. Two or three capacitors in parallel can also be considered.

2.2 The input network

This network is very similar to the output network and, like it, consists of three parts:

1. The combination of L_1 and L_2 forms an unbalanced-to-balanced transformer whose output impedance is 50 Ω (balanced)
2. The combination L_3 and L_4 forms a 4:1 impedance transformer whose output impedance is 12.5 Ω (balanced)
3. The components L_5 to L_8 and C_3 to C_7 form a two-section matching network to match the input impedances of the transistors to 12.5 Ω (balanced).

All the remarks made for the output network also apply to the input network, though several values are different.

The calculation of the input network was made in the same way as that for the output network. However, the total length of the lines L_1 to L_4 became too long for practical use. After dividing the lengths of these lines by 1.6, the other components were re-optimized, raising the input VSWR from 1.20 to 1.27. All component values are given in Table 5.

A consequence of this way of designing is that the power gain at 87.5 MHz is approximately 1.4 dB higher than that at 108 MHz. This variation must be compensated in one of the driver stages.

An alternative design with a nearly flat power gain of about 10 dB can be made, however, the input matching is only good at the high end of the frequency band; at 87.5 MHz, the input VSWR rises to about 3.2. Further details of this alternative are not given here.

2.3 Bias components

Theoretically, point V_B can be grounded directly. However, it may be better to ground it via an RF choke shunted by a 12 Ω resistor as shown in Fig.4 because of:

- Small asymmetries in the transistors and circuit, and
- Possible parasitic oscillation when the transistors operate in parallel rather than push-pull.

Resistors R_1 and R_2 have been added to improve stability during mismatch. For point V_C, the same holds as for point V_B, except that the supply voltage must be connected to the former. In the simplest configuration, point V_C is decoupled for RF frequencies. A better proposition is probably the circuit shown in Fig.5.

3 PRACTICAL 300 W PUSH-PULL AMPLIFIER WITH 2 × BLV25

3.1 General remarks

Having established a theoretical design, let us now look at a practical implementation.

The amplifier has been designed on a double copper-clad epoxy fibre glass (ε_r = 4.5) board, thickness $^1/_{16}$-inch. Figure 6 shows the print board and Fig.7 the layout of the amplifier. Rivets and, at the board edges, soldered copper straps have been used to provide good contact between both sides of the board. Where the emitters are grounded, contact is made with the lower side of the board.

The print board and transistors are attached to a 10 mm thick copper plate which acts as a heat-spreader. This plate is screwed to a standard heatsink with forced air cooling. At an ambient temperature of 25 °C, and with the amplifier operating at 300 W output power, the heatsink temperature is below 55 °C.

3.2 Alignment

The first alignment was done with small signals, starting with the output circuit. The BLV25 transistors were replaced by dummy loads, representing the complex conjugate of the optimum load impedance. The dummy consists of a 2.22 Ω resistance and a 300 pF capacitance.

To reduce parasitic inductance and to maintain the best possible symmetry, we used several components in parallel. These components were soldered to an empty SOT119 header.

The reflection versus frequency was measured at the output terminal and minimized by adjusting the capacitors C_{16}, C_{14}, C_{15} and C_9. Figure 8 shows the schematic diagram and Fig.9 the return losses; the VSWR remains below 1.13.

The alignment of the input network was done with the transistors in circuit and with the supply voltage and load connected. First, alignment was made with the transistors in class-A (I_C = 1.7 A and V_{CE} = 25 V). The reflection versus frequency was then minimized at small-signal levels. Then the operation was altered to class-B, and the amplifier realigned at an output power of 300 W. The required circuit modifications were rather small. Figure 10 shows the final circuit. Resistances R_2 and R_3 are necessary to prevent parallel oscillations. The inductance of these resistors is very important (see Table 6).

In spite of the dummy adjustment of the output circuit, the capacitance of C_9 had to be reduced to improve the collector efficiency, η, of the amplifier. In addition, three capacitors in parallel have been used because of the very high reactive loading at that point.

3.3 Performance

The amplifier has been aligned at an output power of 300 W. Figures 11 to 13 show the gain, input VSWR and collector efficiency as functions of frequency at 300 W output power. Figure 14 shows the variation of efficiency with output power, both measured at 108 MHz.

4 BLW86 DRIVER AMPLIFIER

4.1 Amplifier Design

The required drive power for the 2× BLV25 amplifier described in Section 3 is about 30 W. The input VSWR of this final amplifier varies between 1.45 and 1.7 (see Fig.12), so the load impedance of the driver amplifier differs from 50 Ω and varies with frequency. As the effect of this on the performance of the driver cannot be predicted, some reserve output power was built in and a 45 W driver was designed. The driver is a single-stage class-B amplifier using a BLW86 transistor.

Table 3 shows some properties of the BLW86 from 87.5 to 108 MHz, valid for class-B operation and an output power of 45 W.

Table 3 Some characteristics of the BLW86 at several frequencies in the FM broadcast band

Freq. (MHz)	GAIN (dB)	INPUT IMPEDANCE (Ω)	LOAD IMPEDANCE (Ω)
87.5	13.61	0.76 – j0.00	7.65 + j3.28
89.8	13.40	0.76 + j0.04	7.56 + j3.32
92.2	13.18	0.76 + j0.08	7.48 + j3.36
94.7	12.96	0.76 + j0.12	7.39 + j3.40
97.2	12.75	0.75 + j0.16	7.32 + j3.47
99.8	12.53	0.75 + j0.20	7.23 + j3.51
102.5	12.31	0.75 + j0.24	7.13 + j3.54
105.2	12.10	0.75 + j0.28	7.05 + j3.60
108	11.89	0.75 + j0.32	6.95 + j3.63

The input impedance has to be matched to the 50 Ω source impedance to obtain a good input VSWR and the 50 Ω load impedance has to be transformed into the optimum load impedance, which is given in Table 2. This has been done using Chebychev low-pass LC filter techniques (see Chapter “Reference”).

The driver amplifier was designed on double-clad epoxy glass fibre board (ε_r = 4.5), $^1/_{16}$-inch thick. Figure 16 shows the board and layout of the amplifier. Rivets and straps were again used and the emitter connected to the underside of the board.

4.2 Alignment

The alignment procedure was as described in Section 3.2. The optimal load impedance given in Table 2 suggested a dummy load of 10 Ω resistance in parallel with a 91 pF capacitance. Alignment with this dummy load resulted in a collector efficiency of about 60%. Later, it was found that lowering the dummy capacitance to 56 pF raised the efficiency to about 70%. Figure 17 shows the alignment circuit and Fig.18 the VSWR at the output terminal measured with the 10 Ω // 56 pF dummy load.

The input circuit has been aligned with the transistor in the circuit and the supply voltage connected. Again, alignment was started with the transistor operating in class-A (I_C = 1 A and V_{CE} = 25 V). The small-signal input VSWR has been minimized.

Then, the transistor was set to class-B operation, and the amplifier realigned at an output power of 45 W. Figure 19 shows the final circuit and Table 7 shows the part list. The collector DC biasing coil, L_8, plays an active role in the impedance transformation.

4.3 Performance

Figs 20 and 21 show the gain and input VSWR as functions of frequency. The gain is 12.5 ±0.5 dB and the VSWR remains below 1.3:1 throughout the band.

Figure 21 shows that the collector efficiency is better than 69%. The measurements were taken at 45 W output power.

Figures 23 and 24 show collector efficiency and amplifier gain versus output power at 108 MHz. Note, the amplifier was only aligned at 45 W output power.

5 COMBINATION OF DRIVER AND FINAL AMPLIFIER

Figs 25 and 26 show the gain and input VSWR of the combination of driver and final amplifier at 300 W output power. This gives an indication of the effect of the fluctuating input VSWR of the final amplifier on the performance of the driver amplifier. The efficiency of the combination is more than 63%, as Fig.27 shows.

No additional alignment was made. The required input drive power for 300 W output is less than 1.7 W.

6 STABILITY AND EFFICIENCY IMPROVEMENT

It is recommended to add an inductance L_{CC} between the collectors of the two BLV25 transistors, see Fig.28 (c.f. Fig.10) to improve stability at low output powers. An additional advantage of this modification is that it raises collector efficiency while hardly affecting the input VSWR (which remains below 1.75). Figures 29 to 31 show the results measured on a water-cooled amplifier for three conditions: without L_{CC}, with L_{CC} = 41 nH, and with L_{CC} = 29 nH.

7 CONCLUSION

A 300 W push-pull amplifier using two BLV25 transistors driven by a single-stage amplifier using a BLW86 have been designed. Table 4 shows the main performance parameters of the individual amplifiers and of their combination.

Table 4 Performance overview (basic amplifier without the modification for higher efficiency)

FM BAND 87.5 – 108 MHz	BLW86 DRIVER P_{OUT} = 45 W		2 × BLV25 FINAL AMPLIFIER P_{OUT} = 300 W		COMBINATION AMPLIFIER BLW86 AND 2 × BLV25 P_{OUT} = 300 W	
	MIN.	**MAX.**	**MIN.**	**MAX.**	**MIN.**	**MAX.**
Gain (dB)	12	13	10.4	11	22.6	25
Input VSWR	1.2	1.3	1.45	1.70	1.1	1.85
Efficiency (%)	69	72	70	71	63	66

8 REFERENCE

G.L. Matthaei, Tables of Chebychev impedance transforming networks of low-pass filter form. Proc. of the IEEE, Aug. 1964, pp. 939-963.

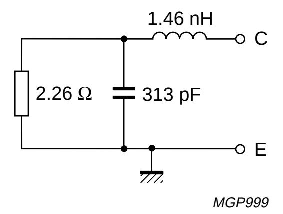


Fig.1 Equivalent circuit of BLV25 output.

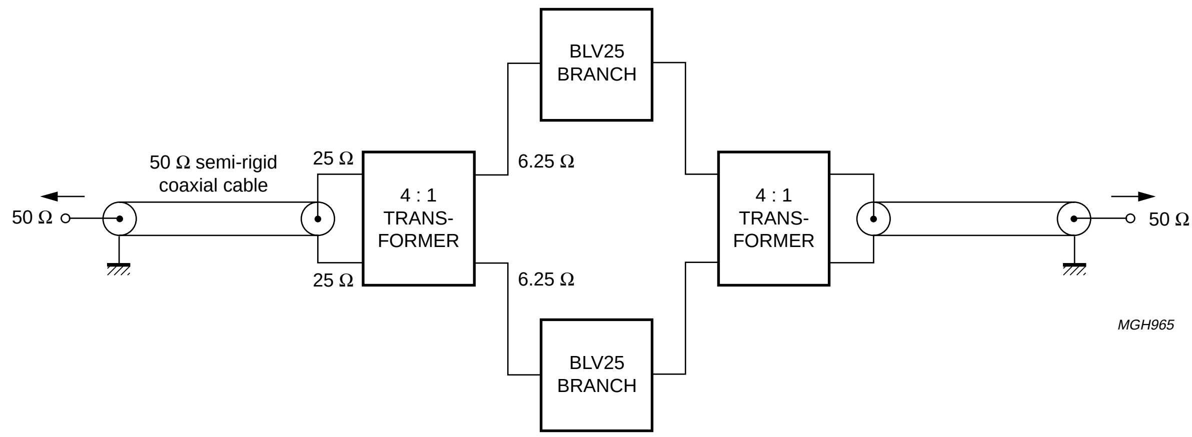
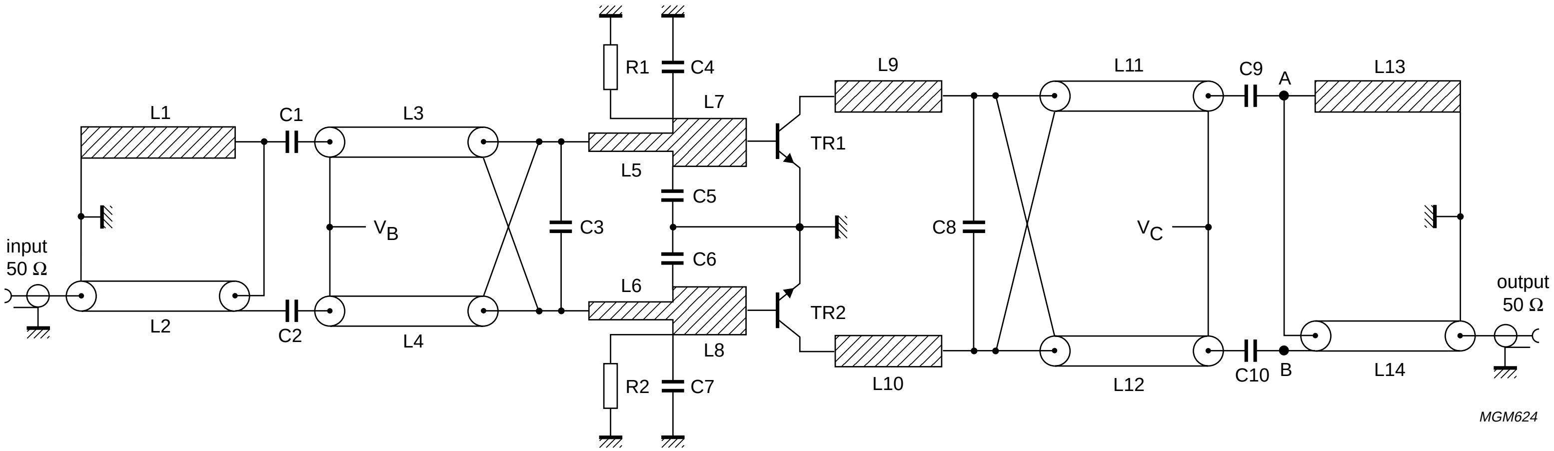


Fig.2 Main amplifier schematic.



For parts list, see Table 5.

Fig.3 300 W push-pull amplifier for the FM broadcast band (Theoretical design).

Table 5 Parts list of the main amplifier (Theoretical design)

R_1 = R_2 = 22 Ω, carbon
C_1 = C_2 = 200 pF chip (ATC 100B)
C_3 = 330 pF chip (ATC 100B)
C_4 = C_5 = C_6 = C_7 = 620 pF chip (ATC 100B)
C_8 = 240 pF, 500 V chip (ATC 100B or ATC 175)
C_9 = C_{10} = 100 pF, 500 V chip (ATC 100B)
L_1 = 50 Ω stripline, w = 2.8 mm, l = 144 mm
L_2 = 50 Ω semi-rigid coaxial cable, d = 2.2 mm, l = 144 mm soldered on 50 Ω stripline, w = 2.8 mm
L_3 = L_4 = 25 Ω semi-rigid coaxial cable, d = 2.2 mm, l = 96 mm; soldered on 50 Ω stripline, w = 2.8 mm
L_5 = L_6 = 50 Ω stripline, w = 2.8 mm, l = 18.1 mm
L_7 = L_8 = 30 Ω stripline, w = 6 mm, l = 4.8 mm
L_9 = L_{10} = 30 Ω stripline, w = 6 mm, l = 14.1 mm
L_{11} = L_{12} = 25 Ω semi-rigid coaxial cable, d = 3.5 mm, l = 60.3 mm soldered on 50 Ω stripline, w = 2.8 mm
L_{13} = 50 Ω stripline, w = 2.8 mm, l = 139.6 mm
L_{14} = 50 Ω semi-rigid coaxial cable, d = 3.5 mm, l = 139.6 mm soldered on 50 Ω stripline, w = 2.8 mm
T_1 = T_2 = BLV25
Print board material: $^1\!/_{16}$-inch epoxy fibre-glass, ε_r = 4.5

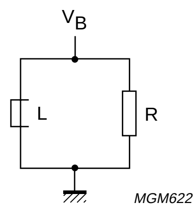


Fig.4 V_b bias, components: R = 12 Ω, carbon; L = Fxc 3B RF choke, part no. 4312 020 36640.

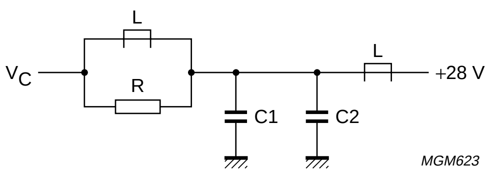


Fig.5 V_c bias. Components: R = 12 Ω, carbon; C_1 = 2.7 nF, chip (NP0 type); C_2 = 100 nF, chip (X7R type); L = FXC3B bead, part no. 4312 020 31500 wound with 3 to 6 wires in parallel.

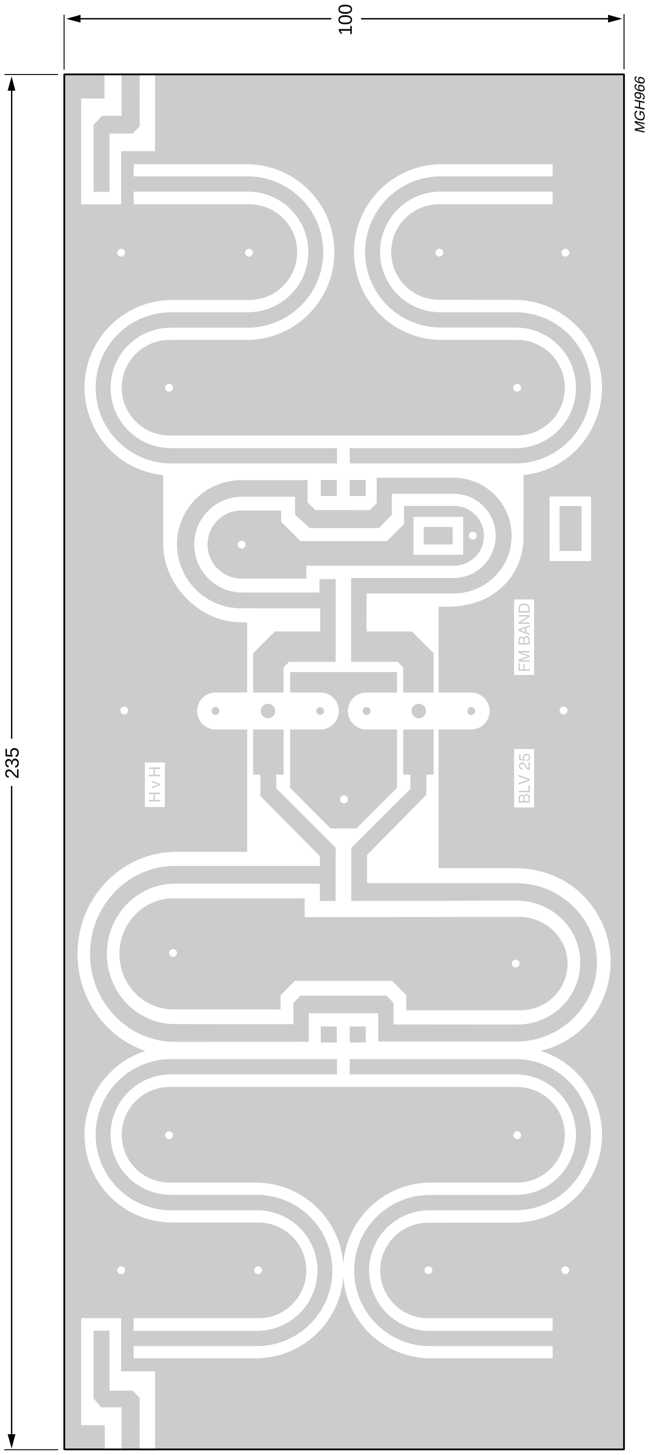


Fig.6 Printed-circuit board.

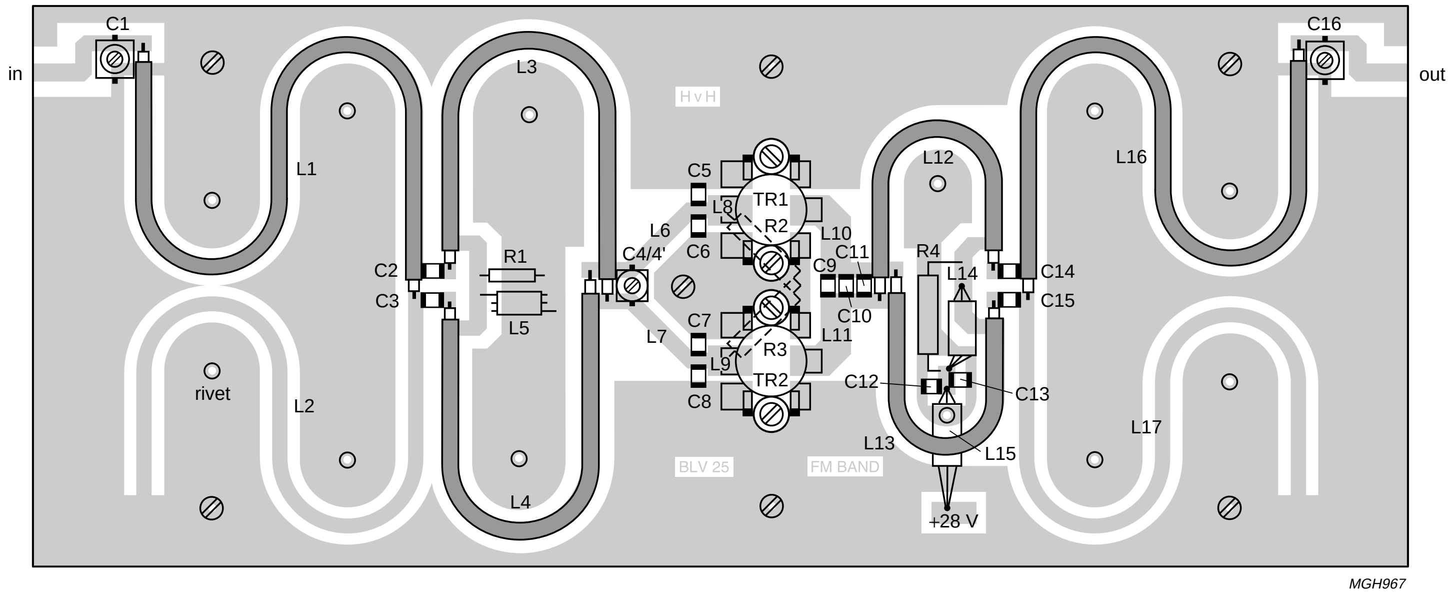


Fig.7 Amplifier lay out.

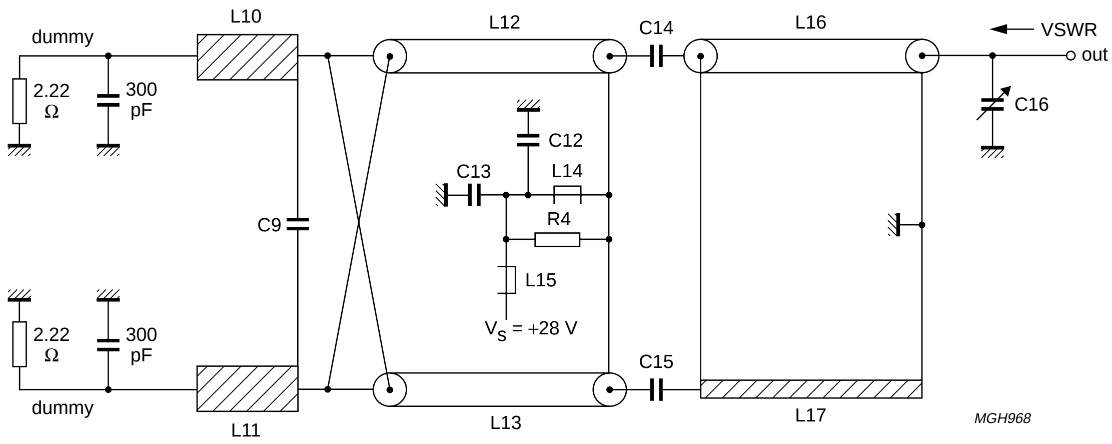


Fig.8 Output alignment circuit.

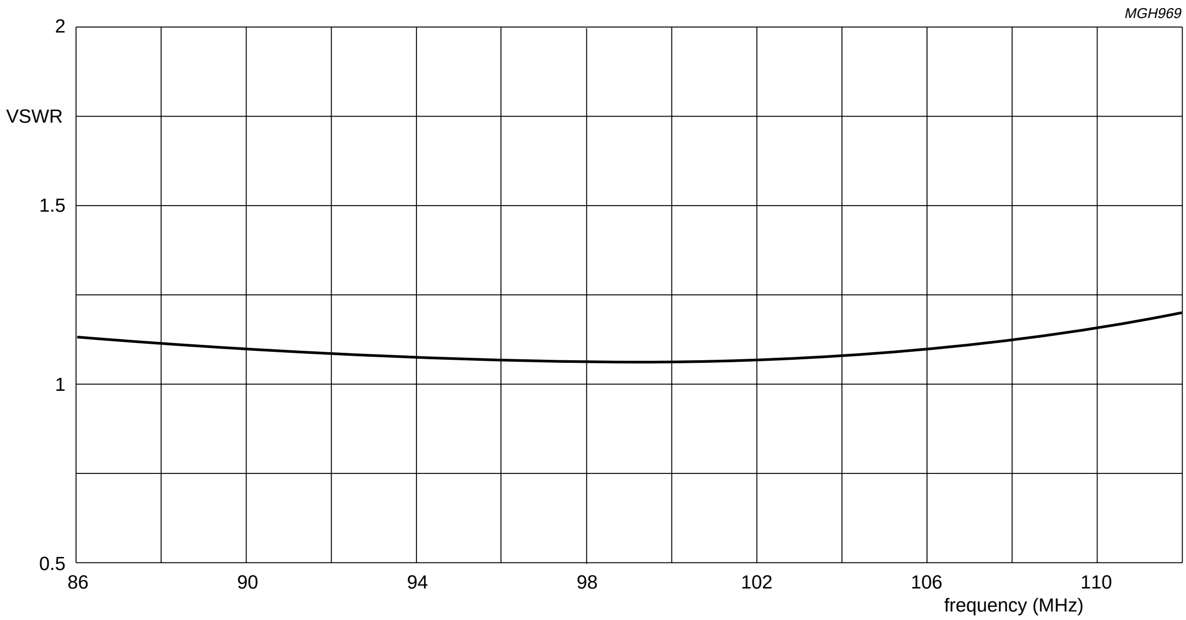
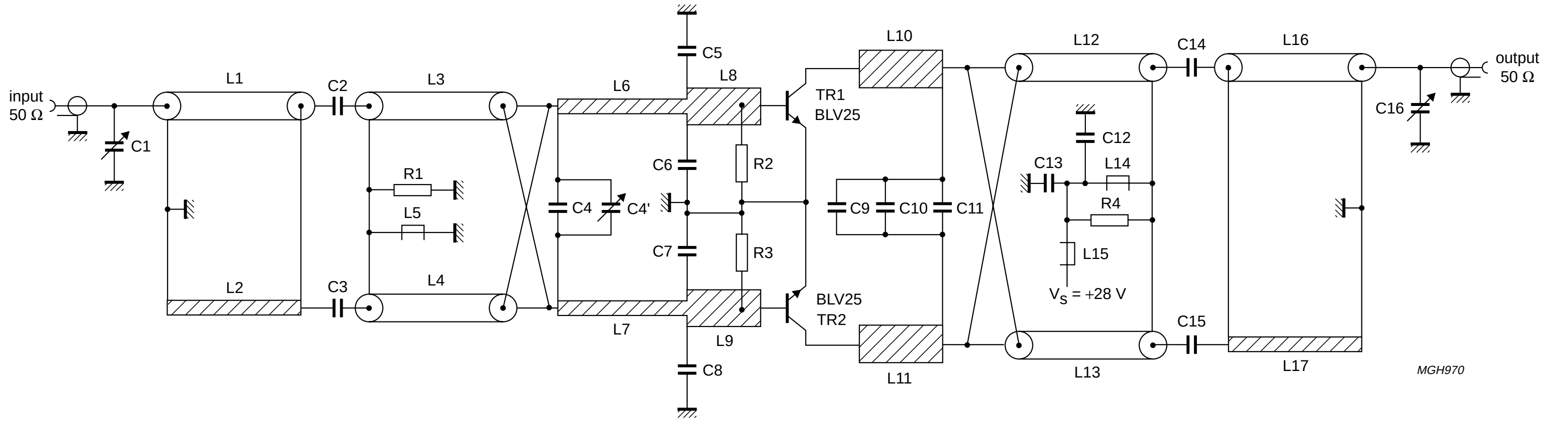


Fig.9 Return loss in circuit of Fig.8.



For parts list see Table 6.

Fig.10 Practical amplifier circuit diagram.

Table 6 Parts list of the main amplifier (Practical design)

R_1 = 12.1 Ω metal film	Philips MR 25, (2322 151 71219)
R_2 = R_3 = 4.99 Ω metal film	Philips MR 52, (2322 153 54998)
R_4 = 12.1 Ω metal film	Philips MR 52, (2322 153 51219)
C_1 = C'_4 = C_{16} = 2 – 18 pF film dielectric trimmer	Philips, (2222 809 05003)
C_2 = C_3 = 200 pF chip	ATC 100B-201-K-Px-300
C_4 = 300 pF chip	ATC 100B-301-K-Px-200
C_5 = C_6 = C_7 = C_8 = 680 pF chip (ATC 100B-681-K-Px-50) in parallel with 150 pF chip	(ATC 100B-151-J-Px-300)
C_9 = 43 pF chip	ATC 100B-430-J-Px-500
C_{10} = 68 pF chip	ATC 100B-680-J-Px-500
C_{11} = 82 pF chip	ATC 100B-820-J-Px-500
C_{12} = 2.7 nF chip	Philips NPO size 1210, (2222 852 13272)
C_{13} = 100k chip	Philips X7R size 1812, (2222 852 48104)
C_{14} = C_{15} = 100 pF chip	ATC 100B-101-J-Px-500
L_1 = 50 Ω semi-rigid coaxial cable, d = 2.2 mm, l = 144 mm, soldered on 50 Ω stripline, w = 2.8 mm	
L_2 = 50 Ω stripline, w = 2.8 mm, l = 144 mm	
L_3 = L_4 = 25 Ω semi-rigid coaxial cable, d = 3.5 mm, l = 96 mm, soldered on 50 Ω stripline, w = 2.8 mm	
L_5 = FXC 3B RF choke	Philips 4312 020 36642
L_6 = L_7 = 50 Ω stripline, w = 2.8 mm, l = 18.1 mm	
L_8 = L_9 = 30 Ω stripline, w = 6 mm, l = 4.8 mm	
L_{10} = L_{11} = 30 Ω stripline, w = 6 mm, l = 14.1 mm	
L_{12} = L_{13} = 25 Ω semi-rigid coaxial cable, d = 3.5 mm, l = 60.3 mm soldered on 50 Ω stripline, w = 2.8 mm	
L_{14} = L_{15} = FXC 3B beads, Philips 4312 020 31500 wound with 6 leads in parallel	
L_{16} = 50 Ω semi-rigid coaxial cable, d = 3.5 mm, l = 139.6 mm soldered on 50 Ω stripline, w = 2.8 mm	
L_{17} = 50 Ω stripline, w = 2.8 mm, l = 139.6 mm	
T_1 = T_2 = BLV25	
Print board material: $\frac{1}{16}$-inch epoxy fibre-glass, ε_r = 4.5	

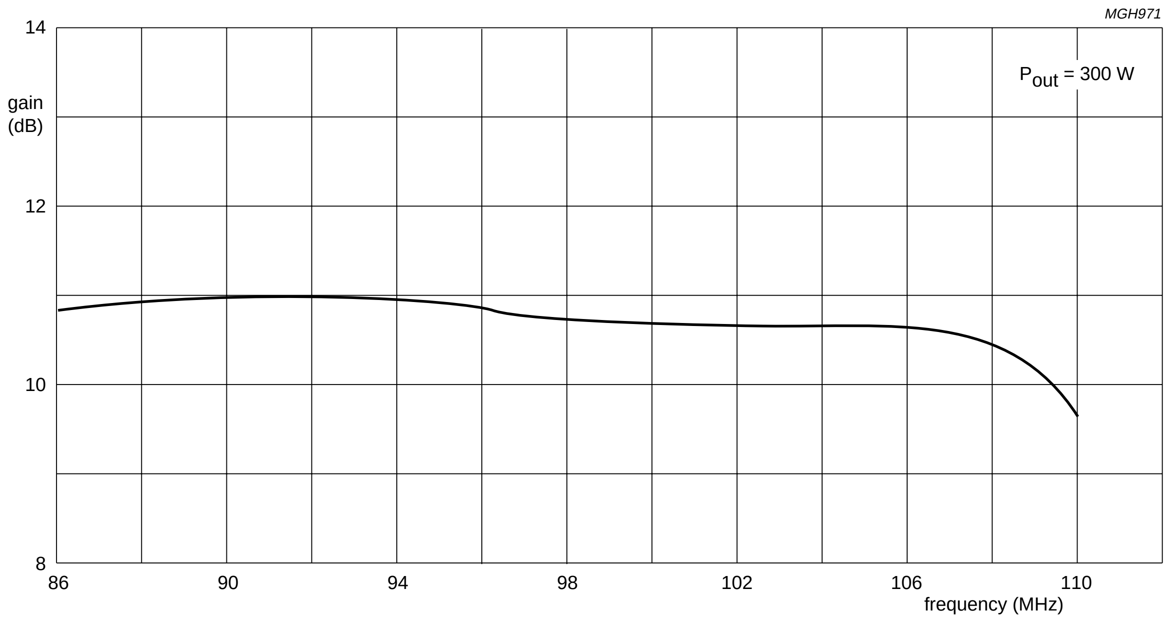


Fig.11 Gain versus frequency (main amplifier).

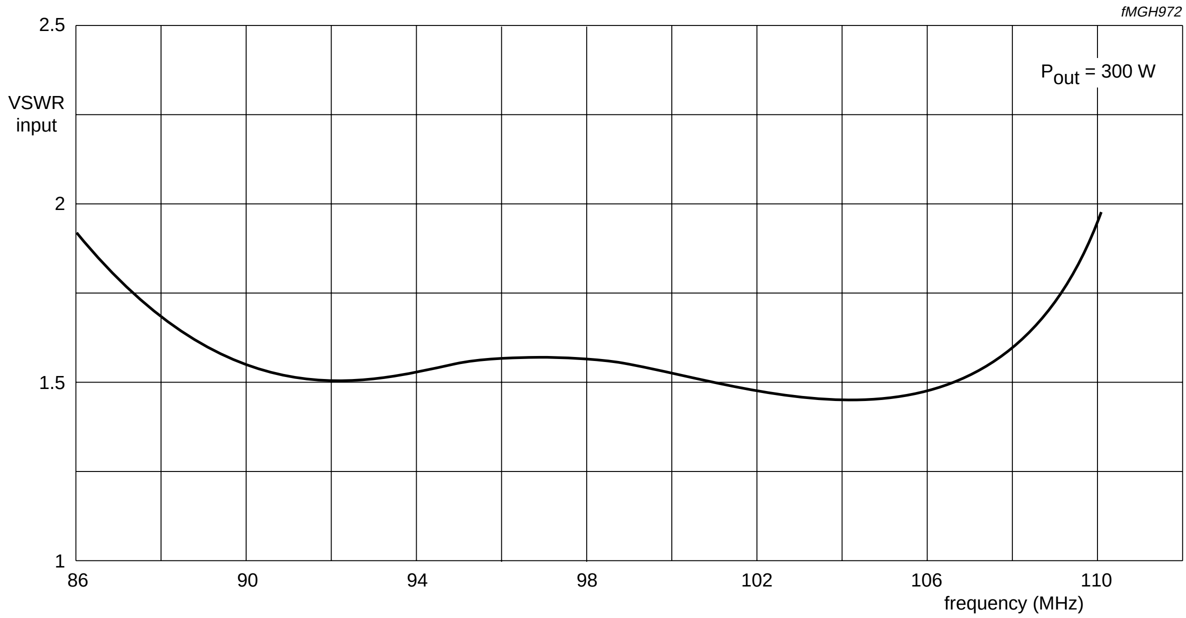


Fig.12 Input VSWR versus frequency (main amplifier).

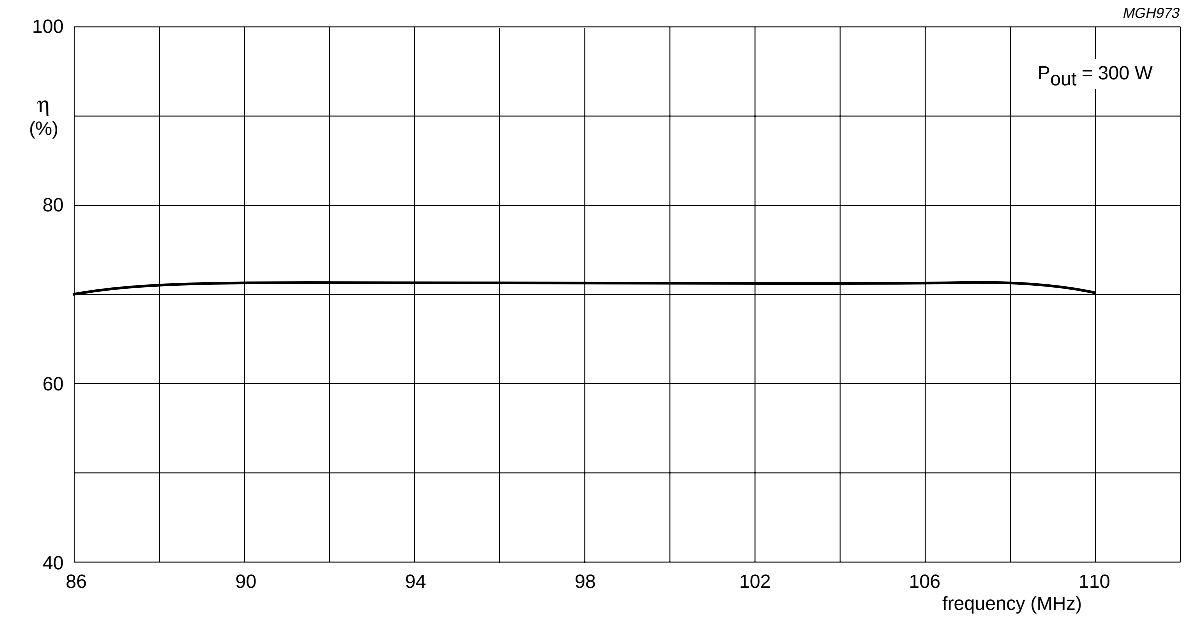


Fig.13 Collector efficiency versus frequency (main amplifier).

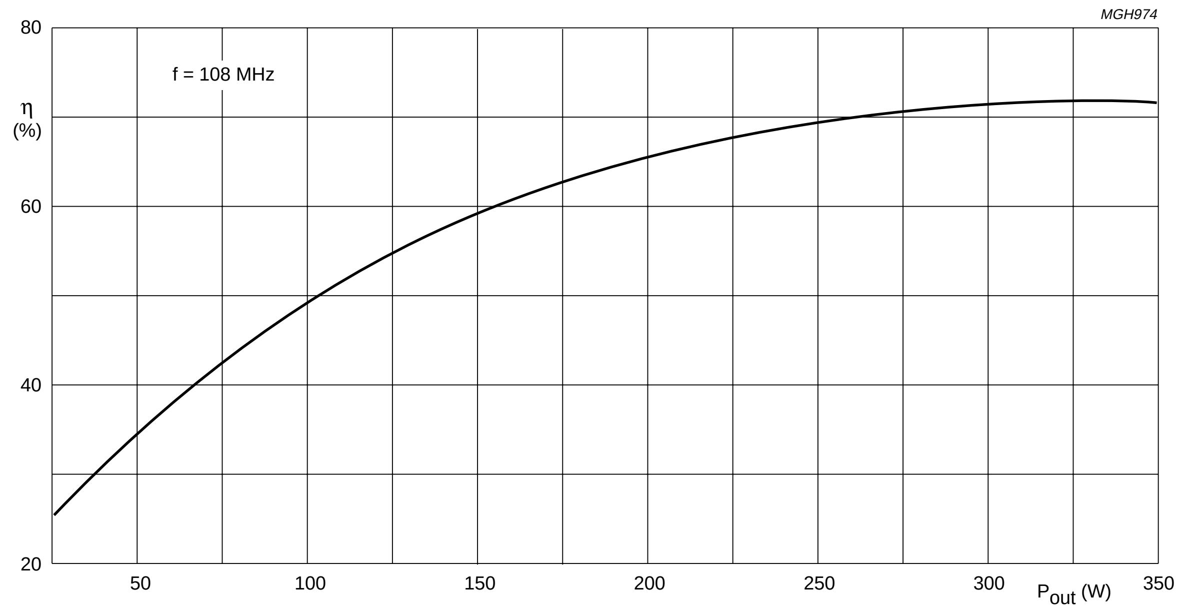


Fig.14 Efficiency, η, versus output power (main amplifier).

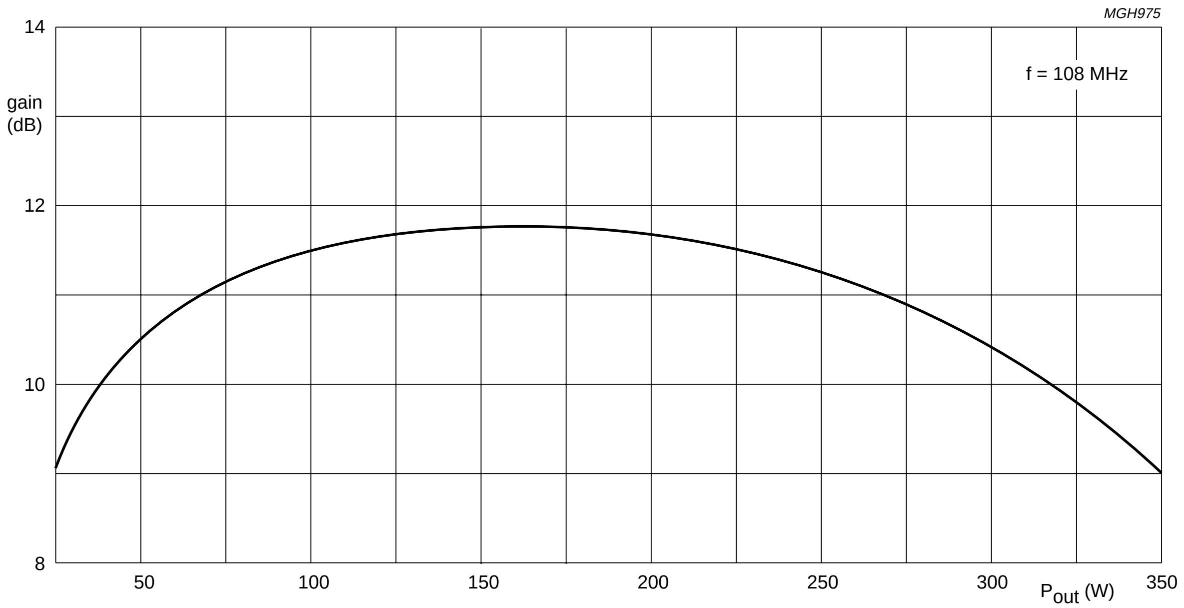


Fig.15 Gain versus output power (main amplifier).

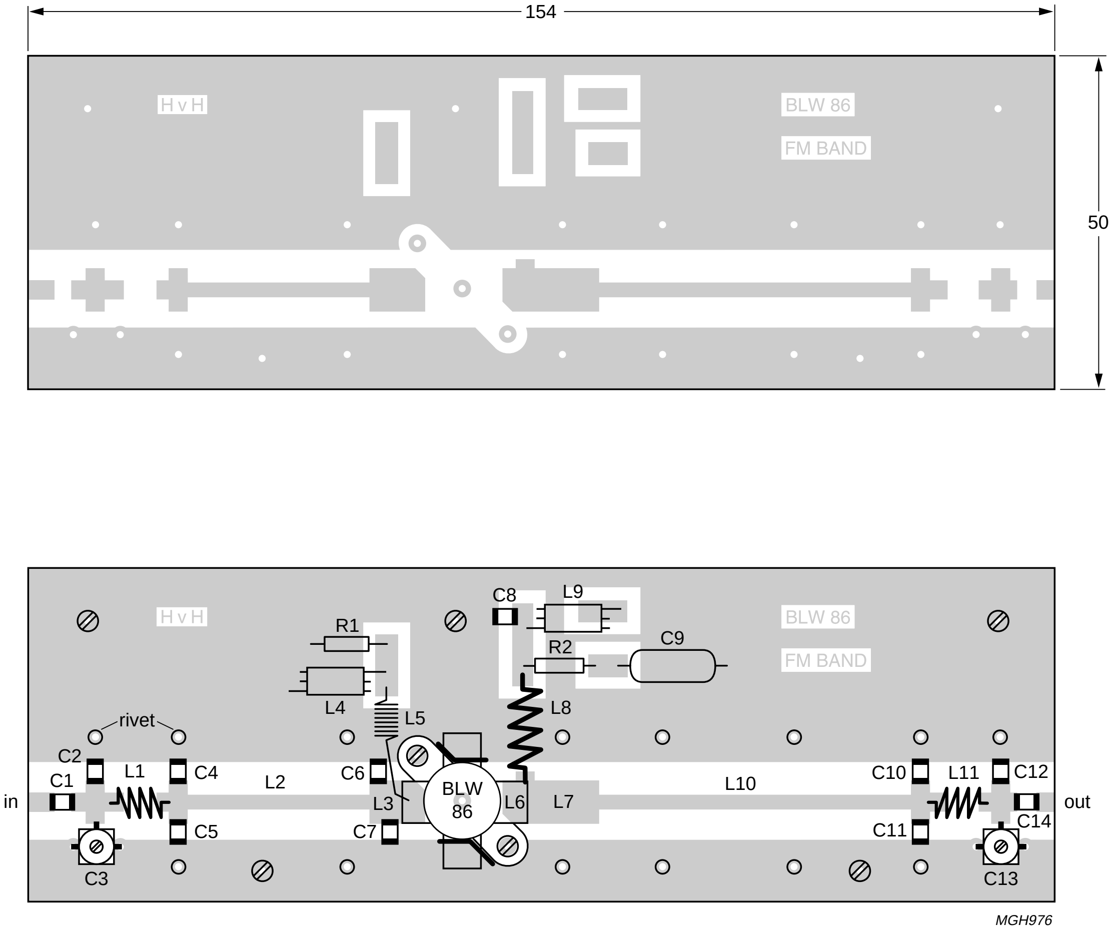


Fig.16 Printed circuit board and lay out of the driver.

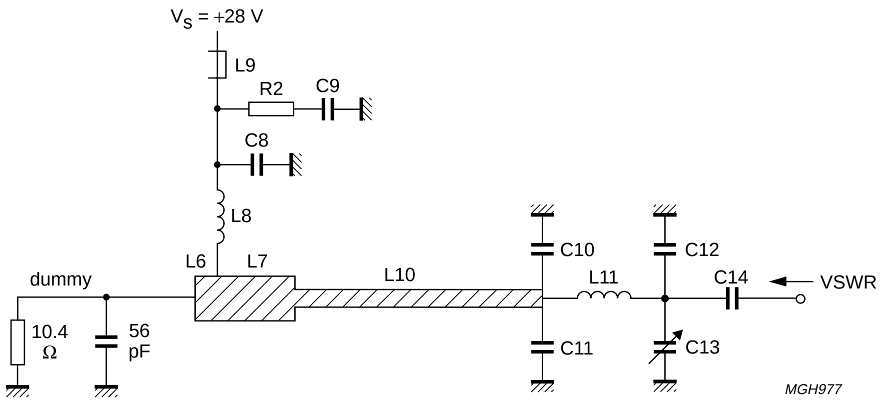


Fig.17 Output alignment circuit (driver).

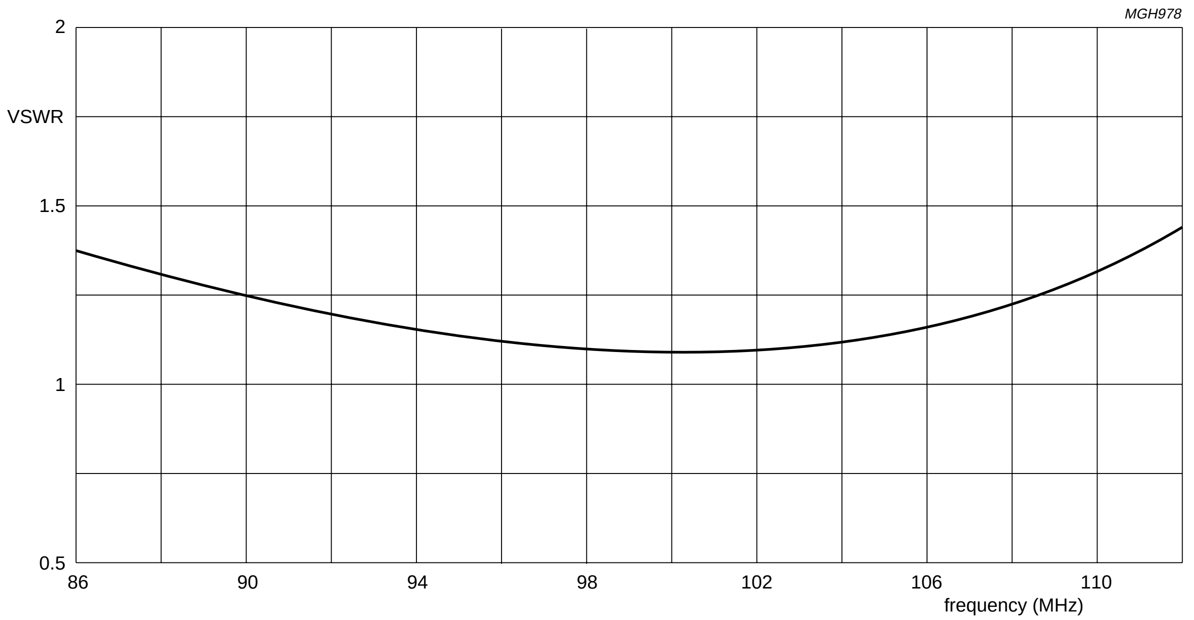


Fig.18 Output VSWR in circuit of Fig.17.

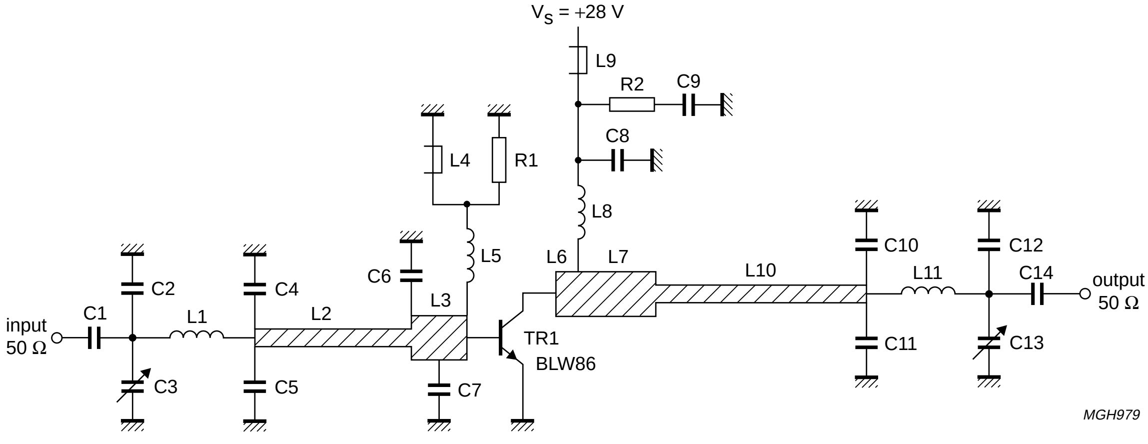


Fig.19 Driver amplifier circuit.

Table 7 Driver amplifier

R_1 = 12.1 Ω metal film	Philips MR 25 (2322 151 71219)
R_2 = 10 Ω metal film	Philips MR 25, (2322 151 71009)
$C_1 = C_8 = C_{14}$ = 2.7 nF chip	Philips NPO size 1210, (2222 852 13272)
C_2 = 33 pF chip	ATC 100B-330-J-Px-500
$C_3 = C_{13}$ = 2 – 18 pF film dielectric trimmer	Philips, (2222 809 09003)
$C_4 = C_5$ = 120 pF chip	ATC 100B-121-J-Px-300
$C_6 = C_7$ = 510 pF chip	ATC 100B-511-M-Px-100
C_9 = 100 nF metallized film capacitor	Philips, (2222 352 45104)
$C_{10} = C_{11}$ = 30 pF chip	ATC 100B-300-J-Px-500
C_{12} = 18 pF chip	ATC 100B-180-J-Px-500
L_1 = 48 nH 4 turns enamelled Cu wire ϕ = 0.8 mm, i.d. 3 mm, closely wound, length 3.5 mm, leads 2 × 5 mm	
L_2 = 60.2 Ω stripline, w = 2 mm, l = 27.2 mm	
L_3 = 30.1 Ω stripline, w = 6 mm, l = 7.9 mm	
$L_4 = L_9$ = FXC 3B RF choke	Philips 4312 020 36640
L_5 = 200 nH 14 turns enamelled Cu wire ϕ = 0.5 mm, i.d. 3 mm, closely wound, length 9 mm	
L_6 = 30.1 Ω stripline, w = 6 mm, l = 3 mm	
L_7 = 30.1 Ω stripline, w = 6 mm, l = 11.8 mm	
L_8 = 27.9 nH 4 turns enamelled Cu wire ϕ = 1 mm, i.d. 4 mm, length 14.3 mm, leads 2 × 5 mm	
L_{10} = 60.2 Ω stripline, w = 2 mm, l = 47 mm	
L_{11} = 55 nH 4 turns enamelled Cu wire ϕ = 1 mm, i.d. 4 mm, length 5.5 mm, leads 2 × 5 mm	
T_1 = BLW86	
Print board material: $^1/_{16}$-inch epoxy fibre-glass, ε_r = 4.5	

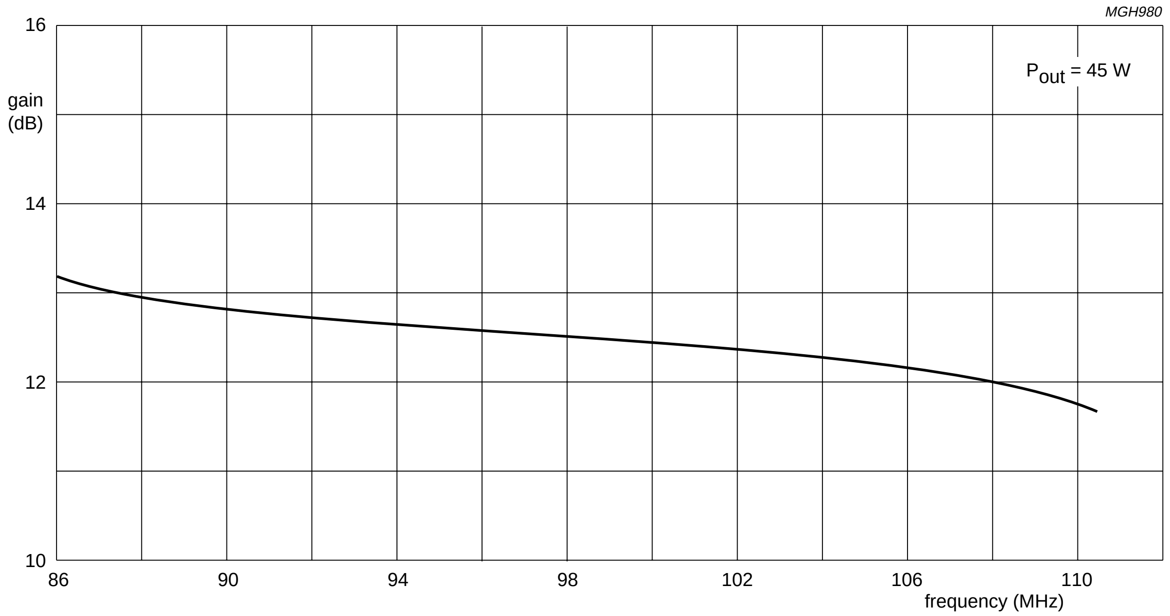


Fig.20 Gain versus frequency (driver).

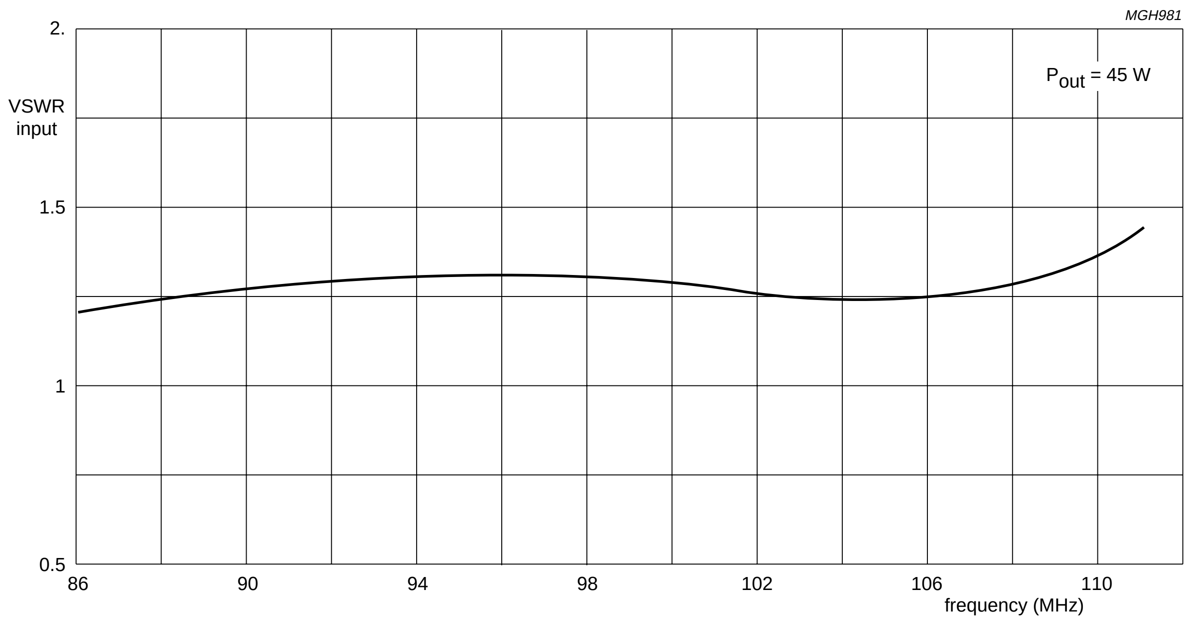


Fig.21 Input VSWR versus frequency (driver).

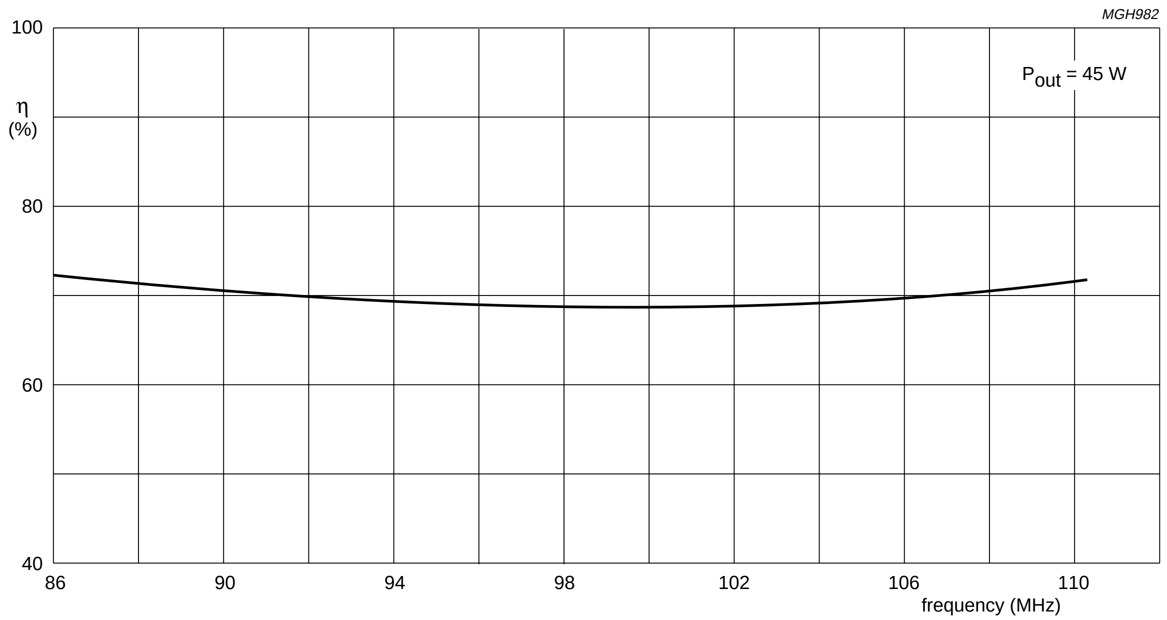


Fig.22 Collector efficiency versus frequency (driver).

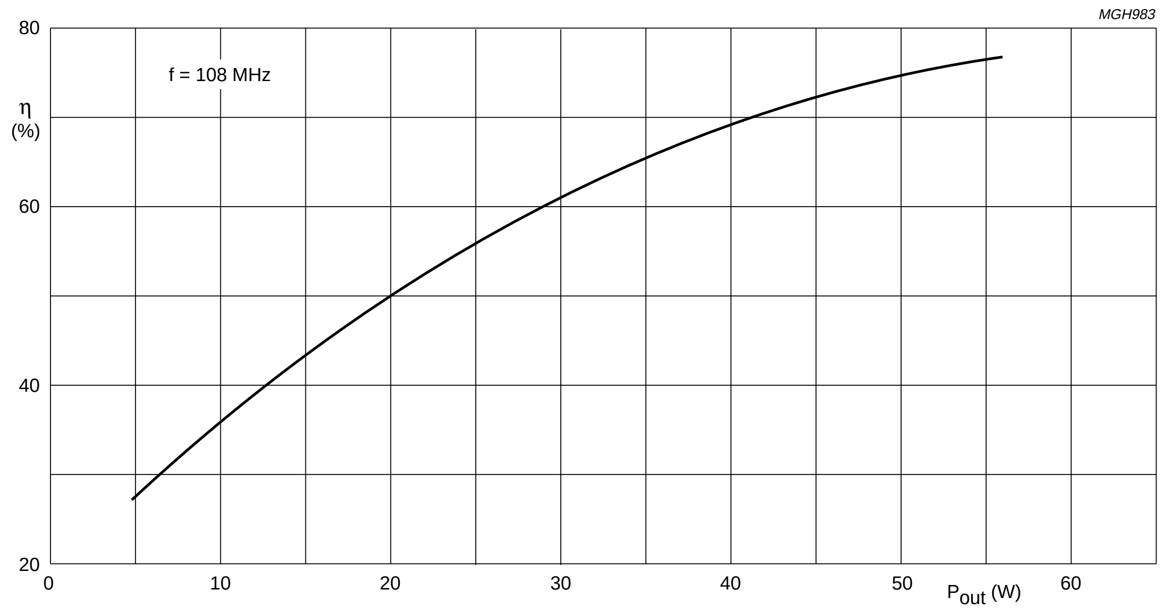


Fig.23 Collector efficiency, η, versus output power (driver).

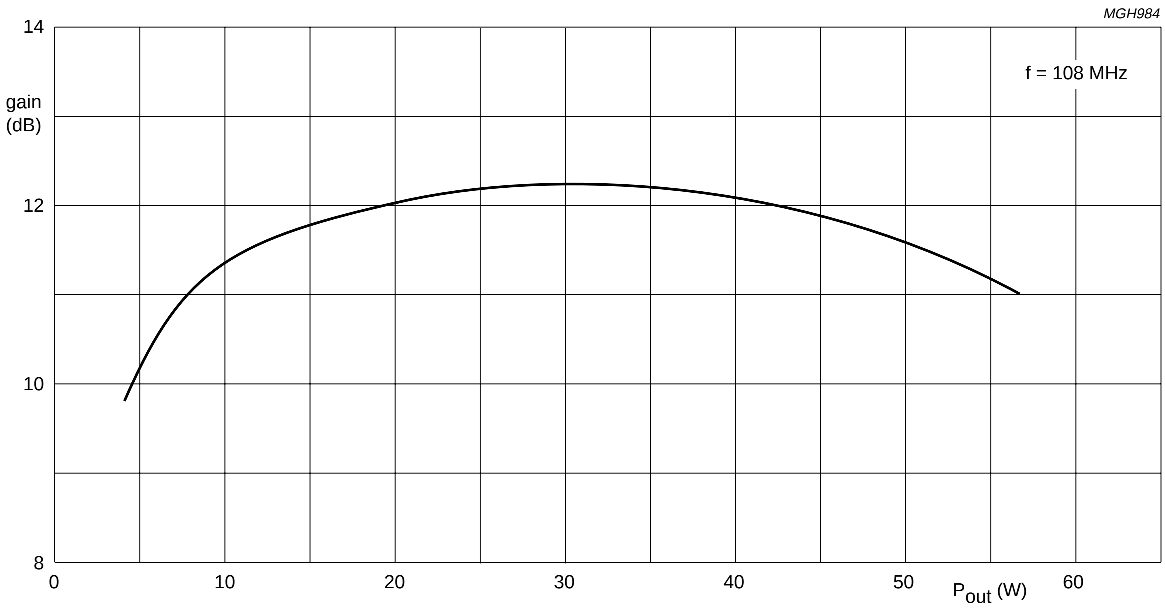


Fig.24 Gain versus output power (driver).

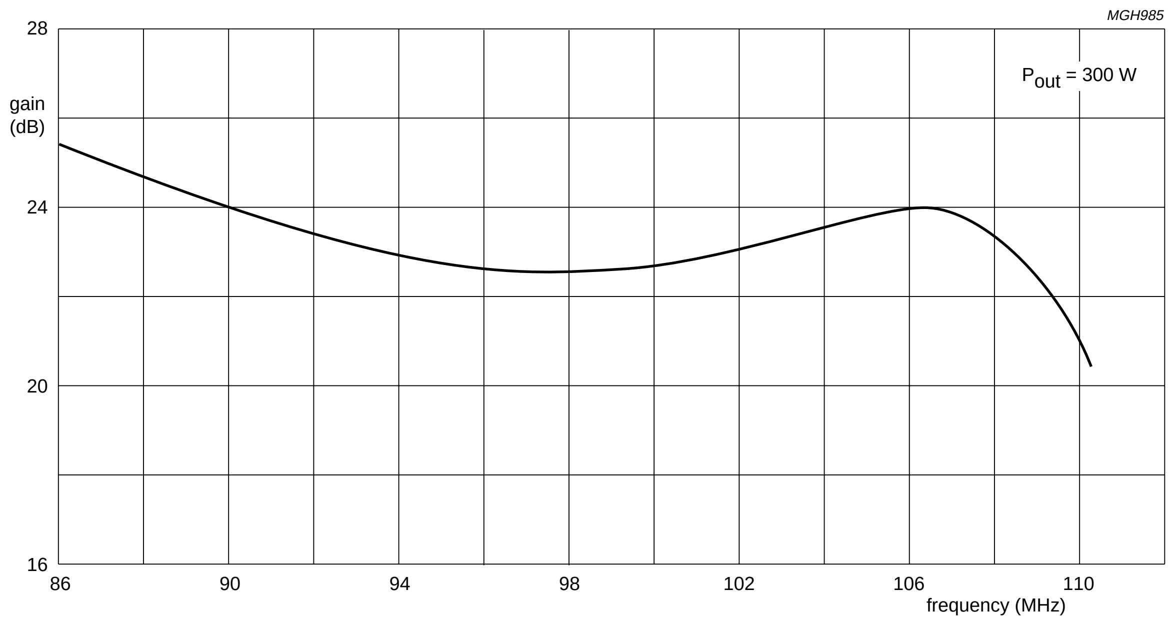


Fig.25 Gain versus frequency (combination amplifier).

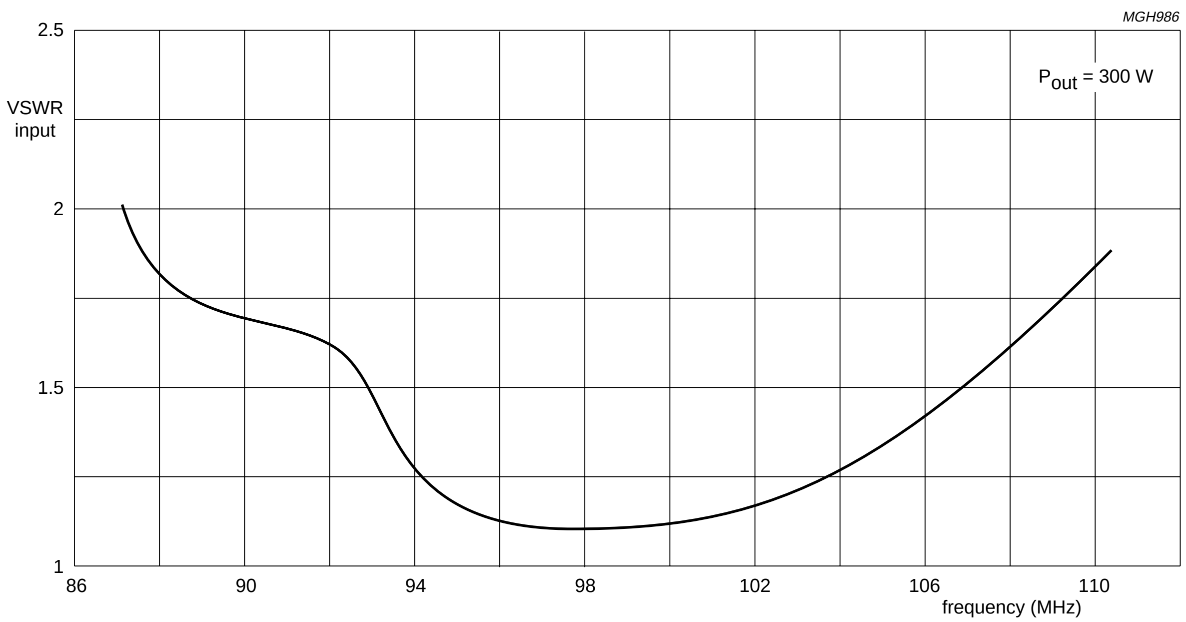


Fig.26 Input VSWR versus frequency (combination amplifier).

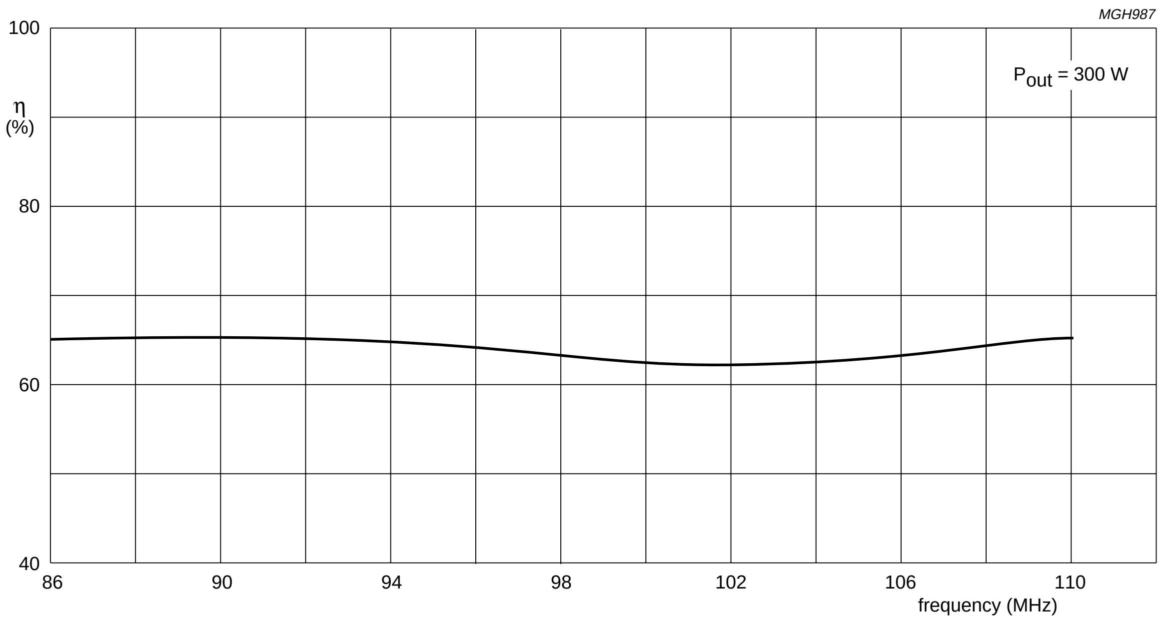


Fig.27 Efficiency versus frequency (combination amplifier).

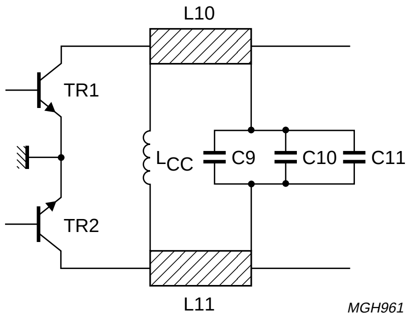
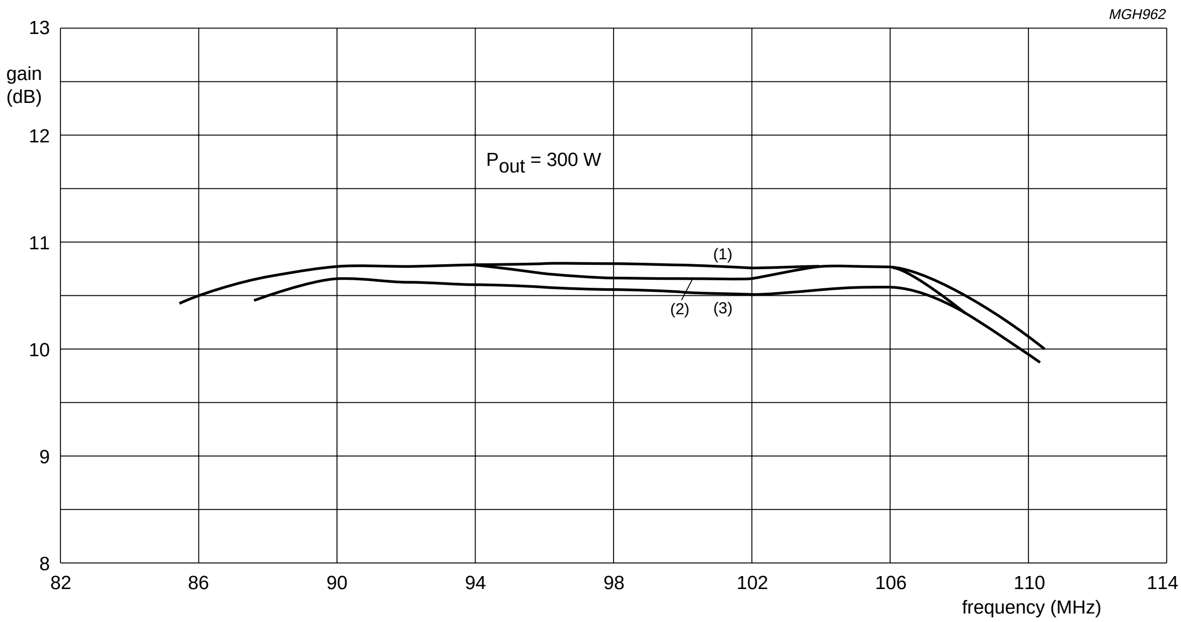


Fig.28 Adding inductance L_{CC} improves stability at low output powers and raises efficiency. Compare this with the relevant part of the circuit shown in Fig.10.



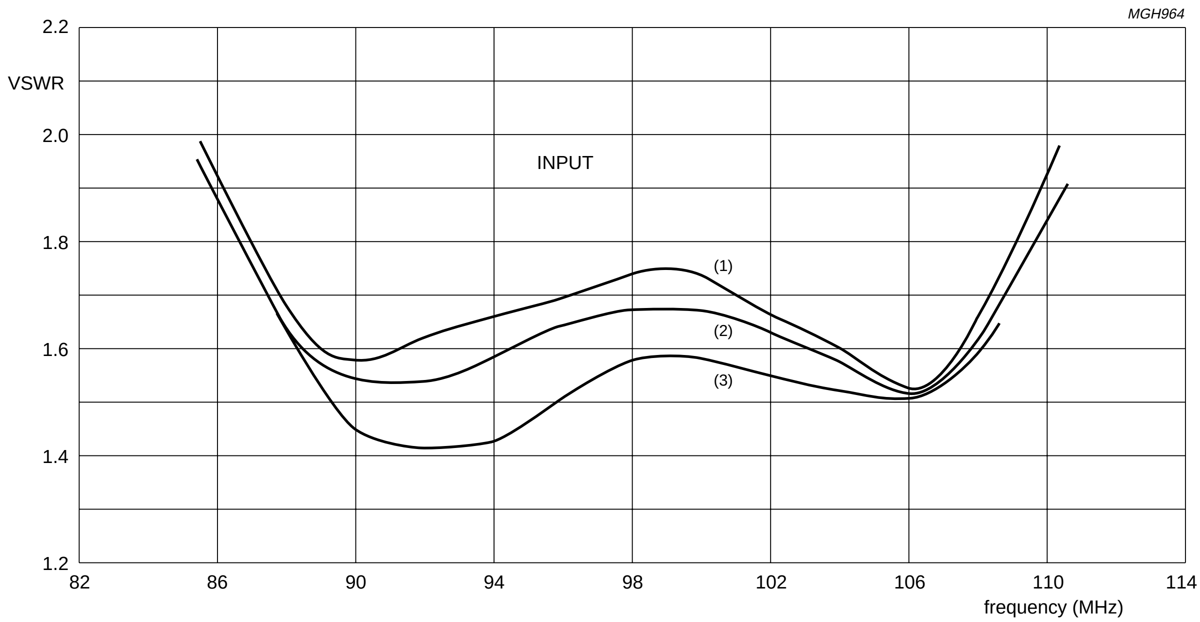
Legend:

(1) no L_{CC}.

(2) L_{CC} = 41 nH; 2 turns enamelled Cu wire ϕ = 1.7 mm, i.d. D = 8 mm, length 6 mm, leads 2 × 10 mm.

(3) L_{CC} = 29 nH 1 turn enamelled Cu wire ϕ = 1.7 mm, i.d. D = 10 mm, leads 2 × 12 mm.

Fig.29 Gain versus frequency.



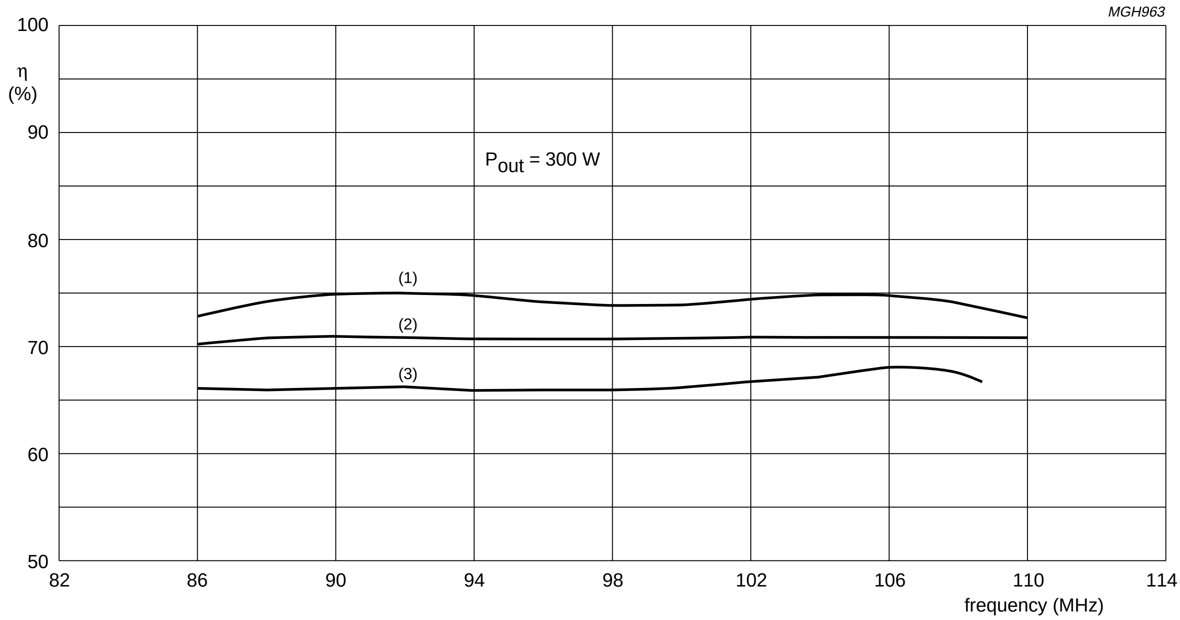
Legend:

(1) no L_{CC}.

(2) L_{CC} = 41 nH; 2 turns enamelled Cu wire ϕ = 1.7 mm, i.d. D = 8 mm, length 6 mm, leads 2 × 10 mm.

(3) L_{CC} = 29 nH 1 turn enamelled Cu wire ϕ = 1.7 mm, i.d. D = 10 mm, leads 2 × 12 mm.

Fig.30 Input VSWR versus frequency.



Legend: as Fig.29.

Fig.31 Efficiency versus frequency.

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Printed in The Netherlands

Date of release: 1998 Mar 23

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