

L^AT_EX
HSLU Elektrotechnik Master
Template, Grundlagen, Tipps, Vorlagen

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MASTER OF SCIENCE IN ENGINEERING

Vertiefungsmodul I

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Vorwort

This work is being done for Aeroscout GmbH, a company that specialized in development of drones. With unmanned vehicles, there are always on-board and off-board components. Data transmission between those components is of vital importance. Depending on the distance between on-board and off-board components, different data transmission technologies have to be used.

In this project, a hardware has been designed where multiple data inputs and outputs and multiple transmitters can be connected to a serial switch. The designed hardware features an SD card with a configuration file where data routing can be configured.

Data from connected devices will be collected and put into a data package with header, checksum, time stamp and other information. The package is then sent out via the configured transmitter. The corresponding second serial switch hardware receives this package, extracts and checks the payload, sends it out to the corresponding device and sends an acknowledge back to the package sender.

When data transmission over one transmission technology fails, the configuration file lets the user select the order of back up transmitters to be used. Data priority can also be configured because reliability of data transmission is extremely important with information such as exact location of the drone but not as important with information such as state of charge of the battery.

The serial switch hardware designed in the scope of this project features four serial RS232 connections where input and output devices can be connected that process or generate data. There are also four RS232 connectors where transmitters can be connected to send or receive data packages. The routing between data generating devices and transmitters to use can be done in a .ini file saved on an SD card.

There are two SPI to UART converters that act as the interface between the four devices connected and the micro controller respectively the four transmitters and the micro controller.

In a first version of the project, a Teensy 3.1 development board has been used as a micro controller unit. The software was written in the Arduino IDE with the provided Arduino libraries. As the project requirements became more complex, the limit of only a serial interface available as a debugging tool became more challenging. In the end, the first version of the software ran with more than ten tasks and an overhaul of the complex structure was necessary.

For this reason, an adapter board has been designed so the existing hardware could be used with the more powerful Teensy 3.5. This adapter board features a SWD hardware debugging interface that was ready to use after removing a single component on the Teensy 3.5 development board.

The Teensy 3.5 was then configured to run with FreeRTOS. Task scheduler and queues provided by this operating system have been used to develop software that extracts data from received packages to output them on the configured interface or generates packages from received data bytes to send them out over the configured transmitter. The concept of acknowledges has also been applied so package loss can be detected and lost packages can be resent.

The software concept implemented is easy to understand, maintainable and expandable. Even though the functionality of the finished project remains the same as in the first version with Teensy 3.1 and Arduino, a refactoring has been necessary. Now further improvements and extra functionalities can be implemented more easily.

Kurzfassung

Hier wird der gesamte Text der Kurzfassung eingefügt.

Inhaltsverzeichnis

1 Task Description	1
2 Starting Situation	3
2.1 Hardware	3
2.1.1 Serial Interfaces	4
2.1.2 RS232 to UART Converter	4
2.1.3 USB Interface	5
2.1.4 SPI to UART Converter	5
2.1.5 Teensy 3.1 Development Board	5
2.1.6 Power Supply	5
2.2 Software	6
2.2.1 Software Development Tools	6
2.2.2 Basic Functionality	6
2.2.3 Configuration	8
2.2.4 Software Concept	11
2.2.5 Wireless Package Structure	14
2.3 Discussion and Problems	15
2.3.1 Overall Functionality Tests	15
2.3.2 Dropping Data when Transmission Unreliable	16
2.3.3 Debugging	16
2.3.4 Software Concept	16
2.3.5 Data Priority	16
3 Hardware	17
3.1 Hardware Redesign Options	17
3.1.1 Complete Hardware Redesign	17
3.1.2 Adapter Board	20
3.2 Component Evaluation	20
3.2.1 Development Board Selection	20
3.2.2 Preparation for Hardware Debugging	21
3.3 To-Do List for next version of UAV serial switch	28
4 Software	29
4.0.1 Start with existing Software	29
4.1 New Software	29
5 Testing	31
5.1 Hardware Tests	31
5.2 Software Tests	31
5.3 Functionality Tests with Modem	31
5.3.1 Test Concept	31

6 Hyperref	33
6.1 Backref	33
6.2 Autoref	33
7 Literaturverweise	35
7.1 Bibliography und Zotero	35
Anhang A Anhangstruktur	37
A.1 Unterkapitel im Anhang	37
A.1.1 Tieferes Kapitel	37
Literaturverzeichnis	39
Bezeichnungen	41

1 Task Description

This project has been done for the company Aeroscout. Aeroscout specialized in the development of drones for various needs.

With unmanned aerial vehicles, the communication between on-board and off-board devices is essential and a reliable connection for data transmission is necessary. While the drone is within sight of the control device, data can be transmitted over a wireless connection. With increasing distances, other means of transmission have to be selected such as GPRS or even satellite.

So far, the switching between different transmission technologies could not be handled automatically. The data stream was directly connected to a modem and transmitted to the corresponding receiver with no way to switch to an other transmission technology in case of data transmission failure. A visualization of this set up can be seen from Bild 1.1

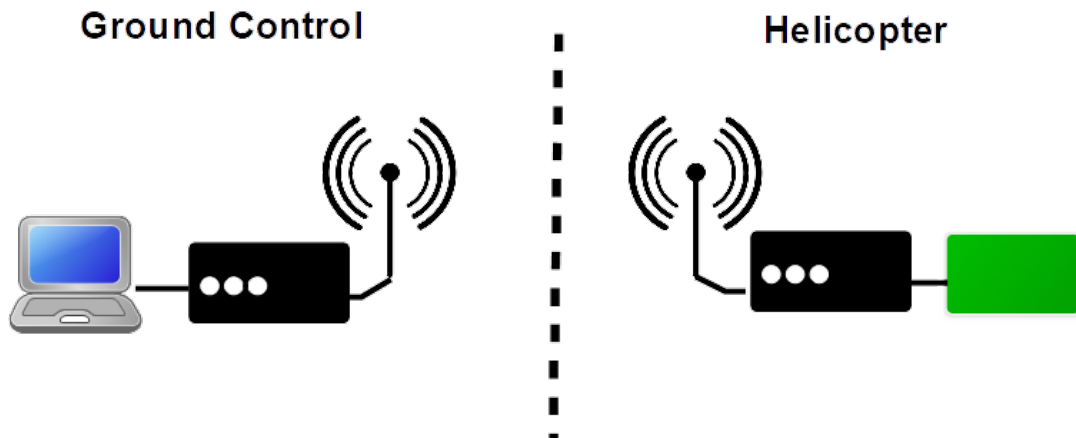


Bild 1.1: Previous system setup for data transmission

The aim of this project is to provide a solution that provides the needed flexibility. The finished product should act as a serial switch with multiple input/output interfaces for connecting devices and sensors and multiple interfaces for connecting transmitters. When one transmission technology fails to successfully transmit data, an other technology can be chosen for the next send attempt. Also, multiple sensors or input streams should be able to send out data over the same wireless connection. A visualization of this set up can be seen in Bild 1.2

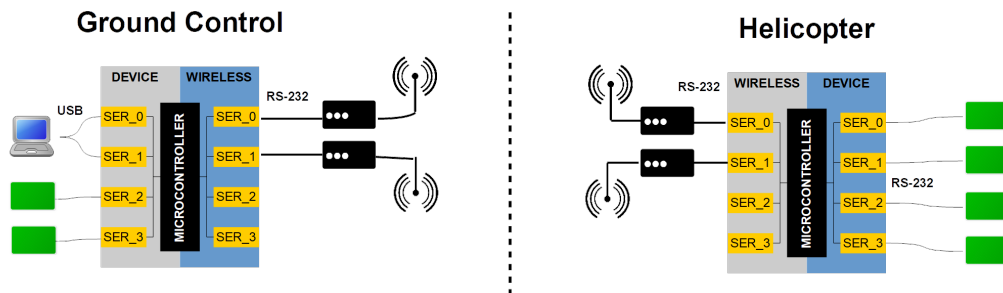


Bild 1.2: New system setup for data transmission

There are various kinds of information exchanged between drone and control device such as state of charge of the battery, exact location of the drone, control commandos etc. Some information such as the exact location of the drone should be prioritized over battery status information when data transmission becomes unreliable. The finished product should therefore take data priority into account. Encryption should be configurable individually for each interface in case sensitive data is exchanged over a connection.

The finished product should have a debugging interface such as SWD and a shell/command line interface. During run time, the software should log system data and any other relevant information to a file saved on an SD card. The SD card should also contain a configuration file so the behavior of the hardware can be changed easily.

A detailed description of all the requirements can be taken from the appendix [Aufgabenstellung](#).

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2 Starting Situation

It was not necessary to start from scratch for this project.

In the beginning of 2017, Andreas Albisser has already started with an implementation and provided a first solution.

He developed a hardware that was used as the interface between input/output data and modem for wireless transmission. He chose the Teensy 3.1 development board as a micro controller and worked with the Arduino IDE and Arduino libraries.

There are various problems still with his work which lead to this follow up project to improve the overall functionality.

More details about the work Andras Albisser has done can be taken from this chapter.

2.1 Hardware

The hardware developed by Andreas Albisser has a total of eight interfaces where peripheral devices can be connected. Four connections are for control units, sensors or any other devices that process or generate data to be transmitted. On the other side, there are four connectors for modems to allow different ways of transmission. An overview can be seen in Bild 2.1.

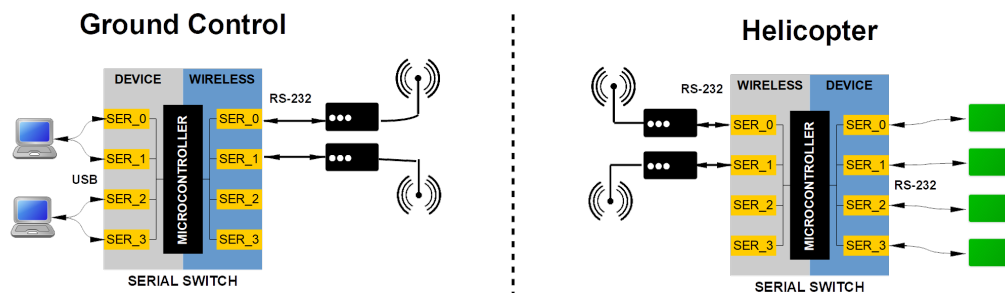


Bild 2.1: Hardware overview

Each interface accessible to the user is bidirectional which means that both sensors and actors can be connected.

From now on, the side where data generating and processing devices can be connected will be referred to as the device side and the side where modems can be connected will be referred to as the wireless side.

On both device side and wireless side, periphery can be connected to the four UART serial interfaces. On device side, the user can choose between a UART interface and a USB mini interface individually for each interface with jumpers. When selecting the USB mini interface, one USB hub acts as a dual COM interface, allowing two serial COM ports to open up to simulate two serial interfaces.

The serial interfaces are not connected to the Teensy 3.1 development board directly. There is a SPI to UART converter that acts as a hardware buffer between serial input/output and micro controller. All serial connections work on RS232 level which is $\pm 12V$. Because the SPI to UART converter is not

RS232 level compatible, a voltage regulator is used between the serial interface accessible to the user and the SPI to UART converter.

Details about the components used on this hardware can be taken from the following section. A block diagram of the on-board hardware components can be taken from Bild 2.2.

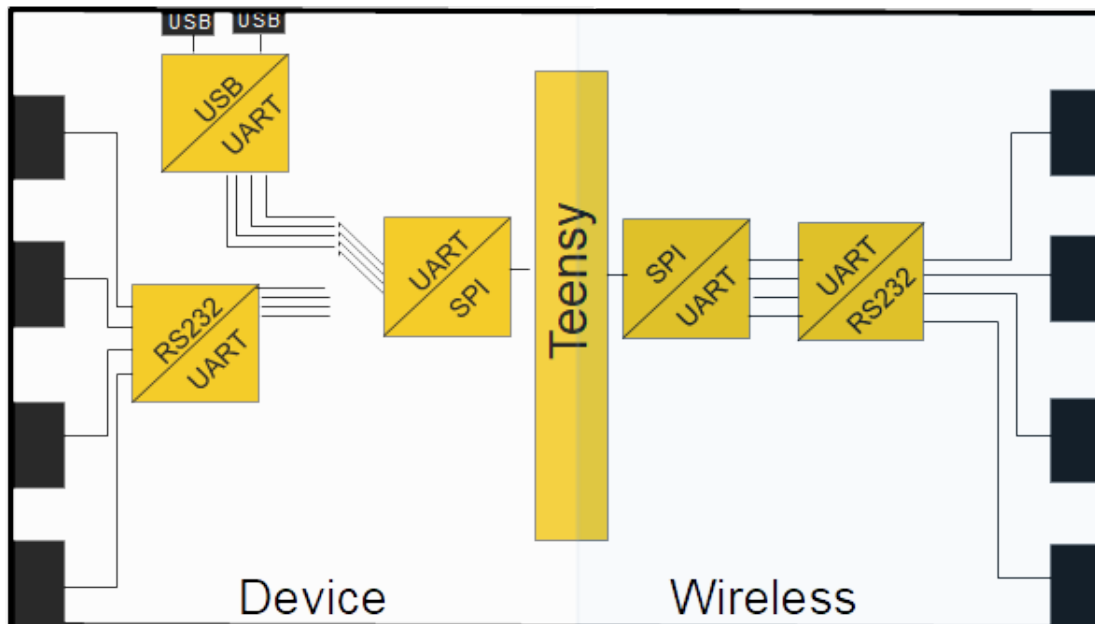


Bild 2.2: Hardware details

2.1.1 Serial Interfaces

There are a total of eight UART serial connections accessible to the user, four on device side and four on wireless side.

The baud rate for each serial connection can be configured individually.

UART is an asynchronous serial interface which means that there is no shared clock line between the two components. Both sides need to be configured with the same baud rate so they can communicate correctly.

A UART interface requires three wires: two unidirectional data lines (RX and TX) and a ground connection. Those three wires are accessible to the user, but with RS232 level, which is $\pm 12V$.

2.1.2 RS232 to UART Converter

The serial interfaces accessible to the user work on RS232 level. Just behind the serial interface, there is a level shifter that converts the RS232 level to TTL (5V).

This level shifter is bypassed on the device side in case the USB serial connection is used instead of the RS232 serial interface.

2.1.3 USB Interface

On device side, the user can chose whether data is provided via USB or via RS232 serial connection. A jumper is used to switch between RS232 input and USB input.

In case when the USB input is selected, each USB hub acts as a dual serial COM port which means that when connecting the hardware to a computer, there will be two COM ports available per USB connection.

The on board USB to UART converter acts as an interface between USB hub and SPI to UART converter.

2.1.4 SPI to UART Converter

UART is an asynchronous serial interface which requires three connections: ground and two unidirectional data lines. If the teensy was to communicate to each serial port directly, it would require eight of those UART interfaces (which would add up to 16 data lines). To facilitate communication to the serial interfaces, a SPI to UART converter was selected as an intermediate interface.

There are two SPI to UART converters on board, one for the four device serial connections and one for the four wireless serial connections. SPI is a synchronous master-slave communication interface where the unidirectional data lines are shared amongst all participants. The only individual line between master and slave is the Slave Select line that determines, which slave is allowed to communicate to the master at a time.

Those converters are used as hardware buffers and can store up to 128 bytes.

2.1.5 Teensy 3.1 Development Board

Andreas Albisser used a Teensy 3.1 as a micro controller as can be seen in Bild 2.3.

The Teensy development boards are breadboard compatible USB development boards. They are small, low-priced and yet equipped with a powerful ARM processor.

The Teensy development boards all come with a pre-flashed bootloader to enable programming over USB. They use a less powerful processor as an interface to the developer to enable the use of Arduino libraries and the Arduino IDE.

There is no hardware debugging interface available to the user on the Teensy development boards. Programming is only possible via USB.

2.1.6 Power Supply

The hardware needs 5V as a power supply. This can be achieved by using any of the USB connections or via a dedicated power connector located on the board.

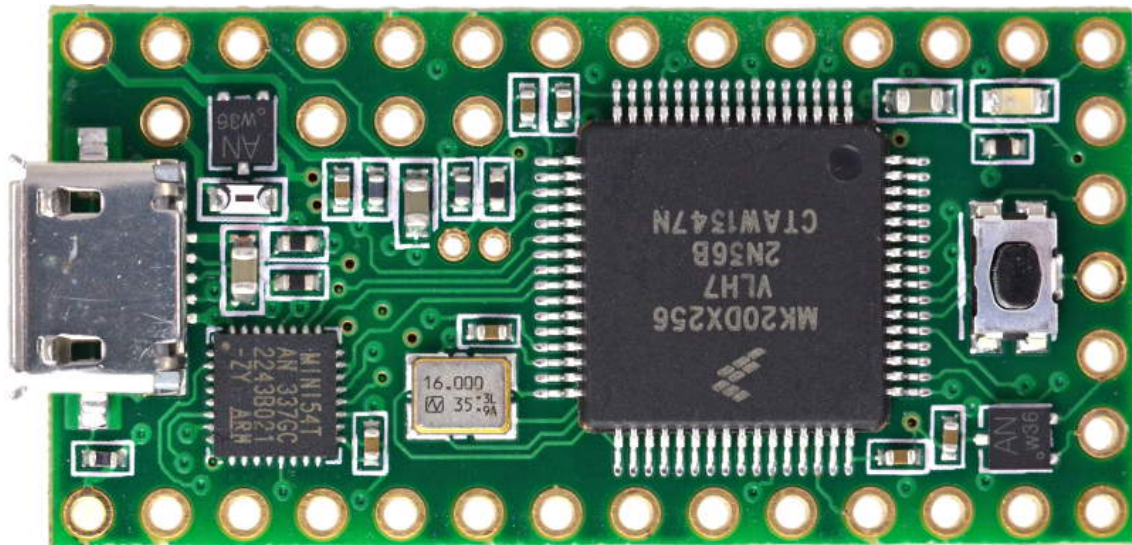


Bild 2.3: Teensy 3.1

2.2 Software

The following section gives you an overview of the Arduino software written by Andreas Albisser. There was only a brief documentation of the software available but fortunately, the comments in the code were helpful to get an understanding.

Any information provided below has been reverse engineered.

2.2.1 Software Development Tools

The software was written in C++ in Visual Studio. To compile the software, install the Visual Studio Enterprise 2015 version 14, the Arduino IDE extension for Visual Studio and the libraries "Queue by SMFSWänd" and "TaskScheduler by Anatoli Arkhipenko". Additionally, the old Arduino IDE version 1.8.1 has to be installed as well, together with the software add-on for Teensy support (Teensyduino). A detailed installation manual for all packages and environments needed can be found in the appendix.

Link zur Installationsanleitung im Appendix

2.2.2 Basic Functionality

The software written by Andreas Albisser provided a good basis and reference for the software developed in the scope of this project.

The basic functionality provided by his software was the transmission of data packages and acknowledgements on wireless side. Generally it can be said that only packages are exchanged over wireless side and bytes are transmitted or received over device side.

The Teensy would frequently poll its SPI to UART hardware buffers for received data. In case the SPI to UART converter had data in its device buffer, the Teensy would read the data in a second SPI command. The read data is then wrapped in a package with header which contained CRC, timestamp and other information and sent out on the wireless side.

The corresponding second hardware would receive this package on its wireless side, extract the payload from it and send the extracted payload out on its device side.

To ensure successful transmission of packages, the concept of acknowledges is applied in the software where the receiver replies with an acknowledge to a successful package reception. A sequence diagram of a successful package transmission can be found in Bild 2.4.

Both Serial Switches continuously do both tasks: poll on device side to generate data packages for sending and poll on wireless side to receive wireless packages and send that payload back out on its device side.

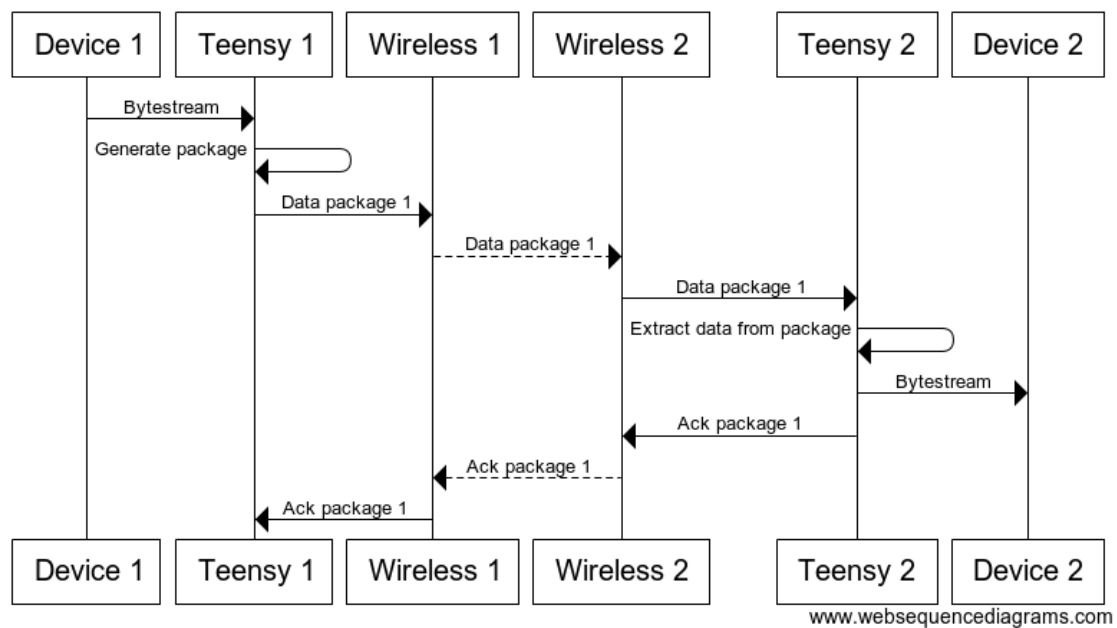


Bild 2.4: Successful package transmission

The maximum number of payload bytes per package can be configured in the software, just like the maximum amount of time the application should wait for a package to fill up until it will be sent anyway.

In case the package transmission was unsuccessful, either if the package got lost or corrupted, the receiving hardware will not send an acknowledge back. The application that sent the package will wait for a configurable amount of time before trying to send the same package again. Details can be found in figure Bild 2.5.

The maximum time to wait for an acknowledge before resending the same package can be configured in the software. The maximum number of resends per package can be configured for each wireless connection.

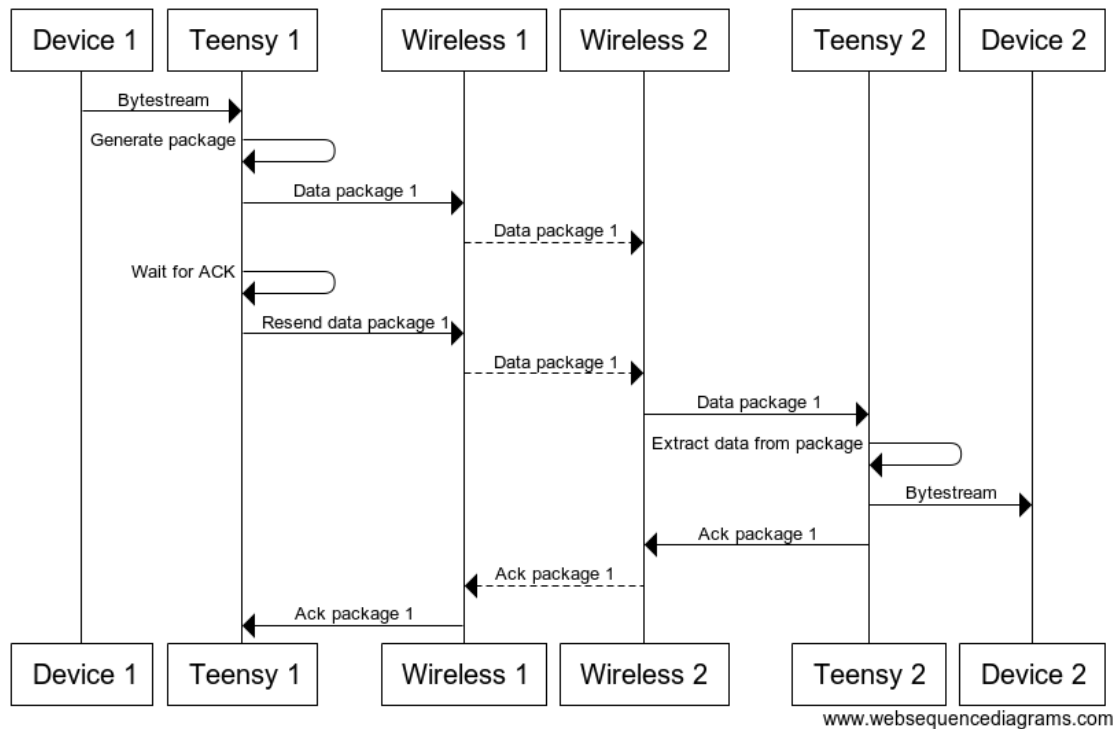


Bild 2.5: Unsuccessful package transmission

2.2.3 Configuration

All basic configuration parameters of the Arduino software are in the file `serialSwitch_General.h`. For changes to be executed, the software has to be recompiled and uploaded. In order to do so, the necessary environment and all packages used by the software have to be installed on the computer as described in the user manual. All configuration possibilities of Andreas Albissers software can be taken from the Tabelle 2.1:

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Configuration parameter	Possible values	Description
BAUD_RATES_WIRELESS_CONNECTION	9600, 38400, 57600, 115200	Baud rate to use on wireless side, configurable per wireless connection. Example: 9600, 38400, 57600, 115200 would result in 9600 baud for wireless connection 0, 38400 baud for wireless connection 1 etc.
BAUD_RATES_DEVICE_CONNECTION	9600, 38400, 57600, 115200	Baud rate to use on device side, configurable per device connection. Example: 9600, 38400, 57600, 115200 would result in 9600 baud for device connection 0, 38400 baud for device connection 1 etc.

PRIO_WIRELESS_CONN_DEV_X 3, 4	This parameter determines over which wireless connection the data stream of a device will possibly be sent out. 0: this wireless connection will not be used. 1: Highest priority, data will be tried to send out over this connection first. 2: Second highest priority, data will be tried to send out over this connection should transmission over the first priority connection fail. 3: Third highest priority. 4: Lowest priority for data transmission. Example: 0, 2, 1, 0 would result in data being sent out over wireless connection 2 first and only sent out over wireless connection 1 in case of failure. All other wireless connections would not be used. Replace the X in the parameter name with 0, 1, 2 or 3.
SEND_CNT_WIRELESS_CONN_DEV_X 5	Determines how many times a package should be tried to be sent out over a wireless connection before moving on to retrying with the next lower priority wireless connection. Example: 0, 5, 4, 0 would result in the package being sent out over wireless connection 1 five times and four times over wireless connection 2. Together with PRIO_WIRELESS_CONN_DEV_X, this parameter determines the number of resends per connection. Replace the X in the parameter name with 0, 1, 2 or 3.
RESEND_DELAY_WIRELESS_CONN_DEV_X 260	Determines how many milliseconds the software should wait for an acknowledge per wireless connection before sending the same package again. Example: 10, 0, 0, 0 would result in the software waiting for an acknowledge for 10ms when having sent a package out via wireless connection 0 before attempting a resend. Together with PRIO_WIRELESS_CONN_DEV_X, this parameter determines the delay of the resend behaviour. Replace the X in the parameter name with 0, 1, 2 or 3.
MAX_THROUGHPUT_WIRELESS_CONN_DEV_X 2996000	Limit of the maximum data throughput in bytes/s per wireless connection. If two devices use the same wireless connection with the same priority but the maximum throughput is reached, data of the lower priority device will be redirected to its wireless connection with the next lower priority or discarded (in case this was the wireless connection with lowest priority already). Example: 0, 10000, 10000, 10000 means that wireless connection 0 will not be used.

USUAL_PACKET_SIZE_DEVICE_CONN	Maximum number of payload bytes per wireless package. 0: unknown payload, the PACKAGE_GEN_MAX_TIMEOUT parameter always determines the payload size. Example: 128, 0, 128, 128 results in a maximum payload of 128 bytes per package and an unknown maximum payload size for wireless connection 0.
PACKAGE_GEN_MAX_TIMEOUT	Maximum time (in milliseconds) that the software should wait for a package to fill up before sending it out anyway. Together with USUAL_PACKET_SIZE_DEVICE_CONN, this parameter determines the size of a package. Example: 50, 50, 50, 50 will result in data being sent out after a maximum wait time of 50ms.
DELAY_DISMISS_OLD_PACKAGE_PER_DEVICE_CONN	Maximum time (in milliseconds) an old package should be tried to resend while the next package with data from the same device is available for sending. Example: 5, 5, 5, 5 results in a package being discarded 5ms after the next package is available in case it has not been sent successfully until then.
SEND_ACK_PER_WIRELESS_CONN	Acknowledges turned on/off for each wireless connection. Example: 1, 1, 0, 0 results in acknowledges being expected and sent over wireless connection 0 and 1 but not over wireless connection 2 and 3.
USE_CTS_PER_WIRELESS_CONN	Hardware flow control turned on/off for each wireless connection. Example: 1, 1, 0, 0 results in hardware flow control (CTS) for wireless connection 0 and 1 only.

Tabelle 2.1: Configuration parameters of arduino software

Further configuration parameters can be found in the file serialSwitch_General.h

There, the you can modify task interval of all tasks, enable hardware loopback and debug output or edit the preamble for a package start.

Configuration parameter	Possible values	Description
TEST_HW_LOOPBACK_ONLY		This parameter enables local echo. Any data received over any serial connection will be returned over the same connection immediately.
ENABLE_TEST_DATA_GEN	0, 1	Random test data will be generated instead of waiting for device data to arrive to fill a package.
GENERATE_THROUGHPUT_OUTPUT	0, 1	Information about the data throughput on wireless side will be printed out on the serial terminal.
X_INTERVAL	0...65535	Task interval in milliseconds for each task. Replace X with the name of the task.

Tabelle 2.2: General software configuration

2.2.4 Software Concept

The software written by Andreas Albisser runs with ten main tasks that make up the basic functionality and several minor task that are responsible for debug output, blinking of LEDs and any other functionalities that can be enabled through the configuration header. The software concept can be seen in Bild 2.6.

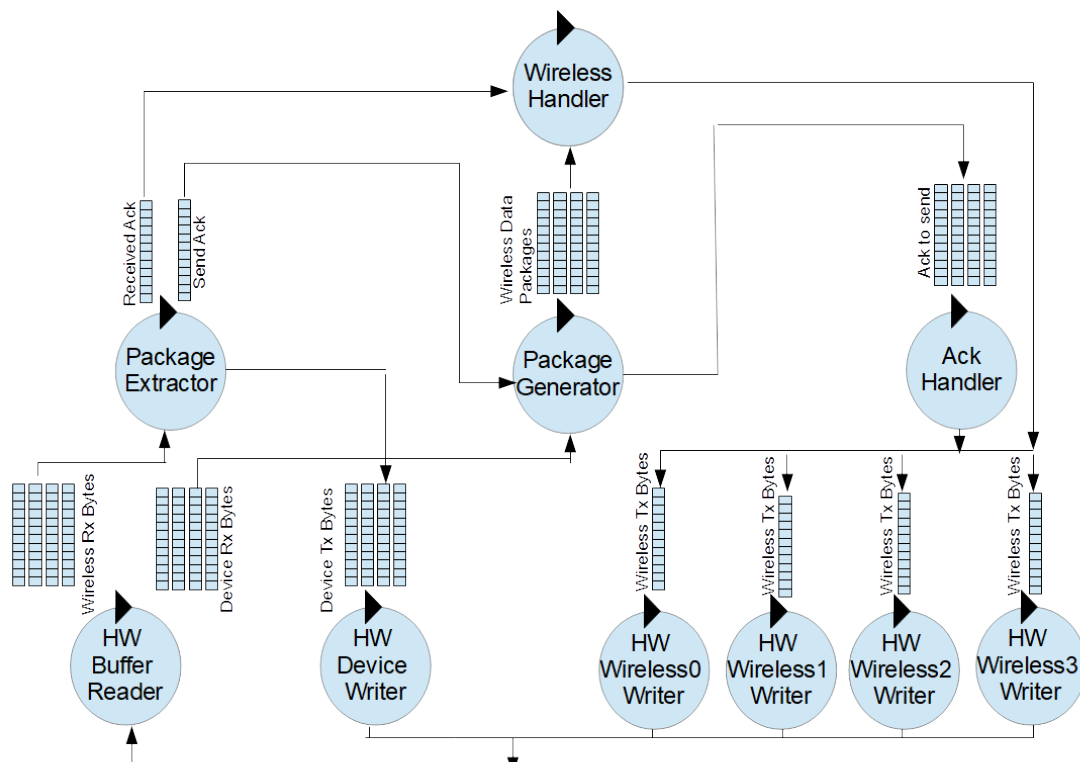


Bild 2.6: Arduino software concept

In the following sections, an overview will be given on the functionality performed by each task.

HW Buffer Reader

This task periodically polls the SPI to UART converters for new data. In case the converters have received data, the HW Buffer Reader will read and store the data in the corresponding queue.

The HW Buffer Reader does not know anything about packages or any data structure. It simply reads bytes and stores them in a queue.

The HW Buffer reader is responsible for the input data of both SPI to UART converters, the one on device side and on wireless side. This task has eight queues where the read data is stored, one queue for each UART interface accessible to the user.

If there is more data available in the hardware buffer (SPI to UART converter) than can be stored in the corresponding output queue of the HW Buffer Reader, the HW Buffer Reader will flush the queue to discard all information previously read from the SPI to UART converter and store its read data in

the now empty queue.

```

1  /* send the read data to the corresponding queue */
2  /*const char* buf = (const char*) &buffer[0]; */
3  for (unsigned int cnt = 0; cnt < dataToRead; cnt++)
4  {
5      if ((*queuePtr).push(&buffer[cnt]) == false)
6      {
7          /* queue is full - flush queue, send character again and set error */
8          (*queuePtr).clean();
9          (*queuePtr).push(&buffer[cnt]);
10         if (spiSlave == MAX_14830_WIRELESS_SIDE)
11         {
12             char warnBuf[128];
13             sprintf(warnBuf, "cleaning full queue on wireless side, UART number %u", (
14                 unsigned int)uartNr);
15             showWarning(__FUNCTION__, warnBuf);
16         }
17         else
18         {
19             /* spiSlave == MAX_14830_DEVICE_SIDE */
20             char warnBuf[128];
21             sprintf(warnBuf, "cleaning full queue on device side, UART number %u", (
22                 unsigned int)uartNr);
23             showWarning(__FUNCTION__, warnBuf);
24         }
25     }
26 }

```

HW Device Writer

This task transmits data to the SPI to UART converter on device side. It takes bytes from its queues and passes them to the SPI to UART converter.

Communication to other tasks has been realized through four byte queues, one for each device interface accessible to the user.

This task does not know anything about data packages or other data structures, it only takes bytes from the queues and writes them to the SPI to UART converter on device side.

HW WirelessX Writer

There are four tasks responsible for writing data to the SPI to UART converter on wireless side. Each task has its byte queue where data will be taken from and transmitted to the corresponding wireless user interface.

These tasks do not know anything about data packages or other data structures, they only take bytes from the queues and write them to the SPI to UART converter on wireless side.

Data is only taken from the queue and written to the hardware buffer if there is space available on the hardware buffer.

Package Extractor

This task reads the wireless bytes from the output queue of the HW Buffer Reader and assembles them to wireless packages.

There are two types of wireless packages, acknowledges and data packages. The Package Extractor detects of which type an assembled package is and puts it on the corresponding queue.

This task also verifies the checksums of both header and payload of a package and discards the package in case of incorrect checksum.

In case of full output queues, new packages will be dropped and not stored in the corresponding queue.

Package Generator

This task reads the incoming device bytes from the output queue of the HW Buffer Reader and generates data packages with this device data as payload. The generated packages are then stored in the corresponding queue for further processing.

The Package Generator also generates acknowledge packages when being told so by the output queue of the Package Extractor. The generated acknowledge are then put into the correct queue for a wireless connection.

If the queue is full, the package is dropped, no matter if acknowledge package or data package.

```

1  /* check if there are some receive acknowledge packages that needs to be created */
2  while (queueSendAck.pull(&ackData))
3  {
4      if (generateRecAckPackage(&ackData, &wirelessAckPackage))
5      {
6          queueWirelessAckPack.push(&wirelessAckPackage);
7      }
8  }
9
10 /* generate data packages and put those into the package queue */
11 if (generateDataPackage(0, &queueDeviceReceiveUart[0], &wirelessPackage))
12 {
13     queueWirelessDataPackPerDev[0].push(&wirelessPackage);
14 }
15 if (generateDataPackage(1, &queueDeviceReceiveUart[1], &wirelessPackage))
16 {
17     queueWirelessDataPackPerDev[1].push(&wirelessPackage);
18 }
19 if (generateDataPackage(2, &queueDeviceReceiveUart[2], &wirelessPackage))
20 {
21     queueWirelessDataPackPerDev[2].push(&wirelessPackage);
22 }
23 if (generateDataPackage(3, &queueDeviceReceiveUart[3], &wirelessPackage))
24 {
25     queueWirelessDataPackPerDev[3].push(&wirelessPackage);
26 }

```

The queue function call for push() returns false if unsuccessful there is no handling of an unsuccessful push in this code.

Ack Handler

This task takes the acknowledge package generated by the Package Generator, splits it into bytes and puts those bytes into the corresponding wireless queue for the HW WirelessX Writer to send out.

Wireless Handler

This task handles the correct sending of wireless packages. It takes wireless packages from the output queues of the Package Generator, splits them into bytes and puts those bytes to the queue of the correct HW WirelessX Writer.

This task has an internal buffer where packages with an expected acknowledge are stored. The Wireless Handler keeps track of the send attempts per wireless connection and handles the resending of packages.

The Wireless Handler also does the prioritizing of data packages.

2.2.5 Wireless Package Structure

There are two types of packages that are exchanged over wireless side: acknowledges and data packages. Each package consists of a header and a payload of arbitrary size. Acknowledges and data packages can be distinguished by a parameter in the header of a package.

More information about the structure of header and payload can be found in the following section.

Header

The structure of a header can be found in Tabelle 2.3.

Parameter name	Description	Value range	Length, bytes
PACK_START	Preamble for a package header start, indicates the beginning of a header.	0x1B	1
PACK_TYPE	Determines whether it is a data package or acknowledge.	1: data pack, 2: acknowledge	1
SESSION_NR	A random number generated upon startup of the software to keep the receiver from discarding all packages in case a reset has been made.	0...255	1
SYS_TIME	Milliseconds since start of the software. This parameter is used as a substitute for package numbering.	0...4294967295	4
PAYLOAD_SIZE	Number of bytes in payload of this package	0...65535	2
CRC8_HEADER	8 bit CRC of this header	0...255	1

Tabelle 2.3: Header structure

When the software receives a package, it checks the system time to decide if it should be discarded. If the system time of a received package is lower than the last one received, it will be discarded. In case of a hardware reset, the system time starts over with 0 which means that all packages would be discarded on receiving side. This is the reason for the session number. When the session number changes, the receiver knows to start over with the system time and not to discard all received packages.

Payload

Talk about payload and CRC32

Parameter name	Description	Value range	Length, bytes
PAYLOAD	Data bytes to send out	0...255	0...65535
CRC16_PAYLOAD	16 bit CRC of the payload	0...65535	2

Tabelle 2.4: Payload structure

2.3 Discussion and Problems

There was no documentation available on test conducted or issues discovered with Andreas Albissers work.

All information below has been recalled by the people involved.

2.3.1 Overall Functionality Tests

The software was only tested briefly and testing was not documented.

When connecting two serial switches directly with a cable, the functionality was as expected. Acknowledges were transmitted and packages resent in case no acknowledge was received. Packages were not acknowledged when the checksum did not match and were resent after the configured delay.

Problems arose when working with modems instead of a direct wired connection. When connecting one modem and one device only, the data stream was still reliable. But once two modems were connected and more than one device was generating data, the connection could not be established and no data stream was output on the receiving side.

Those tests were repeated when no acknowledge was configured but the result was similar: no data link could be established.

One possible reason for this faulty behavior could be the lack of package numbering. The header only contains session number and system time but no variable with a monotonic counter. The system time does not provide any information about missing packages because it might jump up in case no package was generated for some amount of time. The parameter system time corresponds to the runtime of the software since start up in milliseconds.

The following code section is copied from the software Andreas Albisser developed. It shows that packages will be discarded when their time stamp (sysTime) is older than the one of the last package.

```

1  /* make sure to not send old data to the device - but also make sure overflow is handled
   */
2  if ((currentWirelessPackage[wirelessConnNr].sysTime > timestampLastValidPackage[
   currentWirelessPackage[wirelessConnNr].devNum]) ||
3  ((timestampLastValidPackage[currentWirelessPackage[wirelessConnNr].devNum] -
   currentWirelessPackage[wirelessConnNr].sysTime) > (UINT32_MAX / 2)))
4  {
5      /* package OK, send it to device */
6      timestampLastValidPackage[currentWirelessPackage[wirelessConnNr].devNum] =
       currentWirelessPackage[wirelessConnNr].sysTime;
7      Queue* sendQueue;
8      sendQueue = &queueDeviceTransmitUart[currentWirelessPackage[wirelessConnNr].devNum];
9      for (uint16_t cnt = 0; cnt < currentWirelessPackage[wirelessConnNr].payloadSize; cnt
       ++)
10     {
11         if (sendQueue->push(&data[wirelessConnNr][cnt]) == false)
12         {
13             char warnBuf[128];
14             sprintf(warnBuf, "Unable to send data to device number %u, queue is full",
               currentWirelessPackage[wirelessConnNr].devNum);
15             showWarning(__FUNCTION__, warnBuf);
16             break;
17         }
18     }
19 }
20 else
21 {
22     /* received old package */
23     /* also can happen when we have two redundant streams.. */
24     static char infoBuf[128];
25     sprintf(infoBuf,

```

```
26  "received old package, device %u - check configuration if this message occurs often"  
27  ,  
28  currentWirelessPackage[wirelessConnNr].devNum);  
29  showInfo(__FUNCTION__, infoBuf);  
}
```

2.3.2 Dropping Data when Transmission Unreliable

Also, improvements of data handling when the queue is full should be made.

2.3.3 Debugging

The software concept implemented by Andreas Albisser is difficult to debug because Arduino provides no hardware debugging options, only prints on a serial connection are available.

2.3.4 Software Concept

The software is also difficult to debug because of its many tasks. The software concept needs major refactoring and needs to be simplified.

2.3.5 Data Priority

There is no way to prioritize data of a device over data of an other device. When data transmission becomes unreliable, the software needs to know which data is most important to be exchanged.

3 Hardware

The task description for this project as seen in [requires the following hardware changes:](#)

- Optimization of size and weight
- Optimization for outdoor use
- Usage of more powerful processor with more memory and RNG or encryption support
- SWD/JTAG debugging interface
- UART hardware flow control
- On-board SD card (regular or micro)

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There are several options on how to proceed with the implementation. The pro and cons of these choices are listed in this chapter, followed by the chosen solution and its execution.

3.1 Hardware Redesign Options

The hardware Andreas Albisser designed is working as expected. The desired modifications as listed in the task description are merely optimizations. Only the replacement of the Teensy 3.1 is absolutely required for this project because software will later be written for a specific micro controller. Therefore there are two options on how to proceed.

- Redesign entire hardware for/with a new processor.
- Redesign hardware step by step, starting with just an adapter board to use existing hardware with new micro controller.

3.1.1 Complete Hardware Redesign

A redesign of the entire hardware requires careful component selection, adaption of the schematic and footprints and redesign of the PCB.

Changes for the next complete hardware redesign include:

- New RS232 level to TTL level converter with more inputs to convert hardware flow control pins (CTS/RTS) as well.
- A way to switch between RS232 level and TTL level for all serial interfaces accessible to the user.
- More powerful micro controller with support for encryption.
- SD card slot.
- Hardware debugging interface.
- Connectors for all serial interfaces with more pins to include hardware flow control.

Implementing all these changes would require about three weeks, followed by one week of manufacturing and one week of assembly. In case of a faulty hardware, it would be extremely difficult start with the software implementation because there is no hardware to work with and no way to work

standalone. In this case, producing a second version of the hardware would take up a considerable amount of time because of manufacturing time, assembly and testing.

There is simply not enough time to redesign the entire hardware in the scope of this project.

A possible project plan for this scenario can be found in Bild 3.1:

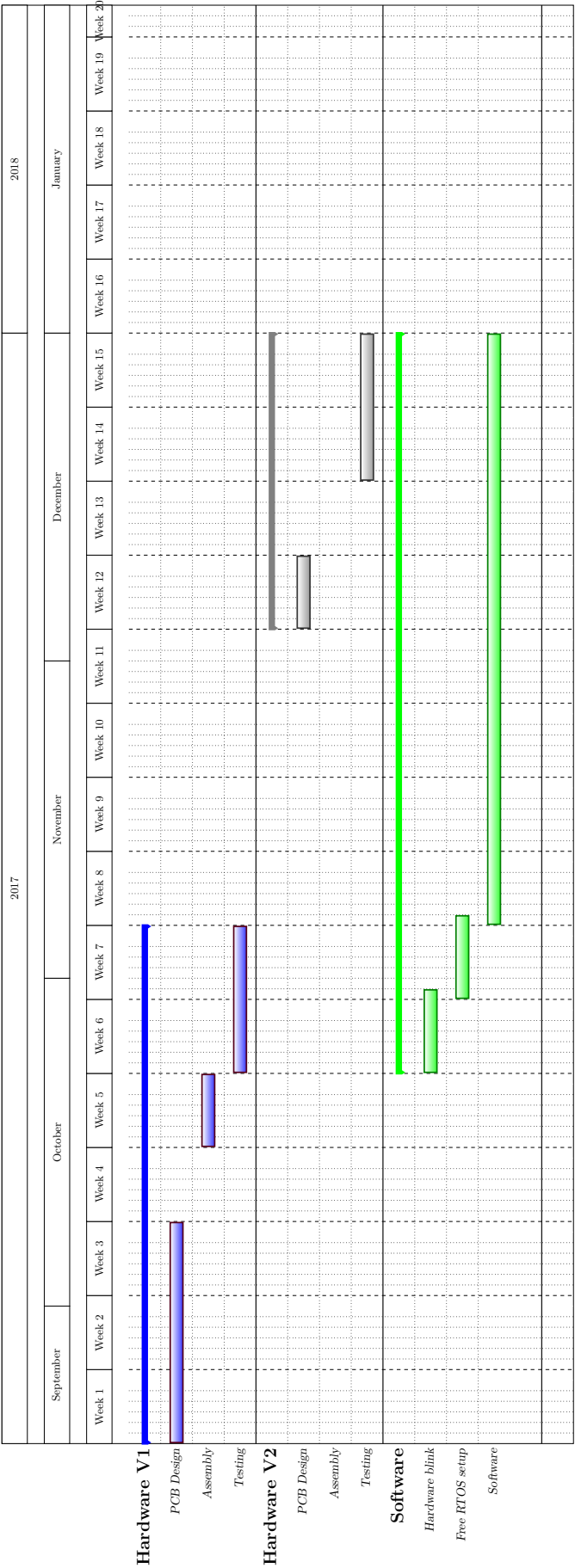


Bild 3.1: Possible project plan of a complete hardware redesign

3.1.2 Adapter Board

The most profound hardware change is the replacement of the Teensy 3.1.

First, a new development board or micro controller has to be selected that supports hardware debugging and meets the requirements for data encryption.

After selecting a replacement for the Teensy 3.1, the fastest way to get started with software development for the new micro controller is by designing an adapter board for the Teensy 3.1 footprint.

The Teensy 3.1 ships with headers that can be soldered onto the development board. Andreas Albisser designed the interface for the Teensy with female header pins so the development board could simply be plugged into the header and exchanged if needed. This makes it easy to design an adapter print with male headers that match the footprint of the previously used Teensy 3.1.

This solution has been chosen in the scope of this work to ensure that the end result of this project would provide solid ground work for further development.

3.2 Component Evaluation

Before starting with the design of an adapter board, a replacement for the Teensy 3.1 development board has to be chosen.

3.2.1 Development Board Selection

The easiest option is to select a more powerful Teensy development board that meets the requirements listed in .

Fortunately, both the Teensy 3.5 and Teensy 3.6 meet the requirements and have an on-board SD card slot. A comparison between the Teensies can be found in Tabelle 3.1 The pins of both Teensy 3.5 and

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	Teensy 3.1	Teensy 3.5	Teensy 3.6
Processor	MK20DX256 32 bit ARM Cortex-M4 72 MHz	MK64FX512VMD12 Cortex-M4F 120 MHz	MK66FX1M0VMD18 Cortex-M4F 180 MHz
Flash Memory [bytes]	262 k	512 k	1024 k
RAM Memory [bytes]	65 k	196 k	256 k
EEPROM [bytes]	2048	4096	4096
I/O	34, 3.3V, 5V tol	58, 3.3V, 5V tol	58, 3.3V, 5V tol
Analog In	21	27	25
PWM	12	17	19
UART,I2C,SPI	3	6	6
SD Card	no	yes	yes
Price	\$19.80	\$25.25	\$29.25

Tabelle 3.1: Teensy comparison

3.6 are backwards compatible to the pin out of Teensy 3.2 which will make it easier to develop the PCB of an adapter board.

The Teensy 3.5 and Teensy 3.6 development board have all pins needed for SWD hardware debugging

available as pads on their backside.

The Teensy 3.5 was chosen for this application because there is more support available for this component and a FreeRTOS that is already configured. This is not the case with the Teensy 3.6.

3.2.2 Preparation for Hardware Debugging

The Teensy development boards are meant for USB programming and debugging. They are equipped with a small micro controller that acts as a boot loader. The small micro controller is in control of the hardware debugging and reset pins of the main micro controller and does the programming of the main micro controller. This way, all Teensies can be used with standard Arduino libraries and programmed with the Arduino IDE.

The schematic of the Teensy 3.5 can be seen in Bild 3.2. The MKL02Z32VFG4 acts as the boot loader and the MK64FX512 is the main micro controller.

The pins available to the user are shown in Bild 3.3 and Bild 3.4.

Serial Wire Debug

As can be seen in Bild 3.4, there are SWD (Serial Wire Debug) pins are available as pads on the back side of the Teensy 3.5.

The pinout of a SWD interface can be seen in Bild 3.5. Only the reset, data, clock and ground pins are absolutely required to be connected.

Even though those SWD pins are available on the backside of both Teensy 3.5 and Teensy 3.6, they are controlled by the boot loader.

There are two ways to communicate to the main micro controller directly without the boot loader interfering on the hardware debugging interface:

- Holding the boot loader in reset mode
- Removing the boot loader

Resetting the Boot Loader

According to the data sheet of the boot loader (see Bild 3.6), pin 15 can have one of three functions:

- Reset
- GPIO input
- GPIO output

As default, the pin will be configured as a reset pin, but this function can be turned off by configuring to any of the other two functions in software.

Even though the Teensies are fully open source, the software for the boot loader is not available. The only way to find out if the reset pin is still configured as such is by pulling it low and attempting a reset.

Before putting the boot loader into reset mode, any other functions that it may be responsible for need to be ensured.

Because the internal pull ups of the boot loader are used for the reset line of the main micro controller, this reset line needs to be pulled up externally first.

A resistor can be soldered onto the Teensy directly for this purpose as seen in Bild 3.7. Afterwards, pin 15 of the boot loader can be pulled low.

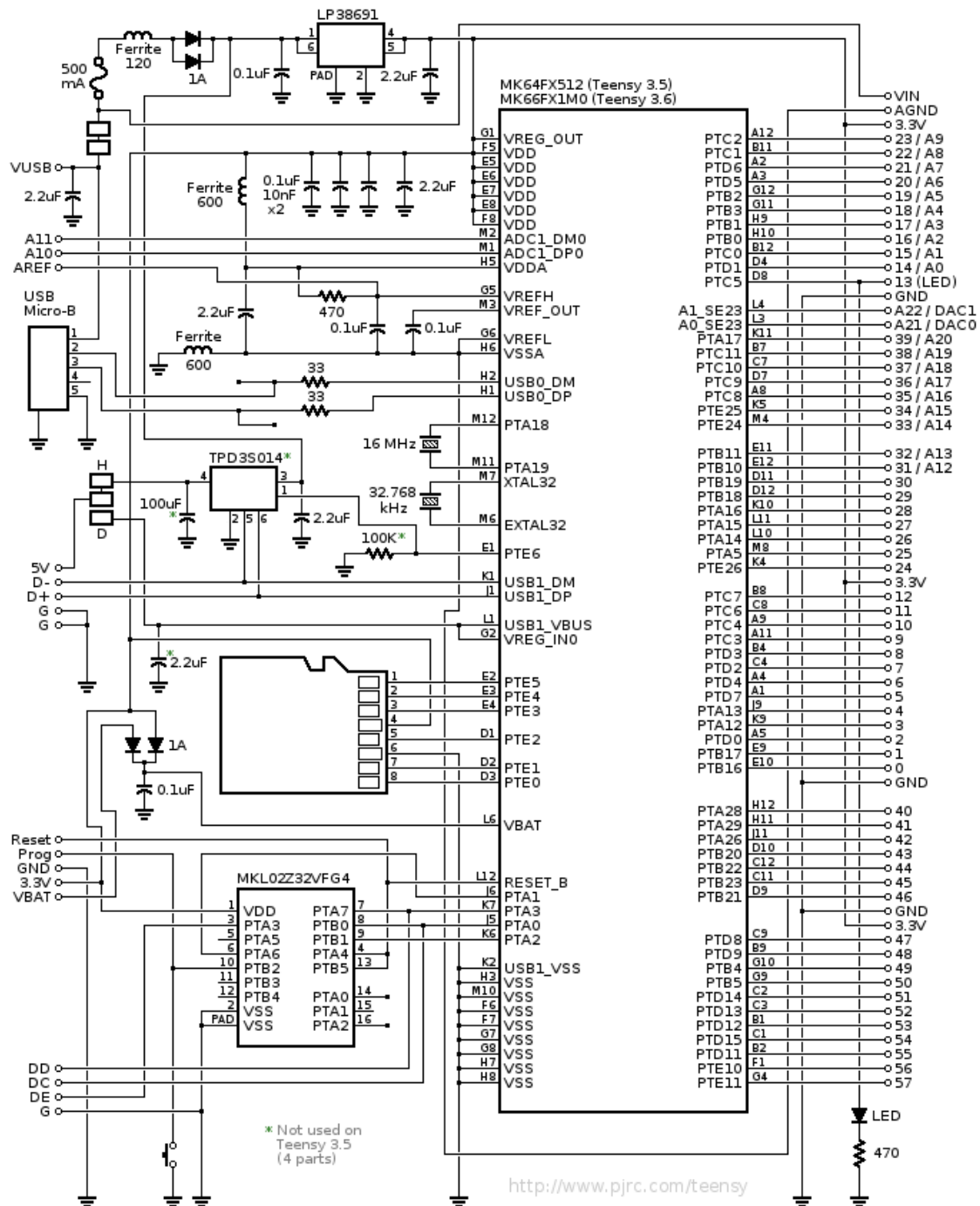


Bild 3.2: Schematic Teensy 3.5

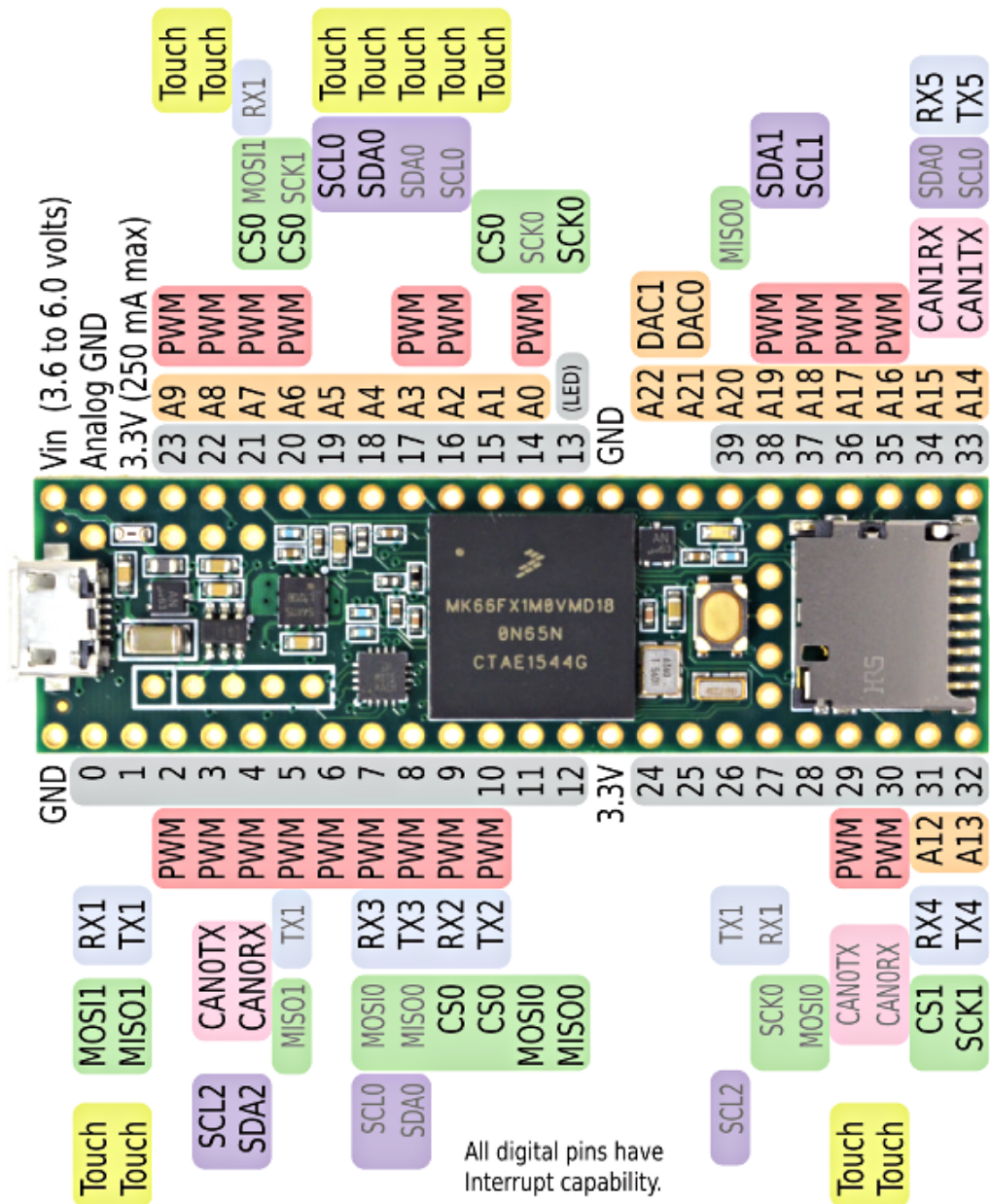


Bild 3.3: Pin assignment, front side

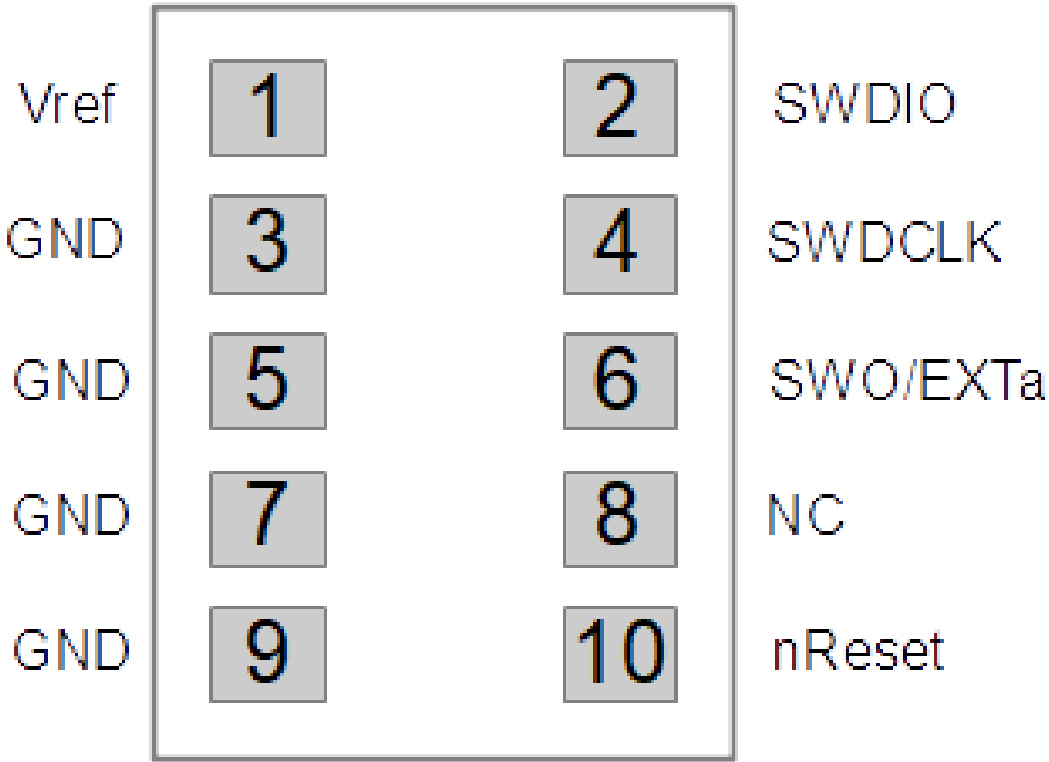


Bild 3.5: SWD pinout

32 QFN	24 QFN	16 QFN	Pin Name	Default	ALT0	ALT1	ALT2	ALT3
16	12	8	PTB0/ IRQ_5	ADC0_SE6	ADC0_SE6	PTB0/ IRQ_5	EXTRG_IN	SPI0_SCK
17	13	9	PTB1/ IRQ_6	ADC0_SE5/ CMP0_IN3	ADC0_SE5/ CMP0_IN3	PTB1/ IRQ_6	UART0_TX	UART0_RX
18	14	10	PTB2/ IRQ_7	ADC0_SE4	ADC0_SE4	PTB2/ IRQ_7	UART0_RX	UART0_TX
19	15	—	PTA8	ADC0_SE3	ADC0_SE3	PTA8	I2C1_SCL	
20	16	—	PTA9	ADC0_SE2	ADC0_SE2	PTA9	I2C1_SDA	
21	—	—	PTA10/ IRQ_8	DISABLED		PTA10/ IRQ_8		
22	—	—	PTA11/ IRQ_9	DISABLED		PTA11/ IRQ_9		
23	17	11	PTB3/ IRQ_10	DISABLED		PTB3/ IRQ_10	I2C0_SCL	UART0_TX
24	18	12	PTB4/ IRQ_11	DISABLED		PTB4/ IRQ_11	I2C0_SDA	UART0_RX
25	19	13	PTB5/ IRQ_12	NMI_b	ADC0_SE1/ CMP0_IN1	PTB5/ IRQ_12	TPM1_CH1	NMI_b
26	20	—	PTA12/ IRQ_13/ LPTMR0_ALT2	ADC0_SE0/ CMP0_IN0	ADC0_SE0/ CMP0_IN0	PTA12/ IRQ_13/ LPTMR0_ALT2	TPM1_CH0	TPM_CLKIN0
27	—	—	PTA13	DISABLED		PTA13		
28	—	—	PTB12	DISABLED		PTB12		
29	21	—	PTB13	ADC0_SE13	ADC0_SE13	PTB13	TPM1_CH1	
30	22	14	PTA0/ IRQ_0	SWD_CLK	ADC0_SE12/ CMP0_IN2	PTA0/ IRQ_0	TPM1_CH0	SWD_CLK
31	23	15	PTA1/ IRQ_1/ LPTMR0_ALT1	RESET_b		PTA1/ IRQ_1/ LPTMR0_ALT1	TPM_CLKIN0	RESET_b
32	24	16	PTA2	SWD_DIO		PTA2	CMP0_OUT	SWD_DIO

Bild 3.6: Pin out MKL02Z32VFG4

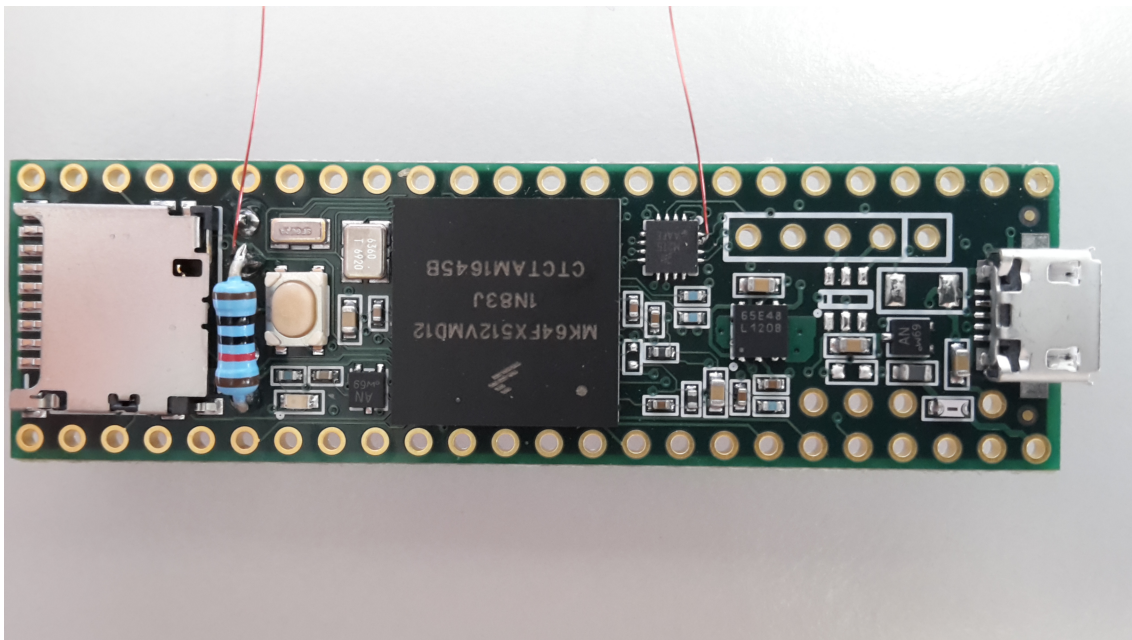


Bild 3.7: Trying to pull the boot loader into reset mode

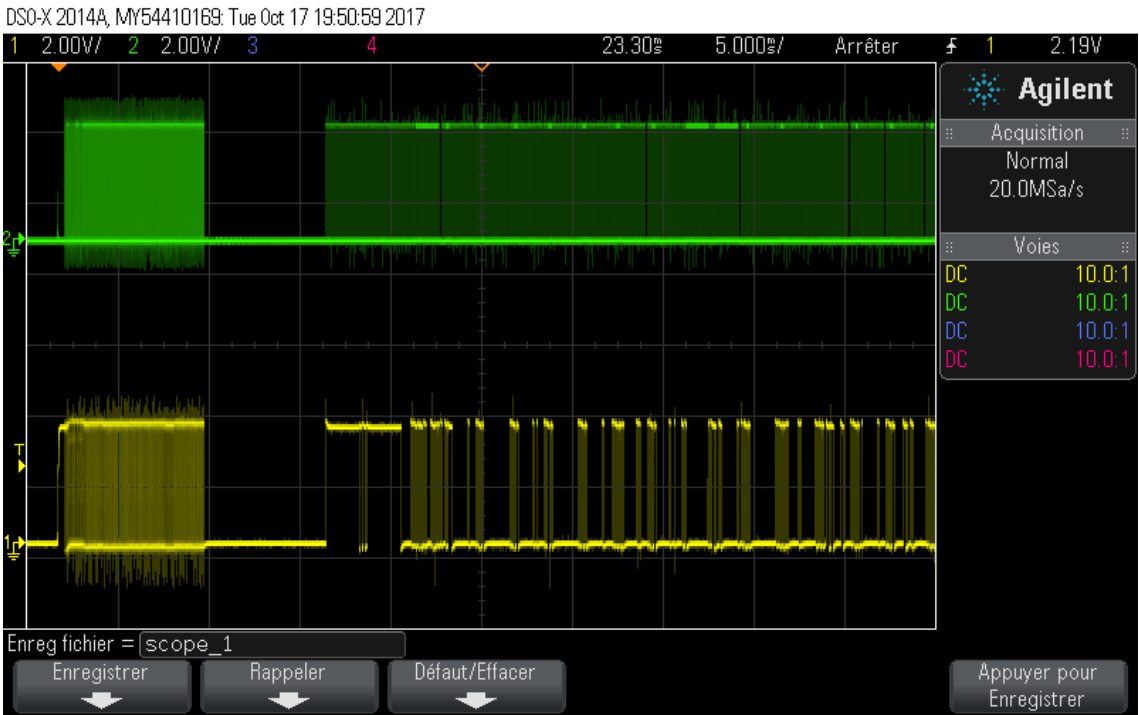


Bild 3.8: The boot loader keeps communicating to the Teensy

3.3 To-Do List for next version of UAV serial switch

List all the changes that are needed on the UAV base board

HW Flow control can't be done without changing HW because lines are RS232 level!

4 Software

A complete documentation of the software written by Andreas Albisser for the Teensy 3.1 can be found in 2.2.

Various issues found with his software can be found in 2.3.

Now there are two options on how to proceed

- Port the existing software to C with FreeRTOS.
- Create a new software concept and implement it.

Both options are evaluated below.

4.0.1 Start with existing Software

4.1 New Software

Talk about new SW concept

To-Do List for new SW

Talk about the things that have not yet been implemented Package numbering instead of waiting for ACK

5 Testing

Testing can be divided into multiple sections:

- Testing of hardware
- Testing of software
- Testing of functionalities with a modem attached

More details about the tests conducted on these items can be found below.

5.1 Hardware Tests

Testing of the core hardware was not done in the scope of this project because it was provided by Andreas Albisser.

Only the Teensy adapter board was tested.

Talk about the wrong footprint used.

5.2 Software Tests

In order to prevent memory leaks and package dropping, the software was tested as well:

- Echo
- Connecting two switches directly, two consoles used
-

5.3 Functionality Tests with Modem

blabla

5.3.1 Test Concept

–

6 Hyperref

Ein mit der vorliegenden Vorlage erstelltes L^AT_EX-Dokument enthält zahlreiche Hyperref-Links. Dies bedeutet, dass sämtliche Verweise im PDF auch direkt als Link fungieren. Klickt man den Verweis an, landet man auf der entsprechenden Seite. Hyperref-Links funktionieren für:

- Bilder
- Tabellen
- Überschriften
- Gleichungen
- Codeblöcke
- Quellenverweise

6.1 Backref

In den Quellenverweisen ist jeweils die Information enthalten, auf welchen Seiten auf diese Quelle verwiesen wird (Zitiert auf Seite ...). Auch diese Verweise funktionieren wiederum als Links im PDF.

6.2 Autoref

Bei Verweisen, welche mit der Funktion „\autoref“, bzw. „\aref“ oder „\autoeqref“ formuliert werden, wird beispielsweise der Begriff „Bild“ automatisch dazugeschrieben. Dabei fungiert zudem im PDF nicht nur die Zahl als Link, sondern auch der ganze dazugehörige Begriff (z.B. ?? anstatt nur ??).das funktioniert natürlich auch mit:

??

??

Kapitel 6

Abschnitt 6.1

??

Im Fall von Anhängen wird der „\aref{ }“-Befehl (*a* für appendix oder Anhang) benötigt:

Anhang A

Anhang A.1

Bei Formeln kann der Befehl „\autoeqref“ angewendet werden:

Gleichung (??)

Tipp

- Labels mit einem Kürzel beginnen, das Auskunft darüber gibt, auf welche Art von Textbaustein es verweist (z.B. „picBeispiel“ für Bild, „tabBeispiel“ für Tabelle, „eqBeispiel“ für Gleichung, „refBeispiel“ für Überschriften).

7 Literaturverweise

7.1 Bibliography und Zotero

Die Einträge im Bibliography-File können mit Zotero erstellt werden. Wenn die entsprechende Literatur dort bereits eingetragen ist, kann sie einfach per Drag-and-Drop in das BibLaTeX-Literaturfile gezogen werden. Als Alternative kann per Rechtsklick auf die Datei über den Befehl “ausgewählten Eintrag exportieren” ein neues BibLaTeX-File mit dem Eintrag erstellt werden. Dies funktioniert auch, wenn mehrere Dateien angewählt sind.

Bei MSE-Berichten sind sämtliche Literaturstellen in der Zotero-Datenbank abzulegen. Zum Eintragen der benötigten Attribute (Titel, Autor etc.) kann Tabelle 7.1 konsultiert werden. Folgende sind Punkte zu beachten:

- **Bevor man bei Zotero eine Literaturstelle hinzufügt, ist zu prüfen, ob diese bereits existiert.** Allfällig bemerkte doppelte Einträge werden fusioniert.
- Der Name der heraufgeladenen PDF-Datei soll dem Schema „Jahr - Autor - Titel“ folgen. Also zum Beispiel „2009 - Seelhofer - Ebener Spannungszustand im Betonbau.pdf“. Bei MSE-Dokumenten schreibt man zusätzlich die das Modul dazu, also beispielsweise: „2013 - Stenz - VM2 - Kontinuierliche Spannungsfeldmodelle.pdf“.
- Beim Eintrag einer Literaturstelle in Zotero ist unter „Datum“ immer nur das Jahr einzutragen, Ausnahme: Zeitschriftenartikel (dort wenn vorhanden den Monat auch berücksichtigen).
- Bei Vertiefungsmodulen ist unter „Art des Berichtes“ der Eintrag „Bericht Vertiefungsmodul 2“ zu machen. Der Zusatz „Bericht“ wird im Hinblick auf die Zitierung in \LaTeX der Verständlichkeit halber benötigt.
- Beim Literaturtyp „Bericht“ werden in Zotero „Seiten“ (von-bis) und nicht die „Anzahl der Seiten“ verlangt. Meistens soll im Literaturverweis aber „123 S.“ (Seitenanzahl) und nicht „S. 123-127“ (gewisse Seiten eines Dokuments) stehen. Die erste Darstellung kann erzwungen werden, wenn in Zotero im Feld „Seiten“ der Eintrag „123 S.“ und nicht nur „123“ gemacht wird. Letzterer Eintrag würde zur meist unerwünschten Darstellung „S. 123“ im Literaturverzeichnis führen.
- Um in \LaTeX auf eine aus Zotero exportierte Literaturstelle zu verweisen, wird im Argument des `\cite`-Befehl folgendes Muster verlangt: „Autor“_ „1.Wort des Titels“ _ „Jahr“ . Beispiel: Auf „Ebener Spannungszustand im Betonbau“ von Seelhofer (2009) wird mit `\cite{seelhofer_ ebener_ 2009}` zitiert.
- Achtung: In Zotero zusätzlich eingegebene Informationen (übrige, unbenutzte Felder) können unter Umständen auch in \LaTeX im Literaturverzeichnis erscheinen (z.B. wenn bei einem Buch der ISBN eingegeben wird, wird dieser am Ende des Verweises im Literaturverzeichnis aufgeführt).
- Die Argumente „@keywords“ und „@file“ in BibLaTeX-Literaturdatenbanken entstehen automatisch beim Export aus Zotero und haben keinen Einfluss auf den Output im Literaturverzeichnis. Sie können also in der Datenbank belassen werden.
- Bei Zeitschriftenartikeln muss bei Verweisen keine Seitenangabe gemacht werden, z.B. [10]. In allen anderen Fällen muss die Seitenzahl, von der die Information aus der Quelle entnommen wurde, angegeben werden, z.B. [11, S. 34] mit `\cite[S. 34]{seelhofer_ ebener_ 2009}`

Literaturtyp	Typ Zotero	Typ \LaTeX	Attribute															
			Titel	Autor	Nr. Bericht	Art Bericht	Ort	Institution	Seiten	Anz. Seiten	Datum	Verlag	Name Konf.	Band	Ausgabe	Publikation		
			title	author	number	type	location	institution	pages	pagetotal	year	publisher	eventtitle	volume	issue /number	journaltitle		
Bericht [5]	Bericht	report	X	X	Nr. 75	Bericht	X	X	000 S.		Jahr							
Buch [17]	Buch	book	X	X						000	Jahr	X						
Dissertation [11]	Dissertation	thesis	X	X			X	X		000	Jahr							
Diskussionsbericht [6]	Bericht	report	X	X	Nr. 124	Diskussionsbericht	X	X	000 S.		Jahr							
Konferenz-Paper, -bericht [14]	Konferenz-Paper	inproceedings	X	X					00-00		Jahr		X	X				
MSE Master-Thesis [1]	Bericht	report	X	X		Master-Thesis	X	X	000 S.		Jahr							
MSE Bericht VM1, VM2 [2]	Bericht	report	X	X		Bericht Vertiefungsmodul 1	X	X	000 S.		Jahr							
Norm [4] [8] [13]	Bericht	report	X				X	X	000 S.		Jahr							
Norm Dokumentation [12]	Bericht	report	X				X	X	000 S.		Jahr							
Anleitung / Manual [15]	Bericht	report	X	X		Anleitung (o.ä.)	X		000 S.		Jahr							
Versuchsbericht [3] [9]	Bericht	report	X	X		Versuchsbericht	X	X	000 S.		Jahr							
Vorlesungsskript [7]	Manuskript	report	X	X		Vorlesungsskript	X	X	000 S.		Jahr							
Zeitschriftenartikel [10] [16]	Zeitschriftenart.	article	X	X					00-00		Monat.Jahr			V. 00 oder 00	No. 00 oder 00	X		

Tabelle 7.1: Für die Literaturverweise benötigte Informationen beim Heraufladen auf Zotero und Zitieren in \LaTeX

Anhang A Anhangstruktur

Hier sollte man am besten jegliche Teile über den `\include`-Befehl importieren. Die Überschriften werden genau gleich wie beim Hauptteil des Berichts über die Befehle `\chapter`, `\section`, `\subsection` und `\subsubsection` eingefügt. Die Layoutstruktur ist analog zu den normalen Kapiteln:

A.1 Unterkapitel im Anhang

Dies hier ist ein Blindtext zum Testen von Textausgaben. Wer diesen Text liest, ist selbst schuld. Der Text gibt lediglich den Grauwert der Schrift an. Ist das wirklich so? Ist es gleichgültig, ob ich schreibe: „Dies ist ein Blindtext“ oder „Huardest gefburn“? Kjift – mitnichten! Ein Blindtext bietet mir wichtige Informationen. An ihm messe ich die Lesbarkeit einer Schrift, ihre Anmutung, wie harmonisch die Figuren zueinander stehen und prüfe, wie breit oder schmal sie läuft. Ein Blindtext sollte möglichst viele verschiedene Buchstaben enthalten und in der Originalsprache gesetzt sein. Er muss keinen Sinn ergeben, sollte aber lesbar sein. Fremdsprachige Texte wie „Lorem ipsum“ dienen nicht dem eigentlichen Zweck, da sie eine falsche Anmutung vermitteln.

A.1.1 Tieferes Kapitel

Noch tieferes Kapitel

Dies hier ist ein Blindtext zum Testen von Textausgaben. Wer diesen Text liest, ist selbst schuld. Der Text gibt lediglich den Grauwert der Schrift an. Ist das wirklich so? Ist es gleichgültig, ob ich schreibe: „Dies ist ein Blindtext“ oder „Huardest gefburn“? Kjift – mitnichten! Ein Blindtext bietet mir wichtige Informationen. An ihm messe ich die Lesbarkeit einer Schrift, ihre Anmutung, wie harmonisch die Figuren zueinander stehen und prüfe, wie breit oder schmal sie läuft. Ein Blindtext sollte möglichst viele verschiedene Buchstaben enthalten und in der Originalsprache gesetzt sein. Er muss keinen Sinn ergeben, sollte aber lesbar sein. Fremdsprachige Texte wie „Lorem ipsum“ dienen nicht dem eigentlichen Zweck, da sie eine falsche Anmutung vermitteln.

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- [2] Amsler, M., *Verstärkung von bestehenden Betontragwerken mit Aufbeton*, VM1, Horw: Hochschule Luzern - Technik & Architektur, Kompetenzzentrum Konstruktiver Ingenieurbau, 2012, 74 S. (Zitiert auf S. 36).
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- [4] *Eurocode 2: Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau*, Lausanne: Europäisches Komitee für Normung, 2010, 246 S. (Zitiert auf S. 36).
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Bezeichnungen

Lateinische Grossbuchstaben

A_c	Fläche eines Betonquerschnitts
B	Belastungsgrad
B_{cr}	Belastungsgrad bei Erreichen des Risslastniveaus
E_c	Elastizitätsmodul von Beton
M	Moment
P	Pol auf dem Mohrschen Kreis der Verzerrungen
P	Einzellast
P_F	Pol auf dem Mohrschen Kreis der aufgetragenen Spannungen
Q	Last, Belastung
RH	Luftfeuchtigkeit

Lateinische Kleinbuchstaben

a_s	längenbezogener Bewehrungsquerschnitt
c_u, c_o	Bewehrungsüberdeckung unten und oben
c_{cIij}	Ungerissene Betonsteifigkeitsmatrix
c_{cIIij}	Gerissene Betonsteifigkeitsmatrix
n_x, n_y, n_{xy}	Plattenschnittkräfte: Längenbezogene Normalkräfte
q_x, q_y, q_z	Flächenlasten
s	Beiwert Abbindegeschwindigkeit
s_{rm}	diagonaler Rissabstand
t_s	Zeitpunkt des Schwindbeginns
u	Umfang des Betonquerschnitts
x, y, z	Kartesische Koordinaten

Griechische Grossbuchstaben

$\Delta\sigma_{ci}$	Tensor Änderung der Betonspannungen
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Griechische Kleinbuchstaben

α	Faktor Abbindegeschwindigkeit, Drehwinkel Transformation
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Bezeichnungen

$\epsilon_{cs}, \epsilon_{csi}$	Schwinddehnung bzw. Schwinddehnungstensor des Betons
$\epsilon_{cs,\infty}$	Endschwindmass
ρ_x, ρ_y	geometrischer Bewehrungsgehalt in x -Richtung bzw. in y -Richtung
φ	Kriechzahl

Sonderzeichen

$\varnothing_x, \varnothing_y$	Stabdurchmesser der Bewehrung in x -Richtung bzw. in y -Richtung
∂	Differenz bei der partiellen Ableitung
∞	unendlich

Abkürzungen

CMM	Gerissenes Scheibenmodell
Emat	Steifigkeitsmatrix (Jakobimatrix)
GH	Modell für gerissene Hauptrichtungen
LE	Modell für linearelastisches Verhalten
MC	Model Code

Lebenslauf

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Liste der noch zu erledigenden Punkte

■ Link zur Aufgabenstellung im Appendix	2
■ Link zur Installationsanleitung im Appendix	6
■ Link zum user manual FW installation von Andreas	8
■ Aufgabenstellung	17
■ Link zu Aufgabenstellung	20