TECHNICAL PUBLICATION

Power transformers for the frequency range of 30 – 80 MHz

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CONTENTS

1 ABSTRACT

In this report design information is given for transformers with a power handling capability up to 300 W in the frequency range of 30 – 80 MHz.

The most suitable core material is ferrite type 4C6. The efficiency of these transformers is typically 98%.

2 SUMMARY

In this frequency range only transmission line transformers can be used. For the windings coaxial cables with P.T.F.E. isolation are recommended.

The size of the core is based on a 1% power loss and a dissipation of 350 mW/cm^3 corresponding with a flux density of 6 Gauss at 80 MHz.

The required number of turns is determined by the ratio R_P/L = 860 Ω/μH in which R_P is the loss resistance and L the inductance in parallel with the input or output terminals.

In the appendix the relation between the above mentioned quantities is derived.

In the report a practical example is given of a symmetrical 1 : 4 impedance transformer with a power handling capability of 120 W.

3 INTRODUCTION

In Ref.1 information was given on the design of power transformers mainly intended for the frequency range of 1.6 to 28 MHz. In this report some additional information will be presented for the frequency range of 30 to 80 MHz.

4 CHOICE OF CORE MATERIAL

The best available ferrite for this frequency range is 4C6. In this material a series of toroids can be obtained in different sizes according to Table 1.

Table 1

D(1) (mm)	d(2) (mm)	h(3) (mm)	A(4) (mm^2)	A/1(5) (mm)	V(6) (mm^3)
36	23	15	97.7	1.06	8500
23	14	7	31.5	0.552	1790
14	9	5	12.5	0.351	445
9	6	3	4.51	0.193	105

Notes

1. Outside diameter.
2. Inside diameter.
3. Height.
4. Cross-section.
5. Average length of the lines of force.
6. Volume.

5 POWER HANDLING CAPABILITY

An important question in the design of a power transformer is how much R.F. power can be handled by a given toroid. Restricting ourselves to the core losses at this moment it can be said that these losses are highest at the maximum frequency of operation i.e. 80 MHz.

From practical experience we have found that a core dissipation of 350 mW/cm^3 can be allowed without excessive rise of the core temperature. As it is a realistic target to keep the core losses below 1% of the power handled by the transformer we come to the following recommendations for the power handling of the different toroids (see Table 2).

Table 2

D × d × h (mm^3)	**P_{RF} (W)**
36 × 23 × 15	300
23 × 14 × 7	60
14 × 9 × 5	15
9 × 6 × 3	3

The core dissipation of 350 mW/cm^3 mentioned above corresponds with a flux density of 6 Gauss at 80 MHz as can be found in earlier versions of Data Handbook MA01 of Philips series on Magnetic Products: Soft ferrites.

6 DETERMINATION OF THE NUMBER OF TURNS

In the frequency range of 30-80 MHz the number of turns is entirely determined by the loss resistance in parallel with the input or output terminals of the transformer being caused by the core losses. According to the Appendix the core loss figures given Chapter 5 can be expressed in another way, viz:

$$\frac{R_P}{L} = \frac{\omega^2 B^2_{max}}{2\mu_o\mu_r} \times \frac{V}{P_L}$$

in which:
R_p = loss resistance in parallel with input or output terminals
L = inductance in parallel with input or output terminals
B_{max} = maximum flux density
μ_r = relative permeability being typ. 120 for 4C6 material
V = volume of transformer core
P_L = power loss in core.
Using the figures given in Chapter 5 we get:

$$\frac{R_P}{L} = 860\Omega/\mu H \text{ at f = 80 MHz.}$$

This ratio is hardly dependent on the flux density and therefore it is very useful for defining the number of turns as will be shown by a practical example in Chapter 8.

Applying the above mentioned criterion ensures a sufficiently high reactance in parallel with the input or output terminals at the lowest frequency of operation. So this reactance caused by the inductance of the winding needs no compensation.

7 WINDING LOSSES

In this frequency range conventional transformers can not be used because of their stray-inductance. The only suitable type is the transmission line transformer. For the windings we can choose a.o:

Twisted enamelled copper wire

Miniature twin lead

Coaxial cable with P.T.F.E. isolation, available in several diameters and characteristic resistances.

The first and second are not recommended for high power operation. The third type is e.g. available in 50 Ohms version with diameters of 1.7 and 2.8 mm. Some important properties of these cables at 80 MHz are given in Table 3.

Table 3

Outside diameter	1.7	2.8	mm
Power loss	0.40	0.24	dB/m
Power handling capability	100	200	W

At lower frequencies the power loss is less and the power handling capability higher.

8 PRACTICAL EXAMPLE

Suppose that in a 100 W transmitter the output transistors are connected in push-pull. The optimum load impedance between the collectors is 12.5 Ω and this must be transformed to 50 Ω. Then we need a symmetrical 1 : 4 impedance transformer plus a balun. The first one will be worked out in detail. A schematic diagram is given in Fig.1.

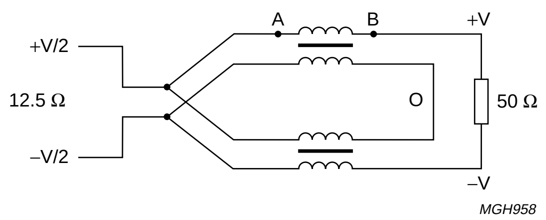

Fig.1 Schematic diagram

From Table 2 we see that this transformer can be made with one 36 mm toroid but also with two 23 mm toroids, in which case the power handling capability is still 120 W. The latter solution is more attractive because it is smaller.

The optimum characteristic impedance for each winding is 25 Ω which can realized by the parallel connection of two 50 Ω cables of 1.7 mm diameter. As the power is transported through 4 cables, each cable is loaded with 25 W being a quarter of the allowable maximum.

The number of turns will be calculated with the 50 Ω output terminals as a reference point. To keep the core losses below 1% we must keep the parallel loss resistance above 5000 Ω. This means an inductance of: $L = \frac{R_P}{860} = \frac{5000}{860} = 5.81\mu H$ (see Chapter 6).

Between the points A and B in Fig.1 the voltage is one quarter of the output voltage. This means that the inductance between these points must be one sixteenth of that across the output terminals, so: $L_{AB} = \frac{L}{16} = \frac{5.81}{16} = 0.363\mu H$

Now the number of turns can be calculated with: $n = \sqrt{\frac{L1}{\mu_o \mu_r A}} = 1.48$

In practice we will choose of course 2 turns by which the core losses reduce to: $\left(\frac{1.48}{2}\right)^2 \times 1\% = 0.55\%$

The inductance in parallel with the output terminals rises to: $\left(\frac{2}{1.48}\right)^2 \times 5.81 = 10.6\mu H$

This corresponds to a reactance of 2000 Ω at 30 MHz which is high enough to be neglected.

To realize the windings cables are required with a length of appr. 98 mm giving a cable loss of 0.039 dB or 0.91%.

So the total calculated loss of this transformer is:

0.55 + 0.91 = 1.46% at f = 80 MHz.

8.1 Reference:

Application report no. ECO6907 ‘Design of H.F. Wideband Power Transformers’ by A.H. Hilbers, June 17th, 1970.

9 APPENDIX

In the Data Handbook, as given in Chapter 5, curves are given showing the core losses expressed in kW/m^3 or mW/cm^3 versus the flux density B with the frequency as a parameter. It is often useful to know what this means in terms of an equivalent loss resistance in parallel with the inductance. The power dissipated in this resistance is equal to:

$$P_L = \frac{E_{max}^2}{2R_p} \tag{1}$$

On the other hand:

$$B_{max} = \frac{E_{max}}{\omega A n} \tag{2}$$

Eliminating E_{max} in (1) and (2) gives:

$$P_L = \frac{\omega^2 B_{max}^2 A^2 n^2}{2R_p} \tag{3}$$

Further we know that:

$$L = \frac{\mu_o \mu_r n^2 A}{l} \tag{4}$$

So that:

$$n^2 A = \frac{Ll}{\mu_o \mu_r} \tag{5}$$

Substituting (5) in (3) we get:

$$P_L = \frac{\omega^2 B_{max}^2 A L l}{2\mu_o \mu_r R_p} \tag{6}$$

The product Al is equal to the volume of the core V, so that:

$$\frac{P_L}{V} = \frac{\omega^2 B_{max}^2}{2\mu_o \mu_r} \times \frac{L}{R_P} \tag{7}$$

or:

$$\frac{R_p}{L} = \frac{\omega^2 B_{max}^2}{2\mu_o \mu_r} \times \frac{V}{P_L}$$

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