1. INTRODUCTION

1.1 Power Line Communication

The advantages in the realizations of a communication network using the same electrical network that supply all the elements of the network are evident. Also in presence of new wide band LAN using RF system, for example Bluetooth, a narrow band communication system using the mains has valid and relevant advantages.

In fact it's a common opinion that in residence or industrial field in parallel to a wide band network for images, films, Internet, will be also active a narrow band LAN used to carry simples information as measure, command to actuators, check systems and so on.

So there are a lot of fields that can be covered by a narrow band communication system, in a residential structure, outside the house or in industrial applications (see figure below).

For example in houses or commercial building possible application are power management, light control, heating o cooling system management, remote control of appliances (by internet or telephone), control of alarm systems.

Figure 1. Typical Power Line Modem Applications Scenario
Considering external applications the main field regard the communication with the meters, in particular automatic measure and remote control, prepaid supply systems, meter or broadcast information home terminal. Another relevant industrial segment can be the street lighting management.

Even if it is some years that the concepts of power line communication and home automation are present, as well different devices dedicated for power line modems are developed, the market segment of this kind of application is developing only in this last period.

There are three main factors that have conditioned up to now the field of the power line communication:
  a) The slow development of international normative and standards;
  b) Some technical constraints related to the electrical network;
  c) Consideration about costs from a general point of view.

The first point regards standards and normative. As general consideration in an open communication system is mandatory to have rules and guidelines to guarantee that every node, independently by the manufacturer, don’t compromise the characteristics of the entire network and the performance of the communication system.

In the home domain this aspect is more relevant for the presences of several and different appliances and manufacturers, and also the consideration about a common language (the protocol) are mandatory.

In the last year the CENELEC (European Committee for Electrotechnical Standardizations) have published or up gradated a series of regulations about the communication on low voltage electrical installations. In particular the are the EN50065-1, concerning general requirements, frequency bands and electromagnetic disturbances; the EN50065-4-2 about the low voltage decoupling filter and safety requirements; the EN50065-7 about the impedance of the devices.

It is also available a preliminary version (1999) of the EN50065-2-1 about immunity requirements.

In the last period there is also a sort of lining among the appliances manufacturers on the EHS (European Home System) protocols, even if a lot of customized protocols are present, mainly in proprietary mains. More information on EHS protocol is available on EHS booklet document.

The second critical consideration regards the technical problems concerning the specific topology of the electrical network.

The figure below represents a typical scenario of the signal present on an electrical network. For several reasons that will be listed in the next paragraph (low impedance, different kind of disturbances, etc.) the received FSK signal has a very low level and it is mixed with a great level of noise.

**Figure 2. Mains Signals**
The aspects of noise and low impedance are more critical in a residential house were a lot of different appliances are present.

Every entity of the network has to be able to manage a reliable communication also in these critical conditions. To realize this goal all the aspects of the application design have to be to consider carefully, from the coupling interface to the power management, from the type of microprocessor to the power line transceiver, considering their mutual influence, too.

Last but not least the consideration about the economic point of view. It isn’t a simple consideration of the node cost respect to an equivalent wire line or wireless solution, but also other aspects as the installation and configuration cost of the entire network.

Another economic issue that has to be considered is the power consumption of a single communication node. The power consumption of each communication unit has to be lower as possible because every unit must stay always on ready to receive commands from a remote transmitter. This constrains is even more relevant in application with a huge number of nodes. Consider for example the control of a street lighting system with thousands of lamps or a metering system with several thousand of electricity meters.

The ST7538 has been designed considering all the issues listed before. With this device is possible to realize high efficient and reliable application for power line communication, characterized by low power consumption, low cost, compliant with the main normative and protocol today presents.

1.2 The Electrical Network

The communication medium consists of everything connected on power outlets. This includes house wiring in the walls of the building, appliance wiring, and the appliances themselves, the service panel, the triplex wire connecting the service panel to the distribution transformer and the distribution transformer itself. Since distribution transformers usually serve more than one residence, the loads and wiring of all residences connected to the same transformer must be included.

1.2.1 Impedance of Power Lines

A power line has very variable impedance depending of several factors as for example its configuration (star connection, ring connection) or the number of entities linked.

An extensive data on this subject has been published by Malack and Engstrom of IBM (Electromagnetic Compatibility Laboratory), who measured the RF impedance of 86 commercial AC power distribution systems in six European countries (see Figure 3).

These measurements show that the impedance of the residential power circuits increases with frequency and is in the range from about 1.5 to 8Ω at 100kHz. It appears that this impedance is determined by two parameters - the loads connected to the network and the impedance of the distribution transformer. In the last period a third element influences in a relevant way the impedance of the power line, in particular in the a residential network. It is represented by the EMI filters mounted in the last generation of home appliances (refrigerators, washing machines, television sets, hi-fi). Wiring seems to have a relatively small effect. The impedance is usually inductive.

For typical resistive loads, signal attenuation is expected to be from 2 to 50dB at 150kHz depending on the distribution transformer used and the size of the loads. Moreover, it may be possible for capacitive loads to resonate with the inductance of the distribution transformer and cause the signal attenuation to vary wildly with frequency.

For the compliance tests the normative EN50065 use two artificial mains networks conforming to sub clause 11.2 of CISPR 16-1:1993. Measurements on real networks have shown that this artificial network do not truly represent practical network impedance. To better evaluate the performance of a real signaling system occurs an adaptive network that has to be used in conjunction with the CISPR 16-1 artificial network. The design of the adaptive circuit is included in the informative annex F of EN50065-1 (revision 2001).
1.2.2 Noise

Appliances connected to the same transformer secondary to which the power line carrier system is connected cause the principal source of noise. The primary sources of noise will be Triacs used in light dimmers, universal motors, switching power supply used in small and portable appliances and fluorescent lamps.

Triacs generate noise synchronous with the 50Hz power signal and this noise appears as harmonics of 50Hz. Universal motors found in mixers or drills also create noise, but it is not as strong as light dimmer noise, and not generally synchronous with 50Hz.

Furthermore, light dimmers are often left on for long periods of time whereas universal motors are used intermittently.

In the last years others two source of strong noise have been introduced in the electrical network. They are the Compact Fluorescent Lamps (CFL) and the switching power supplies of rechargeable battery (for example notebook) or little appliances.

In many cases they have a working frequency or some harmonics in the range of the power line communication band (from 10KHz to 150KHz). Of course the presence of continuous tones exactly at communication channel frequency can affect the reliability of the communication.

The figure 4 shows some of the noise sources we talk about. The measures setup consists of an insulation transformer with a VARIAC, a spectrum analyzer HP4395A coupled by a high voltage Capacitor (1uF) and a 2mH transformer (1:1).

Figure 4. Voltage spectra of a 100W light dimmer, a notebook PC, a desktop PC, a CFL lamp, a TLE lamp, all working with a 50Hz/~220V supply (by Cantone).
1.2.3 Typical Connection Losses
The transmit range of a home automation system depends on the physical topology of the electric power distribution network inside the building where the system is installed. Different connection losses can be measured. For communication nodes connected to the same branch circuit from transmitter to receiver a typical connection loss is about 10-15 dB. If transmitter and receiver are in different branches of the circuit, separated for example by a service panel, there is an additional attenuation of 10-20 dB. In some worst conditions (socket with very low impedance) the attenuation of the transmitted signal can reaches a value of 50-60db.

1.2.4 Standing Waves
Standing wave effects will begin to occur when the physical dimensions of the communication medium are similar to about one-eighth of a wavelength, which are about 375 and 250 meters at 100 and 150kHz respectively. Primarily the length of the triplex wire connecting the residences to the distribution transformer will determine the length of the communication path on the secondary side of the power distribution system. Usually, several residences use the same distribution transformer. It would be rare that a linear run of this wiring would exceed 250 meters in length although the total length of branches might occasionally exceed 250 meters. Thus standing wave effects would be rare at frequencies below 150kHz for residential wiring.

1.3 ST7538 Power Line Modem
ST7538 is a transceiver designed for power line communication application on low voltage (220V) and medium voltage (2KV) mains. Its function is to realize the interface from the electrical network and a system (usually a microprocessor with some sensors), which will manage the application and the upper layers of the communication protocol.

The advanced technology used, a CMOS-LDMOS-BIPOLAR fabrication process, the package, a TQFP44 with dissipating slug, and new design techniques make this device a more versatile and complete instruments than the previous generation of power line modems.

Figure 5. Basic Blocks and Functions of ST7538.
The key points of this device are:
- A smart power consumption management, i.e. very low current consumption in receiving mode (5 mA) and a high efficiency during transmission;
- The integration of a consistent part of the power circuits (a 2Watt power line drivers and a 5V/100mA low drop regulators);
- A very efficient demodulation circuit with a wide dynamic range and an high selectivity;
- An automatic voltage/current regulation loop that adapts the transmitted signal to the low and variable impedance of the mains;
- An internal register in conjunction with efficient and simple digital interface that controls easily all the functions of the device;
- A series of auxiliary function and blocks (zero crossing comparator, crystal driving oscillator circuit, operational amplifier, Band in use, Power Good, etc.);

All the listed above characteristics make this device a powerful tool to develop power line modem application with low power consumption, a reasonable cost, suitable to design communication node compliant with the European normative CENELEC (EN50065), US FCC regulations.

ST7538 is a protocol independent device and it can be used to implement proprietary protocols or standardize protocols like EHS V1.3a or Konnex.

A possible application circuit with the ST7538 is illustrated in figure 6. As you can notice the several features of the ST7538 simplify the overall application reducing the number of the external components. The internal 5V regulator of the devices generates the supply for the microprocessor and other low voltage components the application requires, so only one power regulator is sufficient to supply the application. The reset, the clock can be provided to the microprocessor by the ST7538, so it is possible to avoid the glue logic and the external circuitry to realize them.

The integrated power line interface with an integrated voltage regulation/current protection circuit (patent pending) and few passive external components realizes a very efficient coupling circuit able to transmit a valid signal also in the most critical condition of impedance.

All these issues explain how it is possible to make an efficient and cheaper power line communication node using the ST7538.
1.4 FSK Modulation & ST7538 Architecture

The function of the devices is to receive and transmit through mains or a power line, connected with an appropriated coupling circuit, electrical signals coded according a half duplex FSK modulation (Frequency Shift Key). The FSK modulation technique translates a digital signal in a sinusoidal signal that can have two different frequency values, one for the logic level high of the digital signal (fh), the second one for the low level (fl).

\[ f_h - f_l = \text{BAUD} \cdot \text{dev} \]

The average value of the two tones is the carrier frequency (fc). The difference or distance between the two frequencies is a function of the baud-rate (BAUD) of the digital signal (the number of symbols transmitted in one second) and of the deviation (dev). The relations are:

\[ f_c = \frac{f_h + f_l}{2} \]
The ST7538 is able to communicate using one of 8 different communications channels (60, 66, 72, 76, 82.05, 86, 110, 132.5 KHz), selecting for the chosen channel four baud-rate (600, 1200, 2400, 4800) and two different deviations (1 and 0.5). All these parameters and other setups of the devices are configured writing the internal control register.

**Figure 7. ST7538 Block Diagram.**

The ST7538 in transmitting mode (pin RxTx at a low level) receives a digital signal at the baud-rate on the TXD signal and translate it in a FSK sinusoidal signal at the pins ATOP1/ATOP2 (the signals are in phase opposition).

In the receiving mode (pin RxTx high level), an incoming FSK signal on the RAI pin is demodulated and the digital output is present at the pin RXD. The device recovers also the clock (baud-rate) of the received signal on output pin CLR/T using an internal PLL.

The communication has to use a half-duplex protocol, i.e. only one communication node at a time can transmit. All the other nodes have to wait their turn and be sure that the communication channel isn’t busy before to communicate.

For a more detailed and complete description of the ST7538 devices and of its function please refer to the product datasheet.

**Figure 8. FSK spectrum, random sequence.**
2. DEMO BOARD FOR ST7538

2.1 Main Features

ST7538 Demo Board realizes in a two layer PCB a complete power line communication node, including the power line coupling circuits, a power supply section, a microcontroller and a RS232 serial interface to connect the board to a personal computer (figure 10). This board with the related firmware load in the ST microprocessor and the PC software realizes a complete reference about the mains aspects of the power line communications.

Figure 9. Demo Board Picture.

Figure 10. Demo Board Layout sections.
The aim of this board is to give a useful tool to develop and to evaluate a power line application with the device ST7538. So even if aspects of the board concerning size and cost aren’t optimized, it’s schematic gives a good design reference and a valid start point to develop power line modem applications. Moreover the board structure (a lot of jumpers, test points, few SMD components) allows connecting easily test probes to realize measure and signal verification, as well to customize the application according to specific requirements.

Figure 11. Demo Board Schematic: Micro controller & PC Interface.
Figure 12. Demo Board Schematic: Line Coupling Interface & Power Supply.
2.2 Signal Coupling Interface

The line signal interface links the application board to the mains, realizing an high efficient coupling circuit for the received and transmitted FSK signals and a reliable filtering system for the mains voltage (220V~/50Hz or 110V~/60Hz), for noise and for bursts or surges.

It is possible to implement different topologies of coupling circuits. A first classification is between an isolated solution with a line transformer or a double capacitor and a non-isolated solution with a single high voltage decoupling capacitor. The last one is more simple and cheaper, while the first one realizes better performances using efficiently the differential power output of the devices.

The differential solution has been also preferred for the advantage to reduce the even harmonics of the transmitted signals.

Figure 13. Demo board ST7538 Power Line Interface.

In the design of the coupling interface a lot of technical and standard constrains have to be considered, that are different in a receiving condition respect to a transmitting status.

Here following a list of design specification for signal coupling for the European Market:

- High selectivity in receiving mode (EN50065-2-1);
- Output impedances as greater as possible (EN50065-7);
- Low noise in receiving mode;
- Wide voltage and current signal compatibility in every condition (EN50065-1);
- Very low distortion in transmission mode (EN50065-1);
- High coupling efficiency in transmission mode (also with high loads);
- High reliability to burst and surge spikes (EN50065-2-1).

A series of constraints listed in the EN50065-4-2, "Low voltage decoupling filters - Safety requirements", have to be guarantee by the decoupling elements (transformer or capacitors) to be compliant with a 4KV or 6KV classes.
The solution implemented in the demo board is an isolated circuit with a 1:1 transformer and a X2 class capacitor. In the chosen topology the transmission sections components haven't any relevant influences on the receiving circuits, so the two structures can be analyzed separately. The components values that realize the passive filters have been dimensioned for the 132.5KHz channel, but also with the 110KHz communication frequency the performances of the board have the requirement for a reliable communication.

2.2.1 Transmitting Section

The function of the transmitting coupling circuits is to inject the transmitted signal coming from the power amplifiers (ATOP1/ATOP2) to the mains with the maximum efficiencies and filter noise and spurious signals over the Cenelec mask (EN50065-1, section 7 disturbances limits).

The critical frequencies of the conducted disturbances emitted are the 2nd and 3rd harmonics of the transmitted signal (265 KHz and 497.5 kHz for the channel at 132.5 kHz) the harmonics of the working frequency of the power supply regulator and two spurious tones centered at 1.3 MHz (+/- the channel frequency) produced by the direct synthesis technique used for the transmitted signal generation.

The configuration used for the transmitted circuit realizes a 4th order band pass filter (four poles and two zeros). In order two have a good immunity to the components spread (accuracy and temperature) and to the load variation the filter has a band of about 60 kHz (see figure 16). To obtain this characteristic two poles can be put at a frequency of about 100 kHz and the other at a frequency of about 160kHz.

Figure 14. Demo Board ST7538 transmission coupling circuit.

For a correct dimension of the filters the mutual influence of the various components has to be considered, as well the influences due to the other elements: the leakage inductance of the transformer (from 0.1uH to 10uH), the capacitance of the transil diode (about 2nF), the ESR of the series components C13, LC12, T1, L4, C11 (from 100m ohm to 1 ohm).

For a first approximate rate of the components values the simplified circuit of figure 15 are used only the reactive components and the transformer (1:1 ratio) is considered ideal.
For the correct dimension of the filter it is better to consider the typical impedances expected for the used mains network too (usually an inductive load). If an impedance characterization of the network isn’t available it is possible to use a reference load like the artificial network CISPR16-1 (50 ohms parallel 5 ohm plus 50uH). In the simplified circuit as been considered only the reactive part of the CISPR 16 artificial network \( L_c = 100\mu H \).

**Figure 15. Simplified schematic of the transmission filter.**

![Simplified schematic of the transmission filter](image)

The formulas for the two couple of poles are:

\[
 f_{p1} = f_{p2} \equiv \frac{1}{2 \cdot \pi \cdot \sqrt{L_{C12} \cdot C_A}} \equiv 160\text{kHz}, \quad f_{p3} = f_{p4} \equiv \frac{1}{2 \cdot \pi \cdot \sqrt{L_B \cdot C_B}} \equiv 100\text{kHz}
\]

\[
 \frac{1}{C_A} = \frac{1}{C_{R9}} + \frac{1}{C_{13}}; \quad \frac{1}{C_B} = \frac{1}{C_{R9}} + \frac{1}{C_{11}}; \quad L_B = L_4 + 2 \cdot L_C
\]

The peak value of the signal current can reaches with heavy load a current peak value greater than 1 Ampere so all the components of the coupling interfaces in series to the signal (in particular the inductors \( L_{C12}, L_4 \) and the transformer \( T_1 \)) have to be guarantee for this current without saturation or overheat problems. The maximum current of the inductive elements, as well the series resistance, are proportional to value of the inductance.

In any case the ESR of these inductive elements has to be as lower as possible to realize a good coupling interfaces. In fact with a global impedances series greater than 2 ohm the coupling losses of the transmitted signal with heavy loads could be excessive.

For these reasons are been chosen in this circuit LBC (Large Bobbin Core) inductor with values small as possible (\( L_{C12} = 10\mu H \) and \( L_4 = 22\mu H \))

Another constraints regard the value of the capacitor \( C_{11} \). This is a X2 class capacitor that has the primary function to uncouple the transformer for the mains. Its better to use a value as lower as possible both for an economic reason, both to obtain a 50Hz mains current in the secondary coil of the transformer lower as possible in order to reduce saturation effects. The value choused is 33nF.
Considering that all the mains voltage drop un the $C_{11}$ capacitor the current value in the transformer coil is about:

$$\|i_{\text{rms}}\| = 220V_{\text{rms}} \cdot 2 \cdot \pi \cdot 50\text{Hz} \cdot C_{11} = 2.3mA_{\text{rms}}$$

Using the previous poles formulas can be rated the values of $CR_9$ (100nF) and $C_{13}$ (220nF). The requirements about this type of capacitor are the accuracy, the temperature compensation and a low ESR values. Polyester capacitors or Polypropylene capacitor (better temperature coefficient) are suggested. The accuracy should be at least of ±10%.

**Figure 16. Simulated characteristics of the transmission coupling filter.**

Using components with standard values the real values of the poles are:

$$f_{p1} = f_{p2} = 192\text{kHz}, \quad f_{p2} = f_{p3} = 91\text{kHz}$$

The values obtained are very close to the spec values and in agreement with the simulated results (see figure 16). In any case for a better result it is suggested to use a simulator or an equivalent specific program to design filters.

The $R_{10}$ resistor has been added to fit the output impedance requirement in receiving mode (EN50065-7).
An alternative solution for the transmission coupling circuit is showed in the picture above. It realizes a 2nd order band pass Butterworth filter centered at the channel frequency.

The advantage of this solution is the symmetrical structure that compensates the non-linearity of the components (lower level for the even harmonics).

Also in this case a correct dimension of the filter has to take in account the parasitic elements of the various components, as well the load influence.

Figure 17. Coupling circuit with a 2nd order band pass Butterworth.

One of the most critical components of the application is the signal transformer. In order to have a good power transfer and to minimize the insertion losses it is recommended a transformer with a primary inductance greater than 1mH and a series resistance lower then 0.5 ohm. Another constrains regards the saturation current: a DC or low frequency current (50Hz) should be present.

Another parameter to take in consideration is the leakage inductance. If it has a relevant value (from 10uH to 50uH) the inductance \( L_4 \) can be avoided. The drawback is that this parameter has a great variation that influences the output filter characteristics. For this reason in the demo board is used a transformer with a very low leakage inductance (lower than 1uH).

The European normative (CENELEC) gives another constraint regarding the voltage insulation resistance and dielectric strength of the application that influences the transformer. Two classes are indicated, a 4kV and a 6kV class. The classification and measurement criteria are codified in the EN50065-4-2 CENELEC document.

In case of heavy load a smart solution is to use a 2:1 transformer. The equivalent impedance of the load referred to the primary coils of the transformer has a value four times bigger than with a 1:1 ratio transformer. Also the current supplied by the power interfaces has half value. The only critical point is that to have the same output signal level on the mains the ST7538 power interfaces has to generate a double signal (more problems with odd harmonics).

Seldom a low amplitude signal at high frequency (greater than 10MHz) can be present on the output signal. It should be originates by a resonance from the leakage inductances and the parasitic capacitance of the board and of the ST7538 output stage. Usually the series inductor \( L_{C12} \) stops this kind of oscillations.

2.2.2 Receiving Section

The receiving circuit of the coupling interface has the main function to filter noise tones from network that can overcome the maximum absolute rates of the RAI pin, or in any case degrade the demodulation performances of the device (EN50065-2-1 Narrow-band conducted interference, 7.2.3).
The solution adopted in the demo board consists of a resonant parallel circuit that realizes a 2nd order passive filter \((C_{36}, L_7, R_{11})\). The \(C_{33}\) capacitor is a decouple component that saves the DC value on the RAI pin (2.5V). This DC value realizes the maximum voltage input signal (2Vrms) compatible with the absolute of the devices.

**Figure 18. Demo board ST7538 receiving circuits.**

In the receive mode the ATOP1 pin has a high impedance and a DC polarization at PAVcc/2 while ATOP2 pin is tied to ground internally into the device with a power MOS (few milliohm resistance). With this configuration the two resonant series \(L_4, C_{11}\) and \(LC_{12}, CR_9, R_{10}\) can be considered as first approximation neglected (\(L_4/C_{11}\) has the resonance at the channel frequency while the \(LC_{12}/CR_9\) has the resonance at an higher frequency). The only effect of these components is to attenuate the amplitude of the received signal, about 6 dB with the used values of \(CR_9\) and \(R_{10}\).

According to these consideration the dimension of the input filter frequency depends mainly by the choice of \(C_{36}, L_7\) and \(R_{11}\).

These components realize a 2nd order band pass filter. The center band frequency of the filter is the channel frequency:

\[
f_0 = \frac{1}{2 \cdot \pi \cdot \sqrt{L_7 \cdot C_{36}}} = 132.5\,\text{kHz}
\]

The other parameter to take in account for the receiving filter design is the Quality factor (Q). Its value is a tradeoff between the selectivity requirements (high Q values) and the components and temperatures spreads. Using a polypropylene capacitor with a 5% tolerance and a BC inductor with a tolerance of 10% a Q value between 2 and 3 is acceptable.

\[
Q \equiv R_{11} \cdot \frac{C_{36}}{\sqrt{L_7}} = 2.85
\]

In order to don't influence the transmitting section and to reduce the DC current through the primary coil of transformer the value of \(R_{11}\) should be higher as possible. The drawback of a great value for this resistor is that produces a higher white noise. A value of 750 ohm satisfies these opposite requirements for all the communication channels. Fixed the resistor value and using the previous equations it is possible to rate the values of \(C_{36}\) and \(L_7\).

Here following a table with some possible commercial values for these components referred to different communication channel.
Table 1. Parallel resonance Rx filter components

<table>
<thead>
<tr>
<th>Rx Filter</th>
<th>C36</th>
<th>L7</th>
<th>F0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch 132.5 kHz</td>
<td>6.8nF</td>
<td>220uH</td>
<td>130.1 kHz</td>
</tr>
<tr>
<td>Ch 110 kHz</td>
<td>10nF</td>
<td>220uH</td>
<td>107.3 kHz</td>
</tr>
<tr>
<td>Ch 86 kHz</td>
<td>10nF</td>
<td>330uH</td>
<td>87.6 kHz</td>
</tr>
<tr>
<td>Ch 82.05 kHz</td>
<td>8.2nF</td>
<td>470uH</td>
<td>81.1 kHz</td>
</tr>
<tr>
<td>Ch 76 kHz</td>
<td>10nF</td>
<td>470uH</td>
<td>73.4 kHz</td>
</tr>
<tr>
<td>Ch 72 kHz</td>
<td>22nF</td>
<td>220uH</td>
<td>72.3 kHz</td>
</tr>
<tr>
<td>Ch 66 kHz</td>
<td>18nF</td>
<td>330uH</td>
<td>65.3 kHz</td>
</tr>
<tr>
<td>Ch 60 kHz</td>
<td>22nF</td>
<td>330uH</td>
<td>59.1 kHz</td>
</tr>
</tbody>
</table>

The resonance frequency of the filter is strictly linked to the spread of these components and an excessive spread can produce an excessive attenuation on the received signal. The accuracy of L7 and C36 has to be great.

For the same reason the Q factor has a relevant part in the design of the Rx filter. Some application can use more than one communication channel at the same time, in this case the best choice is to have a resonance frequency at a mean values of used frequencies and a Q factor not too high.

Figure 19. Measured filtering characteristic of the demo board at the RAI pin in receive mode.

Some receiving circuit interfaces, for example with a 2:1 signal transformer, can have a gain greater than 0dB (unit gain). In this case, if the band in use function level of the ST7538 is used, it is necessary an attenuation of the received signal (for example with a resistors divider) to have the same level of the signal present on the mains to be compliant with Cenelec specifications.

2.2.3 Voltage Regulation-Current protection loops
A power line networks requires an appropriate driving circuits able to adapt the output signal characteristic to the different and low values of the mains impedance.

Figure 20. Power Line Output Characteristics.
Figure 20 shows the characteristic of a coupling circuit. The characteristic has a range with constant voltage amplitude of the transmitted signal. When the line impedance has reached a critical $Z_0$ value, corresponding to the maximum power, the amplitude of the output signal is decreased in order to have a constant current.

The value of $Z_0$ depends mainly by the network impedance, while the maximum value of $V_0$ depends by the normative (EN50065-1) and by the maximum current capability of the power line interface.

The ST7538 integrates a control voltage / current protection circuit. It is possible to program the values of $Z_0$ and $V_0$ with external resistors. $R_{13}$ trimmer sets the current protection limit and $R_{14}$ and $R_{12}$ trimmer the peak voltage level. The dimension of these external components influences the design of the coupling interfaces and of the power management, too. For example all the components in series to the signal (transformer, filter inductors, decoupling capacitors, fuses) have to guarantee a maximum current or a saturation current greater than the maximum current programmed with $R_{13}$, as well the dimension of the current capability of the power supply and the capacitors on the supply line have to be choose according to the programmed current values.

The control loop circuit inside the devices is realized by a Voltage Controlled Amplifier (VCA) with a logic circuits that implement the following control (figure 22): the current protection has the priority respect to the voltage loop regulation, so if it is detected an output current greater than the programmed value ($I_{ref} > I_H$) the digital control acts on the VCA to reduces the output signal voltage. When the current reaches the programmed value the gain of the VCA is frozen.

In case of no current protection condition ($I_{ref} < I_L$), the voltage regulation loop assumes the control and modifies the gain of the VCA until the output signal reaches the programmed values.

The VCA changes its gain at steps of about 1dB (10%). The logic samples the current and voltages values with and internal clock of 5Hz, so the transmitted signal is updated every 200usec at step of 1 dB.

**Figure 21. Voltage Regulation and Current Protection Components.**
The value of the transmitted signal is programmed using the resistors divider $R_{12}/R_{14}$ (the capacitor $C_{17}$ has a decoupling function for the DC value on the VSENSE pin).

The regulations loop changes the VCA amplifier gain until the sinusoidal signal on the VSENSE pin reaches the values of $V_{CL\,TH}$ (see datasheet values) with a tolerance of about $\pm 10\%$ ($V_{CL\,HYST}$ hysteresis value).

The following simplified formula calculates the resistors divider ratio.

$$VR_{PK} \approx \frac{R_{14} + R_{12}}{R_{14}} \cdot (V_{CL\,TH} \pm V_{CL\,HIST})$$

For a more precise rate in the formula has to be considered also the input impedance of the VSENSE pin (~36 Kohm), and the decoupling capacitor $C_{17}$ (for values of some nano farad this capacitor can be neglected).

**Figure 22. Voltage regulation/current protection loop logic.**

In the demo board it is possible to link the feedback signal (top of $R_{12}$ resistor) to ATOP1 or to ATOP2 pin through the jumper J36. The choice of the feedback connection point depends on the network coupling circuit topology.

If it is present a big noise coming from the mains that perturbs the voltage control loop a possible solution is to connect the feedback to ATO pin. In this case the output signal has an half value respect to the ATOP pins, so the $R_{12}$ resistor has a half value (or $R_{14}$ resistor has to be doubled)

In the demo board it is possible to change the output signal voltage level acting on the $R_{12}$ trimmer. The following table gives the values of the trimmer to assume some standard output values.
Table 2. Voltage Regulation Loop (divider and R12 resistors values).

<table>
<thead>
<tr>
<th>Vout (Vrms) (1)</th>
<th>Vout (dBuV)</th>
<th>(R_{14}+R_{12})/R_{14}</th>
<th>R_{12} (Kohm) (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.150</td>
<td>103.5</td>
<td>1.1</td>
<td>0.1</td>
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<tr>
<td>0.250</td>
<td>108.0</td>
<td>1.9</td>
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<td>0.350</td>
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<td>2.7</td>
<td>1.7</td>
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<td>2.6</td>
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<tr>
<td>0.625</td>
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<td>3.6</td>
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<td>0.750</td>
<td>117.5</td>
<td>5.8</td>
<td>4.7</td>
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<tr>
<td>0.875</td>
<td>118.8</td>
<td>6.6</td>
<td>5.4</td>
</tr>
<tr>
<td>1.000</td>
<td>120.0</td>
<td>7.6</td>
<td>6.4</td>
</tr>
<tr>
<td>1.250</td>
<td>121.9</td>
<td>9.5</td>
<td>8.3</td>
</tr>
<tr>
<td>1.500</td>
<td>123.5</td>
<td>10.8</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Note: 1. The regulated Vout voltage is the point linked to the voltage feedback divider (top of R_{12}).
2. The rate of R_{14} takes in account the input resistance on the VSENSE pin (36 Kohm).

The resistor connected to the CL pin (the trimmer R_{13} in the demo board) has the function to programs the current protection threshold. The capacitor C_{37} in parallel to the resistor has a filtering function for noise and spikes.

On the CL pin is present a mirrored current (ratio 1:5000) of the p channel power Mos of the power line interface of the device (both ATOP1 and ATOP2). So the voltage on the CL pin will be proportional to the output current and to the resistor connected to the pin.

The peak value of this voltage is compared with an internal reference of the device: if the signal overcomes the threshold the loop acts on the VCA reducing the transmitted signal and therefore the output current.

The resistor value determinates of the output signal that the interface is able to supply. In conjunction with the programmed output voltage V_0 the maximum current level fixes the minimum value of driving impedances (Z_0).

Figure 23. Current Protection Loop Characteristic.

The graphics above gives the value of the CL resistor to program the maximum current value.

In the next figure are showed all the main signal of the control loop feedback, i.e. output signal, load current, VSENSE voltage and CL voltage.
2.3 Board Power Management

The demo board has a main supply with a flyback converter using the monolithic switching regulator L6590. The regulator can have both a 220V or an 110V supply voltage of the mains.

It is possible to use an external power supply connected to CN2, too. In this case the jumpers J4 and J5 has to be removed and the connector CN3 has to be used instead of the standards socket CN1.

The correct supply of the board is evidenced by the green led D5. It is possible to turn off this led removing the J1 jumper.

The 5V internal regulator of the ST7538 (VDC pin) supplies the microcontroller ST7, the ST232 interface device and the led (D9, D10, D11, D12). Using the jumper connections J8 (ST7), J9 (leds) and J10 (ST232) it is possible to monitor the current of these components or remove the supply to these demo-board parts.

The 5V supply is available also on the pin #1 of the CN6 connector.

A typical power consumption of the power line application (switched regulator excluded) is about 18mA in receiving mode 120 mA in transmitting mode without load. Every led ON increases the current consumption of 4 mA.

The current consumption of the RS232 interface is about 12mA. It means that the overall current consumption of the microcontroller plus the ST7538 in receiving mode is about 6 mA.

The current consumption depends also on the clock frequency selected. There is a variation of 5mA from a 4MHz clock to a 16MHz clock.
2.3.1 L6590 Regulator

The flyback converter configuration using the L6590 regulator has a specific topology that realizes the feedback on a willing of the primary side of the flyback transformer. With this configuration it is possible to save the cost of an optocoupler. The drawback of this solution is the wide load range of the regulated voltage. In a condition of low current consumption (20mA) the value of the supply voltage is about 12V, in transmission the value is about 10.5V.

The maximum power of this configuration is about 3 Watt. The dimension of the maximum power consumption of the regulators is related to the current limit of the power line interface programmed with the R13 resistor on the CL pin.

If an external power supply is used it has to verify carefully that also in a continuous transmission condition the supply is able to supplies the requested current.

Another aspect that has to be consider with attention in a continuous transmission condition is the overheat condition of the devices with the thermal protection activation (transmission aborted and signal TOUT high).

In the demo board it is used a socket for the ST7538, therefore the slug of the package can't be sold to a dissipating surface as recommended. For this reason, in presence of a heavy load during a continuous transmission, it is easier to reach the thermal protection threshold.

A critical point common to all the switching solutions, especially for this kind of application, is the electromagnetic noise and the conducted disturbance generated. In particular the mean noise frequencies are due to the switching frequency and to the resonance of the leakage inductance with the drain capacitance.

Figure 25. Power supply EMC disturbances filter circuit.

In the demo board these critical values are at 20KHz or 66KHz (switching frequencies respectively with low and high load condition) and at about 800KHz for the resonance.

It is important that the resonance of the input filter is at a frequency far from the communication bands used, otherwise its low impedance attenuate the communication signals.

For the demo board the resonance frequency is from 10KHz to 20KHz.

The 15 ohm resistor R1 has the double function to protect the input stage of the supply from surge or burst and at the same time it is necessary to make the application board compliant with the EN50065-7 standard.

Another consideration regards the frequencies noise generated by the supply. Even if the noise generated is compliant with the normative mask limit, its mandatory to choose a value of switching frequency (and its first harmonics) far from the communication channel frequency. In fact the modem is able to demodulate very low amplitude signals (500uVrms). Noise, also with a low amplitude value, can degrade the communication.

This consideration is valid only in a receiving condition, during the transmission a little noise at the same frequency of the transmitted signal (2Vrms) can be neglected.
The working frequencies of the L6590 are 20KHz with a low value current (receiving condition), and 66KHz with high current, i.e. in a transmission condition (220 AC MAINS).

In the transmission case the 2\textsuperscript{nd} harmonic at 133KHz (communication channel 132.5KHz) has an irrelevant influence.

The value of the supply voltage is related to the amplitude of the output signal (see ST7538 datasheet), so usually a voltage of at lest 10V is mandatory to avoid distortion problems. The same voltage value doesn't occur in a receiving status. In case of strong constraints regarding the power consumption it is possible to use two different power supply values. For example possible values are 10.5V during the transmission, and 7.5V in the receiving status. This can be done easily changing the feedback resistor divider of the regulator using a switch controlled by the RxTx signal (pin #4) of the ST7538.

For more detailed information about the L6590 and other possible configuration please refer to the product datasheet and related application notes.

2.3.2 ST7538 Power Supply

A fundamental aspect of the board design is the configuration of the ST7538 supply system.

It is recommended to connect all the grounds of the device to a common ground place, connected to the copper plate of the slug.

During the transmission high current (up to 0.3A\textsubscript{rms} = 0.85A\textsubscript{pp}) at the signal frequencies are present over the main supply and the ground plate. In case of ground or supply paths with a "high" resistance (also 2m ohm should be critical) the high current could produce a ripple at the second harmonic of the signal frequency that should be coupled onto the mains:

\[
0.85\text{A}_{pp} \cdot 0.002\Omega = 1.7mV_{pp} = 56dB\mu V
\]

As the rate above shows, the noise contribute has a relevant value respect to the Cenelec mask.

Figure 26. Noise generation in resistive supply or ground path
Concerning the odd harmonics generally they are produced by high current (high load) and are generated by saturations problems of external components or of the power section of the device.

Another origin of the odd harmonics with high amplitude of the voltage output signal should be a low power supply value on PAVCC pin.

A critical aspect of the device power supply is the high peak current request at the start-up phase of the transmission. The peak value requested from the supply from the low impedance present at the ATOP pins can reaches 2A. For this reason its mandatory to use storage capacitor (C_{38}) with a value of at least 10uF and an ESR as low as possible. For example a tantalum capacitor or a smoothing ceramic capacitor (TDK C series) could be used.

The linear low drop voltage regulator of the ST7538 supplies all the low voltage parts of the demo board, including the digital and analog (pin DVDD and AVDD) parts of the device itself. On the regulator output VDC (pin #33) a low ESR 10uH capacitor (C_{14}) is recommended.

In some conditions a noise present on the analog supply AVDD (pin #28) can be transferred to the internal modulation and demodulation blocks. To avoid this situation should be useful to filter this supply pin adding an inductor (L_8) in series to the capacitor (C_{16}) or using a specific EMC component (for example a TDK chip beads series MMZ1602C).

### 2.4 Crystal Oscillator

The ST7538 includes a driver circuit to realize a 16MHz crystal oscillator. The solution implemented it is realized with a MOS amplifier working in a sub threshold condition. This choice allows to have very low current consumption that decrease strongly the overall power consumption of the device and of the communication node.

The circuit is able to drive a maximum load capacitance of 16pF, with a typical quartz ESR of 40 ohm. The stop resistor technique has evidenced an ESR limit of 400 ohm. The worst case-condition is reached at low temperature.

**Figure 27. Crystal oscillator schematic circuit.**

Due to the specific topology used it isn’t possible to add an additional load (for example a probe with 10pF) on the Xin and XOut pins. For the same reason its strongly recommended to use the indicated values for the resonant capacitors, that are fixed value of 18pF for C_{19} and a value from 36pF to 82pF for C_{18}. A lower value of C_{18} produces a higher start up reserve (it is possible to use a quartz with a higher value of ESR), a higher value gives a better performance respect to the burst and surge noise.
Regarding other aspects as the layout topology, noise immunity or wet problems all the standard consideration on the crystal oscillator circuits are valid. It is very important to keep the quartz and the load capacitors as close as possible to the device. A ground plate around the quartz is recommended to realize a good connection of the load capacitors.

The resonant circuit with the quartz has to be placed far from noise sources, as for example the switching power supply, the burst and surge protections, the coupling circuits to the mains.

In presence of high radio disturbances (example a GSM Antenna close to the application) it is mandatory to connect the case of the crystal to ground.

If the application requires stronger or special constrains respect to oscillator and it is possible to provide an external clock with the requested characteristics at the XOOut pin. Probably in this case the global power consumption of the application will increase in a relevant way.

### 2.5 Burst & Surge Protections

The environments encompassed by this application include residential, commercial and light-industrial location, both indoor and outdoor. For this reason a series of immunity specification standard and test have to be applied to the power line application to simulate the environmental phenomenon.

The requirements include EN61000-4-2, EN61000-4-3, EN61000-4-4, EN61000-4-5, EN61000-4-6, EN61000-4-8, EN61000-4-11 and ENV50204. All these tests are listed in the EN50065-2-1 document (part 7, immunity specifications).

These standards include surge tests, both common and differential mode (1kV/0.5kV, Tr=1.2u sec) and fast transient burst tests (2kV, Tr=5n sec, Th=50n sec, repetition frequency 5KHz).

The specific structure of the coupling interfaces circuit of the application is a weak point respect to the high voltage tests. In fact an efficient coupling circuit with low insertion losses realizes consequently a very low impedances path from the mains to the power circuit of the devices that can destroy the internal power circuits of the ST7538.

For this reason is recommended to add some specific protection on the path that links the ATOP pins to the mains.

**Figure 28. Common mode and differential mode spikes example.**

In the demo board has been implemented a solution that uses three transil diodes (P6KE6V8A or SM6T6V8A) connected in a star configuration. A bi-directional transil was not used because for common mode surge it is better to realize a discharge path to ground external to the devices.

In receiving mode the ATOP2 pin polarizes the coupling interface to ground. In this condition without the diode D17 all the external signals greater than 1.4 Volt peak to peak will be clamped by D15 and D16.
In some condition the transil diodes shouldn’t be reliable in presence of fast transient bursts. In this case it is possible to add some fast response ESD diodes as ESDA6V1L (two components) connected in parallel to the transil with the same star configuration.

The solution used for the demo board can give some general guidelines but can’t be generalized to all types of power line communication applications.

Considerations about surge and burst protections depend from several factors as coupling interfaces, the board layout or the characteristics of the components used. Every application needs his specific analysis. For some general considerations or a protection components list refer to the annexed application notes and documentation.

2.6 ST7 Microcontroller & RS232 Interface

To complete an application for the power line communication its necessary to have a microprocessor to manage the upper layer of the communication protocol and eventually to elaborate other signal relatives to the application (signal from sensors, current measures, driving actuators, and so on). According specific application different types of microcontroller can be required.

Some application constrains, as for example real time measure or as communication protocols with heavy CRC algorithmic, can require a lot of microprocessor resources. Sometimes in this situation it is possible to simplify the “work” of the microprocessor using glue logic to realize a frame recognizer (see next paragraph).

The demo board has a ST72C334J2 or ST72C334J4 microprocessor. This component is connected to the ST232 driver interface and to the ST7538.

The loaded firmware has the function to receiver from the PC program interface (through the standard RS232 serial port) some commands to manage the control register writing and reading procedures, the transmitting and receiving functions of the modem. The results of the executed command come back to the PC program interface and are displayed on the monitor.

Figure 29. Microcontroller/RS232 interface
The ST7 microprocessor controls also the led diodes D9, D10, D11, D12. The D9 (red) is turned on during a transmission condition; the green led D12 is turned on when the receiving mode is activated. The D10 yellow diode is switched on when the Band in Use signal is active. The D11 led (red) is on when a Timeout event occurs. To save power consumption the led are turned off removing the jumper J9.

It is possible to customize the ST7 firmware. At the connector CN6 are available some of the I/O digital pins or Analog input pins of the microprocessor, that can be used to monitor some external signal or sensors and to drive relays or other external devices.

The connector CN7 is used for ST7 memory in-situ programming. For a correct programming procedure the ST7538 has to be supplied, it is suggested to use an external 10V supply from connector CN2. The jumper J11 has to be opened.

If an emulator is linked to the board it is recommended to program a 4 MHz clock in the ST7538 internal register.

For more accurate and complete information on the features, characteristics and issues concerning ST microprocessor please refer to the attached documentation or to the reference documents or go to the site www.stmcu.com.

2.6.1 Modem / microcontroller interface

The interface signals between modem ST7538 and the ST2C334 microcontroller can be divided in three categories: the control signals, the communications signals and the auxiliary signals.

In the first group there are the clock signal (MCLK/OSCIN) the reset signal (RSTO/RESET) and the watchdog signal (WD/PD3).

The clock signal of the microcontroller is provided by the ST7538 from the MCLK pin. The default is 4Mhz but it is possible to increase this value (8Mhz or 16 MHz) programming the ST7538 control register.

The reset of the microcontroller is provided by the modem. To the reset line is also connected to the manual reset (C22, R15 and SW1) and to the reset pin of the CN7 connector for the In-Situ Programming mode procedures.

The watchdog signal has to be managed from the microcontroller (PD3 output port). If the ST7538 doesn't detect any activity on the WD pin it generates a reset signal on the RSTO pin. It is possible to disable this function through the modem control register.

The second group of signals consists of the links necessary for the modem/Micro Controller Unit communication. There are the data signals RXD (from the modem to the MCU) and TXD (from MCU to the modem), the transmitting/receiving status selection signal (RX/TX), the internal ST7538 register control access signal REG/DATA, and the recovery clock signal CLRT.

To the communication wires and to the RESET are also linked the ISP (In Situ Programming mode) signals coming from the CN7 connector. Remember to open the jumper J11 during the programming phase. The simplest interfacing mode is the synchronous mode. In this case it is possible to use the SPI interface of the MCU: The PC5/MOSI (Slave In Data) is connected to the RXD pin, the PC4/MISO pin (Slave Out Data) is connected to the TXD pin and the PC6/SCKI (SPI serial clock) pin is connected to the CLRT pin. The SPI Slave select (PC7/SS) is controlled by the MCU itself through the PB0 I/O port.

The CLRT signal is connected to the PB1 I/O pin too.

It is also possible to realize an asynchronous interfacing mode, and for this reason the pin RXD is also connected to the PC3/ICAP1_B pin (timer B input capture).

In this modality of communication the CLRT signal isn't considered and the recovered clock has to be rebuilt internally by the MCU. If the ST7538 control register has to be changed from the default configuration, the first access has to be done at baud rate of 2400.

The idle state of the RXD output is the low state, so with some asynchronous interface could be necessary to invert externally this signal.

On the TXD connection line was inserted a diode (D13) and a pull down resistor R16. With these compo-
nents it is possible to transmit a frame coming from an external devices (for example a BER tester). It is sufficient to configure the modem in a transmitting status and the MCU has to keep low the PC4 pin. The external signal can be applied at the diode cathode.

Figure 30. ST7538/microcontroller interface.

The third group of signal consists of a series of auxiliary signal coming from the ST7538 linked to some standard input of the microcontroller.

The CD/PD and BU signals give information about a carrier (or preamble detection) condition and about the BU condition (according the EN50065-1).

If the zero crossing comparator is used, the ZCOUT signal gives a digital signal synchronized with the mains phase.

The PG, TOUT and REG_OK signals are monitor signals. The PG signal indicates the correct supply level of the internal 5V regulator of the ST7538 (VDC). If the modem regulator supplies the microcontroller or its reset is connected to the RSTO pin it is recommended to monitor this signal. In fact when the PG signal goes down during a shutdown procedure the microcontroller can try to stop correctly the running activities (for example a memory writing) before the UVLO threshold is reached and all the application is resetted, or before the regulator isn’t able to supply correctly the micro. When a PG down is detected the transmission is disabled to avoid uncontrolled access to the mains. In any case a correct shut down procedure has to be complete to perform a correct reset of the application.

The TOUT signal is active when a transmission procedure is aborted, both for a time out event both for a overheat condition.

The REG_OK signal shows a corruption of the internal modem register. Pay attention that the REG_OK function doesn’t check uncontrolled control register write procedure, due for example to a voltage spikes on the REGDATA and RX/TX pins.
### 2.7 Demo Board Components List

#### Table 3. Power Supply Sections

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<th>Item</th>
<th>N</th>
<th>Name</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>CN1</td>
<td>HEADER 2</td>
</tr>
<tr>
<td>2</td>
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<td>CN2</td>
<td>HEADER 2</td>
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(*) Values for 132.5KHz communication channel
## Table 5. ST7/RS232 Section.

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3. DEMO BOARD CHARACTERIZATION

This chapter includes a series of tests and measurements to characterize the demo board. The characterization concerns the most critical aspects required by European standard, those are:

1) Electro conducted disturbances;
2) Immunity to narrow band conducted noise;
3) Output impedance measure.

The results of these measures have evidenced a good match and a very close value to the measured realized according the EN50065-1, EN50065-2-1 and EN50065-7 setup and procedures.

3.1 Conducted Disturbance

The EN50065-1 standard describes test setup and procedures for this kind of tests.

The measures have been done with 220V~ and 110V~ mains voltages. The test pattern consists of a continuous transmission of a fix tone (symbol “0”) or a repetition of random bytes.

The output signal has a peak value of 118dBuV (output CISPR-16 measure of the not modulated signal) that means a 1.6Vrms of signal on the mains.

The spectrum analyzer performs a peak measure instead of a quasi-peak measure. For continuous sinusoidal signals the two types of measures give the same result.

Figure 31. Conducted disturbance set-up.
Figure 32. Output signal spectrum, channel 132.5kHz, mains 220V~, fix tone.

Figure 33. Output signal spectrum, channel 132.5kHz, mains 220V~, random sequence.

Figure 34. Output signal spectrum, channel 132.5kHz, mains 110V~, random sequence.
3.2 Narrow-band Conducted Interference

The setup of the narrow band conducted interference test consists of a first transmitting demo board controlled by a BER (Bit Error Rate) tester that generates a random bit stream. The second board demodulates the received signal that is evaluated by the linked BER tester.

The noise is produced by a waveform generator and injected into the artificial network by a coupling circuit connected to a low distortion power amplifier (EN50065-2-1, 7.2.3).

Two types of signal noises have been used for the test: a pure sinusoidal signal and an amplitude-modulated signal, (modulating signal 1kHz, modulation deep 80%).

The amplitude of the noise signal is decreased until the BER measured is lower than $10^{-3}$ (one error every 1000 transmitted bits).

The noise measure is done disconnecting the signal source and the coupling circuits from the artificial network.

---

**Figure 35. Output signal spectrum, channel 110kHz, mains 220V~, random sequence.**

**Figure 36. Narrow Band conducted interferences set-up.**
Here following different measures are included with a transmitted signal of 79dBuV measured at the CISPR-16 output (minus 6dB versus mains). It is also present a measure of the 110KHz channel (signal level 85dBuV) even if receiving filter of the board is tuned on the 132.5KHz channel. The power amplifier used represents a limit for the measure respect to the maximum noise Voltage level. In fact for the noise tones far from the channel frequency the BER obtained is zero and the power amplifier isn't able to produce a higher sinusoidal noise.

Figure 37. Signal/noise ratio for the 132.5kHz channel, signal level 85 dBuV.

Figure 38. Signal/noise ratio for the 132.5kHz channel, signal level 85 dBuV, mains 110V~.

Figure 39. Signal/noise ratio for the 110kHz channel, signal level 91 dBuV.
3.3 Output Impedance

The last characterization report regards the output impedances of the application. In order to not degrade the communication network it is mandatory to guarantee a minimum value of the output impedance of each component of the system, both in receiving or transmitting condition. In this last case impedance constrains regard only the frequency ranges of the other communication bands.

Figure 40. Output board impedance measurement set-up.

![Diagram](image)

The reference standard is the EN50065-7. To simplify the measure the supply of the board is obtained by a low 10V external power supply and the impedance meter has been connected directly to the mains connector. In the following plots is drawing also the normative mask for the home appliance band (95kHz - 148.5kHz).

Figure 41. Output demo board impedances (CN1) in receiving condition.

![Graph](image)

Figure 42. Output demo board impedances (CN1) in transmitting condition.

![Graph](image)
4. DESIGN IDEAS FOR AUXILIARY BLOCKS

4.1 Zero Crossing Detector

It is possible to synchronize the beginning of the transmission with the mains voltage (phase 0). To realize this function the zero crossing comparator has to be used and a reduced reproduction of the mains frequency (with the same phase) has to be present on the ZCin pin (#16). The maximum voltage of this pin is ±5V.

In case of a not isolated application the circuit consist of a simple resistor divider. For an isolated system a possible solution could be a main transformer. This solution is more expensive and is suggested only if a mains transformed is just used in the application for other purpose too.

It is possible to realize another isolated solution using for example an optocoupler component too.

In both cases a bi-directional transil has to protect the pin from the burst and surge and a capacitor have to be added to filter high frequency noise.

Figure 43. Zero crossing coupling circuit, not isolated solutions.

![Zero crossing coupling circuit, not isolated solutions.](image1)

Figure 44. Zero crossing coupling circuit, isolated solutions.

![Zero crossing coupling circuit, isolated solutions.](image2)
4.2 Frame Recognizer

The electrical network is characterized by a big noise that can produce a lot of false carrier detection and preamble detection, too. In this condition the microprocessor has to manage many not real receiving data request. In same cases, for example with complex network protocols or with real time application, isn't possible to dedicated so many resources of the processor to the receiving activity due to false messages.

This kind of problem should be solved using a simple external logic made with an 8 bits shift register with output latches (M74HC595) and an 8 bits comparator (M74HC688) that realizes a hardware frame detector.

Figure 45. Hardware frame recognizer schematic.

The received bit stream from the RXD pin enters in the serial input of the shift register. An 8 bit sequences (or longer if more components are connected in series) is compared with a determinate bit configuration. In case of matching between the received stream and the fixed one a pulse is produced by the comparator.

Figure 46. Frame recognizer waveforms.

A rising edge of a pulse on the PA3 pin generates a interrupt request to start the receiving procedure. The first data bit of the received frame will be available on the next rising edge of the CLR/T signal.

The reference bit configuration can be part or the full header of a message (if the register has more bit a part of the address can be included, too), and in this case the interrupt for the microcontroller is generated only in presence of a real message. In fact the probability that the noise simulate a header sequence is very low respect to a false carrier detection or preamble recognizing.

The compared sequence of bits can be obtained directly by the microprocessor outputs or by a hardware solution using some jumpers (or both).
5. ANNEX A - DOCUMENTATION

5.1 ST7538
ST7538 Datasheet
Demo board user Manual
EHS Booklet

5.2 L6590 Integrated Power Supply
L6590 Datasheet
Application note AN1261
Application note AN1262
Application note AN1523

5.3 ST7 Microprocessor
ST72 series Datasheet

5.4 Surge & Burst Protections
Protection Guide
Application note AN317
Application note AN576

6. REFERENCES
[2] CENELEC, European Committee for Electrotechnical Standardization - EN 50065-1, Signaling on low-voltage electrical installations in the frequency range 3kHz to 148,5Khz. Part 1: General requirements, frequency bands and electromagnetic disturbances - July 2001;
[3] CENELEC, European Committee for Electrotechnical Standardization - EN 50065-4-2, Signaling on low-voltage electrical installations in the frequency range 3kHz to 148,5Khz. Part 4-2: Low voltage de-coupling filters- Safety requirements - August 2001;
[4] CENELEC, European Committee for Electrotechnical Standardization - EN 50065-7, Signaling on low-voltage electrical installations in the frequency range 3kHz to 148,5Khz. Part 7: Equipment impedance - November 2001;
[5] CENELEC, European Committee for Electrotechnical Standardization - prEN 50065-2-1, Signaling on low-voltage electrical installations in the frequency range 3kHz to 148,5Khz. Part 2-1:Immunity requirements for mains Communications Equipment and systems operating in the range of frequencies 95 kHz to 148,5 kHz and intended for use in Residential, Commercial and Light Industrial Environments - 1999;
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