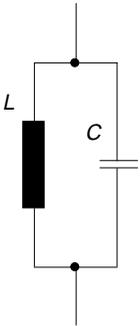


# Application Notes

## 1 Cores for filter applications

### 1.1 Gapped cores for filter/resonant circuits



Basic requirements:

- low  $\tan \delta$
- close tolerance for  $A_L$  value
- close tolerance for temperature coefficient
- low disaccommodation factor  $DF$
- wide adjustment range

Gapped cores are therefore always used in high quality circuits (for materials see application survey, page 34).

In the case of small air gaps (max. 0,2 mm) the air gap can be ground into only one core half. In this case the half with the ground air gap bears the stamp. The other half is blank.

The air gap enables the losses in the small-signal area and the temperature coefficient to be reduced by a factor of  $\mu_e/\mu_i$  in the small-signal area. More important, however, is that close  $A_L$  value tolerances can be achieved.

The rated  $A_L$  values for cores with ground air gap can be obtained from the individual data sheets. The data for the individual cores also include the effective permeability  $\mu_e$  used to approximately determine the effective loss factor  $\tan \delta_e$  and the temperature coefficient of the effective permeability  $\alpha_e$  from the ring core characteristics (see table of material properties).

It should be noted at this point that in cores with a larger air gap the stray field in the immediate vicinity of the air gap can cause additional eddy current losses in the copper winding. If the coil quality must meet stringent requirements, it is therefore advisable to wind several layers of polystyrene, nylon tape or even FPC film under the wire in the part of the winding that is in the proximity of the air gap; with a 3-section coil former this would be the part of the center section near the air gap.

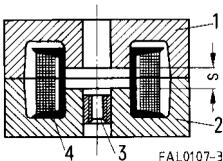


Fig. 9

Schematic drawing showing the construction of a P or RM core set with a total air gap  $s$ , comprising 2 core halves (1 and 2), threaded part (3) and padded winding (4)

## 1.2 P and RM cores with threaded sleeves

P and RM cores are supplied with a glued-in threaded sleeve. S+M Components uses automatic machines featuring high reliability in dosing of the adhesive and in positioning the threaded sleeve in the core.

The tight fit of the threaded sleeve is regularly checked – including a humid atmosphere of 40 °C/93 % r.h. (in accordance with IEC 60068-2-3) over 4 days – and also by periodic tests over 3 weeks. The usual bonding strengths of 20 N for Ø 2 mm holes (e.g. for P 11 × 7, RM 5) and 30 N for Ø 3 mm holes (e.g. for P 14 × 11, RM 6) are greatly exceeded, reaching an average of > 100 N. The threaded sleeve is continuously checked for proper centering. Overall, the controlled automated procedure guarantees higher reliability than manual gluing with its unavoidable inadequacies. Owing to the porosity of the ferrite, tension of the ferrite structure due to hardened adhesive that has penetrated cannot always be avoided. Hence, the relative temperature coefficient  $\alpha_F$  may be increased by approximately  $0,2 \cdot 10^{-6}/K$ .

## 1.3 Inductance adjustment

Inductance adjustment curves are included in the individual data sheets for P and RM cores. These represent typical values. The indicated percentage change in inductance is referred to  $L$  (inductance without adjusting screw). For adjustment the air gap is bridged with a cylindrical or threaded core. Consequently, only gapped cores permit adjustment.

The combinations of gapped cores and adjusting screws recommended in the data sheets ensure a sufficient range of adjustment at stable adjustment conditions.

Suitable plastic adjusting tools are also listed in the data sheets.

## 1.4 Typical calculation of a resonant circuit inductor

The following example serves to illustrate the dependencies to be considered when designing a resonant circuit inductor:

A SIFERRIT pot core inductor is required with an inductance of  $L = 640 \mu H$  and a minimum quality factor  $Q = 400$  ( $\tan \delta_L = 1/Q = 2,5 \cdot 10^{-3}$ ) for a frequency of 500 kHz. The temperature coefficient  $\alpha_e$  of this inductor should be  $100 \cdot 10^{-6}/K$  in the temperature range + 5 to + 55 °C.

a) Choice of material

According to the table of material properties and the  $\tan \delta/\mu_i$  curves (see chapter “SIFERRIT materials”) the material M 33, for example, can be used for 500 kHz.

b) Choice of  $A_L$  value

The Q and temperature coefficient requirements demand a gapped pot core. The relative temperature coefficient  $\alpha_F$  of SIFERRIT M 33 according to the table of material properties is on average about  $1,6 \cdot 10^{-6}/K$ . Since the required  $\alpha_e$  value of the gapped P core should be about  $100 \cdot 10^{-6}/K$ , the effective permeability is

$$\alpha_F = \frac{\alpha_e}{\mu_e} \quad \Rightarrow \quad \mu_e = \frac{\alpha_e}{\alpha/\mu_i} = 100 \cdot 10^{-6}/K \cdot \frac{1}{1,6 \cdot 10^{-6}/K} = 62,5$$

With pot core P 18 × 11 (B65651):  $\mu_e = 47,9$  for  $A_L = 100$  nH.

With pot core P 22 × 13 (B65661):  $\mu_e = 39,8$  for  $A_L = 100$  nH.

## Application Notes

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### c) Choice of winding material

RF litz wire 20x0,05 with single natural silk covering is particularly suitable for frequencies around 500 kHz. The overall diameter of the wire including insulation of 0,367 mm and the average resistivity of 0,444  $\Omega$ /m are obtained from the litz-wire table (refer to pertinent standard). It is recommended that the actual overall diameter always be measured, and this value used for the calculation.

### d) Number of turns and type of core

For an  $A_L$  value of 100 nH and an inductance of 640  $\mu$ H the equation  $N = (L/A_L)^{1/2}$  yields 80 turns. The nomogram for coil formers on page 154 shows that for a wire with an external diameter of 0,367 mm the two-section former for core type P 18 x 11 80 can easily take 80 turns. This type can therefore be used with a two-section former.

### e) Length of wire and DC resistance

The length of an average turn  $l_N$  on the above former is 35,6 mm. The length of litz wire necessary for the coil is therefore  $80 \cdot 35,6 \text{ mm} = 2848 \text{ mm}$  plus say  $2 \cdot 10 \text{ cm}$  for the connections, giving a total length of 3,04 m. The average resistivity of this wire is 0,444  $\Omega$ /m; the total DC resistance is thus  $3,04 \text{ m} \cdot 0,444 \text{ } \Omega/\text{m} \approx 1,35 \text{ } \Omega$ . It should be noted that the length of an average turn  $l_N$  given in the individual data sheets always refers to the fully wound former. If the former is not fully wound, the length of an average turn must be corrected according to the extent of the winding.

### f) Quality test

The mathematical calculation of the total loss, i.e. the losses of the core and windings is very laborious and only approximate. At the specified frequency of 500 kHz considerable dielectric and eddy-current losses occur. The quality is therefore checked on a sample coil wound as specified above, in this case the value being about 550 as shown in the Q factor characteristics for P 18 x 11 in the data sheet.

### g) Checking the temperature coefficient

The core P 18 x 11 with  $A_L = 100 \text{ nH}$  has an effective permeability  $\mu_e = 47,9$ . SIFERRIT M 33 has a relative temperature coefficient  $\alpha_F \approx 1,6 \cdot 10^{-6}/\text{K}$ ; therefore the following temperature coefficient can be calculated

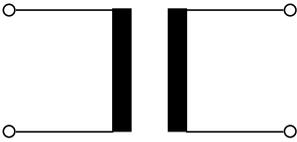
$$\alpha_e = \mu_e \cdot \alpha_F = 47,9 \cdot 1,6 \cdot 10^{-6}/\text{K} = 76,6 \cdot 10^{-6}/\text{K}$$

Actual measurement yielded  $90 \cdot 10^{-6}/\text{K}$ .

It should be pointed out that with pot cores the temperature coefficient of the unwound coil has almost no influence since the flux density lies primarily in the core.

For effective permeabilities  $\mu_e < 80$ , however, due to the influence of the winding an additional temperature coefficient of approx.  $(10 \dots 30) \cdot 10^{-6}/\text{K}$  must be included in the calculation.

## 2 Cores for broadband transformers



General requirements:

- high  $A_L$  values ( $\hat{=}$  high effective permeability) to restrict number of turns
- good broadband properties, i.e. high impedance up to highest possible frequencies
- low total harmonic distortion ( $\hat{=}$  low hysteresis material constant  $\eta_B$ )
- low sensitivity to superimposed DC currents ( $\hat{=}$  highest possible values for  $T_C$  and  $B_S$ )
- low  $\tan \delta$  for high-frequency applications

### 2.1 Precision-ground, ungapped cores for broadband transformers

For fields of application such as matching transformers in digital telecommunication networks, pulse signal transformers or current-compensated chokes, either cores which form a closed magnetic circuit (ring, double E or double-aperture cores) or paired core sets without air gap are used. In order to achieve the highest possible effective permeability here, these cores are precision ground with residual air gaps  $s \sim 1 \mu\text{m}$ . By selecting the low-profile core types, the  $A_L$  value can be further increased, and the number of turns reduced.

For this reason, RM and pot cores made of materials N 30, T 35, T 37, T 38 and T 42 are especially suitable for these applications. For high-frequency applications, N 26, M 33, K 1, K 12 and U 17 are suitable.

### 2.2 Fundamentals for broadband transformers in the range 10 kHz to over 1 GHz – an example

Broadband transformers are constructed primarily using closed core shapes, i.e. ring cores and double-aperture cores. Divided core designs such as P/RM cores or small E/ER cores, which allow more simple winding, are particularly suitable for transformers up to approximately 200 MHz.

The bandwidth  $\Delta f = f_{oG} - f_{uG}$  ( $f_{oG}$  = upper cut-off frequency,  $f_{uG}$  = lower cut-off frequency) is considered the most important transformer characteristic.

Cut-off frequency: Frequency at which the voltage at the transformer drops by 3 dB ( $\hat{=}$  – 30%)

The following holds true for circuit quality  $Q > 10$  (typical value):

$$\Delta f = \frac{f_r}{R_i} \cdot \sqrt{\frac{L_H}{C_0}}$$

$f_r$  = Resonance frequency

$R_i$  = Internal resistance of generator (normally,  $R_i \ll$  loss resistance of ferrite)

$L_H$  = Main inductance

$C_0$  = Winding capacitance

# Application Notes

Transmission loss curve

$$\alpha = \ln \frac{U}{U_r}$$

$U_r$  = voltage at  $f_r$

$\alpha$  = attenuation when matched with line impedance (e.g. 50  $\Omega$ )

Example: 1 : 1 transformer based on E6,3/T38 with  $2 \times 10$  turns

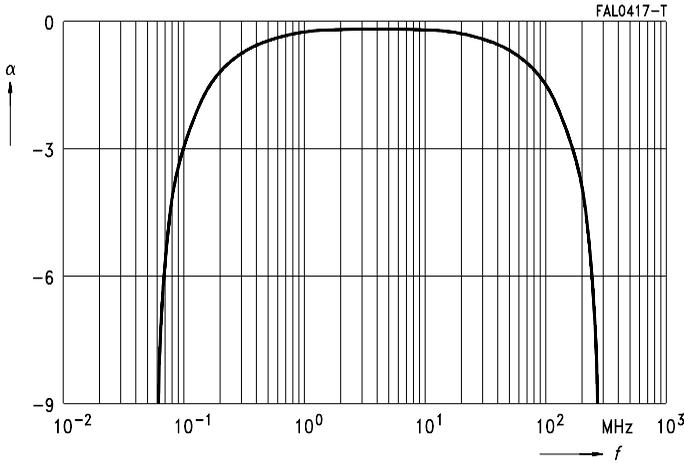


Fig. 10  
Transmission loss curve for transformer E6,3/T38 with  $2 \times 10$  turns (parallel)

## 2.3 Low-distortion transformers for digital data transmission (ISDN, xDSL)

The new digital transmission technologies over copper like ISDN, HDSL (high-rate digital subscriber line) and ADSL (asymmetric digital subscriber line) require very small harmonic distortion in order to maintain maximal line length. This requirement can be calculated from material parameters for the third harmonic distortion with the Rayleigh model for small-signal hysteresis (sinusoidal current).

$$k_3 = \frac{U_3}{U_1} = 0,6 \cdot \tan \delta_h$$

$$= 0,6 \cdot \mu_e \cdot \eta_B \cdot \hat{B}$$

For a typical design a transformer has to be matched to a chipset via the turn ratios  $N1 : N2 : N3 \dots$ , the inductances  $L_1, L_2, L_3 \dots$  and the maximum dc resistances  $R_1, R_2, R_3 \dots$

The third harmonic distortion for winding j can then be calculated as

$$k_3 = \frac{0,6}{\mu_0} \cdot \underbrace{\eta_B}_{\text{Material}} \cdot \underbrace{\frac{\hat{U}}{2\pi f}}_{\text{Circuit conditions}} \cdot L_j \cdot \underbrace{\left[ \frac{\rho}{f_{Cu}} \sum_{j=1}^p \left( \frac{N_j}{N_1} \right)^2 \cdot \frac{1}{R_j} \right]^{3/2}}_{\text{Design constraints}} \cdot \underbrace{\frac{\sum_i I_i}{I_e} \cdot \frac{I_e}{A_e^2}}_{\text{Core Geometry}} \cdot \underbrace{\frac{I_N^{3/2}}{A_N^{3/2}}}_{\text{Coil former Geometry}}$$

This equation shows the contribution of the various design parameters:

- The material is characterized by the hysteresis material constant  $\eta_B$ . Limit values for this parameter are given in the SIFERRIT material tables. The actual level for  $\eta_B$  varies for different cores. In order to select the best material for an application, the normalized temperature dependence  $\eta_B(T)/\eta_B(25^\circ\text{C})$  is of great help (cf. graph on page 48). Being mainly composition-dependent, these curves are thus material-specific.
- The geometry can be taken into account by a core distortion factor (*CDF*) defined as

$$CDF = \frac{\sum I_i}{I_e} \cdot \frac{I_e}{A_e^2} \cdot \frac{I_N^{3/2}}{A_N^{3/2}}$$

The factor  $\sum I_i/I_e$  is the closer to 1, the less the core section varies along the magnetic path (homogeneous core shape). The values for *CDF* are given in the following table for the core shapes preferred for these applications.

Cores w/o hole	<i>CDF</i> (mm <sup>-4,5</sup> )	Cores w. hole	<i>CDF</i> (mm <sup>-4,5</sup> )	EP cores	<i>CDF</i> (mm <sup>-4,5</sup> )
P 9 × 5	1,25	P 3,3	85,9	EP 7	1,68
P 11 × 7	0,644	P 4,6	46,7	EP 10	0,506
P 14 × 8	0,164	P 7	4,21	EP13	0,191
P 18 × 11	0,0470	P 9	1,72	EP17	0,0619
P 22 × 13	0,0171	P 11	0,790	EP 20	0,00945
P 26 × 16	0,00723	P 14	0,217		
P 30 × 19	0,00311	P 18	0,0545		
P 36 × 22	0,00149	P 22	0,0220		
RM 4	0,498	P 26	0,0099		
RM 5	0,184	P 30	0,00366		
RM 6	0,0576	P 36	0,00166		
RM 7	0,0339	P 41	0,00112		
RM 8	0,0162	RM 4	0,814		
RM 10	0,00676	RM 5	0,243		
RM 12	0,00215	RM 6	0,0779		
RM14	0,00100	RM 7	0,0415		
TT/PR 14 × 8	0,205	RM 8	0,0235		
TT/PR 18 × 11	0,0561	RM 10	0,00906		
TT/PR 23 × 11	0,0217	RM 12	0,00273		
TT/PR 23 × 18	0,0119	RM 14	0,00118		
TT/PR 30 × 19	0,00465				

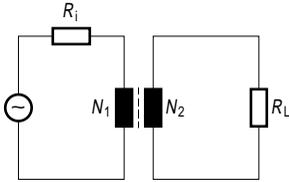
## Application Notes

The values of this parameter indicate that roughly

$$CDF \sim \frac{1}{\sqrt{e^{3/2}}}$$

i.e. the larger the core, the smaller is the distortion. Due to space restriction, however, the choice has to be made among the core shapes of a given size.

- The circuit conditions, i.e. voltage amplitude  $\hat{u}$  and frequency  $f$  affect directly the flux density in the core. For increasing flux density, a deviation of the absolute value of  $k_3$  from the calculated test value is expected, since the  $\tan \delta_h$  vs.  $\hat{B}$  curve deviates from linear.
- The distortion  $k_{3c}$  for a transformer in a circuit with given impedance conditions can be obtained from the following formula:



$$k_{3c} = \frac{k_3}{\sqrt{1 + \left[ 3\omega L_1 \cdot \left( \frac{1}{R_i} + \left( \frac{N_2}{N_1} \right)^2 \cdot \frac{1}{R_L} \right) \right]^2}}$$

$R_i$  = internal resistance of generator

$R_L$  = load resistance

$L_1$  = primary inductance

The actual circuit distortion  $k_{3c}$  will in general be smaller than the calculated sinusoidal current value  $k_3$ .

### 3 Cores for inductive sensors

The proximity switch, widely used in automation engineering, is based on the damping of a high-frequency LC oscillator by the approach of a metal. The oscillator inductor consists of a cylindrical coil and a ferrite core half whose open side forms what is known as the active area. The function of the ferrite core consists in spatially aligning the magnetic field so as to restrict the interaction area.

The oscillator design must take into account that the inductor forms a magnetically open circuit. The inductance and quality are decisively dependent on the coil design, unlike in the case of closed circuits. The initial permeability plays a subordinate role here, as is shown by the following example:

Core: P9 × 5 (B65517-D ...)  
 Coil: 100 turns, 0,08 CuL  
 Current: 1 mA  
 Frequency: 100 kHz

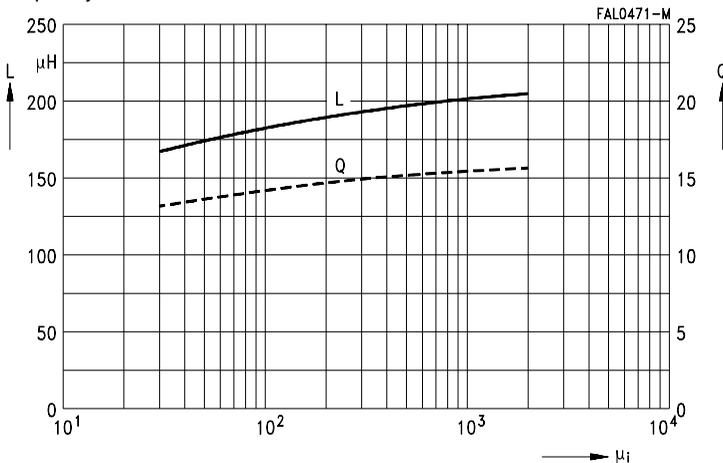


Fig. 11  
 Inductance and quality versus initial permeability  
 $P9,3 \times 2,7$ ,  $N = 100$ ,  $f = 100$  kHz,  $I = 1$  mA

Decisive for this application is the attainment of as high a Q as possible, with the lowest possible dependence on temperature at the oscillator frequency. When the distance between the damping lug and the active area changes, the oscillator Q should however change as strongly as possible.

If the relative change in Q  $\Delta Q/Q$  exceeds a predefined threshold, e.g. 10 %, a switching operation is initiated at the so-called operating distance. Attainment of the target values depends on appropriate coil dimensioning and can generally only be performed empirically.

## 4 Cores for power applications

### 4.1 Core shapes and materials

The enormously increased diversity of application in power electronics has led to a considerable expansion not only in the spectrum of core shapes but also in the range of materials.

To satisfy the demands of higher-frequency applications, the EFD cores have been developed in sizes EFD10, 15, 20, 25 and EFD30. These are characterized by an extremely flat design, optimized cross-sectional distribution and optimized winding shielding.

For many standard applications up to 100 kHz, materials N27, N53 and N41 can be used. For the range up to 200 kHz, materials N62, N67, N72 and N82 are suitable. N87 continues the series up to 500 kHz, while N49 and N59 cover the range from 300 kHz to 1 MHz e.g. for DC/DC (resonance) converters.

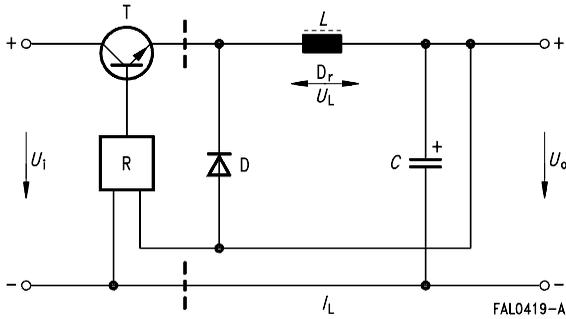
# Application Notes

For detailed information on core shapes see the individual data sheets, for general information on materials see the chapter on SIFERRIT materials.

## 4.2 Correlation: Applications – core shape/material

### 4.2.1 Step-down converters

Typical circuit diagram (Fig. 12)



#### Advantages

- only one choke required
- high efficiency
- low radio interference

#### Disadvantages

- only one output voltage
- restricted short-circuit withstand capability (no line isolation)

#### Application areas

- providing a constant output voltage, isolated from input voltage
- regulation in a forward converter
- regulated voltage inversion
- sinusoidal line current draw

#### Core/material requirements

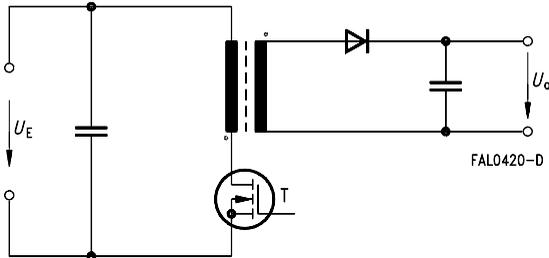
- Standard requirements regarding losses and saturation

#### S+M recommendations for core shape/material

- E/ETD/U cores made of material N27,  
RM cores made of material N41 (specially suitable for nonlinear chokes)

## 4.2.2 Single-ended flyback converter

Typical circuit diagram (Fig. 13)



### Advantages

- simple circuit variant (low cost)
- low component requirement
- only one inductive component
- low leakage losses
- several easily regulatable output voltages

### Disadvantages

- close coupling of primary and secondary sides
- high eddy current losses in the air gap area
- large transformer core with air gap restricts possible applications
- average radio interference
- exacting requirements on the components

### Application areas

- low and medium powers up to max. 200 W with wide output voltage range
- maximum operating frequency approx. 100 kHz

### Core/material requirements

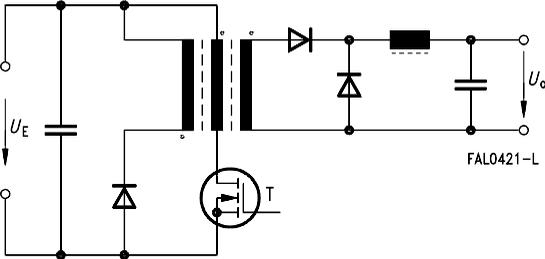
- low power losses at high temperature
- very high saturation with low dependence on temperature
- gapped cores (recently also with  $A_L$  value guarantee)

### S+M recommendations for core shape/material

- E/U cores in
  - N27 (standard)
  - N62 (low losses, high saturation)

## 4.2.3 Single-ended forward converter

Typical circuit diagram (Fig. 14)



### Advantages

- higher power range than flyback converter
- lower demands on circuit components
- high efficiency

### Disadvantages

- 2 inductive components
- large choke
- demagnetization winding
- high radio interference suppression complexity
- increased component requirement, particularly with several regulated output voltages

### Application areas

- medium and high powers (up to 500 W) especially in the area of low output voltages
- PWM (pulse width) modulation up to approx. 500 kHz

### Core/material requirements

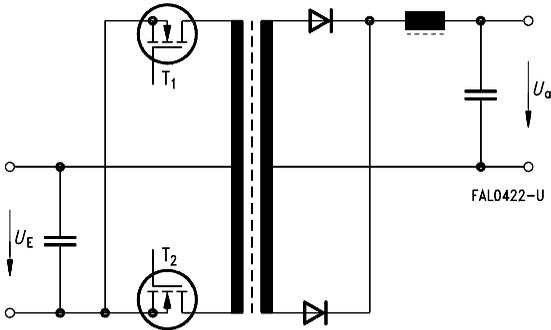
- low losses at high temperatures and at high frequencies (low eddy-current losses)
- generally, ungapped cores

### S+M recommendations for core shape/material

- E/ETD, small EFD cores, RM/PM cores made of  
N27, N41 (up to 100 kHz)  
N62, N67, N72 (up to 300 kHz)  
N87 (up to 500 kHz)  
N49, N59 (500 kHz to 1 MHz)

#### 4.2.4 Push-pull converter

Typical circuit diagram (Fig. 15)



##### Advantages

- powers up to the kW range
- small choke
- high efficiency
- low radio interference suppression complexity

##### Disadvantages

- 2 inductive components
- complex winding
- high component requirement, particularly with several regulated output voltages

##### Application areas

- high powers ( $\gg 100$  W), also at high output voltages
- PWM (pulse width) modulation up to 500 kHz

##### Core/material requirements

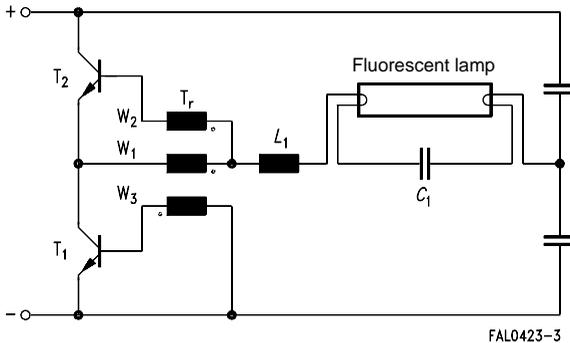
- low losses at high temperatures
- low eddy-current losses since application areas is up to 500 kHz and above
- generally, ungapped cores

##### S+M recommendations for core shape/material

- large E/ETD, RM/PM cores made of N27, N67, N87 (with large core cross sections ( $A_e \geq 250$  mm<sup>2</sup>), on account of eddy-current losses N87 must be used even where  $f < 100$  kHz)

## 4.2.5 Electronic lamp ballast device

Typical circuit diagram (Fig. 16)



### Advantages

- considerably reduced size compared to 50 Hz line solution
- significantly higher efficiency than line voltage regulator

### Disadvantages

- high component requirement

### Application areas

- control unit for fluorescent lamps

### Core/material requirements

- low losses in the range 50 – 80 °C
- pulse power requirements
- gapped and ungapped E cores
- ring cores with defined pulse characteristic

### S+M recommendations for core shape/material

- E/ETD/EFD cores made of N62, N72 for  $L_1$

## 4.3 Selection of switch-mode power supply transformer cores

The previous section (Correlation: Applications – core shape/material) provides a guide for the rough selection of core shape and material.

The following procedure should be followed when selecting the actual core size and material:

- 1) Definition of requirements
  - range of power capacities  $P_{\text{trans}}$
  - specification of the SMPS type
  - specification of pulse frequency and maximum temperature rise
  - specification of the maximum volume
- 2) Selection of “possible” core shapes/materials on the basis of the “Power capacity” tables starting on page 144.

These tables associate core shape/material combinations (and the volume  $V$ ) with the power capacity of the different converter types at a “typical” frequency  $f_{\text{typ}}$  and a “cut-off frequency”  $f_{\text{cutoff}}$ .

The typical frequency specified here is a frequency for which specific applications are known, or which serves as the base frequency for the specified core loss values.

The cut-off frequency is selected such that the advantages of other materials predominate above this frequency and that it is therefore advisable to switch to a different material which is better optimized for this range.

### 3) Final selection of core shape/material

The core shapes/materials selected as possibilities under 2) must now be compared with the relevant data sheets for the specific core types and the material data (typical curves), taking the following points into consideration:

- volume
- accessories (power coil former)
- $A_L$  values of ungapped core
- $A_L$  values/air gap specifications
- temperature minimum for losses, Curie temperature  $T_C$ , saturation magnetization  $B_S$ , magnetic bias characteristic, amplitude permeability characteristic

Core shape/material combinations which are not contained in the individual data sheets can be requested from S + M Components.

# Application Notes

## 4.4 Selection tables: Power capacities

In order to calculate the transmissible power, the following relationship is used (transformer with two equal windings):

$$P_{trans} = C \Delta B f A_e \cdot A_N \cdot j$$

where  $C$  is a coefficient characterizing the converter topology<sup>1)</sup>, i.e.

$C = 1$ : push-pull converter

$C = 0,71$ : single-ended converter

$C = 0,62$ : flyback converter

Both the core losses associated with the flux swing  $\Delta B$  and the copper losses due to the current density  $j$  result in a temperature increase  $\Delta T$ . Assuming that both loss contributions are equal and that  $P_V \sim B^2$ , the power capacity can be approximated by

$$P_{trans} \approx C \cdot \underbrace{\frac{PF}{\sqrt{P_V}}}_{\text{Material}} \cdot \underbrace{\frac{\Delta T}{R_{th}}}_{\text{Thermal design}} \cdot \underbrace{\sqrt{\frac{f_{Cu}}{P_{Cu}}}}_{\text{Winding}} \cdot \underbrace{\sqrt{\frac{A_N \cdot A_e}{I_N \cdot I_e}}}_{\text{Geometry}}$$

The equation shows how the different aspects in the design contribute to the power capacity:

- The material term is the performance factor  $PF$  divided by the square root of the specific core loss level for which it was derived (cf. pages 47 and 120). For a given core shape deviations from this value are possible as given by its data sheet.
- The values for  $\Delta T$  are associated with the material according to the following table.

	$\Delta T_{max}$ K
N59	30
N49	20
N62	40
N82	50
N27	30
N67	40
N87	50
N72	40
N41	30

- The thermal resistance is defined as

$$R_{th} = \frac{\Delta T}{P_{Vcore} + P_{Vcopper}}$$

- These values should be regarded as typical for a given core shape. They were determined by measurement under the condition of free convection in air and are given in the table on page 148 ff.

1) G. Roespel, "Effect of the magnetic material on the shape and dimensions of transformers and chokes in switched-mode power supplies", J. of Magn. and Magn. Materials 9 (1978) 145-49

For actual designs the actual values for  $R_{th}$  should be determined and the tabulated  $P_{trans}$  values adjusted accordingly.

- The winding design was taken into account in the calculations by  $f_{Cu} = 0,4$  and  $\rho_{Cu}$  for DC. In actual design large deviations of the dc resistance due to high frequency effects (skin effect, proximity effect) occur, unless special wire types such as litz wires are used. If the  $R_{AC}/R_{DC}$  ratio for a given winding is known, this can be used to correct the tabulated power capacities accordingly.
- The geometry term is related to the core shape and size. However, note that the thermal resistance is also size-dependent via the empirical relation (cf. figure 17):

$$R_{th} \sim \frac{1}{\sqrt{V_e}}$$

The tabulated power capacities provide a means for making a selection among cores, although the absolute values will not be met in practice for the reasons explained before.

In the calculation of power capacities the following conditions were also applied:

- The application area for flyback converters was restricted to  $f < 150$  kHz.
- The power specifications for N49/N59 should be read as applicable to DC/DC (quasi) resonance converters (single-ended forward operation).
- The maximum flux densities were defined as follows:  
 For flyback converters:  $\Delta B \leq 200$  mT ( $\Delta B \leq 50$  mT for materials N49, N59)  
 For push-pull converters:  $\Delta B \leq 400$  mT.

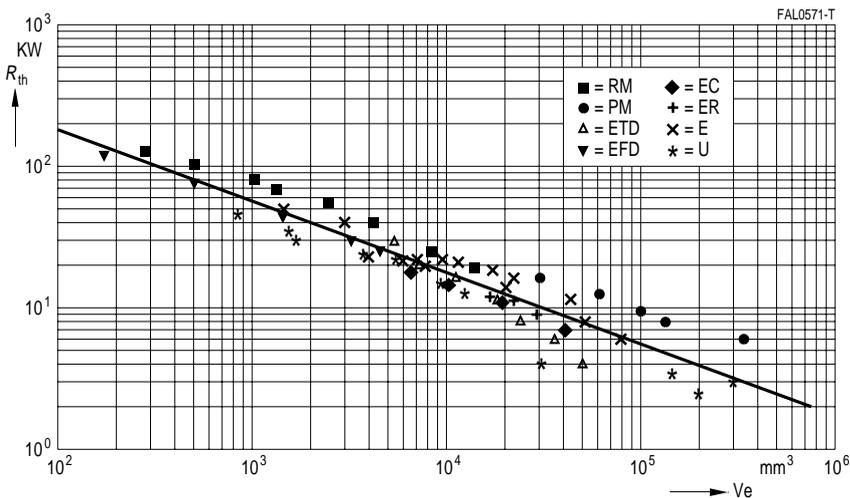


Fig. 17  
Thermal resistance versus core effective volume

## Application Notes

### Selection tables: Power capacities

#### $P_{trans}$ of cores for wound transformers ( $f_{Cu} = 0,4$ )

	N27	N53	N41	N72	N62	N82	N67	N87	N49	N59
$f_{typ}$ [kHz]	25	100	25	25	25	100	100	100	500	750
RM4LP							17	20	19	
RM4							20	24	22	
RM5LP							26	35	29	
RM5			9				36	48	38	
RM6LP							42	56	45	
RM6			17				59	79	64	
RM7LP							62	82	67	
RM7			23				80	107	86	
RM8LP							90	121	97	
RM8			35				121	162	131	
RM10LP							160	214	173	
RM10			63				216	289	234	
RM12LP							339	453	366	
RM12			136				465	622	503	
RM14LP							565	756	611	
RM14			229				782	1046	846	
PM50/39	391							1742		
PM62/49	673							2999		
PM74/59	1131							5036		
PM87/70	1567									
PM114/93	2963									
EP7							12	13		
EP10							22			
EP13							45			
EP17							85			
EP20							246			
P9×5							12			
P11×7							22			
P14×8			12				48			
P18×11							99			
P22×13							173			
P26×16			86				294			
P30×19							458			
P36×22							717			

## $P_{trans}$ of cores for wound transformers ( $f_{Cu} = 0,4$ )

	N27	N53	N41	N72	N62	N82	N67	N87	N49	N59
$f_{typ}$ [kHz]	25	100	25	25	25	100	100	100	500	750
TT/PR14×8								52		
TT/PR18×11								117		
TT/PR23×11								204		
TT/PR23×18								217		
TT/PR30×19								540		
E6,3							2			
E8,8							4			
E13/7/4	5						24			
E16/8/5	13						50			
E16/6/5	9									
E19/8/5	16						61			
E20/10/6	26						88			
E21/9/5	15									
E25/13/7	49						163			
E25.4/10/7	42						141			
E28/13/11							321			
ED29/14/11	128									
E30/15/7	94						312			
E32/16/9	118						392			
E32/16/11							423			
E34/14/9	118									
E36/18/11	146						487			
E40/16/12	172			574			768			
E42/21/15	214						711			
E42/21/20	289						961			
E47/20/16	304						1011			
E55/28/21	538						1791	2396		
E55/28/25	763									
E56/24/19	532						1770			
E65/32/27	1091						3632			
E70/33/32	1453									
E80/38/20	1503									
ER9,5								9		
ER11/5							13	14	15	
ER28/17/11				290						
ER35/20/11	309									

## Application Notes

### $P_{trans}$ of cores for wound transformers ( $f_{Cu} = 0,4$ )

	N27	N53	N41	N72	N62	N82	N67	N87	N49	N59
$f_{typ}$ [kHz]	25	100	25	25	25	100	100	100	500	750
ER42/22/15	384						1280			
ER46/17/18	376									
ER49/27/17	636									
ER54/18/18	482						1605			
ETD29/16/10	96						320	428		
ETD34/17/11	151						504	674		
ETD39/20/13	230						765	1023		
ETD44/22/15	383						1277	1708		
ETD49/25/16	594						1977	2645		
ETD54/28/19	897						2988	3998		
ETD59/31/22	1502						5002	6692		
EC35/17/10	145									
EC41/20/12	220									
EC52/24/14	402									
EC70/35/16	907									
EFD10/5/3								12	13	21
EPF12/6/3								27		
EFD15/8/5								42	38	
EFD20/10/7								115	93	
EFD25/13/9							183	245	198	
EFD30/15/9							239	319	258	
U11/9/6	18									
U15/11/6	31									
U17/12/7	37									
U20/16/7	72									
U21/17/12	116				167					
U25/20/13	199									
U26/22/16	267									
U30/26/26	1139									
UI93/104/16	1028									
UU93/152/16	1413									
UI93/104/20	1283									
UU93/152/20	1780									
UI93/104/30	1784									
UU93/152/30	2874									
UR29/18/16	199	477			326	873	663			

**$P_{trans}$  of cores for wound transformers ( $f_{Cu} = 0,4$ )**

	N27	N53	N41	N72	N62	N82	N67	N87	N49	N59
$f_{typ}$ [kHz]	25	100	25	25	25	100	100	100	500	750
UR35/28/12,5	354	848			581	1550	1178			
UR38/32/13	433	1037			710	1897	1441			
UR39/35/15	494	1183			811	2165	1645			
UR42,7/33/14	552	1323			906	2420	1839	2460		
UR42/34/16	562	1346			922	2463	1872			
UR42/36/15	628	1504			1031	2753	2091	2798		
UR46/37/15	691	1656			1135	3030	2302			

**$P_{trans}$  of low-profile cores for planar transformers ( $f_{Cu} = 0,1$ )**

	N67	N87	N49
RM4LP	8,5	10	9,5
RM5LP	13	17,5	14
RM6LP	21	28	22
RM7LP	31	41	33
RM8LP	45	60	48
RM10LP	80	107	86
RM12LP	170	226	183
RM14LP	282	378	305
ER9.5		4,5	
ER11/5	6,5	7	7,5
EILP14		11	12
EELP14		17	16
EILP18		37	30
EELP18		55	44
EILP22		96	78
EELP22		134	109
EILP32		177	143
EELP32		252	203
EILP38		323	262
EELP38		470	380
EILP43		445	360
EELP43		619	500
EILP64		991	800
EELP64		1397	1130

## Application Notes

### 4.5 Thermal resistance for the main power transformer core shapes

Core shapes	$R_{th}$ (K/W)	Core shapes	$R_{th}$ (K/W)	Core shapes	$R_{th}$ (K/W)
RM 4	120	TT/PR 14 × 8	77	ER 9,5	164
RM 4 LP	135	TT/PR 18 × 11	54	ER 11/5	134
RM 5	100	TT/PR 23 × 11	39	ER 28/17/11	22
RM 5 LP	111	TT/PR 23 × 18	31	ER 35/20/11	18
RM 6	80	TT/PR 30 × 19	24	ER 42/22/15	14
RM 6 LP	90			ER 46/17/18	13
RM 7	68	E 5	308	ER 49/27/17	9
RM 7 LP	78	E 6,3	283	ER 54/18/18	11
RM 8	57	E 8,8	204		
RM 8 LP	65	E 13/7/4	94	ETD 29/16/10	28
RM 10	40	E 14/8/4	78	ETD 34/17/11	20
RM 10 LP	45	E 16/8/5	65	ETD 39/20/13	16
RM 12	25	E 16/6/5	76	ETD 44/22/15	11
RM 12 LP	29	E 19/8/5	60	ETD 49/25/16	8
RM 14	18	E 20/10/6	46	ETD 54/28/19	6
RM 14 LP	21	E 21/9/5	59	ETD 59/31/22	4
		E 25/13/7	40		
PM 50/39	15	E 25,4/10/7	41	EC 35/17/10	18
PM 62/49	12	ED 29/14/11	24	EC 41/20/12	15
PM 74/59	9,5	E 30/15/7	23	EC 52/24/14	11
PM 87/70	8	E 32/16/9	22	EC 70/35/16	7
PM 114/93	6	E 32/16/11	21		
		E 34/14/9	23	EFD 10/5/3	120
EP 7	141	E 36/18/11	18	EFD 15/8/5	75
EP 10	122	E 40/16/12	20	EFD 20/10/7	45
EP 13	82	E 42/21/15	19	EFD 25/13/9	30
EP 17	58	E 42/21/20	15	EFD 30/15/9	25
EP 20	32	E 47/20/16	13		
		E 55/28/21	11	EV 15/9/7	55
P 3,3 × 2,6	678	E 55/28/25	8	EV 25/13/13	27
P 4,6 × 4,1	390	E 56/24/19	9,5	EV 30/16/13	21
P 5,8 × 3,3	295	E 65/32/27	6,5		
P 7 × 4	214	E 70/33/32	5,5	DE 28	41
P 9 × 5	142	E 80/38/20	7	DE 35	25
P 11 × 7	106	EI LP 18	61		
P 14 × 8	73	EE LP 18	56		
P 18 × 11	51	EI LP 22	38		
P 22 × 13	37	EE LP 22	35		
P 26 × 16	27	EI LP 32	26		
P 30 × 19	22	EE LP 32	24		
P 36 × 22	17	EI LP 43	16		
P 41 × 25	15	EE LP 43	15		
		EI LP 64	9,5		
		EE LP 64	9		

continued on next page

Core shapes	$R_{th}$ (K/W)	Core shapes	$R_{th}$ (K/W)	Core shapes	$R_{th}$ (K/W)
U 11/9/6	46	UU 93/152/16	4,5	UR 29/18/16	19
U 15/11/6	35	UI 93/104/16	5	UR 35/28/12,5	15
U 17/12/7	30	UU 93/152/20	4	UR 38/32/13	12,5
U 20/16/7	24	UI 93/104/20	4,5	UR 39/35/15	11,5
U 21/17/12	22	UU 93/152/30	3	UR 43/34/16	11
U 25/20/13	15	UI 93/104/30	4	UR 42/36/15	10
U 26/22/16	13	U 101/76/30	3,3	UR 42,7/33/14	11
U 30/26/26	4	U 141/78/30	2,5	UR 46/37/15	10