WIRELESS TEMPERATURE SENSOR NETWORK
Wireless Sensor Data Transfer as Well as Processing

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Abstract: The realized system for wireless measurement of temperature in the many different places is described. The paper describes a new architecture of a multisensor system for remote temperature measurement using wireless communications. The system is composed of temperature sensors with digital output. The system ensures RF wireless data transfer, wireless communication between control unit and sensors as well as wireless switch unit. The integrated RF chip nRF9E5 ensures wireless communication. The control unit controls communications, sensor data processing as well as switching of actuator unit. The control unit contains main control microprocessor ATMEL as well as wireless communication unit. The actuator switch unit communicates with control unit using RF wireless way. Partial control programmes were designed for wireless unit control. There are many program functions implemented. The control software of the whole system has been designed. The designed system, i.e. hardware and software has been realized and tested. The system can operated in the range of 300 m in the free space. The number of sensor can be extensible. The system can be use to operate with different type of sensor, i.e. for measurement other type of quantities. PDA or mobile phone can be used to communication with control unit.

1 INTRODUCTION

Wireless transmission is very popular today for sensor data transmission. Most RF chips are capable to perform coding, decoding and transmitted data synchronization at least partly, they can also feature enhanced data security by adding CRC, parity bits etc. These circuits perform these activities without the need of programmed control, simplifying the programmer's work considerably. The RF chips are frequently fabricated in the form of transceivers, i.e. they include both a transmitter and a receiver in a single package; then, the same chip can be used in all instruments, bidirectional communication presents no problems (Varadan, 2003). Many producers also combine transceivers with other circuits like A/D converters or microprocessors.

The ZigBee communication system fits well to sensor data transmission. The standard makes possible mutual communication of numerous instruments over a distance of hundreds of meters. It is distinguished by low requirements on hardware and by extremely low power consumption. It is described by the IEEE 802.15.4 specification. ZigBee replaces the data transmission by RS232 or RS485 series bus.

In our case we have used a RF module in the Nordic technology. Its principle of operation is similar to ZigBee. The chips operate at frequencies 433 MHz, 868 MHz, 915 MHz or 2.4 GHz. Transmission speed is 50 kb/s and 250 kb/s in the 2.4 GHz band. In the 868 MHz band, Nordic has 7 channels, as compared with 1 channel in ZigBee, 83 channels in the 2.4 GHz band compared to 16. The data frame is smaller, too, in addition to data it only contains a 10-bit header, 32-bit address and a 16-bit CRC. All chips are capable of bidirectional operation.

The system is designed with temperature sensors. With small adjustments, the above mentioned principle can be used for quantities from other energy domains (the pressure system, flow multisensor system, humidity multisensor system, etc.), (Kirianaki,N.V., 2002).

2 COMMUNICATION CIRCUITS DESIGN

The communication circuit. The type nRF9E5 circuit was selected for the communication circuits design. The circuit contains a RF transceiver, an 8051

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architecture compatible microprocessor and an AD converter (nordicsemi, 2006).

The transceiver consists of a frequency synthesizer, power amplifier, modulator and receiver unit. It operates in the 433/868/915 MHz ISM bands with adjustable frequency and output power. GFSK (Gaussian Frequency Shift Keying) modulation is used for the transmission, featuring a lower bandwidth than conventional frequency modulation. The modulation width is ±50 kHz. The data are internally coded/decoded according to Manchester code, resulting in 50 kb/s effective transmission speed. The transceiver communicates with the built in microprocessor through an internal SPI interface. Three operating modes are available in the transceiver: standby, transmission and reception.

The AD converter in this circuit has 4 inputs and 10 bits. The inputs can be operated as differential and the supply voltage can be measured internally. Resolution can be adjusted in 4 steps from 6 to 12 bits. The internal SPI interface is used for A/D converter control just like the transceiver. The circuit also has an input for AD converter reference voltage. Alternately it is possible to use the internal 1.22 V reference source. It is further possible (when the external input is left free) to measure the circuit supply voltage. In this case, internal reference is used and 1/3 of the supply voltage is measured. Conversion time is 8 to 14 µs, depending on resolution.

As further hardware the circuit contains a single channel PWM modulator, controlled by PWMCON and PWMDUTY registers. Further the Watchdog, Wakeup timer and low power consumption clock pulse source. The watchdog timer is a 16 bit counter serving to reset the microprocessor in case of an error or endless loop in the program. The Wakeup timer serves for interrupt or finish of some of the economy modes. It is a 24 bit counter with automatic fresh value recording, calling the required operation upon reaching.

The main microprocessor. The microprocessor is 8051 architecture compatible. It includes 4 kB program memory, 256 bytes of data memory and special function registers. The upper 128 bits are accessible by indirect addressing since they are shared with special function register addresses. The program memory is a RAM type and the program is recorded in it by the Bootloader after SPI from the EEPROM memory after resetting. A header must be present in front of the program in the memory, containing the memory speed, crystal frequency and user data.

An ATMEL 89S8253 type was selected as the control processor. It is a 8051 architecture compatible microprocessor, containing additional 2 kB data EEPROM, 12 kB FLASH program memory, SPI interface and further hardware. Both the program and data memories are In System Programmable (ISP), by series programming through the included SPI interface. Further the circuit contains a 256 byte ARM memory, whose upper 128 bits are accessible by indirect addressing since they are shared with SFR special function register addresses. The lower 32 bytes of RAM are four register banks. Instructions are fully compatible with the 8051 architecture and operate identically (atmel, 2006). The instruction timing is the same as in the preceding case.

The sensors. The DS620 sensor as example can be used for the measurement of temperature. The circuit contains a temperature sensor, A/D converter, comparator and a series interface. It does not need any external components for its operation (DS620, 2006). The temperature measurement range is -55 ^{0}C to +125 ^{0}C. The A/D converter resolution can be adjusted from 10 to 13 bits, corresponding to 0.5 ^{0}C to 0.0625^{0}C resolution. The conversion duration depends on resolution and takes between 25 ms and 200 ms. A twin lead I_2C bus is used for communication. The SCL terminal serves for reception of clock pulses and the SDA terminal for data reception or transmission. The circuit also contains an EEPROM memory to which a part of registers can be copied and so preserve the setting even when the power supply is disconnected.

The real time circuit. DS1302 is a real time circuit, counting seconds, minutes, hours, day of the week and date including the year. For its operation the circuit needs only an external crystal with 32768 Hz frequency and an optional battery for continuing function even when the primary power supply is switched off. The circuit also contains 31 bytes of user RAM memory, supported by the secondary supply voltage (DS1302, 2006).

3 SENSOR SYSTEM CONCEPT

The suggested wireless thermostat consists of several parts. The control unit is the basic part, securing communication with the user by means of the display and keyboard. The unit communicates with wireless temperature sensors and wireless switch units. It is provided with custom-set programs "temperature intervals", controlling the whole system. Second part of the system is represented by the wireless temperature sensors. The sensors are placed in required localities. The sensors measure temperature periodically and convey the measured data tot the control unit. The third part is the wireless switch units. The units communicate with the control unit periodically and switch relays on or off according to the measured temperatures and values set by the user. A block schematic diagram of the whole system is shown in Figure 1. The temperature sensors and switch units can be placed at random individually and independently according to the user's needs. The only condition they have to fulfill is that they must lie within the wireless communication range. The communication with the user is performed by means of six push buttons and a 4 line display. Most user program settings and settings of further parameters is dome with the aid of a menu appearing on the display upon pressing the appropriate button. During normal operation, information from individual zones are displayed periodically. They indicate the set and measured temperature in a particular zone, sensor and control unit battery voltage as well as an indication of on or off state of the relay contacts.

The communication runs according the following scheme: Before start of a transmission, each temperature sensor or switching unit checks if another unit is not transmitting. Then the sensor transmits its data to the control unit and waits for reception acknowledgement. If no acknowledgement arrives until a certain time interval, the whole process is repeated. When the control unit receives data from a sensor, it first checks if it can transmit and then sends the acknowledgement reply. The reply to a switch unit also contains the information on required new relay state.

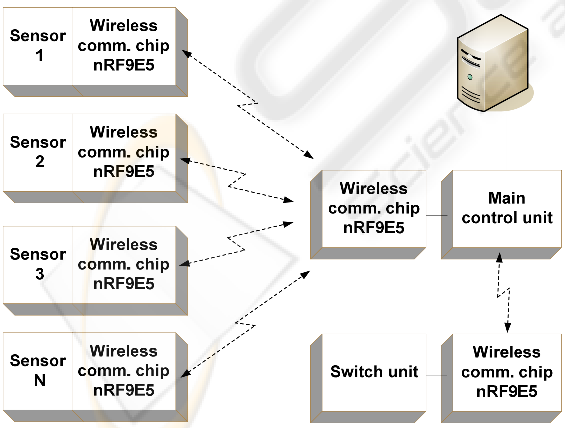

Figure 1: Architecture of wireless sensor system.

3.1 Wireless Sensor Unit

Every sensor unit consists of a nRF9E wireless chip, program memory and a symmetrical output element - Figure 2. The input block is the temperature sensor. The sensor used contains an AD converter and a series interface. The communication with the microprocessor takes place over an I^2C bus. The second block is the microprocessor with integrated transceiver, processing the sensor data and communicating with the control unit. The program 25320 EEPROM memory serves to store the microprocessor program. The memory is connected through the SPI series bus. The external antenna is connected through a symmetrizing transformer (balun).

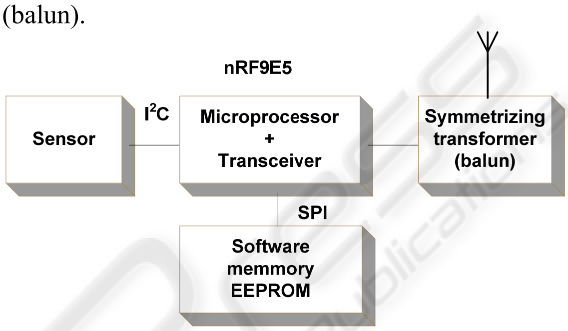

Figure 2: Wireless sensor unit.

3.2 Wireless Switch Unit

The base of the wireless switch unit is a wireless sensor unit, followed by the power switch part. A block diagram is shown in Figure 3. The core is a microprocessor with a transceiver, with program memory connected through SPI and an antenna connected through a balun like in the temperature sensor. The output block is a power switch unit controlled by two signals from the microprocessor. The power switch device is a polarized bistable relay. The relay is advantageous especially due to its low power consumption (battery supply).

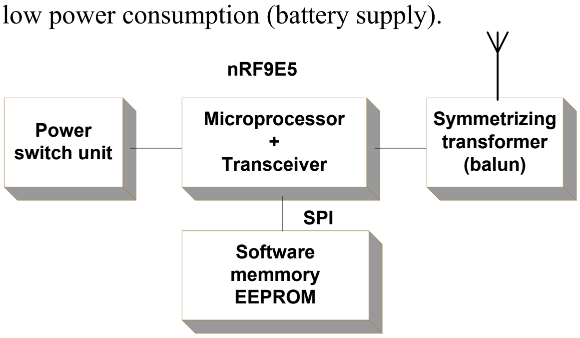

Figure 3: Wireless switch unit.

Its contacts remain in the "on" or "off" state without the need for any power. Power is consumed in the form of short pulses only, needed to change the relay state. Contact switching is performed by connecting a voltage of proper polarity to the relay. The relay selected is type G6CU-2117P-US made by OMRON (omron, 2006). Nominal coil voltage is 3 V and the maker guarantees correct function at 70% of nominal voltage. The coil power consumption is about 200 mW and minimum pulse duration for state changeover is 200 ms.

3.3 Wireless Control Unit

The block diagram of the wireless control unit is in Figure 4. A keyboard and a display serve for communication with the user. The keyboard uses matrix connection and is connected to the microprocessor through five conductors. The display is connected by means of a buffer circuit. Four data and four control signals serve for communication (one microprocessor port). The main part is the control microprocessor, t which all remaining parts of the system are connected. The real time circuit communicates by means of a serial bus. The bus consists of the SCLK signal for clock frequency transmission, the I/O signal for data and chip select signal transmission. The transmitting and receiving parts are very similar to those of the wireless temperature sensor and the switch unit. The microprocessor, memory and antenna connections are the same, the SPI bus is used for connection with the controlling microprocessor (MISO, MOSI, SCK signals). The slave select signal is software on one of the microprocessor ports. Two voltages are needed for control unit supply, namely 3.3 V and 5 V. The 5 V supply is used for of the LCD display and its buffer circuit. All other circuits are supplied by the 3.3 V. A type HD4478U controller, common with character type LCDs is used to control the display (alldatasheet, 2006). A type AT89S8253 circuit is the core of the control unit. Since the nRF9E5 circuit has the SPI hardware as master only, the control processor must be operated in slave mode.

A simple converter serves for communication with a PC over RS232 line. It is based on a type MAC3232 circuit. The circuit contains a doubler and voltage inverter in addition to the RS232 line drivers/converters (maxim, 2006).

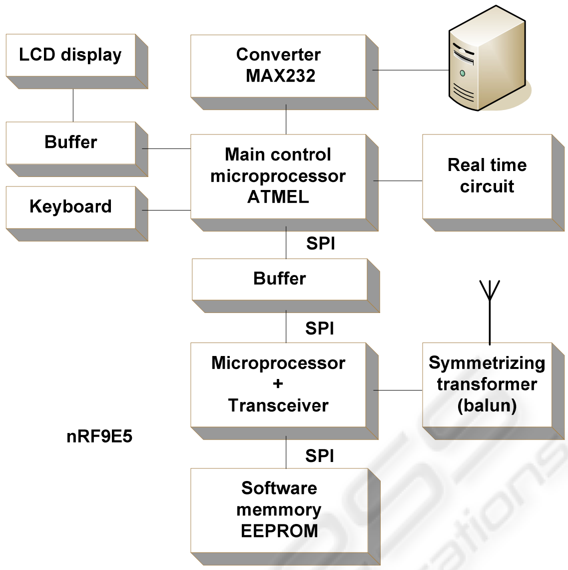

Figure 4: Wireless control unit.

4 CONTROL SOFTWARE

Wireless temperature sensor unit control program. The wireless sensor unit control program is based on an endless loop, repeatedly performing the required operations, value measurement by the sensor, communication with the control unit, and low power consumption waiting mode. The operation sequence is shown in Figure 5. The circuit is waked up from this mode by means of the Wakeup timer, set during initialization, running in the economy mode constantly. The wakeup period is given by the Wakeup timer setting, in this case approximately 30 seconds. After the wakeup from the economy mode the program run on by the next instruction (following the instruction that caused the set on of the economy mode), namely jumping to the start of an endless loop and the whole process keeps repeating. So the system is operating in the waiting mode most of the time, with current consumption just tens of µA, the consumption rises to approximately 8 mA for just several hundred ms and to about 30 mA during maximum RF power transmission.

Wireless switch unit control program. The program is basically similar to the preceding temperature sensor program. The current consumption diagram of this circuit is similar to that of the temperature sensor. Ten of µA are consumed, increase to 6.5 mA for 200 ms, up to 30 mA during maximum RF power transmission and only during the relay changeover the consumption rises to 70 mA for 250 ms. The largest consumption appears during the relay changeover, which, of course, lasts for only a short time and the switching period is very.

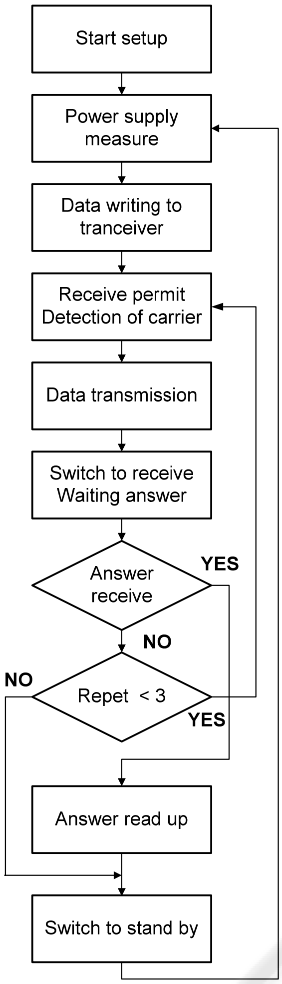

Figure 5: Flow diagram of wireless sensor unit.

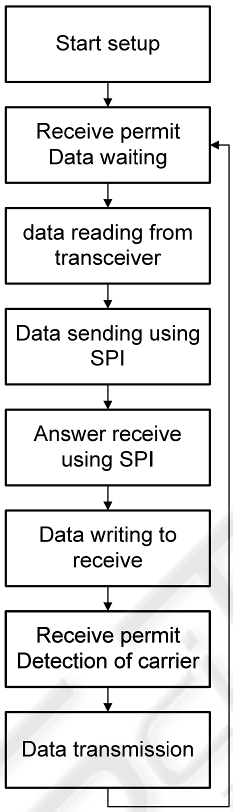

Figure 6: Control program of the wireless transmission and reception section of the control unit.

Control program of the wireless transmission and reception section of the control unit. The program secures the control unit wireless communication with individual sensors and switch units. Its graph is shown in Figure 6. The program composition and its initializing part are similar to the two preceding programs. The transceiver is receiving most of the time in order to be able to accept all data packets transmitted from the other units, and only during short intervals it transmits replies or acknowledgements of data received from sensors or switch units. The control unit circuit current consumption is 13 mA and 30 mA (transmission).

Control unit program. The control program of the Atmel processor in the control unit is the largest program in the system. The program graph is shown in Figure 7. The main endless loop of the program refreshes the displayed data, evaluates and processes data from individual zones of the memory. Communication with the wireless part takes place during interrupts.

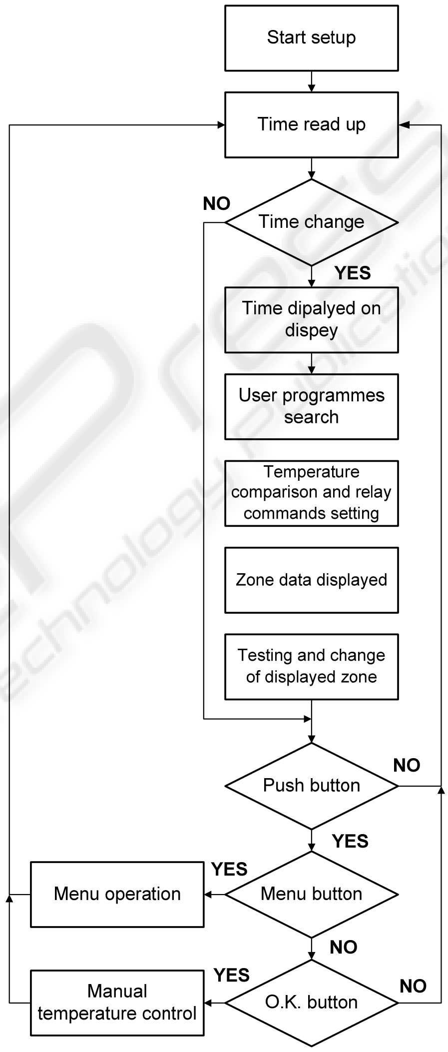

Figure 7: Control unit program.

User control. There are six pushbutton provided for the control unit handling. All stored programs can also be listed through a PC.

5 RESULTS OF THE WORK

The programmable RF output power can be set in four levels from -10 dBm to +10 dBm, with corresponding communication range. The highest

RF, output power +10 dBm, or 10 mW, means a free space more than 300 m. The operating frequency can also be adjusted. Setting channel number 117 means a 868.2 MHz frequency. During tests, the system worked flawlessly even in close presence of common interference sources like TV receivers, PCs, microwave ovens etc. The response time is determined, first of all, by the wakeup period and sensor and switch unit communication with the control unit. The temperature measurement resolution can be adjusted from 10 to 13 bits. This influences the conversion time, corresponding to about 200 ms in case of maximum resolution.

The example of the circuit connection of the temperature sensor unit is shown in Figure 8. The same way of the design was used in the other units.

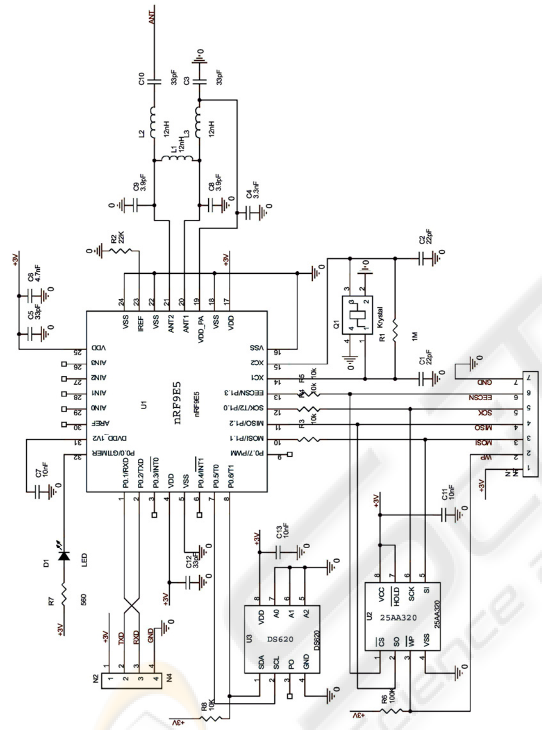

Figure 8: Circuit connection of the temperature unit.

6 CONCLUSIONS

Research contribution of that work is design of the sensor system with wireless data transfer. The system can be used with minor modification in the all energy domains for processing of physical as well as biochemical quantities. In the work was used example of the temperature domain. Where is made design with other sensor type, it is necessary adjust output parameters of the sensor to input parameters of the wireless unit. Sensor with analog output must used amplifier and AD converter. Wide amount of sensors can be used for realization of the above design system.

The system is designed like multisensor system to be able to work with independent thermal sensors and switch units. The reach of arrangement on of free space is 300 m, the reach decreases in housing development. The communication is two bidirectional among parts of system, i.e. the data transmission to the control unit as well as also to the wireless sensors and switch units. Used circuit includes also AD converter. Therefore is possible to measure and data transfer after minority adjustments of wireless sensors. Designed programme of control unit occupies only part memoirs. That makes next development of function and user's up-to-date facilities. The program expansion is possible also in wireless units. The control unit is patchable with computer and one makes it possible extract user's programmes. The cooperation with computer is possible to extend using set-up, entry programmes or transmission measured data to PC. The system can be extended also alongside hardware.

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