APPLICATION NOTE

A wide-band linear power amplifier (470 – 860 MHz) with two transistors BLW34

ECO7901

CONTENTS

1 ABSTRACT

For application in driver or final stages of TV-transposers in band IV/V (470-860 MHz) a linear wideband power amplifier has been designed with 2 transistors BLW34 coupled by means of 3 dB –90° hybrids. Each transistor is adjusted in class-A at V_{CE} = 25 V and I_c = 0.6 A. The peak sync output power for a 3-tone I.M. distortion of –60dB varies between 3.6 and 5.4 W. The power gain is 9.1 ± 0.3 dB. Input and output VSWR are below 1.3.

2 INTRODUCTION

This report describes the realisation of a wide-band UHF power amplifier for TV transposer service in band IV and V (470 – 860 MHz).

The amplifier is designed with the BLW34 transistor being developed for ultra linear applications operating in class A.

Each device is able to deliver at least 1.8 W peak sync output. The BLW34 forms a series with the smaller devices BLW33 (1.0 W) and BLW32 (0.5 W).

The power gain at 860 MHz is at least 9 dB.

The BLW34 is encapsulated in a 1/4 inch capstan envelope with ceramic cap.

3 THEORETICAL CONSIDERATIONS

3.1 The equivalent circuit of the BLW34

For class A operation the BLW34 is specified at V_{CE} = 25 V; I_c = 600 mA.

The corresponding typical gain, input and load impedance according to the Data sheets are given in Table 1.

Table 1

f (MHz)	GAIN (dB)	R_i (SERIES) (Ω)	X_i (SERIES) (Ω)	R_L (SERIES) (Ω)	X_L (SERIES) (Ω)
470	15.2	1.46	1.93	12.8	11.0
636	12.6	1.39	2.84	8.85	9.97
860	10.1	1.27	4.00	5.36	7.67

To facilitate calculations an approximate equivalent circuit for the transistor input and output impedance can be given. It is shown in Fig.1.

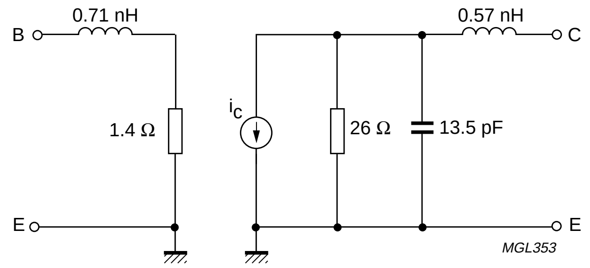


Fig.1

3.1.1 THE OUTPUT NETWORK

The circuit will be designed on printed circuit board with PTFE fibre glass as a dielectric having an ε_r = 2.74 and thickness of 1/32 inch.

The input and output network start with a piece of stripline having a width of 6 mm, being the width of the base and collector leads. For a dielectric of 1/32 inch the characteristic resistance is 21 Ω. The length for the collector lead amounts to 3 mm, but the base lead is different in length.

The first step in the matching is to tune out the output capacitance of the transistor by means of the collector R.F. choke.

This choke is executed as a stripline with a width of 1 mm corresponding with a characteristic resistance of 72 Ω to keep the parallel capacitance at this point as low as possible.

For practical reasons the choke is connected to the main transmission line at a distance of 3 mm from the transistor edge. For the design procedure one is referred to Part 1 of this handbook (SC19B).

The results of the calculations before and after computer optimization are given in Fig.2 and Table 2.

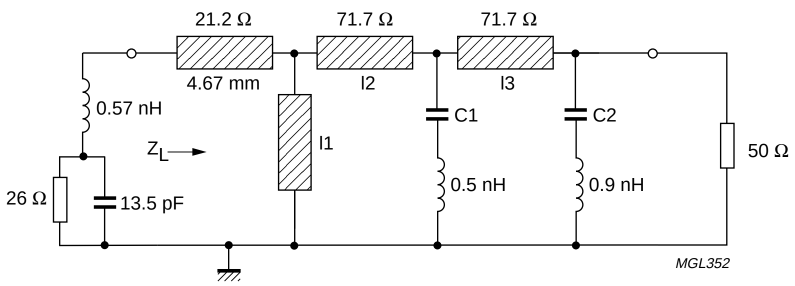


Fig.2

Table 2

ELEMENT	BEFORE OPTIM.	AFTER OPTIM.	UNIT
l_1	16.8	22.1	mm
l_2	18.2	20.8	mm
C_1	8.58	9.76	pF
l_3	38.2	43.5	mm
C_2	3.91	3.09	pF
$S_{max.}$	2.48	1.23	–

S_{max} is the maximum VSWR of the network.

The lenghts given hold for air lines. The actual lengths on the printed-circuit board are shorter; the reduction factors are: 1.445 for the 72 Ω lines and 1.556 for the 21 Ω line.

The predicted minimum output power of the complete amplifier with two transistors BLW34 is:

$$Po_2 = \frac{2Po_1}{S_{max}} \cdot 0.95 = \frac{2 \cdot 1.8}{1.23} \cdot 0.95 \cong 2.8\,W$$

Po_1 is the minimum output power of one transistor in a narrow band circuit, S_{max} is as specified above and the factor 0.95 represents the power loss of the hybrid coupler at the output.

3.1.2 THE INPUT NETWORK

The design procedure can be found in Part 1 of this handbook (SC19B).

The results of the calculations are summarized in Fig.3 and Table 3.

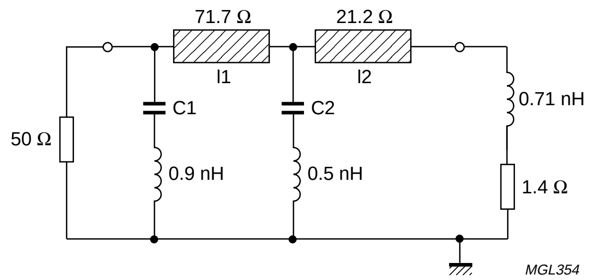


Fig.3

Table 3

ELEMENT	BEFORE OPTIM.	AFTER OPTIM.	UNIT
C1	4.78	4.41	pF
l1	25.9	32.1	mm
C2	21.9	19.9	pF
l2	13.3	10.5	mm
ΔG	±1.93	±0.12	dB

ΔG is the resulting power gain variation caused by the transistor and the input network over the frequency band. The lengths of the lines hold for air as a dielectric. Transformation to striplines on a printed-circuit board is done in the same way as in the previous section.

The minimum power gain of the complete amplifier with two transistors BLW34 is expected to be:

$$G_o = G_t - 2A_H - A_1 - A_2$$

in which: G_t = minimum power gain of BLW34 in a narrow band circuit.

A_H = power loss of one hybrid coupler

A_1 = reflection loss of input network

A_2 = reflection loss of output network.

In practical figures this means:

$G_o = 9.0 - 2 \times 0.2 - 0.15 - 0.05 = 8.4$ dB.

The input VSWR of a single amplifier was calculated to vary from 11 at 470 MHz down to 1.45 at 860 MHz.

4 THE HYBRID COUPLED AMPLIFIER

4.1 Practical considerations

On previous pages the theoretical approach of a single amplifier has been discussed.

In practice, it was the intention to realize a small compact amplifier on a printed-circuit board with the input and output terminal (Rc = 50 Ω) in line for easy cascading of several amplifiers.

Besides the wide-band properties it is the intention to obtain a higher output power, so two BLW34 branches are connected in parallel.

At the same time it is of course rather unacceptable that the amplifier loads a driver stage with a mismatch causing a VSWR of 11 at 470 MHz.

Both problems may be solved sufficiently by applying two BLW34 branches in parallel with the aid of two wide-band 3 dB –90 °C. coaxial hybrids on a 50 Ω basis.

In this configuration the output power will be nearly doubled; reduction of the input VSWR of the complete system to a value of around 1.2 may be explained from the properties of the coupler applied. The reflected power will be absorbed in the resistor matching the isolated port. This resistor is 50 Ω and consists of two 100 Ω power metal film resistor in parallel. The same has been done on the output side.

The printed-circuit board needs to be double copper clad with a PTFE fibre glass dielectric ($\varepsilon_r = 2.74$) for low losses at UHF.
A thickness of 1/32 inch has been chosen; so the 72 Ω lines are 1 mm wide.

Figure 4 shows the circuit diagram of the complete 2× BLW34 class A amplifier. The biasing circuit is drawn in Fig.5.

The printed-circuit board and the amplifier lay-out in Fig.6.

For a correct earthing the upper earth sheet parts are connected to the lower sheet by soldering copper straps at the edges of the printed-circuit board. The black parts in Fig.6 are the soldered copper straps.

The emitters are grounded as short as possible by applying copper straps under the emitter leads. For that reason the holes in the board are square instead of round.

Both transistors are screwed to a water-cooled brass heatsink. So, several heatsink temperatures can be applied by means of a TAMSON unit supplying water with a thermostatically controlled temperature.

The tuning capacitors in the circuit are of the film dielectric type with three tags of which both earth terminals are fed through small holes and soldered to the upper as well as the lower plane. Fixed capacitors in the r.f. path are of the multi-layer ceramic chip type.

The coaxial connectors are of the SMA 50 Ω type, being soldered to upper and lower sheet.

4.2 Practical optimization

We started with optimization on a small signal basis with the circuit inserted in a network analyzer chain, having swept S-parameter facilities.

So far, similar tuning methods have been applied as described in Ref. 2.

Because it is rather complicated to find the best compromise between an acceptable flat gain curve (S_{21}) and sufficient output power with low i.m.d. a dynamic large signal optimization method has been realized. Figure 7 shows the block diagram.

This tuning method is based on the correlation between the single tone 1dB compression point and the i.m.d figure of a linear amplifier.

In this set-up the swept output power level of the amplifier under test is kept constant and the required (detected) drive power monitored on an oscilloscope screen (PM3260).

The swept drive power is available from the sweep generator HP8620C in combination with RF plug-in unit HP86222A. Because the output power of this system is too low viz. appr. 20 mW (+13 dBm) a combined amplifier with BLW32 and BLW33 (Ref. 2) has been added. The latter combination shows an overall gain of approx. 20 db in the range 470 – 860 MHz. When the circuit under test is inserted in the chain of Fig.7, the input power measured on port C of hybrid 1 corresponds in principle with the gain curve (S_{21}) being measured with the network analyzer; in fact one is the inverse of the other.

When the drive level is slowly increased, the shape of the gain curve changes somewhat when compression starts. By careful retuning of the amplifier the shape of the gain curve can be corrected again in the direction of the original smaller signal curve.

The actual single tone output power has been measured with the aid of the calorimetric watt meter HP435A when the action of the sweep is stopped. Also it is possible to examine the output signal itself by means of a spectrum analyzer being loosely coupled via a 50 Ω pick-off device.

Resuming it can be said that the advantage of applying this high level tuning system is characterized by the fact that the output power is leveled and so compression does not start earlier due to gain fluctuations of the amplifier. This makes the judgement of the compression level easier.

4.3 Intermodulation, VSWR and gain measurements

For i.m.d. measurements on television systems the post offices advice and apply the 3-tone test method (vision carrier –8 dB, sound carrier –7 dB, sideband signal –16 dB; zero dB corresponds to peak sync level).

For this reason a wideband test set-up has been realized. The block diagram is in Fig.8. In this set-up first the sound and vision carriers are joined in the wide-band coaxial hybrid H_1.Then the sideband signal from the (smaller) generator SMLU is added in hybrid H_2.

The complete 3-tone signal passes a low-pass filter (700 or 1000 MHz cut-off depending on input frequency) a continuously variable attenuator and a circulator (three different types needed to cover at least the range 470 – 860 MHz).

The output power is measured with a HP435A calorimetric watt meter and the i.m.d. observed with a spectrum analyzer (HP8558B).

Figure 9 shows the 3-tone i.m.d. results measured on the complete hybrid coupled 2 × BLW34 amplifier. To get an idea of the $P_{o\ sync}$ drop for different heatsink temperatures, measurements have been done for T_{HS} = 23 °C and T_{HS} = 70 °C. The maximum drop in $P_{o\ sync}$ amounts to 1.1 dB.

Besides the 3-tone test the peak envelope power has been measured in a two-tone way for a third order i.m.d of d_3 = –47 dB.

It can be proved that there is a correlation between the afore described –60 dB 3-tone and the –47 dB two-tone test method.

It is known that the advantage of video precorrection on i.m.d. amounts to values up to 10 dB. Calculating with an average of 8 dB, the two-tone i.m.d. for d_3 = 39 dB is interesting. From Fig.10 it may be seen that the output power is more than doubled. Both tests have been done for heatsink temperatures of resp. 23 and 70 °C.

Finally input and output VSWR and gain figures were measured only under small signal conditions. The results of amplifier branches 1 and 2 for a heatsink temperature of 70 °C are shown in Figs 11 to 13. The VSWR figures of the input and output are expressed in reflection damping (resp. S_{11} and S_{22}) on a 50 Ω basis.

According to Fig.11 the minimum reflection damping of the input amounts to S_{11} = –1 dB (VSWR = 17.4) at 470 MHz and to S_{11} = –10 dB (VSWR = 1.93) at 860 MHZ.

On the output side the worst reflection damping amounts to S_{22} = –5.5 dB (VSWR = 3.26) in the middle of the passband (Fig.13).

The power gain, represented by S_{21}, is appr. 9.5 dB (Fig.12).

Resuming it can be said that, as Figs 11 to 13 show, the differences in gain, input and output VSWR between both branches are rather small.

Figs 14 to 16 show the final results of the complete hybrid coupled amplifier. Examining the S_{11} and S_{22} figures it appears that the minimum input reflection damping (S_{11}) amounts to appr. 18 dB, what corresponds with a maximum VSWR of 1.29.

The latter value may be mainly explained from the specified maximum VSWR = 1.25 of the applied Anaren hybrids. If more attention is paid to matching of the isolated ports the results may be improved. The matching consists of two metal film power transistors of 100 Ω in parallel. They have low-frequency tolerances of 5%.

The small signal gain of the complete amplifier amounts to 9.1 ±0.3 dB for T_{HS} = 23 °C, whilst the dashed line shows the results for T_{HS} = 70 °C being 8.9 ± 0.3 dB.

The temperature influence on the S_{11} and S_{22} figures is almost negligible.

5 CONCLUSIONS

On preceding pages the theoretical and practical design has been described of the wide-band (470 – 860 MHz) high quality linear amplifier being equipped with two BLW34 transistors operating in class A.

There are some small differences between the theoretical design and the practical circuit.

- The calculated value for the chip capacitors $C_{11} = C_{12} = C_{13} = C_{14}$ in Fig.4 was 10 pF. In practice 8.2 pF appeared to be a better choice.
- Also the values of $C_{19} = C_{20} = C_{21} = C_{22}$, being calculated as 4.7 pF are changed. The new value is 3.9 pF.
- In the first instance a chip capacitor of 1.5 pF in parallel with C_{23} and C_{26} was planned. However this capacitor could be omitted in the operational circuit.

The excepted results for a single amplifier: $G_{p\ min.}$ = 8.8 dB; and $P_{o\ sync}$ = 1.5 W at a 3-tone i.m.d. of –60 dB and $G_{p\ min}$ = 8.4 dB and $P_{o\ sync}$ = 2.8 W for $T_{HS} \leq 70$ °C are realized in this design.

Here, we have calculated with a total insertion loss of 0.4 dB for the applied hybrids. They are specified for a maximum of 0.25 dB per device (1.06 × power).

6 REFERENCES

Ref. 1: O. Pitzalis Jr. and R.A. Gilson - Tables of impedance matching networks which approximate prescribed attenuation versus frequency slopes. IEEE Transactions on microwave theory and techniques, Vol. MTT-19, no. 4, April 1971, pp. 381-386.

Ref. 2: A.H. Hilbers and M.J. Köppen - Wide-band linear power amplifier (470 – 860 MHz) with the transistors BLW32 and BLW33. C.A.B. report ECO7806.

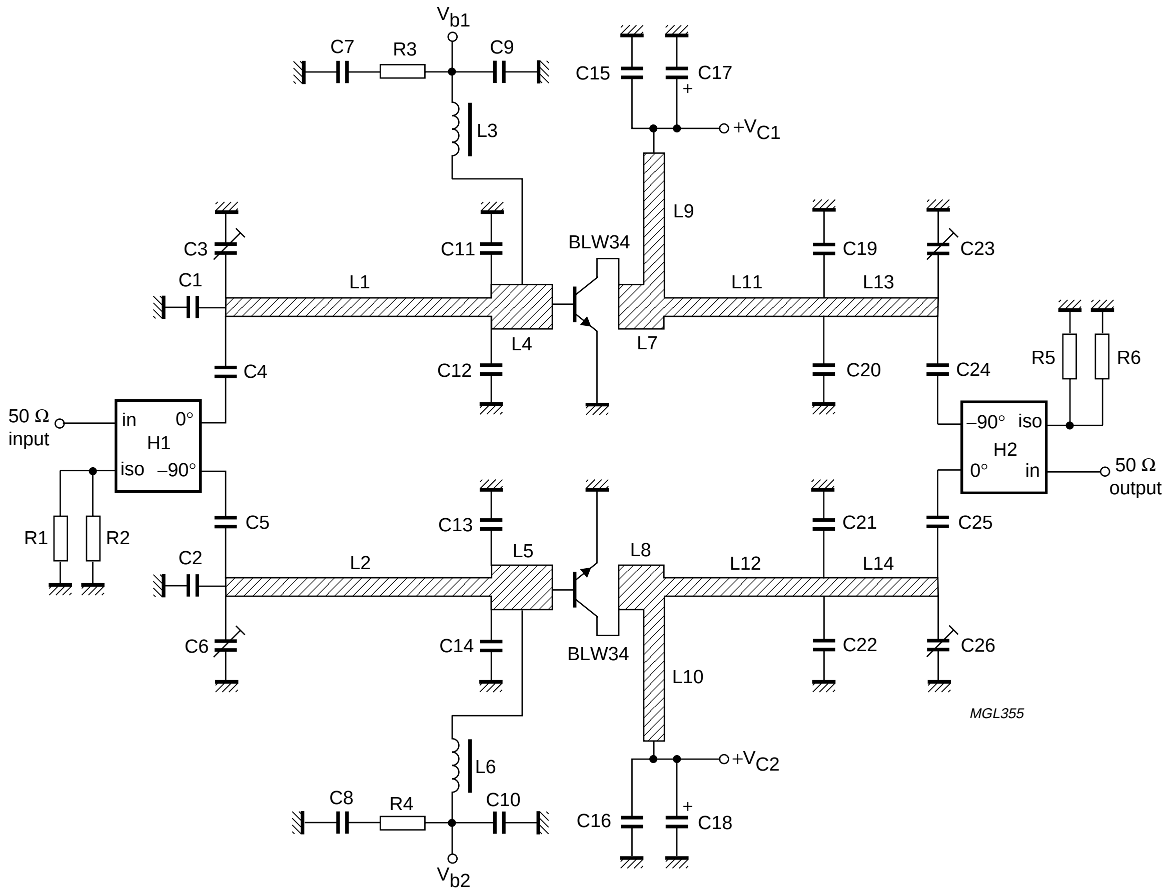

Vb1
C7
R3
C9
C15
C17
+VC1
L3
L9
C3
C11
BLW34
C19
C23
C1
L1
L11
L13
L4
L7
R5
R6
C4
C12
C20
C24
50 Ω
input
in
0°
H1
iso
−90°
−90°
iso
H2
0°
in
50 Ω
output
R1
R2
C5
C13
C21
C25
C2
L2
L5
L8
L12
L14
C6
C14
BLW34
C22
C26
L10
MGL355
L6
+VC2
C8
R4
C10
C16
C18
Vb2

Fig.4

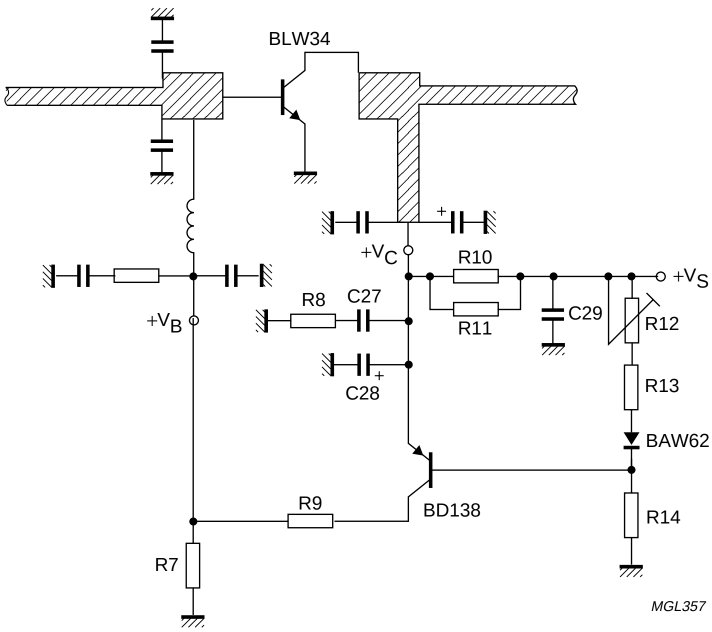

BLW34
+VC
R10
+VS
R8
C27
R11
C29
R12
+VB
C28
R13
BAW62
R9
BD138
R14
R7
MGL357

Fig.5

Table 4

LIST OF COMPONENTS	
$C_1 = C_2 = 2.2$ pF	multilayer ceramic chip capacitor Tekelec-Airtronic part no. 500 R15 N2R2 BA
$C_3 = C_6 = C_{23} = C_{26} = 1.4$ to 5.5 pF	film dielectric trimmer (cat. no. 2222 809 09001)
$C_4 = C_5 = C_{24} = C_{25} = 100$ pF	multilayer ceramic chip capacitor (cat. no. 2222 851 13101)
$C_7 = C_8 = C_{29} = 100$ nF	polyester capacitor
$C_9 = C_{10} = C_{15} = C_{16} = 100$ pF	multilayer ceramic chip capacitor (cat. no. 2222 852 13101)
$C_{11} = C_{12} = C_{13} = C_{14} = 8.2$ pF	multilayer ceramic chip capacitor, ATC (American Technical Ceramics) type 100A-8R2-J-Px-50
$C_{17} = C_{18} = C_{28} = 6.8$ µF, 63 V	electrolytic capacitor
$C_{19} = C_{20} = C_{21} = C_{22} = 3.9$ pF	multilayer ceramic chip capacitor, Tekelec-Airtronic part no. 500 R15 N3R9 CA
$C_{27} = 470$ nF	polyester capacitor
$R_1 = R_2 = R_5 = R_6 = 100\ \Omega$ (±5%)	power metal film resistor PR37 type (cat. no. 2322 191 31001)
$R_3 = R_4 = R_8 = 10\ \Omega$ (±5%)	carbon resistor; CR25 type
$R_7 = 33\ \Omega$ (±5%)	carbon resistor; CR25 type
$R_9 = 220\ \Omega$ (±5%)	power metal film resistor PR52 type (cat. no. 2322 192 32201)
$R_{10} = 5.6\ \Omega$ (±5%)	enamelled wire-wound resistor WR0617E style
$R_{11} = 8.2\ \Omega$ (±5%)	enamelled wire-wound resistor WR0617E style
$R_{12} = 100\ \Omega$	cermet preset potentiometer
$R_{13} = 120\ \Omega$ (±5%)	carbon resistor; CR25 type
$R_{14} = 1.8$ kΩ (±5%)	carbon resistor; CR25 type
$H_1 = H_2$ = ultra-miniature 3 dB –90° coupler model no. 10264-3, range 0.5 – 1,0 GHz; Anaren Microwave Inc.	
$L_1 = L_2$	stripline (Zc = 72 Ω), 22.1 × 1.0 mm^2; note 1
$L_3 = L_6 = 1$ µH	microchoke
$L_4 = L_5$	stripline (Zc = 21 Ω), 6.7 × 6.0 mm^2; note 1
$L_7 = L_8$ = stripline	(Zc = 21 Ω), 3.0 × 6.0 mm^2; note 1
$L_9 = L_{10}$ = stripline	(Zc = 72 Ω), 15.2 × 1.0 mm^2; note 1
$L_{11} = L_{12}$ = stripline	(Zc = 72 Ω), 14.3 × 1.0 mm^2; note 1
$L_{13} = L_{14}$ = stripline	(Zc = 72 Ω), 29.9 × 1.0 mm^2; note 1

Note

1. These striplines are printed on double Cu-clad printed-circuit board with PTFE fibre-glass dielectric ($\varepsilon_r = 2.74$); thickness 1/32”.

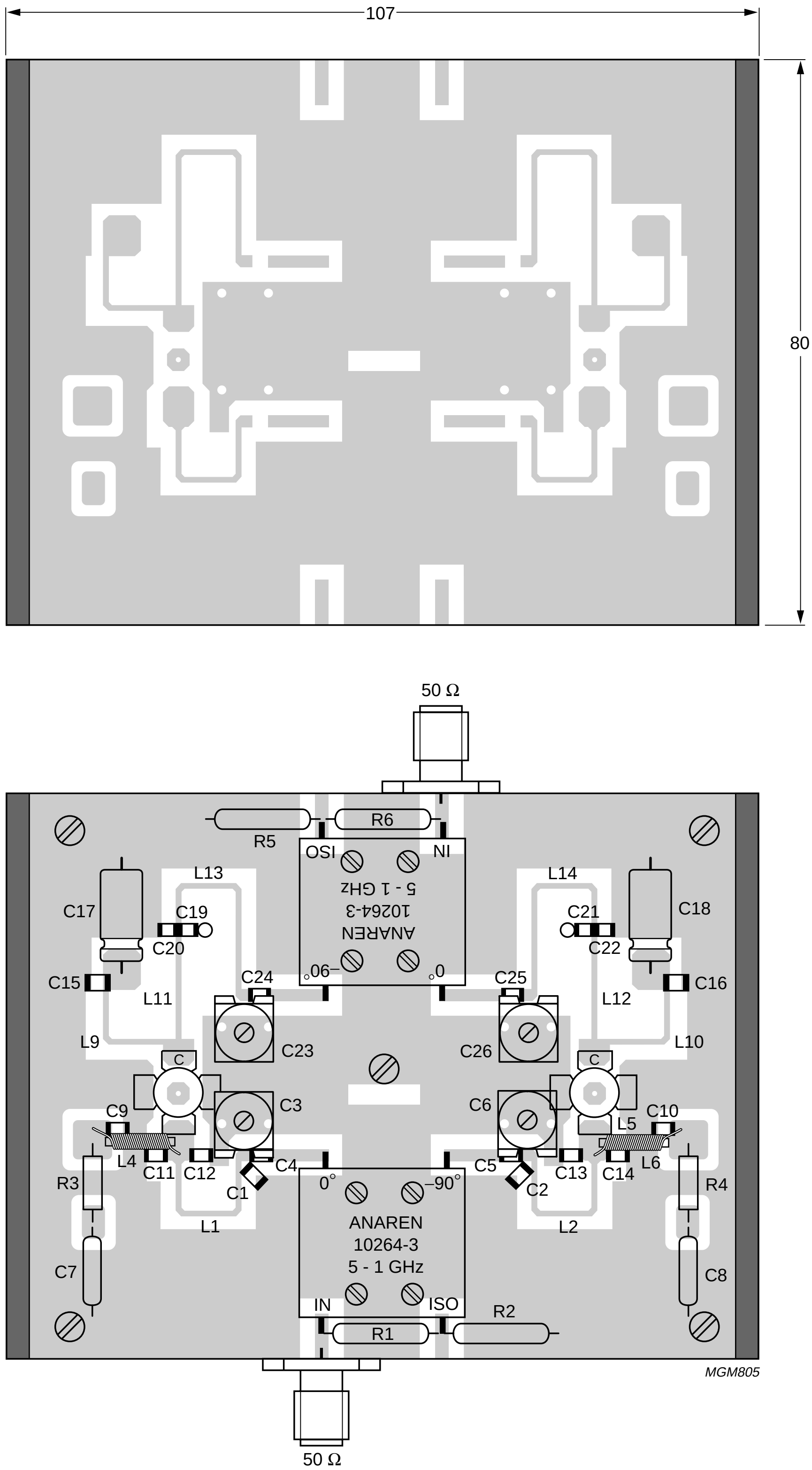


Fig.6 Printed-circuit board and amplifier lay-out.

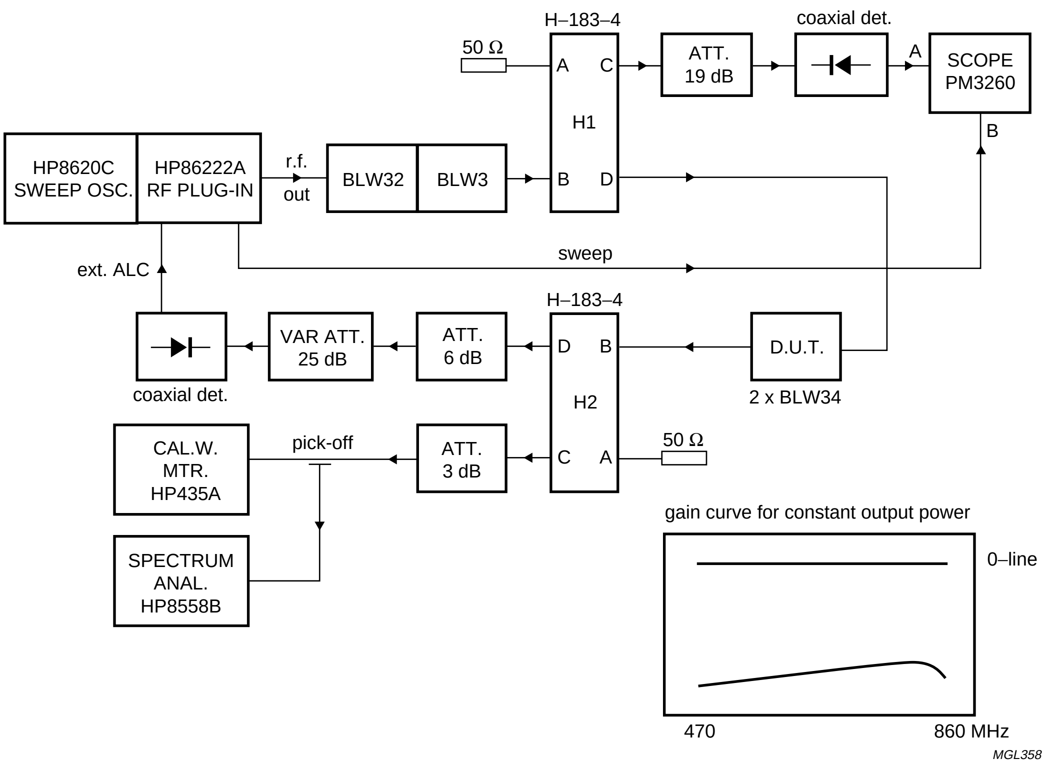
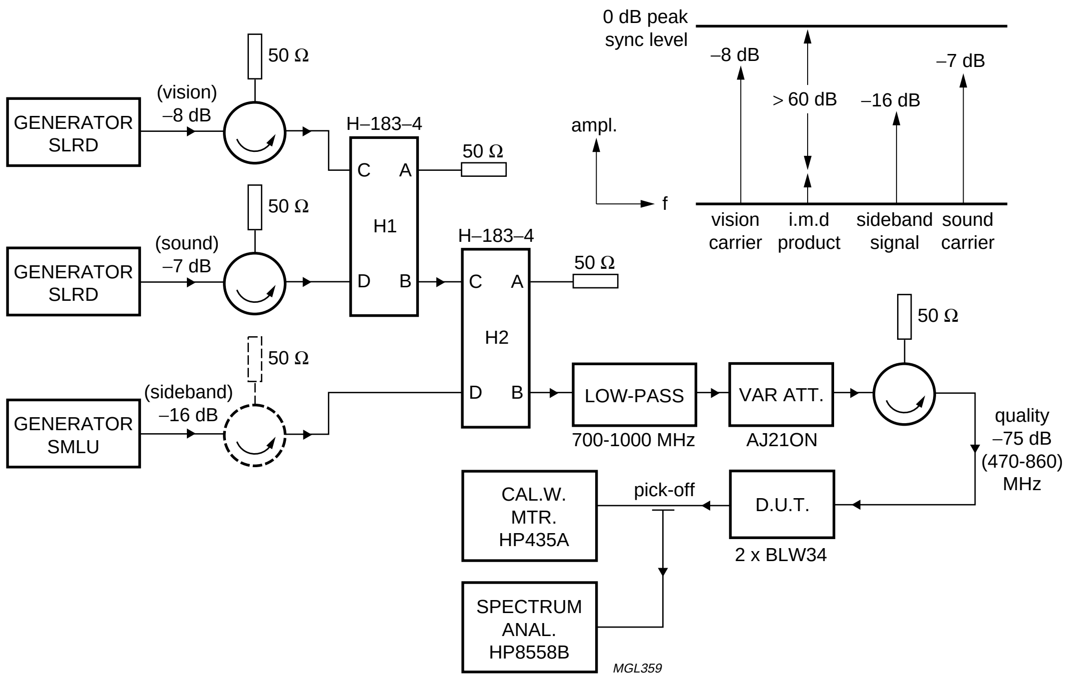


Fig.7 Dynamic compression test set-up.



Circulator ranges:
(1) 470 – 600 MHz.
(2) 600 – 800 MHz.
(3) 790 – 1000 MHz.

Fig.8 3-tone test set-up 470 – 860 MHz.

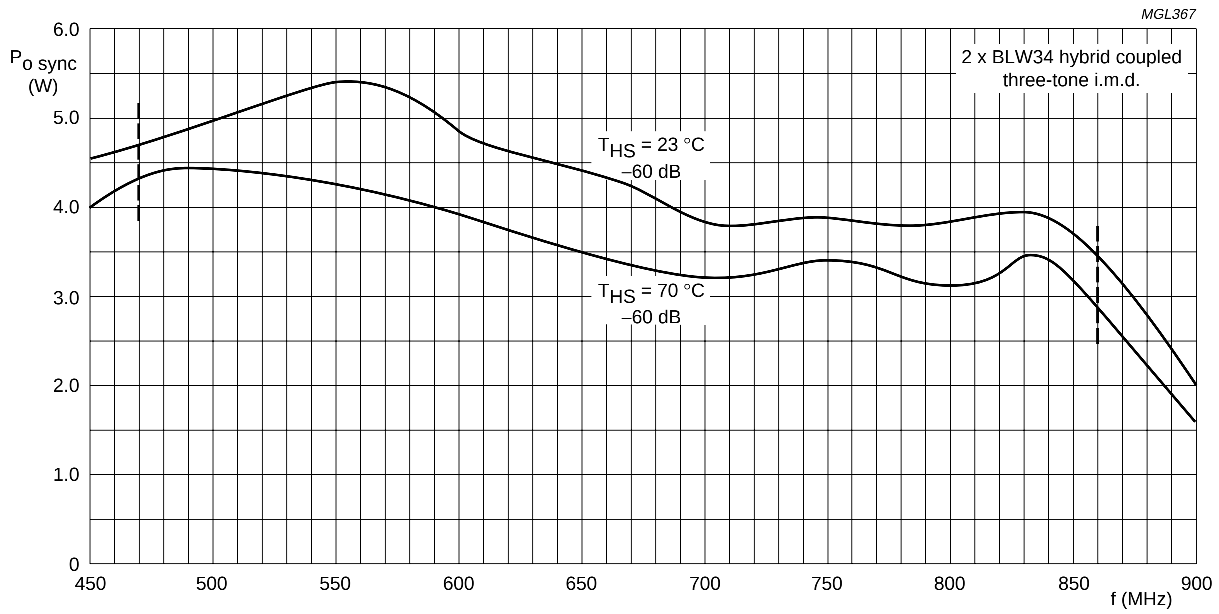

MGL367
6.0
$P_{o\ sync}$ (W)
5.0
4.0
3.0
2.0
1.0
0
450
500
550
600
650
700
750
800
850
900
f (MHz)
2 x BLW34 hybrid coupled three-tone i.m.d.
T_{HS} = 23 °C –60 dB
T_{HS} = 70 °C –60 dB

Fig.9

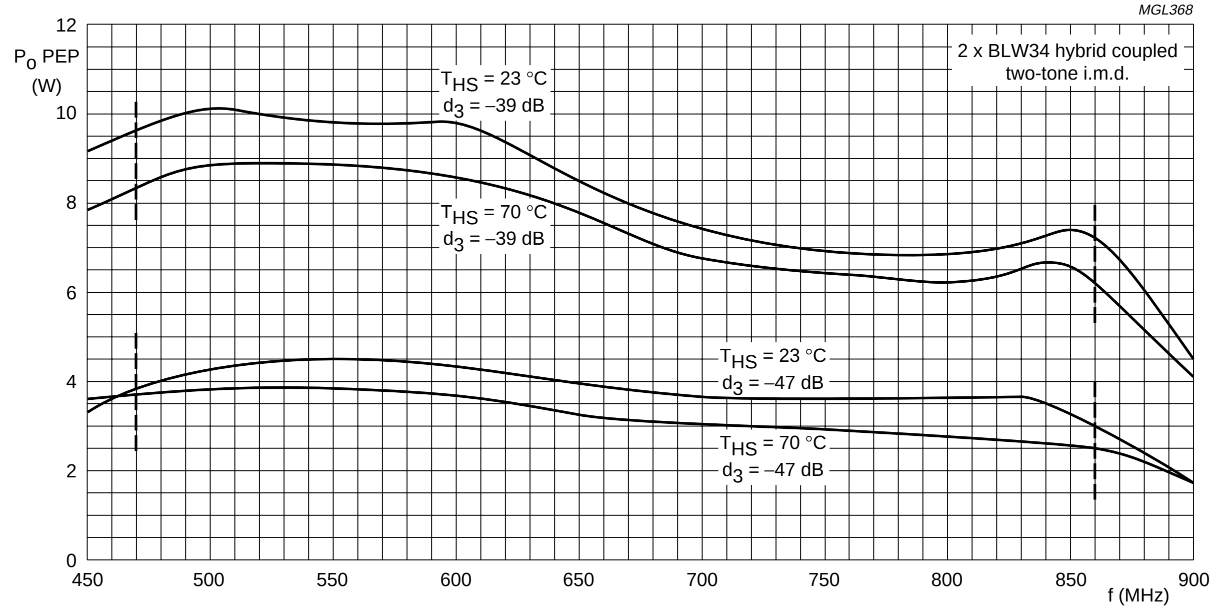

MGL368
12
P_o PEP (W)
10
8
6
4
2
0
450
500
550
600
650
700
750
800
850
900
f (MHz)
2 x BLW34 hybrid coupled two-tone i.m.d.
T_{HS} = 23 °C d_3 = –39 dB
T_{HS} = 70 °C d_3 = –39 dB
T_{HS} = 23 °C d_3 = –47 dB
T_{HS} = 70 °C d_3 = –47 dB

Fig.10

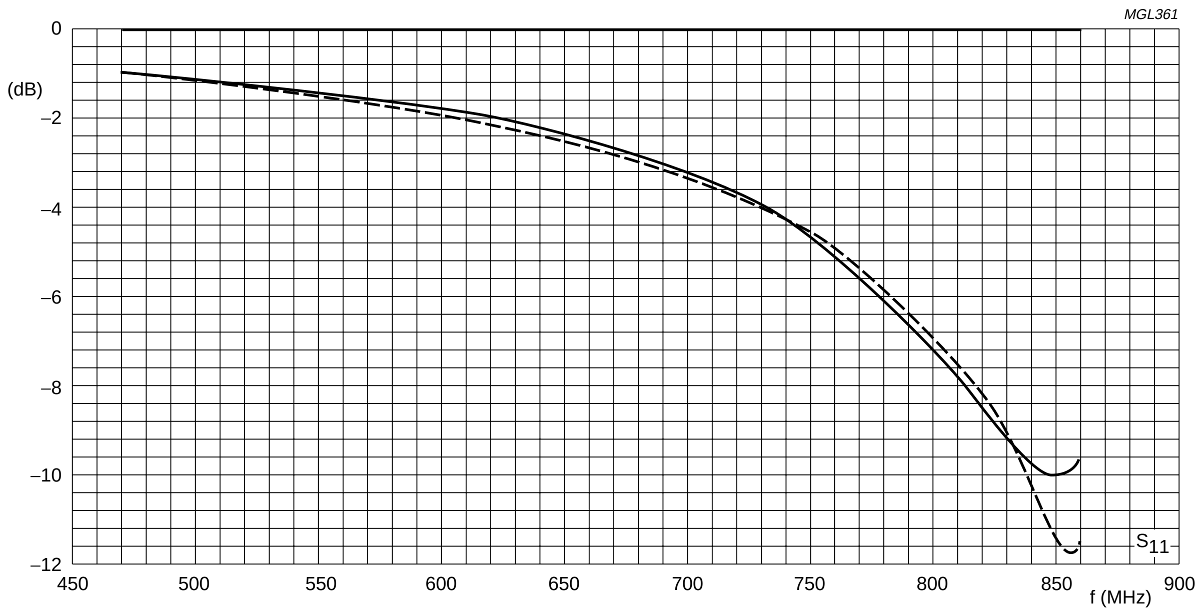
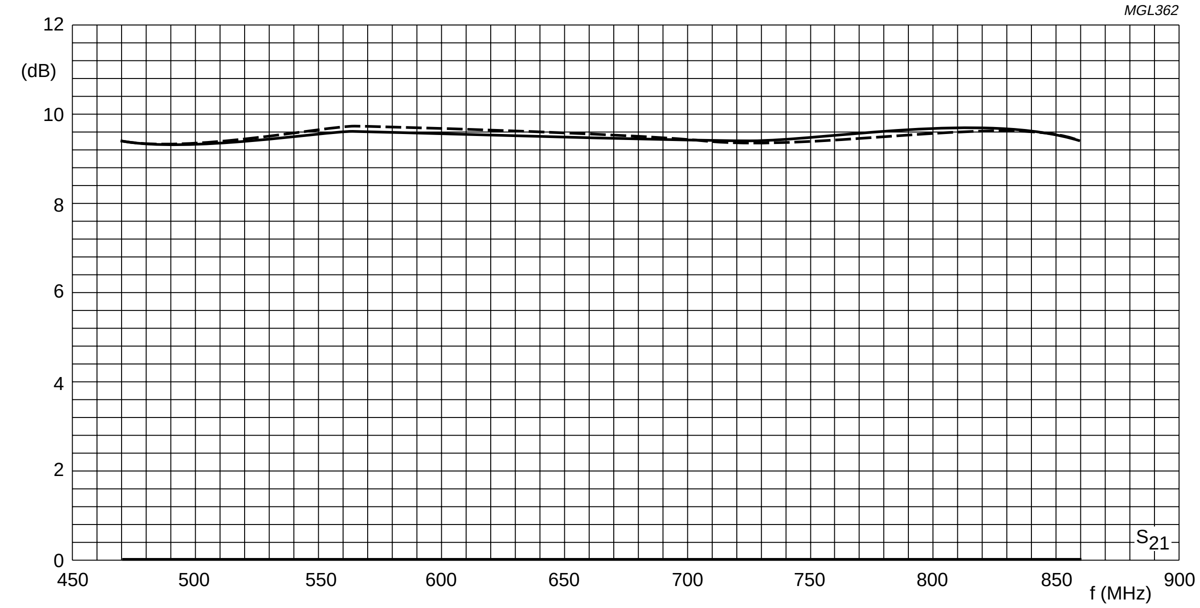


Fig.11



T_{HS} = 70 °C.
V_{CE} = 25 V.
I_C = 600 mA.

Branch 1.
Branch 2.

Fig.12

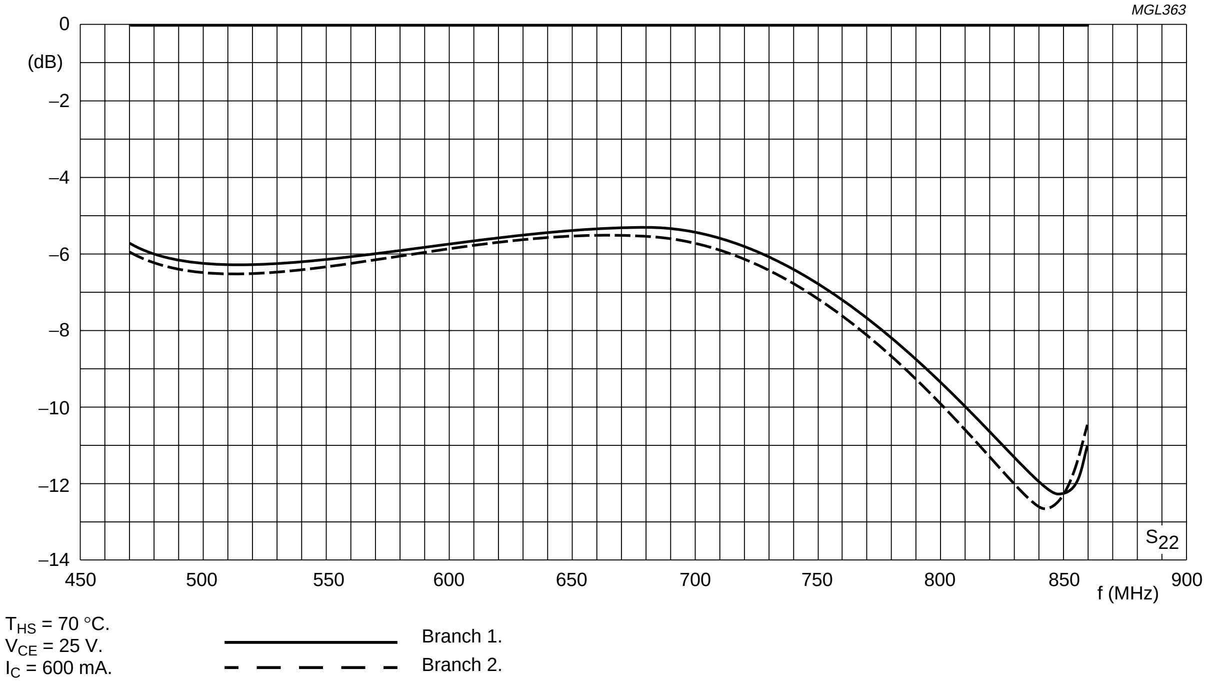

MGL363
0
(dB)
−2
−4
−6
−8
−10
−12
−14
450
500
550
600
650
700
750
800
850
900
f (MHz)
S_{22}
T_{HS} = 70 °C.
V_{CE} = 25 V.
I_C = 600 mA.
Branch 1.
Branch 2.

Fig.13

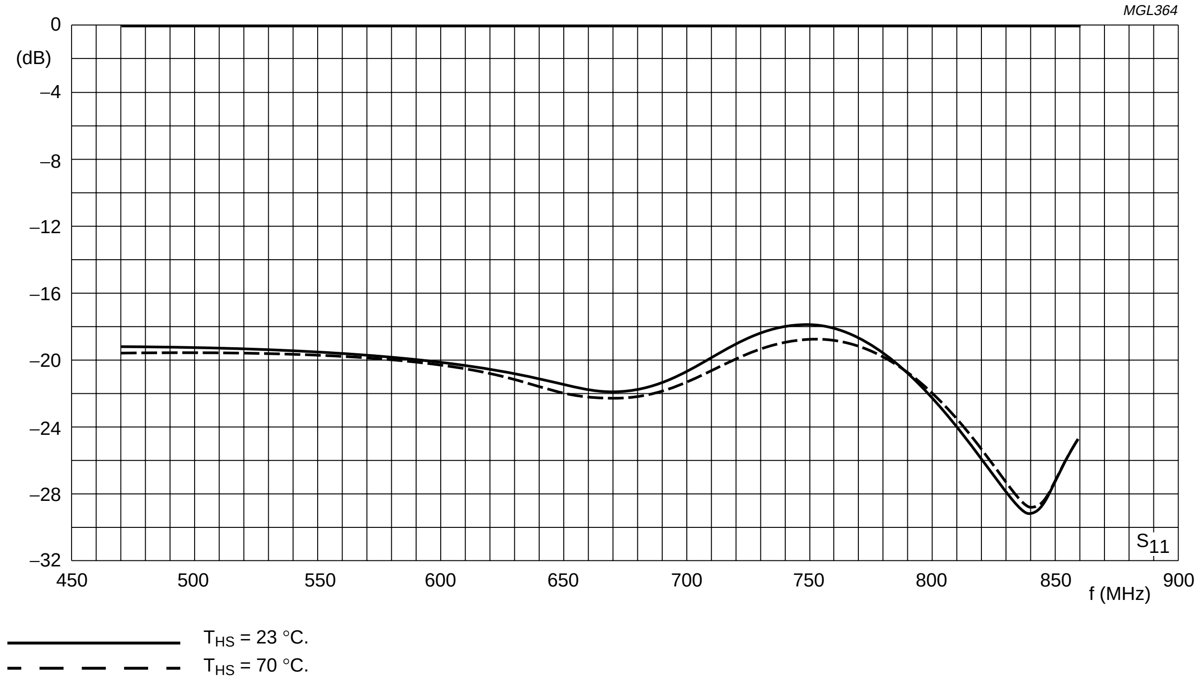

MGL364
0
(dB)
−4
−8
−12
−16
−20
−24
−28
−32
450
500
550
600
650
700
750
800
850
900
f (MHz)
S_{11}
T_{HS} = 23 °C.
T_{HS} = 70 °C.

Fig.14

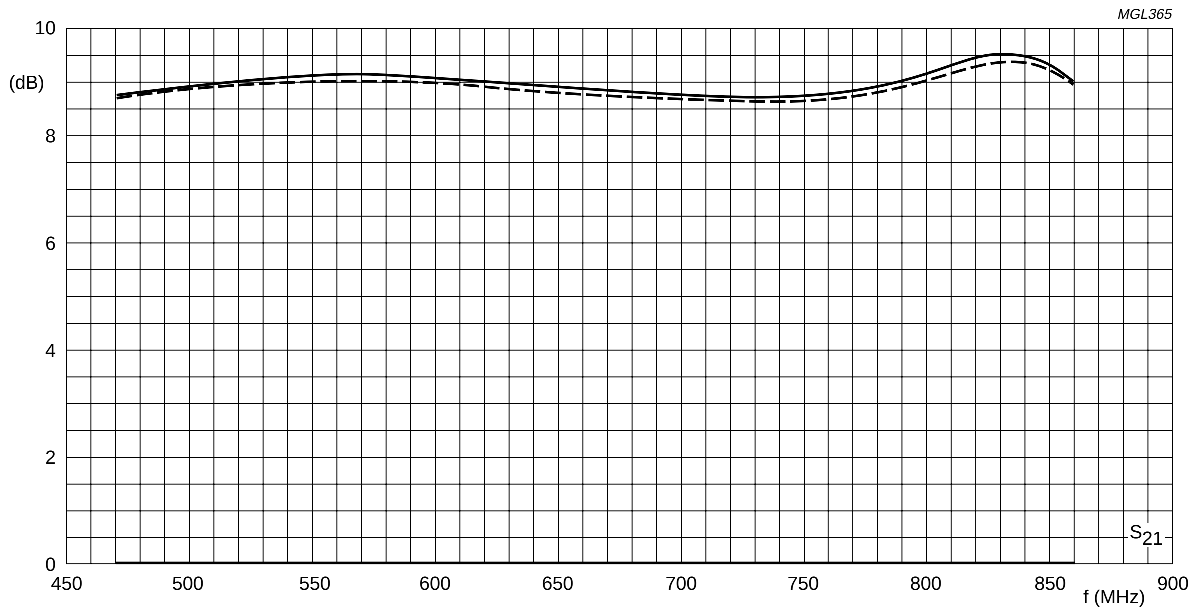

MGL365
10
(dB)
8
6
4
2
0
450
500
550
600
650
700
750
800
850
900
f (MHz)
S21

Fig.15

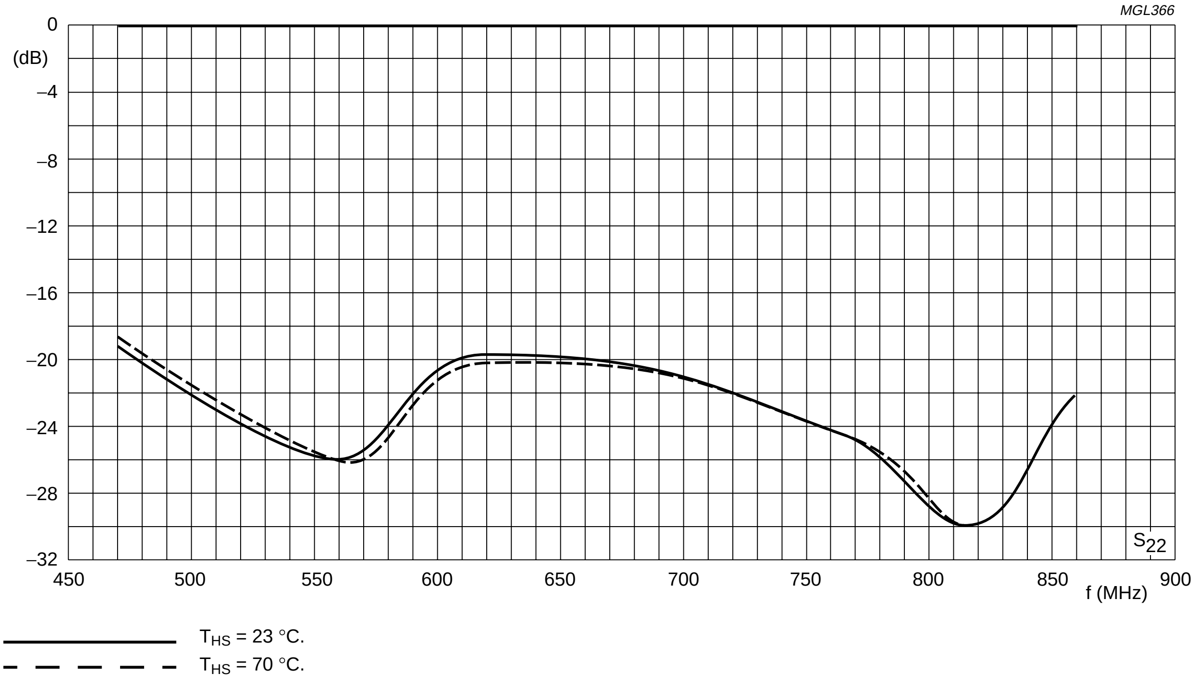

MGL366
0
(dB)
−4
−8
−12
−16
−20
−24
−28
−32
450
500
550
600
650
700
750
800
850
900
f (MHz)
S22
THS = 23 °C.
THS = 70 °C.

Fig.16

Philips Semiconductors – a worldwide company

Argentina: see South America

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

Austria: Computerstr. 6, A-1101 WIEN, P.O. Box 213, Tel. +43 160 1010, Fax. +43 160 101 1210

Belarus: Hotel Minsk Business Center, Bld. 3, r. 1211, Volodarski Str. 6, 220050 MINSK, Tel. +375 172 200 733, Fax. +375 172 200 773

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Brazil: see South America

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Czech Republic: see Austria

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