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Power Line Communication (PLC)

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Abstract

Powerline distribution networks are available nearly in each building, mainly used for electrical power supply. Using the same infrastructure as transmission media in transmitting data is very interesting task. The ever-increasing demand of low cost telecommunication, broadband and access to internet services has applied a driven force leading to further research in the field of power line communication. More advance schemes are being proposed day by day to use with PLC (power line communication) so that a new dimension could be added to the potential application of established wire line infrastructure.

Powerline communication is a technology that uses medium and low voltage electrical network to provide communication services. Communication over powerline has a history of about hundred years old. In early days communication was started using very low frequencies. Today, due to increasing demand of networking in home, offices, buildings, industrial organizations etc, the power lines are considered as a medium for high speed data(>2Mbps) transmission. PLC Broadband technology is capable of transmitting data via the electrical supply network, and therefore can extend an existing local area network or share an existing Internet connection through electric plugs with the installation of specific units.

In addition to the high frequency data transmission, one of the popular applications of PLC is Home automation. As no new wires needed it is inexpensive and easy to apply. Although this might seem a perfect system, it faces some serious problems which will be discussed here.

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1 General Description of PLC System

1.1 Introduction

Power-line communication (also known as power-line carrier or PLC) carries data on a conductor that is also used simultaneously for AC electric power transmission or electric power distribution to consumers.

A wide range of power-line communication technologies are needed for different applications, ranging from home automation to Internet access which is often called broadband over power lines (BPL). Most PLC technologies limit themselves to one type of wires (such as premises wiring within a single building), but some can cross between two levels (for example, both the distribution network and premises wiring). Typically, transformers prevent propagating the signal, which requires multiple technologies to form very large networks. Various data rates and frequencies are used in different situations.

A number of difficult technical problems are common between wireless and power-line communication, notably those of spread spectrum radio signals operating in a crowded environment. Radio interference, for example, has long been a concern of amateur radio groups.

PLC is a technology which has been in use since years but came now in more demand after the launch of new communication technologies which are being supported by PLC i.e. PLC would be a reliable communication medium for applications like Internet-of-things (IoT) and Smart Grids. Building automation is now a day very widespread in all the industrialized countries, meaning with the term the application of automation and information technologies for the management of buildings like schools, hospitals, public edifices, private houses and so on. A younger sister of building automation is domotics, which is actually the application of the same techniques and tools in a domestic scenario, instead of a very big building. In this application domain, the cost, still very high, is the most important limit to the diffusion of these systems. Moreover, the lack in standardization and uniformity of communication protocols for home automation systems (i.e. Konnex–EIB®, MyHome BTicino®, Lonworks®, to mention a few) is often a trouble for technicians required to design and install such plants, especially when the plant has to be installed in a pre-existing building whose electrical cabling is not prearranged to support that level of automation. In this case the solution proposed by the application of power line communication links (such as the U.S. X10 protocol) could be very interesting.

1.2 WHAT IS POWER LINE COMMUNICATION?

The method of transferring power and data for communication through the same existing network of wires from one end to the other end is said as Power Line Communication. It provides broadband data communications on conductors which are already in use for the transmission of electric power using a modular signal. Now, this can be done through the home or premises wiring and may also be done through the existing electric power distribution system.

BPL (Broadband over Power Line) is also known as power-line Internet which supports PLC technology to allow Internet access through the transmission lines. The BPL technology with PLC is often used in remote locations where there is low amount of Internet access by cable or PDSL connections.

Power line communication (PLC) systems utilize existing electrical power systems as a communication medium to enable data transmission over power lines, whereas the main task of the power lines is the delivery of AC (at 50 or 60 Hz frequency) or DC electric power from energy generation plants to the users/customers. The main superiority of the PLC systems is evident that these systems can save new channel establishment cost because of the fact that power lines are in use all over the world. Therefore, in last two decades, PLC systems have attracted much interest in the field of communication and smart grid (SG) systems, and in several application areas such as home automation, in-vehicle communication, automatic meter reading (AMR) and demand response and so forth.

Although the PLC systems have become more popular in the last two decades, the idea behind of the PLC dates back to the 1800s. The first PLC applications were related to remote meter reading and remote load management, and the first two patents of PLC regarding these applications were available in 1898 and 1901. Various applications related to measurement, control and protection via power lines have been appeared after the patents, and researchers have been widely focused on the applications over medium voltage (MV) and high-voltage (HV) power lines. One of the most popular applications was ripple control that was a load management system for protecting and distribution of loads. A ripple control system (RCS) was enabled one-way communication with low data rates. It operated between 125 Hz and 3 kHz frequencies for passing signals over distribution transformers. The most important disadvantage of the RCS was its high power requirement. For instance, a few megawatts may be needed for data transmission. A number of important developments have been made for RCSs until the 1950s. The employed modulation schemes in these advanced systems were amplitude shift keying (ASK) and frequency shift keying (FSK). According to utilizing digital modulation schemes, not only the high power requirements for data transmission was eliminated, but also higher data rates have been obtained. Afterwards, at the beginning of the 1980s, several studies were carried out to realize bidirectional PLC systems that were based on PLC systems developed for automation and AMR applications. In 1984, Enermet Melko was introduced as a bidirectional data transmission system that served between frequencies of 3.025 and 4.825 kHz with phase shift keying (PSK) modulation scheme. In 1990, Echelon introduced local operation networks (LonWorks) system that was a networking platform. In addition, LonWorks was built on a special protocol to meet control application requirements. The frequency bands defined by International Telecommunication Union (ITU) and the utilization of these bands in the PLC applications are illustrated in the Fig. 1.1. The frequency bands are defined as super low (SLF), ultra-low (ULF), very low (VLF), low (LF), medium (MF), high (HF), very high (VHF), ultra-high (UHF), super high (SHF), extremely high (EHF) and tremendously high frequency (THF), respectively.

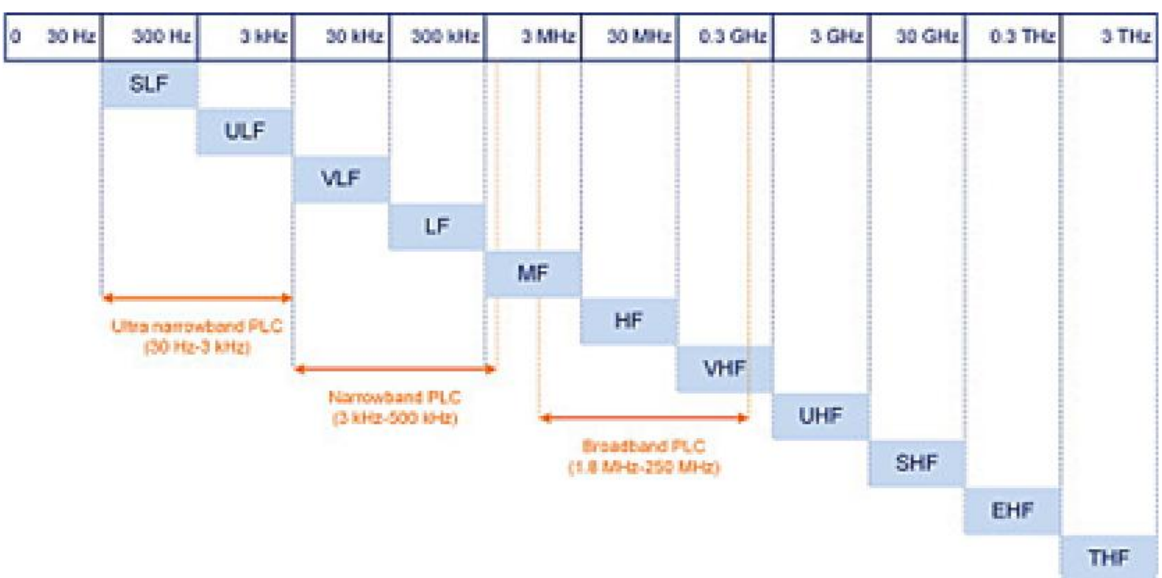


Figure 1.1

1.3 Types of Power Line Communication (PLC)

Basically, there are four types of PLC:

- In-house networking: High-speed data transmission can be provided for home networking using the In-House mains power wiring.

- Broadband over Power Line: Broadband internet access can be offered through the outdoor mains power wiring.

- Narrowband in-house applications: Low bit rate data services like home automation and intercoms can be controlled and used for communication through the In-house power mains.

- Narrowband outdoor applications: Narrowband outdoor applications can be used for automatic meter reading and remote surveillance or control.

1.4 How Does PLC Work?

Like any other communication technology PLC also consists of a sender who modulates the data that is to be sent through a communication medium, and then the receiver will demodulate the data for further use. Apart from sending the signals for communication, PLC also allows the user to control and monitor all the connected devices to the power line because it is implemented in the same wiring system.

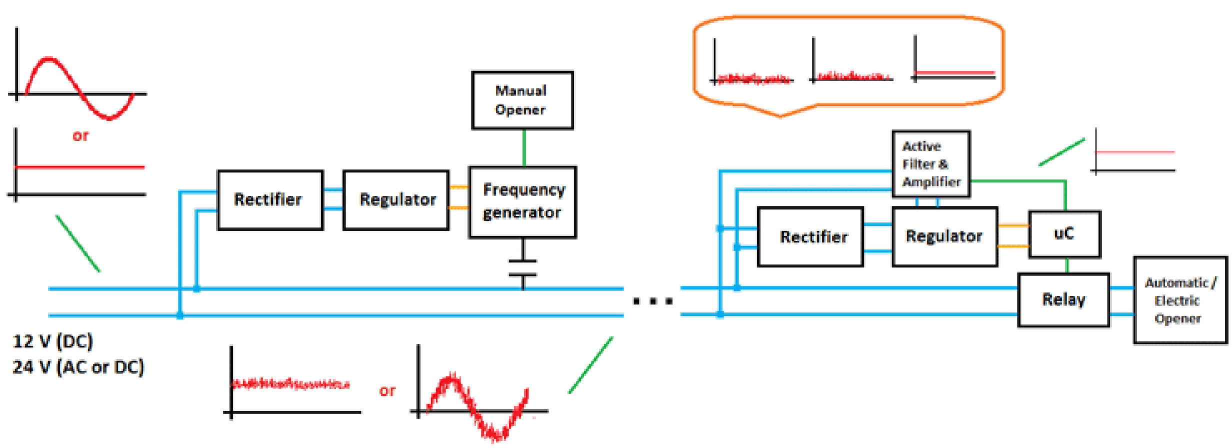


Figure 1.2

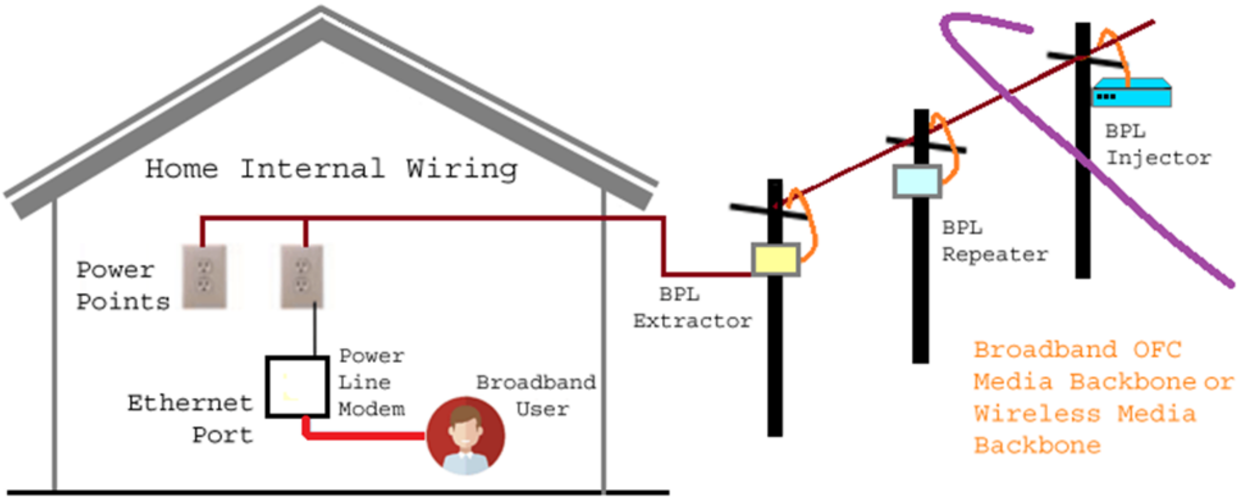


Figure 1.3

PLC sends a less fluctuating output compared to the old system. As you can see the diagram above, in the old system which had a rectifier and frequency generator for getting as stable as possible output of desired frequency but there was a small fluctuation in the output whereas the PLC system uses a Rectifier with a Filter & a Microcontroller which provides a stable & desired value output with the help of relay switch. As a result, the transmission of data is more accurate & more stable with good output signals.

1.5 Modulation Schemes Used in PLC.

The modulation schemes used in PLC are Orthogonal Frequency Division Multiplexing (OFDM), Binary Phase Shift Keying (BPSK), Frequency Shift Keying (FSK), Spread-FSK (S-FSK), Amplitude Shift Keying (ASK) and proprietary schemes too (like the Differential Code Shift Keying (DCSK)).

OFDM provides high data rates but requires good computational horsepower for Fast Fourier Transforms (FFT) and Inverse-FFT (IFFT) output. While, on the other hand, BPSK, FSK are quite standard and simple modulation schemes that can be used in PLC but they offer low data rates. So, the currently running modulation scheme for PLC is OFDM with PSK modulation that can handle such a heavy computation.

1.6 Uses of PLC

The PLC is used for transmitting radio programs, utility company control switching mechanisms, transmission line protection, and automatic meter reading. Apart from that, there are also some automotive uses where the data, voice, and music are sent over direct current (DC) battery power line with some special filters to remove the line noise from the final output.

The term Power Line Communication (PLC) is known with a various name like as power line carrier, power-line digital subscriber line (PDSL), power line telecom (PLT), power line networking (PLN), mains communication, and broadband over power lines (BPL).

1.7 Advantages and Disadvantages of PLC

Although PLC has been around for some time is still ben used for some reasons but the most important on is the low construction cost as it require no installation of new wires instead it uses the already existing wiring. And another major advantage is the ability to communicate with hard-to-reach nodes where RF wireless signal suffers from high levels of attenuation like in the underground structures or the buildings with obstructions and metal walls, or simply wherever the wireless signal is undesirable due to the EMI issues in places like hospitals.

as every communication system it has some serious disadvantages some of them can be reduced and some will still have significant effects. As mentioned earlier that the wiring system constructed for AC power transmission is not suitable for high rates of transmission. Therefore, the I has low transmission speed. And of course another result of the unsuitable wiring the signal suffers from attenuation. The longer the distance the higher the attenuation. And it is hard to resolve this problem as it mainly depend on the wiring. Also as a lot other appliances are connected to the power line, the signal is disturbed easily. Also the distortion caused by the medium is non-linear so it is hard to equalize it. The signals transmitted through the line suffers from Cross-modulation between channels. And of course in any system the cost is a major parameter. In the case of power line communication, the most of the cost goes into large size capacitors and inductors used or in general the high power components.

1.8 Why Power Line Communications?

Considering that data transmission over power lines has been around for some time, one might wonder why it is receiving such renewed attention now? Especially considering, the data rate for protection and telemetering purposes is at most a few kb/sec and is not comparable to the mb/sec data that needs to be sup- ported for multimedia applications. The answer is a combination of effects that took place during the mid-thru late 1990s. The most prominent one is, of course, the unparalleled growth of the Internet. This growth was fueled with the technological advancements of very large scale integration (VLSI) and digital signal processing (DSP). The final piece was the telecommunications market deregulation, first in the US and then in Europe and Asia. All these events have made power line communications a viable technology for high speed home networking as well as being a possible solution for the "last mile" problem.

The market for power line communications (PLC) is two-fold: to the home, or "last mile" access; and in the home, or "last inch" access. According to the study, "Jumping on the Broadband Wagon" (a Morgan Stanley Dean Witter industry report in April, 2000) power line communications could be better than the other last-inch access technologies such as cable, wireless and HomePNA.

Phone-line networking most commonly referred to as HomePNA is based on the specifications developed by Home Phone Networking Alliance. It is ubiquitous—multiple sockets in each room provide considerable and dispersed capacity—and no new wiring is necessary. The development of the "last inch" by Home-networking companies in the form wireless network adapters and power-line adapters is gradually leading to widespread home networking; i.e., a wide array of devices connected inside the home in an intra-home network. This "in-home networking" could transform all power outlets in the household into broadband connections for PCs, telephones and their accessories, as well as other 'enabled' electric appliances. Fig 1.4 illustrates the concept of "last mile", while Fig 1.5 illustrates the concept of "last inch" or in-home networking.

For the “last mile” access, power line communication is one of the several possible technologies that include cable modem, and different types of Digital subscriber lines (xDSL) and broad- band wireless. PLC is not widely thought to be superior to other technologies, nor are the other technologies without problems or clearly superior to PLC in all respects.

The major attraction of PLC is that the power lines often already exist. Hence, they would be the preferred medium for providing broadband connection to rural or remote areas where telephone and cable connections may not exist. However, it suffers from a number of problems.

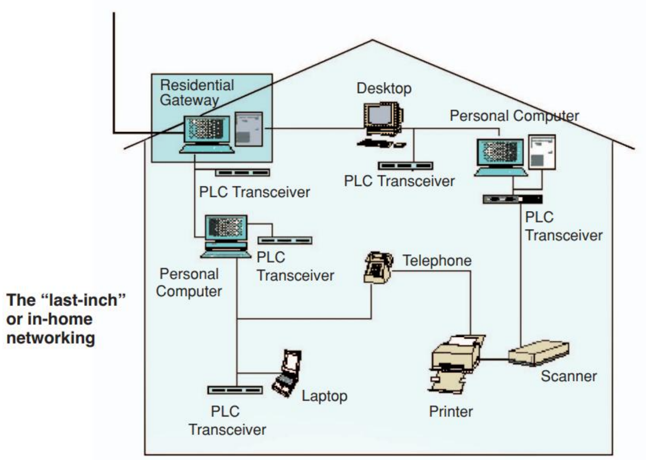


Figure 1.5 last inch networking

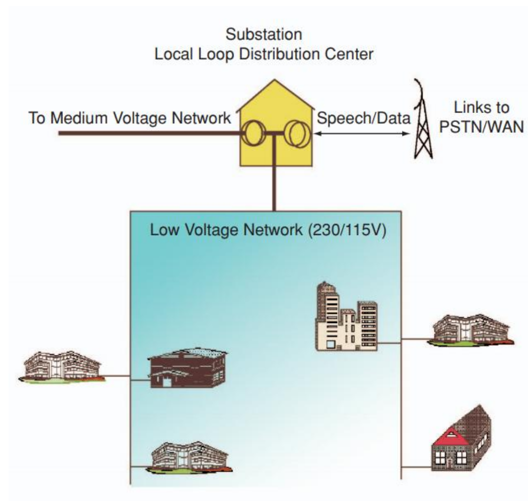


Figure 1.4 the last mile concept

2 Power line Channel Characteristics

2.1 Introduction

In this chapter, we discuss the main characteristics of PLC channel to understand how they affect end user performance.

A power line is a very harsh channel in terms of noise and attenuation. Noise consists of unwanted external signals in the medium. It is often characterized by its power spectral density (PSD), which is the magnitude squared of the Fourier transform of a signal. Attenuation is the reduction of the amplitude of the original signal at the receiver and is usually measured in decibels (dB). Compared to the wireless medium, the power line has diverse types of noise that cannot be modeled as Gaussian, which is the typical wireless noise distribution. Moreover, it exhibits multipath effects and high-frequency selectivity

2.2 Channel Characteristics

PLC signals are transmitted via electrical wires between outlets. Hence they “share” the channel with multiple electrical appliances and grid components (such as circuit breakers and distribution lines) that create a harsh environment for communications. We explain the main components of the channel, that is, attenuation and noise, which affect both the spatial (across different outlets) and temporal (for a certain pair of outlets, over time) variations of PLC capacity. Consider an example of a simple electrical network with a transmitter (TX) and a receiver (RX), as given in Figure 2.1. The main sources of attenuation and noise are the electrical appliances plugged in. Modeled with dashed boxes in Figure 2.1, each connected appliance has an impedance and produces a noise process that is non-Gaussian and that depends on the device type.

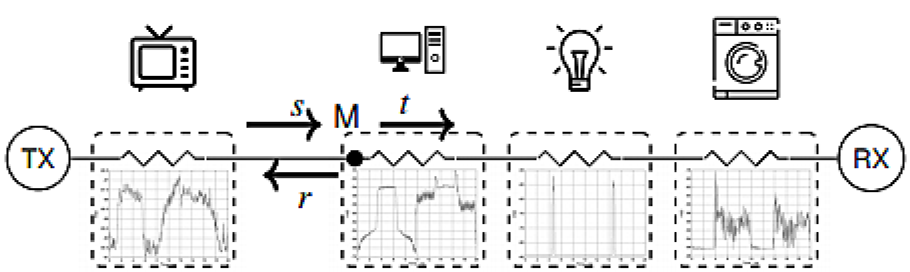


Figure 2.1

2.2.1 Attenuation and Frequency Selectivity

With respect to communications, the electrical cable becomes a transmission line with a characteristic impedance. The connection of appliances creates impedance mismatches to this transmission line, causing the transmitted signal to be reflected multiple times. The signal reflection amplitudes at impedance mismatches depend on the type and working mode of the appliances, that is, on/off and idle/active. For example, in Fig 2.1, at point M, we have an impedance mismatch, and any signals arriving at M is partly reflected (signal r) and partly propagates (signal t) in the same direction as the original signal s. Reflections of signals at various impedance-mismatched points result in multiple versions of the initially transmitted signal arriving at different times at the receiver, thus establishing a multipath channel for PLC.

Attenuation is determined by the distance between TX and RX due to cable losses and by the reflections of the signal. The delay spread – that is, the delay difference between the arrival of strong reflections at the receiver – of the PLC channel is typically in the order of 1–2 µs, with a few exceptions over 5 µs. The physical layer of PLC is designed to mitigate this delay spread and these multipath effects. Multipath effects cause intersymbol interference and frequency selectivity. They induce more severe attenuation than potential losses due to long cable lengths.

Frequency selectivity may cause the signal to experience different, uncorrelated attenuation levels based on frequency. The spatial variation of PLC channel is mainly dictated by the position, the impedance, and the number of appliances connected to the electrical grid, rather than by the cable length between the stations – although the number of appliances and the cable length can be correlated. Since the aggregate electrical activity in residential or enterprise environments varies during the day, the channel transfer function and attenuation change at large timescales (order of minutes or hours). Hence temporal variation of the PLC channel is caused by the electrical activity, that is, the appliances' impedances, on long-term timescales, whereas it is caused mainly by noise on short-term timescales. Meaning that the network topology changes with plugging in or switching off of devices connected to the network.

The level of attenuation depends on the number of reflection points, also called branches. It has been found that links of distance up to 100–200 m and with up to four branches mostly exhibit typical attenuation values starting from a few decibels at 500 kHz and reaching 40–70 dB at 20 MHz frequency. Longer links (>300 m) exhibit 10–30 dB at 500 kHz and might exceed 80 dB at frequencies of 5–8 MHz (which corresponds to the noise floor).

It has been observed from channel measurements that at higher frequencies the channel attenuation increases. Hence, the channel may be described as random and time varying with a frequency dependent signal to noise ratio (SNR) over the transmission bandwidth. Fig 2.2 depicts a generalized channel model for the power line physical layer. In Fig 2.3, the generalized channel model has been simulated between the frequency ranges 200 KHz to 22 Mhz. The channel exhibits a high level of attenuation with an increasing frequency.

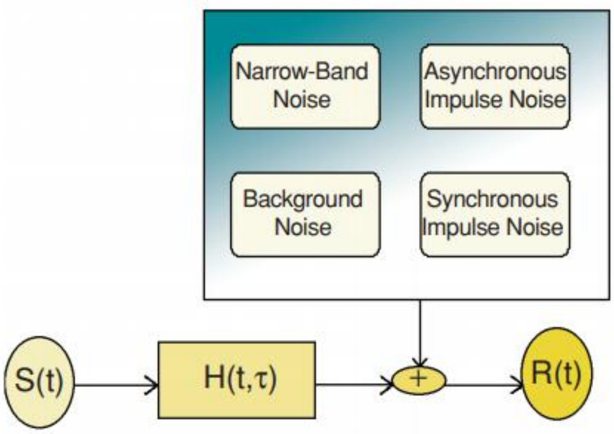


Figure 2.3 channel model

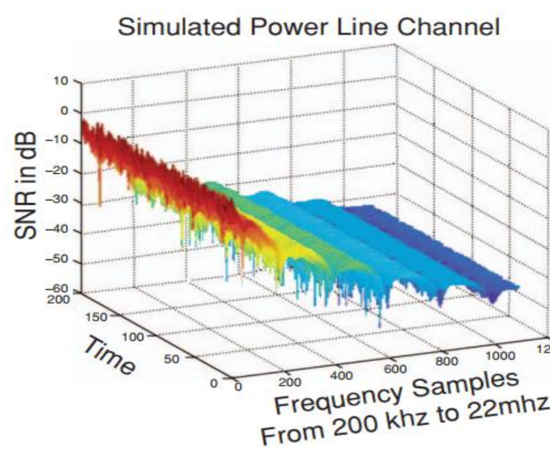


Figure 2.2 Simulated Power line channel

2.2.2 Types of Noise

Noise in power lines is a significant problem for data transmission. This is because it rarely has properties similar to the easily analyzed white Gaussian noise of the receiver front ends. Typical sources of noise are brush motors, fluorescent and halogen lamps, switching power supplies and dimmer switches. The noise in power lines can be impulsive or frequency selective in nature and, sometimes both.

Several studies on the noise characteristics of power lines have been conducted. Recent papers have discussed not only the type of noise encountered but, also, the distribution of duration, amplitude and inter-arrival time of impulse noise encountered in power lines. According to them, the noise in power lines can be classified into three categories:

Colored background noise is due to different low-power noise sources present in the network and is usually characterized with a power spectral density decreasing with frequency. This noise can be modeled by a colored Gaussian power spectral density.

Narrowband interferences are caused by radio broadcasters and are usually sinusoidal signals with modulated amplitudes (due to radio modulations).

Impulsive noise is caused by electrical appliances: they create synchronous or asynchronous noise to AC mains and aperiodic noise when switched on/off. It is further distinguished into three classes that we describe next. Usually, the impulses in PLC channels are modeled with damped sine waves. Impulsive noise has high variability and is the most severe and intricate type of noise, because each noise source (electrical appliance) exhibits unique characteristics, from both time and frequency perspectives. In detail, the three classes of impulsive noises are as follows.

Periodic, synchronous to the mains noise is a cyclostationary noise, synchronous with the mains and with a frequency of 50/60 Hz (depending on the country). It is often generated by rectifier diodes used in electrical appliances.

Periodic, asynchronous This is the most detrimental type of noise for data trans- mission. Its duration varies from a few microseconds to milliseconds and has a random inter-arrival time. The PSD of such impulse noise may be as much as 50dB above the background noise spectrum. Hence, it is capable of wiping out blocks of data symbols during high data transmission at certain frequencies. It is caused from switching transients in the system network.

Aperiodic noise is caused by people switching electrical appliances on and off and plugging them in. The short-term variation of the channel is due to noise. Two timescales describing this variation, called invariance and cycle scales. An invariance scale is defined at a level of subintervals of the mains cycle and is associated with the noise synchronous to mains, whereas the cycle scale represents different mains cycles and is caused by noise asynchronous to mains. PLC modulation and coding are tailored to the noise variation within or across the mains cycle. The root mean square (rms) amplitudes of the colored background noise and narrowband interference vary slowly over time, and they can be classified as background noise.

2.2.3 PLC: A Broadcast Medium

PLC devices connected to the same distribution board form a broadcast network, where almost all stations can overhear each other's transmissions. To understand the reasons for such good connectivity, consider the power distribution network: it forms a star topology where power flows from the board to any circuit breaker, and then to power outlets. From a circuit breaker to the wall outlets, the wiring has a tree topology. Any cable can form a communication "antenna." Hence any signal from an outlet could potentially reach any other outlet connected to the same board. PLC usually forms almost a fully connected network on a single distribution board. In addition, we find that connectivity between devices connected to different distribution boards within the same building is also possible. Such links suffer from severe attenuation due to long cable length and additional impedance introduced by board components. The extremely good connectivity and the star like topology of PLC result in the tragedy of the commons. Similarly, to Wi-Fi, which is also a broadcast medium, PLC stations cannot transmit simultaneously. Collision detection (detection of interference during transmission) is currently not supported in PLC due to near-far effects – where the self-interference of the device drowns out weaker interfering signals – and to the lack of appropriate interference cancellation techniques. Hence collision avoidance protocols are needed in the presence of multiple transmissions.

3 PLC System

3.1 Communicating at The PLC Physical Layer

Modulation techniques such as frequency shift keying (FSK), code-division multiple access (CDMA) and orthogonal frequency division multiplexing (OFDM) have been discussed as appropriate modulation schemes for PLC. For low cost, low data rate applications, such as power line protection and telemetering, FSK is seen as a good solution. For data rates up to 1Mbps, the CDMA technique may provide an effective solution. However, for high data applications beyond that, OFDM is the technology of choice for PLC.

Frequency selective fading as experienced by the power line channel severely impairs the capacity of FSK for data rates beyond a few kilobytes per second. A high degree of error control coding would be needed. Combined with the low spectral efficiency of FSK, it would limit the data rate achieved.

For CDMA, the signal of each user is spread using a spreading code at the transmitter. It is recovered at the receiver by de-spreading using the same code. CDMA provides robustness against narrowband noise and other forms of interference. Therefore, it seems to be an attractive candidate for PLC. However, in CDMA systems, the processing gain needs to be high to effectively counter narrowband noise and interference from other users. With low processing gain, the robustness against interference and noise is lost and the signal quality may deteriorate to unacceptable levels for all users. The processing gain (PG) of a CDMA system may be expressed as:

$$P_G = \frac{B_t}{B_d} \qquad (1)$$

Where, B_t denotes the transmission bandwidth and B_d denotes the data bandwidth. It is quite evident that for high data rates and for a reasonably high P_G, the transmission bandwidth B_t would have to be very high. Unfortunately, this is where the problem lies. The fissured spectrum for transmission—due to frequency selective fading—does not provide large contiguous bands for data transmission. Hence, the main advantage of CDMA cannot be fully exploited for PLC.

Since the symbol time is inversely proportional to the data rate, as the data rate increases the symbol duration correspondingly decreases. While trans- mitting over the power line channel at high data rates, the symbol duration is so small that delayed versions of one symbol—due to multi-paths—gets smeared over a large number of other symbols. This makes the detection process complicated since it requires complex equalization techniques to counter the inter-symbol interference (ISI). Despite equalization at the receiver, the bit error rate may still be unacceptably high for high data rates over harsh channels with multi-paths.

In the case of OFDM modulation, the serial data of a traffic channel is passed through a serial-to-parallel converter. It splits the data into a number of parallel channels. The data in each channel is applied to a modulator, such that for N channels there are N modulators whose carrier frequencies are f0, f1, …., fN-1. These N carriers are referred to as sub-carriers in the literature. This is because they split the work of a single carrier amongst themselves. This scheme offers various advantages.

With OFDM, since the data is split among N sub-carriers, each sub-carrier carries 1/Nth of the original data rate. This means that the symbol duration for each sub-carrier increases N times. Moreover, a part of the end of a symbol is appended at its beginning in what forms the "cyclic prefix." The length of the cyclic prefix is made longer than the longest delay path. This solves the inter-symbol interference (ISI) problem to a large extent. As a result, a simple linear equalizer may be enough to remove the ISI.

Another significant advantage of OFDM, while transmitting over a frequency selective fading channel, is that is allows us to adopt adaptive schemes so we can avoid transmitting at frequencies in deep fade. Sub-carriers in which the signal to noise ratio (SNR) drops below a certain threshold are switched off. Sub-carriers with high SNR are made to carry more bits; i.e., they are modulated to a higher-level constellation. This is known as a bit loading technique and is illustrated in Fig. 3.1. The application of OFDM with bit loading for a wired channel such as the power line is widely known as Discrete Multi-tone (DMT).

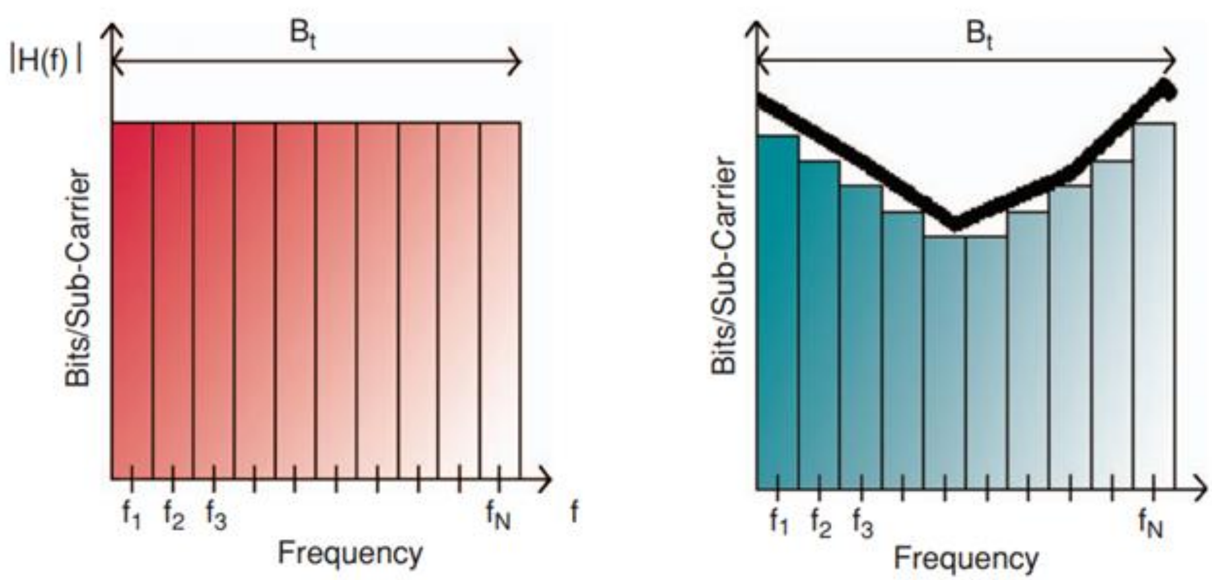


Figure 3.1

Channel estimation is necessary for the bit loading technique to work. The transmitter has to know the noise variance and the attenuation being experienced by each sub-carrier. DMT transceivers use pilot signals for channel estimation. For time varying channels such as the PLC, the pilot signal is repeated periodically for dynamic channel estimation. In general, bit loading algorithms may be classified as margin- adaptive or rate-adaptive algorithms.

In margin-adaptive algorithms, the objective is to minimize the bit error rate while keeping the data transmission rate constant. For rate-adaptive algorithms, the data rate is maximized while maintaining a constant error rate. In PLC standards, rate-adaptive algorithms have been adopted. This is because the power line channel can be too harsh at times to guarantee a constant data rate that the margin-adaptive algorithms required.

Channel coding plays an important role for maintaining a constant error rate. The input bit stream is encoded using Reed-Solomon coding followed by interleaving and trellis coded modulation. The complete functional block diagram of the DMT transceiver as implemented on the power line physical layer is shown in Fig 3.2.

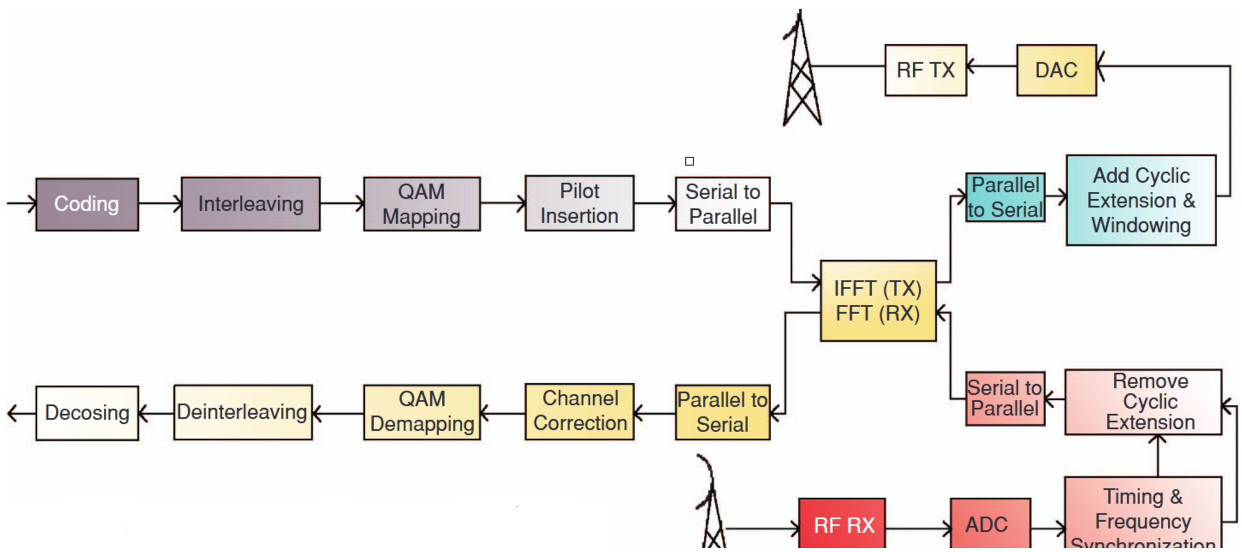


Figure 3.2 DMT transceiver

3.2 The PLC Medium Access Control (MAC) Layer

A MAC protocol specifies a resource sharing strategy: the access of multiple users to the network transmission capacity based on a fixed resource sharing protocol. Generally, there are two categories of access schemes:

- Fixed access
- Dynamic access

Transmissions using fixed access schemes assign to each user a predetermined or fixed channel capacity irrespective of whether the user needs to transmit data at that time. Such schemes are not suitable for bursty traffic such as data transmission that is provided by PLC. Hence, dynamic access is provided for power line communication. Dynamic access protocols may be classified into two separate categories:

- Contention based protocols: collisions occur.
- Arbitration protocols: collision free.

Contention protocols may not be able to guarantee a quality of service (QOS), especially for time critical applications, since collisions might occur and data might have to be retransmit- ted. Arbitration based protocols are more capable of guaranteeing a certain QOS. However, contention based protocols may actually provide higher data rates in applications which do not have stringent QOS requirements (e.g., Internet applications). This is because they require much less overhead com-pared to arbitration protocols (polling, reservation, token passing).

Polling and Aloha are the two most studied protocols for medium access. Polling is a primary/secondary access method in which the primary station asks the secondary station if it has any data to send. Aloha is a random access protocol in which a user accesses a channel as soon as it has data to send. The transmitter waits for an acknowledgement from the receiver for a random period of time. It retransmits if it does not receive one. The main disadvantage of Aloha is the low throughput as the load increases as well as the lack of QOS.

Arbitration based polling can handle heavy traffic and does provide QOS guarantees. However, polling can be inefficient under light or highly asymmetric traffic patterns or when polling lists need to be updated frequently as network terminals are added or removed. Similarly, token passing schemes (e.g., token ring, token bus) are efficient under heavy symmetric loads. However, they can be expensive to implement and serious problems can arise with lost tokens on noisy unreliable channels such as power lines.

Carrier Sense Multiple Access (CSMA) with overload detection has been proposed for PLC. CSMA is a contention based access method in which each station listens to the line before transmitting data. CSMA is efficient under light to medium traffic loads and for many low-duty-cycle bursty terminals (e.g. Internet browsing). The primary advantage of CSMA is its low implementation cost. This is due to the fact that it is the dominant technique in today's wired data networks.

Collision detection (CSMA/CD) senses the channel for a collision after trans- mitting. When it senses a collision, it waits a random amount of time before retransmitting again. CSMA/CD used in Ethernet networks does enhance the performance of CSMA. But on power lines the wide variation of the received signal and noise levels make collision detection difficult and unreliable.

An alternative to collision detection that can be easily employed in case of PLC is collision avoidance (CSMA/CA). As in the CSMA/CD method, each device listens to the signal level to determine when the channel is idle. Unlike CSMA/CD, it then waits for a random amount of time before trying to send a packet. Packet size is kept small due to the PLC's hostile channel characteristics. Though this means more over- head, overall data rate is improved since it means less retransmission. CSMA/CA is the chosen medium access protocol for the Home plug standard that has been developed for in-home networking using power lines.

3.3 Perspective, applications and standards

The PLC market is expanding dynamically. Some applications and research developments are reported in the International Symposium for Power- line Communications and its Applications (ISPLC) conferences each year. Advanced energy services include applications such as automatic meter reading, programmable controllers and demand supply management. Traditionally, this application area has been pushed by energy companies and related manufacturers. PLC networking in the home would be serving two goals: 1) providing a local home net- work with the advantages of the power line, and 2) combining access and in- home network capabilities for service and system integration. There are sever- al applications for a PLC network in the home: shared Internet, printers, files, home control, games, distributed video and remote monitoring/security.

The key asset here is “no new wires.” In the United States, the Home plug Power line Alliance was founded by Cogency, Conexant, Enikia, Intellon, Netgear, RadioShack Co., Sharp, Panasonic, Cisco systems, Motorola and Texas Instruments, together with several other participants and adopters <http://www.homeplug.org>. The Home Plug Power line Alliance is a non-profit corporation formed to pro- vide a forum for creating open specifications for high-speed home power line networking products and services.

Adopters of the Home plug 1.0 standard have developed products for in- home networking reaching data rates up to 14Mb/s. The Home plug standard uses OFDM in a burst mode as the physical layer modulation. The Home plug technology contains a combination of sophisticated forward error correction (FEC), interleaving, error detection and automatic repeat request (ARQ) to ensure that the channel appears completely reliable to the net- work layer protocols. The MAC proto- col for the Home plug standard is the CSMA/CA protocol described earlier.

The European Home System (EHS) consortium <www.ehsa.com> defines a bus and a communication protocol for communication between appliances and the central processing unit in the home. The EHS specification, EHS 1.3, covers several medium types to trans- port control data, power and information. All share the logical link control (LLC) sublayer. For the moment, the supported medium types are Power Line Carrier (230 Vac + data, 2.4 kbps, CSMA/ack, topology free) and Low Speed Twisted Pair (15 VDC, 48 kbps, CSMA/CA, topology free).

One major issue under considerable debate for the PLC local loop distribution network is the radiation emission of power lines and its effect on other frequency bands for communication. Another area of concern is security and privacy. The networking signals generated in one home may show up (albeit attenuated) on the power line in another home. This creates urgent concerns about privacy similar to those encountered in wireless systems. Right now, the Home plug standard uses Data Encryption Standard (DES) encryption technology as a solution.

4 PLC for Home and Industry Automation

4.1 Introduction

PLC The low 'media cost' for power line communication (PLC) technology renders it suitable for home and industry automation purposes. PLC uses an infrastructure already existing in every home and industrial facility, which eliminates the unnecessary expense and the difficulties of installing new wires for achieving high signal penetration. This enables a plug and play type use of PLC-enabled systems. This chapter provides a brief discussion on the use of PLC for home and industry automation and it presents an overview of the most important protocols for home automation. First the X10 narrowband PLC protocol for communication between electronic devices is introduced. Then, the KNX/EIB standard for in home and building automation bus systems is discussed.

4.2 Home and Industry Automation Using PLC

Home and industry automation is a main part of modern life that helps to control and monitor the large variety of home and industry devices such as air-condition, refrigeration or lighting systems. In addition to the functionality and comfort these systems provide, they also help to improve energy efficiency of appliances and other electrical devices. The fast development of communication technologies has spurred the integration of automation systems into cyber physical networks which enables managing these systems remotely, but on the other hand calls for improved measures to ensure security and also privacy. PLC provides a large range of communication frequencies and systems are broadly classified into two categories. Narrowband PLC is used mainly for automation in a general sense, and broadband PLC enables home networking (multimedia) applications. A large number of home and industry automation solutions based on PLC are now available. Fig 4.1 illustrates the connection of appliances, sensors and controllers via power lines in a home automation setting. Sensors like light, temperature and smoke sensors are deployed in every room of a modern home and their signals are sent through a communication interface such as Ethernet, RS232, etc. to the control unit, which is a central unit in a home automation system that records data and determines the required commands and sends them to actuator and regulators to switch appliances on and off. Appliances like air-condition units with thermostat and washing machines are also directly connected to actuators and switched off according to demand response notifications from the communication interface during peak times and cut off from the power board when unused. Central control units usually provide a friendly graphical user interface (GUI) for end users with a screen and keyboard to manage the system. The sensors, control unit(s), appliances and actuators are connected to each other via a communication channel, which in the case of PLC are the existing power lines. Only relatively few companies developed and provided power line modem chip-sets and a limited number of applications reached quantities that allowed the development of individual chip-sets.

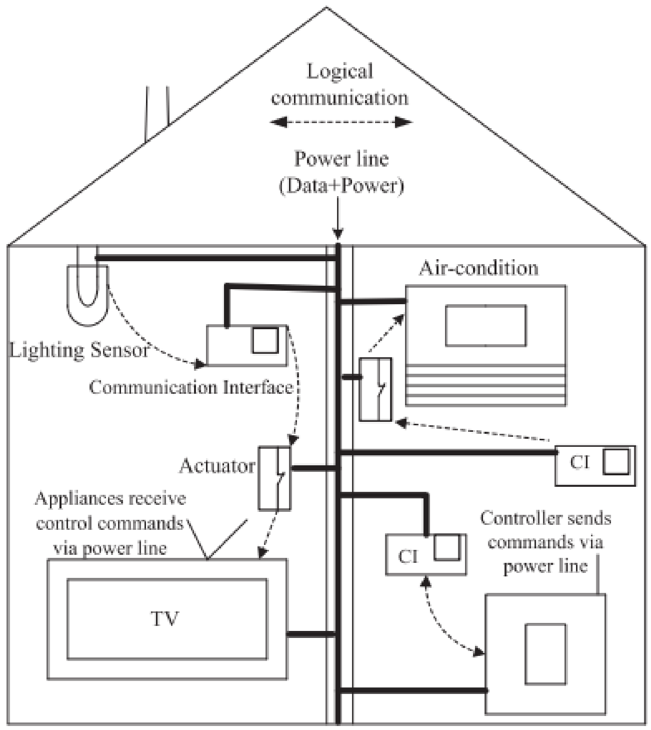


Figure 4.1

4.3 Popular Home Automation Protocols

Many popular home and building automation system protocols have been developed some time ago. In the following, we present a brief overview of some protocols.

4.3.1 X10 Protocol

X10 is a narrowband PLC protocol for communication between electronic equipment for home automation. The X10 protocol delivers signals among transmitters and receivers over the house electrical wiring. These signals are short radio frequency (RF) bursts that represent the transmitted information and control the electrical devices, such as lighting systems and audio/video equipment. X10 was developed in 1975 by Pico Electronics of Glenrothes, Scotland, and is also known as domotics network technology. It remains the most popular technology available for home automation systems because of the millions of installed units worldwide, and the low price of new units.

Table 3.1 Overview of PLC home and industrial automation standards

Protocol	Rate (bit/sec)	Frequency Band (kHz)	Modulation Scheme
X10	60	95–125	Short 120 kHz pulses
KNX	1200	110	BFSK
LONWorks	5400/3600	132/86	BPSK
ISO 10368:2006(E)	1200/134400	53.9–56.1/130–400	FSK/BPSK
AMIS CX1-Profile	600–3000	39–90	DPSK
digitalSTROM	n.a.	10–120	Current on/off switching

4.3.1.1 X10 Physical Layer Specification and Transmission

X10 transmissions are synchronized to the zero crossing point of the AC power line. The transmission bursts should be done as close to the zero crossing point as possible from negative to positive of the power signal, within 200 microseconds of the zero crossing point. Bursts are 120 kHz signals of 1 ms duration. The presence of a burst represents a ‘1’, while the absence of a burst means ‘0’. Except for the Start Code (see below) binary information is encoded into burst pairs. That means, a binary ‘1’ is transmitted as the presence of a pulse in one half cycle followed by no pulse in the next half cycle. A binary ‘0’ is transmitted as the absence of a pulse, immediately followed by the presence of a pulse. In three-phase systems, the burst is sent three times, to reach the zero crossing point of each phase. Fig 4.2 shows the timing of the X10 signals in a 60 Hz system. Timing the signal at the zero crossings simplifies the receivers, by reading only from the power line for a short time after it detected a zero crossing point. Since the system only transmits one bit per cycle of the carrier, the raw signaling bit rate of the X10 system is 60 bps. A complete code transmission includes eleven cycles of the power line. The first two cycles represent a Start Code. The next four cycles represent the House Code and the last five cycles represent either the Number Code (1 through 16) or a Function Code (On, Off, etc.).

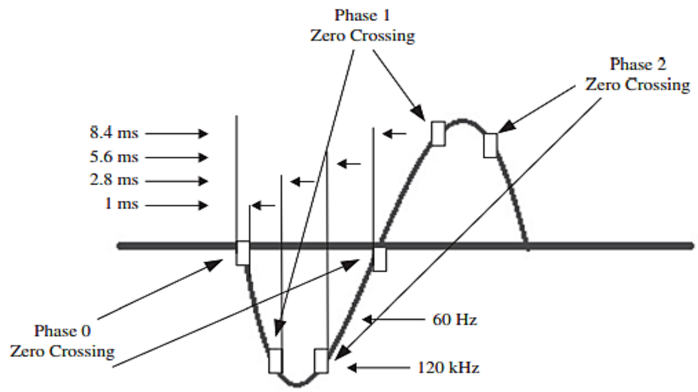


Figure 4.2

This complete block, (Start Code, House Code, Key Code) should always be transmitted in groups of 2 with 3 power line cycles between each group of 2 codes, as shown in Fig 4.3.

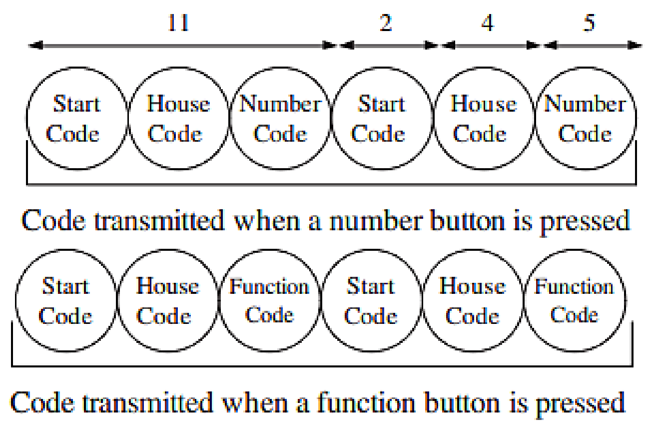


Figure 4.3 X10 coding and transmission, numbers are mains cycles

4.3.1.2 X10 Limitations

The most common problem of X10 is the large attenuation of signals between the two live conductors in the 3-wire 120/240-volt system that is used in North America because of the high impedance of the distribution transformer winding between the live conductors. This problem could be overcome by installing a capacitor between the leg wires as a path for the X10 signals. Furthermore, a bare uninsulated wire is used for the ground connection. If the sender is connected to phase 1 and the receiver is connected to phase 2, the signal would sometimes be so poor that the X10 units would react intermittently.

The X10 protocol is also slow and takes three quarters of a second to transmit an electronic device address and a command.

4.3.2 KNX/EIB PL 110 Standard

KNX/EIB is an open standard used in home and building automation bus systems. The standard is based on the Open Systems Interconnection network communication protocol of EIB but amended with the physical layers, configuration modes and application experience of BatiBUS and European Home Systems (EHS). It is optimized for low-speed control applications like lighting systems. KNX/EIB is specified over various physical media, including power line (KNX PL 110), twisted pair, radio, infrared and Ethernet, and designed to be independent of any particular hardware platform.

4.3.2.1 KNX PL 110 Physical and Data Link Layer Specification

The KNX standard provides the possibility for developers to select between several physical layers, or to combine them. The KNX PL 110 enables communication over the power lines. The main communication characteristics are spread frequency-shift keying (FSK) signaling, asynchronous transmission of data packets and half duplex bi-directional communication. It uses a center frequency of 110 kHz and the rate is 1200 bit/s, which corresponds to a bit duration of 833 µs. The frequency for transmission a logical '0' is 105.2 kHz ± 100 ppm and the frequency for transmission a logical '1' is 115.2 kHz ± 100 ppm. The transmission starts at the mains zero crossing with a maximum level of 122 dBµV according to EN 50065-1. Each telegram starts with a 4-bit training sequence and a 16-bit preamble. The training sequence enables the receivers to adjust their reception to the network conditions. The preamble field has two purposes. First, it marks the start of the transmission and second, it controls the bus access. All frame information, except training sequence and preamble, is coded into 12-bit characters which allows to correct any two bits in the transmitted character as shown in Figure 4.4. The Link Layer Protocol Data Unit (LPDU) contains the following fields as shown in Figure 4.5.

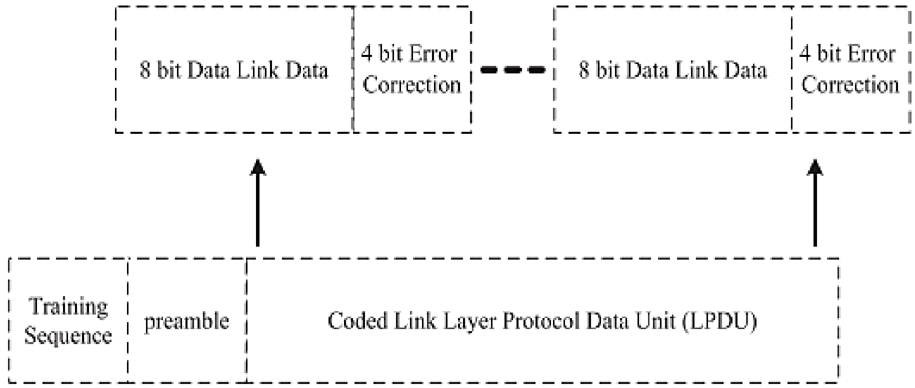


Figure 4.4 KNX telegram transmission

Figure 4.5 LPDU frame

- Control Field (CTRL): Contains information about the data link service, its priority (alarm messages, etc.), frame type (standard or extended) and whether the LPDU is a repeated one.

- Source Address (SA): The originator's unique address.

- Destination Address (DA): The unique address of destination node or the destination address of a group of nodes (multicast).

- Address Type (AT): Defines if the destination address belongs to a single node or a group of nodes.

- Network layer Protocol Control Information (NPCI): Controlled by network layer and contains the hop count information for routing.

- TPDU (Transport layer Protocol Data Unit): The payload from upper layer.

- Length (LG): Defines TPDU length.

- Check Octet (FCS): Helps ensure data consistency and reliable transmission.

The KNX PL110 protocol uses medium access control (MAC) mechanisms to avoid collisions, and an ACK/NACK telegram must be transmitted from the receiver to inform the telegram generator about the telegram delivery. The ACK telegram consists of a 20-bit training sequence and preamble, followed by a single character acknowledging or not acknowledging the received telegram, as shown in Figure 4.6. If the reply telegram is not sent, the telegram is repeated.

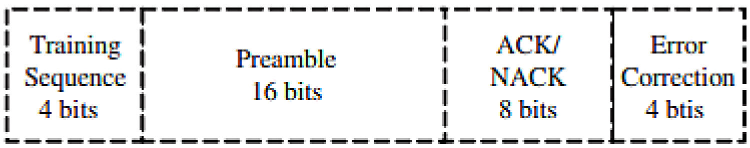


Figure 4.6 KNX reply telegram

4.3.2.2 KNX PL 110 Topology and Addressing

The logical addressing of KNX-PL 110 is compatible with the KNX-TP1 standard for twisted pair transmission media. KNX organizes devices into areas and lines, with up to 8 areas, 16 lines per area and 256 devices per line. In larger installations, band-stop filters can be used for physical separation of areas.

4.3.2.3 KNX vs. X10 KNX

system implementation is more expensive than using X10. The implementation is only worthwhile if several systems are to be connected with each other or if an installation needs to be more flexible so that it could be fast and effectively modified.

5 Simple PLC system for home automation

5.1 Introduction

In this chapter we present a simple PLC system, which introduce the practical idea of PLC home automation. It consists of transmitter to generate a 129 kHz signal and couple it to the AC line. On the other end the receiver responds to this particular frequency.

5.2 Hardware description

5.2.1 Transmitter

As it a simple introduction to the idea of PLC, the circuits used are kept as simple as possible. The transmitter circuit is shown in fig 5.1. the left most part of the circuit the power supply. It rectifies the AC signal with diode bridge and regulate it using 220 uF capacitor and a zener diode to keep the output DC voltage maximum 5.6 V. The middle part is the 129 kHz signal generator. Using a 555 timer circuit with proper capacitors and resistor values as shown in figure can generate 129kHZ signal with 50% duty cycle. On the output of the Timer a power transistor is used to amplifies the signal as the signal suffers from attenuation on the power line. The last part is an LC resonance circuit tuned on the same generated frequency and two capacitors used to couple the signal to the power line.

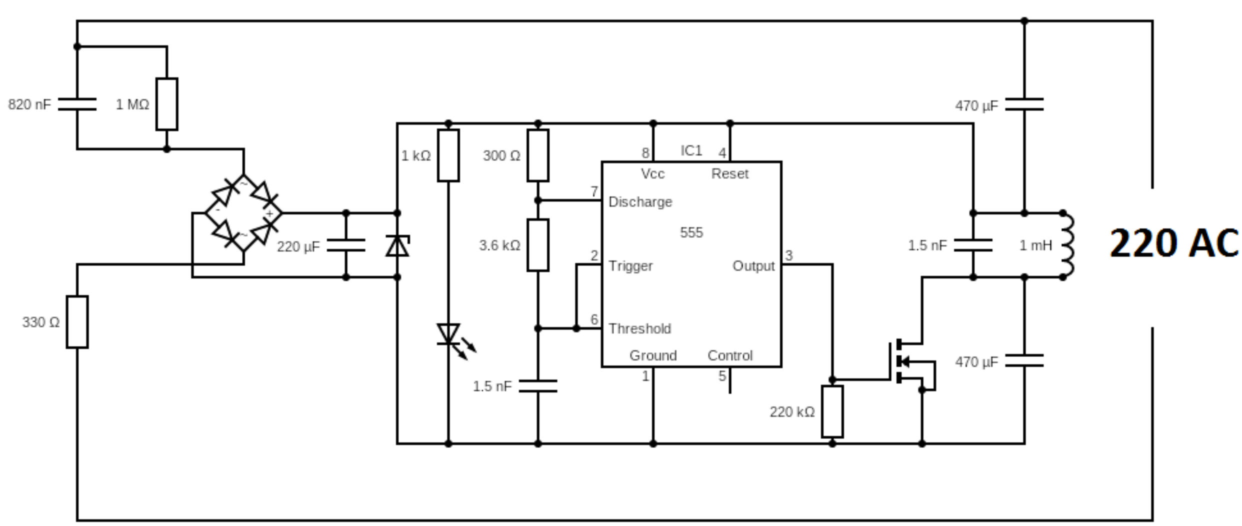


Figure 5.1 signal transmitter

5.2.2 Receiver

The receiver consists of three parts as shown is Fig 5.2. mainly as those used in the commercial products put in a much simpler way. The first part is a series LC circuit tuned on the desired frequency (the 129 KHz). The second part a tuned amplifier tuned on the same frequency. The last part is an envelope detector.

The frequency response of the receiver circuit is as shown in Fig 5.3. the signal experience maximum gain at 129 kHz, yet it allows for other near frequencies to pass with high gain too. This undesired band contributes in channels interference in case of multiple channels existed on the power line.

Figure 5.4 shows time domain simulation for the receiver.

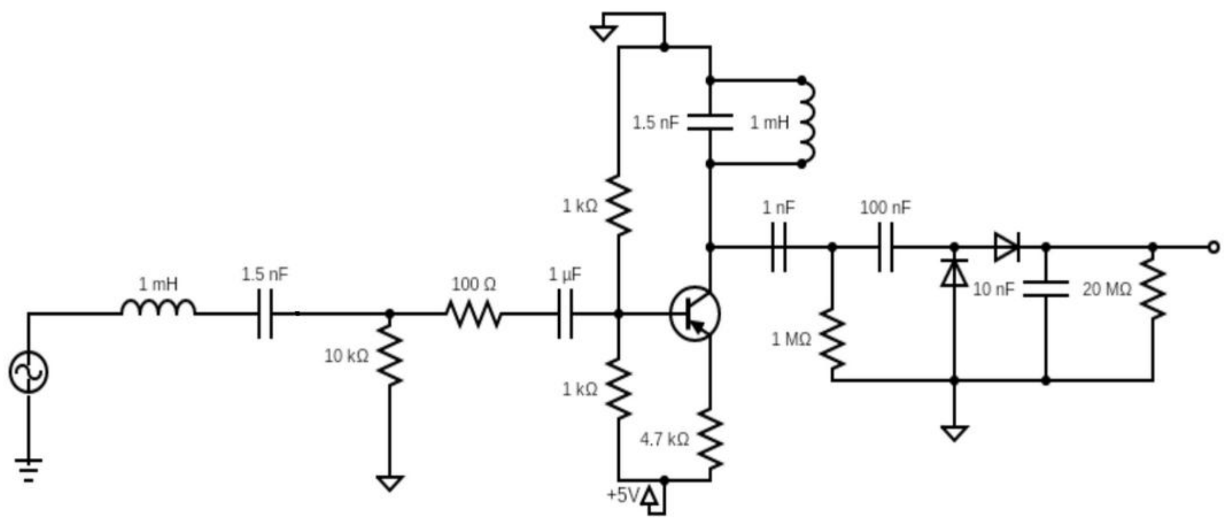


Figure 5.2 signal Receiving

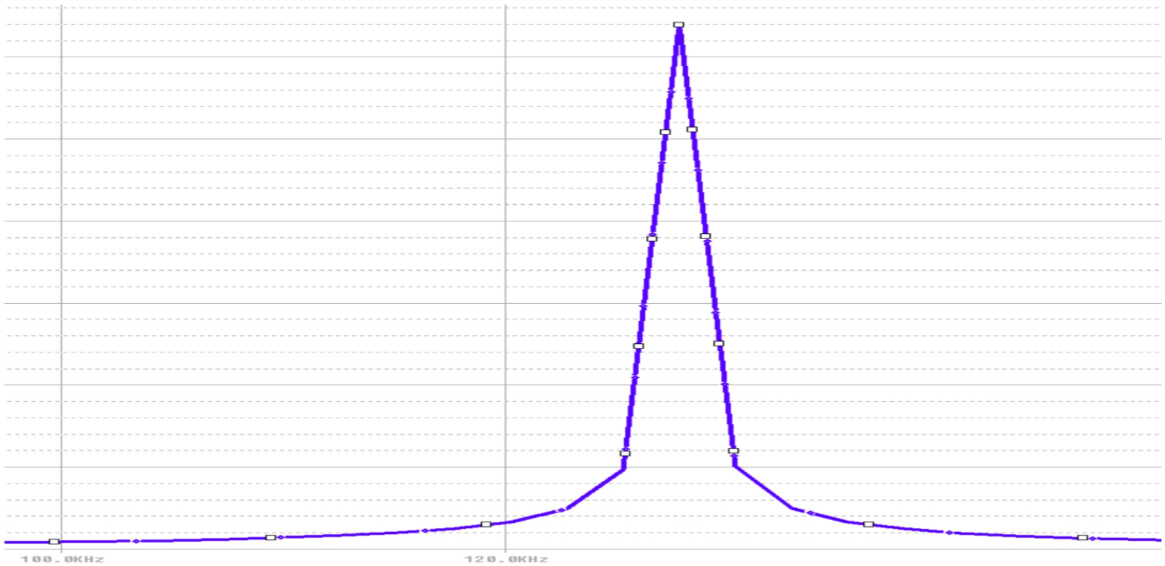


Figure 5.4 Frequency Response

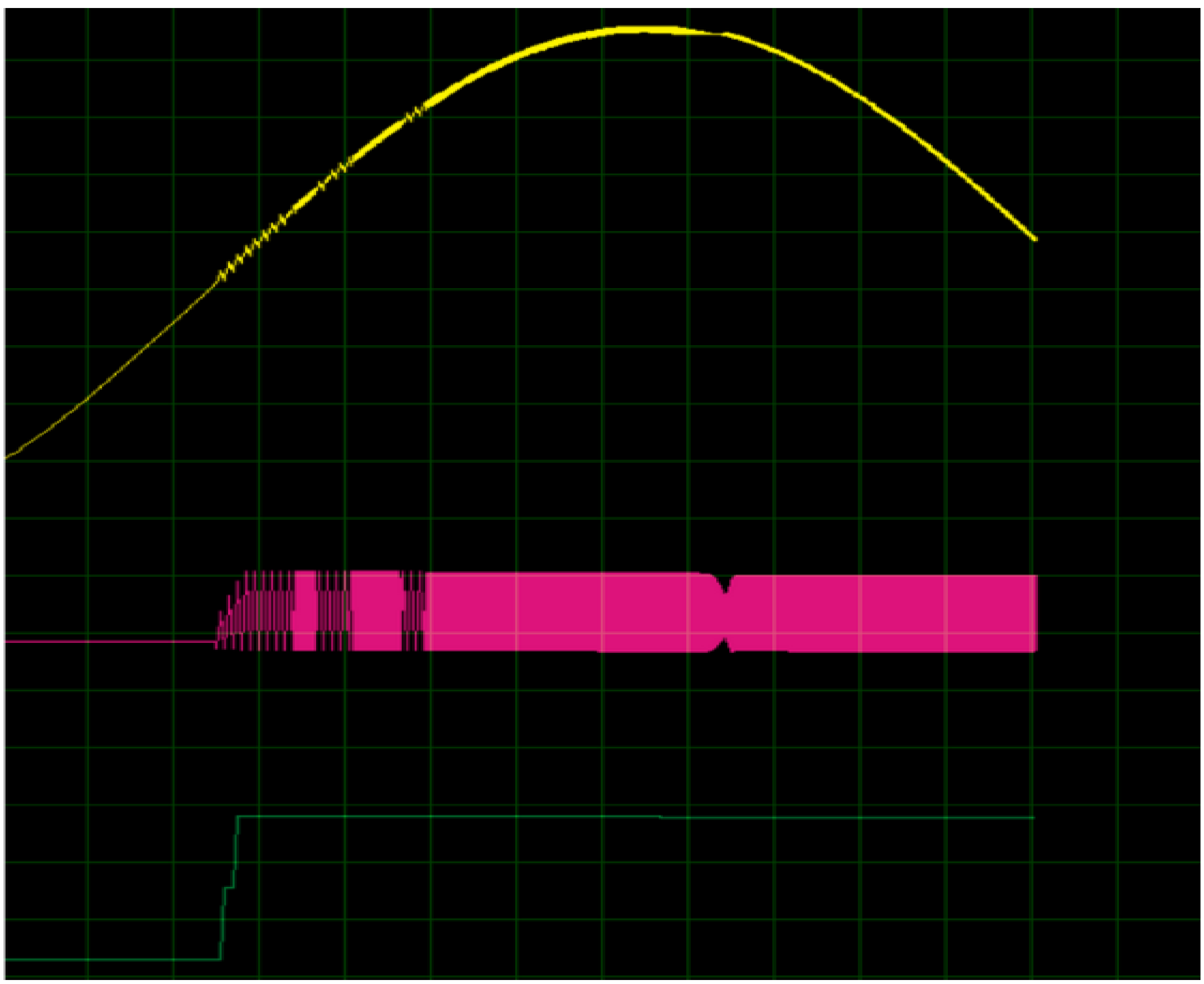


Figure 5.3 Time domain simulation

6 X-10 Protocol Hardware Implementation

6.1 Introduction

X-10 is a communication protocol designed for sending signals over 120 VAC wiring. X-10 uses 120 kHz bursts timed with the power line zero-crossings to represent digital information. Plug-in modules available from various vendors enable users to create home automation systems by using the AC wiring already installed within a home.

AVR microcontrollers can easily be used in conjunction with X-10 technology to create home automation applications. The specific AVR microcontroller (MCU) used should be selected based on RAM, ROM, operating frequency, peripheral, and cost requirements

of the particular application. The ATMEGA32 was selected for this application because of its versatility as a general purpose microcontroller, its Flash program memory (for ease of development), data EEPROM and ample I/O.

6.2 Hardware Description

An overview of the home controller application hardware is shown in Fig 6.1

The hardware functionality of X-10 circuitry can be divided into four functional blocks:

- Zero-crossing detector
- 120 kHz carrier detector
- 120 kHz signal generator
- Transformerless power supply

There are several application functions that are not directly associated with the X-10 interface for example user interface functions are accomplished with an LCD display and five push buttons.

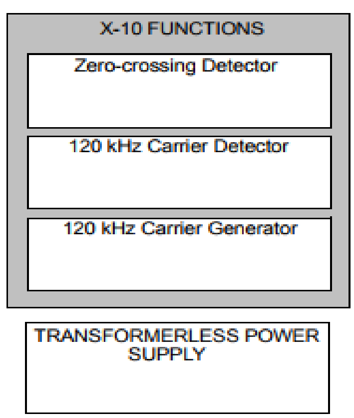


Figure 6.1

6.3 Zero Crossing Detector

In X-10, information is timed with the zero-crossings of the AC power. A zero-crossing detector is easily created by using the external interrupt.

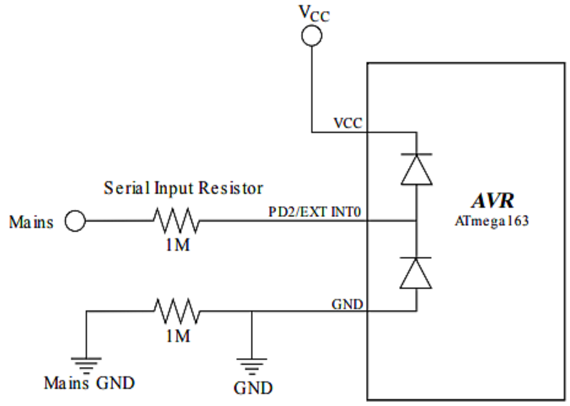


Figure 6.2

6.3.1 Zero Crossing Detector Hardware

To protect the device from voltages above VCC and below GND, the AVR has internal clamping diodes on the I/O pins (see Figure 6.2). The diodes are connected from the pins to VCC and GND and keep all input signals within the AVR's operating voltage (see the figure below). Any voltage higher than VCC + 0.5V will be forced down to VCC + 0.5V (0.5V is the voltage drop over the diode) and any voltage below GND - 0.5V will be forced up to GND - 0.5V. By adding a large resistor in series, these diodes can be used to convert a high voltage sinus signal down to a low voltage square wave signal, with amplitude within the AVR's operating voltage ±0.5V. The diodes will thus clamp the high voltage signal down to the AVR's operating voltage.

As the square wave signal is in phase with the AC mains, using the falling edge will tell very accurately where the zero crossing happens. By using this signal the AVR can be programmed to be a very accurate zero cross detector with a very small and interrupt-driven code. The square wave is the mains signal with its tops cut off and will have the same voltage from VCC - 0.5V to VCC + 0.5V as the mains signal (see the figure below). When the square wave triggers the AVR's falling edge interrupt at around VCC/2, the mains amplitude will also be at VCC/2 and just before a zero crossing. If this is done on a falling edge the AVR will get an interrupt just before the zero crossing and will have time to start a zero crossing action at the actual crossing point. The interrupt will be triggered at around VCC/2, as this is the middle of the AVR's logical threshold voltage. The signal is connected to the External Interrupt 0-pin, which makes it possible to place the zero cross detection routine in an interrupt routine and make the detection fully interrupt driven. The second figure below shows an oscilloscope screen-shot of the actual input signal. Note that the Mains signal is scaled and the rising edge of the external int0 pin is the same edge as for the Mains, because of the scaling, the Mains edge looks like it appears after the external int0 edge.

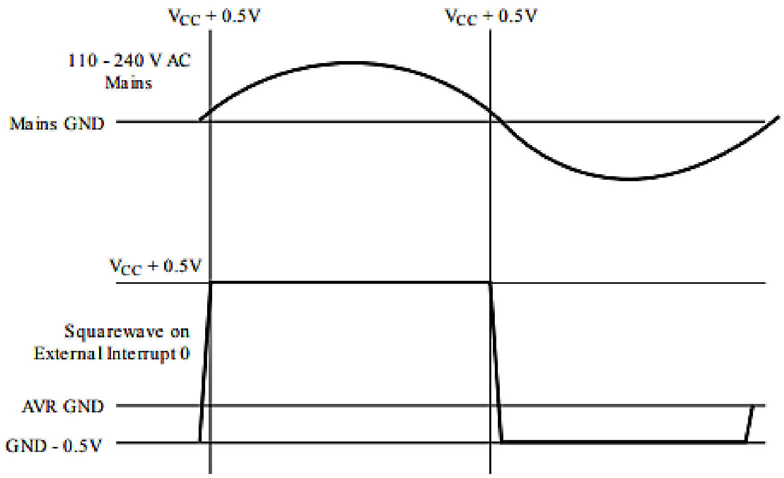


Figure 6.3 Square Wave Input Signal on External Interrupt 0-pin

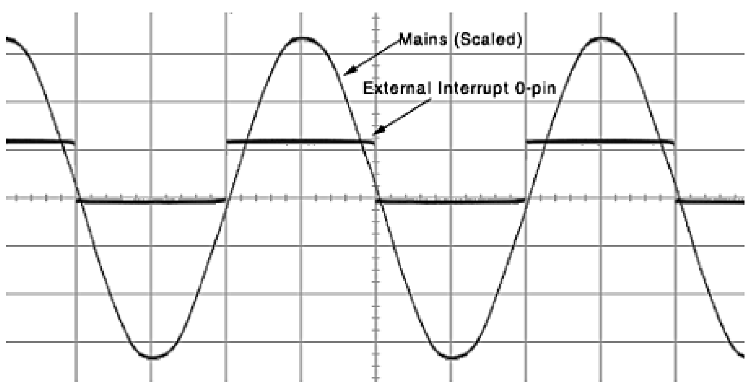


Figure 6.4 Oscilloscope Screen-shot of Square Wave Input on External Interrupt 0 pin

The series input resistor is a 1MΩ resistor. It is not recommended that the clamping diodes are conducting more than maximum 1mA, and 1MΩ will then allow a maximum voltage of approximately 1,000V. Any voltage higher than 1,000V would probably be spikes or surges. The clamping diodes are able to handle spikes for a short period of time but not surges. The application note will not go into how to protect against surges, but simply recommend implementing protection against surges in the design. Most resistors have an upper maximum voltage limit. Make sure that the resistors used in the application can handle the highest possible AC mains voltage, including high voltage spikes. For systems with lower mains voltages the resistor value can be changed, but in general it should be able to sense 110 - 240V AC systems without any problems. The 1MΩ resistor in series to mains GND will ensure a correct ground potential for the application.

6.3.2 Zero Crossing Detector Software

The external hardware and internal clamping diodes will make a square wave signal on the AVR's External Interrupt 0-pin. As described in the hardware section the square wave will have the same frequency as the AC mains. The high period of the signal will be when the AC mains amplitude is above VCC/2. This gives mains zero crossings very close to the edges of the square wave. The rising edge of the square wave is slightly after the crossing, and the falling edge is slightly before the crossing. As the falling edge of the square wave is just before a zero crossing, the falling edge interrupt will occur so close to the actual crossing that it immediately can start the zero crossing action.

6.4 120 kHz Carrier Detector

To receive X-10 signals, it is necessary to detect the presence of the 120 kHz signal on the AC power line. This is accomplished with a decoupling capacitor, a high-pass filter, a tuned amplifier, and an envelope detector. The components of the carrier detector are illustrated in Figure 6.5.

Because the impedance of a capacitor is: Zc = 1/(2*pi*f*C), a 0.1 uF capacitor presents a low impedance (13Ω) to the 120 kHz carrier frequency, but a high impedance (26.5 kΩ) to the 60 Hz power line frequency. This high-pass filter allows the 120 kHz signal to be safely coupled to the 60 Hz power line, and it doubles as the coupling stage of the 120 kHz carrier generator described in the next section. Since the 120 kHz carrier frequency is much higher than the 60 Hz power line frequency, it is straightforward to design an RC filter that will pass the 120 kHz signal and completely attenuate the 60 Hz. A high-pass filter forms the first stage of the High-Pass Filter and Tuned Amplifier Block.

For a simple high-pass filter, the -3 dB breakpoint is:

*ƒ*3 dB = 1/(2*pi*R*C). For C = 150 pF and R = 33 kΩ, *ƒ*3 dB = 1/ (2*pi*150 pF *33 kΩ) = 32kHz. This *ƒ*3 dB point assures that the 60 Hz signal is completely attenuated, while the 120kHz signal is passed through to the amplifier stages. Next, the 120 kHz signal is amplified using a series of inverters configured as high gain amplifiers. The first two stages are tuned amplifiers with peak response at 120 kHz. The next two stages provide additional amplification. The amplified 120 kHz signal is passed through an envelope detector, formed with a diode, capacitor, and resistor. The envelope detector output is buffered through an inverter and presented to an input to the AVR MCU. Figure 6.6 shows a simulation for the X10 protocol.

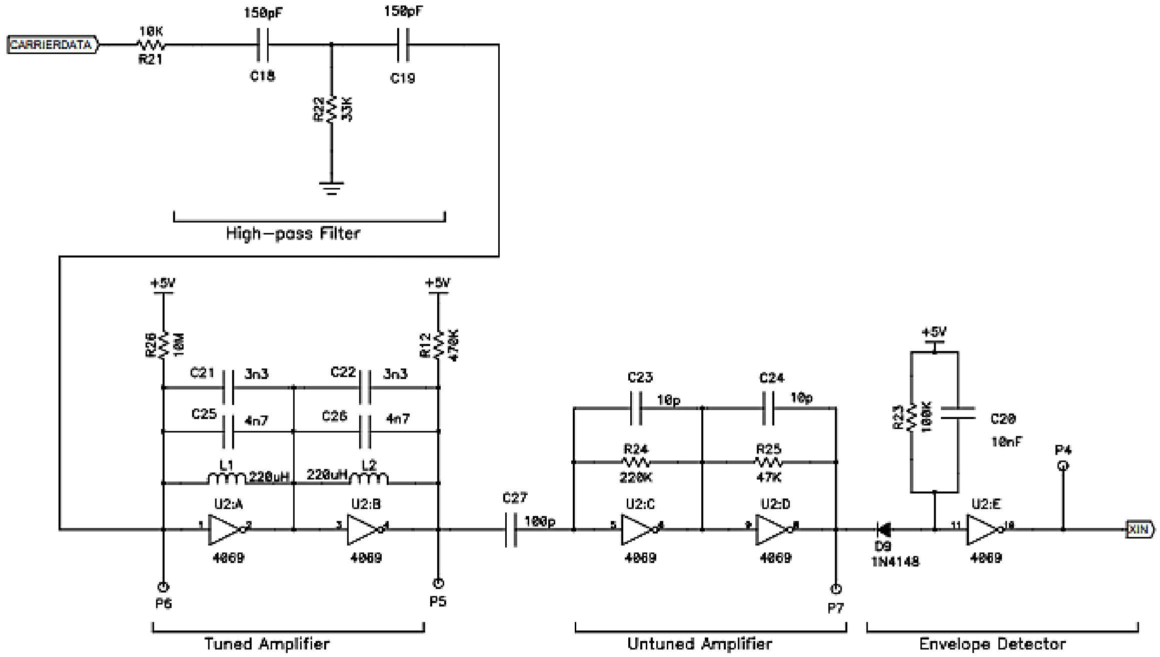


Figure 6.5 Carrier detector

Figure 6.6

6.5 120 kHz Carrier Generator

X10 uses 120 kHz modulation to transmit information over 60 Hz power lines. It is possible to generate the 120 kHz carrier with an external oscillator circuit. A single I/O pin would be used to enable or disable the oscillator circuit output. However, an external oscillator circuit can be avoided by using Timer in AVR.

The CCP1 module is used in PWM mode to produce a 120 kHz square-wave with a duty cycle of 50%. Because X-10 specifies the carrier frequency at 120 kHz.

the 120 kHz signal is coupled to the AC power line through a transistor amplifier and capacitor. Since the impedance of a capacitor is Zc = 1/(2*π*f*C), a 0.1 MF capacitor presents a low impedance to the 120 kHz carrier frequency, but a high impedance to the 60 Hz power line frequency. This high-pass filter allows the 120 kHz signal to be safely coupled to the 60 Hz power line, and it doubles as the first stage of the 120 kHz carrier detector.

6.6 Load switch

A load switch is included on the home controller so that it may act as a lamp module, with its own house and unit address. A Triac was selected as the load switch, because its medium power switching capacity and rapid switching capability make it well-suited for lamp control and dimming.

A Triac is an inexpensive, three-terminal device that basically acts as a high-speed, bidirectional AC switch. Two terminals, MT1 and MT2, are wired in series with the load. A small trigger current between the gate and MT1 allow conduction to occur between MT1 and MT2.

Current continues to flow after the gate current is removed, as long as the load current exceeds the latching value. Because of this, the Triac will automatically switch off near each zero-crossing as the AC voltage falls below the latching voltage.

6.7 X10 Protocol Code

6.7.1 Transmitter

```c
/*
 * main.c
 * X10 Protocol Code
 * Transmitter
 */
 #define F_CPU 8000000UL
 #include "util/delay.h"
#include "std_types.h"
#include "BIT_MATH.h"

#include "Dio_interface.h"
#include "EXTI_interface.h"
#include "Timer1_interface.h"
#include "LCD_interface.h"
#include "Global_Interrupt_interface.h"

#define DATAWIDTH          12
#define STORAGE            4

#define WRITETIME      1000
#define READTIME   350

#define RECEIVEPORT                DIO_u8PORT_B
#define RECEIVEPIN         DIO_u8PIN_0

#define SIGNALPORT         DIO_u8PORT_D
#define SIGNALPIN          DIO_u8PIN_5

#define BUTTONSPORT                DIO_u8PORT_A
#define BUTTONSPINSVALUE   0x00

void Send(u8 Copy_Cross);
void Pulse(u8 Copy_BitValue);
void WelcomeChoices();
void ZeroCrossing();
void Devices(void);
static u8 Data[STORAGE][DATAWIDTH] = {
                            {1,0,0,0, 0,0,0,0, 0,0,0,0}
                       ,{1,1,1,1, 0,1,0,0, 1,0,0,1}
                       ,{1,1,1,1,0,0,1,0,0,1,0,0}
                     ,{1,1,1,1,0,0,0,1,1,1,0,0}};
```

```
static u8 status[4] = {0,0,0,0};
static u8 CrossingCounter = 0;
static u8 DataType = 0;
int main(void){
/*activate LCD screen*/
   LCD_voidInit();
/*activate i/p and o/p Pins*/
   DIO_voidSetPortDirection(BUTTONSPORT,BUTTONSPINSVALUE);//input Pins
   DIO_voidSetPinDirection(SIGNALPORT,SIGNALPIN,DIO_u8OUTPUT);
   DIO_voidSetPinDirection(RECEIVEPORT,RECEIVEPIN,DIO_u8INPUT);
/*external interrupt */
   EXTI_u8INT0SetCallback(ZeroCrossing);
   EXTI0_voidInit(EXTI_RISING_EDGE);
/*enable Timer1 for transmit signal*/
   Timer1_voidInit();
/*disable global interrupt */
   GlobalInterrupt_Disable();
   while(1){
      WelcomeChoices();
   }
}
void WelcomeChoices(){
    static u8 input = 0;
    LCD_voidClearScreen();
    LCD_voidGotoxy(0,0);
    LCD_voidSendString(" Welcome home : ");
    LCD_voidGotoxy(1,0);
    LCD_voidSendString("1-menu ");
    LCD_voidGotoxy(2,0);
    LCD_voidSendString("2-exit ");

    while( (input=DIO_u8GetPortValue(BUTTONSPORT) )==0){
      //wait till input not zero
    }
    switch( input ){
      case 1:
  Devices();
  while(DIO_u8GetPinValue(DIO_u8PORT_D,DIO_u8PIN_2)==1){
  //wit until int2 pin == 0 i.e. the next zero crossing edge
  }
  GlobalInterrupt_Enable();
  break;
      case 2:
  LCD_voidClearScreen();
  LCD_voidSendString(" Exited");
```

```
    LCD_voidGotoxy(1,0);
    LCD_voidSendString(" 1 to start");
    while( DIO_u8GetPortValue(BUTTONSPORT)!= 1){
    //wait till started
    }
    break;
   }//end switch 1

 }//end welcomeChoices
void Devices(void){
     _delay_ms(500/8);
     static u8 press = 0;
     LCD_voidClearScreen();
       if(status[0]==0) LCD_voidSendString(" 1-device 1 is off");
       else             LCD_voidSendString(" 1-device 1 is on ");
       LCD_voidGotoxy(1,0);
       if(status[1]==0) LCD_voidSendString(" 2-device 2 is off");
       else             LCD_voidSendString(" 2-device 2 is on ");
       LCD_voidGotoxy(2,0);
       if(status[3]==0) LCD_voidSendString(" 3-device 3 is off");
       else             LCD_voidSendString(" 3-device 3 is on ");
       LCD_voidGotoxy(3,0);
       LCD_voidSendString(" 4-back");

       while( (press =  ( DIO_u8GetPortValue( BUTTONSPORT ) ) ) == 0 ){
                    //wait till button pressed
       }


       switch( press ){
            case 1:
                    DataType = press;
                    break;
            case 2:
                    DataType = press;
                    break;
            case 4:
                    DataType = press;
                    break;
            case 8://back
                    break;
            }//end switch 2
  }
```

```
void ZeroCrossing(){

    while( DIO_u8GetPinValue(DIO_u8PORT_D, DIO_u8PIN_2) ==0 ){
                //wait till the rising edge
    }
    if( ( DataType <= STORAGE ) ){
        switch(DataType  ){
        case 1:
                Send(1);
                break;
        case 2:
                Send(2);
                break;
        case 4:
                Send(3);
                break;
        }//End switch
    }//End if
}
void Send( u8 Copy_DataType ){

   Pulse( Data[Copy_DataType][CrossingCounter]); //enables the OC0 pin
   CrossingCounter++;

   if( CrossingCounter == DATAWIDTH ){
      CrossingCounter = 0;
      GlobalInterrupt_Disable();

      while( DIO_u8GetPinValue(DIO_u8PORT_D,DIO_u8PIN_2) == 1 ){
                //wait till falling edge then receive check bit
      }
      _delay_us( READTIME );

      if( DIO_u8GetPinValue( RECEIVEPORT,RECEIVEPIN)==1 ){
           status[DataType-1] = !status[DataType-1];
      }
      DataType = 0;
   }//End if
}//End Send
void Pulse( u8 Copy_BitValue ){
   Timer1_SetCompareMatchA_Value( ( 8000000/(2*129000) ) - 1 );
   Timer1PWM_A_OC1A( Copy_BitValue );
   _delay_us( WRITETIME );
   Timer1PWM_A_OC1A( 0 );
}//End Pulse
```

6.7.2 Receiver

```
/*
 * main.c
 *  X10 Protocol
 *  Receiver */
#define F_CPU 8000000UL
#include "util/delay.h"

#include "std_types.h"
#include "BIT_MATH.h"

#include "Dio_interface.h"
#include "EXTI_interface.h"
#include "Timer1_interface.h"

void ZeroCrossing();
void Display(void);
void Pulse(u8 Copy_BitValue);

#define DATAWIDTH  12
#define READTIME   250
#define WRITETIME  1000

#define INPUTPORT  DIO_u8PORT_D
#define INPUTPIN   DIO_u8PIN_0

#define DISPLAYPORT_2               DIO_u8PORT_B
#define DISPLAYPINVALUE_2  0x9f
#define DISPLAYPORT_1               DIO_u8PORT_C
#define DISPLAYPINVALUE_1  0xff

#define ADDRESSPORT                 DIO_u8PORT_A
#define ADDRESSPINS                 0x00

#define TRANSMITPORT                DIO_u8PORT_D
#define TRANSMITPIN                 DIO_u8PIN_5

static u8 display[DATAWIDTH] = {0,0,0,0 ,0,0,0,0 ,0,0,0,0 };
static u8 CrossZero = 0;
static u8 on_off = 0; // state of device controlled by the receiver
static u8 start = 0;
static u8 count = 0;

```

```c
int main(void){
  DIO_voidSetPinDirection(DIO_u8PORT_D,DIO_u8PIN_1,DIO_u8OUTPUT);
  DIO_voidSetPortDirection(ADDRESSPORT,ADDRESSPINS);//defining address pins
  DIO_voidSetPinDirection(INPUTPORT,INPUTPIN,DIO_u8INPUT); // input Data  pin
  DIO_voidSetPortDirection(DISPLAYPORT_1,DISPLAYPINVALUE_1);
  DIO_voidSetPortDirection(DISPLAYPORT_2,DISPLAYPINVALUE_2);
  DIO_voidSetPinDirection(TRANSMITPORT,TRANSMITPIN,DIO_u8OUTPUT);//transmit pin
  /*Enable external interrupt for zeroCrossing detection*/
  EXTI_u8INT0SetCallback(ZeroCrossing);
  EXTI0_voidInit(EXTI_RISING_EDGE);
  /*Enable Timer1 */
  Timer1_voidInit();
  DIO_voidSetPinDirection(DIO_u8PORT_D,DIO_u8PIN_7,DIO_u8OUTPUT);//test
  while(1){
  }
}// End main

void ZeroCrossing(){
   static u8 address = 0;
   _delay_us(READTIME);
   /*Read Pulse for indication*/
   DIO_voidSetPinValue(DIO_u8PORT_D,DIO_u8PIN_7,DIO_u8HIGH);
   _delay_us(100);
   DIO_voidSetPinValue(DIO_u8PORT_D,DIO_u8PIN_7,DIO_u8LOW);
   /**************************/
   display[CrossZero] = DIO_u8GetPinValue(INPUTPORT,INPUTPIN);

    if( (display[CrossZero]==1)&&(count<4)  ){
        count++;
        CrossZero++;
     }
     else if(count==4){
        CrossZero++;
        address = display[4]*1+display[5]*2+display[6]*4+display[7]*8;
        if( (CrossZero >= DATAWIDTH)&&
            (address == DIO_u8GetPortValue(DIO_u8PORT_A))  ){
            Display();
            while(DIO_u8GetPinValue(DIO_u8PORT_D,DIO_u8PIN_2) == 1){
               //wait till falling edge then send pulse
             }
            Pulse(1);
        }

        else if(CrossZero >= DATAWIDTH){
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_0,DIO_u8LOW);
```

```
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_1,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_2,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_3,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_4,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_5,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_6,DIO_u8LOW);
            DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_7,DIO_u8LOW);
            DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_0,DIO_u8LOW);
            DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_1,DIO_u8LOW);
            DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_2,DIO_u8LOW);
            DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_3,DIO_u8LOW);

            CrossZero = 0;
            count = 0;

            for(u8 count=0;count<DATAWIDTH;count++){
               display[count]=0;
            }
        }
    }
    else{
        count = 0;
        CrossZero = 0;
    }
}//End zero crossing

void Display(void){
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_0,display[0]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_1,display[1]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_2,display[2]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_3,display[3]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_4,display[4]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_5,display[5]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_6,display[6]);
     DIO_voidSetPinValue(DIO_u8PORT_C,DIO_u8PIN_7,display[7]);

     DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_0,display[8]);
     DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_1,display[9]);
     DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_2,display[10]);
     DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_3,display[11]);
     if( on_off == 0 ){
         DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_4,DIO_u8HIGH);
         on_off = 1;
     }

```

```
        else if( on_off == 1 ){
            DIO_voidSetPinValue(DISPLAYPORT_2,DIO_u8PIN_4,DIO_u8LOW);
            on_off = 0;
        }
        CrossZero = 0;
        start = 0;
        count = 0;
        for(u8 count=0;count<DATAWIDTH;count++){
            display[count]= 0;
        }
}//End Display
void Pulse(u8 Copy_BitValue){

        Timer1_SetCompareMatchA_Value((8000000/(2*129000))-1);
        Timer1PWM_A_OC1A( Copy_BitValue );
        _delay_us(WRITETIME);
        Timer1PWM_A_OC1A( 0 );
}//End Pulse
```

7 TD5051A Home Automation Modem

7.1 Introduction

The TDA5051A is a Power Line Modem (PLM) IC, specifically dedicated to ASK transmission by means of home power line network at 600 baud or 1200 baud data rate. It operates from a single 5 V supply. The TDA5051A employs control logic which provides full digital carrier generation and shaping, a high clock rate of 6-bit D/A (Digital-to-Analog) converter which provides rejection of aliasing components. The IC contains a fully integrated output power stage with overload protection. The receiver employs an AGC (Automatic Gain Control), 8-bit A/D (Analog-to-Digital) converter and narrowband digital baseband filtering and digital demodulator. The modulation and demodulation frequency is set by clock source from microcontroller or on-chip crystal oscillator.

The TDA5051A paired with an encoding and a decoding scheme provides a very robust and easy method for creating a home automation system.

7.2 Hardware Description

The hardware for the home automation application can be divided into two sides a transmitter side and a receiver side , the transmitter side ideally would contain a microcontroller which would be used to provide user interface through an LCD and a couple of push buttons to specify which commands the user would want to send and to which receiver as in our application the transmitter can address multiple receiver units , each unit has an address specific to it, but for the sake of simplicity we would first introduce a home automation system without the use of a microcontroller and another one but with the use of a microcontroller , generally speaking the only use the microcontroller has in this application is to provide user interface.

7.2.1 Transmitter Side Hardware

An overview of the home automation application hardware at the transmitter side is shown in Figure 7.1 The hardware functionality can be divided into two functional blocks:

- An encoding scheme
- the TDA5051A Power line modem

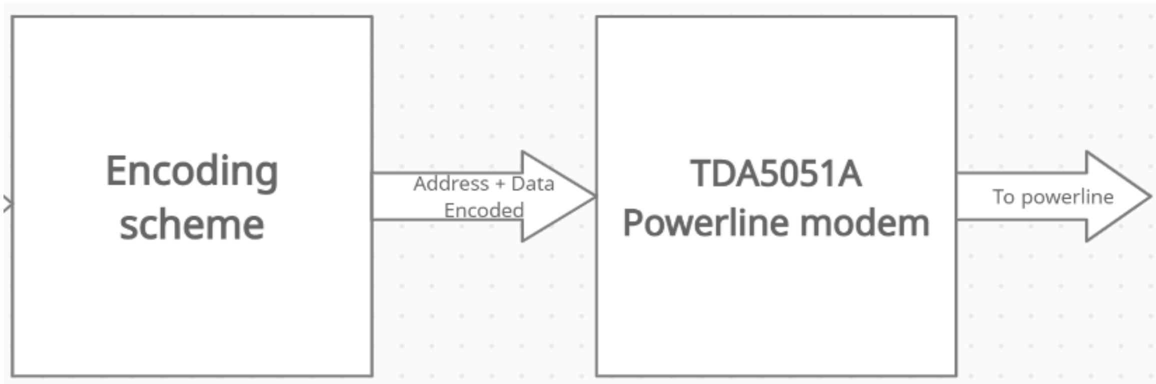


Figure 7.1

7.2.2 Encoding Scheme

For our application we will use the HT12E IC from farnell to provide us with an encoding scheme that serves our needs
HT12E is an encoder integrated circuit of 2^12 series of encoders. They are paired with 2^12 series of decoders for use in remote control system applications. It is mainly used in interfacing RF and infrared circuits. The chosen pair of encoder/decoder should have same number of addresses and data format.

7.2.2.1 HT12E Functional Description

Simply put, HT12E converts the parallel inputs into serial output. It encodes the 12-bit parallel data into serial for transmission through an RF transmitter. These 12 bits are divided into 8 address bits and 4 data bits.

HT12E has a transmission enable pin which is active low. When a trigger signal is received on TE pin, the programmed addresses/data are transmitted together with the header bits via an RF or an infrared transmission medium. HT12E begins a 4-word transmission cycle upon receipt of a transmission enable. This cycle is repeated as long as TE is kept low. As soon as TE returns to high, the encoder output completes its final cycle and then stops.

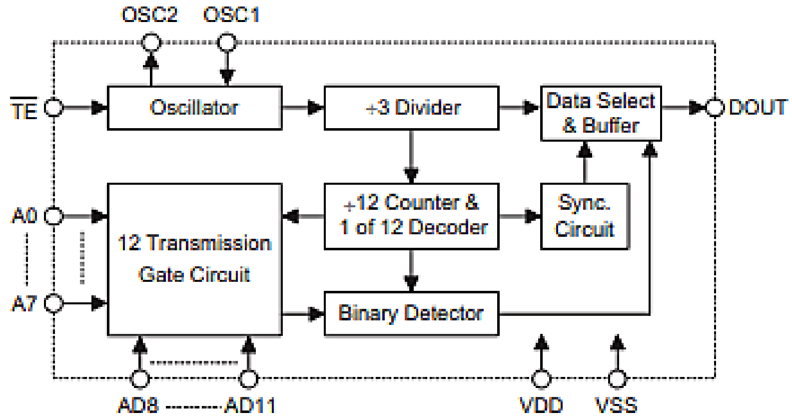


Figure 7.2 HT12E block diagram

Table 7.2 *HT12E Characteristics*

Function / Part No.	Address No.	Address/ Data No.	Data No.	Oscillator	Trigger	Carrier Output	Negative Polarity	Package
HT12E	8	4	0	RC oscillator	$\overline{TE}$	No	No	18DIP, 20SOP

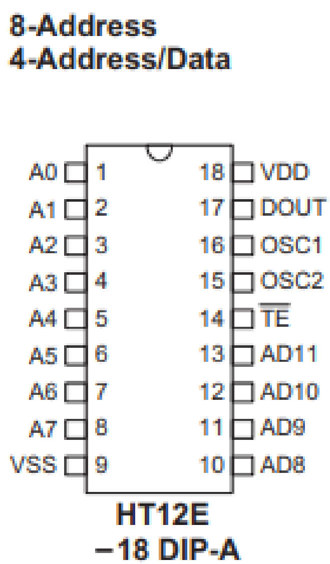


Figure 7.3 HT12E pin-out

7.2.2.2 Pin Description of IC HT12E

The pin Description of the IC HT12E was pretty simple to understand with total of 18 pins.

- VDD and VSS: Positive and negative power supply pins.
- OSC1 and OSC2: Input and output pins of the internal oscillator present inside the IC.
- TE: This pin is used for enabling the transmission, a low signal in this pin will enable the transmission of data bits.
- A0 – A7: These are the input address pins used for secured transmission of this data. These pins can be connected to VSS for low signal or left open for high state.
- AD0 – AD3: This pins are feeding data into the IC. These pins may be connected to VSS for sending LOW since it is an active low pin
- DOUT: The output of the encoder can be obtained through this pin and can be connected to the RF transmitter.

7.2.2.3 HT12E Output Frame

The 2^12 series of encoders begin a 4-word transmission cycle upon receipt of a transmission enable (TE for the HT12E or D8~D11 for the HT12A, active low). This cycle will repeat itself as long as the transmission enable (TE or D8~D11) is held low. Once the transmission enable returns high the encoder output completes its final cycle and then stops as shown below.

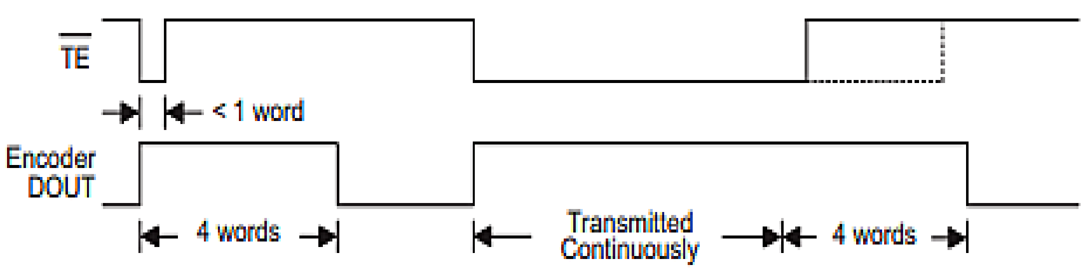


Figure 7.4 Transmission timing for HT12E

7.2.2.4 Address Data Programming and Waveform

Each programmable address/data pin can be externally set to one of the following two logic states as shown below.

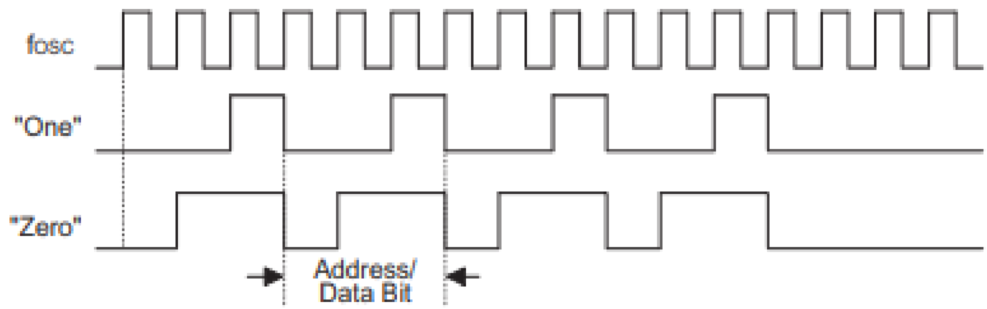


Figure 7.5 Address/Data bit waveform for HT12E

Address/Data Programming (Preset)

The status of each address/data pin can be individually pre-set to logic high or low. If a transmission-enable signal is applied, the encoder scans and transmits the status of the 12 bits of address/data serially in the order A0 to AD11 for the HT12E encoder. During information transmission these bits are transmitted with a preceding synchronization bit. If the trigger signal is not applied, the chip enters the standby mode and consumes a reduced current of less than 1uA for a supply voltage of 5V. Usual applications preset the address pins with individual security codes using DIP switches or PCB wiring, while the data is selected by push buttons or electronic switches for our purposes we will be using an 8 dip switch to define the address and data to be sent.

Pilot & Sync.	A0	A1	A2	A3	A4	A5	A6	A7	AD8	AD9	AD10	AD11
	1	0	1	0	0	0	1	1	1	1	1	0

Figure 7.6 example of a frame for HT12E

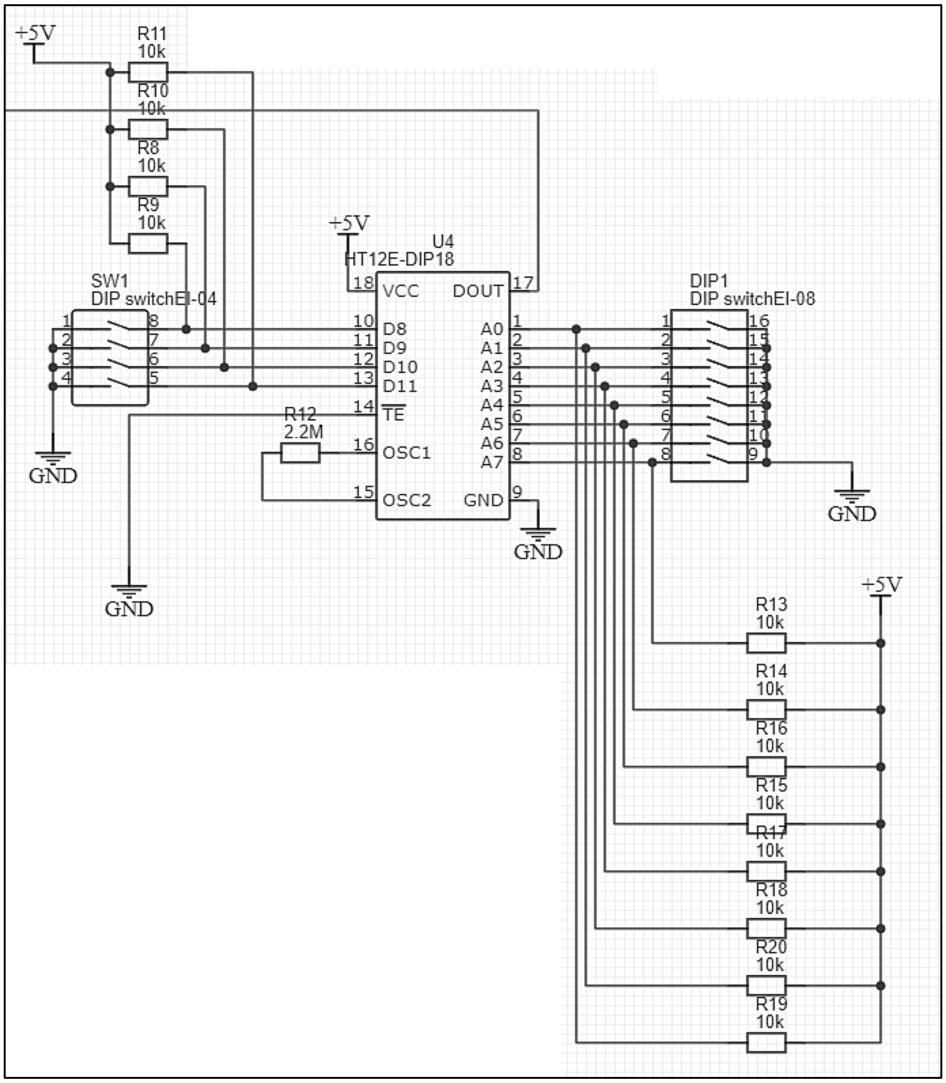


Figure 7.7 schematic of HT12E connection in our application

7.2.2.5 HT12E'S Function in Home Automation Application

The HT12E provides us with a way to first encode the data that is being sent to mitigate and attenuate the effects of the channel on our signal.

second it provides us with a way to communicate with multiple devices through the address functionality it provides it has 8 address bits which means that we are able to address 256 distinct devices from a single transmitting unit and it gives us 4 data bits which provides us with 16 distinct combinations for the data/commands being sent so we can have up to 16 commands which is more than enough for home automation purposes.

third it provides means to convert the parallel data we want into serial data to be fed into the TDA5051 PLM modem so that this data can be transmitted on the AC Power line.

7.2.2.6 Components Description and Functionality

Fig 7.8 shows how the HT12E IC is connected in our application.

- 4 DIP Switch: is used to determine the data we want to send.
- Resistors from R9 to R20: pull up resistors.
- 8 DIP Switch: Used to determine the address of the device we want to communicate with.
- Resistor R12: Provides the HT12E with oscillation frequency of about 1.6kHZ

some notes to be taken is that the TE (transmission enable) pin is connected to ground which means that we are using the HT12E in continuous transmission mode which means that the HT12E keeps transmitting whatever is on its address pins and data pins

ideally we would want the TE pin to be connected to a pulse source producing a low pulse less than the length of one word as described previously in section 7.2.2.3

another thing to note is that the DOUT pin feeds the TDA5051A so that the data and address are transmitted serially on the power line.

7.2.3 The TDA5051A Powerline Modem

The NXP TDA5051A is a complete Amplitude Shift Keying (ASK) modem for transmitting and receiving digital signals on standard power line or any two-wire AC or DC network. It is a cost-effective solution that transmits at a rate of 600 baud (typical) and 1200 baud (maximum), operates from a single 5 V supply, and enables easy connection to standard microcontrollers, including NXP's LPC11xx series of low power ARM-based microcontrollers.

The IC requires only a few external components for full operation. Its fully-digital transmission and reception circuitry provides efficient bidirectional communication of low baud rate data signals between a control unit and lighting fixture, and one or more household appliances connected to the mains.

7.2.3.1 TDA5051A Features and Benefits

- Full digital carrier generation and shaping.
- Modulation/demodulation frequency set by clock adjustment, from microcontroller or on-chip oscillator.
- High clock rate of 6-bit D/A (Digital to Analog) converter for rejection of aliasing components.
- Fully integrated output power stage with overload protection.
- Automatic Gain Control (AGC) at receiver input.
- 8-bit A/D (Analog to Digital) converter and narrow digital filtering.
- Digital demodulation delivering baseband data.
- Easy compliance with EN50065-1 with simple coupling network.
- Few external components for low cost applications.
- SO16 plastic package.

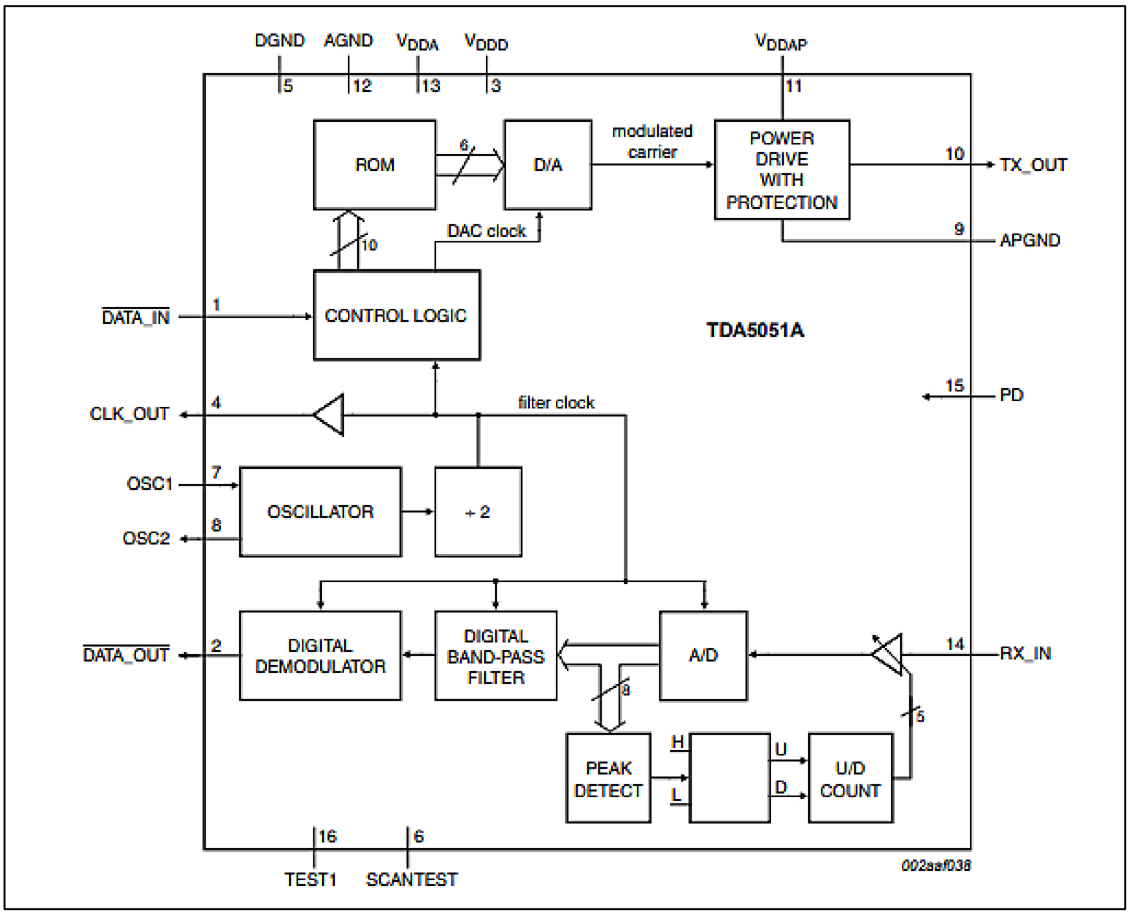


Figure 7.8 Block diagram of the TDA5051A

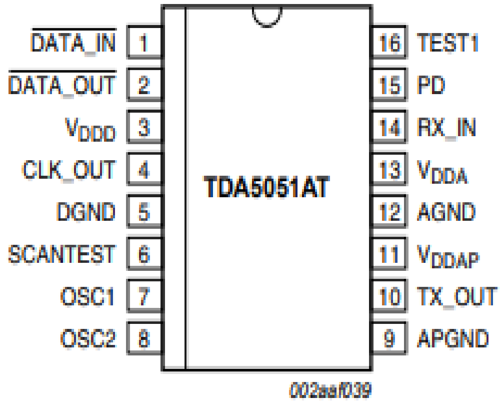


Figure 7.9 TDA5051AT Pinout

7.2.3.2 Pins Description

Table 7.2

Symbol	Pin	Description
DATA_IN	1	digital data input (active LOW)
DATA_OUT	2	digital data output (active LOW)
VDDD	3	digital supply voltage
CLK_OUT	4	clock output
DGND	5	digital ground
SCANTEST	6	test input (LOW in application)
OSC1	7	oscillator input
OSC2	8	oscillator output
APGND	9	analog ground for power amplifier
TX_OUT	10	analog signal output
VDDAP	11	analog supply voltage for power amplifier
AGND	12	analog ground
VDDA	13	analog supply voltage
RX_IN	14	analog signal input
PD	15	power-down input (active HIGH)
TEST1	16	test input (HIGH in application)

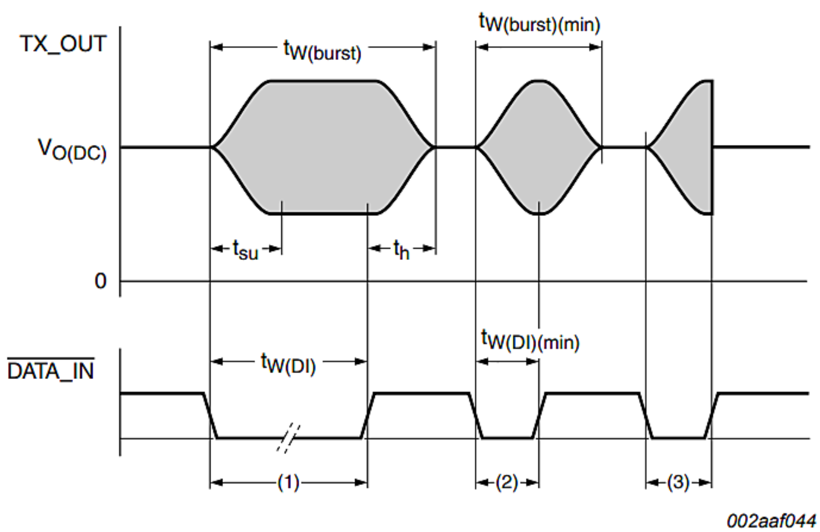
7.2.3.3 Functional Description

Both transmission and reception stages are controlled either by the master clock of the microcontroller or by the on-chip reference oscillator connected to a crystal. This ensures the accuracy of the transmission carrier and the exact trimming of the digital filter, thus making the performance totally independent of application disturbances such as component spread, temperature, supply drift and so on. The interface with the power network is made by means of an LC network. The device includes a power output stage that feeds a 120 dBµV (RMS) signal on a typical 30 Ω load. To reduce power consumption, the IC is disabled by a power-down input (pin PD): in this mode, the on-chip oscillator remains active and the clock continues to be supplied at pin CLK_OUT. For low-power operation in reception mode, this pin can be dynamically controlled by the microcontroller. When the circuit is connected to an external clock generator the clock signal must be applied at pin OSC1 (pin 7); OSC2 (pin 8) must be left open-circuit. All logic inputs and outputs are compatible with TTL/CMOS levels, providing an easy connection to a standard microcontroller I/O port. The digital part of the IC is fully scan-testable. Two digital inputs, SCANTEST and TEST1, are used for production test: these pins must be left open-circuit in functional mode (correct levels are internally defined by pull-up or pull-down resistors).

7.2.3.4 Transmission Mode

To provide strict stability with respect to environmental conditions, the carrier frequency is generated by scanning the ROM memory under the control of the microcontroller clock or the reference frequency provided by the on-chip oscillator. High frequency clocking rejects the aliasing components to such an extent that they are filtered by the coupling LC network and do not cause any significant disturbance. The data modulation is applied through pin DATA_IN and smoothly applied by specific digital circuits to the carrier (shaping). Harmonic components are limited in this process, thus avoiding unacceptable disturbance of the transmission channel (according to CISPR16 and EN50065-1 recommendations). A −55 dB Total Harmonic Distortion (THD) is reached when the typical LC coupling network (or an equivalent filter) is used. The DAC and the power stage are set in order to provide a maximum signal level of 122 dBµV (RMS) at the output. The output of the power stage (TX_OUT) must always be connected to a decoupling capacitor, because of a DC level of 0.5VDD at this pin, which is present even when the device is not transmitting. This pin must also be protected against over voltage and negative transient signals. The DC level of TX_OUT can be used to bias a unipolar transient suppressor, as shown in the application diagram. Direct connection to the mains is done through an LC network for low-cost applications. However, an HF signal transformer could be used when power-line insulation has to be performed.

The data input (DATA_IN) is active LOW: this means that a burst is generated on the line (pin TX_OUT) when DATA_IN pin is LOW. Pin TX_OUT is in a high-impedance state as long as the device is not transmitting. Successive logic 1s are treated in a Non-Return-to-Zero (NRZ) mode, see pulse shapes in Figure 7.10 and Figure 7.11.



(1) $t_{W(DI)} > t_{W(DI)(min)}$

(2) $t_{W(DI)(min)} = t_{su} + 1/f_{cr}$

(3) $t_{W(DI)(min)} < t_{su}$; wrong operation

Figure 7.10 Relationship between DATA_IN and TX_OUT

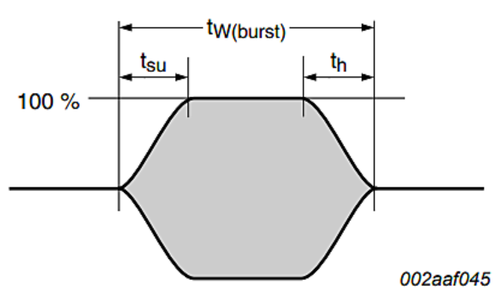


Figure 7.11 Pulse shape characteristics

7.2.3.5 Reception Mode

The input signal received by the modem is applied to a wide range input amplifier with AGC (−6 dB to +30 dB). This is basically for noise performance improvement and signal level adjustment, which ensures a maximum sensitivity of the ADC. An 8-bit conversion is then performed, followed by digital band-pass filtering, to meet the CISPR16 normalization and to comply with some additional limitations met in current applications. After digital demodulation, the baseband data signal is made available after pulse shaping. The signal pin (RX_IN) is a high-impedance input which has to be protected and DC decoupled for the same reasons as with pin TX_OUT. The high sensitivity (82 dBμV) of this input requires an efficient 50 Hz rejection filter (realized by the LC coupling network), which also acts as an anti-aliasing filter for the internal digital processing.

7.2.3.6 Power Down Mode

Power-down input (pin PD) is active HIGH; this means that the power consumption is minimum when pin PD is HIGH. Now, all functions are disabled, except clock generation.

7.2.4 Interfacing the TDA5051A Power Line Modem with HT12E IC

In our application we will be using the HT12E to provide the TDA5051A with 12 bits to be transmitted on the power line , the first 8 bits represent the address bits which specify which device or receiver we are trying to communicate with the last 4 bits represent our command or data , the TDA5051A receives theses bits serially from the HT12E's DOUT pin then it modulates these bits using amplitude shift keying and transmits them serially on our power line , we are using an 8 DIP switch to specify the address and a 4 DIP switch to specify the data we want to send , for a complete circuit diagram check figure 7.12.

The TE pin should be connected to a pulse source that generates a low pulse of a duration that is less than 1 word but since we are using the HT12E in a continuous transmission mode the TE pin is connected to ground.

The TDA5051A connection and interface with the power line is provided from the TDA5051A datasheet as in Fig 7.12.

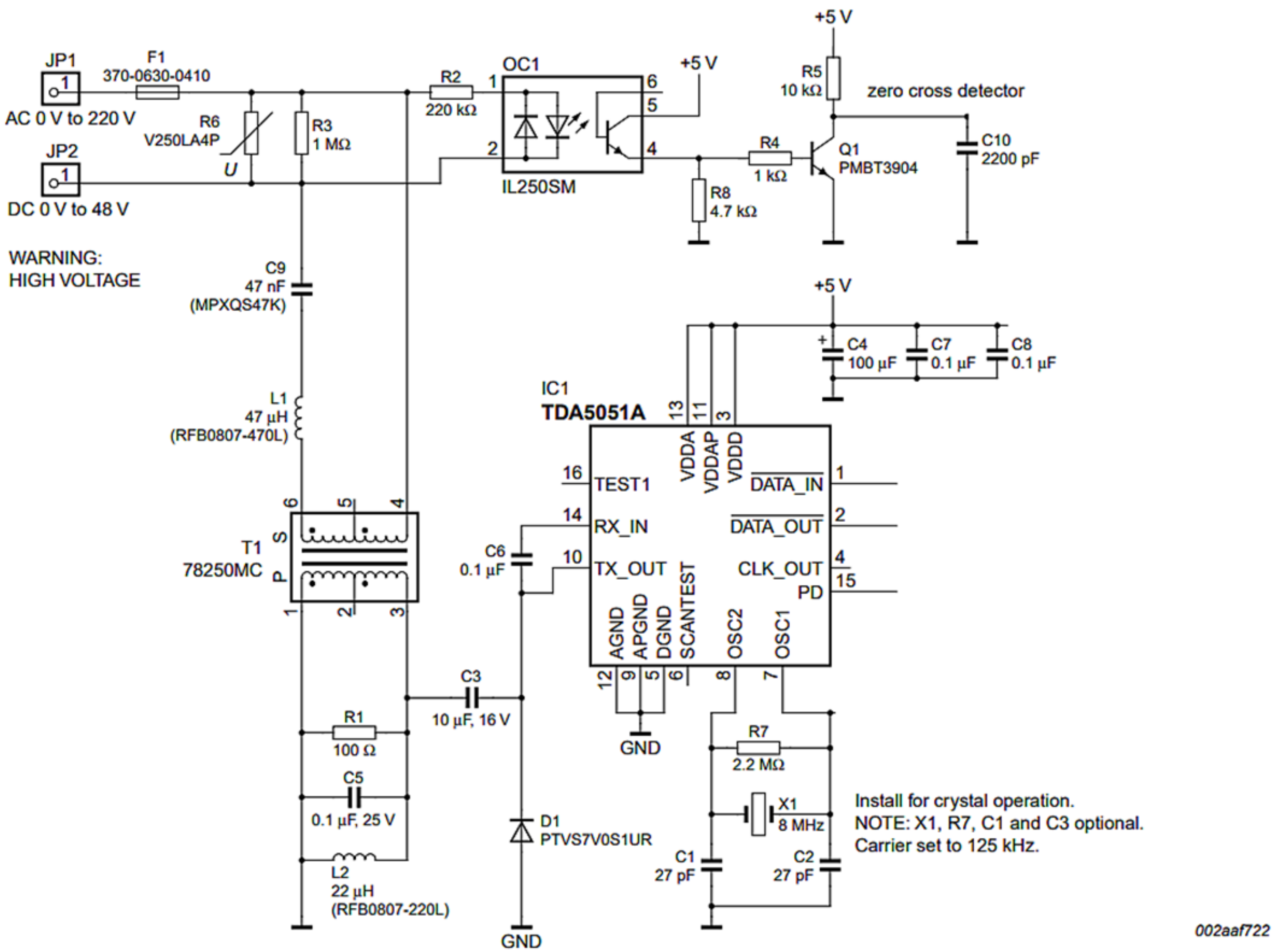
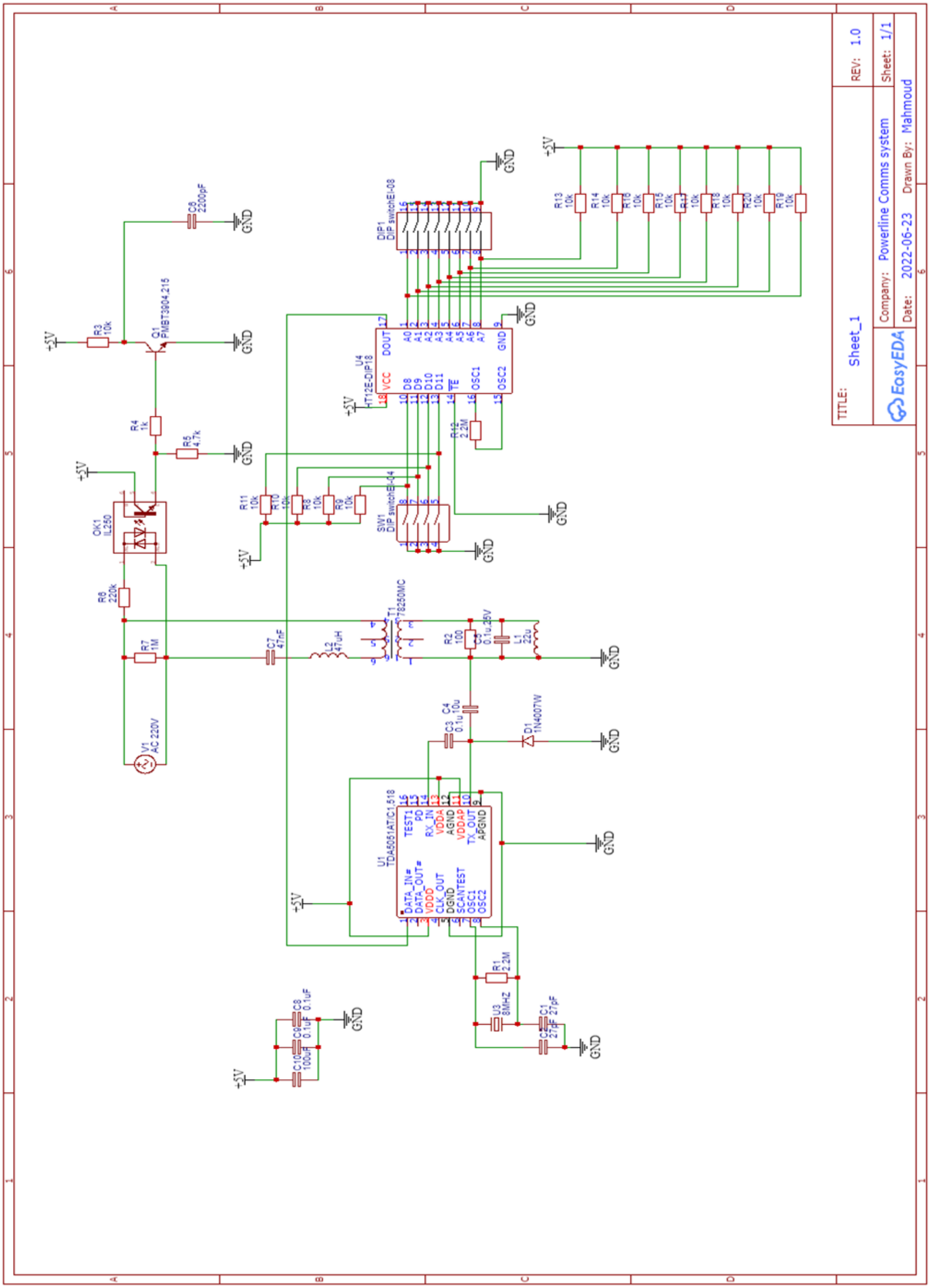


Figure 7.12 TDA5051A interface with the powerline

A Complete Circuit diagram of the TDA5051A interfacing the HT12E IC is provided in the next page.


TITLE: Sheet_1
REV: 1.0
Company: Powerline Comms system
Sheet: 1/1
Date: 2022-06-23
Drawn By: Mahmoud
EasyEDA
U1 TDA5051AT/C1,518
U4 HT12E-DIP18
DIP1 DIP switchEI-08
SW1 DIP switchEI-04
T1 78250MC
OK1 IL250
Q1 PMBT3904,215
V1 AC 220V
D1 1N4007W
U3 8MHZ

7.2.4.1 Waveforms

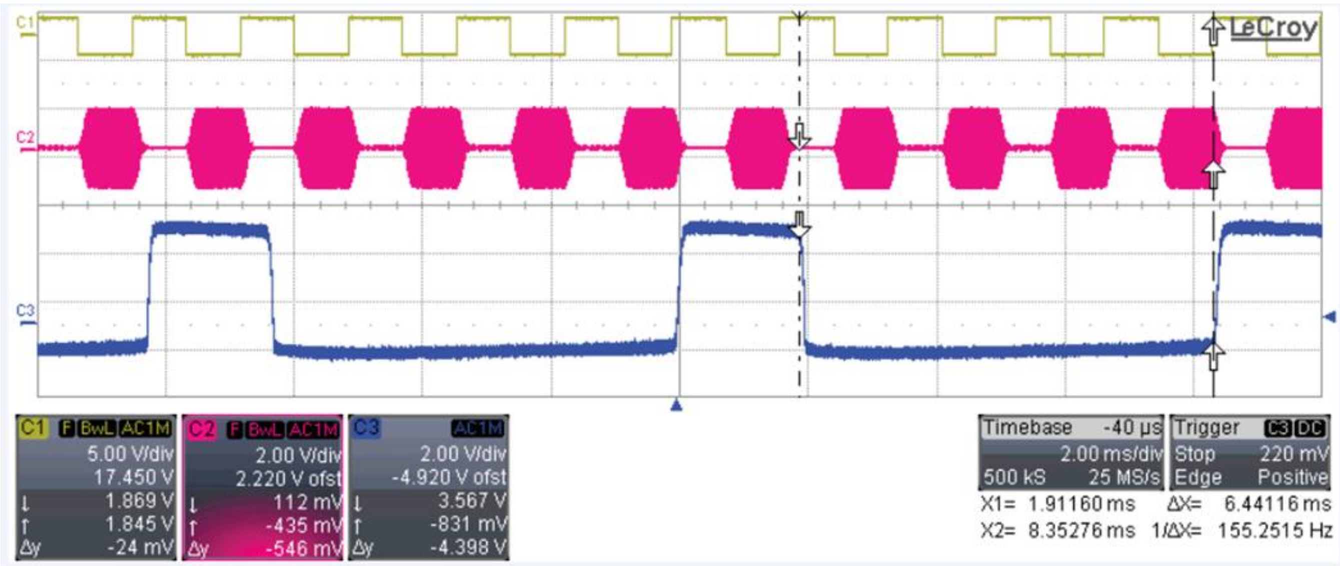


Figure 7.14 1C2 TX_OUT , C1 DATA_IN ,C3 Zero Cross detection

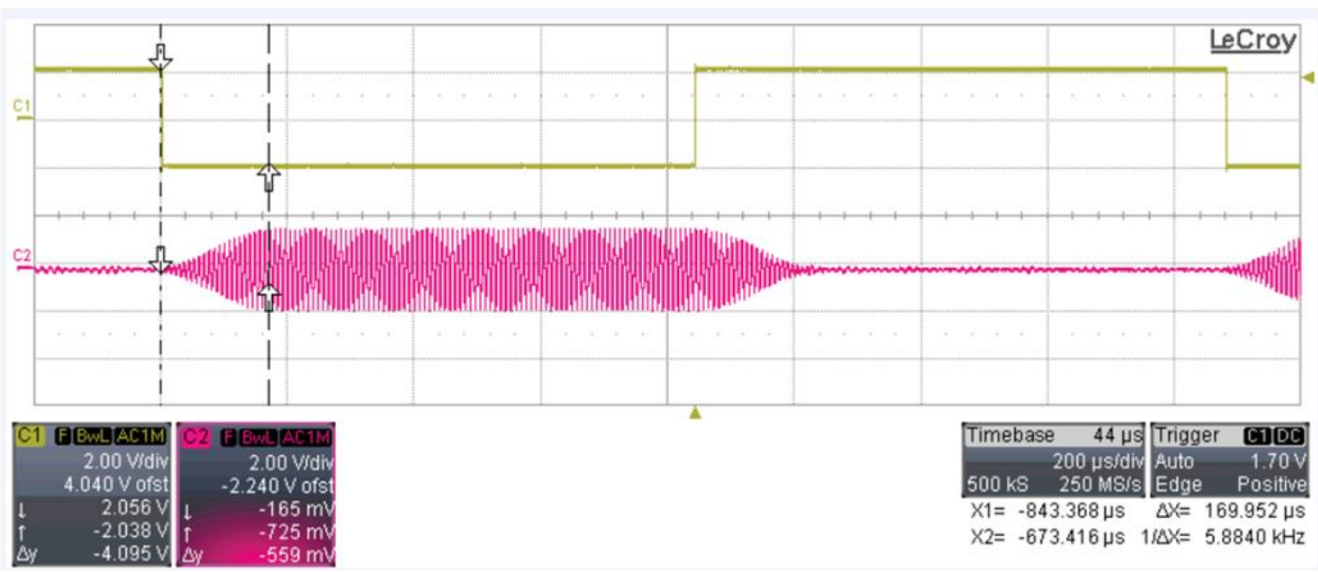


Figure 7.13 C1 DATA_IN, C2 TX_OUT

we can observe that modulated output on TX_OUT pin suffers from a delay of about 169.95 us relative the DATA_IN pin.

7.2.5 Receiver Side Hardware

Much like the transmitter the receiver is divided into two main blocks, the first is the TDA5051A IC which interfaces with the power line and receives the modulated signal then filters the received signal and proceeds to demodulate it and finally outputs the encoded transmitted bit stream which is then passed on to the decoder to decode it and covert it from a serial bit stream to parallel data. So the two main blocks are as follows in

- TDA5051A in reception mode.
- HT12D IC to decode the incoming bit stream.

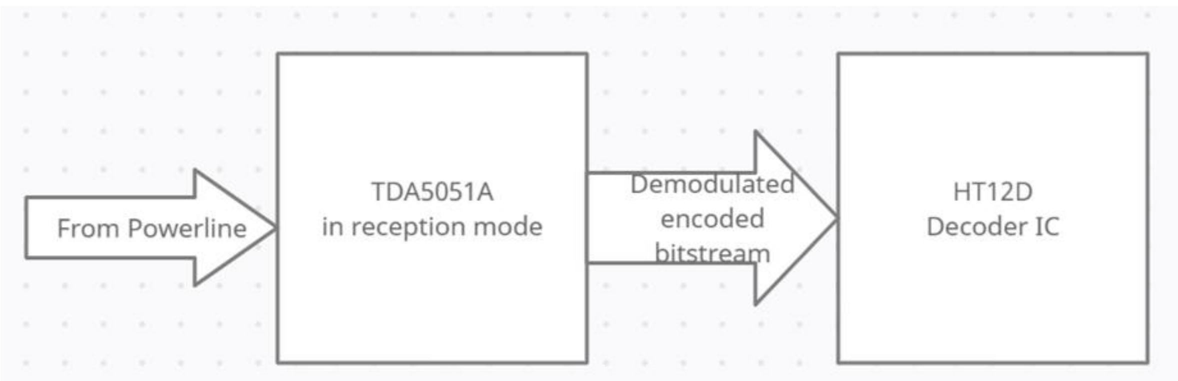


Figure 7.15 Block Diagram of the receiver

7.2.6 HT12D Decoder IC

The HT12D is a 2^12 decoder in 18 pin DIP package. This decoder is a series of CMOS LSIs for remote control system applications. It is paired with Holtek's 2^12 encoder. For proper operation, a pair of encoder/decoder with same number of addresses and data format should be chosen. The decoder receives serial addresses and data from programmed 2^12 encoder that is transmitted by a carrier using an RF or an IR transmission medium. It compares serial input data three times continuously with its local address. If no error or unmatched codes are found, the input data codes are decoded and then transferred to output pins. The HT12D is capable of decoding information that consists of N bits of address and 12 N bits of data.

- 8 address bits and 4 data bits
- Operating voltage range from 2.4V to 12V
- Low power and high noise immunity CMOS technology

- Low standby current and minimum external components
- Capable of decoding 12bits of information
- Binary address setting
- Built-in oscillator needs only 5% resistor
- Valid transmission indicator
- Oscillator frequency of 150KHz
- Operating temperature range from -20°C to 75°C

the decoders receive serial addresses and data from a programmed 2^12 series of encoders that are transmitted by a carrier using an RF or an IR transmission medium. They compare the serial input data three times continuously with their local addresses. If no error or unmatched codes are found, the input data codes are decoded and then transferred to the output pins. The VT pin also goes high to indicate a valid transmission.

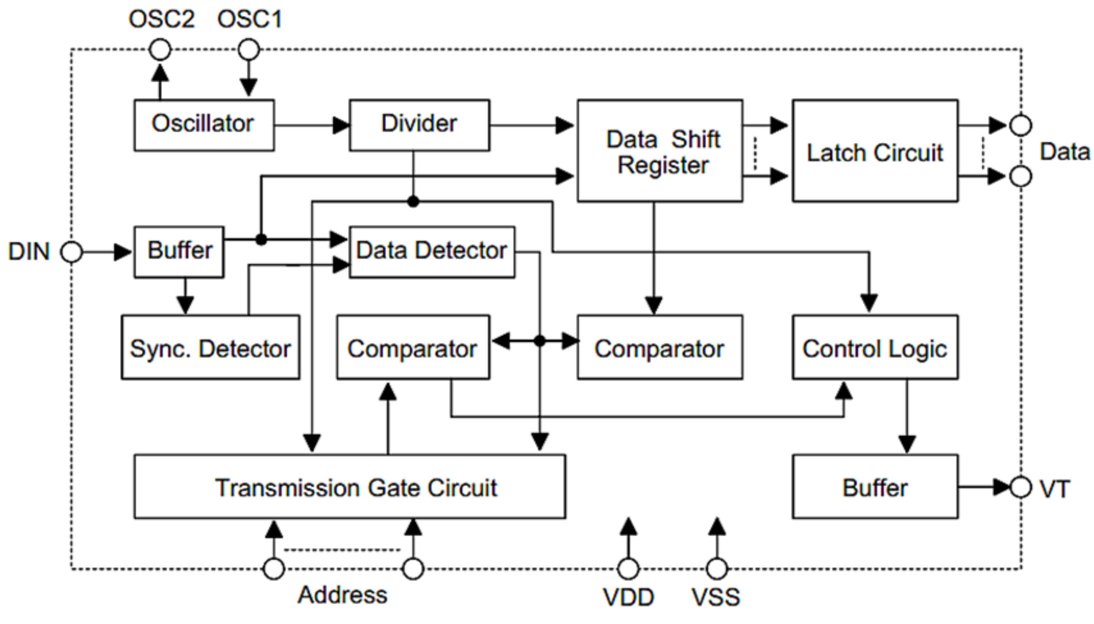


Figure 7.16 Block diagram for the HT12D IC

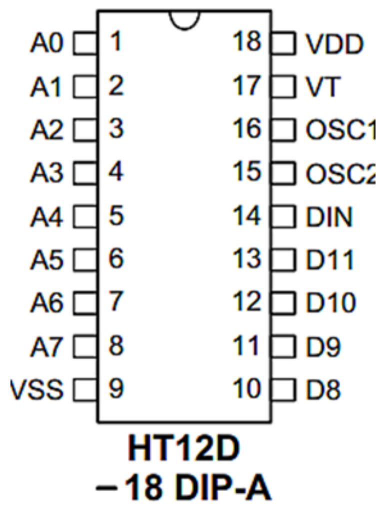


Figure 7.17 HT12D Pinout

7.2.6.1 HT12D Pin Description

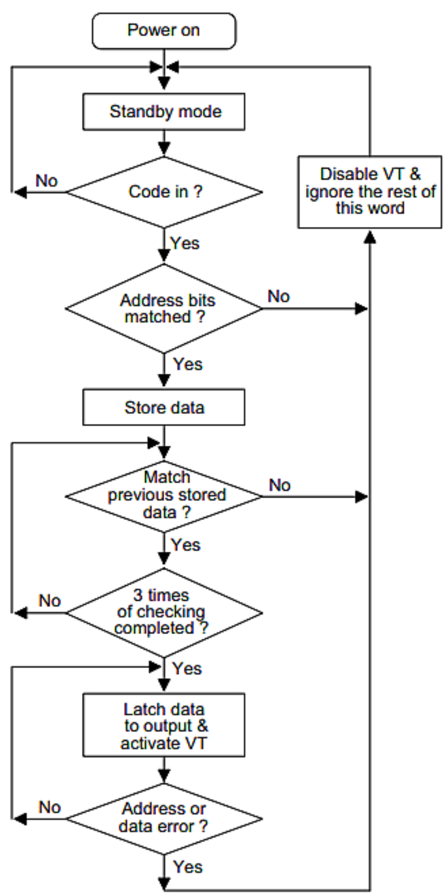
Table 7.3

Pin name	I/O	Internal connection	Description
A0~A7 (HT12D)	I	NMOS Transmission Gate	Input pins for address A0~A7 setting These pins can be externally set to VSS or left open.
D8~D11 (HT12D)	O	CMOS OUT	Output data pins, power-on state is low.
DIN	I	CMOS IN	Serial data input pin
VT	O	CMOS OUT	Valid transmission, active high
OSC1	I	Oscillator	Oscillator input pin
OSC2	O	Oscillator	Oscillator output pin
VSS	-	-	Negative power supply, ground
VDD	-	-	Positive power supply

7.2.6.2 Functional Description

Functional Description Operation The 2^12 series of decoders provides various combinations of addresses and data pins in different packages so as to pair with the 212 series of encoders. The decoders receive data that are transmitted by an encoder and interpret the first N bits of code period as addresses and the last 12-N bits as data, where N is the address code number. A signal on the DIN pin activates the oscillator which in turn decodes the incoming address and data. The decoders will then check the received address three times continuously. If the received address codes all match the contents of the decoders local address, the 12-N bits of data are decoded to activate the output pins and the VT pin is set high to indicate a valid transmission. This will last unless the address code is incorrect or no signal is received. The output of the VT pin is high only when the transmission is valid. Otherwise it is always low. The HT12D provides 4 latch type data pins whose data remain unchanged until new data are received.

7.2.6.3 HT12DTiming and Flowchart



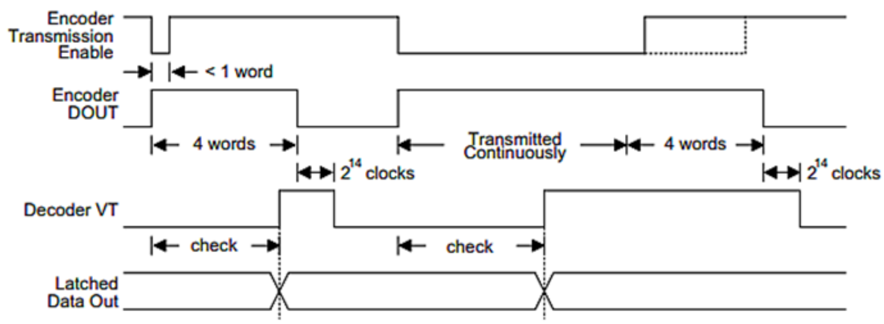


Figure 7.18

The oscillator is disabled in the standby state and activated when a logic high signal applies to the DIN pin. That is to say, the DIN should be kept low if there is no signal input.

7.2.7 TDA5051A in Reception Mode

For TDA5051A to be configured in reception mode we must disable any kind of transmission it makes, as the TDA5051A can operate as a transceiver but in this section we will be configuring the TDA5051A as either a transmitter or a receiver i.e. it will operate in a simplex mode, in a later section we will be discussing how to configure the TDA5051A to operate as a transceiver in a half-duplex mode. To configure the TDA5051A in reception mode we must pull the DATA_IN pin of the TDA5051A at the receiver side high other than that the TDA5051A is connected the same way as in the transmitter side.

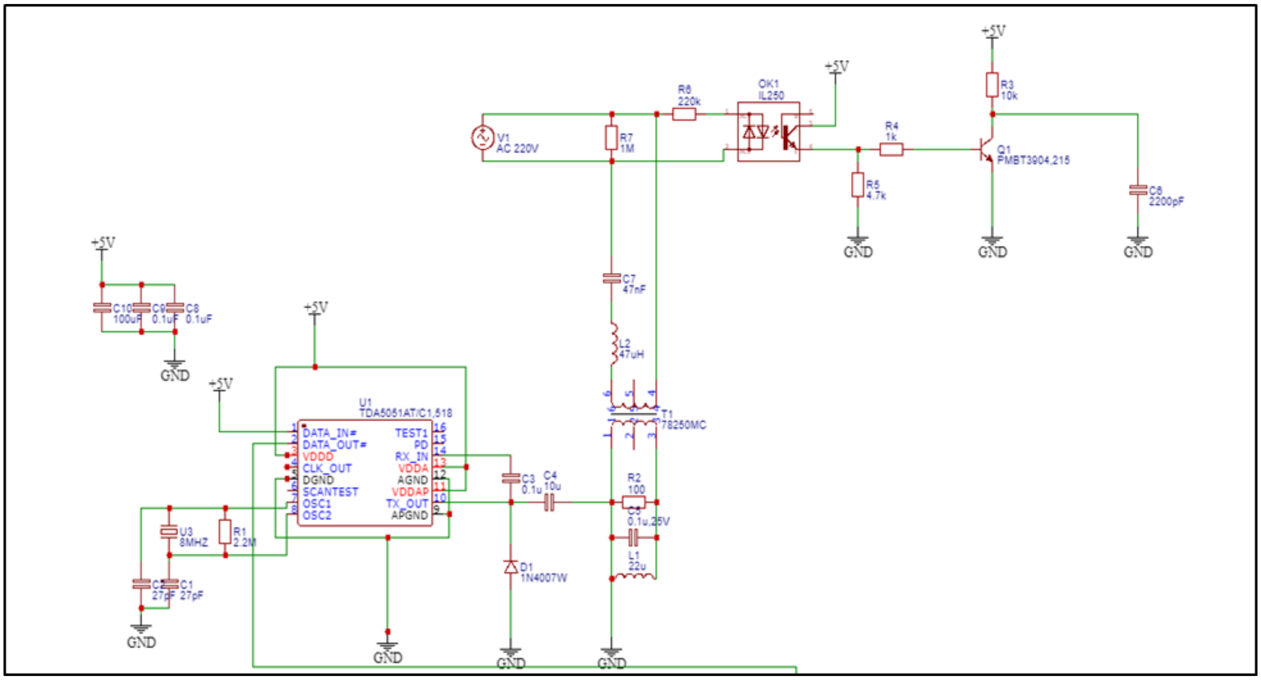


Figure 7.19 TDA5051A in reception mode

7.2.7.1 Receiver Waveform

we can observe that there is an input delay of about 132.3 us from RX input to DATA_OUT output.

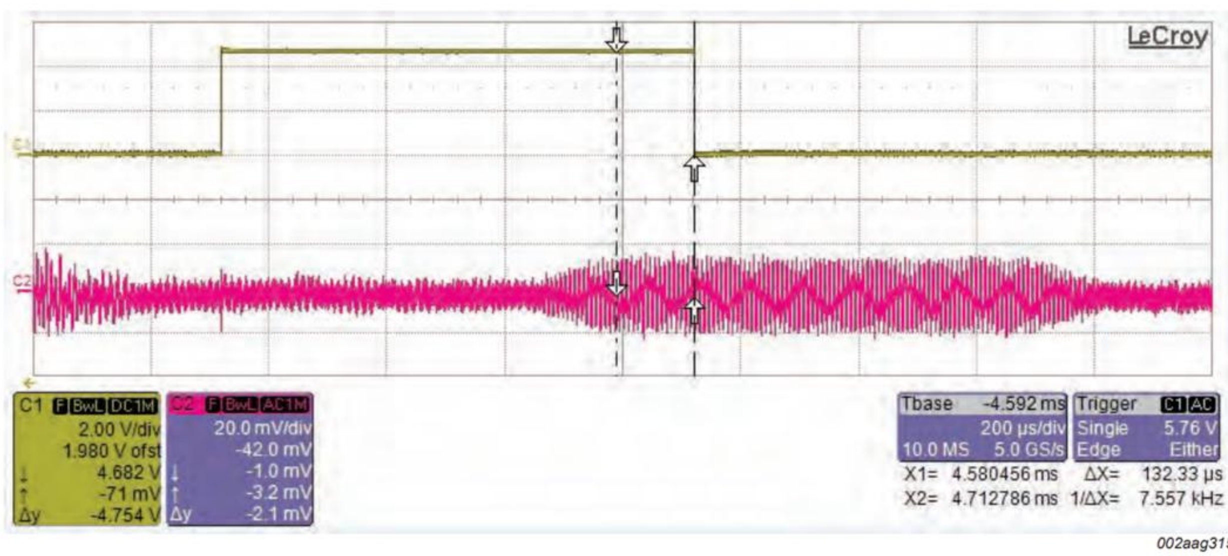


Figure 7.20 RX_INPUT to DATA_OUT delay C1 DATA_OUT, C2 RX_IN

7.2.8 Interfacing the TDA5051A Power Line modem with HT12D IC

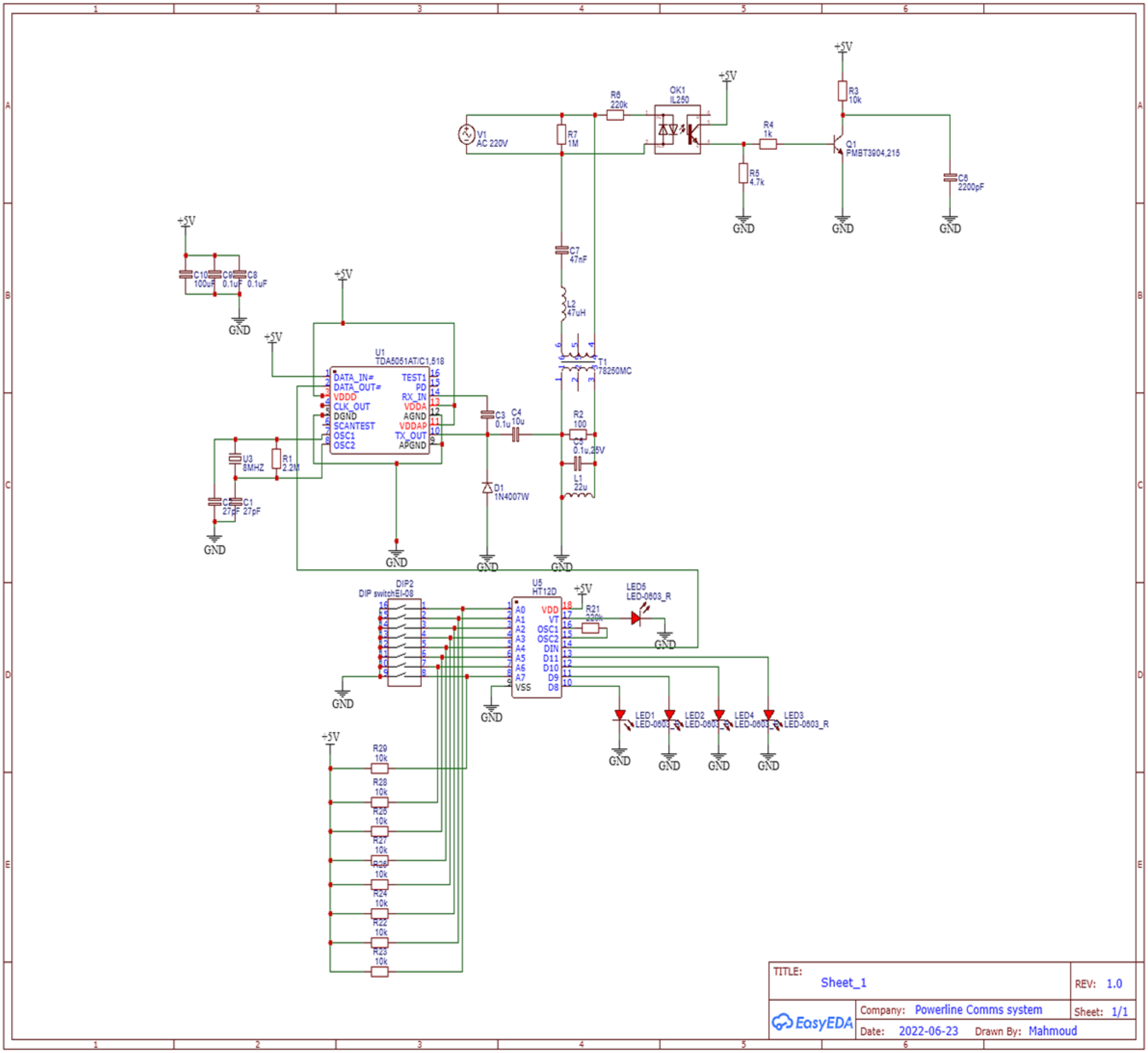
the TDA5051A receives the modulated signal from the power line then it filters it and demodulates it and produces the correct output bitstream on the DATA_OUT pin, to interface the TDA5051A with HT12D IC we simply connected the DATA_OUT pin of the TDA5051A to the DIN pin of the HT12D, The HT12D compares the serial input data three times continuously with their local addresses. If no error or unmatched codes are found, the input data codes are decoded and then transferred to the output pins. The VT pin also goes high to indicate a valid transmission. a full schematic of the receiver system is provided in the next page.

the 8 DIP switch is used to configure the address of the receiver unit so that when the HT12D receives the serial input it first compares the address received to its local address which is set by the 8 DIP switch if the addresses match it decodes the data bit stream and outputs it on the 4 data pins (D0~D3) which are connected to 4 LEDs for visual display and debugging purposes.

7.3 Feedback Based System

As it currently stands the transmitter unit has no way of knowing whether transmission succeeded or not which could introduce some problems , so to solve this issue a feedback system could be introduced where the receiver sends a certain code or an acknowledgment packet to signify that transmission was correct and data was received successfully , since that the TDA5051A operates as both a transmitter and receiver we could create a half-duplex system whereby the transmitter first sends its data and after the receiver receives this data if it was received correctly the receiver sends a confirmation packet to the transmitter to signal that transmission was successful.

the feedback system could also be expanded upon to create a fully functioning half duplex system where the feedback is not only used to send the confirmation packet but can also be used to send other codes and data back to the transmitter.


V1
AC 220V
R6
220k
R7
1M
OK1
IL250
+5V
R4
1k
R5
4.7k
R3
10k
Q1
PMBT3904,215
C6
2200pF
GND
C7
47nF
L2
47uH
T1
78250MC
C10
100uF
C9
0.1uF
C8
0.1uF
U1
TDA5051AT/C1,518
DATA_IN#
DATA_OUT#
VDDD
CLK_OUT
DGND
SCANTEST
OSC1
OSC2
TEST1
PD
RX_IN
VDDA
AGND
VDDAP
TX_OUT
APGND
C3
0.1u
C4
10u
R2
100
C5
0.1u,25V
L1
22u
D1
1N4007W
U3
8MHZ
R1
2.2M
C2
27pF
C1
27pF
DIP2
DIP switchEI-08
U5
HT12D
A0
A1
A2
A3
A4
A5
A6
A7
VSS
VDD
VT
OSC1
OSC2
DIN
D11
D10
D9
D8
R21
220k
LED5
LED-0603_R
LED1
LED-0603_R
LED2
LED-0603_R
LED4
LED-0603_R
LED3
LED-0603_R
R29
10k
R28
10k
R26
10k
R27
10k
R25
10k
R24
10k
R22
10k
R23
10k
TITLE:
Sheet_1
REV: 1.0
EasyEDA
Company: Powerline Comms system
Sheet: 1/1
Date: 2022-06-23
Drawn By: Mahmoud

7.3.1 Half Duplex System

A *half-duplex* (HDX) system provides communication in both directions, but only one direction at a time, not simultaneously in both directions. Typically, once a party begins receiving a signal, it must wait for the transmission to complete, before replying.

An example of a half-duplex system is a two-party system such as a walkie-talkie, wherein one must use "over" or another previously designated keyword to indicate the end of transmission and ensure that only one party transmits at a time. An analogy for a half-duplex system would be a one-lane section of road with traffic controllers at each end. Traffic can flow in both directions, but only one direction at a time, regulated by the traffic controllers.

Half-duplex systems are usually used to conserve bandwidth, at the cost of reducing the overall bidirectional throughput, since only a single communication channel is needed and is shared alternately between the two directions. For example, a walkie-talkie or a DECT phone or so-called TDD 4G or 5G phones requires only a single frequency for bidirectional communication, while a cell phone in the so-called FDD mode is a full-duplex device, and generally requires two frequencies to carry the two simultaneous voice channels, one in each direction.

In automatic communications systems such as two-way data-links, time-division multiplexing can be used for time allocations for communications in a half-duplex system. For example, station A on one end of the data link could be allowed to transmit for exactly one second, then station B on the other end could be allowed to transmit for exactly one second, and then the cycle repeats. In this scheme, the channel is never left idle.

In half-duplex systems, if more than one party transmits at the same time, a collision occurs, resulting in lost or distorted messages.

7.3.2 Half Duplex System Using TDA5051A and HT12E and HT12D IC

to implement a half-duplex system using TDA5051A and the HT12E and HT12D IC's we have to consider two things, first we need to figure out when will the transmission end so that the receiver can start sending the confirmation packet, second we have to ensure proper synchronization between the transmitter and the receiver so that only one party transmits at the same time to avoid contention and collision on the power line.

so we need to come up with a scheme to allow only one TDA5051A at a time to operate in transmission mode while the other operates in the reception mode.

from previous sections we have already established that for the TDA5051A to be in reception mode we need to pull the DATA_IN pin high while in reception so what we need to do is as follows.

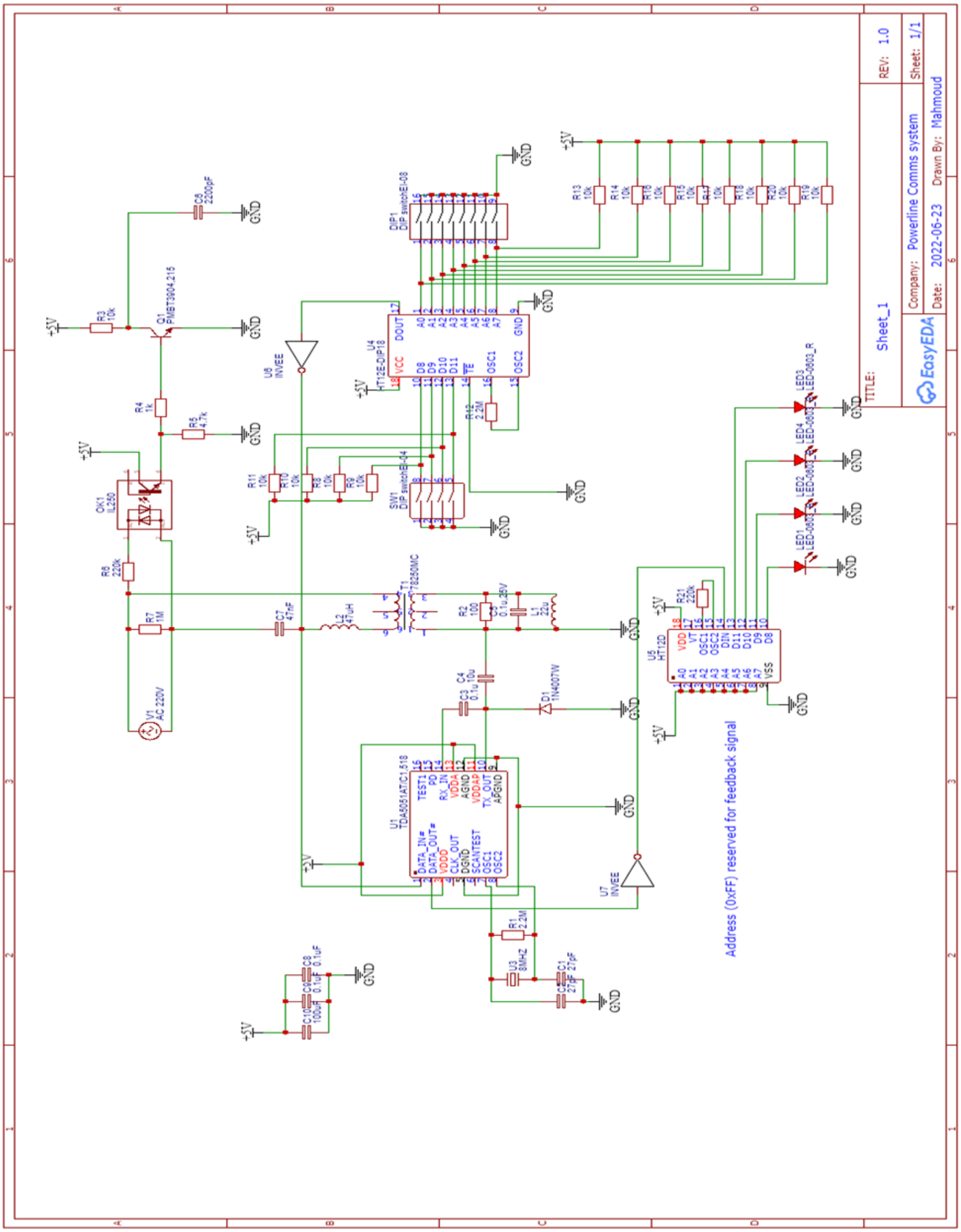
1. During operation of the transmitter the DATA_IN pin of the receiver unit is pulled high to disable transmission.
2. after the transmitter ends transmission the receiver now must operate in transmission mode to send the confirmation packet back to the transmitter.
3. when the receiver is sending the confirmation packet the DATA_IN pin of the transmitter must be disabled i.e we operate the TDA5051A at the transmitter side in reception mode.

7.3.2.1 Reconfiguring the Transmitter side to Receive the Feedback Signal

we will introduce 2 inverters at the side of the transmitter , since default the output level of the HT12E in standby mode is at logic level of "0" we can invert this to produce a logic level of "1" which is then fed into the DATA_IN pin of the transmitter effectively disabling transmission while the HT12E is in standby mode but by doing so our bit stream will be inverted so we need to invert the data received at the receiver side before it is fed into the HT12D decoder IC to obtain the correct data .

to receive data at the transmitter side we need to setup an HT12D decoder IC we will configure it at address 0xFF which will be reserved for the feedback confirmation packet the input DIN to the HT12D will be connected to the DATA_OUT pin of the TDA5051A but an inverter must be introduced from the DATA_OUT pin to the DIN pin of the HT12D IC for reasons that will be discussed in the next section.

a full schematic of the transmitter side is provided in the next page.


Address (0xFF) reserved for feedback signal
TITLE: Sheet_1
REV: 1.0
Company: Powerline Comms system
Sheet: 1/1
Date: 2022-06-23
Drawn By: Mahmoud
EasyEDA

7.3.2.2 Reconfigure the Receiver Side to Send the Feedback Signal

To configure the receiver side to generate a feedback signal we need a method to know when will the signal reception be completed.

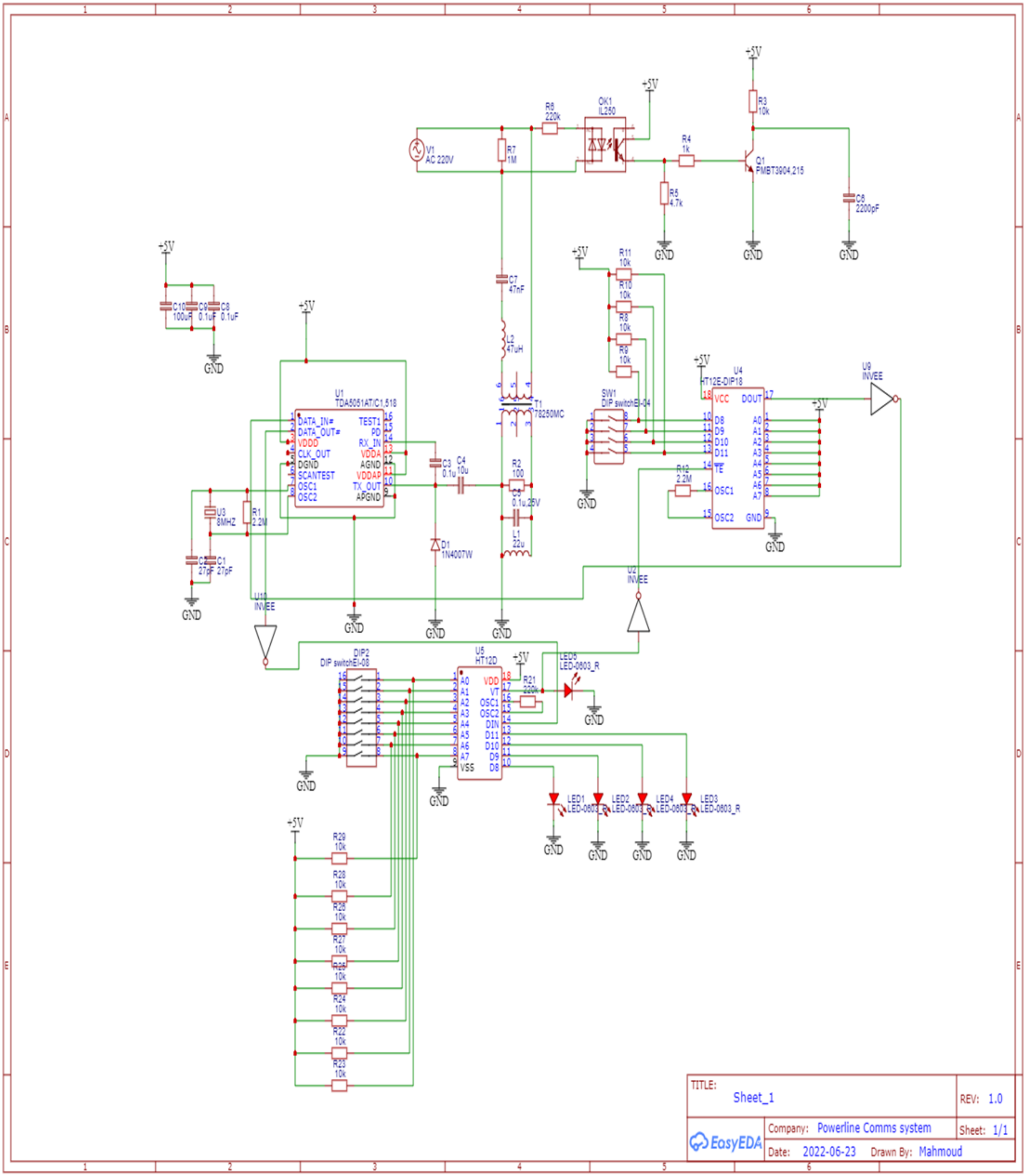
The HT12D IC provides such a signal on the VT (Valid transmission) pin the signal generates a short pulse after transmission is completed and the validity of the data has been checked we can use this signal to initiate the transmission of the feedback signal

So we will first setup an HT12E encoder IC at the receiver side to send the encoded feedback confirmation signal, as we have stated previously address 0xFF is reserved for the feedback confirmation signal, as for the data pins we have stated in a previous section that we have 16 different commands since we have 4 data bits so for the feedback confirmation signal we will be using command 0x0F (1111) in binary

After the HT12D decodes the data and checks for its validity the VT pin goes high for a short duration we will invert this signal and then feed it into the encoder's TE (transmission enable) pin as it is an active LOW signal to initiate transmission of the confirmation packet.

the output of HT12E encoder IC is connected to an inverter which is then connected to the DATA_IN pin of the TDA5051A IC to disable transmission when the HT12E is in standby mode.

the input to the HT12D decoder IC is connected to an inverter because the data sent is inverted so we need to install an inverter to obtain the correct bit stream. a full schematic is provided in the next page


U1
TDA5051AT/C1,518
U4
HT12E-DIP18
U5
HT12D
OK1
IL250
Q1
PMBT3904,215
T1
78250MC
V1
AC 220V
TITLE:
Sheet_1
REV: 1.0
Company: Powerline Comms system
Sheet: 1/1
Date: 2022-06-23
Drawn By: Mahmoud

8 DC POWERLINE COMMUNICATIONS

8.1 Introduction

The popularity of PLC adoption in smart grid applications has led to significant focus on PLC over AC power lines. However, narrowband PLC over DC lines is also gaining ground in home networking, lighting and solar applications as well as in transportation vehicles (electronic controls in airplanes, automobiles and trains). The use of PLC in these applications reduces wiring complexity, weight, and ultimately cost of communications.

One common question asked by system integrators is how to compare PLC over DC versus low-power wireless technology. While both PLC over DC and low-power wireless do not require new wire installation, with PLC, the connection is maintained even underground, through walls, and around corners. The communication channel is owned by the operator or utility, so the risks of sharing bandwidth are eliminated. PLC has no line-of-sight limitation and is not affected by weather.

In this chapter we focus on the use of PLC over DC power lines and present a reference design that can help adopt PLC over DC power lines quickly and effectively

8.2 Flexibility DC Solutions

Developing an effective PLC solution has its challenges. Typically, power lines are noisy and require a robust system architecture to ensure data reliability. Each end application and operating environment is different, thereby requiring a flexible design able to accommodate a wide variety of conditions. System designers need a flexible platform that enables them to optimize designs to the particular requirements of each application, and allows designs to adapt to new standards and market opportunities as they arise. In this way, intellectual property can be reused across multiple applications to accelerate development and speed time-to-market while expanding market opportunities. A key part to achieving flexibility is a modular architecture in terms of hardware and software. Breaking down complex PLC systems into a number of independent subsystems allows developers to change one aspect of a design (such as the modulation scheme or network protocol used) without having to completely redesign the entire system.

8.3 16x2 LCD Controlled over Power Line

This 16x2 LCD is too traditional and still very much popular in the world of electronics and embedded system. I remember I started programming on PIC for displaying text on these LCDs around 8 years ago. Now I just found one of these LCD from my junk box and want to try it out because it is nostalgic. It reminded me the 4-bit data lines plus additional 2 control pins, a total of 6 minimum signal pins and obviously additional 2 mandatory power wires +5v and GND, so a total of 8 wires. If this display is designed in 2019, for sure it will have only Vcc, GND and a single wire data pin or in worst case the 2 wire i2c or TWI. Then we thought why even 1 wire for data? Because we can easily multiplex the 1 wire data line with the Vcc line by keeping a diode plus capacitor combination towards the LCD power supply pin.

we are using an Arduino board to do the serial to parallel conversion plus some packet parsing and lcd backlight brightness control. we are not a huge fans of Arduino but for this simple proof of concept, we don't want to bring out a Makefile folder with multiple files. we picked the Arduino UART RX as the serial receiver. RX pin is connected directly to the input Vcc, but before the schottky diode. After the diode a capacitor is used to hold the DC voltage when the Vcc gets modulated with the UART TX of the other end. Better explained in Fig 8.1.

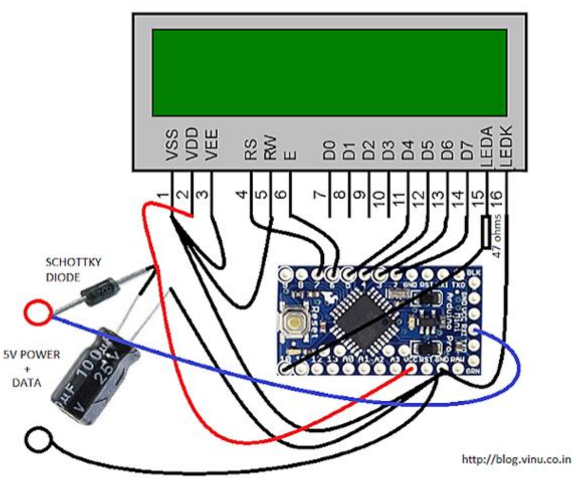


Figure 8.1

we haven't written any LCD related initialization in the Arduino, we just used it for serial to parallel converter plus backlight LED contrast control. So the entire display initialization could be sent from current-buffered UART port. There are 4 types of single byte commands which is implemented inside the Arduino.

(x is lower nibble, command is higher nibble)

0xA[x] where x is the lower nibble which will be placed on LCD pins 4 to 7

0xB[x] where if x is 1, RS will be SET HIGH, if zero, RS will be cleared or SET LOW.

0xC[x] where if x is 1, EN will be SET HIGH, if zero, EN will be cleared or SET LOW.

0xD[x] where if x is PWM value for LED backlight, its range is from 0 to 15 where it gives max brightness at 15.

we are using a USB to UART converter to connect the device to a laptop. A python script is doing the LCD initialization and data streaming. A small modulator circuit is used to convert the UART TX low power signal to a power signal which can load high current. we cannot use the TX pin as it is because it cannot load the current which is required to operate the LCD with backlight. So this buffer circuit is used and we are using 9600 baud rate so that the 2.2K resistor is low enough to maintain the fall time when the output stage MOSFET is OFF.

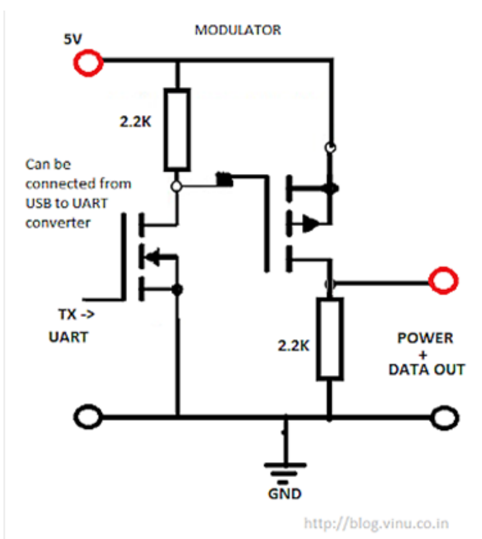


Figure 8.2 Modulator

Both MOSFETs are power MOSFETs with a bit higher current rating (say 5A) and for this application 200mA MOSFETs can also do the job, but I don't have such low current rated MOSFETs, so we just used whatever available with us.

We can do with NPN, PNP BJT as well, but in that case, series base resistors need to be connected to prevent base burnout).

The circuit and it's working is self-explanatory. Default level of UART TX is high. So the left MOSFET will be ON by default which turns ON the right side P-channel MOSFET. This provides 5V power to the output, when uart TX sends any bytes, it starts lowering the TX pin and that will cut the 5V power and the 2.2K output resistor will pull the power rail to zero. This zero is reflected to the Arduino RX pin, but since there is a diode and a capacitor, the capacitor holds enough power to maintain the display circuitry to work when the power input is modulated to zero by the UART. The role of diode is to prevent reverse discharge of the capacitor and thereby allowing the diode front-end voltage to follow the UART TX by not corrupting it. A schotkky diode is preferred. Also a low dropout is more preferred because this old LCD is kind of stricter about 5V input, if not the display fades, and there are some workarounds by giving negative voltage to VEE pin etc. So anyways, the RX pin see the signal as pure incoming UART bytes and it decode the byte according to the above mentioned 4 type of packets. It accordingly set the data lines, EN pin and RS pin.

Now a simple python script from PC side can imitate the LCD command and data along with the EN and RS control, the same was how we do with a microcontroller. The good part of this setup is that it is just working with 2 wires which provides the power to the system, so maybe we can say a kind of simple DC power line communication.

8.3.1 Firmware

```
void setup() {
  Serial.begin(9600);
  pinMode(2, OUTPUT); //D7
  pinMode(3, OUTPUT); //D6
  pinMode(4, OUTPUT); //D5
  pinMode(5, OUTPUT); //D4
  pinMode(6, OUTPUT); //EN
  pinMode(7, OUTPUT); //RS
  analogWrite(10, 255); //set backlight to maximum brightness
}

void setData(uint8_t d) {
 //not optimized. But it is okay.
  digitalWrite(5, 0);
  digitalWrite(4, 0);
  digitalWrite(3, 0);
  digitalWrite(2, 0);
  if (d & 1) digitalWrite(5, 1);
  if (d & 2) digitalWrite(4, 1);
  if (d & 4) digitalWrite(3, 1);
  if (d & 8) digitalWrite(2, 1);
}

void setEN(uint8_t d) {
  if (d) digitalWrite(6, 1);
  else digitalWrite(6, 0);
}

void setRS(uint8_t d) {
  if (d) digitalWrite(7, 1);
  else digitalWrite(7, 0);
}

void setLED(uint8_t d) {
  analogWrite(10, (d << 4));
}

void loop() {

  if (Serial.available()) {
    uint8_t a = Serial.read();
```

```
//Serial.write(a);
if ((a & 0xF0) == 0xA0) { //MS nibble A means LS nibble is 4 bit data
      setData(a & 0xf);
 } else if ((a & 0xF0) == 0xB0) {//MS nibble B means LSBit is RS
      setRS(a & 0xf);
 } else if ((a & 0xF0) == 0xC0) {//MS nibble C means LSBit is EN
      setEN(a & 0xf);
 } else if ((a & 0xF0) == 0xD0) {//MS nibble D means LS nibble is led
 brightness. MAX 15, min 0
      setLED(a & 0xf);
   }
 }
}
```

8.3.2 Python Script

```python
import serial,time

ser=serial.Serial()
ser.timeout=5
ser.port='COM7'
ser.baudrate=9600
ser.open()
time.sleep(1)
ser.flush()

ones = 1;

def write_lcd(byte):
    ser.write( (byte))


def send_command(command):
    hn = command >> 4
    hn = hn & 0x0f
    hn = hn | 0xa0
    write_lcd(chr(hn))
    write_lcd(chr(0xB0)) #RS LOW
    write_lcd(chr(0xC1)) #EN HIGH
    #time.sleep(0.01)
    write_lcd(chr(0xC0)) #EN HIGH
    #time.sleep(0.01)

    hn = command
    hn = hn & 0x0f
    hn = hn | 0xa0
    write_lcd(chr(hn))
    write_lcd(chr(0xB0)) #RS LOW
    write_lcd(chr(0xC1)) #EN HIGH
    #time.sleep(0.01)
    write_lcd(chr(0xC0)) #EN HIGH
    #time.sleep(0.01)

def send_data(data):

    hn = data >> 4
    hn = hn & 0x0f
```

```
    hn = hn | 0xa0
    write_lcd(chr(hn))
    write_lcd(chr(0xB1)) #RS LOW
    write_lcd(chr(0xC1)) #EN HIGH
    #time.sleep(0.01)
    write_lcd(chr(0xC0)) #EN low
    #time.sleep(0.01)

    hn = data
    hn = hn & 0x0f
    hn = hn | 0xa0
    write_lcd(chr(hn))
    write_lcd(chr(0xB1)) #RS LOW
    write_lcd(chr(0xC1)) #EN HIGH
    #time.sleep(0.01)
    write_lcd(chr(0xC0)) #EN HIGH
    #time.sleep(0.01)

def lcd_string(string):
    for i in range(len(string)):
        send_data(ord(string[i]))


#initialize the LCD
send_command(0x33)
send_command(0x33)
send_command(0x32)
send_command(0x28)
send_command(0x0e)
send_command(0x01)
send_command(0x6)
send_command(0x80)


cnt = 0;
send_command(0x80) #SET CURSOR TO 0,0
lcd_string("DATA OVER POWER ")

while 1:
  #THIS LOOP CONTINUOUSLY SENT "TESTING %d" on second line
    send_command(0xC0)
    lcd_string("TESTING " + str(cnt))
    time.sleep(.3)
    cnt = cnt + 1
```

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