INTEGRATED CIRCUITS

APPLICATION NOTE

TDA5051
ASK Power Line Modem

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Eric MICHAT

Philips Semiconductors

PHILIPS

SUMMARY

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1. INTRODUCTION

1.1 TDA 5051 - ASK MODEM FOR POWER LINE DATA TRANSMISSION

The TDA5051 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.

Main features of the IC:

- **CMOS process IC**: low power consumption, reliability and high temperature stability, on-chip ESD protection.
- **Single +5V 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 (122dBuV maxi rms).
- **Input amplifier with Automatic Gain Control**: provides a very high sensitivity of 66 dBuV rms, allowing the detection of small signals in heavy loaded power line conditions.
- **Digital Narrowband Filter with 8-bit A/D converter**: equivalent to a 8'th order analogue 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 MAX.**
- **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.

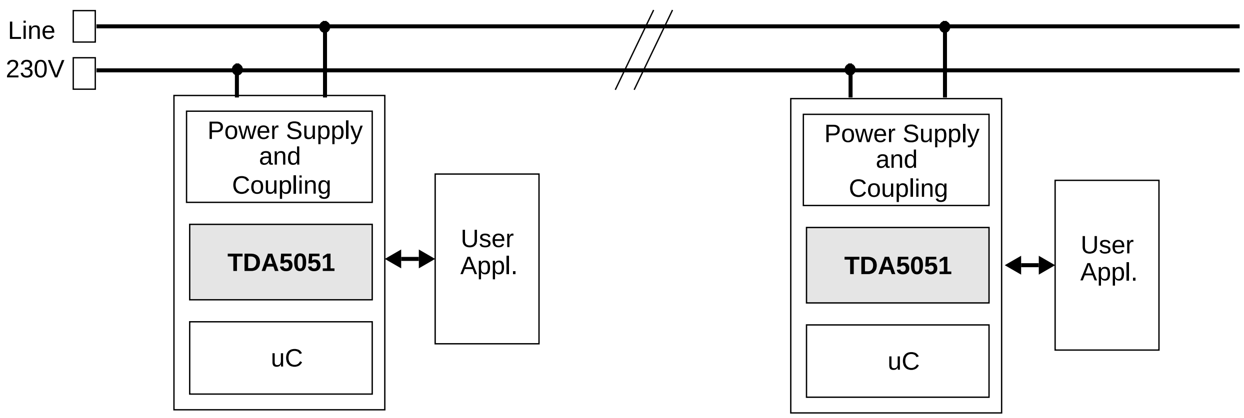


Fig.1 Typical application with power line modems

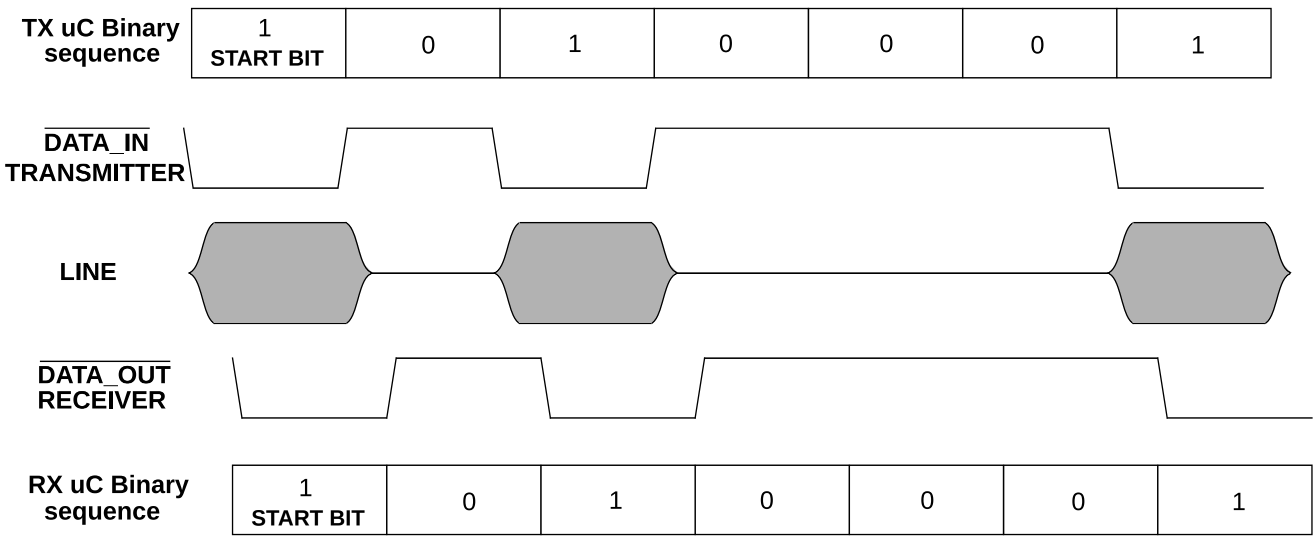


Fig.2 Data transmission using ASK with NRZ code

1.2 BLOC DIAGRAM

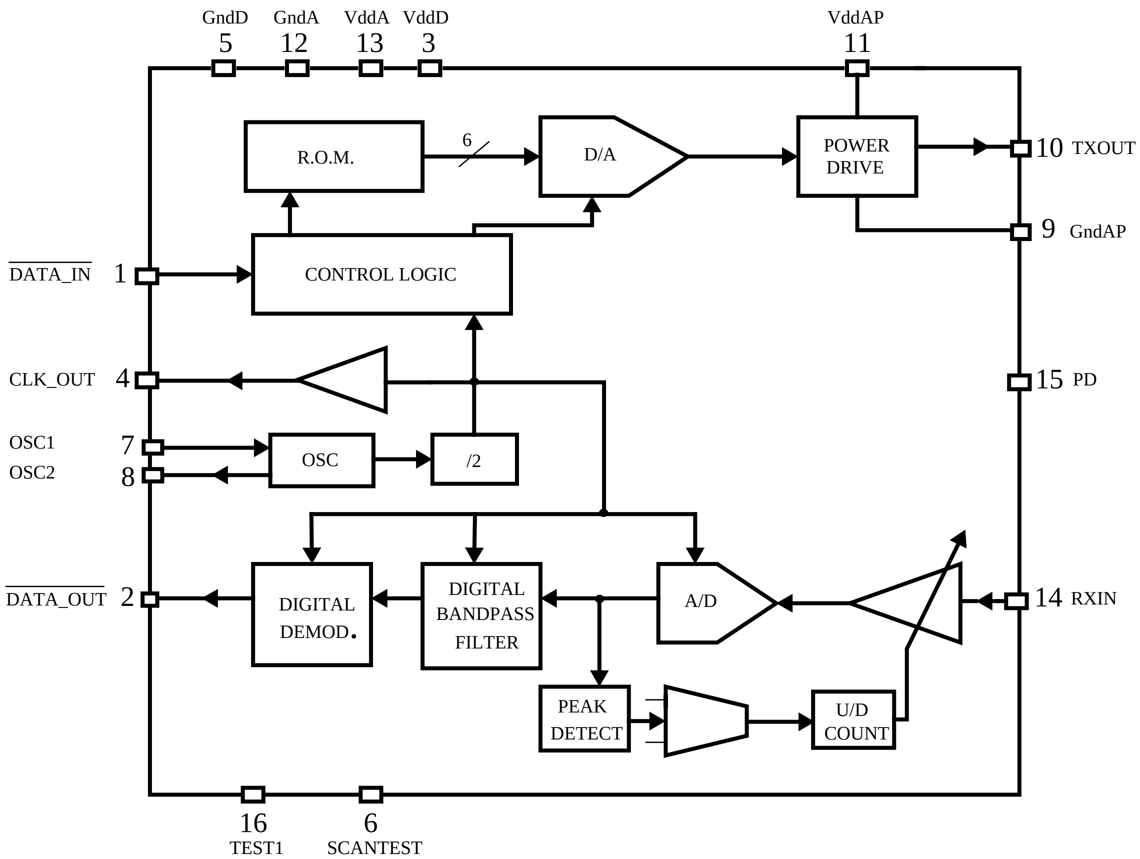


Fig.3 Bloc diagram

1.3 PIN DESCRIPTION

Table 1

SYMBOL	PIN	DESCRIPTION
DATA_IN	1	Digital Data input (Active-low)
DATA_OUT	2	Digital Data output (Active-low)
VddD	3	Digital supply
CLK_OUT	4	Clock output
GndD	5	Digital ground
SCANTEST	6	Test input (Low in application)
OSC1	7	Oscillator input
OSC2	8	Oscillator output
GndAP	9	Analog ground for power amplifier only
TXOUT	10	Analog Signal output (DC coupled)
VddAP	11	Analog supply for power amplifier only
GndA	12	Analog ground
VddA	13	Analog supply
RXIN	14	Analog Signal input (DC coupled)
PD	15	Power Down input (Active-high)
TEST1	16	Test input (High in application)

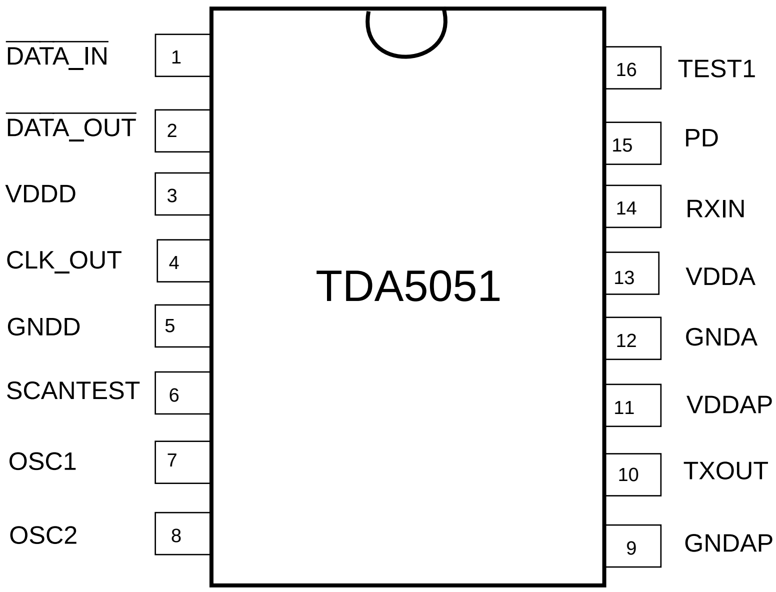


Fig.4 Pinning of the TDA5051 - SO16L Package (SOT 162 AH14)

Note

PIN 6 - SCANTEST	On-chip Pull Down resistor
PIN 15 - PD	On-chip Pull Down resistor
PIN 16 - TEST1	On-chip Pull Up resistor

2. COMPLIANCE WITH STANDARDS

2.1 Compliance with the EN50065-1 (Main points only - Please refer to the norm for further details).

- **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 this table.:

Table 2

OSCILLATOR FREQUENCY	CLOCK OUTPUT FREQUENCY	CARRIER AND DETECTION FREQUENCY
Fosc	Fosc / 2	Fosc / 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

9KHz to 95KHz	95KHz to 125KHz	125KHz to 140KHz	140KHz to 148.5KHz
Restricted use	Free for consumers	Free for consumers	Free for consumers
	No access protocol	Requested protocol: Use 132.5KHz 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 centre frequency) higher than 95KHz and lower than 148.5KHz; for example 98KHz to 145.5KHz is a good compromise.

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

For instance, using commercial quartz crystals gives the following set of carrier frequencies: (Note that 8.48MHz is still not a standard frequency...)

Table 4

Fosc XTAL MHz	Fclock_out Clock Output Pin MHz	Fc Carrier KHz
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 -	4.24000	132.50
8.867230 *	4.43361	138.55

- **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 Ohms spectrum analyser, the carrier amplitude of the complete system (modem+coupling network) on a standard load, called the CISPR16 load.

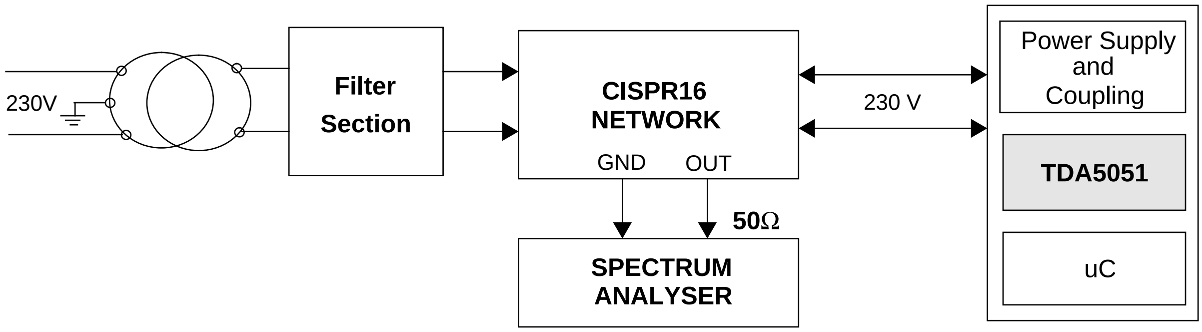


Fig.5 Test set-up for measuring Vout and conducted power line disturbances

The CISPR16 Network provides an attenuation of 6dB, due to its structure. The maximum rms voltage measured on the analyser must be in the following range:

Table 5

Domestic use only	Industrial or specific use
MAX 116 dBuV with CISPR16 network	MAX 134dBuV with CISPR16
Effective value at the modem output is **122 dBuV** 3.56 V peak to peak	Effective value at the modem output is 140 dBuV 28.3 V peak to peak

The internal power amplifier of the TDA5051 is designed to supply the voltage required for domestic applications; of course, for a higher voltage value, an extra power amp should be used.

- **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 Ohms analyser (resolution bandwidth of 9KHz) can give a good idea of the conducted disturbances.

  Anyway, the peak value of these harmonics must be within the following limitis:

Table 6

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

2.2 Compliance with EN50065-2 (project stage)

- **Immunity requirements - Narrow band 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 narrow band test, is a **80% 1KHz modulated sinewave**, supplied by a signal generator as shown in the following figure:

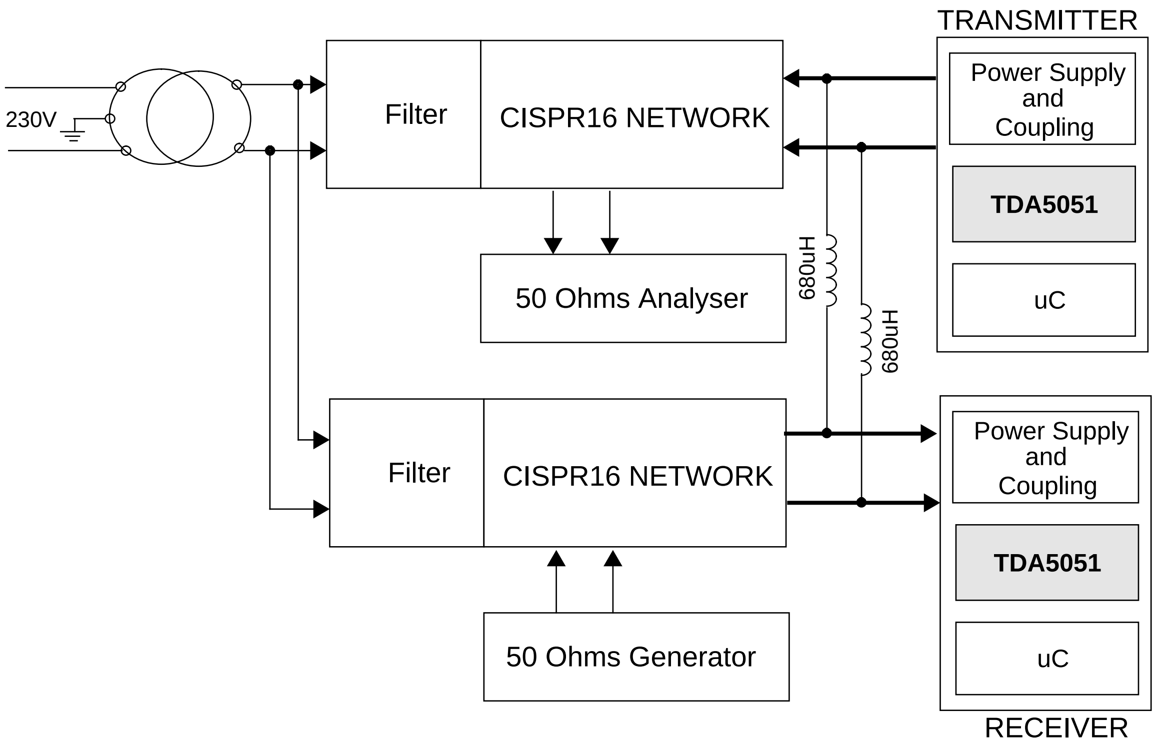


Fig.6 Test set-up for narrow band immunity

Then, this interference signal, is swept through a wide frequency range from 3KHz to 30MHz, excluding of course, 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 the following table:

Table 7

Frequency Range	Interference signal amplitude	Performance criterion of the complete system
3 - 8 KHz	**134 dBuV**	**The system shall continue to operate correctly**
10 - 94 KHz	**134 to 120 dBuV**	**The system shall continue to operate correctly**
96 - 124 KHz	134 dBuV	Self recoverable temporary loss of function or performance
126 - 139 KHz	134 dBuV	Self recoverable temporary loss of function or performance
141 - 147.5 KHz	134 dBuV	Self recoverable temporary loss of function or performance
150 KHz - 30 MHz	130 dBuV	Self recoverable temporary loss of function or performance

The behaviour 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 “centred” 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 - Use preferably an “acknowledge based” protocol.

5- If possible, use binary codes with error correction capabilities.

The structure of the TDA5051 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.

- **Immunity requirements - Broad band noise interferences**

  For this test, the generator of the Fig.6 is replaced by a random noise generator producing an uniform spectrum from 3KHz to 150KHz, having a spectral density of 43dBuV / sqrt(Hz).

  The system must operate correctly under these conditions.

  The remarks 3, 4, 5 given above this section are still valid.

- **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 and in the power supply section.

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

3. COUPLING WITH THE POWER LINE

3.1 INTRODUCTION

The coupling network is the interface between the power line and the low voltage TXOUT / RXIN 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 adjustement or tunable components. When an insulation is mandatory, a HF transformer should be used.

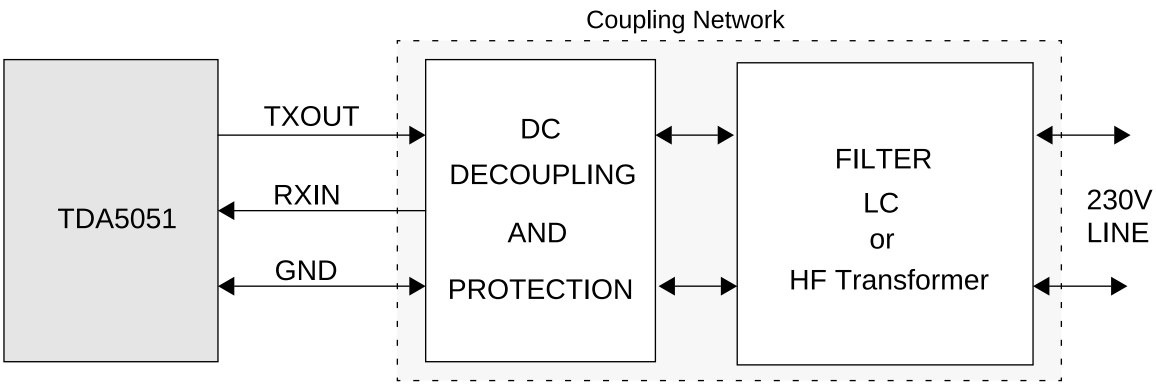


Fig.7 Coupling with the power line

- **Decoupling TXOUT and RXIN pins**

The following table shows the electrical characteristics of TX and RX pins in different operation modes:

Table 8

Characteristics of the TXOUT pin			
	Reception / Standby mode	Transmission mode	Power Down Mode
Impedance	HIGH	Approx. 5 Ω	HIGH
DC offset	undefined	2.5V	undefined
Characteristics of the RXIN pin			
	Reception / Standby mode	Transmission mode	Power Down Mode
Impedance	50 KΩ	50 KΩ	50 KΩ
DC offset	2.5V	2.5V	2.5V

It is mandatory to provide a DC decoupling for both TXOUT and RXIN pins !

It is **not possible to tie together TXOUT and RXIN**, even if the DC offset is the same: the RXIN pin is very sensitive to a small shift of the DC voltage which is intenally set to bias the input amplifier at an optimum level.

- **Filter**:

  The filter has two purposes:

- **1/ In reception mode**: it provides an efficient rejection of the 50Hz 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 Fc component of the carrier, but also the +/-Fc components located around the sampling frequency (Fosc/2) and its multiples.

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

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

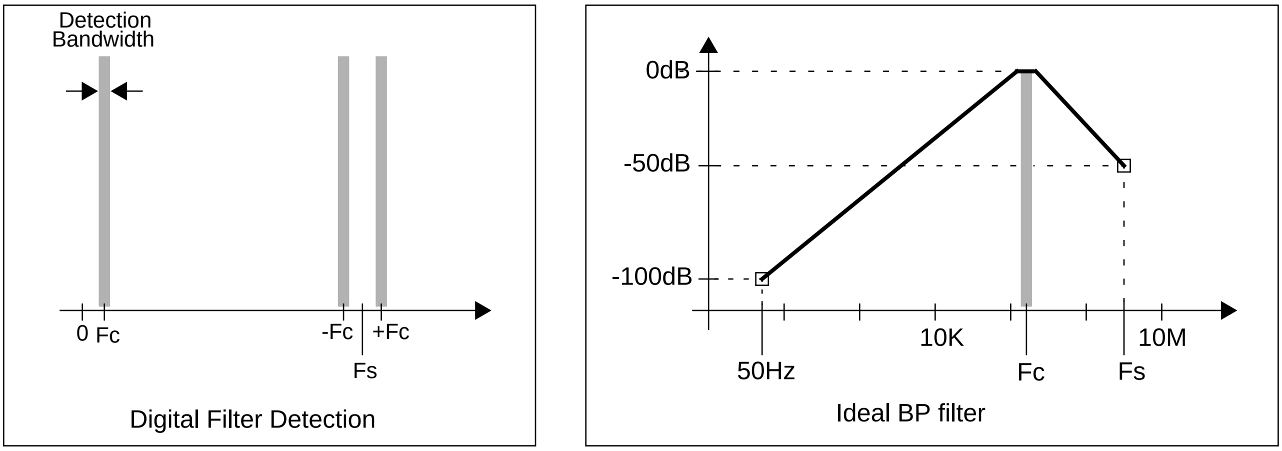


Fig.8 Digital Filter Detection and ideal bandpass filter

- **2/ 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 (Fosc/2) and its multiples (Fosc, 3Fosc/2, 2Fosc, etc.), with decreasing amplitude.

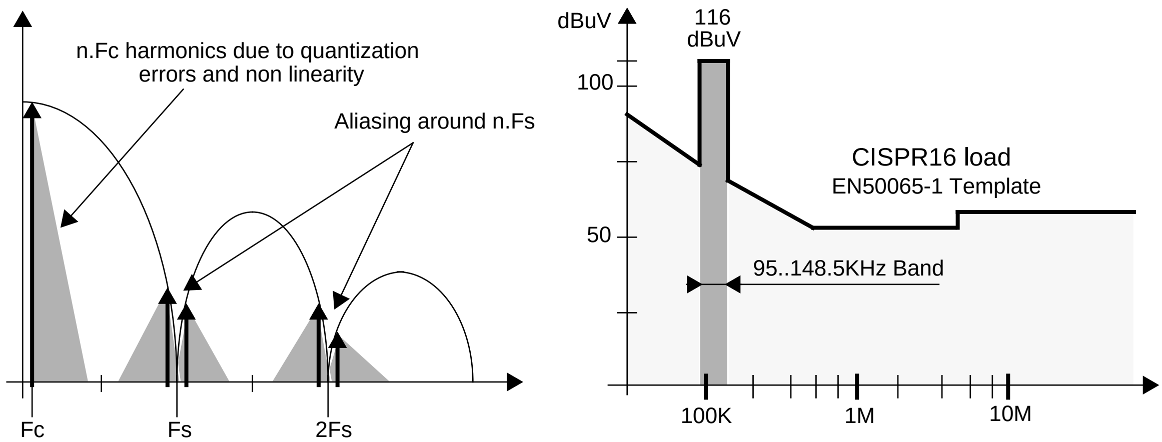


Fig.9 Spectrum of the digital carrier and compliance with the standard

3.2 LOW COST COUPLING

3.2.1 INTRODUCTION

This coupling uses a double LC bandpass filter. It does not provide any insulation from power line.

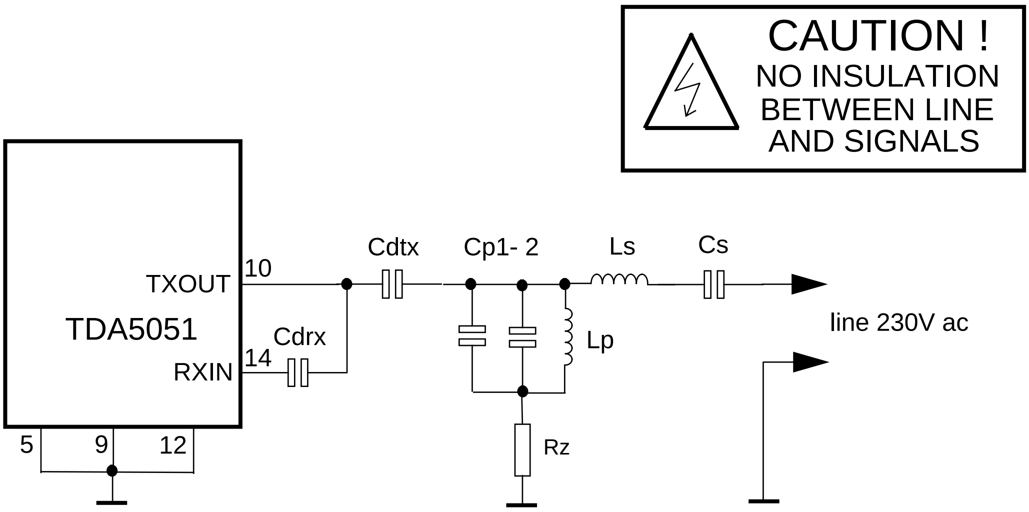


Fig.10 Low cost coupling using a LC bandpass filter

- **DC decoupling of TXOUT and RXIN**

The values of Cdtx and Cdrx are not critical.

Cdtx must be chosen to provide a low impedance at the carrier frequency (less than 1Ω for instance).The table 9 shows the recommended values for these capacitors.

Table 9

RECOMMENDED VALUES FOR CDRX AND CDTX CAPACITORS	
Cdtx	1uF to 10uF non polarized electrolytic
Cdrx	1nF to 10nF ceramic or plastic

- **Design of the LC filter**

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

$$Fc = \frac{1}{2\pi \cdot \sqrt{Ls \cdot Cs}} = \frac{1}{2\pi \cdot \sqrt{Lp \cdot (Cp1 + Cp2)}} = \frac{Fosc}{64}$$

With Fc and Fosc in Herz, 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 Ls-Cs part of the filter: that means a low serial resistor for Ls and good tuning at the carrier frequency. That also means a good balance between the values of Ls and Cs 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 Rz resistor (Fig. 10) can be chosen from **0 to 5.6 Ohms**, in order to limit the minimum input impedance of the filter (EN standard is at a project stage about this point).

Warning: one have to take into account that a too high value for Rz may affect the rejection of HF harmonics in transmission (The best rejection is carried out with Rz=0).

The following table shows an example of values for the filter components, according to standard quartz crystals.

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 LS, LP, CP1, CP2, CS AND XTAL FOR DIFFERENT CARRIER FREQUENCIES							
Fosc XTAL MHz	Fclock_out MHz	Fc Carrier KHz	Ls (Low Rs) uH	Cs (250Vac) nF	Lp uH	Cp1 nF	Cp2 nF
6.553600 *	3.27680	102.4	56	47	47	47	4.7
7.372800 *	3.68640	115.2	47	47	47	33	6.8
7.864320 *	3.93216	122.88	47	33	47	33	2.2
8.000000 *	4.00000	125.00	47	33	47	33	-
8.192000 *	4.09600	128.00	47	33	47	33	-
8.480000 -	4.24000	132.50	47	33	47	27	3.3
8.867230 *	4.43361	138.55	56	22	47	27	-

Notes

1. XTAL * are standard HC49 quartz crystals; each carrier frequency belongs to the EN50065-1 transmission band.
2. 8.48MHz is still not a standard frequency.
3. Cs ***must be*** a X2 type capacitor, suited for 250 V AC line voltage; Ls is preferably a low Rs inductor.

3.2.2 DESIGN EXAMPLE OF A TYPICAL COUPLING NETWORK

Designer choices:

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

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

- The components should be: Ls=47uH +/-10% with Rs=2 Ω, Cs=47nF +/- 20% X2 (suited for 230V ac) , Lp=47uH +/-10% with Rs=5 Ω SMD inductor, Cp1=33nF 25V SMD, CP2=6.8nF SMD, Rz=5.6 Ω .

- The decoupling Cdtx is a 10uF / 16V non polarized capacitor and Cdrx is a 10nF 25V 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.

a/ Reception mode - Transfer characteristic of the LC filter

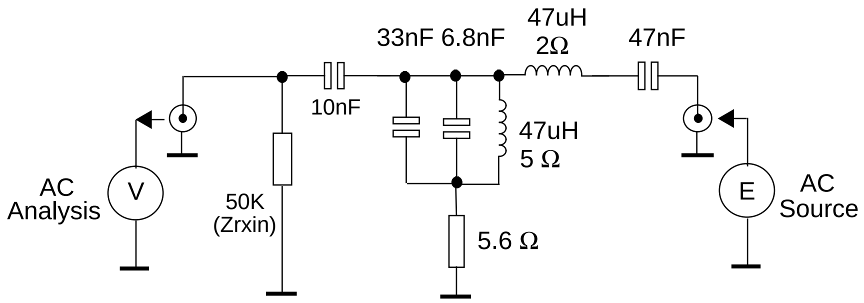
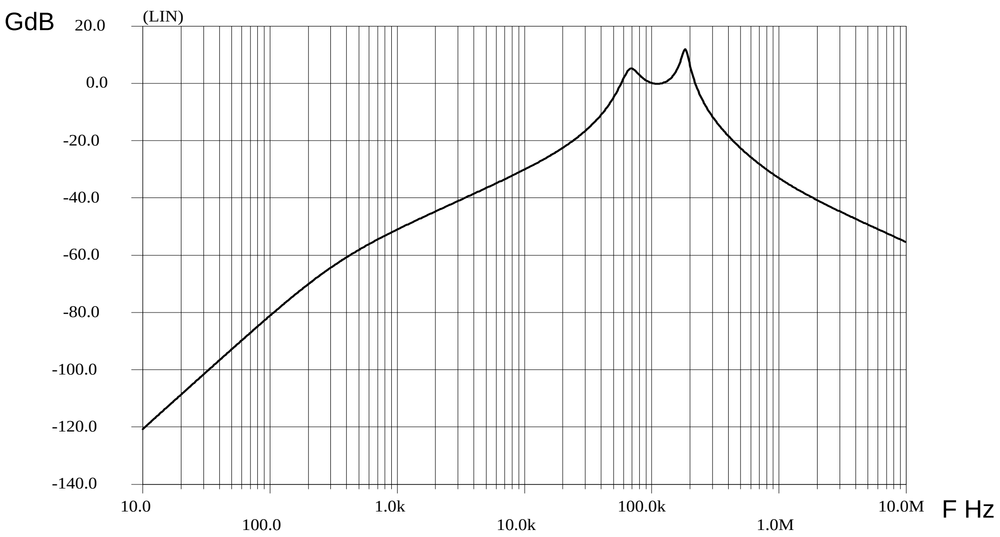


Fig.11 Simulation diagram for the transfer characteristic



Note: 50Hz rejection > 90dB ; Rejection around Fs >45dB

Fig.12 Bandpass filter - reception -- GdB *versus* Frequency

b/ Reception mode - Input impedance of the LC filter

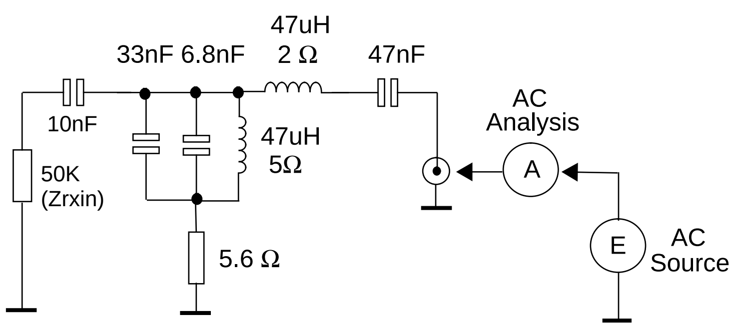


Fig.13 Test set-up for measuring input impedance

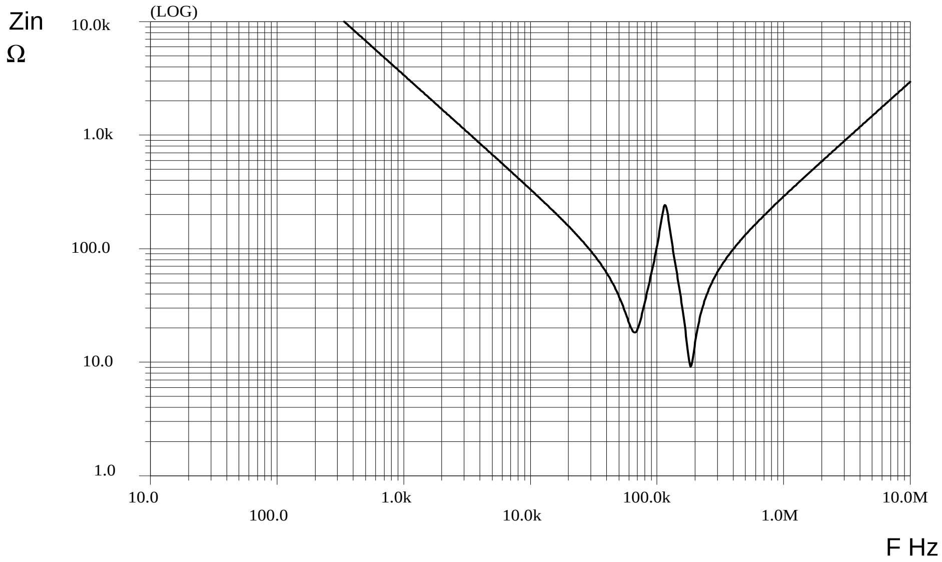


Fig.14 Input impedance - Zin *versus* Frequency

c/ Transmission mode - Transfer characteristic of the LC filter with a CISPR16 load

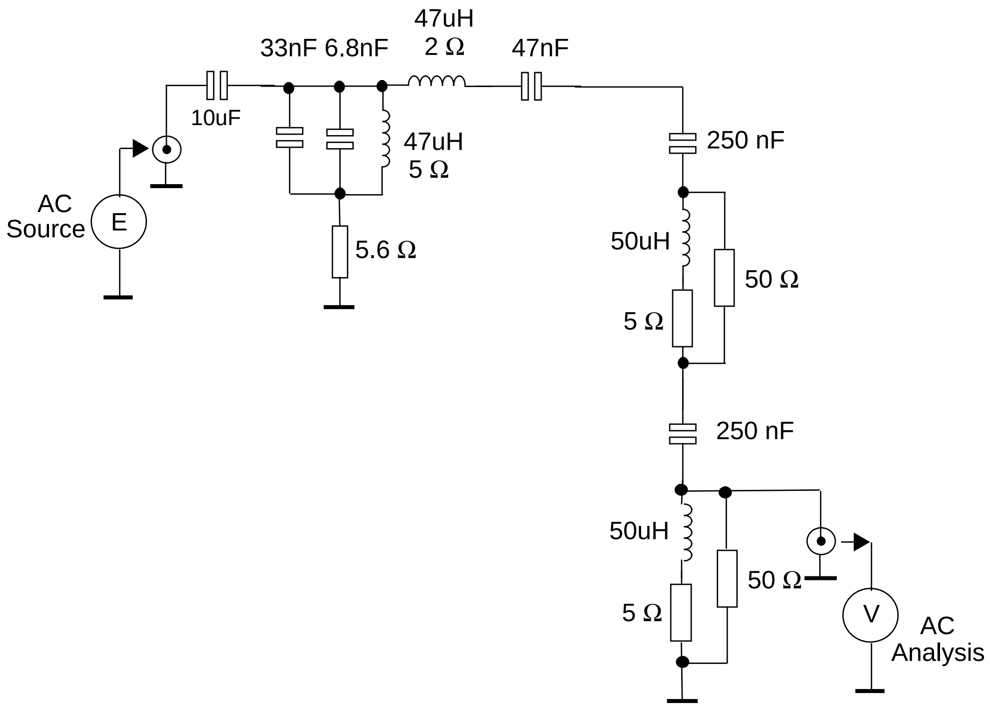
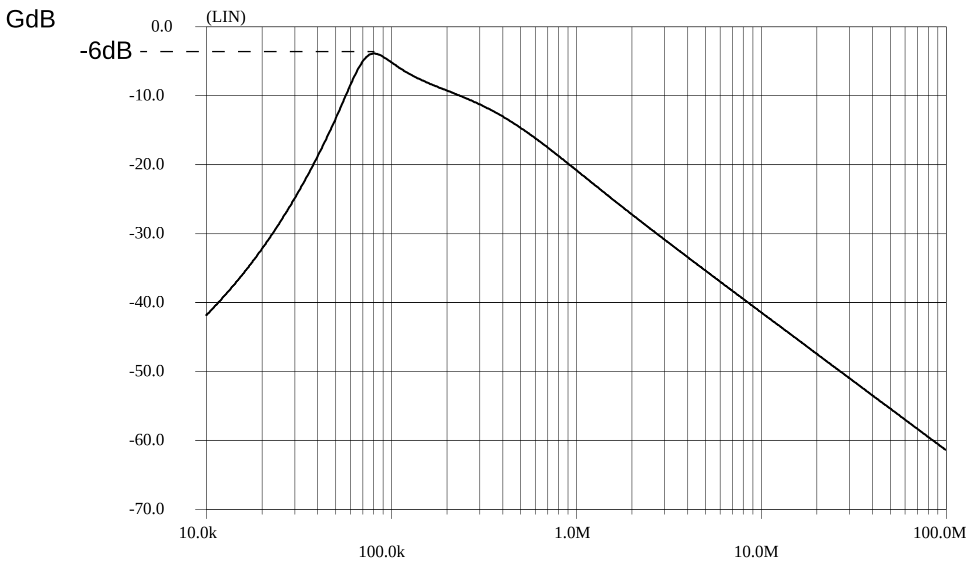


Fig.15 Measurement set-up - Transfer characteristic in transmission on CISPR16 load



Note: Top of the curve: -6dB (due to the network)

Fig.16 Bandpass filter - transmission - GdB *versus* Frequency

d/ Transmission mode - Efficiency of the LC filter

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

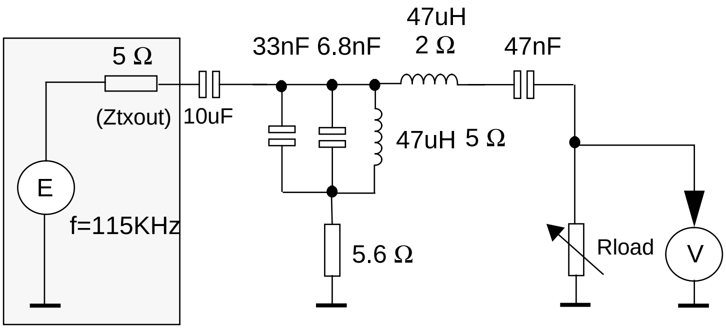


Fig.17 Simulation set-up - Vout= 20log(V*1e6) = f(Rload)

The Fig. 18 shows the coupling efficiency on a resistive load, with optimum values for Cs=47nF and Ls=47uH; the maximum rms level is 122dBuV and the minimum is 103dBuV, for 1 Ω load.

The Fig.19 shows marginal conditions, with Cs=47nF +/-20% and Ls=47uH +/-10% (4 plots). In the worst case (47nF +20%, 47uH +10%), the output voltage is still higher than 98dBuV for the maximum load. The variation of Cp and Lp has no significant effect on the efficiency.

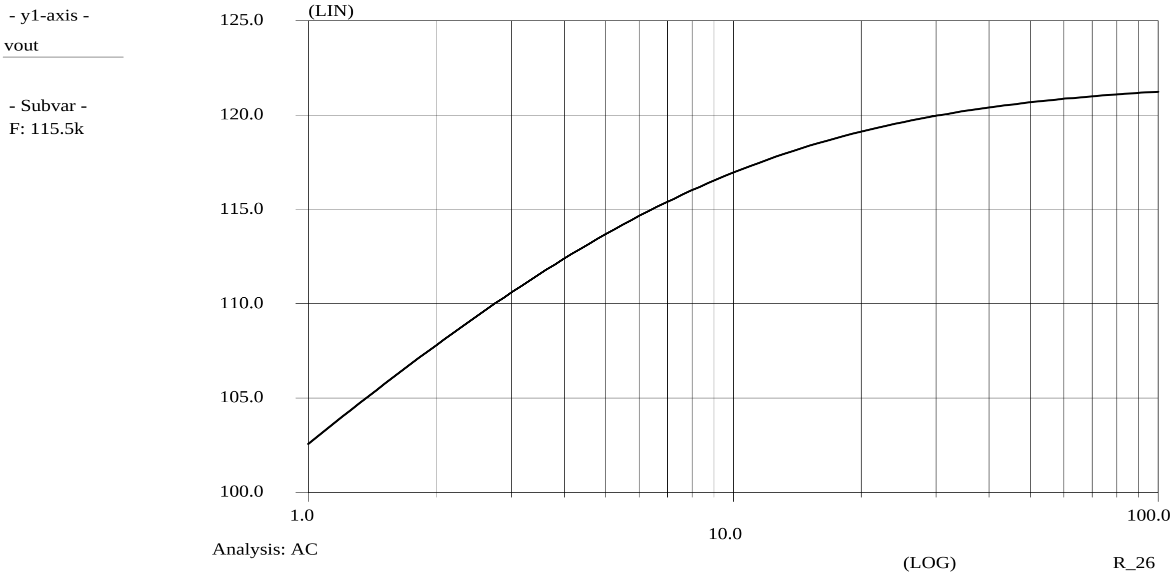


Fig.18 Vout(dBuV) *versus* load impedance - nominal values for filter components

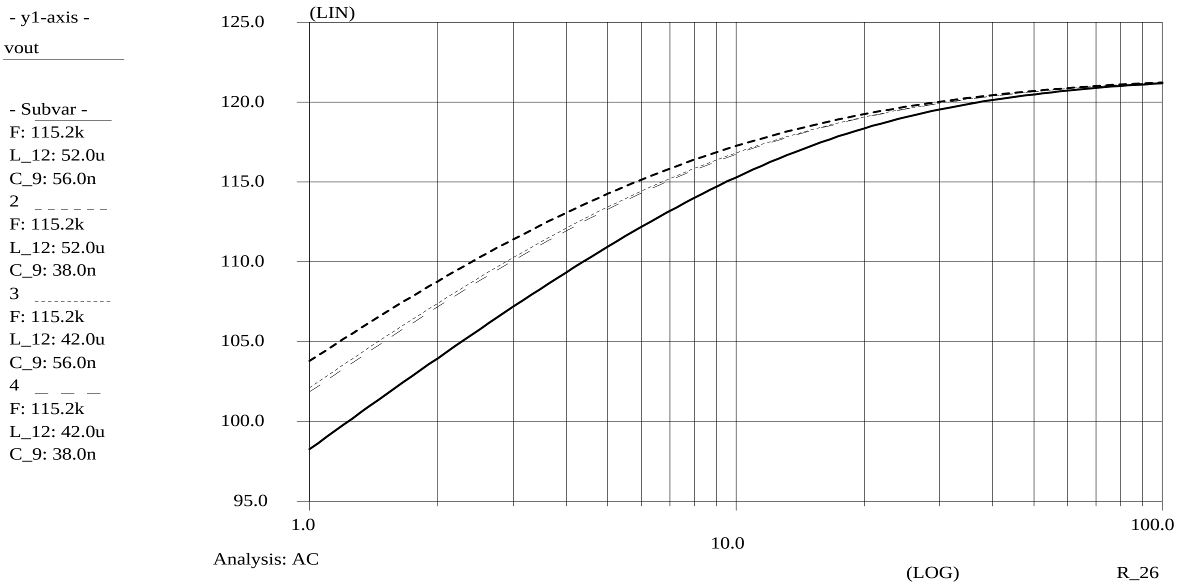


Fig.19 Vout(dBuV) *versus* load impedance with +/-20% Cs and +/-10% Ls

e/ Transmission mode - Spectrum of the carrier signal with low cost coupling network

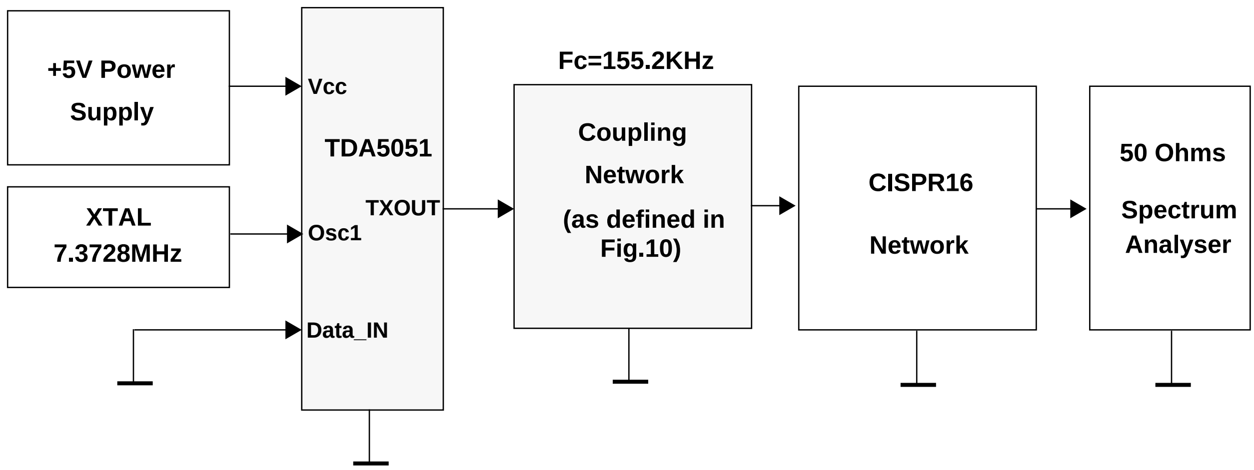


Fig.20 Test set-up for carrier spectrum measurement

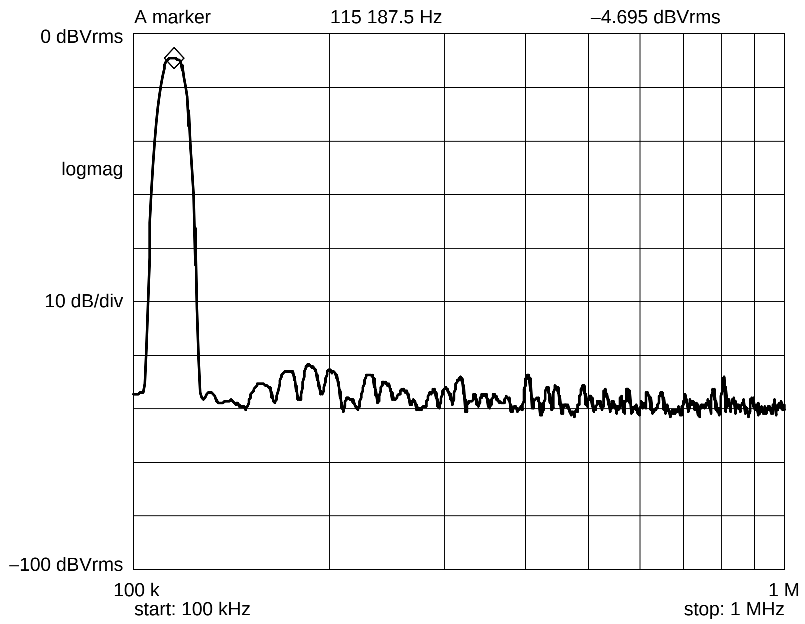


Fig.21 Vout(dBVrms) Spectrum - Carrier frequency 115.2KHz

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 TOKO T1002 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 Ct, which can be placed on the serial connection of the two secondary windings, as shown in Fig 22.

L1=9uH Value of 1 turn winding

L4=150uH Value of 4 turns winding

and Lequ(1+4)=L1+L4+2M with

$$M = 0.7 \cdot \sqrt{(L1 \cdot L4)}$$

Then, Lequ=200uH and the relation

$$Fc = \frac{1}{2\pi \cdot \sqrt{(Lequ \cdot Ct)}}$$ is used to calculate Ct.

(Medium position of the tuning screw)

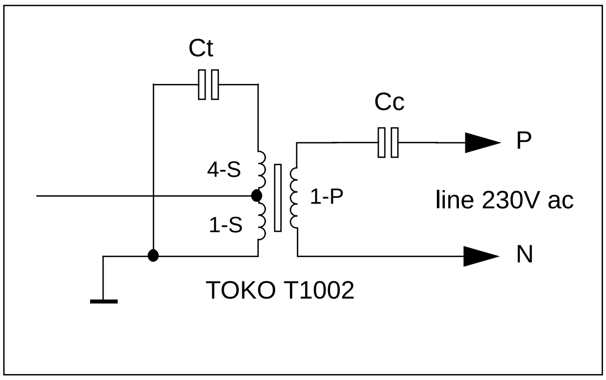


Fig.22 Tuning of the TOKO transformer

The value of Ct can be easily calculated for a given carrier frequency Fc.Then, the Cc capacitor is used to couple with the power line and must be a X2 type, rated for mains voltage.

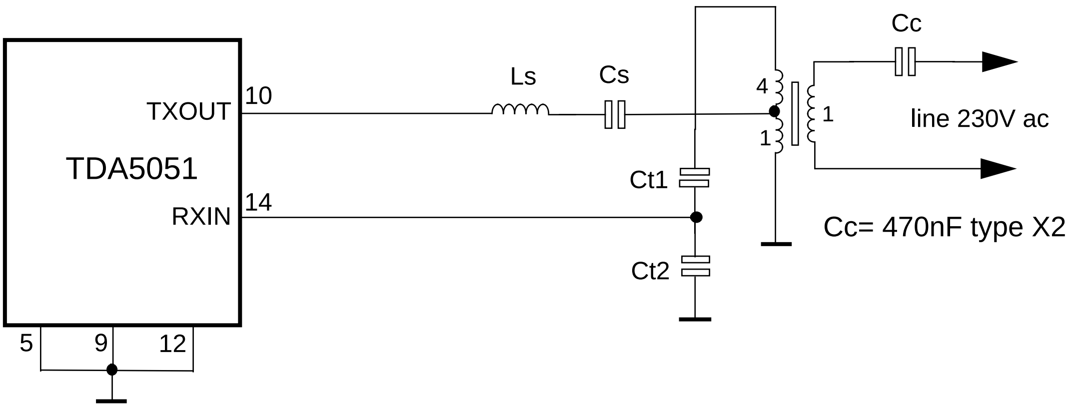


Fig.23 Coupling with TOKO T1002

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 behaviour of the 1:1 winding is mainly a high pass filter, and does not provide efficient filtering of high frequency harmonics.

In reception mode, the (4:1 + 1:1) secondary windings, fitted with the tuning capacitor, provides a very efficient bandpass filter, with high rejection of 50Hz 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 Ct and a voltage ratio of 1/5. The complete diagram is given in Fig 23.

The values of Ct1, Ct2, Cs and Ls must be calculated with the following equations:

$$Fc = \frac{1}{2\pi \cdot \sqrt{(Lequ \cdot Ct)}} = \frac{1}{2\pi \cdot \sqrt{Ls \cdot Cs}} = \frac{Fosc}{64} \quad \text{with}$$

$$Ct = \frac{Ct1 \cdot Ct2}{Ct1 + Ct2} \quad \text{and} \quad \frac{1}{5} = \frac{Ct1}{Ct1 + Ct2} \quad \text{and Lequ=200uH}$$

For the serial LC filter, at standard frequency (132.5KHz), Ls=3.3uH and Cs=470 nF is a good compromise.

Ct1 and Ct2 calculation for a carrier frequency of Fc can be done with the simple formula:

$$Ct = \frac{1}{4 \cdot \pi^2 \cdot Fc^2 \cdot 200 \times 10^{-6}} \qquad Ct1 = 1.25 \cdot Ct \qquad Ct2 = 5 \cdot Ct$$

Fc in Herz, Ct, Ct1, Ct2 in Farad.

3.3.2 DESIGN EXAMPLE

Designer choices:

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

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

- The components should be:

* LC filter: Ls=3.3uH +/-10% with Rs < 1 Ω, Cs=630nF +/- 10% 25V.

* Cc: coupling capacitor type X2 (230V rms) 470nF.

* Ct=9.5nF (see equation above with Fc=115KHz) ==> Ct1=12nF +/-10% 25V, Ct2=47nF +/-10% 25V.

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

Of course, this simulation does not take into account the effect of the transformer’s core material and the parasitic capacitors of the windings. In fact, these simulation results have been compared with real measurements, and the behaviour was very close to the computer analysis in a frequency range from 10KHz to 10MHz.

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.

a/ Reception mode - Transfer characteristic of the coupling network

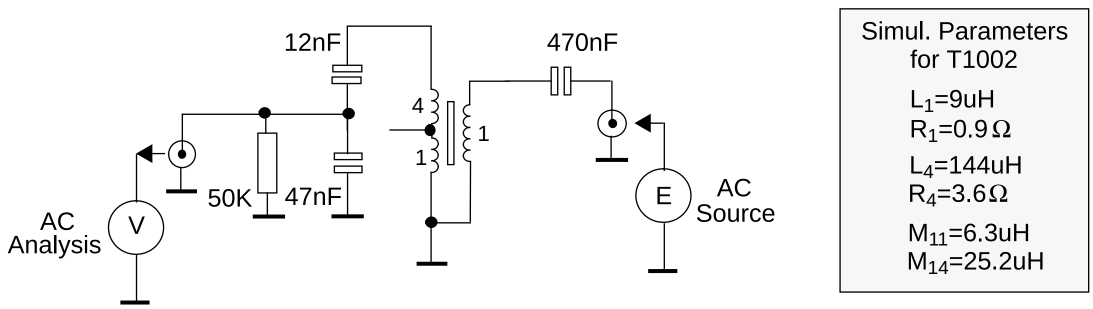


Fig.26 Simulation set-up for the transfer characteristic in reception mode

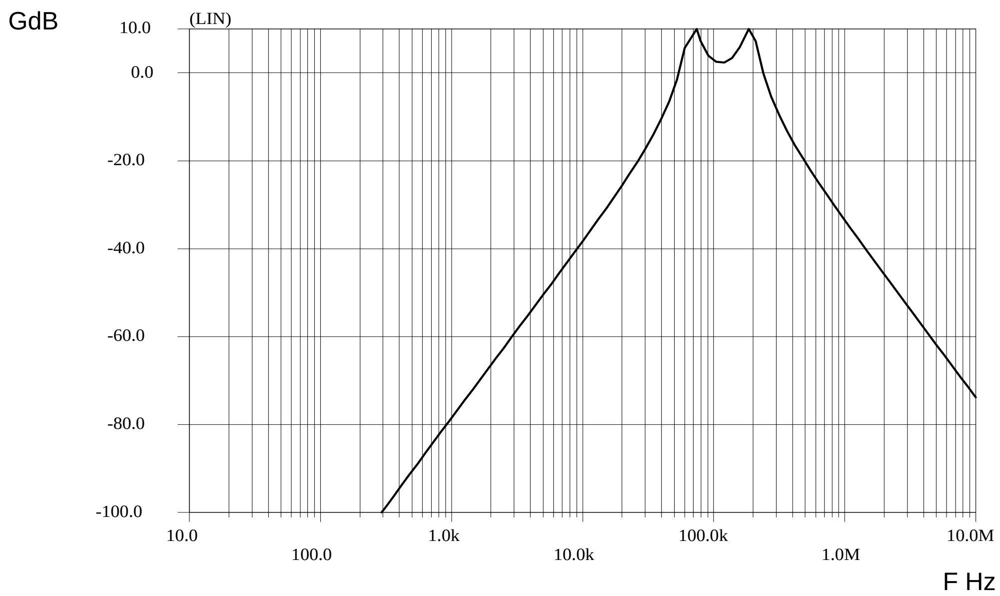


Fig.27 Transfer characteristic - reception -- GdB *versus* Frequency

b/ Reception mode - Impedance characteristic of the coupling network

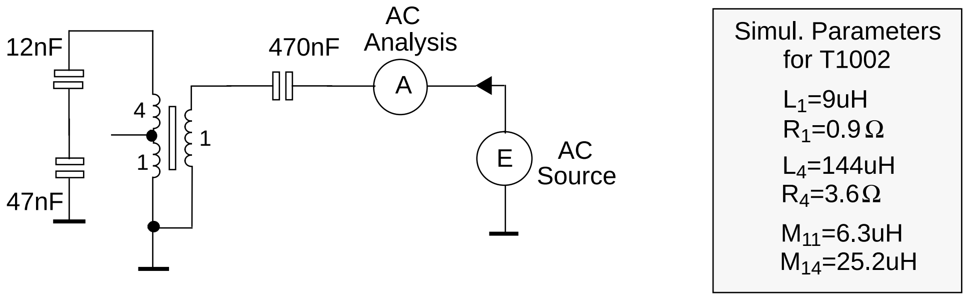


Fig.28 Simulation set-up for the impedance characteristic in reception mode

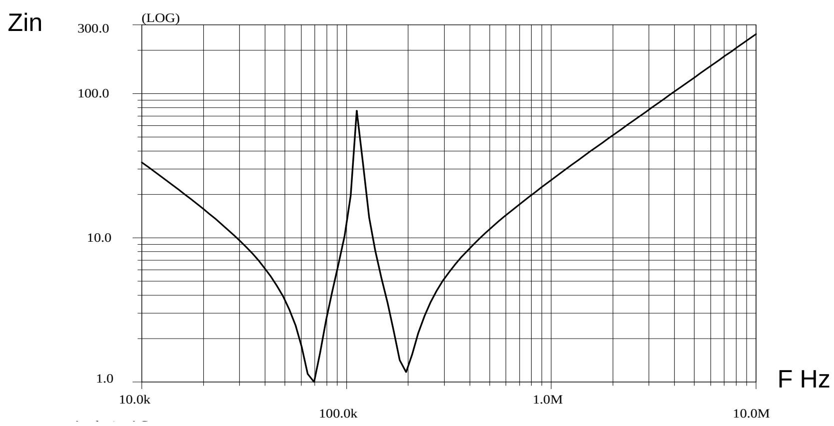


Fig.29 Input impedance - reception -- Zin *versus* Frequency

The problem for this coupling network is the impedance limitation in reception, around the centre frequency. One can see in the Fig. 29 that the impedance is very low for two different frequencies, 70KHz and 200KHz.

However, the input impedance is higher than 5 Ohms within the 95K..148.5KHz frequency range.

c/ Transmission mode - Transfer characteristic of the coupling network

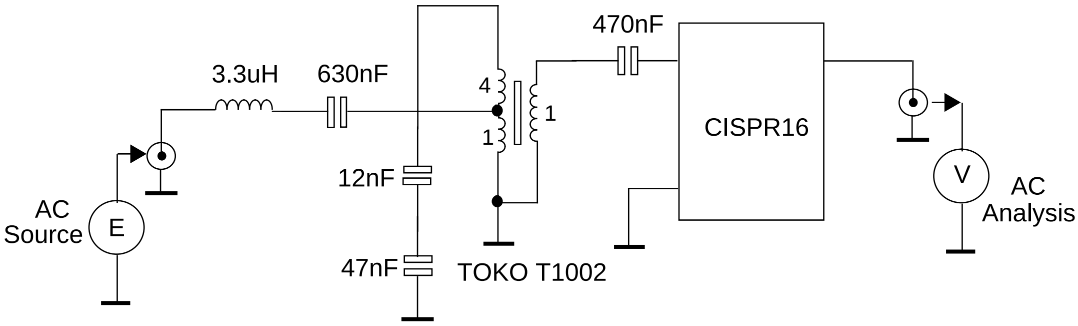


Fig.30 Simulation set-up for the transfer characteristic in transmission mode

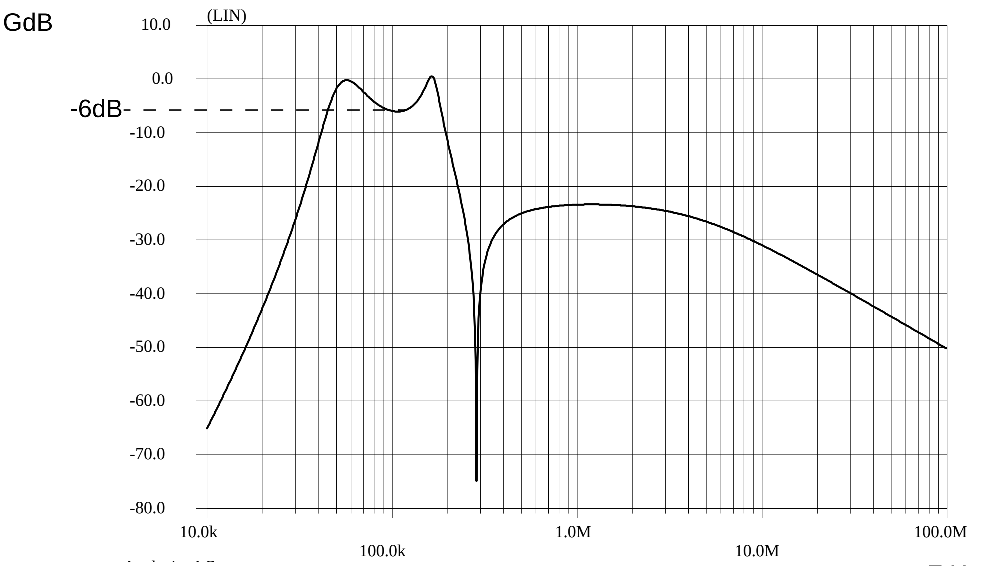


Fig.31 Transfer characteristic - transmission -- GdB *versus* Frequency

d/ Transmission mode - Spectrum of the carrier signal with transformer coupling network

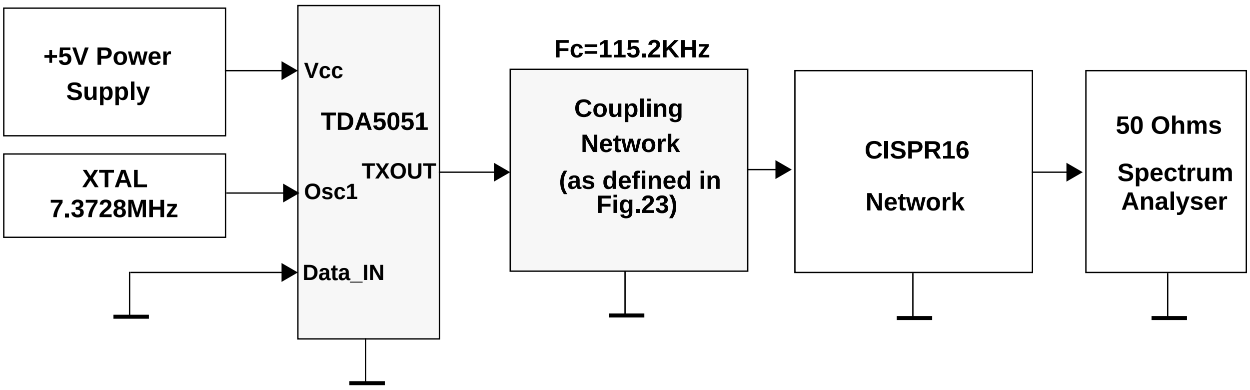


Fig.32 Test set-up for carrier spectrum measurement

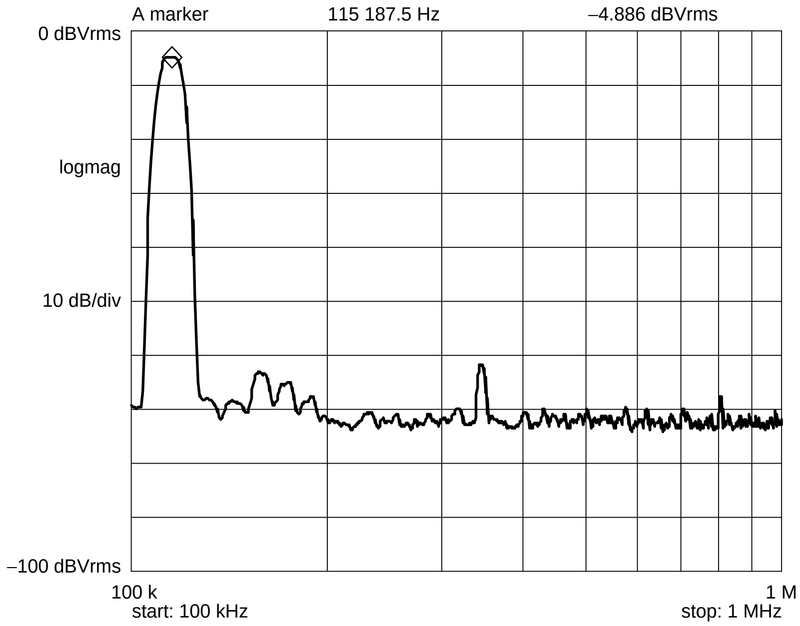


Fig.33 Vout(dBVrms) Spectrum - Centre frequency 115.2KHz

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 TDA5051 is internally protected against electrostatic discharges, but **has not a dedicated protection** for severe external stresses.

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

  2/ 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. Of course, 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.

  1/ 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.

  2/ 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

The Fig.34 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.

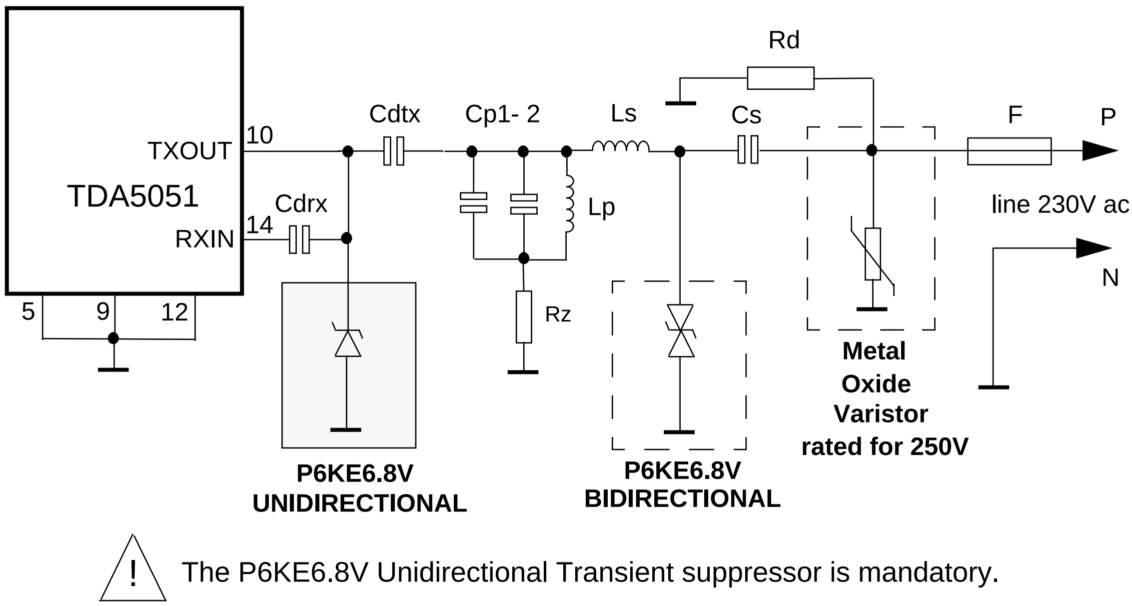


Fig.34 Full protection application diagram

- The primary protection (optional) is possible with a Metal Oxide Varistor, rated at 230V power line operation. It will be able to limit overvoltage spikes which could damage the Cs (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 !

Anyway, for safe design of the set MOV-FUSE, refer to the supplier’s DATA SHEET.

- The second protection device (optional) is a bidirectional Transil, type P6KE6.8V, which limits the voltage applied to the Cp1 and Cp2 capacitors and the peak current into Ls and Lp inductors. If the designer decides to avoid the use of this protection, he has to measure the transient voltage applied on Cp1 and Cp2 and the peak current into the inductors Ls and Lp. 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 TXOUT and RXIN pins from overvoltage. It protects also TXOUT from **NEGATIVE transient voltage** which may **destroy the circuit’s output amplifier**. This Transil must be connected directly to TXOUT pin, as close as possible, with a strong short strip on the printed circuit board.

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

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

- Then, a high value resistor Rd can be used to discharge Cs if the system is removed from the mains. The value could be chosen between 100K (1W) and 1MOhms (1/4 Watt) depending of the requested time to discharge Cs.

3.4.3 COUPLING WITH HF TRANSFORMER

The following diagram shows the complete coupling network with the protection components.

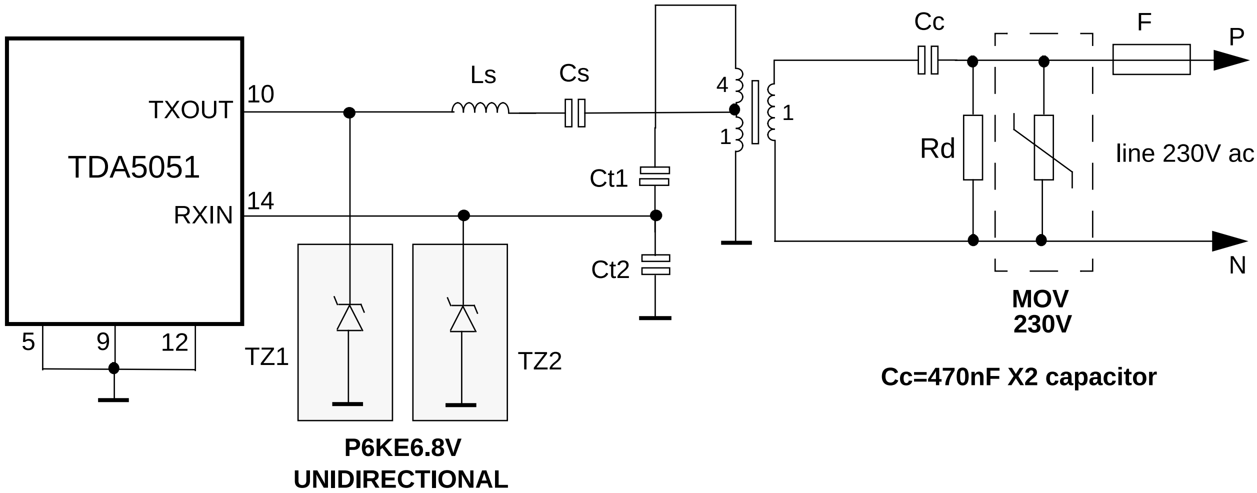


Fig.35 Application diagram using a T1002 transformer

In this configuration, it is not so easy to protect both TXOUT and RXIN pins with only one Transil as shown in the previous diagram, because of the different connections with the transformer.

The 2 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 TXOUT 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 TXOUT pin, for different overvoltage and stress on the line input; this voltage must be always lower than 7V.

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

The Rd resistor may be ommited 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 usefull to add an extra Cc capacitor on the other power line wire of the system, as shown in Fig. 36. In this case, the value of these two X2 capacitors must be 1uF.

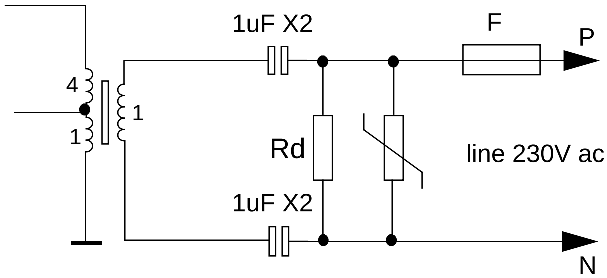


Fig.36 Improvement of the power line insulation

4. CONNECTION WITH THE CONTROLLER

4.1 CLOCK CONFIGURATIONS

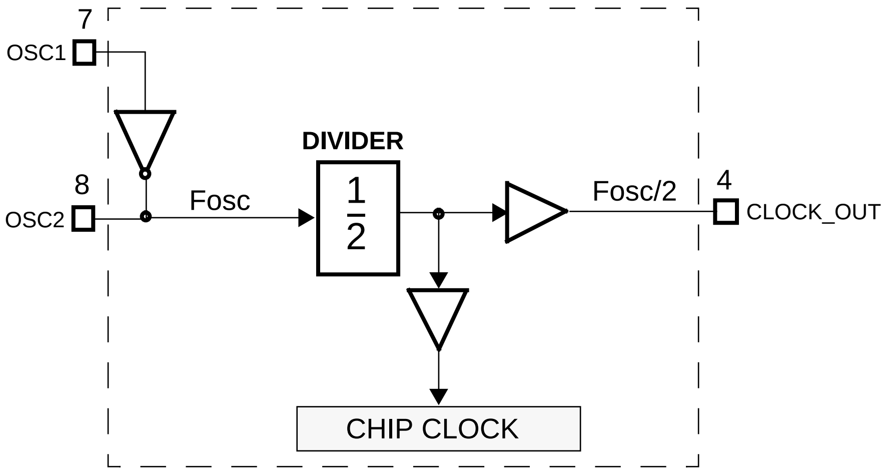


Fig.37 IC clock circuitry (simplified)

The TDA5051 can be used with two different clock configurations:

1- EXTERNAL CLOCK: A clock signal, TTL/CMOS compatible, is applied to the OSC1 pin of the circuit and sets the operation frequency called Fosc. Then, the carrier and detection frequency is Fosc / 64.

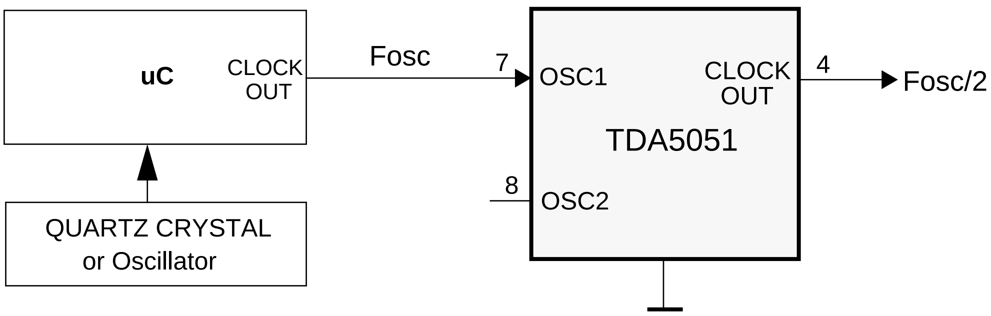


Fig.38 EXTERNAL CLOCK OPERATION

Table 11

OSC1 - PIN 7	INPUT - Signal frequency Fosc
OSC2 - PIN 8	MUST BE LEFT OPEN
CLOCK_OUT - PIN 4	OUTPUT - Signal frequency Fosc/2
Carrier and Detection Frequency	$\frac{Fosc}{64}$

2- ON-CHIP CLOCK: An external quartz crystal is connected to the circuit and sets the operation frequency Fosc. In this configuration, the CLOCK_OUT pin of the TDA5051 is a clock output, which is able to supply a TTL/CMOS compatible clock signal to an external controller, at a Fosc/2 frequency. The carrier and detection frequency is also Fosc/64.

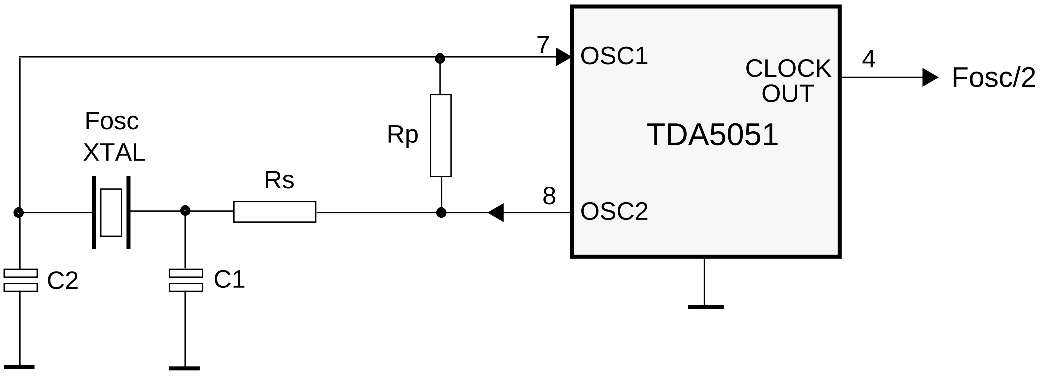


Fig.39 ON-CHIP CLOCK OPERATION

Table 12

OSC1 - PIN 7	XTAL connection
OSC2 - PIN 8	XTAL connection
CLOCK_OUT - PIN 4	OUTPUT - Signal frequency Fosc/2
Carrier and Detection Frequency	$\frac{Fosc}{64}$

The on-chip clock circuit is basically a *Pierce* oscillator, which uses an inverter implemented on the silicon and other external components. The Rp resistor is used to bias the inverter in the linear region and the Rs resistor limits the dissipation and the peak current in the crystal. The Rs 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 6.2MHz and 9.3MHz. For these values, the external components must be chosen as shown in the following table.

Table 13

C1 and C2	22pF to 47pF Ceramic capacitors
Rp	1M to 10 M
Rs	0 to 3.9 K
XTAL	HC49 standard quartz crystal 6.2MHz to 9.3MHz

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 degrees: the inverter has a phase shift of 180 degrees and the passive part must have the same.

With **Rp=2.2M Ohms**, **Rs=0 and C1=C2=27pF**, 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.

4.2 DATA SIGNALS - CONTROL SIGNALS

4.2.1 CONNECTION TO A MICROCONTROLLER

The TDA5051 can be connected to any controller having a TTL/CMOS compatible I/O port, as shown in Fig.42.

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 tied them to the correct level.

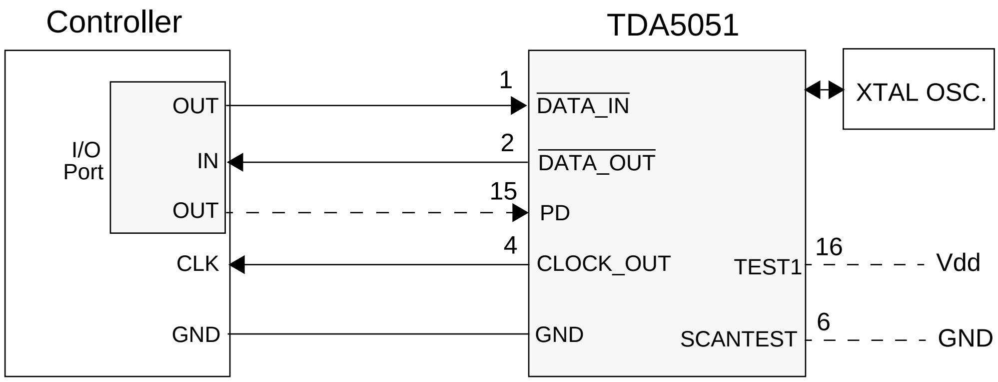
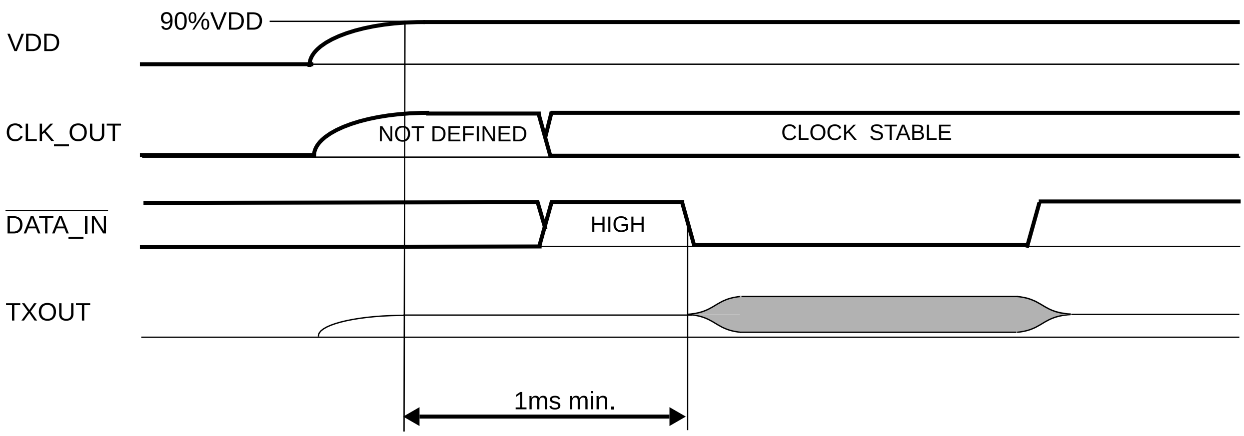


Fig.40 Connection to the controller (on-chip clock configuration)

DATA_IN and DATA_OUT signals are active LOW, and special care must be taken with DATA_IN. As explained in the DATA SHEET, after power-up, t**his signal must be HIGH before starting any transmission**. If after power-up, DATA_IN remains low or undefined, the circuit may **stay in a dummy state**.



Note: DATA_IN is an EDGE sensitive input and must be HIGH before starting a transmission

Fig.41 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 set-up, which depends on the coupling configuration of the MODEM.

A/ 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.

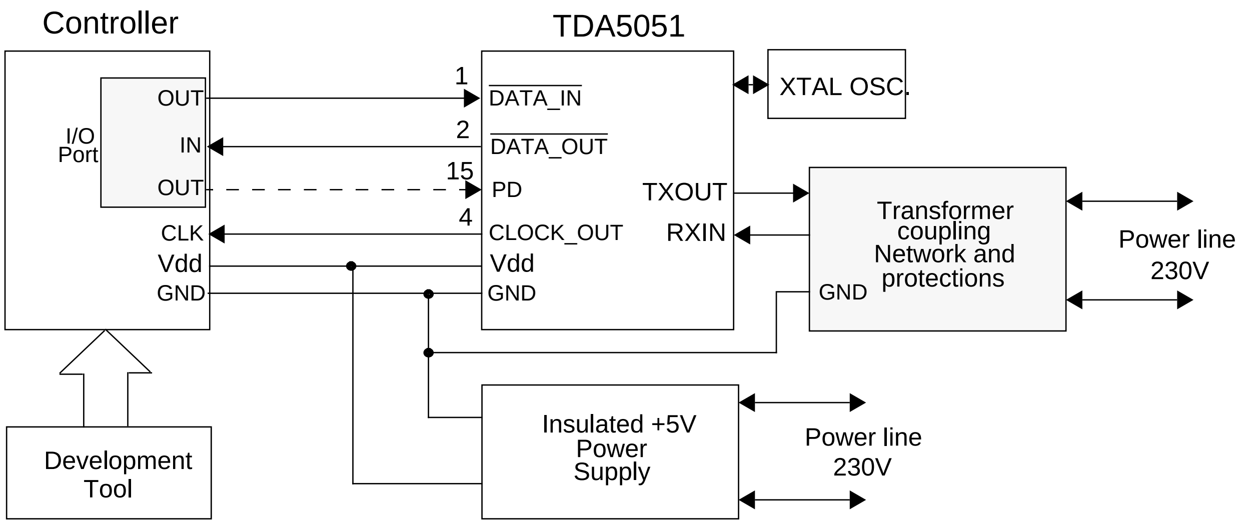


Fig.42 Development set-up with HF transformer coupling

B/ 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.

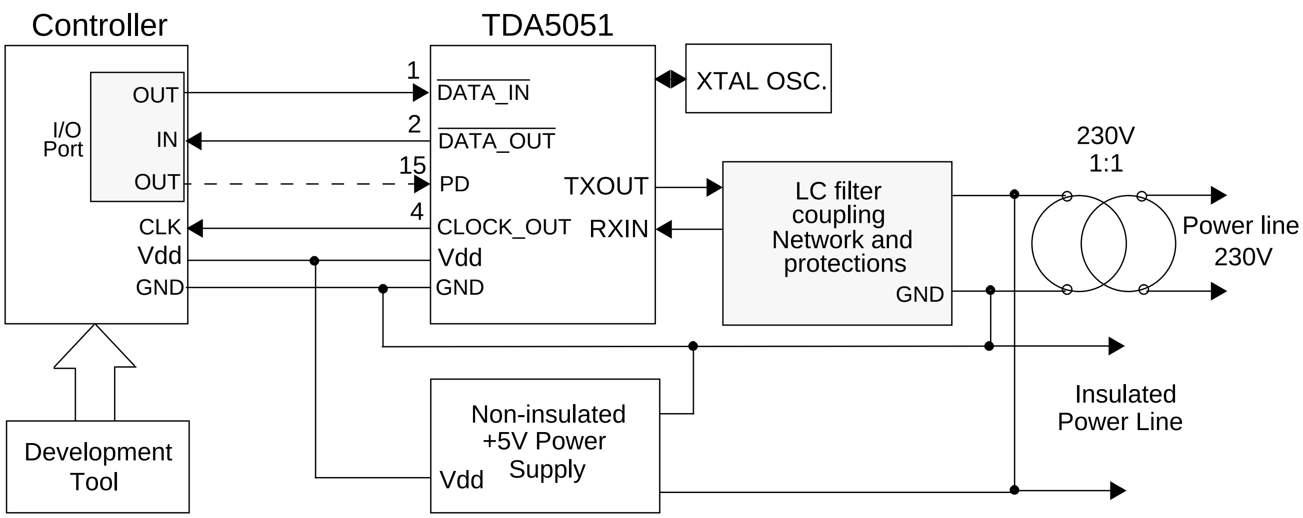


Fig.43 Development set-up with LC coupling network

C/ 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 Fig.44), even with a LC coupling network, by using electrical insulation of the TDA5051 data signals. That provides more realistic coupling conditions, because of the direct connection of the MODEM to the mains.

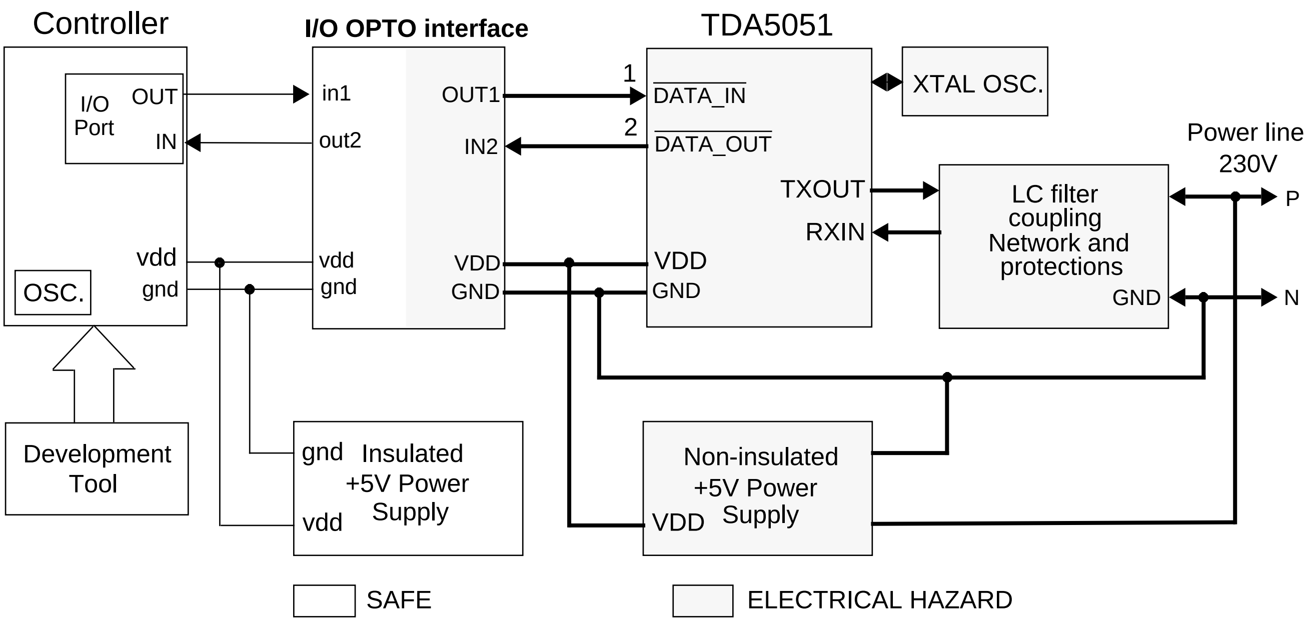


Fig.44 DATA I/O signals insulation with an OPTO interface

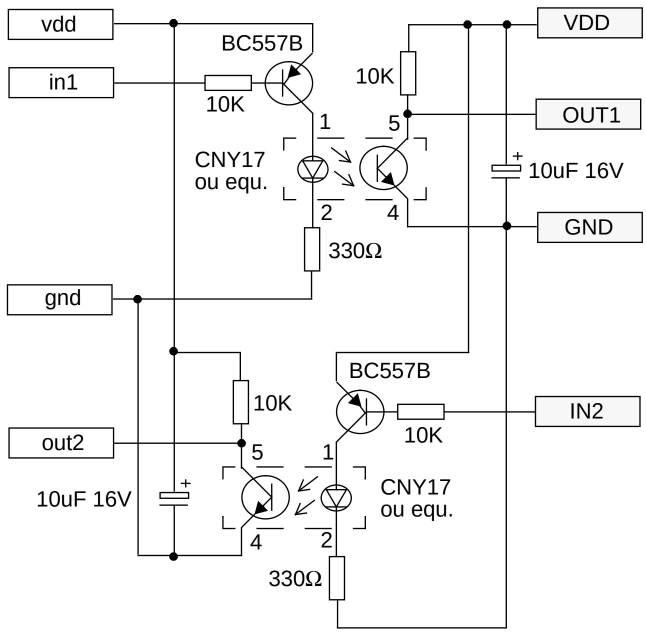


Fig.45 Example of OPTO interface

5. POWER SUPPLY DESIGN

5.1 POWER CONSUMPTION

The TDA5051 has 6 pins dedicated to the power supply, corresponding to 3 groups of Vdd / Gnd, as shown in the Fig. 46.

In the application, the VddA-VddD-VddAp pins have to be connected together to the +5V power supply. It is the same for the GndA-GndD-GndAp pins, which have to be connected to the ground.

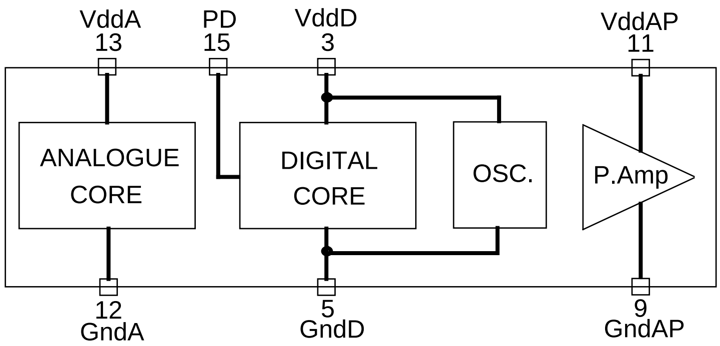


Fig.46 Vdd and Gnd pins of the TDA5051

As mentionned in the DATA SHEET, the POWER DOWN pin only changes the behaviour of the digital part of the MODEM and its consumption; the oscillator remains active and the CLOCK_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. The folowing table shows different power consumption levels in different conditions, for a typical circuit.

Table 14

CONDITIONS	IddA	IddD	IddAP	Idd total
Standby Mode @8.48MHz	12mA	12mA	0.05mA	24mA
Reception Mode @8.48MHz	12mA	16mA	0.05mA	28mA
Power Down Mode @8.48MHz	12mA	2.5mA	0.05mA	14.5mA
Transmission Mode @8.48MHz load=30Ω	12mA	16mA	19mA	47mA
Transmission Mode @8.48MHz load=10Ω	12mA	16mA	47mA	75mA
Transmission Mode @8.48MHz load=1Ω	12mA	16mA	70mA	98mA

Notes:

1- Oscillator: External quartz crystal with Rs=0, Rp=2.2M, C1=C2=27pF, XTAL @ 8.48MHz; VddA=VddD=VddAP=+5V; Ambiant temperature is 25 ^{O}C.

2- Standby Mode: No signal applied at RXIN pin; no signal applied at $\overline{\text{DATA\_IN}}$ pin.

3- Reception Mode: Signal (at the carrier frequency) applied at RXIN with a 10nF capacitor, 120dBuV amplitude.

4- Power Down Mode: Power Down pin is HIGH.

5- Transmission Mode: $\overline{\text{DATA\_IN}}$=0, resistive load with a 10uF capacitor on the TXOUT pin.

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

In order to prevent extra-distorsion of the output signal, and a good decoupling of the power supply, it is mandatory to connect, as close as possible, two capacitors: for example, a high value electrolytic capacitor of 100uF...220uF/10V and a 47nF..100nF 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.

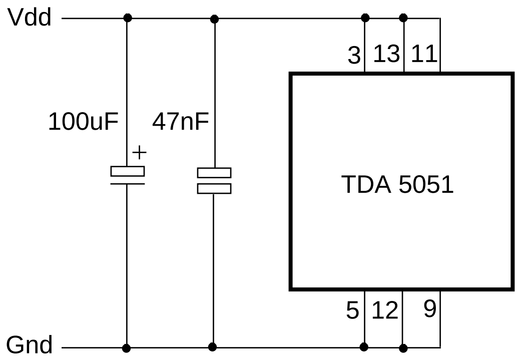


Fig.47 Decoupling of the power supply pins

5.2 EXAMPLE OF A R-C POWER SUPPLY

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

An example of electric diagram is shown in the Fig 48.

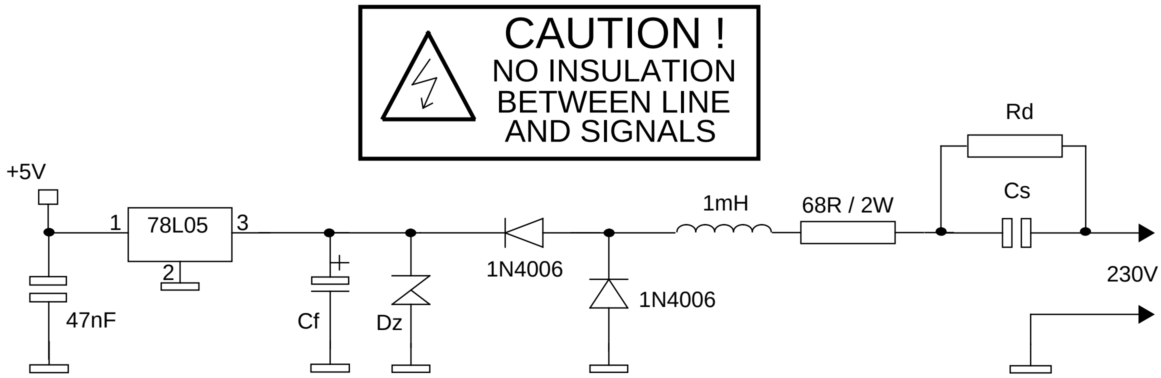


Fig.48 Example of a simple capacitor power supply

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

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

2- 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 1mH is used with an extra 68R resistor.

3- The peek current, during power-up must be limited. It is also the reason why the set L-R is before the rectifier.

4- Dz and Cf must be chosen to provide the minimum voltage required by the 78L05.

5- If another type of linear regulator is used, the quiescent current must be as low as possible.

6- To reduce the commutation noise induced by the rectifiers, it may be usefull to add small capacitors (1nF for example) in parallel with the 1N4006 diodes.

7- To discharge the high voltage capacitor Cs, a high value resistor Rd is used (100K 1W to 1M 1/2W depending on the requested discharge time).

The following table gives an example of component values and the maximum output current of the power supply.

Table 15

Cs	Dz	Cf	Iout max
1uF	8V2 1W3	470uF 16V	25mA
1.5uF	8V2 1W3	470uF 16V	35mA
2.2uF	8V2 1W3	470uF 16V	50mA

R-C power supply improvement

It is possible to improve the output current of the power supply without increasing the size of the Cs capacitor, by using a full bridge rectifier instead of the two diodes 1N4006 on the previous diagram.

The efficiency is twice as better, for the same value of Cs capacitor, BUT it is not possible to couple the MODEM to the power line with a LC filter ! The ground connection of the MODEM to the power line is lost; then, it is **mandatory to use a HF coupling transformer**.

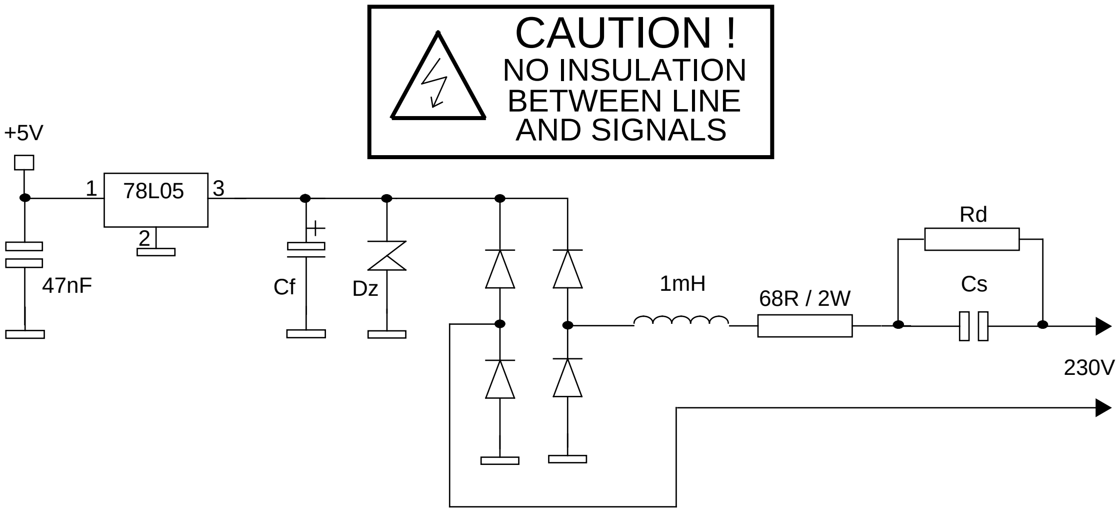


Fig.49 R-C power supply Improvement

Table 16

Cs	Dz	Cf	Iout max
1uF	8V2 1W3	470uF 16V	50mA
1.5uF	8V2 1W3	470uF 16V	70mA
2.2uF	8V2 1W3	470uF 16V	100mA

5.3 EXAMPLE OF SWITCHING MODE POWER SUPPLY

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

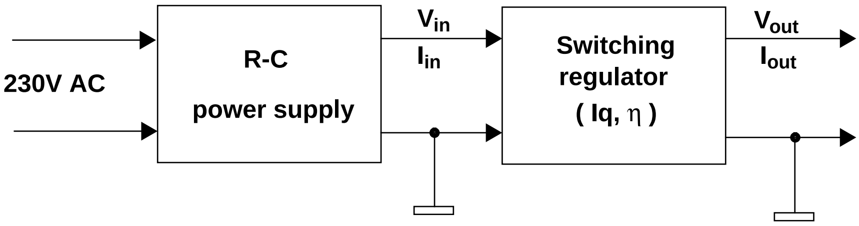


Fig.50 Mixed solution R-C/swicthing power supply

V_{in} is the input voltage of the regulator and **I_{in}** the input current; **V_{out}** the output voltage and **I_{out}** the output current, **I_q** is the quiescent current and η the efficiency of the switching converter, then:

$$I_{in} = \frac{V_{out} \cdot I_{out}}{V_{in} \cdot \eta} + I_q$$

Example: Power supply using the LT1372 (Linear Technology) 500KHz High Efficiency Switching Regulator

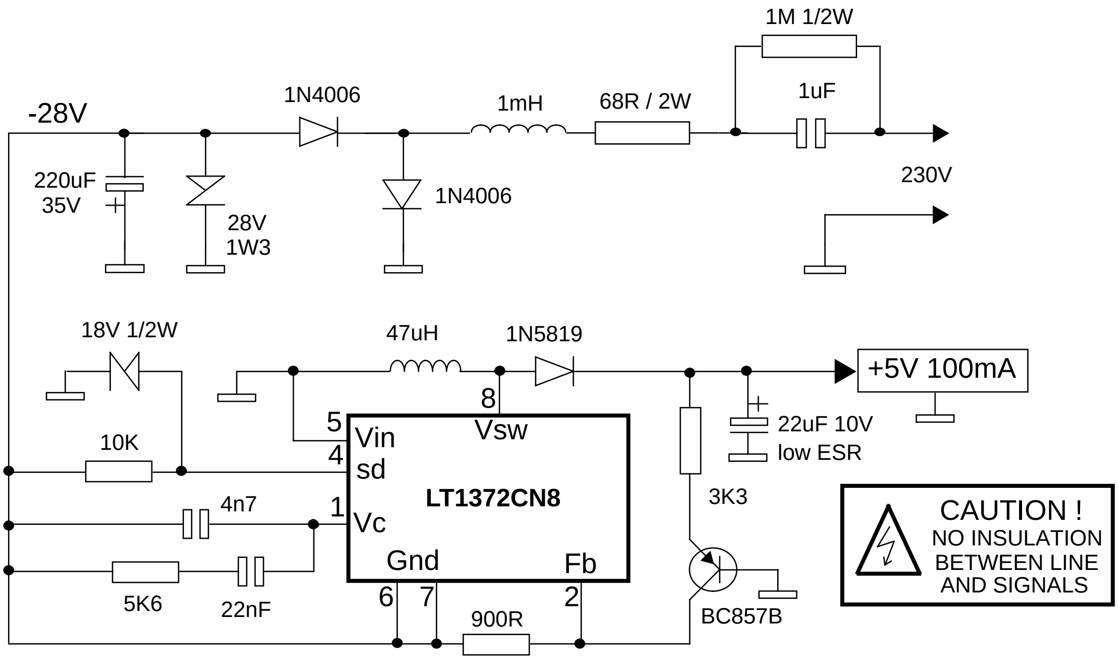


Fig.52 Example of mixed solution