APPLICATION NOTE

Two-stage wideband HF linear amplifier for 400 W PEP using BLW96 and BLW50F

AN98030

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CONTENTS

1 PART 1
SINGLE-STAGE WIDEBAND (1.6 – 30 MHz) LINEAR AMPLIFIER FOR 400 W PEP USING TWO BLW96 TRANSISTORS

2 PART 2
A SINGLE-STAGE WIDEBAND (1.6 – 30 MHz) LINEAR AMPLIFIER FOR 25 W PEP USING BLW50F TRANSISTORS IN

3 PART 3
A TWO-STAGE WIDEBAND H.F. LINEAR AMPLIFIER FOR 400 W PEP USING TWO BLW96 AND BLW50F TRANSISTORS

SUMMARY

This report is in three parts, each numbered separately.

Part 1 shows that a wideband power amplifier module providing up to 400 W PEP from 1.6 to 30 MHz can be made using two BLW96 transistors. Operating from a 50 V supply, the IMD at 400 W PEP over the band is better than –26 dB when loaded with a 50 Ω wideband load.

Part 2 describes a suitable drive amplifier using two BLW50F transistors in class A (at the same supply voltage (50 V). The IMD of the drive amplifier is better than –40 dB into a 50 Ω load.

Part 3 describes a complete design in which the driver and main amplifiers are combined using direct inter-stage impedance transformation.

1 PART 1
SINGLE-STAGE WIDEBAND (1.6 – 30 MHz) LINEAR AMPLIFIER FOR 400 W PEP USING TWO BLW96 TRANSISTORS

1 INTRODUCTION

The design of this amplifier was to exploit the performance of the BLW96 in a wideband circuit to provide up to 400 W PEP from 1.6 to 30 MHz.

2 CIRCUIT DESCRIPTION

Figure 1 shows the circuit diagram; Fig.2a shows the circuit board layout, and Figs 2b and 3 show the component lay-out.

It will be noted that baluns are used in input and output circuits. This improves the balance of the collector currents over the frequency range, offsetting any capacitive unbalance in the impedance matching transformers.

Cross neutralisation has been found to be detrimental with these devices, the practical application of neutralisation results in excessive phase changes and results in higher intermodulation distortion over parts of the band.

The input matching network which was designed with aid of a computer program is primarily intended to provide a constant overall gain with frequency and reasonably constant load impedance to a driver circuit.

In practice, a capacitive centre tap (C_4 and C_5) at the secondary of the input impedance matching transformer T_1 is desirable, which is earthed via a 2.2 Ω resistor.

It is preferable in realising C_4 and C_5, to employ three capacitors of 470, 470 and 390 pF in parallel for both, leaving the centre connection such that alternative connections of R_1 can be selected, as shown in Fig.1. This technique allows the best compromise to be found for the intermodulation distortion peaks which typically occur between 14 and 20 MHz, and which can be undesirably high at spot frequencies. A separate, temperature compensated, bias control circuit is necessary to give adjustable constant class-AB bias condition in the BLW96 transistors. The bias circuit diagram is shown in Fig.1.

3 DESIGN DETAILS

To obtain the best performance from the amplifier over the complete range 1.6 – 30 MHz, the quality of the matching transformers used is very important as accurate impedance transformation and low losses are essential. Low losses can be achieved by using toroids of 4C6 material. To obtain accurate matching it is essential to make transformers with very low leakage reactance at 30 MHz combined with sufficient primary inductance at 1.6 MHz (Refs 1 and 2).

3.1 The output transformer

The load impedance required by the transistors is 9.6 Ω, collector to collector. A transformer is required to match to the 50 Ω load. To handle the expected power of 400 W, the transformer must be wound using two 4C6 cores each of 36 × 23 × 15 mm. The best results were obtained using two separate transformers, each on one core, and connecting primary and secondary windings in parallel to give an acceptable value of leakage reactance at 30 MHz.

The complete transformer, wound as detailed in the parts list had a secondary reactance (50 Ω winding) of 200 Ω at 1.6 MHz (20 µH) and a leakage reactance of 50 Ω at f = 30 MHz (265 nH).

3.2 The input transformer

The design impedance of the gain correction network is 5.55 Ω, so a transformer is required to match the input network to a 50 Ω drive source.

The required drive input power assuming a minimum gain of 13 dB is about 20 W which requires two 4C6 toroids 14 × 9 × 5 mm. Again, the best results were obtained by the parallel connection of two transformers each using a separate core.

The complete transformer, wound as detailed in the parts list, had a primary reactance (50 Ω winding) of 220 Ω at 1.6 MHz (22 μH) and a leakage reactance of 50 Ω at 30 MHz (265 nH).

3.3 The bias unit

The circuit uses a BD433 as the temperature sensor and a BD203 emitter follower. The unit can supply a maximum bias current of 800 mA, dependent on the value of resistor in the collector of the BD203. The bias unit should be thermally connected to the amplifier by mounting on the heatsink close to the BLW96s. The collector load resistor (three 17 W wire-wound resistors in parallel) can be mounted separately on stand-off insulators at any convenient part of the heatsink.

3.4 The centre tapped choke

The collector DC supply to each BLW96 is fed via a centre-tapped coil arrangement which consists of a ferrite aerial rod (4A10 grade or equivalent) and has an inductance of 4.6 μH which forms part of the total collector load.

4 PERFORMANCE OF THE AMPLIFIER

4.1 General

The measured performance of the amplifier i.e. intermodulation distortion, gain and input VSWR is given in Figs 4 to 7. A water-cooled heatsink was used for all measurements, and a wideband 50 Ω load was used in conjunction with a thermal power measurement system. The PEP was assumed to be twice the RMS power indicated, ignoring the harmonic content of the output signal.

4.2 Harmonic output

The amplifier was driven with C.W. signals at specific frequencies to 400, 300 and 200 W. The driving signal had a harmonic content lower than –45 dB. Harmonic component measurements are shown in Table 1.

Table 1 Harmomonic output v. frequency

LOAD POWER (W)	TEST FREQUENCY (MHz)	HARMONIC CONTENT (dB)								
		f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}
400	1.6	–31	–20	–37	–34	–39	–44	–43	–46	–52
	3.5	–36	–21	–45	–34	–63	–40	–48	–49	–47
	7	–38	–17	–47	–29	–45	–34	–64	–64	
	10	–45	–15	–45	–29	–50				
	14	–39	–16	–45	–46					
	20	–48	–24	–50	–44					
	28	–44	–41							
300	1.6	–31	–21	–39	–33	–40	–47	–43	–46	–52
	3.5	–36	–23	–45	–32	–65	–42	–48	–52	–49
	7	–40	–22	–52	–30	–48	–38	–65	–64	
	10	–48	–16	–45	–29	–50				
	14	–42	–18	–48	–47					
	20	–42	–25	–50	–46					
	28	–45	–42							
200	1.6	–32	–22	–40	–33	–42	–49	–44	–47	–55
	3.5	–35	–24	–46	–33	–65	–43	–50	–53	–50
	7	–40	–23	–62	–30	–59	–39	–65	–64	
	10	–50	–19	–45	–30	–50				
	14	–44	–19	–47	–47					
	20	–38	–27	–49	–47					
	28	–44	–42							

4.3 Collector efficiency

The collector efficiency varies over the band, and as the output matching was designed for 400 W, reduced efficiency is apparent at reduced levels of output. Typical efficiencies are:

Two-tone signals between 1.6 and 30 MHz

PEP LOAD (W)	BEST COLLECTOR EFFICIENCY (%)	WORST COLLECTOR EFFICIENCY (%)
400	50	37.7
300	44	32

Taking the worst case and assuming equal sharing and zero circuit losses, each transistor would dissipate 170 W.

C.W. signals between 1.6 and 30 MHz

P_{LOAD} (W)	BEST COLLECTOR EFFICIENCY (%)	WORST COLLECTOR EFFICIENCY (%)
400	65.5	47.5

Taking the worst case and assuming equal sharing and zero circuit losses, each transistor would dissipate 220 W.

The published RF thermal resistance of the BLW96 is 0.65 K/W (junction-heatsink) and the maximum permissible junction temperature is 200 °C. Therefore the maximum possible heatsink temperature for continuous C.W. operation is 200 – (220 × 0.65) = 57 °C.

5 BIAS ADJUSTMENT

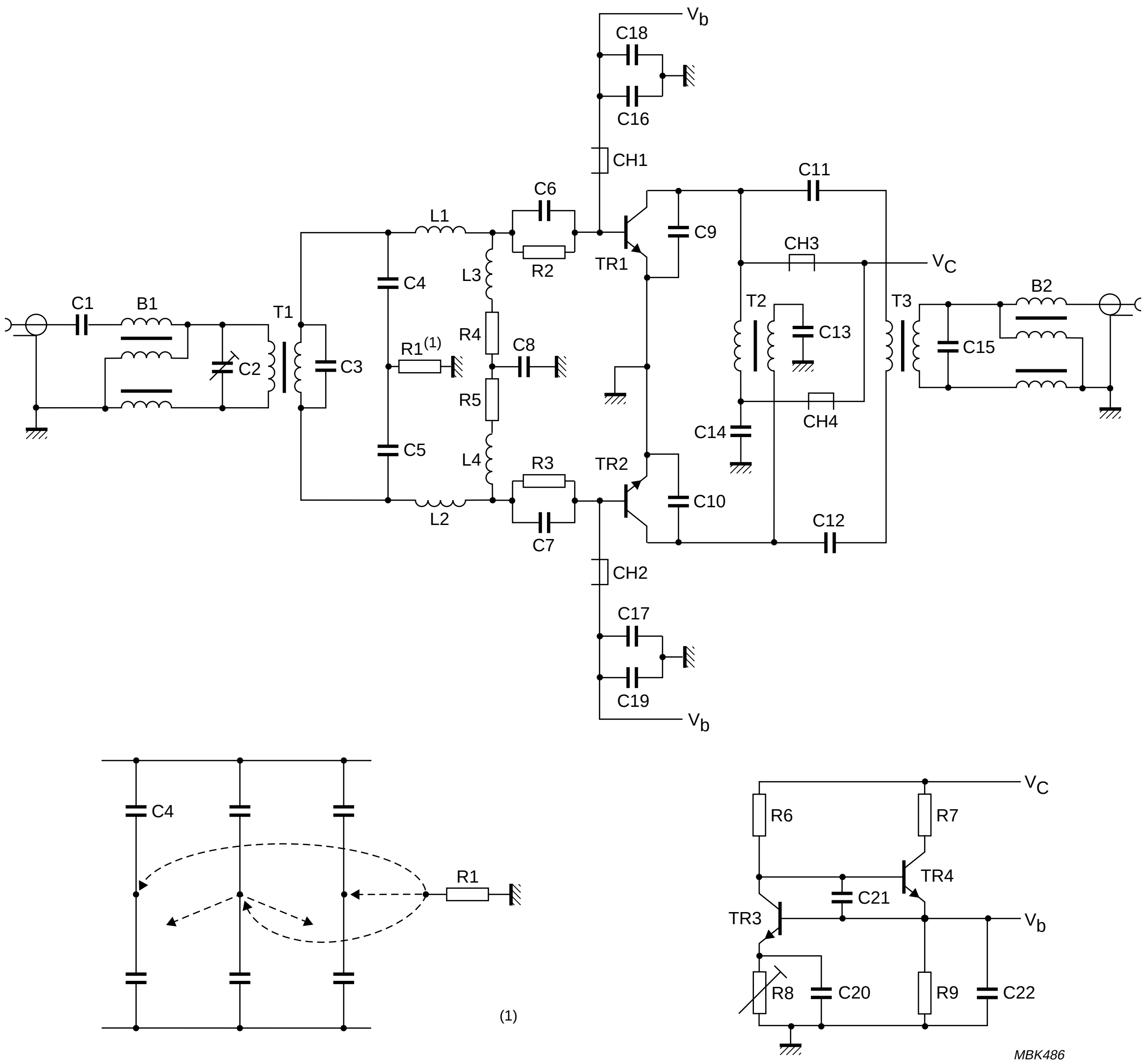
The zero signal collector currents should be adjusted by the bias potentiometer to 2 × 100 mA when operating from a 50 V supply.

6 CONCLUSIONS

- A single stage amplifier using 2 × BLW96s in class-AB can deliver up to 400 W PEP with intermodulation distortion better than –26 dB over the band 1.6 – 30 MHz.
- Measurements indicate that when used under C.W. conditions at the frequencies where the maximum collector dissipations occurs, the devices should be capable of operation with heatsink temperatures up to 57 °C.

7 REFERENCES

1. A.H. Hilbers, ‘On The Design of HF Wideband Power Transformers.’ CAB Report ECO6907.
2. A.H. Hilbers, ‘Design of HF Wideband Transformers Part II.’ CAB Report ECO7213.



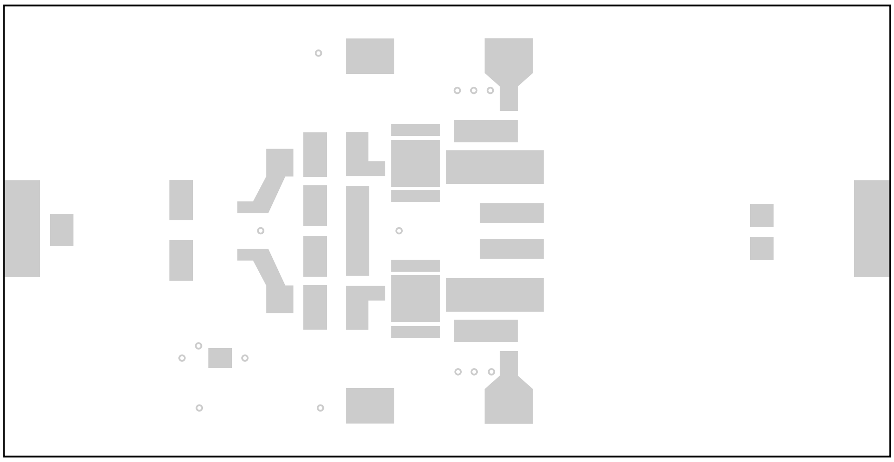
(1) See note in Chapter 2.

Fig.1 Circuit diagram of BLW96 power amplifier for 1.6 – 30 MHz, 400 W PEP, see Table 2 for parts list.

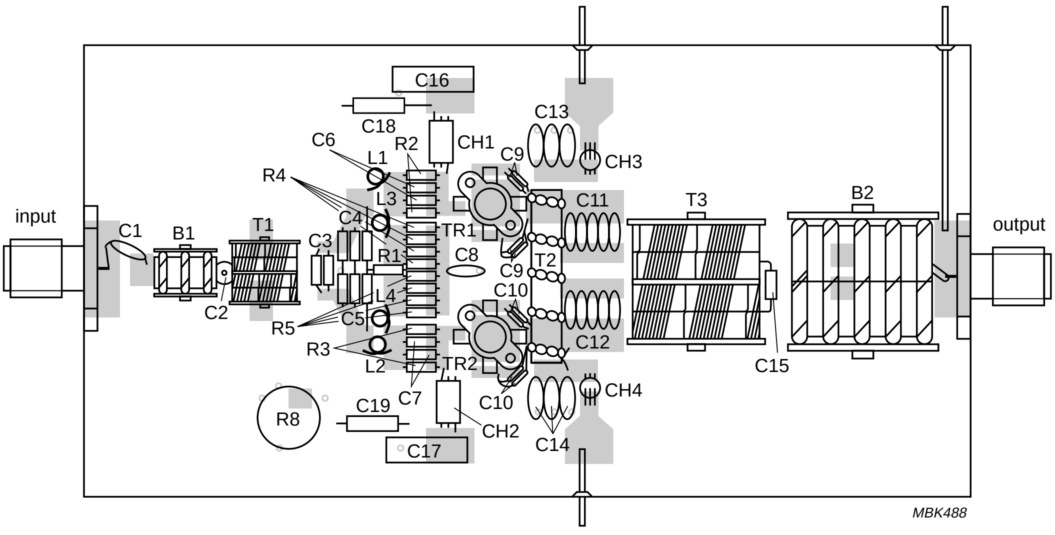
Table 2 Parts list for Fig.1

Transistors and resistors			
TR1 = TR2	BLW96		
TR3	BD433		
TR4	BD203		
R1	2.2 Ω	CR 37, ±5%	2322 212 13228
R2 = R3	18 Ω	PR 37, ±5%	2322 191 31809
R4 = R5	2 × 12 Ω, in parallel	PR 37, ±5%	2322 191 31209
	2 × 15 Ω, in parallel	PR 37, ±5%	2322 191 31509
R6	1.5 kΩ	PR 37, ±5%	2322 191 31502
R7	3 × 180 Ω, in parallel	EH 15, ±5%	2306 330 03181
R8	3.3 Ω adjustable	TPW22	2322 011 02338
R9	22 Ω	CR 37, ±5%	2322 212 13229
Capacitors			
C1	10 nF	polyester, ±20%	2222 342 44103
C2	60 pF	trimmer	2222 809 08003
C3	330 pF, in parallel	polystyrene, ±1%	2222 426 43301
	300 pF, in parallel		2222 426 43001
C4 = C5	2 × 470 pF, in parallel	polystyrene, ±1%	2222 426 44701
	1 × 390 pF, in parallel		2222 426 43901
C6 = C7	2 × 1000 pF, in parallel	polystyrene, ±1%	2222 426 44102
	1 × 820 pF, in parallel		2222 426 48201
C8	3 × 100 nF, in parallel	polyester, ±20%	2222 342 44104
C9 = C10	2 × 47 pF, in parallel	ceramic, ±2%	2222 650 34479
	2 × 56 pF, in parallel		2222 650 34569
C11 = C12	5 × 10 nF, in parallel	polyester, ±20%	2222 342 44103
C13 = C14	3 × 100 nF, in parallel	polyester, ±20%	2222 342 44104
C15	33 pF	ceramic, ±2%	2222 650 34339
C16 = C17	3.3 µF	±10%	2222 344 21335
C18 = C19	220 µF	4 V, electrolytic	2222 016 2221
C20 = C21	100 nF	polyester, ±20%	2222 342 44104
C22	220 µF	10 V, electrolytic	2222 016 4221
Inductors			
L1 = L2	12.9 nH; consists of $^3/_4$ turn of 1.3 mm Cu wire 5 mm diameter		
L3 = L4	21 nH; consists of 1 turn of 1.3 mm Cu wire 7.5 mm diameter		
Ch1 = Ch2	2.5 turns through 6 hole ferrite bead grade 3B		4312 020 31500
Ch3 = Ch4	3 parallel turns through 6 hole bead grade 3B		4312 020 31500

Transformers	
T1	Two transformers with parallel connected primary and secondary windings. Each transformer wound on 4C6 toroids 14 × 9 × 15 mm, (4322 020 91020). Primary winding consists of 10 turns of copper tape approximately 1.5 mm wide. Secondary winding consists of 30 turns of 0.45 mm chain enamelled Cu wire. Windings separated by a layer of PTFE tape approximately 0.025 mm thick.
T2	4 turns of 2 × 1.0 mm enamelled Cu wire twisted, on a 50 mm length of 4A10 or equivalent grade aerial rod 10 mm diameter, (4311 020 55390).
T3	Two transformers with parallel connected primary and secondary windings. Each transformer wound on 4C6 toroids 36 × 23 × 15 mm, (4322 020 91090). Primary winding consists of 6 turns copper tape 8.0 mm wide. Secondary winding consists of 14 turns of 4 × 0.5 mm diameter Cu wire in parallel. Windings separated by a layer of PTFE approximately 0.025 mm thick.
B1	11 turns of 50 Ω co-axial cable approximately 3 mm external diameter with PTFE dielectric and 11 turns of 0.5 mm enamelled Cu wire wound on 4C6 toroid 23 × 14 × 7 mm, (4322 020 91070).
B2	8 turns of 50 Ω co-axial cable approximately 4 mm external diameter with PTFE dielectric and 8 turns of 1 mm enamelled Cu wire wound on two 4C6 toroids 36 × 23 × 15 mm, (4322 020 91090).



a.



b.

Fig.2 BLW96 power amplifier circuit board (a) and component lay-out (b).

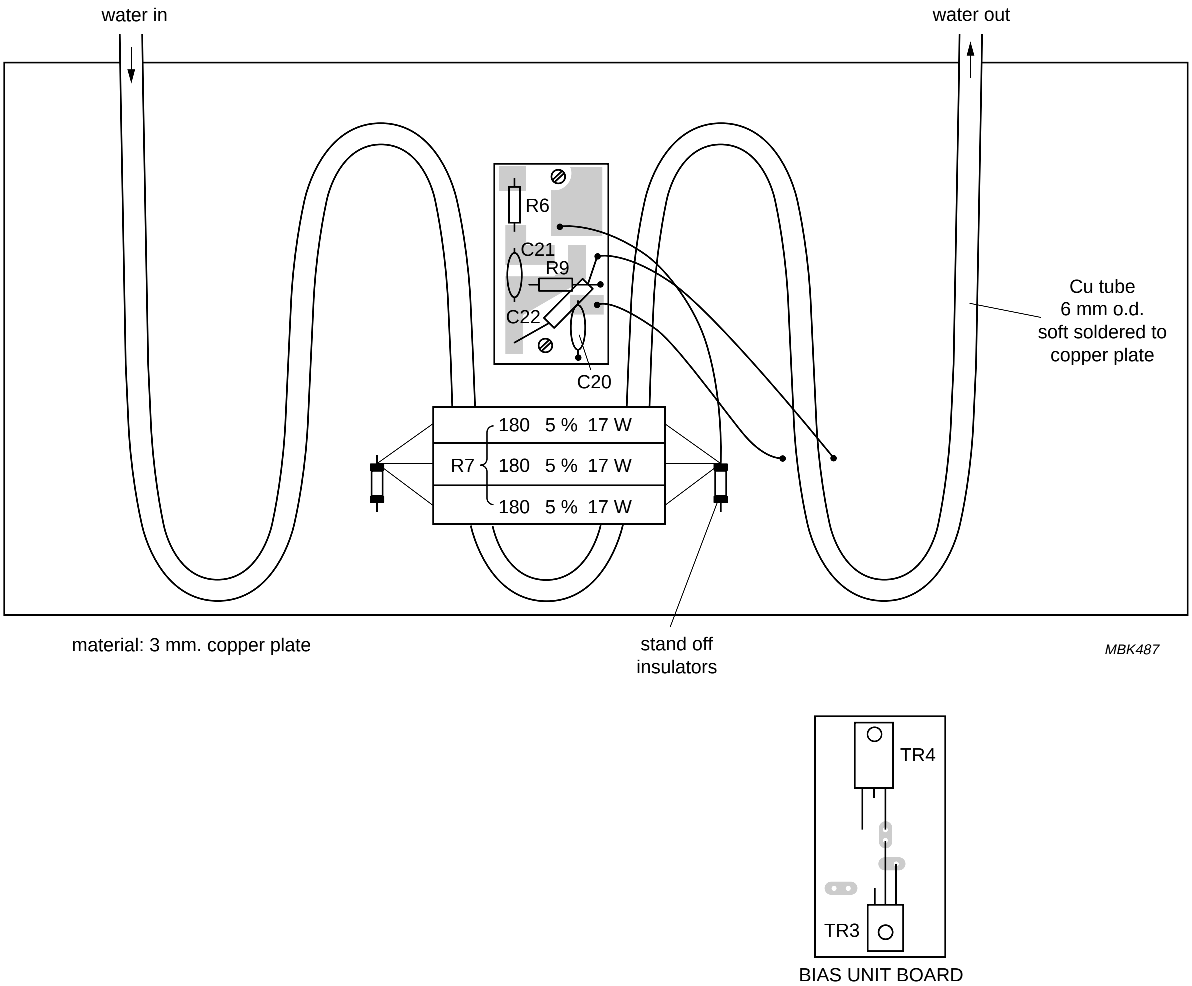


Fig.3 BLW96 power amplifier component lay-out, underside of heatsink.

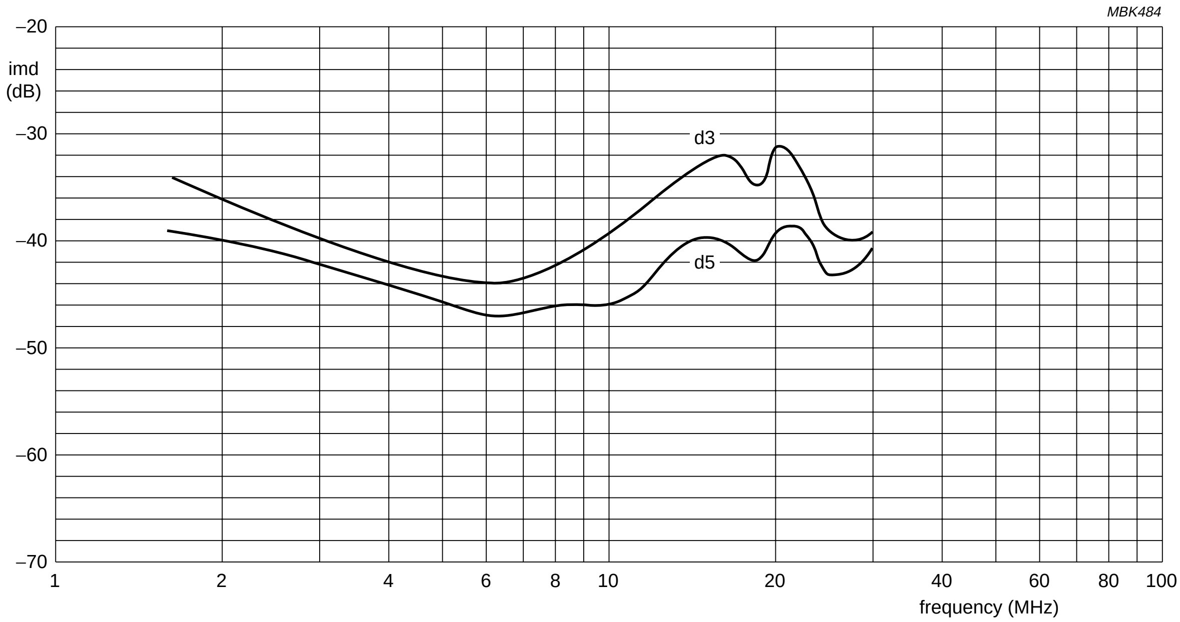


Fig.4 Intermodulation performance of BLW96 amplifier at 200 W PEP.

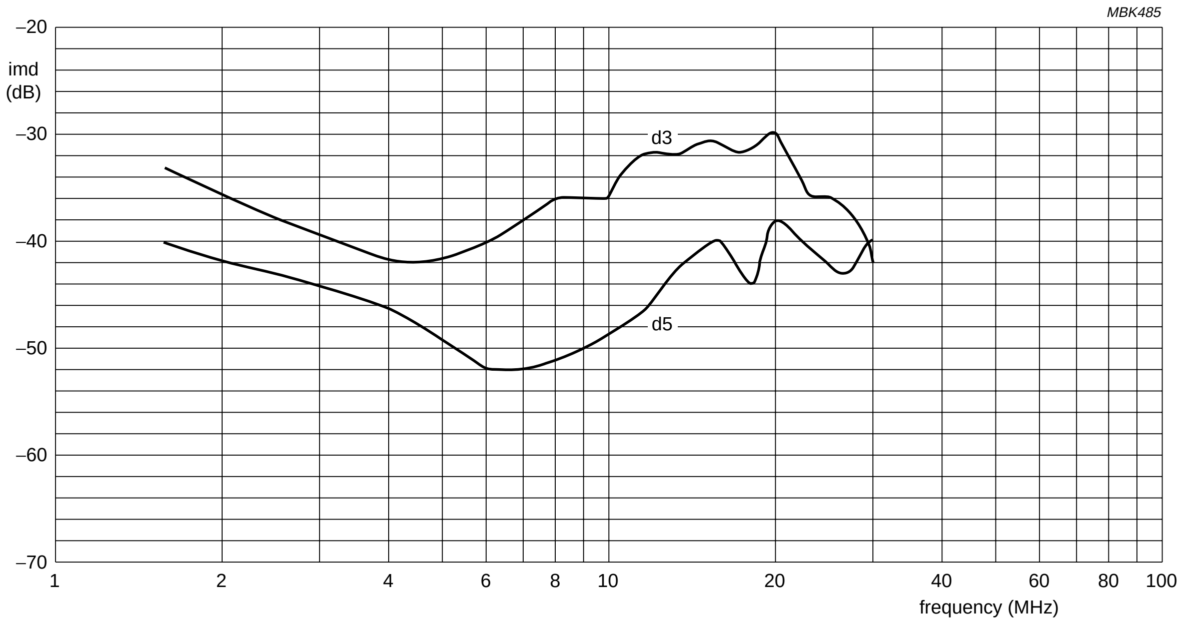


Fig.5 Intermodulation performance of BLW96 amplifier at 300 W PEP.

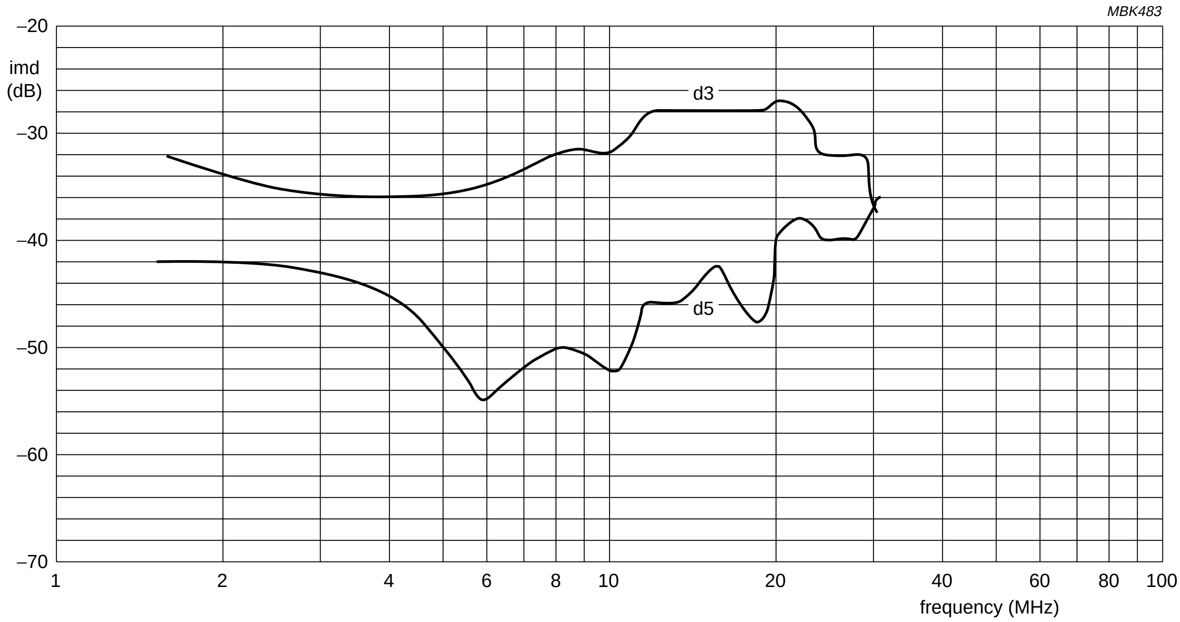


Fig.6 Intermodulation performance of BLW96 amplifier at 400 W PEP.

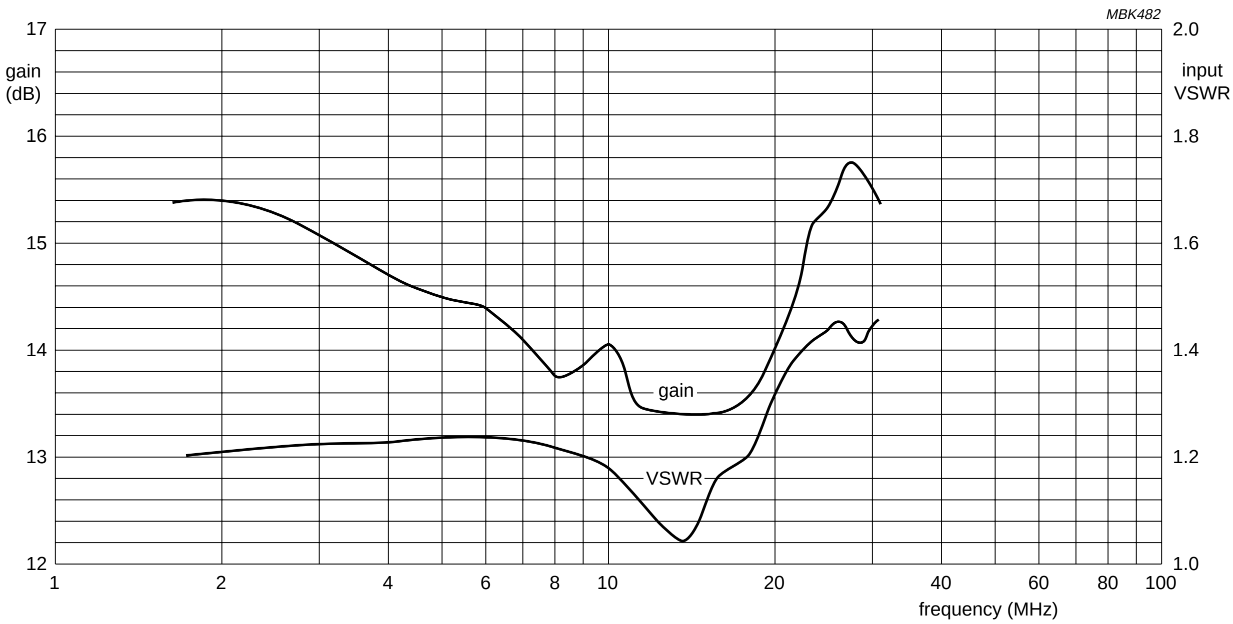


Fig.7 Gain and input VSWR of BLW96 at 400 W C.W.

2 PART 2
A SINGLE-STAGE WIDEBAND (1.6 – 30 MHz) LINEAR AMPLIFIER FOR 25 W PEP USING BLW50F TRANSISTORS IN CLASS A

1 INTRODUCTION

This amplifier was developed to drive a 400 W linear amplifier using BLW96 transistors in class AB and to provide data for future development of a two stage amplifier for the same power with both driver and p.a. stages working from a nominal 50 V supply.

The driver amplifier described herein was designed to give 25 W PEP into a 50 Ω load sufficient to drive the amplifier described in Chapter 2. Class A operation is necessary because the required intermodulation distortion of the driver circuit alone should be substantially less than that of the p.a., the driver circuit distortion being somewhat degraded when working into the non-linear input impedance of the p.a. A target figure of intermodulation products < –40 dB over the frequency band 1.6 to 30 MHz was therefore required.

As with the BLW96 p.a., 50 Ω input and output impedances were assumed initially, but direct inter-stage impedance matching is used in the two stage amplifier which will be reported subsequently.

2 GENERAL CIRCUIT DESCRIPTION

The circuit diagram of the amplifier is given in Fig.8, and follows conventional class-A push-pull linear HF amplifier design practice.

Some shunt and series feedback is applied: the shunt feedback resistors are also used to determine bias conditions.

The design and construction of the broadband input and output impedance matching transformers is critical in overall amplifier performance.

Details of these and other construction features are given in Chapter 3.

3 DESIGN AND CONSTRUCTION

3.1 Bias condition

In the design of linear class-A amplifiers, in order to arrive at the best intermodulation performance, a suitable starting point is to assume maximum bias current and voltage permitted by the maximum anticipated heatsink temperature.

In this design, therefore, a practical maximum operating heatsink temperature of 70 °C was assumed. At this heatsink temperature, the practical bias conditions for the BLW50F of V_{CE} = 44 V, I_C = 1 A are permissible.

Note that the BLW96 amplifier of Part 1 shows a worst case gain of about 13.5 dB and a worst case VSWR of about 1.45 (these two conditions do not occur at the same frequency however). But, conservatively, we may say that a suitable driver should be capable of about 18.7 W in a 50 Ω load.

In addition, if this power (18.7 W) is to be available at intermodulation products d3, d5, < –40 dB, experience has shown that the maximum available power from the amplifier (class A) into a linear resistive load should approach 35 W, at which power intermodulation products will of course exceed –40 dB.

Further, with the circuit configuration chosen (Fig.8), it will be seen that appreciable power is dissipated in the shunt feedback resistors.

We expect about 15% of the available power will be so dissipated; therefore the maximum available power requirement becomes about 40 W from the transistors.

The projected initial bias conditions, V_{CE} = 44 V, I_C = 1 A correspond to a collector dissipation of 44 W per transistor. Under class-A operation, the maximum output power would then be 22 W per transistor, 44 W total.

There is therefore some margin compared with the estimated capability requirement of 35 W and this is reasonable, in part because some further degradation of intermodulation performance may be expected when directly driving into the somewhat non-linear input impedance of the p.a., instead of the linear, non reactive design load (50 Ω).

Having chosen V_{CE} = 44 V, a further voltage drop of 2 V may be assumed across the external emitter resistor for bias stabilisation.

3.2 Components and lay-out

Figure 9 gives details of the circuit board and component lay-out. The parts list in Table 3 includes details of wound components including the two wideband matching transformers.

A suitable heatsink must be provided, sufficient to limit the junction temperature to <200 °C under DC (bias) conditions.

The total current required at 46 V is about 2.25 A, which includes base bias current flowing in the feedback resistors.

The total dissipation of the BLW50F transistors is, however approximately 44 × 2 = 88 W.

The feedback resistors and external emitter resistors together dissipate a further 14 W approximately.

If these resistors are mounted so that they do not contribute to the heatsink surface temperature close to the transistors, then the required heatsink thermal resistance, $\theta_{h\text{-}amb}$, which determines a heatsink temperature of 70 °C in a 25 °C laboratory ambient, for example is given by: $\theta_{h\text{-}amb} \leq \frac{70 - 25}{88}$

i.e. <0.51 °C/W.

To obtain the best compromise between input VSWR and gain, particularly between 26 and 30 MHz, C_2 is made adjustable; this accommodates the inevitable spread of leakage reactance of the input transformer T_1.

Similarly, to allow for leakage reactance spreads in T_2, C_3 is also made adjustable.

4 AMPLIFIER PERFORMANCE

Figures 10 and 11 show the measured amplifier performance.

Figure 11 shows 3rd and 5th order intermodulation products relative to the amplitude of each tone (6.25 W) under standard 2-tone drive conditions.

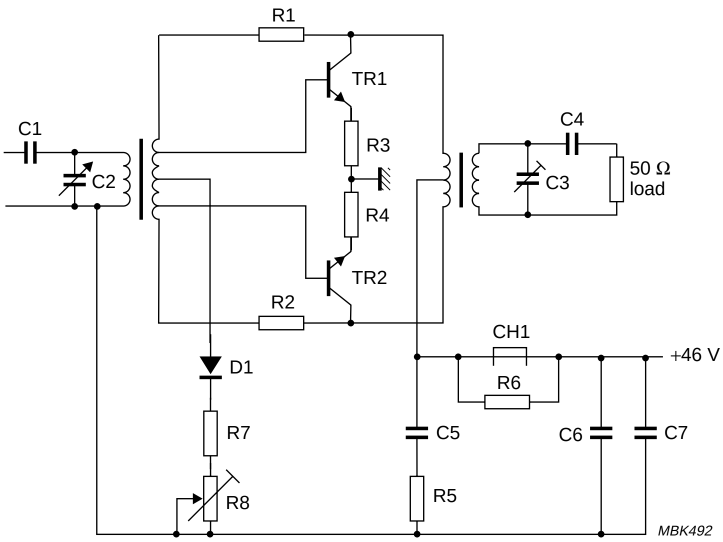
Figure 10 shows amplifier gain and input VSWR under single tone drive at P_{load} = 25 W.

Note that d_3 is substantially < –40 dB over the frequency range of interest; the minimum gain and worst case VSWR are 15.7 dB, 1.36 respectively, both occurring at the lower frequencies.

5 CONCLUSIONS

A wideband linear HF amplifier has been designed and constructed, using BLW50F transistors in class A which can give up to 25 W PEP over the band 1.6 to 30 MHz with 3rd and 5th order intermodulation better than –40 dB between 2 and 28 MHz.

Amplifier gain and input VSWR are better than 15.7 dB and 1.4:1 respectively over the frequency range. The amplifier should be suitable to drive a further linear amplifier using BLW96s in class AB to 400 W PEP.



D1 = BY206;
TR1, TR2 = BLW50F.

Fig.8 Circuit diagram of 25 W linear amplifier.

Table 3 Parts list for Fig.8

Resistors			
R1 = R2	2 × 200 Ω, in series	PR52, ±5%	2322 192 32001
R3 = R4	5 × 12 Ω, in parallel	CR25, ±5%	2322 211 13129
R5	6.8 Ω	CR25, ±5%	2322 211 13688
R6	22 Ω	CR37, ±5%	2322 211 13229
R7	15 Ω	CR25, ±5%	2322 211 13159
R8	3.3 Ω, adjustable	TPW22	2322 011 02338
Capacitors			
C1 = C4	10 nF	polyester, ±20%	2222 352 44103
C2 = C3	60 pF	trimmers	2222 809 08003
C5	22 nF	polyester, ±20%	2222 352 44223
C6 = C7	2 × 47 nF, in parallel	polyester, ±20%	2222 352 44473
Transformers			
T1	1 : 1.5 turns ratio, wound on twin hole bead Philips grade 4B1, (4312 020 31525). Primary 4 turns of 2 × 0.45 mm enamelled Cu wire in parallel, tapped at centre and 2 × 1 turn from centre.		
T2	1 : 1.4 turns ratio, wound on a Philips 4C6 toroid 23 × 14 × 7 mm, (4322 020 91070). Primary 22 turns of 2 × 0.45 mm enamelled Cu wire centre tapped. Secondary 16 turns of copper tape approx. 1.5 mm wide. Primary wound on top of secondary winding and insulated by PTFE tape approximately 0.025 mm thick.		
Ch1	2.5 turns on 6 hole bead grade 3B, (4312 020 31500).		

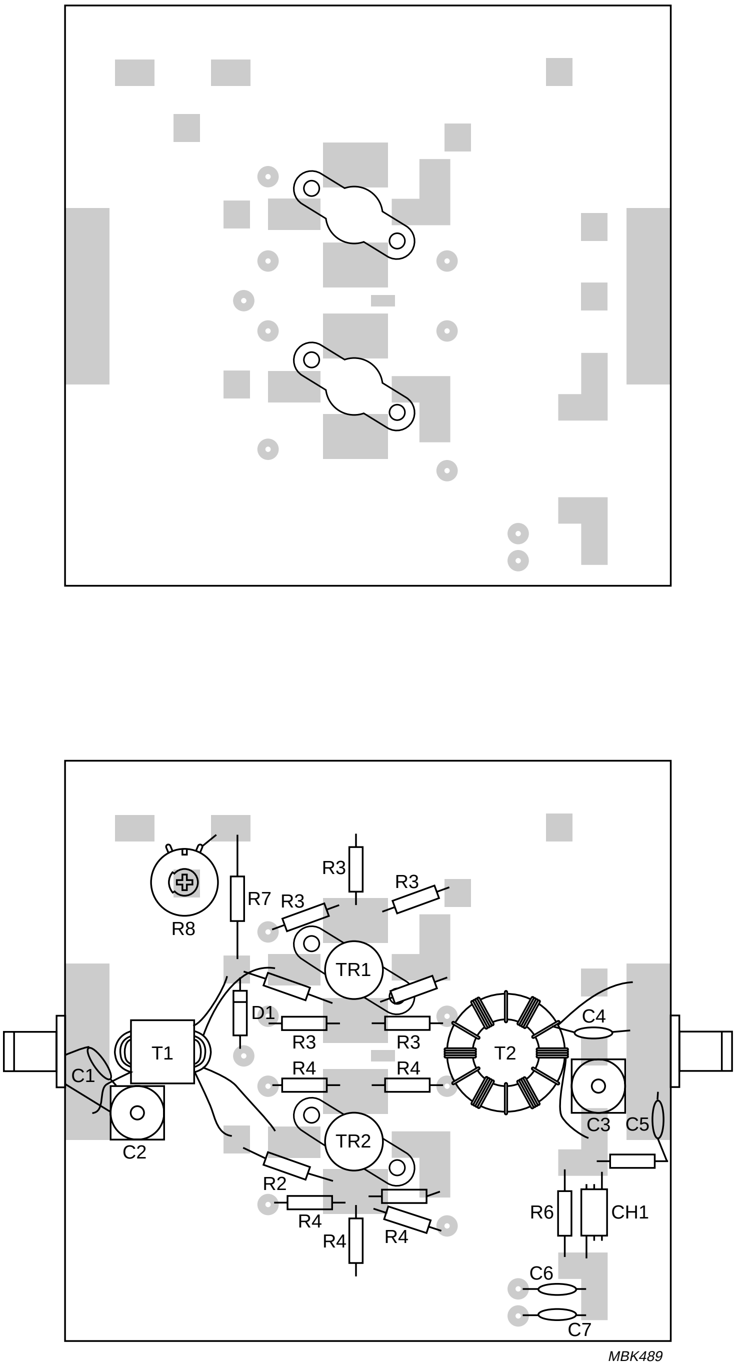


Fig.9 Printed circuit board and lay-out.

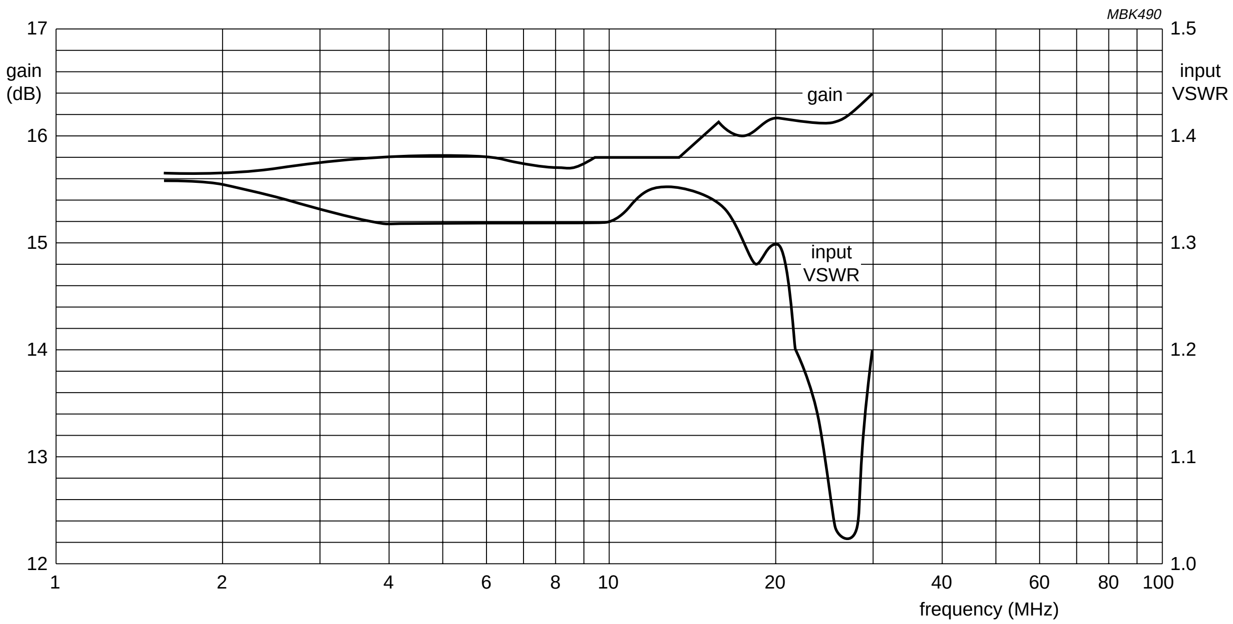


Fig.10 BLW50F linear amplifier gain and input VSWR versus frequency.

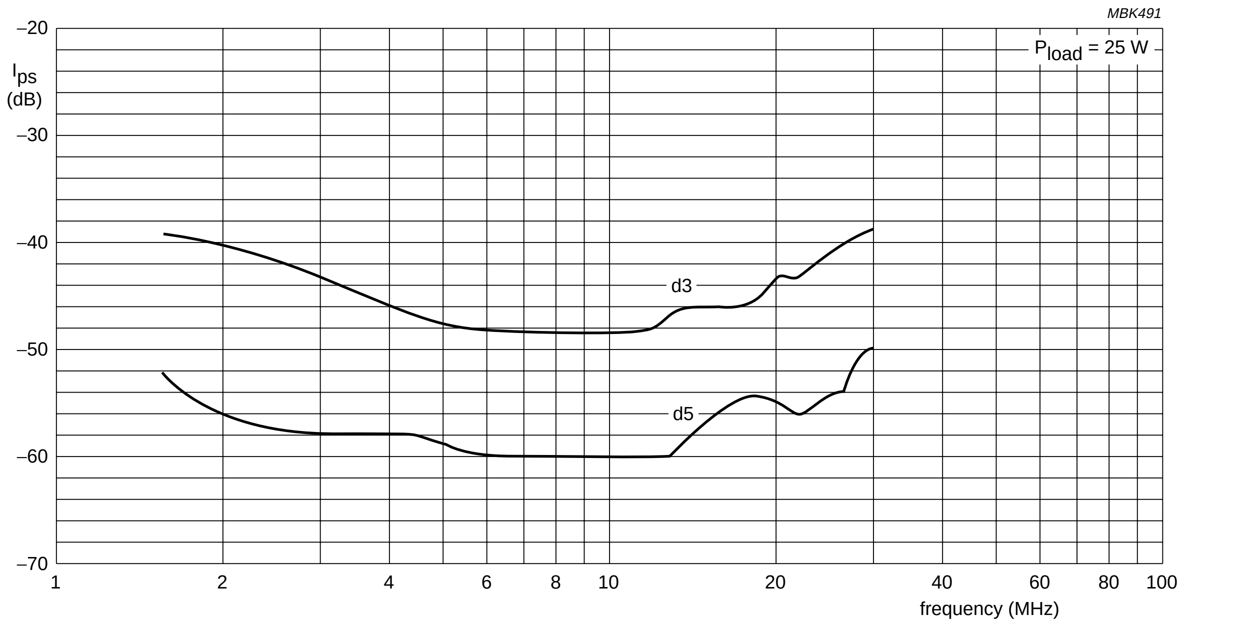


Fig.11 BLW50F linear amplifier-intermodulation products versus frequency.

3 PART 3 A TWO-STAGE WIDEBAND H.F. LINEAR AMPLIFIER FOR 400 W PEP USING TWO BLW96 AND BLW50F TRANSISTORS

1 INTRODUCTION

It has been shown in Part 1 that two BLW96 transistors in a wideband class-AB push-pull amplifier can give 400 W PEP under two-tone drive with intermodulation products < –26 dB in the band 1.6 – 30 MHz.

Part 2 described a suitable drive amplifier using two BLW50F transistors in class-A at the same supply voltage (50 V nominal). The intermodulation performance of the drive amplifier is < –40 dB into a 50 Ω load.

The two amplifiers have been combined using direct inter-stage impedance transformation and the overall design is described here in Part 3.

2 CIRCUIT DESCRIPTION

The circuit diagram of the complete amplifier is shown in Fig.12.

Standard design practice for the individual BLW96 and BLW50F push-pull linear amplifiers has been closely followed. The differences are:

1. Direct impedance matching between the driver stage output (100 Ω) and the p.a. input (5.5 Ω).
2. Replacement of adjustable capacitors by fixed-value capacitors, because it is considered impractical to have the complication of adjustments in a two-stage circuit.

   The fixed capacitors are chosen to compensate for leakage reactance of cricital transformers towards the higher frequency limit of the band, assuming good winding and mounting technique.
3. Omission of the balun and adjustable centre-tap arrangement in the p.a. input circuits, which are unnecessary with balance provided by a push-pull driver.

3 CONSTRUCTIONAL DETAILS

Figure 14 shows the printed circuit board and component layout.

Figure 15 shows the general arrangement of a water-cooled copper heatsink on the underside of which the temperature compensated p.a. bias unit is mounted.

The parts list (Table 5) includes winding instructions and inductors and transformers.

4 AMPLIFIER PERFORMANCE

The separate performance of the basic driver and p.a. circuits with 50 Ω terminations is summarised below

	DRIVER	P.A.
Bias		
V_{CE}	44 V	50 V
I_C	2 × 1 A	2 × 100 mA (zero signal)
Single tone 1.6 – 30 MHz		
P_L	25 W	400 W
Gain		
(mid band)	15.8 dB	13.4 dB
(min., max.)	15.7 dB, 16.4 dB	13.4 dB, 15.8 dB
Input VSWR		
(mid band)	1.35 : 1	1.1 : 1
(max)	1.36 :1	1.45 : 1
Two tone 1.6 – 30 MHz		
P_L (PEP)	25 W	400 W
Efficiency		37.7% (min)
3rd order intermodulation		
(mid band)	–46 dB	–28 dB
(max)	–39 dB	–27 dB

4.1 GAIN, VSWR and INTERMODULATION

The overall performance of the two stage amplifier is shown in Figs 16 to 20.

Figure 16 shows gain and input VSWR under single tone drive with 50 V supply and P_{load} = 400 W. Minimum gain and VSWR are seen to be 25 dB and 2 : 1 respectively. Figures 17 to 19 show 3rd and 5th order intermodulation under two tone drive conditions with 50 V supply and P_{load} 200, 300 and 400 W PEP.

It is seen that at 400 W PEP, $d_3 < -26$ dB, and at 300 W PEP, $d_3 < -30$ dB.

In addition, Fig.20 shows intermodulation performance at 300 W PEP, but with 45 V supply. It is seen that d_3 is still < -30 dB.

4.2 Harmonic content

The amplifier was driven to 400 W C.W. and the amplitude of the harmonics measured relative to the fundamental signal in the wideband load.

Table 4

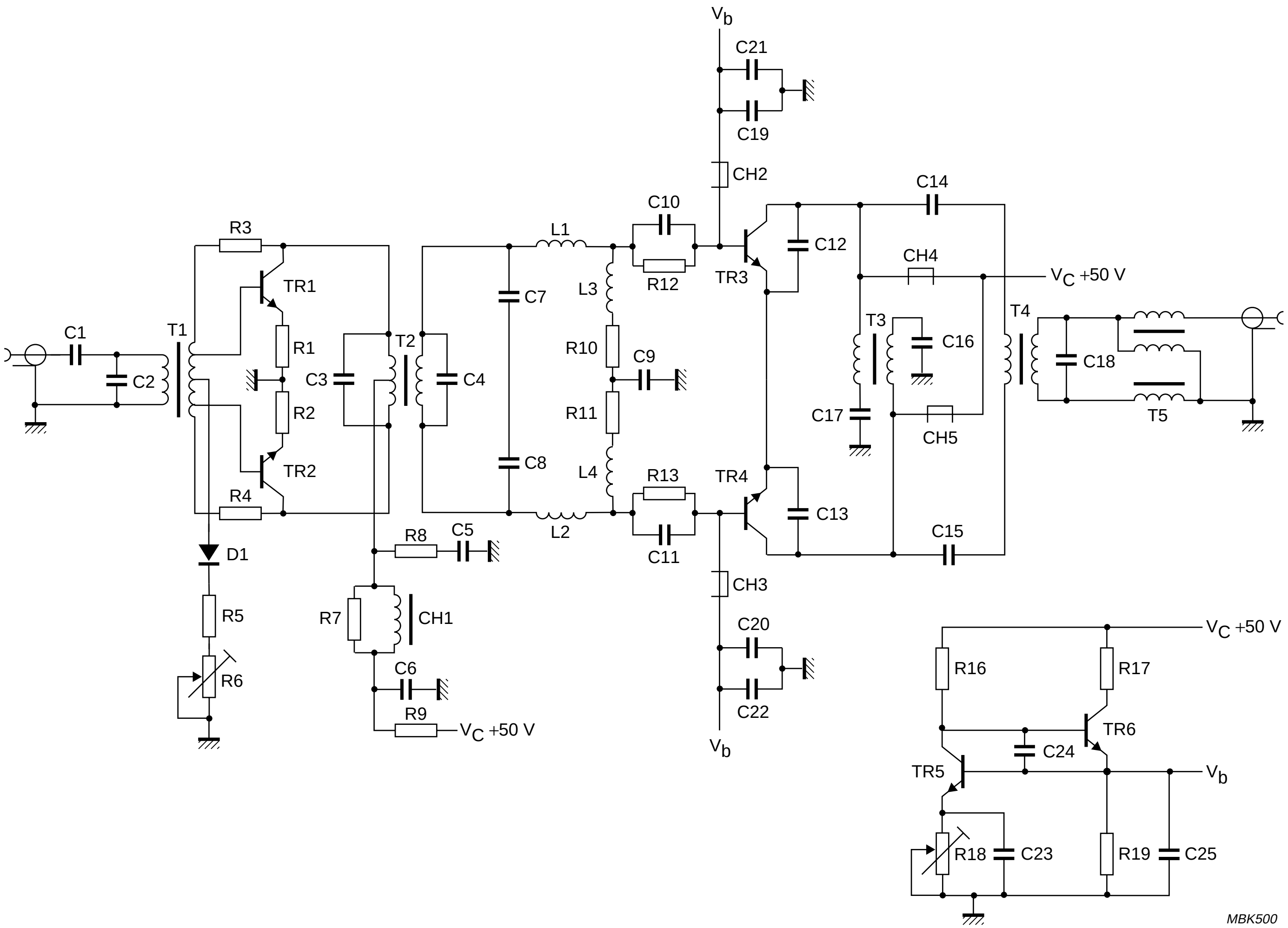
TEST FREQUENCY (MHz)	f_2 (dB)	f_3 (dB)	f_4 (dB)	f_5 (dB)	f_6 (dB)	f_7 (dB)	f_8 (dB)	f_9 (dB)	f_{10} (dB)
1.6	–46	–19	–56	–34	–48	–48	–50	–45	–59
3.5	–45	–19	–50	–33	–58	–44	–56	–45	–60
7	–54	–18	–50	–29	–48	–40			
10	–48	–17	–45	–32	–55	–50			
14	–43	–16	–50	–44					
20	–34	–25							
28	–40	–45							

5 CONCLUSION

A wideband linear HF amplifier has been designed using BLW96 output and BLW50F driver transistors. The overall amplifier gain is in the range 25 – 29 dB over the band 1.6 – 30 MHz and the input VSWR is less than 2:1.

When operated at 400 W PEP, the (2-tone) intermodulation products are < –26 dB.

An intermodulation product of < –30 dB may be obtained at 300 W PEP even with the supply rail reduced to 45 V.



L1, L2 = 1 turn 1.3 mm Cu wire 5 mm dia.
L3, L4 = 1 turn 1.3 mm Cu wire 7.5 mm dia.

Fig.12 Circuit diagram of the complete amplifier.

Table 5 Parts list for Fig.12

Resistors			
R1, R2	5 × 12 Ω, in parallel	CR25, ±5%	2322 211 13129
R3, R4	2 × 200 Ω, in series	PR52, ±5%,	2322 192 32001
R5	15 Ω	CR25, ±5%	2322 211 13159
R6 = R18	3.3 Ω, adjustable	TPW22	2322 011 02338
R7 = R14 = R15	22 Ω	CR25, ±5%	2322 211 13229
R8	6.8 Ω	CR25, ±5%	2322 211 13688
R9	1.8 Ω	AC10, ±10%	2322 329 10188
R10 = R11	18 Ω	PR37, ±5%	2322 212 31209
R12 = R13	2 × 12 Ω, in parallel	PR37, ±5%	2322 212 31209
	2 × 15 Ω, in parallel		2322 212 31509
R16	1.5 kΩ	PR37, ±5%	2322 212 31502
R17	3 × 180 Ω, in parallel	EH15, ±5%	2322 330 03181
R19	22 Ω	CR37, ±5%	2322 212 13229
Capacitors			
C1 = C23 = C24	10 nF	polyester, ±20%	2222 352 44103
C2	39 pF	ceramic, ±2%	2222 632 10399
C3	27 pF	ceramic, ±2%	2222 632 10279
C4	680 pF	polystyrene, ±2%	2222 426 6801
C5	22 nF	polyester, ±20%	2222 352 44223
C6	2 × 47nF, in parallel	polyester, ±20%	2222 352 42473
C7 = C8	2 × 470 pF, in parallel	polyester, ±2%	2222 426 4701
	1 × 390 pF, in parallel	polyester, ±2%	2222 426 3901
C9 = C10	2 × 1000 pF, in parallel	polyester, ±2%	2222 426 1002
	1 × 820 pF, in parallel	polyester, ±2%	2222 426 8201
C11	100 nF	polyester, ±20%	2222 352 44104
C12 = C13	2 × 47 pF, in parallel	ceramic, ±2%	2222 632 34479
	2 × 56 pF, in parallel	ceramic, ±2%	2222 632 34569
C14 = C15	5 × 10 nF, in parallel	polyester, ±20%	2222 352 44103
C16 = C17	3 × 100 nF, in parallel	polyester, ±20%	2222 352 54104
C18	60 pF	trimmer	2222 809 08003
C19 = C20	3.3 µF	polyester, ±10%	2222 344 21335
C21 = C22	220 µF	4 V, electrolytic	2222 016 2221
C25	220 µF	10 V, electrolytic	2222 016 4221
Inductors			
Ch1 = Ch2 = Ch3	2.5 turns through 6 hole ferrite bead grade 3B		4312 020 31500
Ch4 = Ch5	3 parallel loops through 6 hole ferrite bead grade 3B		4312 020 31500
L1 = L2	13.9 nH; see diagram on Fig.12		
L3 = L4	21 nH; see diagram on Fig.12		

Transformers	
T1	1:1.5 turns ratio, wound on twin hole bead Philips grade 4B1 (4312 020 31525). Primary: 4 turns of 2 × 0.45 mm enamelled Cu wire in parallel. Secondary: 6 turns of 2 × 0.45 mm enamelled Cu wire in parallel tapped at centre and at 2 × 1 turns from centre. See Fig.13. Typical primary reactance at f = 1.6 MHz = (secondary o/c) = j160, typical leakage reactance at f = 30 MHz = (secondary s/c) = j25.
T2	4.5 : 1 turns ratio. Consists of two transformers with primary and secondary windings connected in parallel, each wound on twin hole bead Philips grade 4B1 (4312 020 31500). Primary winding 9 turns 0.45 mm enamelled Cu wire centre tapped. Secondary 2 turns of 2 × 0.45 mm enamelled Cu wire in parallel. Typical primary reactance of combination at f = 1.6 MHz (secondary o/c) = j400. Typical leakage reactance of combination at f = 30 MHz (secondary s/c) = j90.
T3	The centre tapped choke, wound on a 50 mm length of 4A10 aerial rod (or equivalent), (4311 020 55390), 4 turns of twisted enamelled Cu wire 1.0 mm, typical total reactance at f = 1.6 MHz = j40.
T4	2.33 : 1 turns ratio, consists of two transformers with primary windings and secondary windings connected in parallel, each wound on 4C6 toroids 36 × 23 × 15 mm (4322 020 91090). Primary winding 6 turns of Cu tape 8 mm wide. Secondary winding 14 turns of 4 × 0.5 mm enamelled Cu wire in parallel. Windings are separated by PTFE tape approximately 0.25 mm thick. Typical primary reactance of combination at f = 1.6 MHz (primary o/c) = j200. Typical leakage reactance of combination at f = 30 MHz (primary s/c) = j50.
T5	Output balun transformer. Wound on two 4C6 toroids 36 × 23 × 15 mm, (4322 020 91090), with 8 turns of 50 Ω coaxial cable having PTFE insulation and approximately 4 mm external diameter and 8 turns of 1 mm enamelled Cu wire for the balancing winding - see diagram

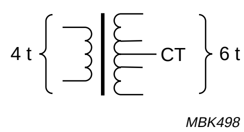


Fig.13 Transformer T_1.

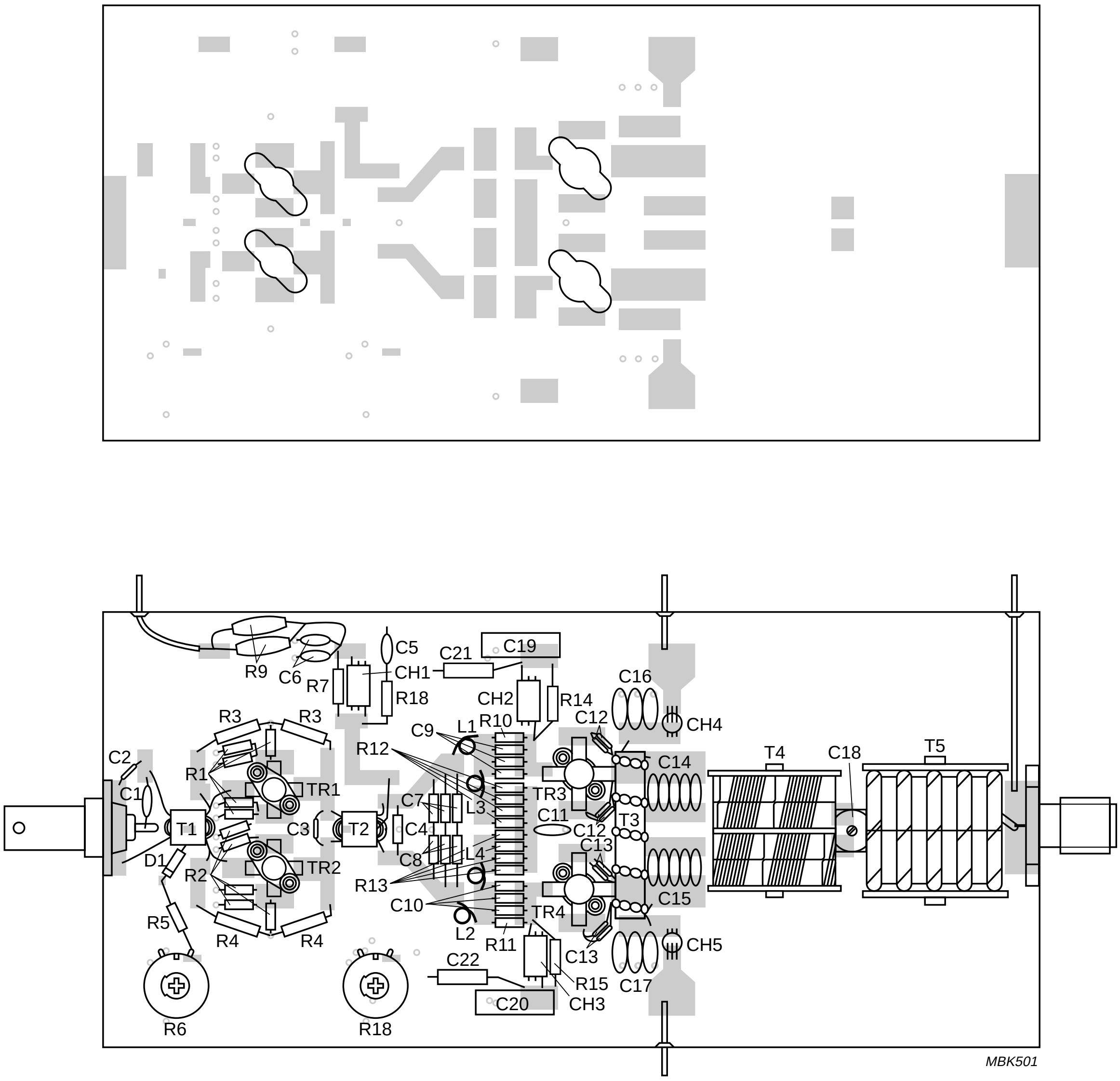


Fig.14 Printed circuit board and lay-out.

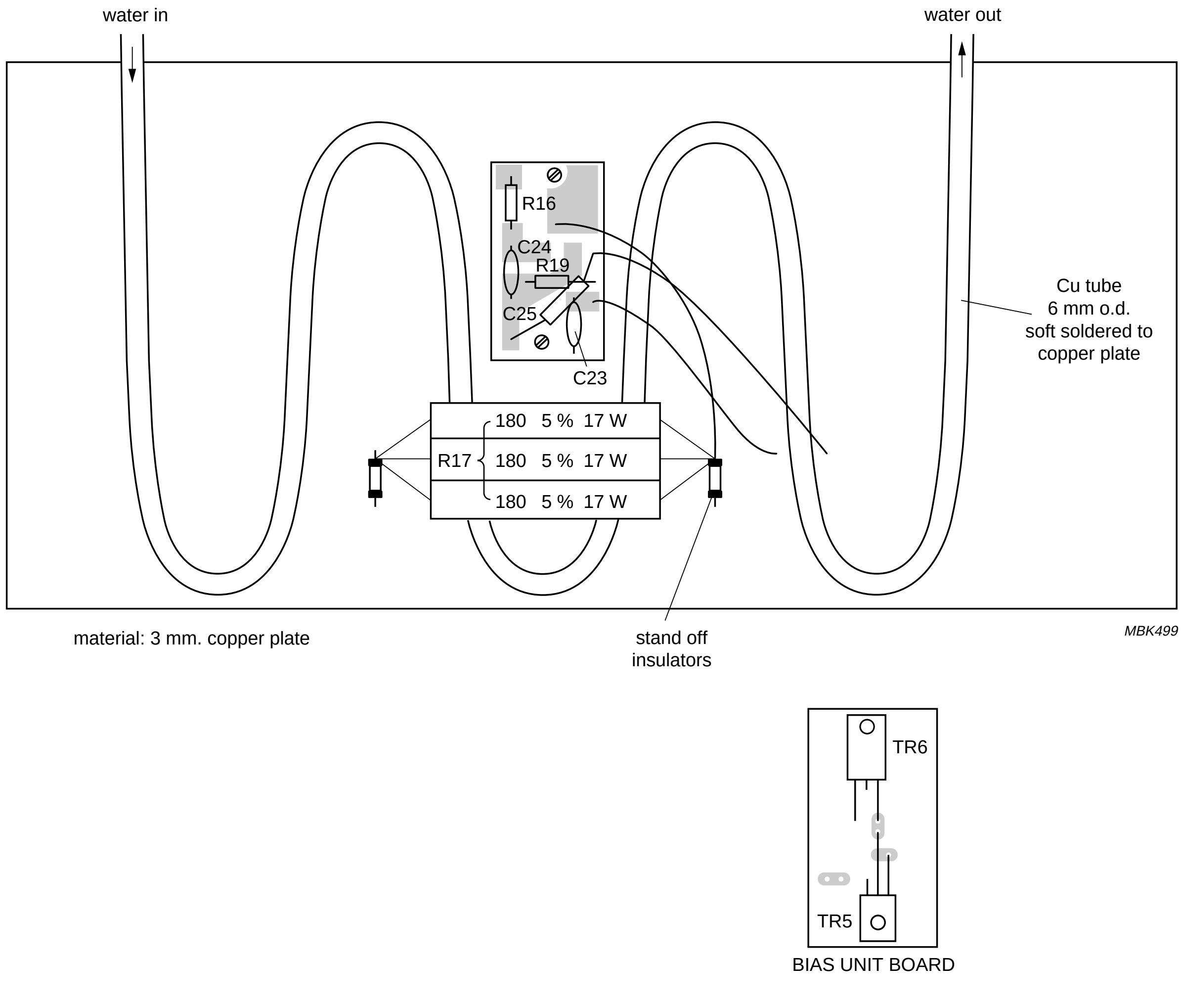


Fig.15 Water cooled heatsink.

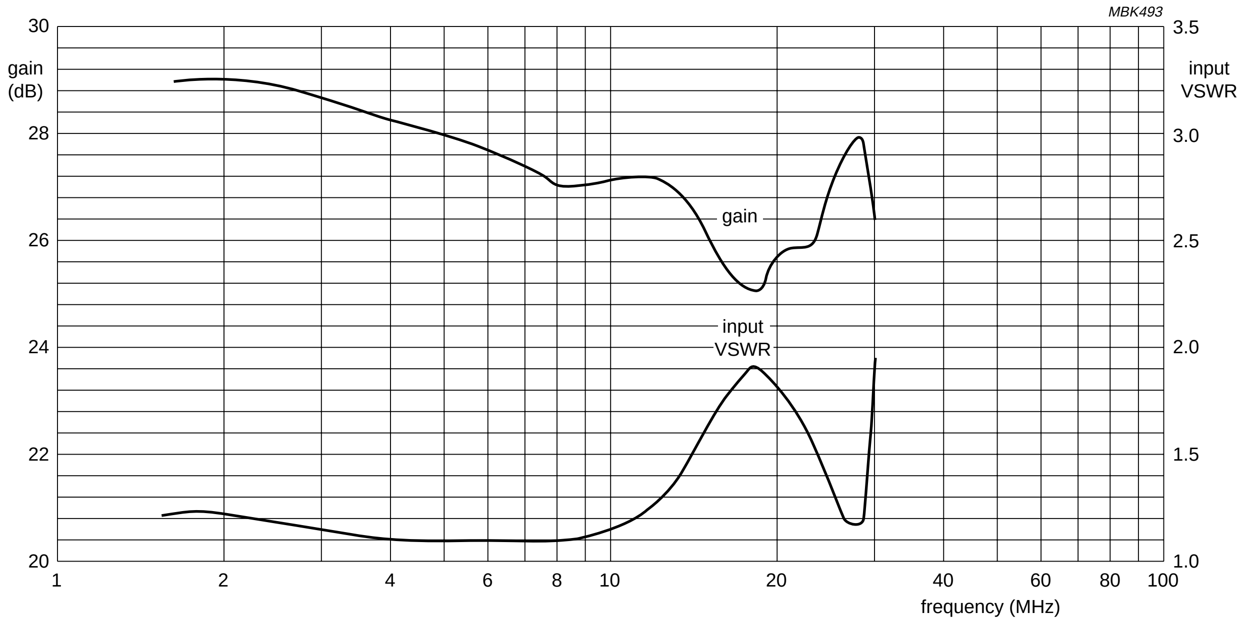


Fig.16 Amplifier gain and VSWR.

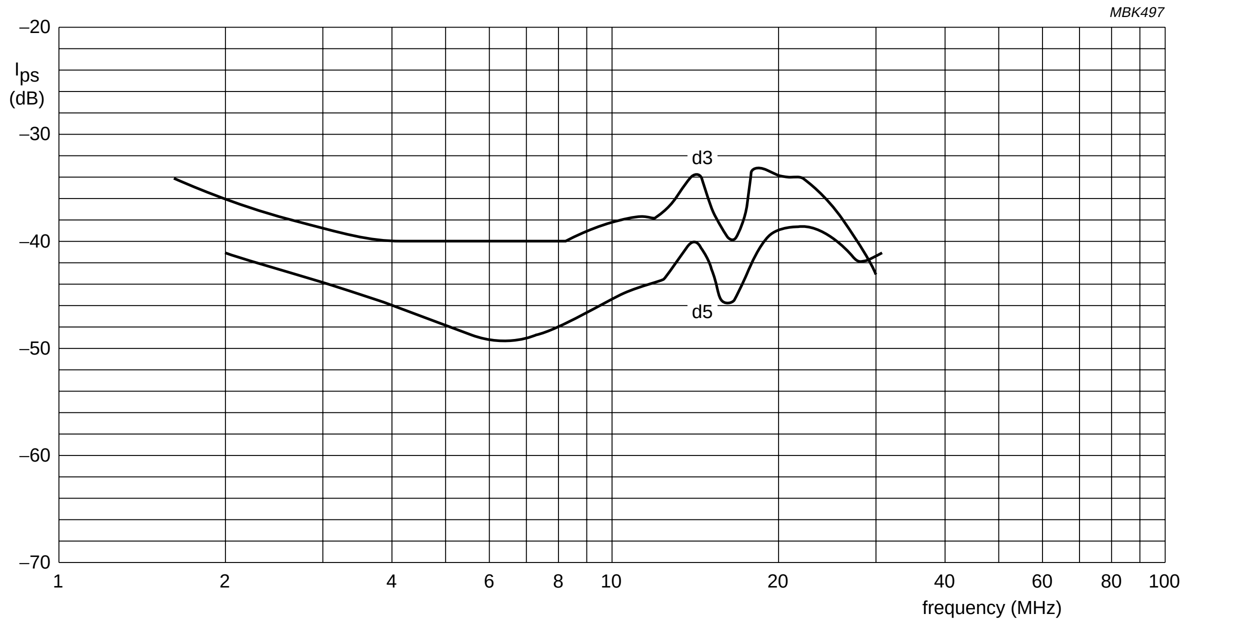


Fig.17 Intermodulation performance (50 V, 200 W PEP).

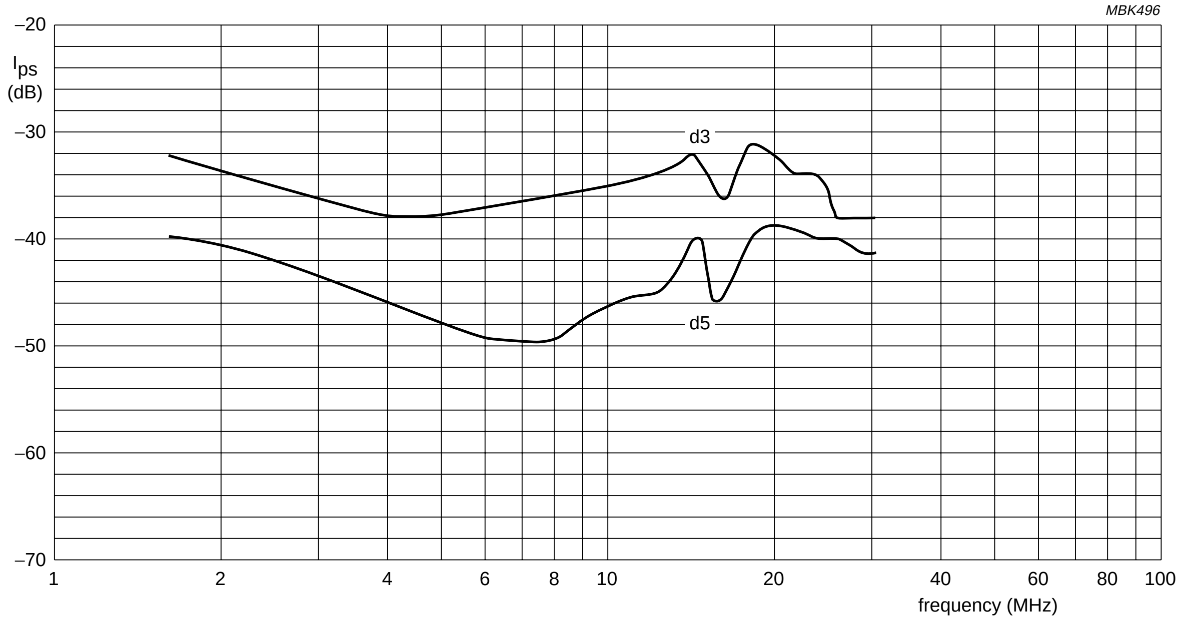


Fig.18 Intermodulation performance (50 V, 300 W PEP).

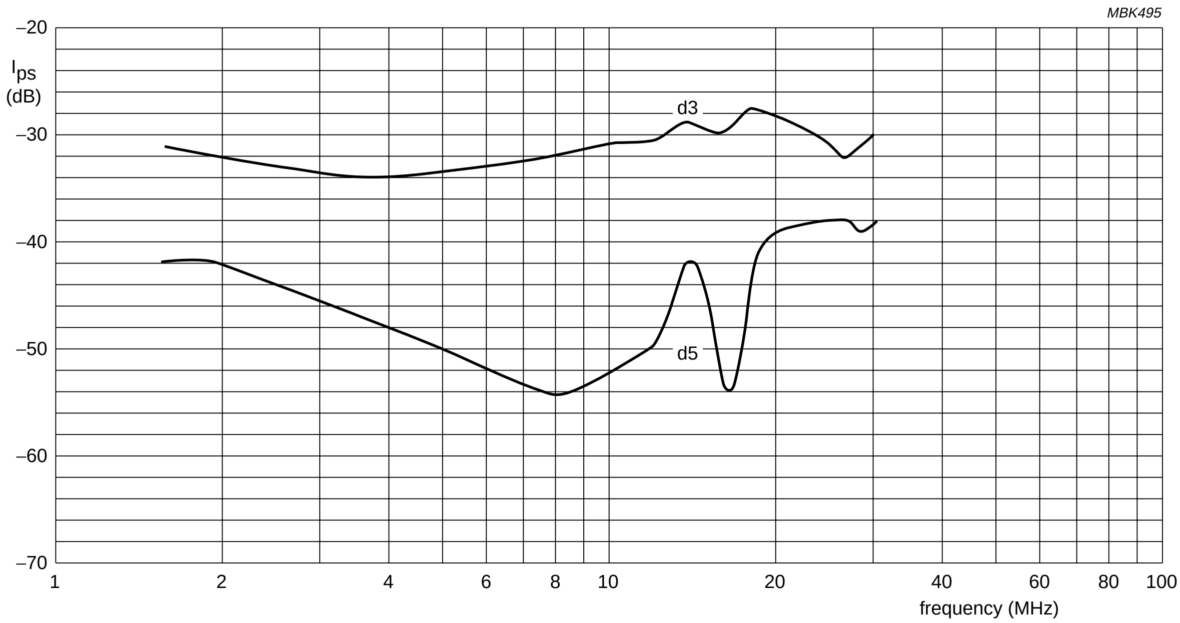


Fig.19 Intermodulation performance (50 V, 400 W PEP).

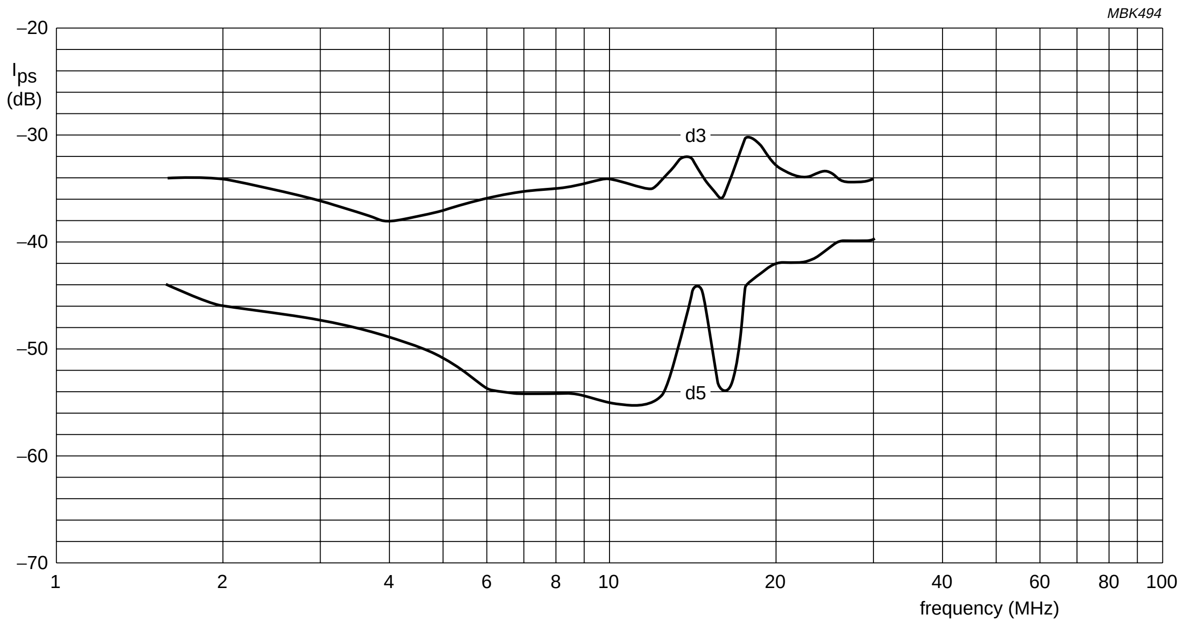


Fig.20 Intermodulation performance (45 V, 300 W PEP).

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