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TDA5051A ASK power line modem

Rev. 1 — 17 December 2010 **Application note**

Document information

Info	Content
Keywords	Home automation modem, ASK power-line modem, EN50065-1 and EN50065-2 compliant, home lighting and appliance control
Abstract	The NXP TDA5051A is a complete Amplitude Shift Keying (ASK) modem for transmitting and receiving digital signals on standard power line or any two-wire AC or DC network. It is a cost-effective solution that transmits at a rate of 600 baud (typical) and 1200 baud (maximum), operates from a single 5 V supply, and enables easy connection to standard microcontrollers, including NXP's LPC11xx series of low power ARM-based microcontrollers.
	The IC complies with EN50065-1, EN50065-2 and SC105A, and requires only a few external components for full operation. Its fully-digital transmission and reception circuitry provides efficient bidirectional communication of low baud rate data signals between a control unit and lighting fixture, and one or more household appliances connected to the mains. This application note discusses the requirements, filtering circuits and interface networks necessary to be fully compliant and to obtain robust, reliable operation in a power line communication network.

Revision history

Rev	Date	Description
v.1	20101217	application note; initial version

Contact information

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1. Introduction

1.1 TDA5051A ASK modem for power line data transmission

The TDA5051A is a complete ASK modem dedicated to data transmission on power line network, requiring very few external components. It could be also used on any two-wire network for exchanging informations by means of ASK carrier current technique (DC or AC network).

The use of a digital structure for both transmission and reception part provides an efficient solution for modulating and demodulating low baud rate data signals. A standard quartz crystal is required to set the operation frequency; in transmission mode, it defines the carrier frequency and in reception mode it defines the detection frequency.

1.1.1 Main features of the IC

- **CMOS process IC:** low power consumption, reliability and high temperature stability, on-chip ESD protection

- **Single +5 V power supply.** The same power supply can be used to feed the controller.

- **On-chip clock circuit.** Using an external quartz crystal, the oscillator sets the operation frequency and the clock output pin gives the possibility to supply the clock to a microcontroller. It is also possible to apply an external clock signal to the chip by using one of the oscillator pins as an input.

- **Full digital modulation with signal shaping.** Using ROM and a 6-bit D/A converter provides high stability of the carrier frequency, limitation of the signal bandwidth and easy choice of the frequency within a large range.

- **On-chip power amplifier with overload protection.** Low distortion, low output impedance amplifier for limiting the number of external components and the size of the complete system. An internal feedback controls the output voltage to comply with the EN50065-1 standard (122 dBμV maximum (RMS)).

- **Input amplifier with Automatic Gain Control (AGC).** Provides a very high sensitivity of 66 dBμV (RMS), allowing the detection of small signals in heavily loaded power line conditions.

- **Digital narrowband filter with 8-bit A/D converter.** Equivalent to an 8th-order analog filter, for an accurate and sharp filtering of the input signal.

- **Digital demodulation.** A digital demodulator with variable threshold calculates the optimum level in order to restore the baseband signal with the highest accuracy.

- **600 baud typical rate, 1200 baud maximum**

- **TTL/CMOS compatible data pins** for direct connection to the controller.

- **Digital part fully scan testable** for a complete digital production check, before and after packaging of the IC.

- **Low cost external coupling network** using a simple LC filter without any tunable components.
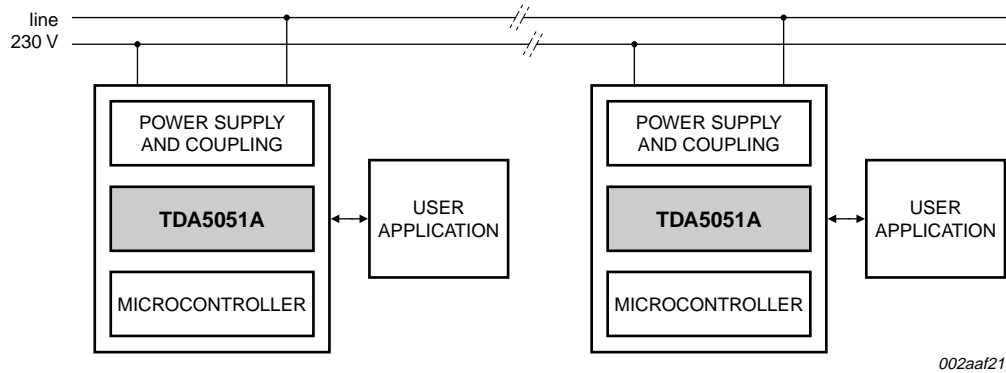
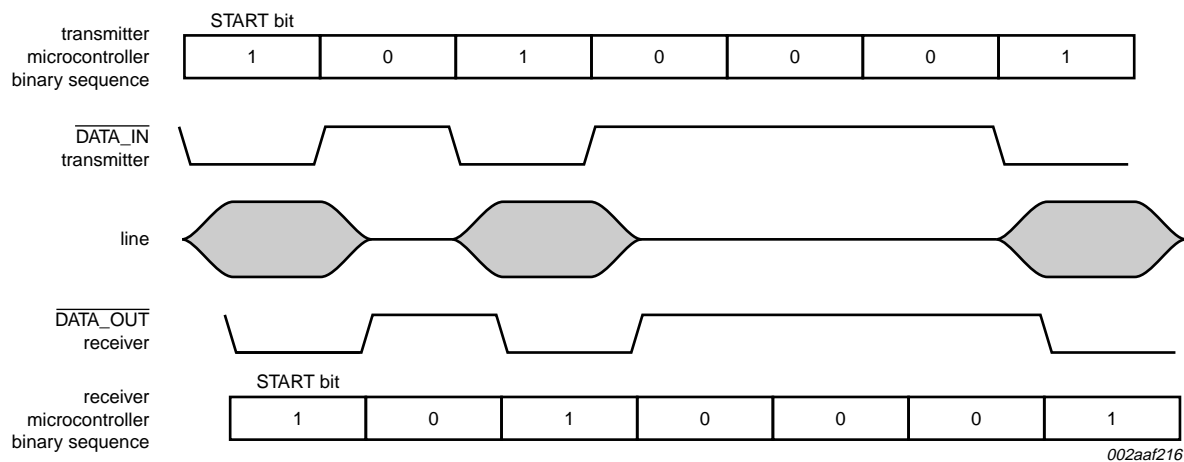**Fig 1.   Typical application with power line modems**

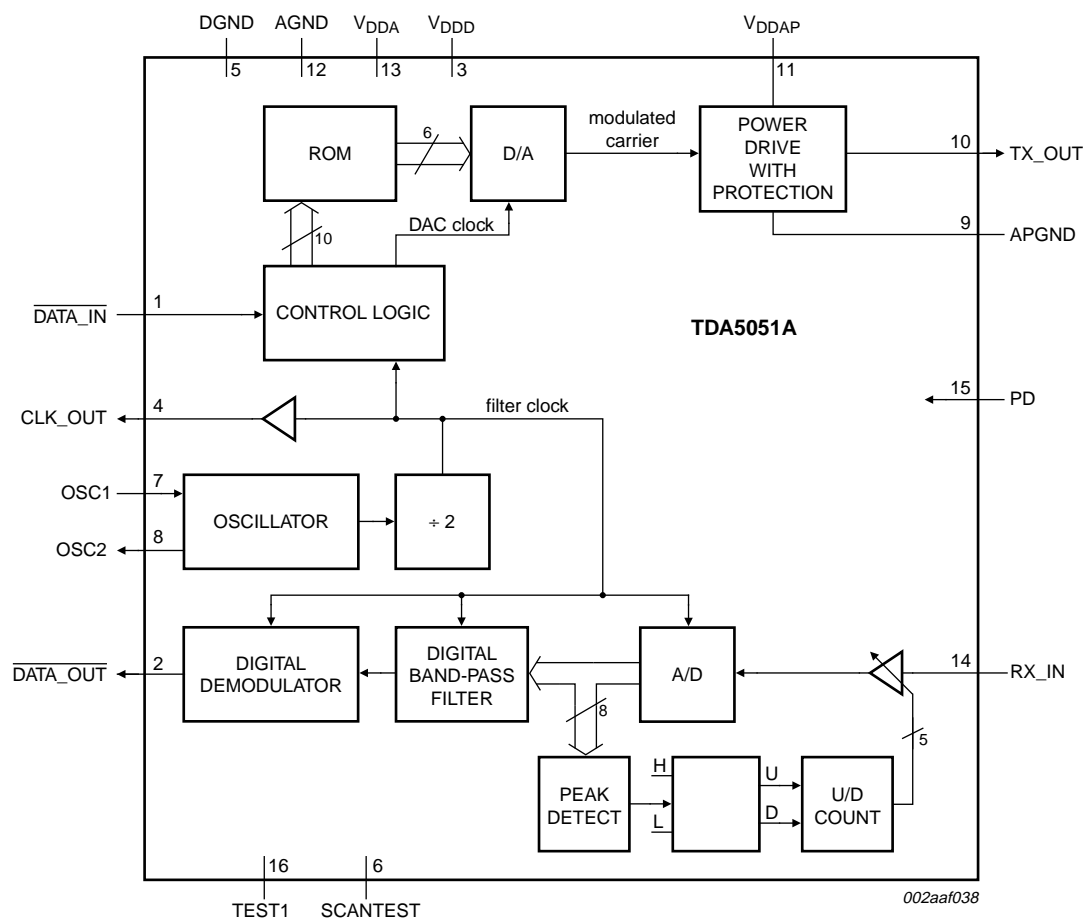
Fig 2.   Data transmission using ASK with NRZ code

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1.2 Block diagram

Fig 3.   Block diagram

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1.3 Pinning
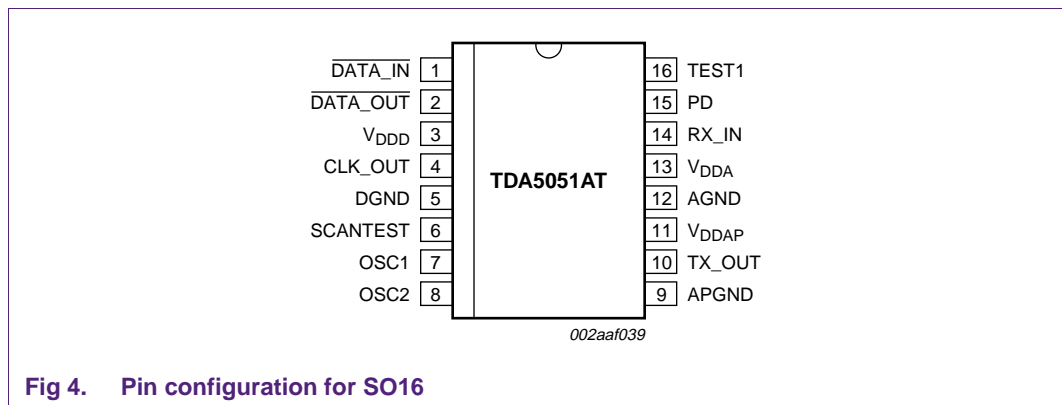
Fig 4. Pin configuration for SO16

Table 1. Pin description

Symbol	Pin	Description
$\overline{DATA\_IN}$	1	digital data input (active LOW)
$\overline{DATA\_OUT}$	2	digital data output (active LOW)
V_{DDD}	3	digital supply voltage
CLK_OUT	4	clock output
DGND	5	digital ground
SCANTEST	6	test input (LOW in application); on-chip pull-down resistor
OSC1	7	oscillator input
OSC2	8	oscillator output
APGND	9	analog ground for power amplifier
TX_OUT	10	analog signal output
V_{DDAP}	11	analog supply voltage for power amplifier
AGND	12	analog ground
V_{DDA}	13	analog supply voltage
RX_IN	14	analog signal input
PD	15	power-down input (active HIGH); on-chip pull-down resistor
TEST1	16	test input (HIGH in application); on-chip pull-up resistor

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2. Compliance with standards

2.1 Compliance with EN50065-1

(Main points only; please refer to the norm for further details.)

2.1.1 Choice of the carrier frequency

The operating frequency of the modem is only defined by the choice of the quartz crystal or by the frequency of the signal applied at the oscillator input, as shown in Table 2.

Table 2.   Carrier frequency

Oscillator frequency	Clock output frequency	Carrier and detection frequency
f_{osc}	f_{osc} / 2	f_{osc} / 64

However, to comply with the EN50065-1 norm, the carrier frequency for power line data transmission must be chosen within the following range:

Table 3.   Power line data transmission carrier frequency

9 kHz to 95 kHz	95 kHz to 125 kHz	125 kHz to 140 kHz	140 kHz to 148.5 kHz
restricted use	free for consumers	free for consumers	free for consumers
-	no access protocol	requested protocol: use 132.5 kHz to inform that a transmission is in progress	no access protocol

In order to avoid problems with the bandwidth of the modulated signal, it would be better to choose a carrier frequency (which is in fact a 'center frequency') higher than 95 kHz and lower than 148.5 kHz; for example 98 kHz to 145.5 kHz is a good compromise.

Then, the oscillator frequency range is 64 times higher than these two values, which gives 6.272 MHz to 9.312 MHz. For the special frequency of 132.5 kHz, a crystal of 8.48 MHz should be used.

For instance, using commercial quartz crystals gives the set of carrier frequencies shown in Table 4.

Table 4.   Carrier frequency choice

f_{osc} (MHz); XTAL	f_{CLK_OUT} (MHz); CLK_OUT pin	f_c (kHz); carrier (center)
6.553600	3.27680	102.4
7.372800	3.68640	115.2
7.864320	3.93216	122.88
8.000000	4.00000	125.00
8.192000	4.09600	128.00
8.480000[1]	4.24000	132.50
8.867230	4.43361	138.55

[1]   Note that 8.48 MHz is still not a standard frequency.

2.1.2 Modem output voltage

The maximum output voltage of a power line modem is also defined by the norm, and the measurement of this voltage must be performed as described in the EN50065-1.

Basically, it consists of measuring, with a 50 Ω spectrum analyzer, the carrier amplitude of the complete system (modem + coupling network) on a standard load, called the CISPR16 load.
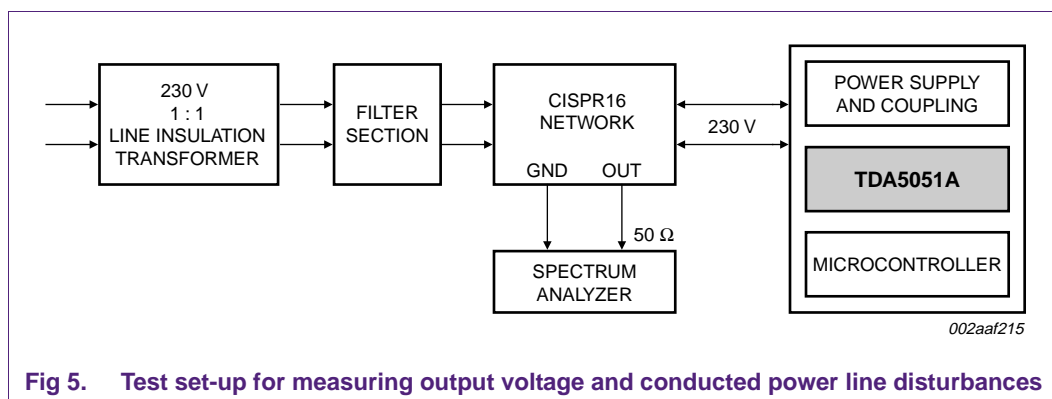

Fig 5. **Test set-up for measuring output voltage and conducted power line disturbances**

The CISPR16 Network provides an attenuation of 6 dB, due to its structure. The maximum RMS voltage measured on the analyzer must be in the range given in Table 5.

Table 5. **Maximum RMS voltage range**

Domestic use only	Industrial or specific use
maximum 116 dBμV with CISPR16 network	maximum 134 dBμV with CISPR16
effective value at the modem output is 122 dBμV	effective value at the modem output is 140 dBμV
3.56 V peak-to-peak	28.3 V peak-to-peak

The internal power amplifier of the TDA5051A is designed to supply the voltage required for domestic applications. For a higher voltage value, an extra power amplifier should be used.

2.1.3 Limiting conducted power line disturbances

One of the most important points of the EN50065-1 standard concerns the amplitude limitation of non-expected harmonics outside the transmission band. To be officially approved, this test requires specific equipment, but a measurement with a CISPR16 network and a 50 Ω analyzer (resolution bandwidth of 9 kHz) can give a good idea of the conducted disturbances.

The peak value of these harmonics must be within the limits given in Table 6.

Table 6. **Amplitude limitation of non-expected harmonics outside transmission band**

Frequency range (MHz)	Peak limit (dBμV)
0.15 to 0.5	66 to 56; decreasing linearity with the log of frequency
0.5 to 5	56
5 to 30	60

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2.2 Compliance with EN50065-2 (project stage)

2.2.1 Immunity requirements: narrowband conducted interferences

This is another important point of specification for power line modems, which is closely tied to the application.

The EN50065-2 (SC105A) norm defines the operation conditions of two systems (emitter and receiver) connected to an artificial network, with a given level of conducted interference signal.

This signal, for the narrowband test, is an 80 % 1 kHz modulated sine wave, supplied by a signal generator as shown in Figure 6.

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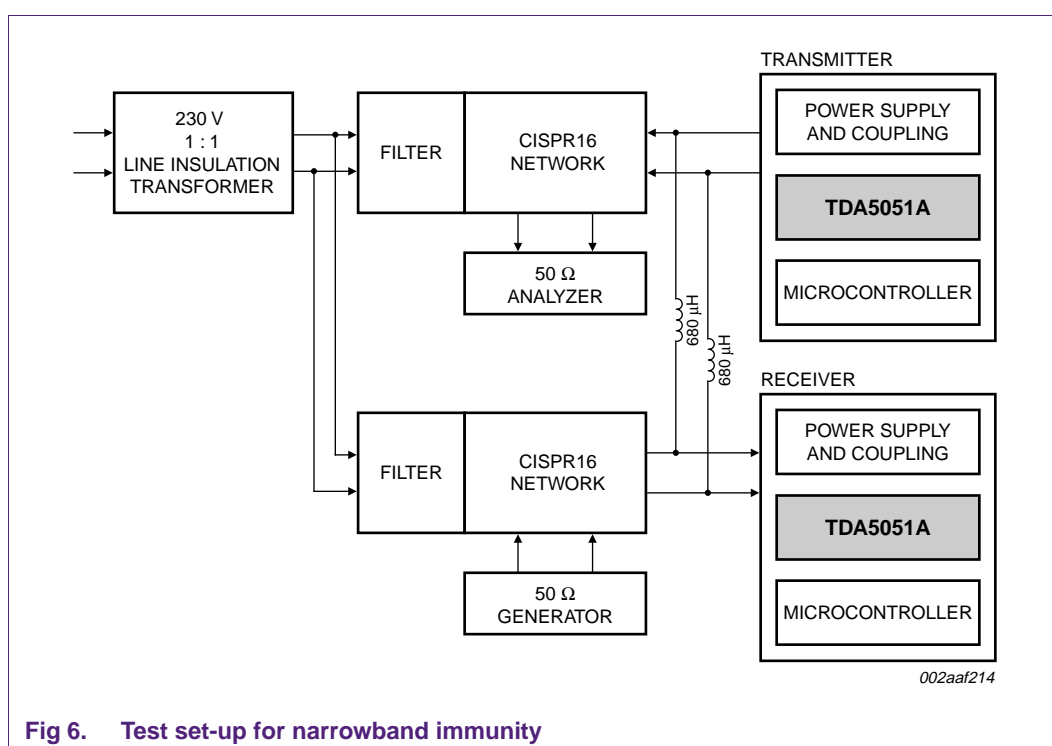
Fig 6.   Test set-up for narrowband immunity

Then this interference signal is swept through a wide frequency range from 3 kHz to 30 MHz, excluding the band defined in Table 3, in which the system operates. The interference signal must have the amplitude (measured unmodulated at the output of the generator) given in Table 7.

Table 7.   Interference signal amplitude

Frequency range	Interference signal amplitude	Performance criterion of the complete system
3 kHz to 8 kHz	134 dBμV	system will continue to operate correctly
10 kHz to 94 kHz	134 dBμV to 120 dBμV	system will continue to operate correctly
96 kHz to 124 kHz	134 dBμV	self-recoverable temporary loss of function or performance
126 kHz to 139 kHz	134 dBμV	self-recoverable temporary loss of function or performance
141 kHz to 147.5 kHz	134 dBμV	self-recoverable temporary loss of function or performance
150 kHz to 30 MHz	130 dBμV	self-recoverable temporary loss of function or performance

The behavior of the system during this test is not only dependant on the modem performances.The implemented software of the application and the protocol may be decisive to successfully do this test.

However, these elementary rules should be used for designing the system:

1. Avoid the edges of the allowed bands by choosing a 'centered' carrier frequency.
2. Design the external filter (see Section 3) for high rejection of unexpected frequencies.
3. Implement a software able to perform multi-sampling on the received data signal.
4. Avoid 'open loop' control; preferably use an 'acknowledge based' protocol.
5. If possible, use binary codes with error correction capabilities.

The structure of the TDA5051A has been designed to cope with severe test conditions by using very efficient digital filtering and a variable threshold demodulator. However, under certain operating conditions, correct detection is not guaranteed.

2.2.2 Immunity requirements: broadband noise interferences

For this test, the generator shown in Figure 6 is replaced by a random noise generator producing a uniform spectrum from 3 kHz to 150 kHz, having a spectral density of 43 dBμV / square root (Hz).

The system must operate correctly under these conditions.

The rules 3, 4 and 5 given in Section 2.2.1 are still valid.

2.2.3 Input impedance of the power line equipment

In order to allow the coexistence of several power line modems on the same network, a minimum value of the input impedance has been proposed by the SC105A standard.

That means, a guaranteed minimum input impedance for the coupling network (external filter) but also for the power supply. These aspects are mentioned in the filter design section (Section 3.2.1) and in Section 5 "Power supply design".

This value has been set to 5 Ω, in the frequency range of 95 kHz to 148.5 kHz.

3. Coupling with the power line

3.1 Introduction

The coupling network is the interface between the power line and the low voltage TX_OUT and RX_IN pins of the modem. For low cost applications, when the insulation with the mains is not required, a double LC network can be used, providing efficiency without any adjustment or tunable components. When an insulation is mandatory, an HF transformer should be used.
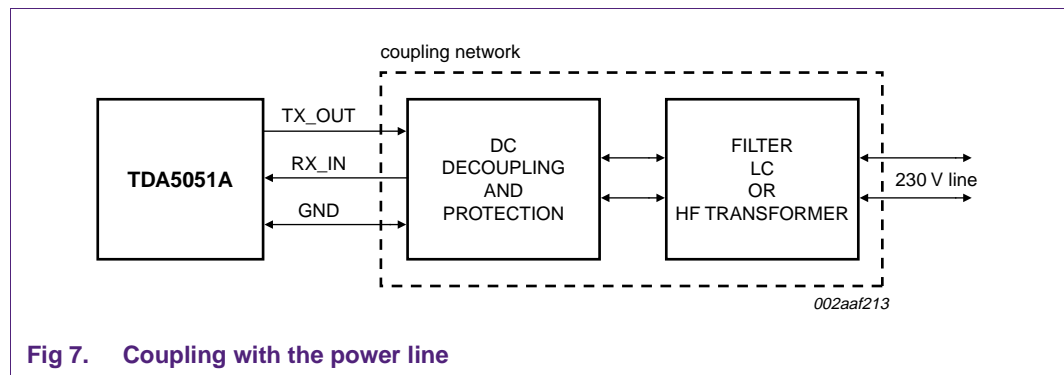

Fig 7. Coupling with the power line

3.1.1 Decoupling TX_OUT and RX_IN pins

Table 8 shows the electrical characteristics of TX_OUT and RX_IN pins in different operation modes.

Table 8. TX_OUT and RX_IN pin characteristics

Characteristic	Reception/Standby mode	Transmission mode	Power-down mode
TX_OUT pin			
impedance	HIGH	approximately 5 Ω	HIGH
DC offset	undefined	2.5 V	undefined
RX_IN pin			
impedance	50 kΩ	50 kΩ	50 kΩ
DC offset	2.5 V	2.5 V	2.5 V

Remark: It is mandatory to provide a DC decoupling for both TX_OUT and RX_IN pins.

It is not possible to tie together TX_OUT and RX_IN, even if the DC offset is the same. The RX_IN pin is very sensitive to a small shift of the DC voltage, which is internally set to bias the input amplifier at an optimum level.

3.1.2 Filter

The filter has two purposes:

- **In reception mode:** It provides an efficient rejection of the 50 Hz signal (high-pass) and anti-aliasing (low-pass) for the digital filter. It is important to keep in mind that the digital filter is able to detect the f_c component of the carrier, but also the $\pm f_c$ components located around the sampling frequency (f_{osc} / 2) and its multiples.

For instance, the 50 Hz amplitude is 230 V (RMS) or 167 dBμV, and the maximum sensitivity of the modem is 66 dBμV; to take advantage of the detection performance, the filter must reject the 50 Hz of more than 100 dB, which means an efficiency higher than 30 dB / decade.

For the anti-aliasing rejection around the sampling frequency, 50 dB seems to be a good compromise.
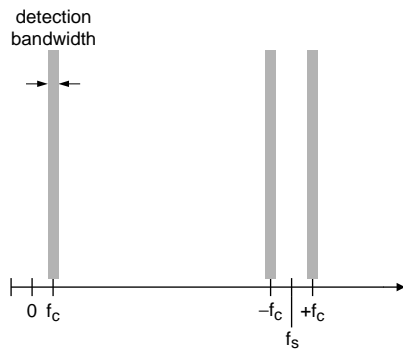

a. Digital filter detection
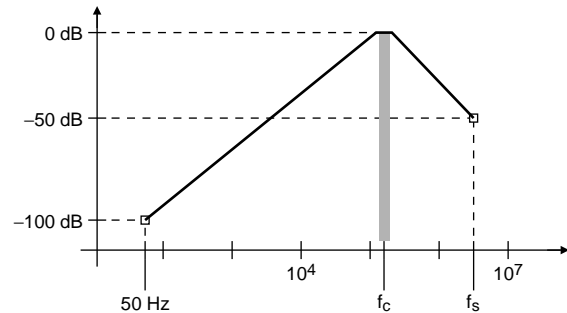
b. Ideal band-pass filter

Fig 8. **Digital filter detection and ideal band-pass filter**

- **In transmission mode:** It provides a rejection of unexpected harmonics in order to comply with the EN50065-1 standard. The carrier being synthesized by scanning a ROM, its spectrum is repeated around the sampling frequency ($f_{osc} / 2$) and its multiples (f_{osc}, $3 \times f_{osc} / 2$, $2 \times f_{osc}$, etc.), with decreasing amplitude.
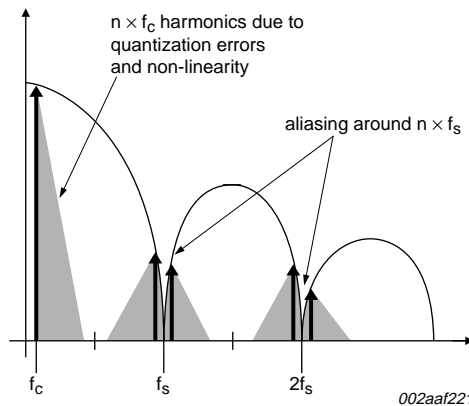
a. Digital carrier spectrum
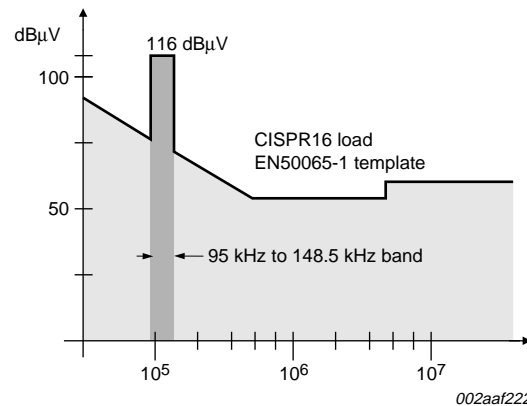
b. Compliance with standard

Fig 9. **Spectrum of the digital carrier and compliance with the standard**

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3.2 Low cost coupling

3.2.1 Introduction

This coupling uses a double LC band-pass filter. It does not provide any insulation from power line.
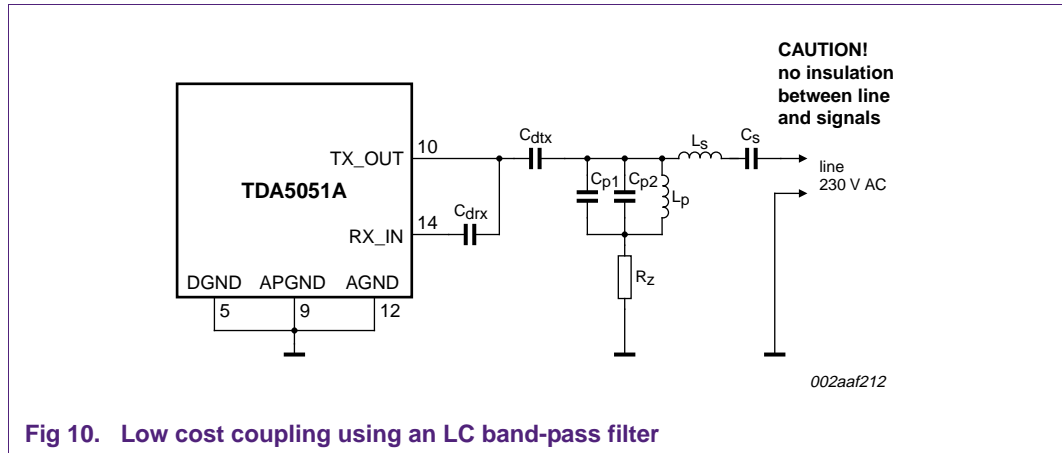
Fig 10. Low cost coupling using an LC band-pass filter

3.2.1.1 DC decoupling of TX_OUT and RX_IN

The values of C_{dtx} and C_{drx} are not critical.

C_{dtx} must be chosen to provide a low-impedance at the carrier frequency (less than 1 Ω for instance).Table 9 shows the recommended values for these capacitors.

Table 9. Recommended values for C_{drx} and C_{dtx} capacitors

Capacitor	Recommended value
C_{dtx}	1 μF to 10 μF non-polarized electrolytic
C_{drx}	1 nF to 10 nF ceramic or plastic

3.2.1.2 Design of the LC filter

The LC filter must be tuned for the chosen carrier frequency. One can use the simple formula in Equation 1:

$$f_c = \frac{1}{2\pi \times \sqrt{L_s \times C_s}} = \frac{1}{2\pi \times \sqrt{L_p \times (C_{p1} + C_{p2})}} = \frac{f_{osc}}{64} \tag{1}$$

with f_c and f_{osc} in Hertz, L in Henry, and C in Farad.

Apart from rejection characteristics mentioned above, the other features of this network should be:

Minimum impedance in transmission for the L_s-C_s part of the filter: that means a low serial resistor for L_s and good tuning at the carrier frequency. That also means a good balance between the values of L_s and C_s for the same tuning frequency, taking into account the possible variation of standard components (±20 % for high voltage capacitors, ±10 % or ±5 % for inductors).

Minimum input impedance of the filter: if required, the R_z resistor (see Figure 10) can be chosen from 0 Ω to 5.6 Ω, in order to limit the minimum input impedance of the filter (EN standard is at a project stage about this point).

Remark: One must take into account that a too high value for R_z may affect the rejection of HF harmonics in transmission. (The best rejection is carried out with R_z = 0 Ω.)

Table 10 shows an example of values for the filter components, according to standard quartz crystals.

Remark: Depending on the complete application of the customer (power supply, routing of the board, placement, etc.), the compliance with EN50065-1 is not guaranteed, and must be checked anyway.

Table 10.   Values of L_s, L_p, C_{p1}, C_{p2}, C_s and XTAL for different carrier frequencies

f_{osc} XTAL (MHz)	f_{CLK_OUT} (MHz)	f_c carrier (kHz)	L_s (low R_s) (μH)	C_s[3] (250 V AC) (nF)	L_p (μH)	C_{p1} (nF)	C_{p2} (nF)
6.553600[1]	3.27680	102.4	56	47	47	47	4.7
7.372800[1]	3.68640	115.2	47	47	47	33	6.8
7.864320[1]	3.93216	122.88	47	33	47	33	2.2
8.000000[1]	4.00000	125.00	47	33	47	33	-
8.192000[1]	4.09600	128.00	47	33	47	33	-
8.480000[2]	4.24000	132.50	47	33	47	27	3.3
8.867230[1]	4.43361	138.55	56	22	47	27	-

[1]   XTAL are standard HC49 quartz crystals; each carrier frequency belongs to the EN50065-1 transmission board.

[2]   8.48 MHz is still not a standard frequency.

[3] C_s must be an X2 type capacitor, suited for 250 V AC line voltage; L_s is preferably a low R_s inductor.

3.2.2 Design example of a typical coupling network

Designer choices:

- Frequency band: no protocol used, so the 95 kHz to 125 kHz band is chosen.

- Carrier frequency: within this frequency range, a standard quartz crystal of 7.3728 MHz gives a carrier of 115.2 kHz.

- The components should be: L_s = 47 μH $\pm$10 % with R_s = 2 Ω, C_s = 47 nF $\pm$20 % X2 (suited for 230 V AC), L_p = 47 μH $\pm$10 % with R_s = 5 Ω SMD inductor, C_{p1} = 33 nF 25 V SMD, C_{p2} = 6.8 nF SMD, R_z = 5.6 Ω.

- The decoupling C_{dtx} is a 10 μF / 16 V non-polarized capacitor; C_{drx} is a 10 nF 25 V SMD capacitor.

With this filter, one can simulate the reception transfer characteristics, the input impedance and the transmission transfer characteristics on the standard load. It is also possible to simulate the losses in transmission on different resistive loads.

The last check for a coupling network consists of carrying out a spectrum measurement with a CISPR16 load; a real example is given at the end of this chapter.

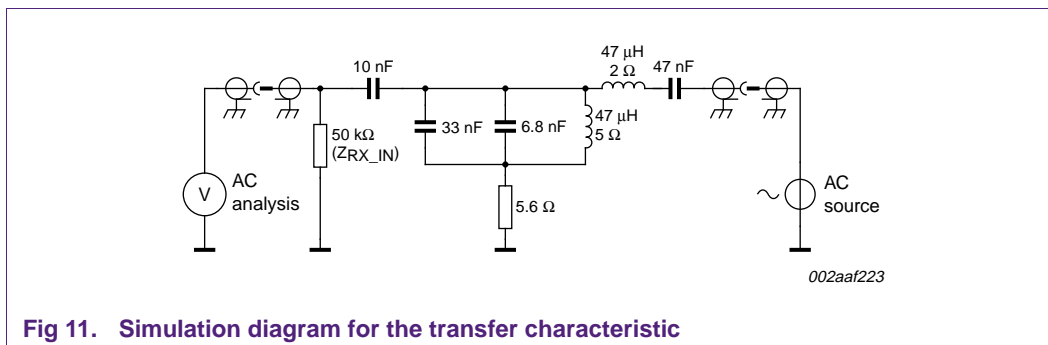### 3.2.2.1 Reception mode — transfer characteristic of the LC filter

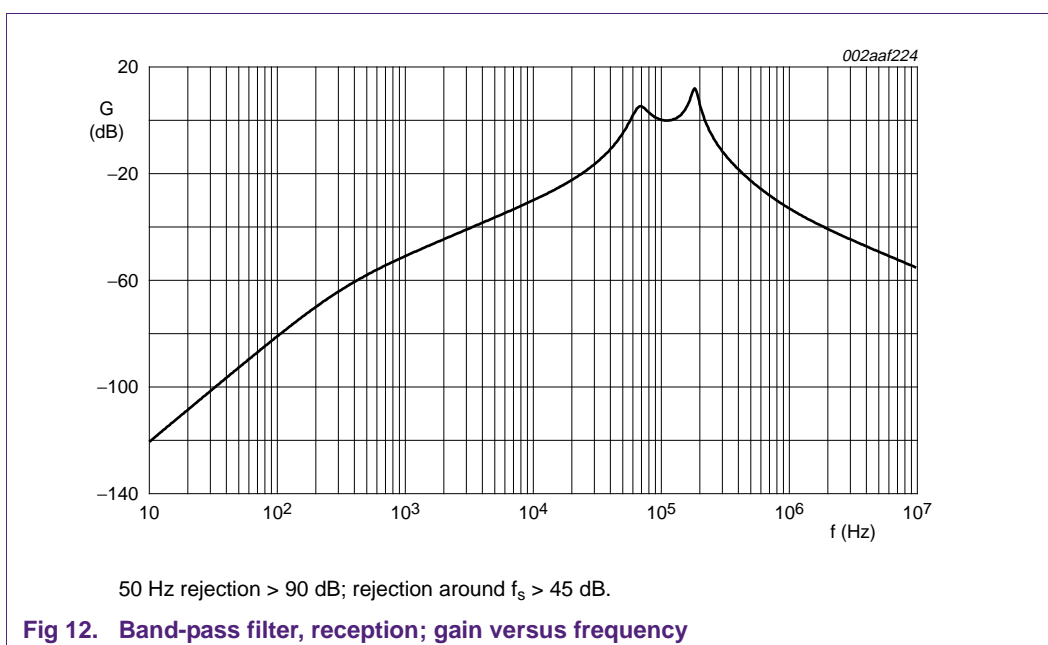**Fig 11. Simulation diagram for the transfer characteristic**

50 Hz rejection > 90 dB; rejection around f_s > 45 dB.

Fig 12. Band-pass filter, reception; gain versus frequency

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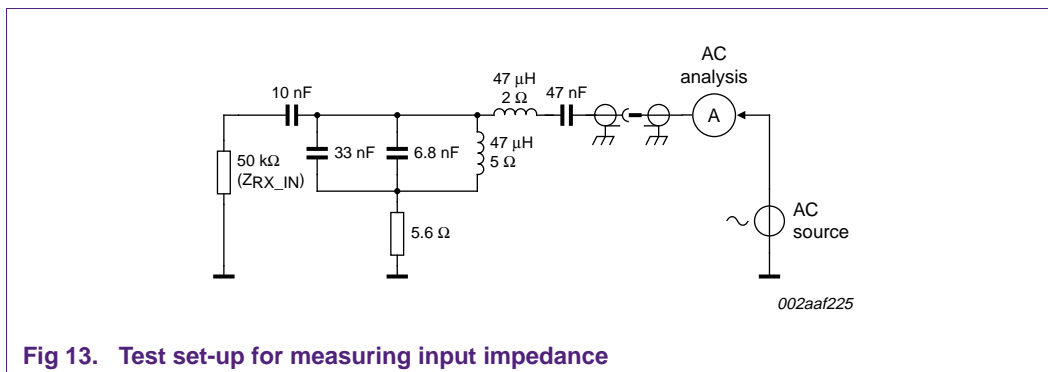
3.2.2.2 Reception mode — input impedance of the LC filter
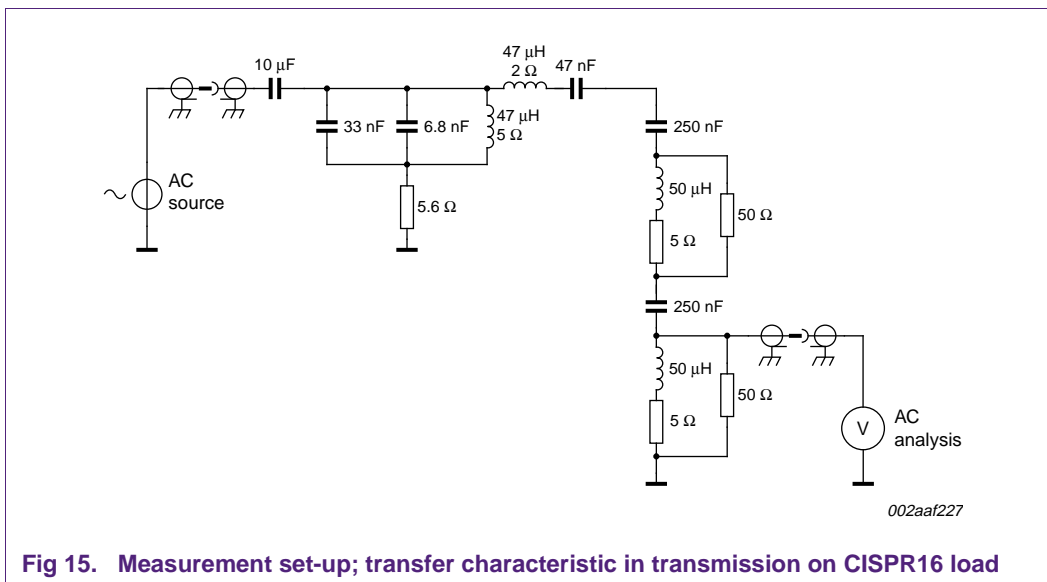

Fig 13. Test set-up for measuring input impedance

Fig 14. Input impedance versus frequency

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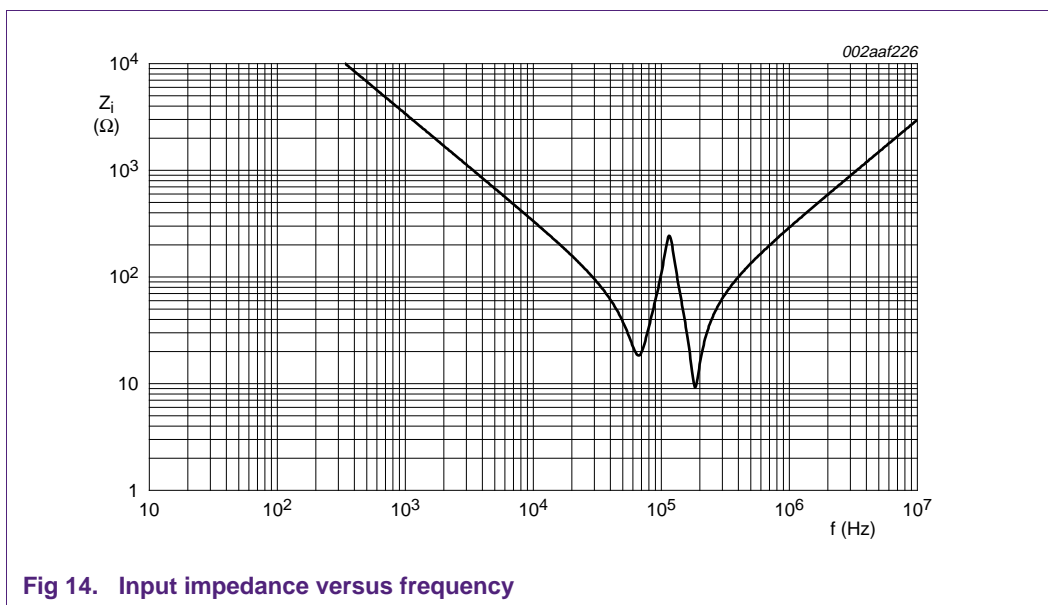
3.2.2.3 Transmission mode — transfer characteristic of the LC filter with a CISPR16 load

Fig 15. Measurement set-up; transfer characteristic in transmission on CISPR16 load

Remark: Top of curve: −6 dB (due to the network).

Fig 16. Band-pass filter, transmission; gain versus frequency
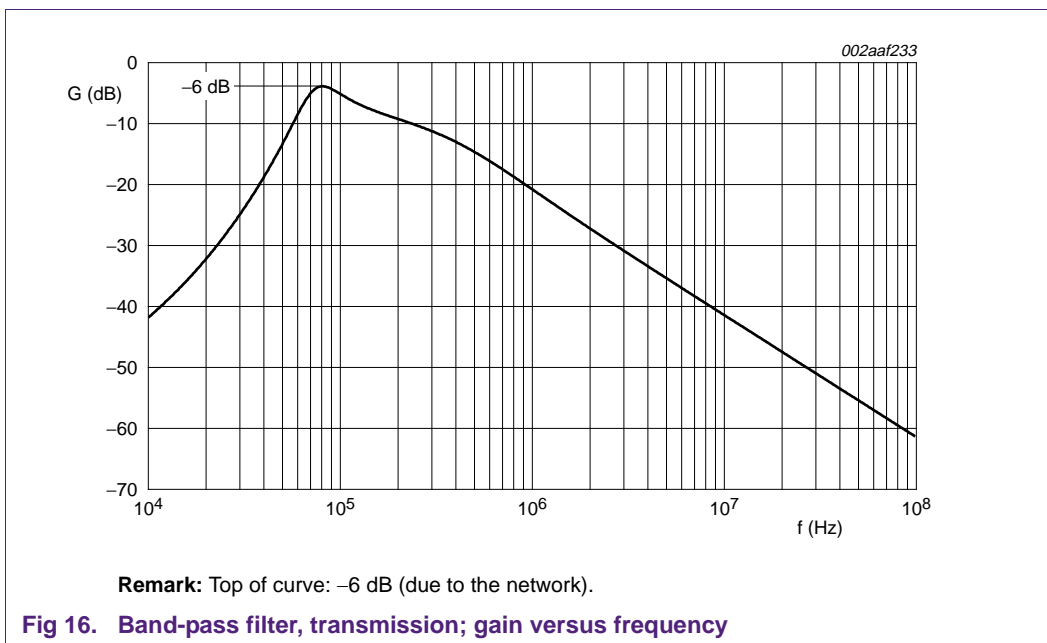
3.2.2.4 Transmission mode — efficiency of the LC filter

It could be useful to simulate the efficiency of the coupling for different loads and for different marginal conditions in the values of C_s and L_s. For this simulation, a fixed frequency and voltage generator is used with a serial resistor of 5 Ω, to represent the output amplifier.

$V_O = 20log(V \times 1e6) = f(R_L)$

Fig 17. Simulation set-up
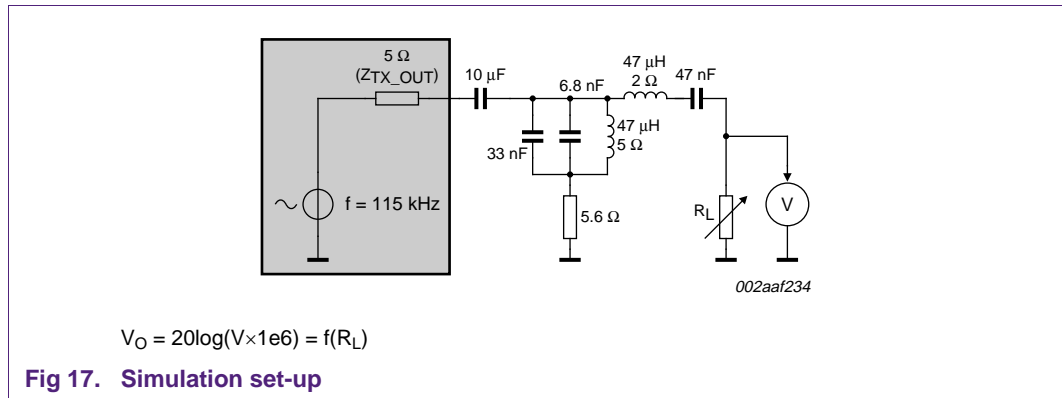
Figure 18 shows the coupling efficiency on a resistive load, with optimum values for C_s = 47 nF and L_s = 47 μH; the maximum RMS level is 122 dBμV and the minimum is 103 dBμV, for 1 Ω load.

f = 115.2 kHz

Fig 18. Output voltage versus load impedance; nominal values for filter components
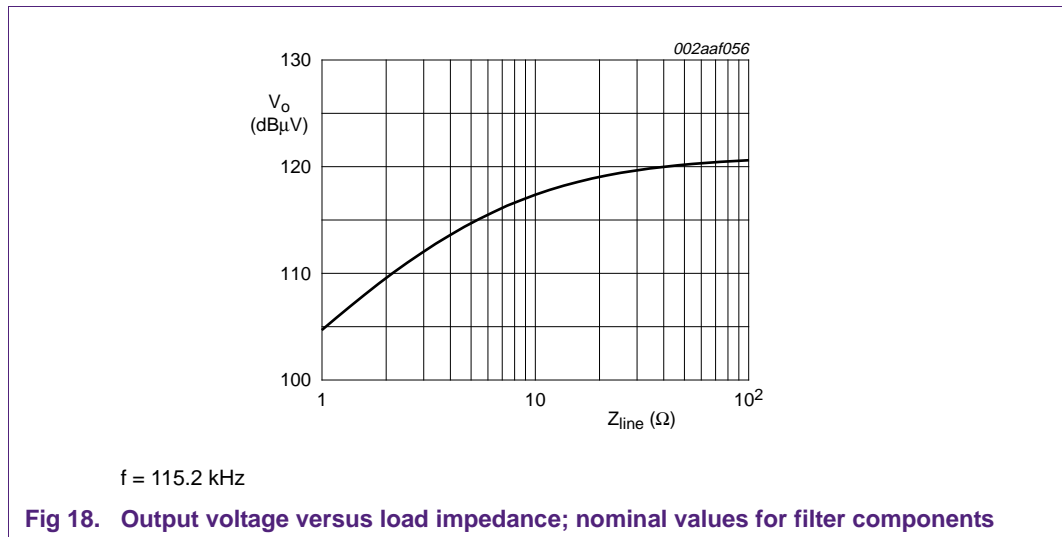
Figure 19 shows marginal conditions, with C_s = 47 nF $\pm$ 20 % and L_s = 47 μH $\pm$ 10 % (4 plots). In the worst case (47 nF + 20 %, 47 μH + 10 %), the output voltage is still higher than 98 dBμV for the maximum load. The variation of C_p and L_p has no significant effect on the efficiency.

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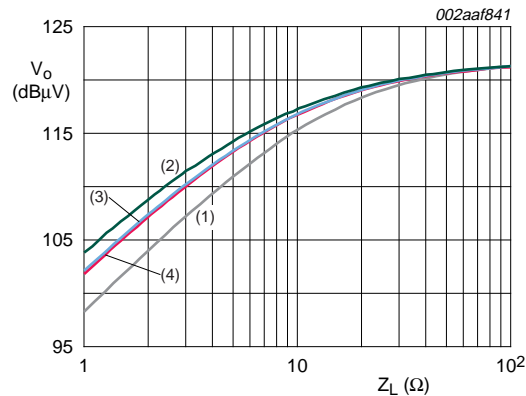
(1) f = 115.2 kHz; L12 = 52.0 μH; C9 = 56.0 nF
(2) f = 115.2 kHz; L12 = 52.0 μH; C9 = 38.0 nF
(3) f = 115.2 kHz; L12 = 42.0 μH; C9 = 56.0 nF
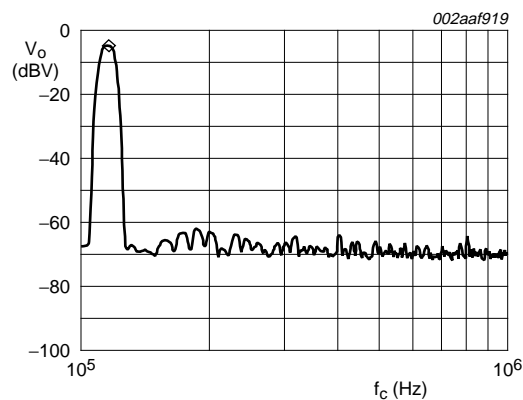(4) f = 115.2 kHz; L12 = 42.0 μH; C9 = 38.0 nF

Fig 19. Output voltage versus load impedance; $\pm$20 % C_s and $\pm$10 % L_s

3.2.2.5 Transmission mode — spectrum of the carrier signal with low cost coupling network
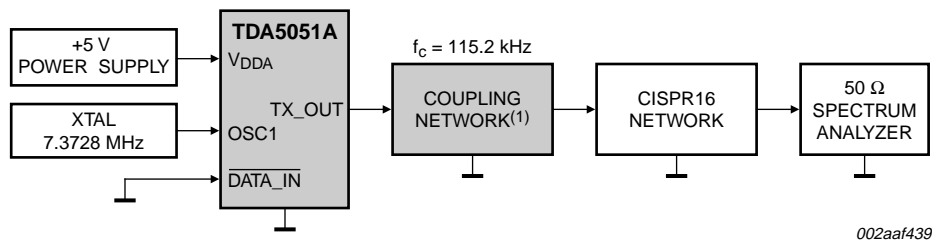
(1) As defined in Figure 10.

Fig 20. Test set-up for carrier spectrum measurement

A marker: 115.1875 kHz; −4.695 dBV

Fig 21. V_o (RMS) spectrum; carrier frequency 115.2 kHz

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3.3 Coupling with HF transformer

3.3.1 Introduction

If the application requires insulation between the modem and the power line, it is mandatory to use a small signal transformer. Apart from the insulation with the power line, the transformer also has to realize the appropriate filtering, both in transmission and reception. The Murata 78250MC can be used for this application; it has a primary and two secondary winding, one of them having a ratio of 4 : 1.

To operate correctly, the transformer has to be tuned (with the tuning screw) to the carrier frequency, and requires an external capacitor C_t, which can be placed on the serial connection of the two secondary windings, as shown in Figure 22.
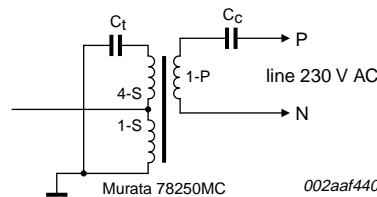
L1 = 9 μH value of 1 turn winding.

L4 = 150 μH value of 4 turns winding and $L_{equ(1+4)}$ = L1 + L4 + 2M with $M = 0.7 \times \sqrt{(L1 \times L4)}$,

then L_{equ} = 200 μH and the relation $f_c = \dfrac{1}{2\pi \times \sqrt{(L_{equ} \times C_t)}}$ is used to calculate C_t.

(Medium position of the tuning screw.)

Fig 22. Tuning of the transformer

The value of C_t can be easily calculated for a given carrier frequency f_c. Then, the C_c capacitor is used to couple with the power line and must be an X2 type, rated for mains voltage.
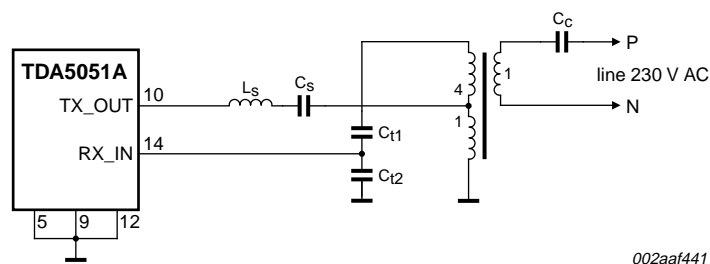
C_c = 470 nF type X2.

Fig 23. Coupling with Murata 78250MC

To provide efficient transmission coupling, the 1 : 1 secondary winding can be used, but needs an extra LC serial filter in order to comply with standards. In fact, the behavior of the 1 : 1 winding is mainly a high-pass filter, and does not provide efficient filtering of high frequency harmonics.

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In Reception mode, the (4 : 1 + 1 : 1) secondary windings, fitted with the tuning capacitor, provides a very efficient band-pass filter, with high rejection of 50 Hz and anti-aliasing capabilities. The only problem is the ratio of 5 : 1 of the complete secondary winding, which may apply to the reception input a voltage 5 times higher than expected.

A solution is to use a capacitor divider, providing an equivalent value of C_t and a voltage ratio of 1 / 5. The complete diagram is given in Figure 23.

The values of C_{t1}, C_{t2}, C_s and L_s must be calculated with Equation 2:

$$f_c = \frac{1}{2\pi \times \sqrt{(L_{equ} \times C_t)}} = \frac{1}{2\pi \times \sqrt{L_s \times C_s}} = \frac{f_{osc}}{64} \; with \tag{2}$$

$$C_t = \frac{C_{t1} \times C_{t2}}{C_{t1} + C_{t2}} \; and \; \frac{1}{5} = \frac{C_{t1}}{C_{t1} + C_{t2}} \; and \; L_{equ} = 200 \; \mu H$$

For the serial LC filter, at standard frequency (132.5 kHz), L_s = 3.3 μH and C_s = 470 nF is a good compromise. C_{t1} and C_{t2} calculation for a carrier frequency of f_c can be done with the simple formula given in Equation 3:

$$C_t = \frac{1}{4 \times \pi^2 \times f_c^2 \times 200 \times 10^{-6}} \tag{3}$$

$$C_{t1} = 1.25 \times C_t$$

$$C_{t2} = 5 \times C_t$$

where f_c is in Hertz; C_t, C_{t1}, C_{t2} in Farad.

3.3.2 Design example

Designer choices:

- Frequency band: no protocol used, so the 95 kHz to 125 kHz band is chosen.
- Carrier frequency: within this frequency range, a standard quartz crystal of 7.3728 MHz gives a carrier of 115.2 kHz.
- The components should be:
  - LC filter: L_s = 3.3 μH ± 10 % with R_s < 1 Ω, C_s = 630 nF ± 10 % 25 V
  - C_c: coupling capacitor type X2 (230 V (RMS)), 470 nF
  - C_t = 9.5 nF (see Equation 3 with f_c = 115 kHz) → C_{t1} = 12 nF ± 10 %, 25 V; C_{t2} = 47 nF ± 10 %, 25 V

With these components, one can simulate the transfer characteristic in transmission, reception and the input impedance.

This simulation does not take into account the effect of the transformer's core material and the parasitic capacitance of the windings. In fact, these simulation results have been compared with real measurements, and the behavior was very close to the computer analysis in a frequency range from 10 kHz to 10 MHz.

The last check of the transformer coupling is also a spectrum measurement on a CISPR16 load; a diagram is shown at the end of the chapter.

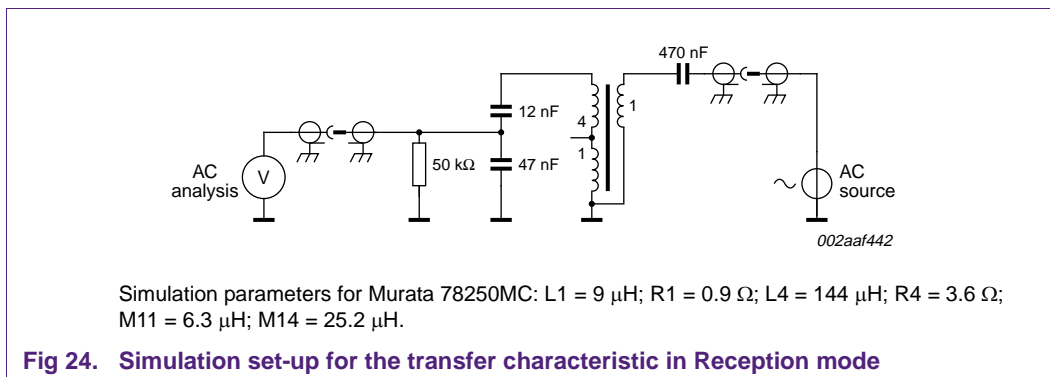### 3.3.2.1 Reception mode — transfer characteristic of the coupling network

Simulation parameters for Murata 78250MC: L1 = 9 μH; R1 = 0.9 Ω; L4 = 144 μH; R4 = 3.6 Ω; M11 = 6.3 μH; M14 = 25.2 μH.

Fig 24. Simulation set-up for the transfer characteristic in Reception mode
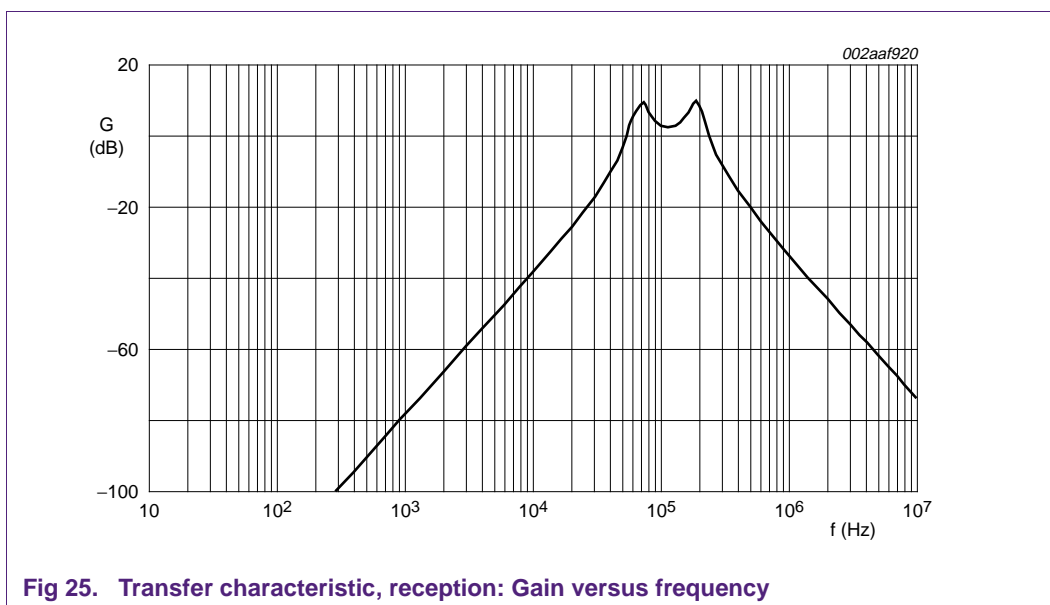
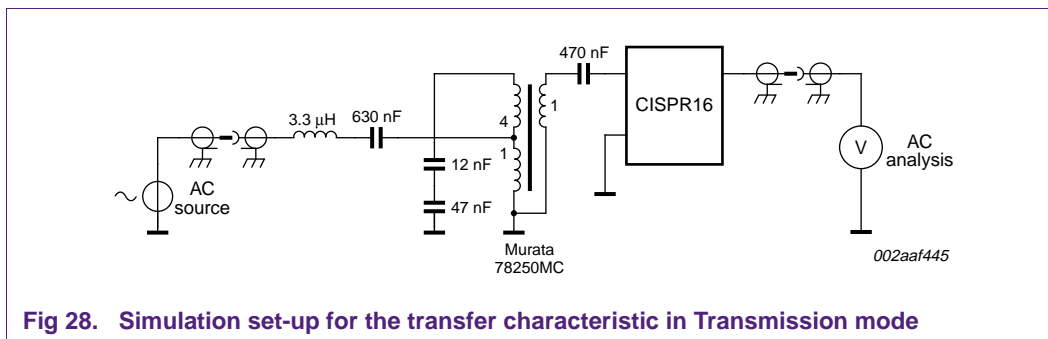**Fig 25. Transfer characteristic, reception: Gain versus frequency**

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3.3.2.2 Reception mode — impedance characteristic of the coupling network

Simulation parameters for Murata 78250MC: $L1 = 9\ \mu H$; $R1 = 0.9\ \Omega$; $L4 = 144\ \mu H$; $R4 = 3.6\ \Omega$; $M11 = 6.3\ \mu H$; $M14 = 25.2\ \mu H$.

Fig 26. Simulation set-up for the impedance characteristic in Reception mode

Fig 27. Input impedance, reception: input impedance versus frequency
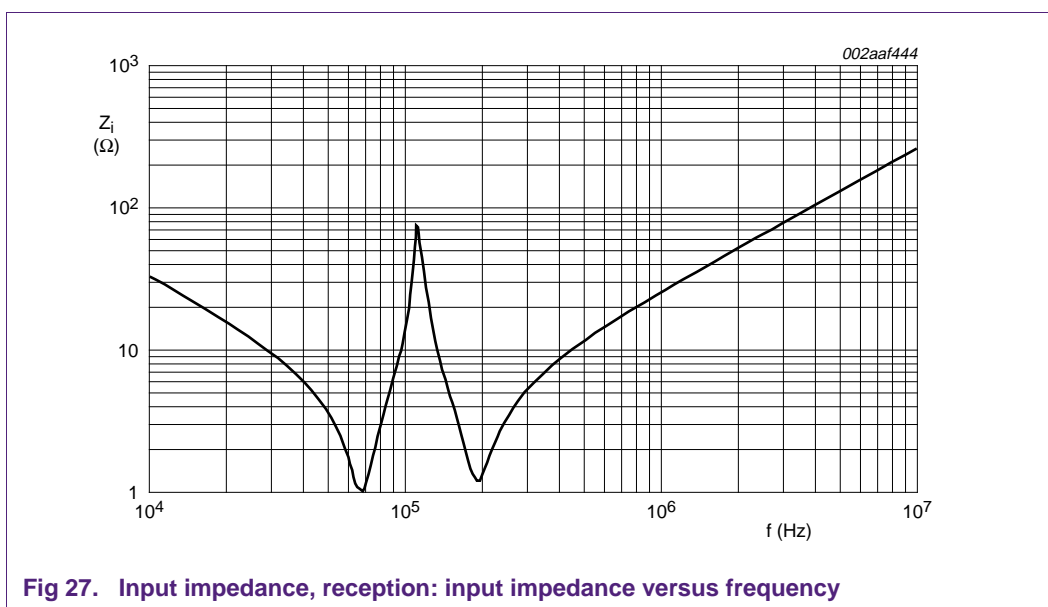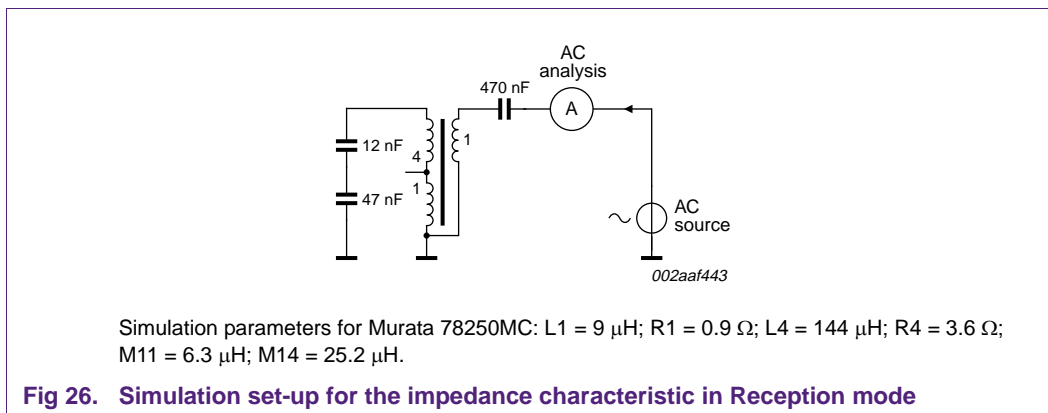
The problem for this coupling network is the impedance limitation in reception, around the center frequency. One can see in Figure 27 that the impedance is very low for two different frequencies, 70 kHz and 200 kHz. However, the input impedance is higher than $5\ \Omega$ within the 95 kHz to 148.5 kHz frequency range.

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3.3.2.3 Transmission mode — transfer characteristic of the coupling network

Fig 28. Simulation set-up for the transfer characteristic in Transmission mode
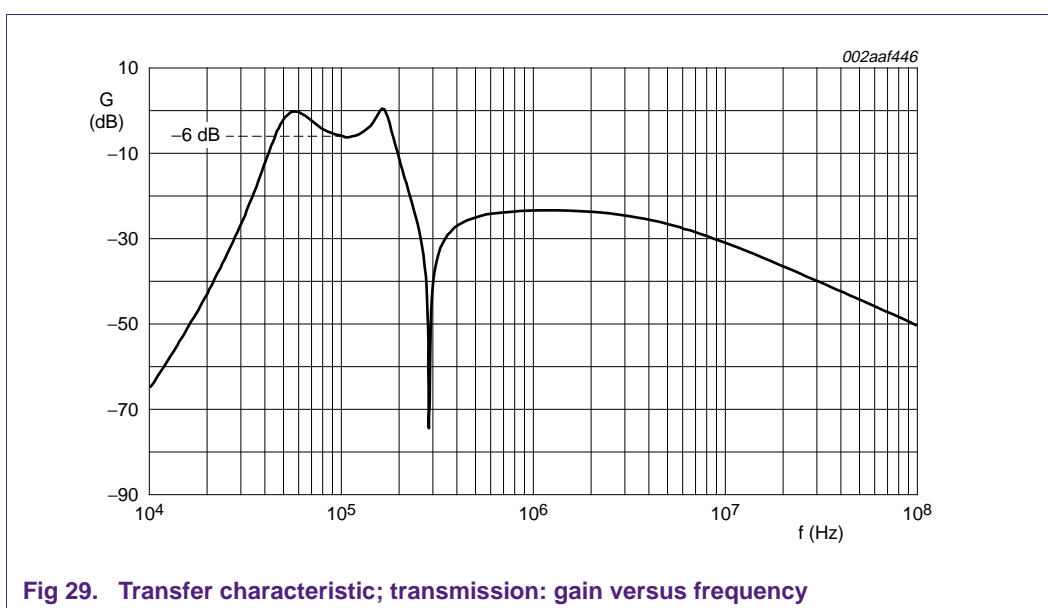
Fig 29. Transfer characteristic; transmission: gain versus frequency

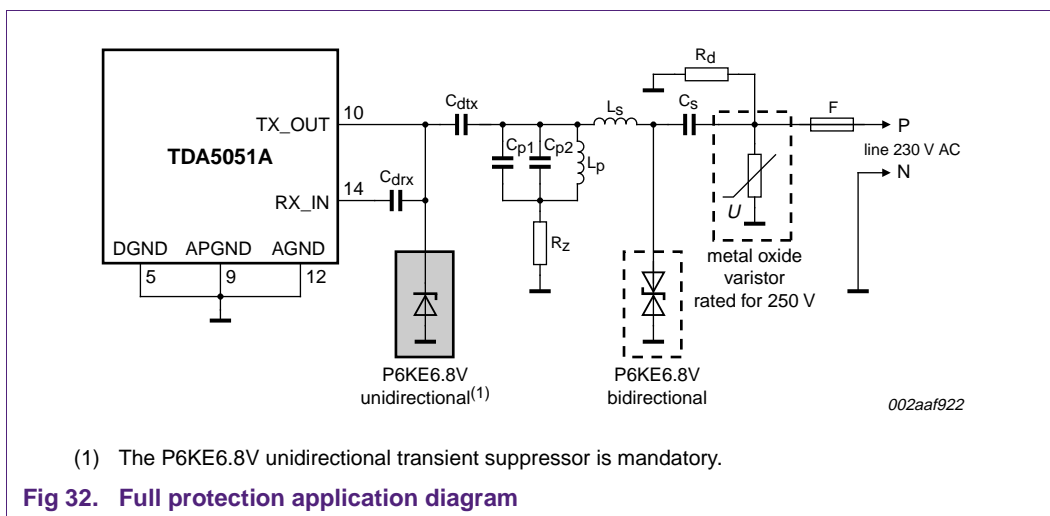### 3.3.2.4 Transmission mode — spectrum of the carrier signal with transformer coupling network

(1) As defined in Figure 23.

Fig 30.   Test set-up for carrier spectrum measurement

A marker: 115.1875 kHz; −4.886 dBV

Fig 31. V_o (RMS) spectrum; center frequency = 115.2 kHz

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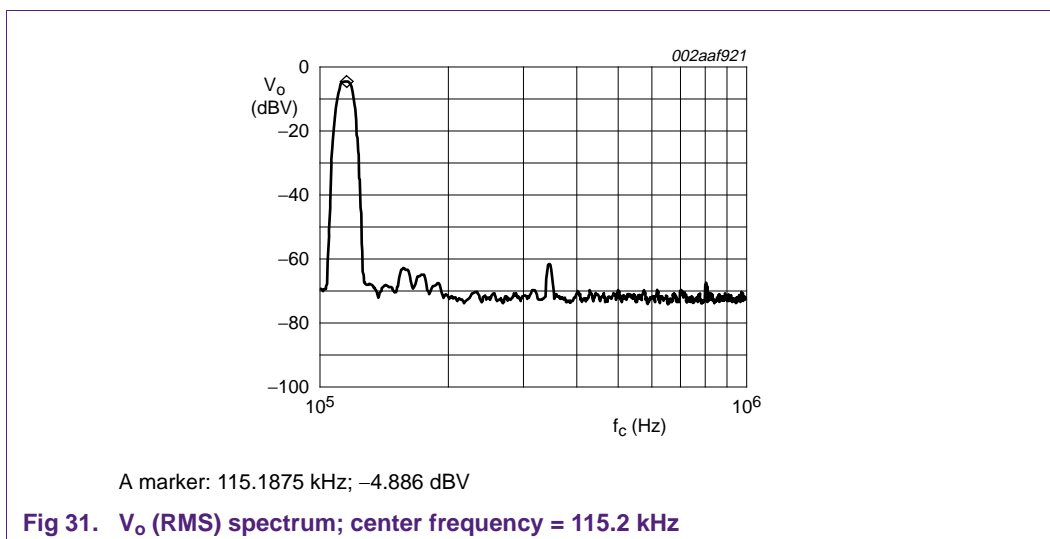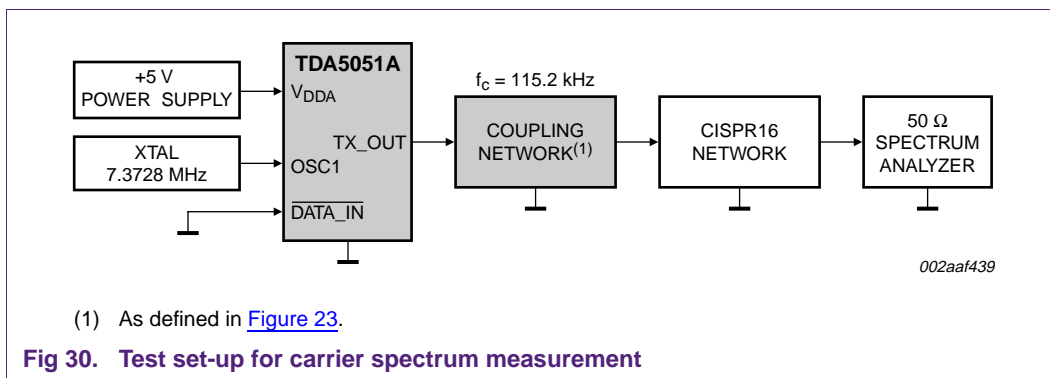
3.4 Transient and overvoltage protections - electrical hazard

3.4.1 Introduction

- More than any other electronic equipment, a power line modem has to be protected against many risks of damage, mainly due to the direct connection to the mains. The TDA5051A is internally protected against electrostatic discharges, but **does not have a dedicated protection** for severe external stresses.

  - **Transient overstress during power-up:** The coupling network, LC filter or HF transformer, is basically a passive network having inductors and capacitors that are discharged before power-up. That means a particular behavior during power-up which may cause the modem **irreversible damage**.

  - **Overvoltage on the power line:** The power line of the modem is shared with other equipment, which may cause severe disturbances and overvoltage during operation or on/off switching. The power line itself may carry transient overvoltage due to indirect effects of lightning (protecting domestic electronic equipment from direct effects of lightning is not realistic and goes beyond the purpose of this note).

- The other protection aspect depends on the application and concerns the electrical hazards for people when using the power line equipment.

  - **Insulation with the mains:** If the application requires an insulation with the power line, the coupling network with HF transformer must be used. For software development, it is also recommended to use a transformer coupling, or to work on a dedicated power line, insulated from the mains with a 1 : 1 power transformer.

  - **Discharge of high voltage capacitors:** In some cases, the modem can be disconnected from the power line by the user of the system. If the coupling network is not loaded, the high voltage capacitors remain charged, and a shock hazard may exist.

3.4.2 Coupling with LC filter

Figure 32 shows one of the best solutions for a complete protection of the modem. Obviously, it is not the cheapest, but it provides a high safety level.

(1) The P6KE6.8V unidirectional transient suppressor is mandatory.

Fig 32. Full protection application diagram

The primary protection (optional) is possible with a Metal-Oxide Varistor (MOV), rated at 230 V power line operation. It will be able to limit overvoltage spikes which could damage the C_s (X2 type) capacitor. A problem may occur if a long or severe overvoltage is applied to the MOV: in this case the extra-fast fuse 'F' **must** be destroyed **before** the MOV itself!

Refer to the supplier's data sheet to verify that the set MOV-FUSE has an adequate overvoltage specification.

The second protection device (optional) is a bidirectional Transil, type P6KE6.8V, which limits the voltage applied to the C_{p1} and C_{p2} capacitors and the peak current into L_s and L_p inductors. If the designer decides to avoid the use of this protection, he has to measure the transient voltage applied on C_{p1} and C_{p2} and the peak current into the inductors L_s and L_p. Then, he must decide of voltage and current ratings for these components.

The last protection device is the unidirectional transient suppressor P6KE6.8V (or equivalent) which is **mandatory** in this application diagram. This device protects both TX_OUT and RX_IN pins from overvoltage. It protects also TX_OUT from **negative transient voltage** which may **destroy the circuit's output amplifier**. This Transil must be connected directly to the TX_OUT pin, as close as possible, with a strong short strip on the printed-circuit board.

The DC output voltage (2.5 V) of the TX_OUT pin is used to bias the Transil in Transmission mode, in order to avoid carrier signal clipping and distortion.

It could be useful to keep in mind that a Transil has an equivalent capacitance of up to 4 nF for a unidirectional type (depending of the bias voltage) and half for a bidirectional one. That could explain some tuning variation when it is used with a narrow LC filter.

Then, a high value resistor R_d can be used to discharge C_s if the system is removed from the mains. The value could be chosen between 100 kΩ (1 W) and 1 MΩ ($\frac{1}{4}$ W) depending of the requested time to discharge C_s.

3.4.3 Coupling with HF transformer

Figure 33 shows the complete coupling network with the protection components.

Fig 33. Application diagram using a 78250MC transformer

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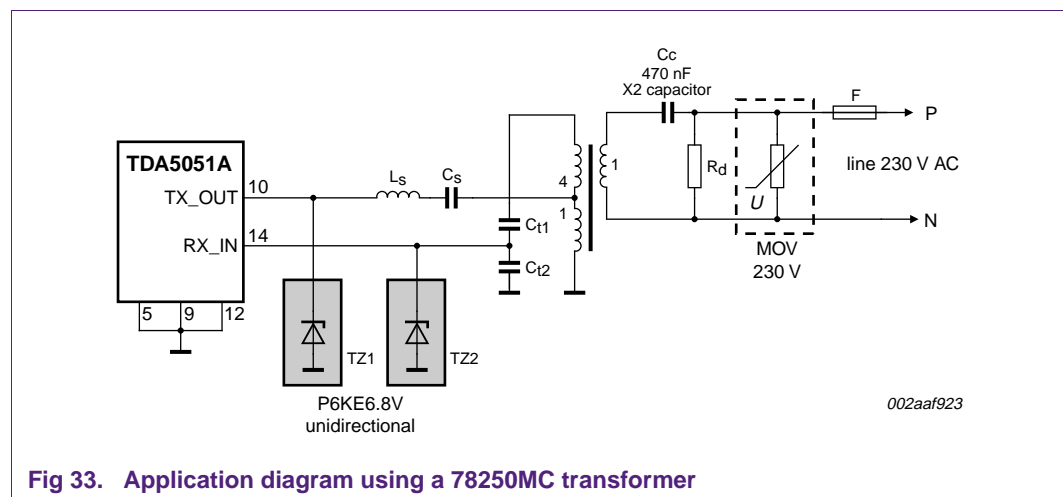
In this configuration, it is not so easy to protect both TX_OUT and RX_IN pins with only one Transil as shown in Figure 32, because of the different connections with the transformer.

The two unidirectional Transils are now **mandatory** to clamp the transformer's surge voltage of the secondary windings and avoid any stress and reverse voltage at the TX_OUT pin.

It may be possible to replace the unidirectional Transil TZ1 with a fast recovery diode, only used to clamp the negative transient voltage. In this configuration, the designer will have to check the maximum voltage applied at the TX_OUT pin, for different overvoltage and stress on the line input; this voltage must be always lower than 7 V.

The MOV device is not mandatory, but recommended only if an appropriate fast fuse is used.

The R_d resistor may be omitted if the system is never disconnected from the mains, or if another load is always connected to the same power wires (for example, the primary winding of a power supply transformer).

In some cases, to improve the insulation with the mains and to guarantee the decoupling, it could be useful to add an extra C_c capacitor on the other power line wire of the system, as shown in Figure 34. In this case, the value of these two X2 capacitors must be 1 μF.
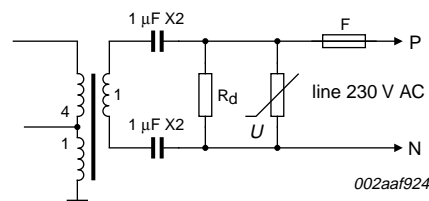
Fig 34. Improvement of the power line insulation

4. Connection with the controller

4.1 Clock configurations
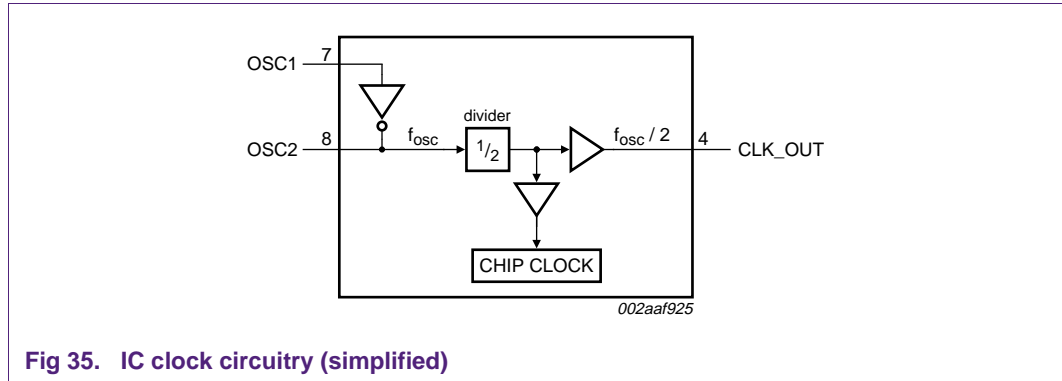
Fig 35. IC clock circuitry (simplified)

The TDA5051A can be used with two different clock configurations: external clock and on-chip clock.

4.1.1 External clock

A clock signal, TTL/CMOS compatible, is applied to the OSC1 pin of the circuit and sets the operation frequency called f_{osc}. Then, the carrier and detection frequency is $f_{osc} / 64$.
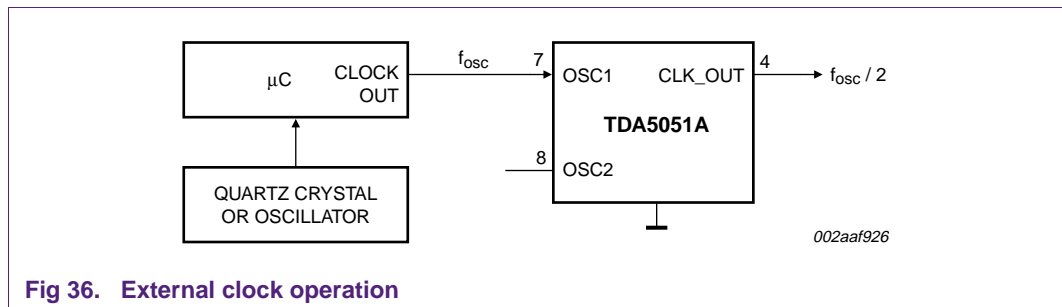

Fig 36. External clock operation

Table 11. External clock settings

TDA5051A	External clock
OSC1, pin 7	input; signal frequency f_{osc}
OSC2, pin 8	**must be left open**
CLK_OUT, pin 4	output; signal frequency $f_{osc} / 2$
carrier and detection frequency	$f_{osc} / 64$

4.1.2 On-chip clock

An external quartz crystal is connected to the circuit and sets the operation frequency f_{osc}. In this configuration, the CLK_OUT pin of the TDA5051A is a clock output, which is able to supply a TTL/CMOS compatible clock signal to an external controller, at an $f_{osc} / 2$ frequency. The carrier and detection frequency is also $f_{osc} / 64$.

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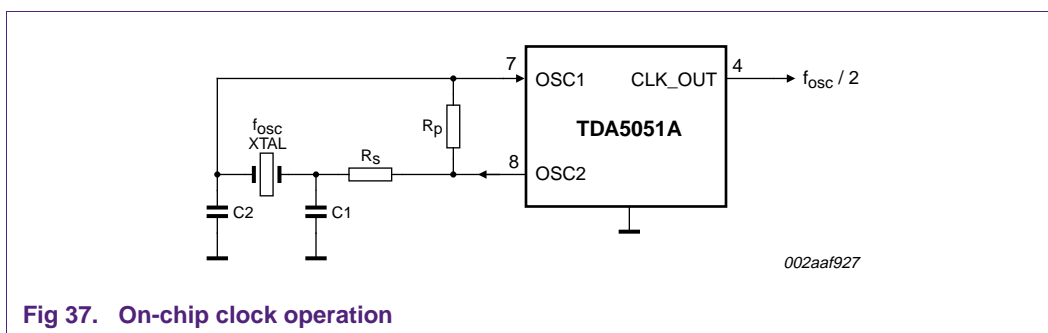
Fig 37. On-chip clock operation

Table 12. On-chip clock settings

TDA5051A	External clock
OSC1, pin 7	external quartz crystal (XTAL) connection
OSC2, pin 8	external quartz crystal (XTAL) connection
CLK_OUT, pin 4	output; signal frequency f_{osc} / 2
carrier and detection frequency	f_{osc} / 64

The on-chip clock circuit is basically a Pierce oscillator, which uses an inverter implemented on the silicon and other external components. The R_p resistor is used to bias the inverter in the linear region and the R_s resistor limits the dissipation and the peak current in the crystal. The R_s resistor is not mandatory and could be avoided to reduce the number of external components.

This oscillator can operate within a very large frequency range, but for the recommended values of carrier frequency, defined in the EN50065-1 standard, the XTAL must be chosen between 6.2 MHz and 9.3 MHz. For these values, the external components must be chosen as shown in Table 13.

Table 13. External component selection

Component	Recommended values
C1 and C2	22 pF to 47 pF ceramic capacitors
R_p	1 MΩ to 10 MΩ
R_s	0 Ω to 3.9 kΩ
XTAL	HC49 standard quartz crystal; 6.2 MHz to 9.3 MHz

For this oscillator, the requirements for a good start-up are:

- A loop gain larger than 5: that means an amplifier gain 5 times larger than the attenuation of the passive part.

- A loop phase of 360°: the inverter has a phase shift of 180° and the passive part must have the same.

With **R_p = 2.2 MΩ, R_s = 0 Ω and C1 = C2 = 27 pF**, a large set of crystals have been successfully checked for start-up and continuous operation, over the IC specified temperature range. However, the designer will have to check carefully the oscillator in the complete application.

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4.2 Data signals — control signals

4.2.1 Connection to a microcontroller

The TDA5051A can be connected to any controller having a TTL/CMOS compatible I/O port, as shown in Figure 38.

The PD connection is not mandatory and may be omitted if the PD mode is not used. Then, this pin could be tied to GND or could be left opened (the IC has an internal pull-down resistor).

The pins TEST1 and SCANTEST are only used for production tests. They have internal pull-up and pull-down resistors, but it is also possible to tie them to the correct level.
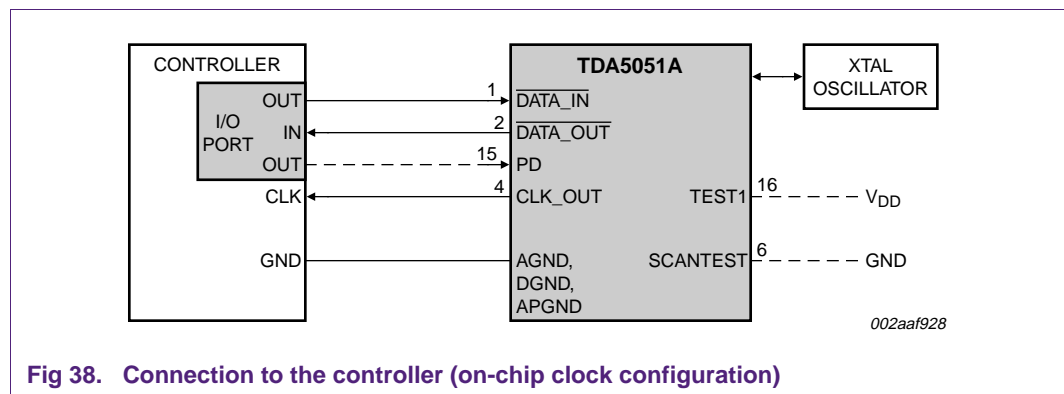
Fig 38. Connection to the controller (on-chip clock configuration)

$\overline{\text{DATA\_IN}}$ and $\overline{\text{DATA\_OUT}}$ signals are active LOW, and special care must be taken with $\overline{\text{DATA\_IN}}$. As explained in the data sheet, after power-up, **this signal must be HIGH before starting any transmission**. If after power-up, $\overline{\text{DATA\_IN}}$ remains LOW or undefined, the circuit may **stay in a dummy state**.

Remark: $\overline{\text{DATA\_IN}}$ is an edge-sensitive input and must be HIGH before starting a transmission.

$t_{d(pu)(TX)} = 1$ ms minimum.
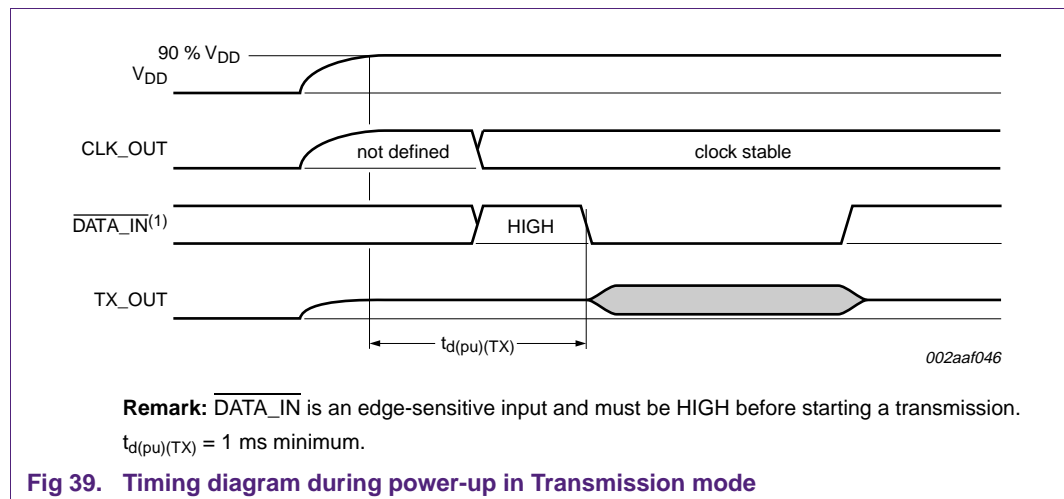
Fig 39. Timing diagram during power-up in Transmission mode

4.2.2 Connection to the controller for evaluation or software development

To prevent from electrical hazards or risks of damage to the equipment, it is important to choose the best development setup, which depends on the coupling configuration of the modem.

4.2.2.1 Modem coupled to the mains with HF transformer

This is probably the safest approach for the equipment and the designer! The power line has no common wire with the application and/or the equipment.

002aaf929
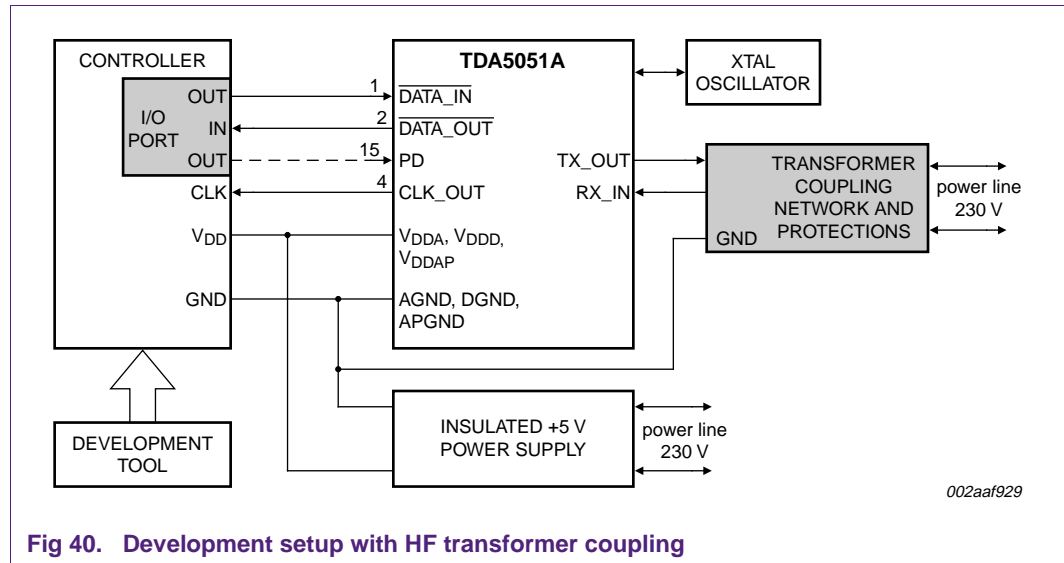
Fig 40. Development setup with HF transformer coupling

4.2.2.2 Modem coupled to the mains with LC filter

In this case, it is **mandatory** to use a 1 : 1 line insulation transformer, in order to create an artificial power line, used to connect together several modem applications. Then the GND wire of the application will be directly tied to one of the artificial power line.

002aaf930
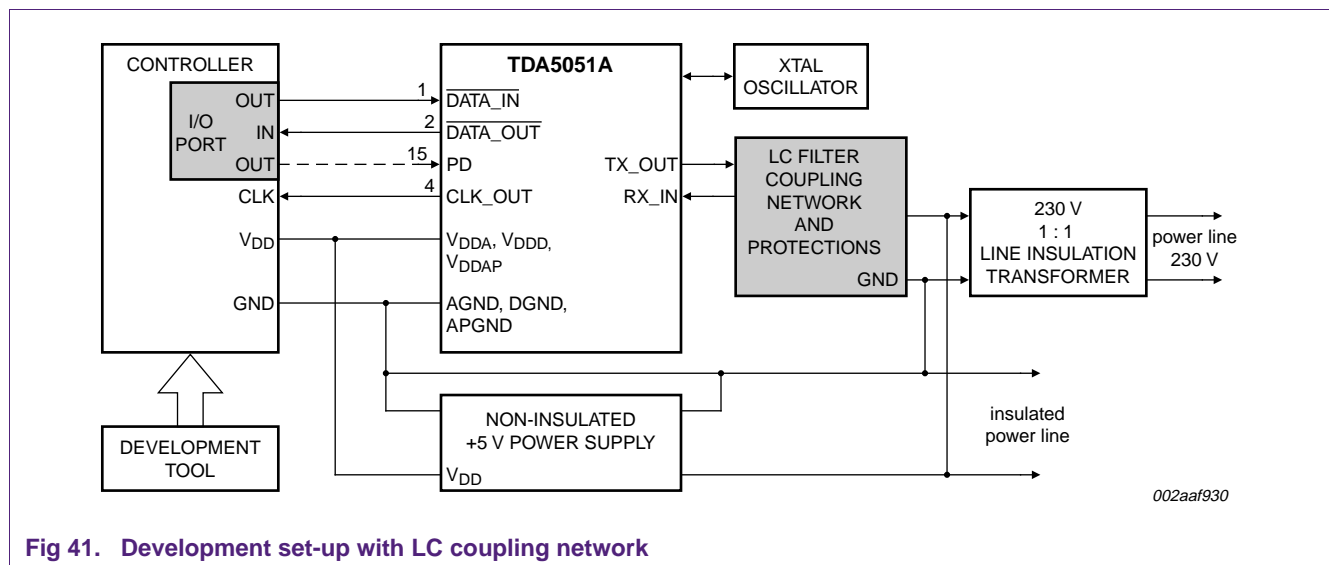
Fig 41. Development set-up with LC coupling network

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4.2.2.3 Modem coupled to the mains with LC filter — Example of signals' insulation

It is possible to avoid the use of an artificial power line (as shown in Figure 42), even with a LC coupling network, by using electrical insulation of the TDA5051A data signals. That provides more realistic coupling conditions, because of the direct connection of the modem to the mains.
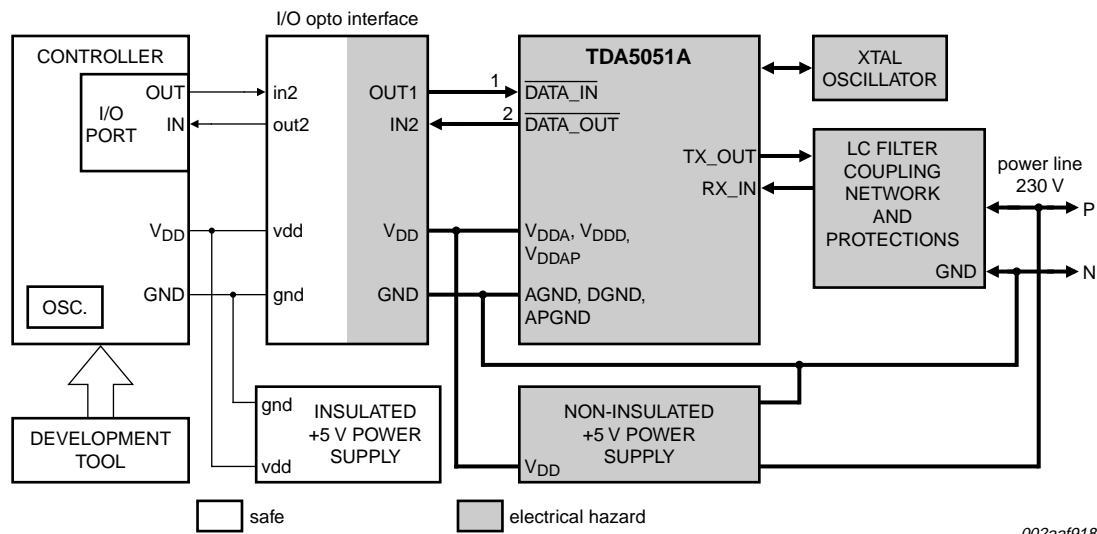
Fig 42. Data I/O signals' insulation with an opto interface
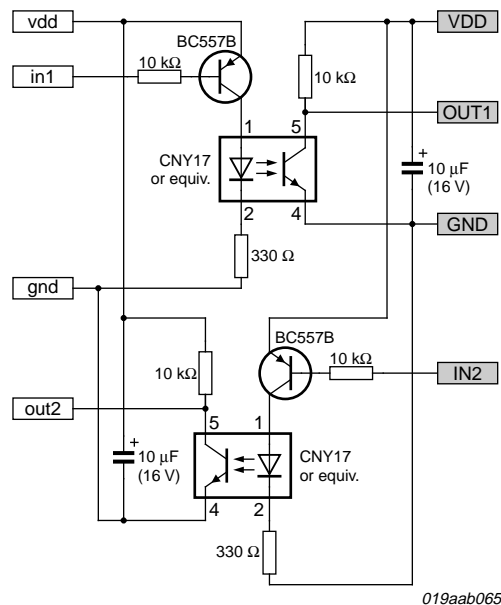
Fig 43. Example of opto interface

5. Power supply design

5.1 Power consumption

The TDA5051A has 6 pins dedicated to the power supply, corresponding to 3 groups of power supply / ground, as shown in Figure 44.

In the application, the V_{DDA}-V_{DDD}-V_{DDAP} pins have to be connected together to the +5 V power supply. It is the same for the AGND-DGND-APGND pins, which must be connected to the ground.
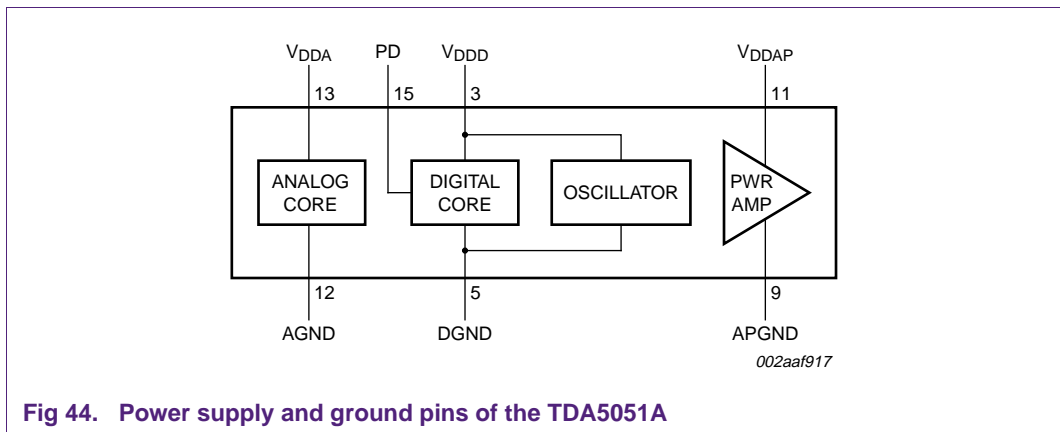
Fig 44. Power supply and ground pins of the TDA5051A

As mentioned in the data sheet, the Power-Down (PD) pin only changes the behavior of the digital part of the modem and its consumption; the oscillator remains active and the CLK_OUT signal continues to be generated to the controller.

The consumption of the modem depends on many parameters, like oscillator frequency and operation mode. However, the maximum 'possible' power consumption is the power amplifier, and depends on the power line impedance. Table 14 shows different power consumption levels in different conditions, for a typical circuit.

Table 14. Power consumption levels[1]

Conditions	I_{DDA}	I_{DDD}	I_{DDAP}	I_{DD} total
Standby mode[2] at 8.48 MHz	12 mA	12 mA	0.05 mA	24 mA
Reception mode[3] at 8.48 MHz	12 mA	16 mA	0.05 mA	28 mA
Power-down mode[4] at 8.48 MHz	12 mA	2.5 mA	0.05 mA	14.5 mA
Transmission mode[5] at 8.48 MHz; load = 30 Ω	12 mA	16 mA	19 mA	47 mA
Transmission mode[5] at 8.48 MHz; load = 10 Ω	12 mA	16 mA	47 mA	75 mA
Transmission mode[5] at 8.48 MHz; load = 1 Ω	12 mA	16 mA	70 mA	98 mA

[1] Oscillator: external quartz crystal with R_s = 0 Ω, R_p = 2.2 MΩ, C1 = C2 = 27 pF, XTAL at 8.48 MHz; V_{DDA} = V_{DDD} = V_{DDAP} = +5 V; T_{amb} = 25 °C.

[2] Standby mode: no signal applied at RX_IN pin; no signal applied at $\overline{DATA\_IN}$ pin.

[3] Reception mode: signal (at the carrier frequency) applied at RX_IN with a 10 nF capacitor, 120 dBμV amplitude.

[4] Power-down mode: PD pin is HIGH.

[5] Transmission mode: $\overline{DATA\_IN}$ = 0, resistive load with a 10 μF capacitor on the TX_OUT pin.

It is important to notice that a **high peak current may be required** during low-impedance operation on heavily loaded power line, for example.

In order to prevent extra distortion of the output signal, and a good decoupling of the power supply, it is mandatory to connect, as close as possible, two capacitors: e.g., a high value electrolytic capacitor of 100 μF to 200 μF / 10 V and a 47 nF to 100 nF ceramic capacitor.

The ground strip on the printed-circuit board should be as large as possible (ground plane under the IC, if possible), and the connection between the IC and these capacitors should be very short.
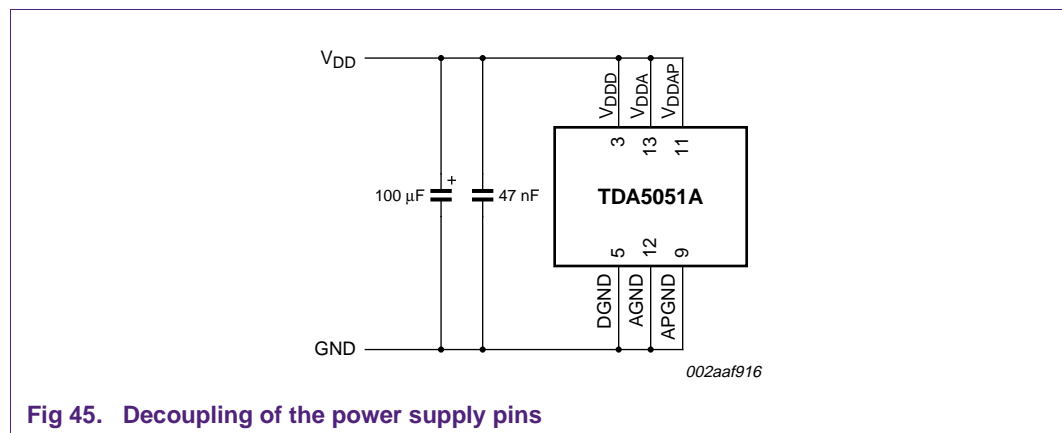
Fig 45. Decoupling of the power supply pins

5.2 Example of an R-C power supply

It is one of the most popular types of non-insulated power supply, which uses the 50 Hz impedance of a capacitor (C_s) to supply a rectifier and a DC capacitor, followed by a linear +5 V regulator.

An example is shown in Figure 46.
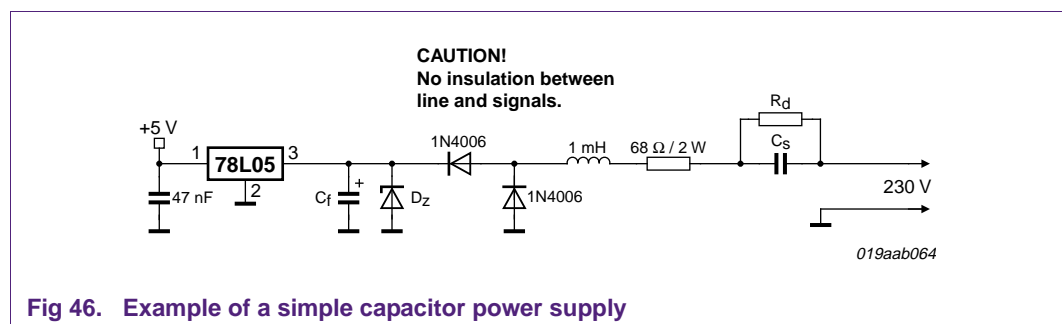
Fig 46. Example of a simple capacitor power supply

In this configuration, the designer must take into account several parameters:

- The C_s capacitor must be an X2 type, rated for 230 V power line operation.

- The input impedance of the passive network must be high in the modem operation frequency range, and must comply with the standards. For these reasons, an inductor of 1 mH is used with an extra 68 Ω resistor.

- During power-up, the peak current must be limited. This is also why the inductor/resistor set is before the rectifier.

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- D_z and C_f must be chosen to provide the minimum voltage required by the 78L05.
- If another type of linear regulator is used, the quiescent current must be as low as possible.
- To reduce the commutation noise induced by the rectifiers, it may be useful to add small capacitors (1 nF, for example) in parallel with the 1N4006 diodes.
- To discharge the high voltage capacitor C_s, a high value resistor R_d is used ([100 kΩ, 1 W] to [1 MΩ, 1/2 W], depending on the requested discharge time).

Table 15 gives an example of component values and the maximum output current of the power supply.

Table 15.   Component values and maximum output current of the power supply

C_s	D_z	C_f	$I_{O(max)}$
1 μF	8.2 V, 1.3 W	470 μF, 16 V	25 mA
1.5 μF	8.2 V, 1.3 W	470 μF, 16 V	35 mA
2.2 μF	8.2 V, 1.3 W	470 μF, 16 V	50 mA

5.2.1 R-C power supply improvement

It is possible to improve the output current of the power supply without increasing the size of the C_s capacitor by using a full bridge rectifier instead of the two diodes 1N4006 in Figure 46.

The efficiency is twice as good for the same value of C_s capacitor, but it is not possible to couple the modem to the power line with an LC filter. The ground connection of the modem to the power line is lost, then it is **mandatory to use an HF coupling transformer**.
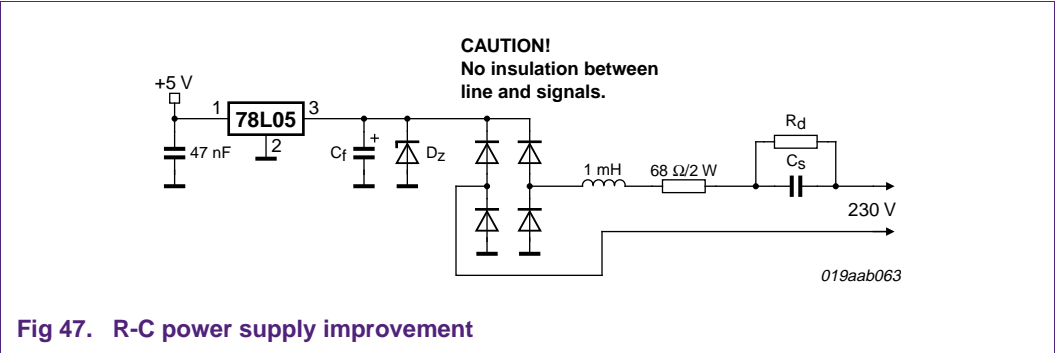
Fig 47.   R-C power supply improvement

Table 16.   Component values and maximum output current of the improved power supply

C_s	D_z	C_f	$I_{O(max)}$
1 μF	8.2 V, 1.3 W	470 μF, 16 V	50 mA
1.5 μF	8.2 V, 1.3 W	470 μF, 16 V	70 mA
2.2 μF	8.2 V, 1.3 W	470 μF, 16 V	100 mA

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5.3 Example of switching mode power supply

In order to reduce the size of the components, a solution could be to use an R-C power supply in association with a switch mode converter. The R-C supply is used to reduce the mains voltage from 230 V AC to 28 V DC, for example, and then the switch mode converter provides the +5 V regulated output.

The quiescent current of the switch mode regulator must be as low as possible, and the switching frequency (or its harmonics) must be chosen to avoid the modem band.
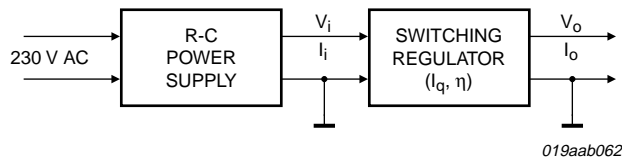
Fig 48. Mixed solution R-C/switching power supply

$$I_i = \frac{V_o \times I_o}{V_i \times \eta} + I_q \qquad (4)$$

Where:

V_i = input voltage of the regulator

I_i = input current

V_o = output voltage

I_o = output current

I_q = quiescent current

η = efficiency of the switching converter

Figure 49 is an example of power supply using Linear Technology LT1372 500 kHz high efficiency switching regulator.
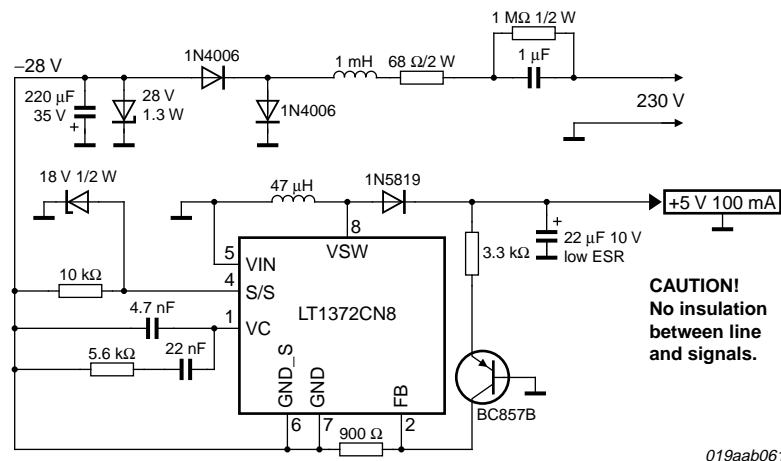
Fig 49. Example of mixed solution

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6. TDA5051A power line modem demonstration board
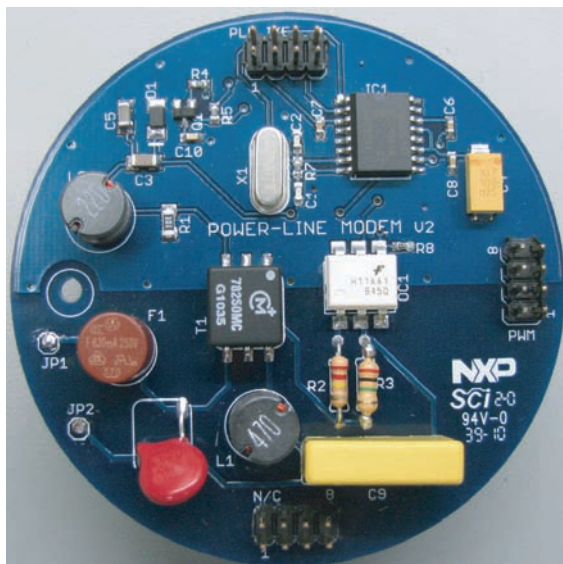
019aaa515

Fig 50. Evaluation board photo

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel that is qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.
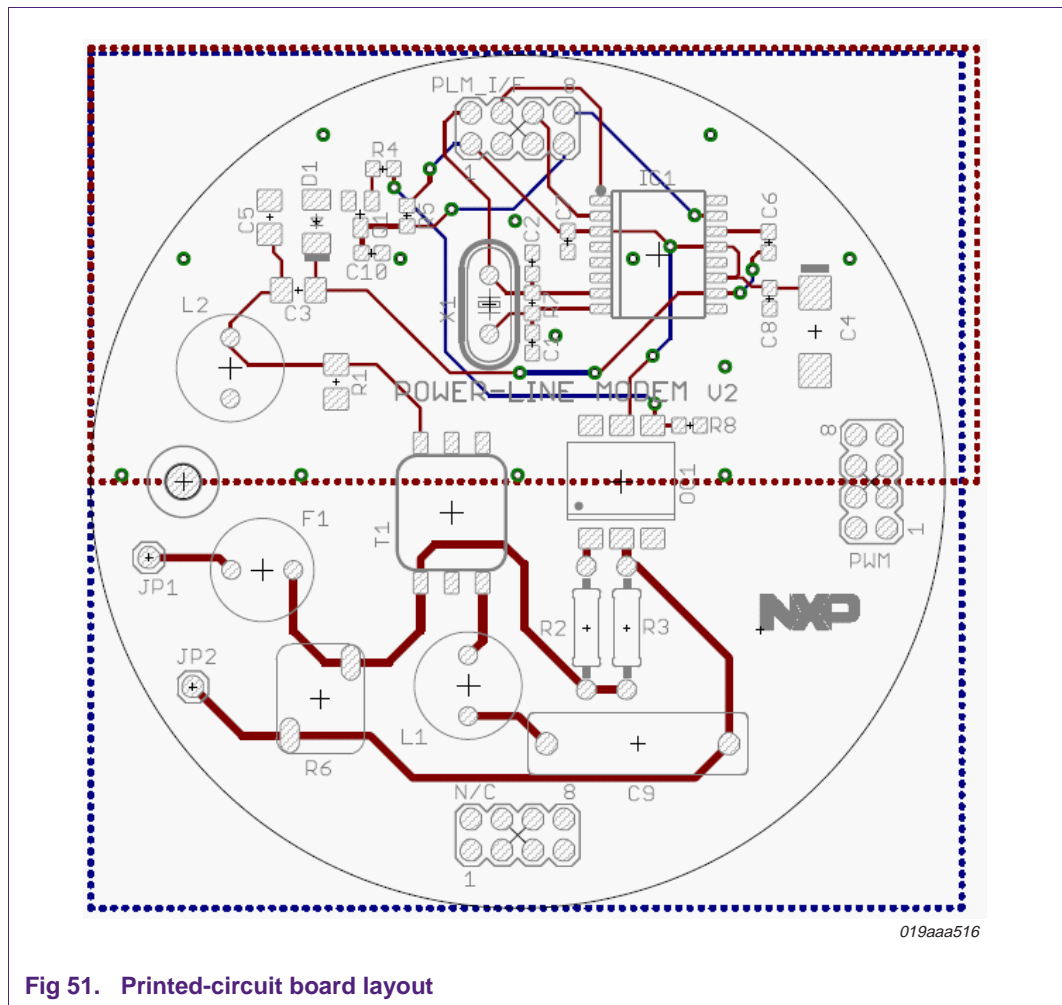
Fig 51.   Printed-circuit board layout
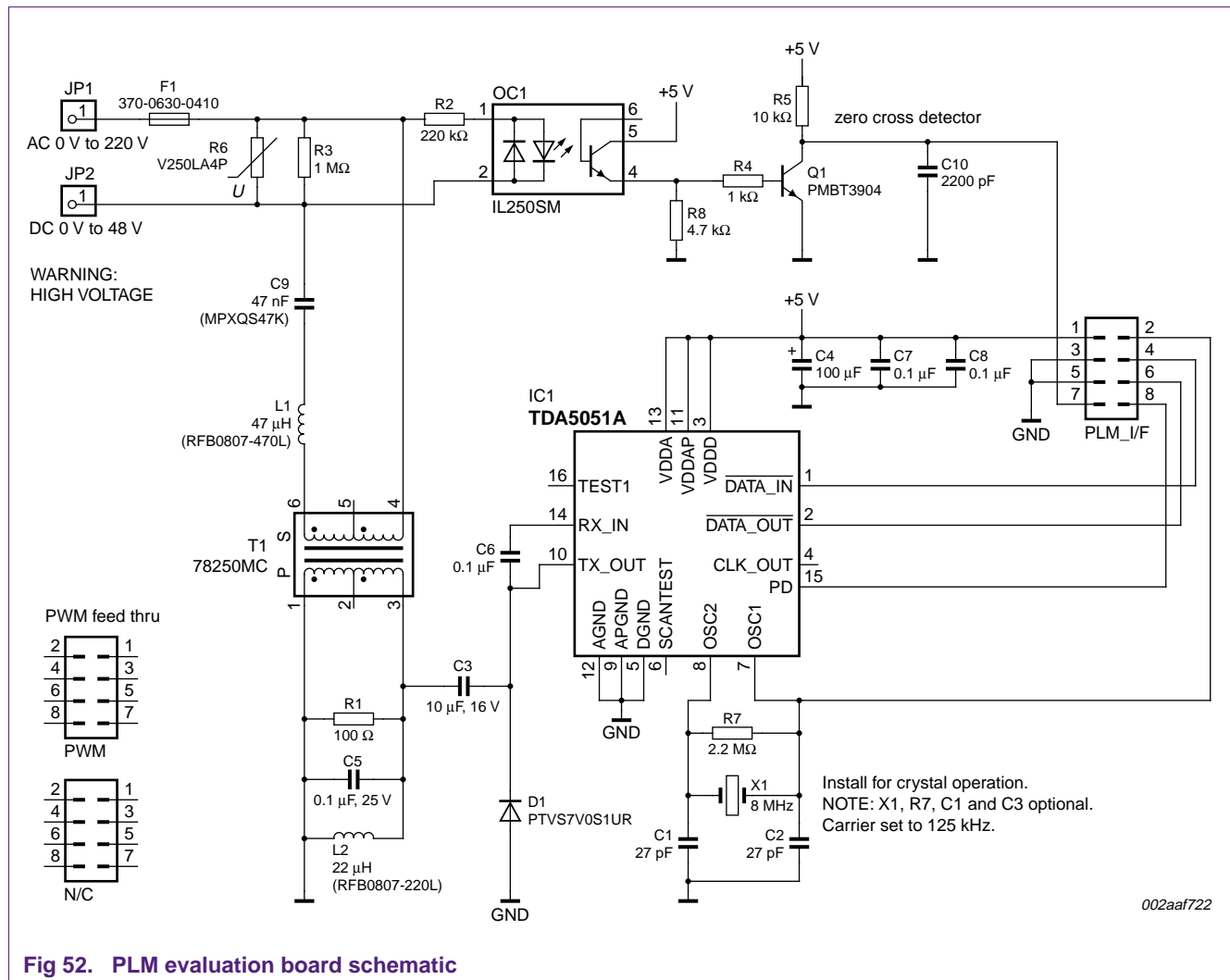
Fig 52. PLM evaluation board schematic

Table 17. Power line modem Bill Of Materials (BOM)

Component	Description	Manufacturer	Package	Type number
C1[1]	27 pF		C0603	
C2[1]	27 pF		C0603	
C3	10 μF, 16 V		C1206	
C4	100 μF		CT7343	
C5	0.1 μF at 25 V		C1206	
C6	0.01 μF		C0603	
C7	0.1 μF at 25 V		C0603	
C8	0.1 μF at 25 V		C0603	
C9	47 nF (MPXQS47K)			C150-054X183
C10	2200 pF		C0603	
D1	PTVS7V0S1UR	NXP	SOD123, Mini-SMA	CGRM4001-G
F1	FUSELITTLEFUSE_S370	Little Fuse	LITTLE_S370	370-0630-0410
IC1	Power Line Modem	NXP	SO16W	TDA5051AT
JP1	header		1X01	
JP2	header		1X01	
L1	47 μH inductor	Coilcraft	RFB0807	RFB0807-470L
L2	22 μH inductor	Coilcraft	RFB0807	RFB0807-220L
N/C			MA04-2	MA04-2
OC1	IL250SM		IL250SM	DIL6-SMD
PLM_I/F			MA04-2	MA04-2
PWM			MA04-2	MA04-2
Q1	transistor	NXP	SOT23	PMBT3904
R1	100 Ω resistor		R1206	
R2	220 kΩ resistor		0207/10	
R3	1 MΩ resistor		0207/10	
R4	1 kΩ resistor		R0603	
R5	10 kΩ resistor		R0603	
R6	V250LA4P resistor		V250LA4P	
R7[1]	2.2 MΩ resistor		R0603	
R8	4.7 kΩ resistor		R0603	
T1[2]	transformer	Murata	78250	78250MC
X1	8.00 MHz crystal		HC49U-V	CRYSTALHC49U-V

[1] Optional for XTAL.

[2] Specifications for component T1 signal transformer can be found at www.nxp.com/redirect/murata-ps.com/data/magnetics.

7. Abbreviations

Table 18. Abbreviations

Acronym	Description
AGC	Automatic Gain Control
ASK	Amplitude Shift Keying
CMOS	Complementary Metal-Oxide Semiconductor
DAC	Digital-to-Analog Converter
ESD	ElectroStatic Discharge
HF	High-Frequency
IC	Integrated Circuit
LC	inductor-capacitor filter
MOV	Metal-Oxide Varistor
NRZ	Non-Return to Zero
PD	Power-Down
PLM	Power Line Modem
RMS	Root Mean Squared
ROM	Read-Only Memory
TTL	Transistor-Transistor Logic

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