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DALI MASTER CONTROLLER UNIT WITH A WIRELESS CONNECTION AND APPLICATION SOFTWARE

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ABSTRACT

In this study DALI controller device with a wireless connection will be constructed. The device will be used as a platform for studying software solutions to implementing embedded DALI system, the feasibility of DALI, the electrical performance of DALI interface and the wireless connection. The major tasks of this study are developing the embedded software for DALI controller, for the wireless module and the application software for a PC. The hardware for the platform requests various types of technologies. Evaluation boards and modules will be utilized as far they are available. However, at least DALI interface circuitry and DALI power unit must be entirely self-made. The platform and the software will be tested with several light ballasts. The wireless link will be tested in indoor environment. RF propagation tests will show what power levels will be required and how sensitive the RF-link is for the mutual orientation of the antennas. The device is named as a master controller unit because it serves as the main controller and commissioning tool, allowing the user to enter short addresses for the light ballasts, defining groups and scenes and executing other configuration tasks.

Keywords: DALI, digital lighting control, indoor wireless communication.

INTRODUCTION

DALI (Digital Addressable Lighting Interface) is a digital light control bus which uses two wires or twisted wire pair. DALI is based on standard IEC60929 [1] which was published in 2003. DALI was introduced already in the 1990s. A new standard IEC60386 was released in 2009. In that standard DALI was the first time introduced with LED lighting. During the following decade DALI become the most advanced digital lighting control interface in use. DALI is European origin technology. At the same time, DALI was developed in Europe; it was introduced also in the USA. NEMA (North American Electronics Manufacturer's Association) has published it own copy of DALI standard [2-3]. These two documents and the first IEC standard [1] are the documents which are in freely distribution at the moment. The more recent standard releases are available from IEC and various national standardization agencies.

The improvement DALI brings to lighting control is its bidirectional communication. Bidirectional means a controller can send request to ballast(s) and the ballast (s) can answer for that. There can be more than one controller in the bus. In addition to lighting ballasts there can be also some other devices and accessories used normally with lighting or in building automation. Such devices are for example: switches, scene controllers, dimmers, proximity-, occupancy- and daylight sensors and communications modules. DALI standard defines the connected device to be either a slave or a master. Controllers are masters as they can command or start communication. The others are slaves. In terminology of DALI, slaves are often called electronic control gears (ECG). Communication modules mean converters between DALI and other control systems like DMX512 (lighting) and KNX (home/building automation).

DALI TECHNOLOGY

Hardware

The hardware of DALI is rather simple and it can be build using inexpensive components. DALI device has an interface circuit with an opto-coupled connection to the bus. Using just two wires DALI supports half-duplex communication. Communication takes place using a rather slow speed, 1200 bits/s and using rather high voltage levels. High voltage levels mean high immunity to noise from other electrical wires or devices. Voltage of the bus is nominally 16 V, but it can vary between 11.5 V and 22.5 V. Logic levels are: logic zero -6.5 - 6.5 V and logic one 9.5 - 22.5V. According to the standard, devices connected to the bus are either ballasts (slaves) or controllers (masters). The maximum number of devices in the bus is 64 ballasts and 64 controllers. DALI standard does not request specific type of cable to be used. Typically, DALI is wired using the same kind of electrical cable as is used for electrical installations in a building. The maximum length depends on the conductor cross section. The standard sets the maximum allowed voltage difference between two devices, and that voltage is 2 V. The maximum current in the wire is specified to 250 mA. These values with the resistivity of the conductor set the limit for maximum cable length.

At the initial state DALI line voltage is high which also indicates logic 1. Logic zero is done by pulling down the line. At that moment, power is consumed. There must be a power supply unit connected to the bus. Like the

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cable type, the wiring topology can be chosen quite freely. Various topologies are possible, like a star or a mesh, but a ring is not recommended. Data is transmitted differentially, which means the wires are equal in DALI. There is no risk to connect the device wrongly. DALI includes both hardware and software protocol. It is indeed a wired control bus. While the use of DALI has expanded and integrated into home automation [4-5], DALI protocol has been adopted also to many wireless solutions [5]. Strictly speaking DALI is only a wired control bus defining both the hardware and the software protocol.

Software

Software brings the complexity to DALI. Communication means sending frames in two directions. Controlling light ballast can simply be unidirectional communication where the controller sends commands to the slave. This communication uses 2 byte commands. The response from a slave is a backward frame with only one data byte. Communication between controller type devices uses 3 byte commands. Figure-2 shows DALI forward and backward frames used in communication between a master and a slave unit. Each frame starts with a start bit. In a forward frame the first byte indicates whether the address is for an individual device (short address) or for a group or all devices (broadcast). The next six bits are address bits (max 64 addresses). The last bit indicates whether the next byte will be direct set or a command. The possible 3 rd. byte (with controllers) would be data. The backward frame is an answer from the slave, normally from ballast. Both frames end at the stop condition which is caused by leaving the line to the idle state (high) for the duration of 4 TE.

DALI includes a large number of general commands and a method of expanding the commands in order to access even a larger command set. The broadcast commands address all devices or for all the devices of selected type or for a selected group of devices. At symbol level DALI uses Manchester coding. DALI uses CSMA/CD principle and five priority levels. Figure-1 shows the principle of Manchester coding.

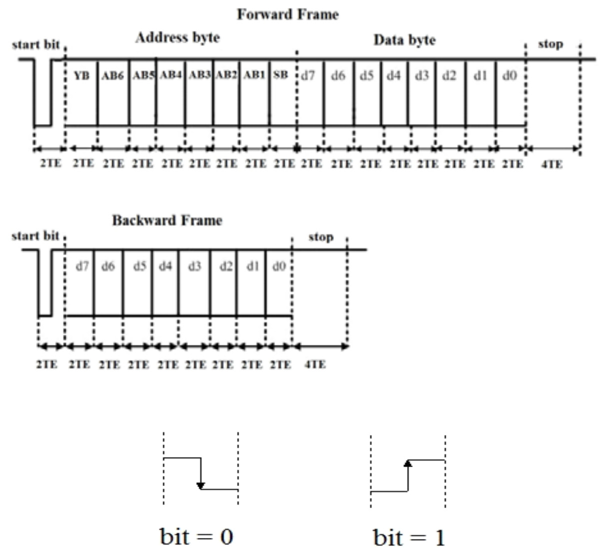

Figure-1. Above are DALI frames. A forward frame with one data byte and a backward frame. Timing is based on TE which is 416.67 us +/- 10%. Below is the principle of Manchester coding.

Wireless lighting control

LED lighting business focuses strongly to the wireless control of LED luminaires. Wireless means easiness for the users and in some cases a wireless solution can become less expensive than a solution which needs cable installations inside a building. Among many wireless technologies available, EnOcean and ZigBee are becoming the most famous wireless technologies in LED lighting [12]. A special version of ZigBee has been introduced for lighting application, namely ZigBee Light Link. Major interest focuses on short range wireless light control for situations which normally exist in indoor environments. Some studies have investigated a possibility to control light ballasts with a smart phone [13]. Wireless technology with smart phones is typically Bluetooth or WiFi. Some studies have proposed the use of wireless control in outdoor applications like in street lighting [9-10]. In such an application use of a mesh network can extend the control distance theoretically without any limits although the RF coverage of each mesh node is limited. In this study, a short range point-to-point wireless link will be developed. The idea is to improve the feasibility of the DALI master controller and especially enhance its use as a commissioning tool.

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DALI MASTER CONTROLLER UNIT

Embedded software of DALI controller

In Manchester coding, the transition direction indicates whether the bit is one or zero. Low-to-high means the bit is one and high-to-low means the bit is zero. In DALI bit zero means the line is low for the duration of TE = 416 us. If the next bit is one, the duration the line remains low is 2 TE. At that moment, the switching component will draw quite a high current from DALI line. DALI encoding procedure is rather simple. It is shown in Figure-2. However, the procedure is a bit simplified as it does not show the selection of the right time slot. In case the priority is not 0, but 1-4, the controller must wait for the right number of timeslots before starting the transmission. The software must monitor possible collision on line which happens when another device is trying to use the line at the same time. As only logic zero can be detected, this means that a collision can be detected at the moment logic high should be send but another device is driving the line to low. In this case DALI standard dictates the device which detects the collision should stop transmission and let the other device to proceed. Unlike many other CSMA/CD protocols, DALI does not feature priority enhancement in case of an interrupted transmission. The new transmission starts at the same priority as the interrupted one.

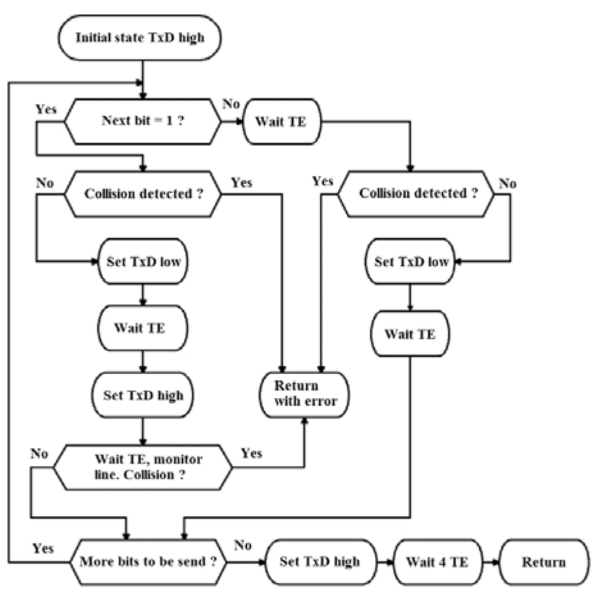

Figure-2. DALI encoding procedure. TE is 416 us +/- 10%. Priority slot implementation is not shown in this procedure.

The decoding procedure is somewhat more complex than the encoding. Several procedures for Manchester decoding exist. In this study, a new procedure was developed. The main target was to generate a procedure which could easily be implemented using a small microcontroller. The result is shown in Figure-3. At the procedure consecutive edges are monitored and time between the edges is measured. One additional variable must be introduced. In this figure it is labelled as "skip". This means that some of the edges must be skipped. Edge detection and time measurement between edges is based on the input capture functions of the microcontroller. The microcontroller must monitor the line to detect possible transmission interrupt. If the transmission proceeds normally, it ends at an idle line condition. The idle line (line remains at high) should last at least 4 TE to be recognized as the stop condition. This releases the line to the use of other connected devices.

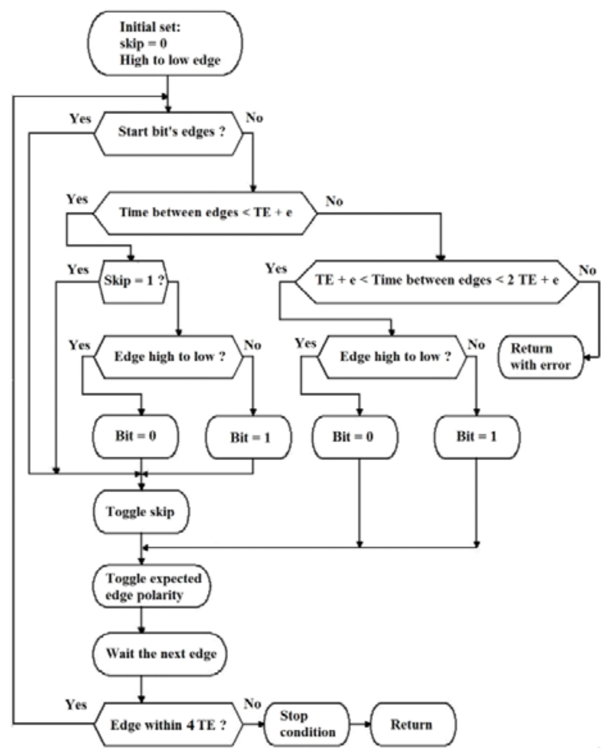

Figure-3. The developed novel DALI decoding procedure. Parameter e is the tolerance +/- 10% in timing as specified in DALI standard.

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Principally one timer could provide all the timer functions of DALI application. However, the embedded software becomes more compact if several timers are involved. The used microcontroller has a total of four timers. They can all be utilized in this application. Table-1 lists the use of these timers. TimerA0 features the time measurement capability needed for the decoding as shown in Figure-3. TimerA1 provides the most important time base of 416 us needed throughout the embedded software. TimerA2 is used to detect two time durations, namely the minimum time between two consecutive frames and the stop condition. TimerB0 is left for monitoring DALI line and the available priority slots continuously.

Table-1. Timers of the microcontroller MSP43F5529 and their use in DALI master controller unit.

Timer	Function in DALI master unit
Timer A0	Time measuring in decoding input stream
Timer A1	Time base for TE = 416 us
Timer A2	Time between frames 22 x TE Stop condition duration 4 x TE
Timer B0	Time measuring for priority slots

Testing the embedded software

The tests were made with a commercial DALI LED driver connected to the line. Cable length was 25 m. DALI line voltage was 15.4V close to the nominal voltage of DALI specification. There is a small overshoot on the rising edge of the waveform. This could be compensated on the interface circuit. The commercial driver also shows equal size overshoot at the rising edge. That causes no problems. Some measured waveforms in Figure-4 show how the software conform the basic DALI timing.

Figure-4 (top) shows command "set to default values" 0xFF 0x20. This is a command which has to be repeated within 100 ms. In this case, the priority is manually set to 0, meaning the resend is initiated after the minimum forward frame spacing, 22 TE.

Figure-4 (bottom) shows the request command "request the version number" 0xFF 0x97 and its response 0x01. This means the driver conforms DALI version 1.0. The response starts approximately 15.3 TE after the end of the forward frame. This is over 7 TE and less than 22 TE as the specification demands. The build DALI interface is able to drive the line down to 2.8 V as logical zero. For some reason the logic zero voltage level of the commercial driver is quite high, 9.8 V. This is slight outside the DALI specs. However, the response will be decoded successfully.

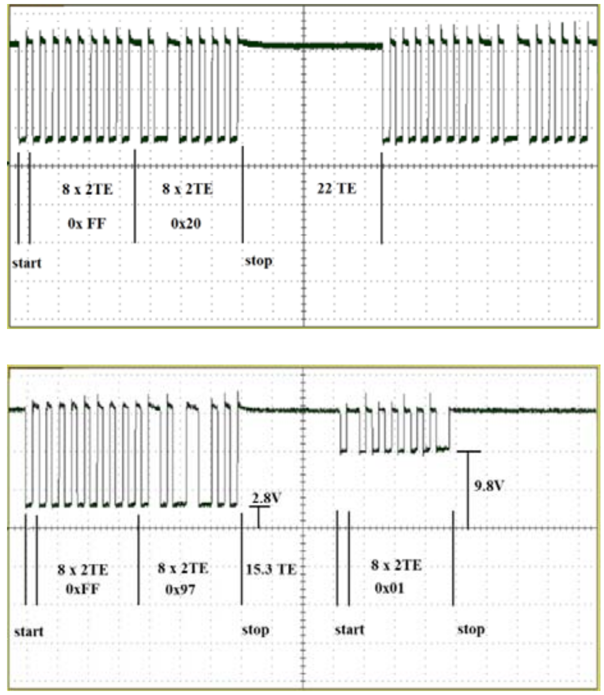

Figure-4. Measured waveforms with added time marks. Horizontal division is 2 ms, vertical 5V. Above is a repeated command. Below are a request command and its response.

DALI controller hardware

The hardware setup utilizes some evaluation platforms like MSP430F5529 LaunchPad, eZ430-RF2500 wireless module and USB-UART module with circuit CP2102 (Silicon Labs Inc.). DALI interface circuit and DALI power unit are specially made for this project as well as the linear power supply for the wireless module. The hardware is composed of two parts. A RF-dongle is needed for the side of a PC. DALI controller unit with RF link and DALI interface is used on the side of DALI network. A simplified diagram for the hardware setup is shown in Figure-5 and a photo in Figure-6. The RF-dongle is not shown in this photo.

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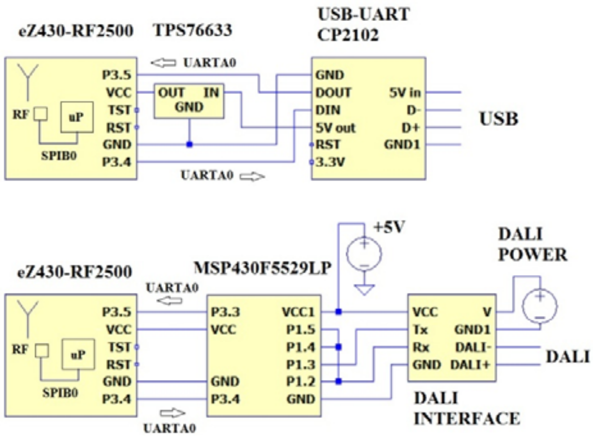

Figure-5. The schematics of the developed platform. RF-dongle (above) and DALI module with the RF transceiver module (below).

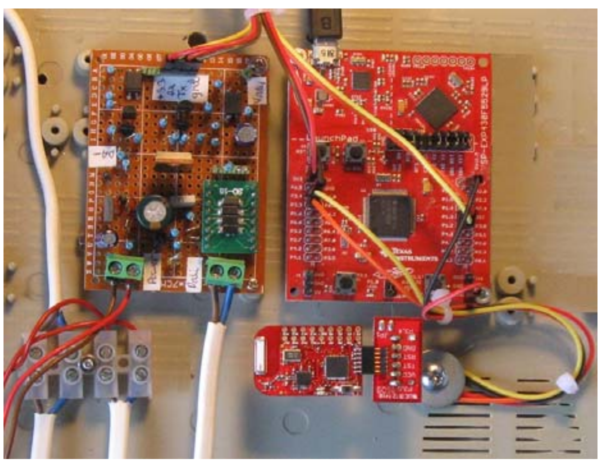

Figure-6. The developed platform. On the left is DALI interface circuitry, on the right MSP430F5529LP and below eZ430-RF2500 wireless module and its socket.

DALI interface circuit provides the physical connection to DALI network cable. It also features level exchange between 3.3V logic and higher DALI signal levels. The interface is opto-isolated.

Wireless connection

DALI is a wired technology. The standard specifies the physical layer which normally is built by using a standard electrical cable. The maximum cable length is specified by the maximum voltage drop between two DALI devices. The maximum cable length of DALI network is typically 150-300 m. This distance sets the target for the needed wireless link coverage.

In this study, a short range wireless link is designed and demonstrated in order to help the use of DALI master controller as DALI commissioning tool. In such an arrangement, a RF-dongle is connected to the terminal device (in this case for a PC) and DALI controller device with a RF-link is connected to DALI cable connector. With such a terminal device in hand a person can freely move inside a building in the range of the DALI network.

The RF-link will be based on the use of ISM frequencies. Considering the frequency there are some choices below 1 GHz and 2.4 GHz band. As the frequency increases the attenuation increases as well. Therefore frequencies 433 MHz and 868-870 MHz (Europe) or 902-928 MHz (USA), could allow longer coverage than 2.4-2.5 GHz. But the size of an antenna is smaller at the higher frequencies. If antennas are made equal in sizes, the antenna gain will be higher at the higher frequencies. For this application the higher frequency is more favourable. 2.4 GHz was selected as distance between DALI devices is rather small and the small size of a RF-link is desirable.

The second choice is made between the protocols of wireless networks. There are a number of short range RF protocols available. Among them ZigBee seems to be favoured [14] in wireless LED lighting controls. In this study it was decided not to favour any of those protocols. The choice was made for a transceiver circuit without any protocol. The idea is to develop a light protocol for this application. For just providing a wireless connection between two nodes the protocol can be simple. The RF-link forms a packet which includes the message, an address byte, CRC check sum and the content of RSSI register (Received Signal Strength Indicator). In the reception, these are disassembled from the packet. The content of RSSI register is a good indicator of the quality of the wireless connection.

For this study, the choice was made for Chipcon transceiver circuit CC2500. This circuit is mounted on eZ430-RF2500 Development Tool (Texas Instruments) printed circuit board. On the board there is also a ceramic multilayer antenna and a microcontroller MSP430F2274. This board is ideal for the wireless DALI application. The transceiver circuit is a rather complex device. There are more than 50 registers which must be set in a proper way during the initialization of the RF-link. The communication between the transceiver and the microcontroller is based on 3-wire SPI bus. This leaves one 2-wire UART bus available for the communication between the microcontroller and an external device. UART-USB module with a linear regulator is added to the hardware of the RF-dongle. This completes the hardware design on the side of the terminal device. For ZigBee protocol, one could find a complete RF-dongle for a design [11].

Without a power amplifier on eZ430-RF2500 module, the maximum power the transceiver can source to the antenna is limited to +1 dBm. This is slightly over 1 mW. To make sure the power is adequate for the application some RF propagation measurements were

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carried on. Antenna source power was varied in range -30 - -22 dBm. The maximum distance between the link devices was measured. The antenna radiation pattern [6] shows the maximum gain is within an angle of 60 degrees. The antennas were set horizontally at the same level, elevated 1.5 m from the floor level and directed towards each other to get the maximum gain. The results are shown in Table-2. When one of the antennas was turned horizontally 90 degrees, antenna gain minimum was observed. The measured distances drop to approximately half of the maximum. The measurements were done for the data rate of 250 kbit/s using MSK modulation (Minimum Shift Keying). In these conditions, the receiver sensitivity is -89 dBm. If the data rate is reduced to2.4 kbit/s, the sensitivity is improved to -104 dBm. Table-2 lists calculated distances for that case. For DALI application the data rate can be set to 1.2 kbit/s which also happens to be the minimum available data rate of the transceiver.

The results indicate that the output power and receiver sensitivity of Z430-RF2500 module results in adequate RF coverage. This is valid also for cases where the mutual orientation of the antennas is not optimal.

Table-2. The measured maximum distance for given RF-power using 250 kbit/s data rate and MSK modulation. Values for 2.4 kbit/s using FSK-2 modulation are calculated.

Power [dBm]	Data rate 250 kbit/s	Data rate 2.4 kbit/s
-30	6.0 m	23.0 m
-28	7.0 m	27.5 m
-26	8.5 m	33.0 m
-24	10.0 m	39.5 m
-22	13.0 m	50.0 m

The propagation loss can be calculated using a general equation (1) which includes the frequency, the distance and the path loss exponent. This equation is valid both for outdoor and indoor conditions. The path loss exponent n must be set according to the environment. For a free space conditions, where the transmitter and the receiver are located the line of sight, n is 2. In other conditions where attenuation is caused by absorption, reflections and multipath propagation, n is higher than 2. For the most indoor office environments, n is in range 2.5-4. For heavily furnished or populated rooms, n can be higher than 4 and for the most RF unfriendly environments n rises up to 8.

$$L_p = -27.55 + 20\log_{10}(f) + n10\log_{10}(d) \qquad (1)$$

L_p = loss [dB]
f = frequency [MHz]
d = distance [m]
n = path loss exponent

The measured maximum distances and the calculated attenuation were set in a drawing showing attenuation versus distance. Attenuations were calculated by using the output power, the average antenna gain and the typical receiver sensitivity. Then equation (1) was calculated with various values of n. It becomes clear that measured values fit the best for a curve calculated with n = 2.55. This is an expected result for the rather empty office environment.

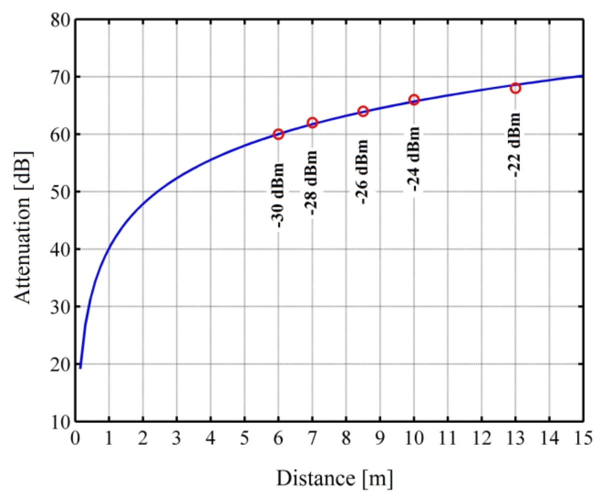

Figure-7. The measured attenuation and the maximum distance between two wireless DALI units using eZ430-RF2500 modules. Transceiver parameters: Modulation MSK, 250 kbits/s, f = 2.433 GHz, Rx filter 540 kHz and receiver sensitivity -89 dBm. Transmitter powers are shown. Antenna gains +1 dBi. Path loss exponent n = 2.55.

RF-signal propagation in indoor environments has been widely studied. Particularly 2.4 GHz band has been studied much as 802.11 WiFi/WLAN networks operate at these frequencies. [7] reports typical results of RF attenuation in short range communication inside a building. Structure of the building, the number or walls, type of building materials etc. have an effect on the attenuation. It is interesting to note that corridors can help in RF propagation as the measured attenuation in a corridor could be less than attenuation in free space. Multipath propagation and reflections have an effect on overall attenuation. Objects outside a building, like other buildings nearby, can also affect the attenuation inside the building. Special models for buildings of certain kind, like for an office, a library or an airport terminal can be developed as shown by [8].

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DALI application software

Application software for a PC was developed with MS Visual Studio as C++ project. In this application MS Foundation Class objects were utilized. These are edit boxes, drop boxes, slide bars etc. In the first version, basically all functions are available on the same window. The user first sets the UART parameters and establishes the connection to the RF-dongle. The user is then free to enter DALI commands. First the user should select the addressing mode: the group address, the short address (individual device), or broadcast (all devices). Then the user chooses the command. In this software, those are listed in groups: direct set (for example lighting level set), indirect commands (a large number of commands which utilizes programmed scenes, fade rates etc.), request commands (commands which return a value), configuration commands (commands which set groups and define scenes etc.), extension commands (expands command set), extended commands (those which are used after the extension command), and special commands (the rest of the commands). The user interface allows user to enter values numerically or by using a slider. After pressing "send", command is send. The software chooses appropriate priority for the command. The possible response will be shown. The hole command set of DALI is huge. In this project, the supported command set is some extent limited.

CONCLUSIONS

DALI master lighting controller unit with a wireless connection has been experimented. Embedded software for the microcontroller used in the DALI controller and software for the microcontroller on the RF transceiver module has been developed. Application software for a PC has been developed as MS Visual Studio C++ project. For the embedded DALI software, a procedure for Manchester encoding and new Manchester decoding procedure has been presented. These procedures can easily be implemented for a low-cost microcontroller. The wireless connection needs a USB RF-dongle for the PC which utilizes a protocol free RF transceiver for 2.4 GHz ISM bands. Wireless functionality has been tested in indoor environment to specify the required transmission power for distances typical for this application. The measured free space path losses matched the values calculated by using a loss coefficient of approximately 2.5, a value typical for non-densely furnished or populated indoor space. The developed device is a controller unit which can be used as DALI commissioning tool. The wireless connection lets the user freely move inside a room or a floor of a building while executing the commissioning tasks for example giving short addresses for the light ballasts, defining groups, scenes and executing other configuration tasks.

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