# EE3DSD: Digital System Design (Coursework 1)

The following report details the first work undertaken while developing a decoder for the UK MSF and German DCF77 low frequency radio clock signals using the GNU/Linux VHDL toolchain. This beginning work is focused on analysing and decoding the received clock signals and button inputs.

## Methodology

In the laboratory session, the Spartan-6 FPGA was connected to the MSF and DCF signal receivers for inputs, and via a serial port and USB adapter to a computer for taking and processing readings. The supplied Logic Analyser VHDL sources were built using the GHDL compiler and then synthesised and uploaded to the FPGA. The minicom modem controller was then used to record logs to disk of the incoming signals from the FPGA, in the form of plaintext data files containing singly entry per line data entries in the form:

<msf> <dcf> <unused> <right btn> <left btn> <center btn> <down btn> <up btn> <timestamp>

Where timestamp was a numerical value followed by a unit to indicate the uptime of the device. All other information is encoded in single bits. For example:

0 1 1 0 0 0 0 0 0 1504.00394 ms

0 0 1 0 0 0 0 0 0 1622.44050 ms

0 1 1 0 0 0 0 0 0 2404.29367 ms

1 1 1 0 0 0 0 0 0 2409.46444 ms

0 1 1 0 0 0 0 0 0 2602.13484 ms

0 0 1 0 0 0 0 0 0 2619.81661 ms

Two trace files were captured: the purpose of the first log was to record incoming data from the MSF and DCF receivers, and for the second log session the clock receivers were disabled, and all input was provided by pressing the buttons.

The Radio Clock test signal VHDL program

A small bash script (Figure 1) was created in order to automate the process of testing the

#!/bin/bash

usage **()** **{**

echo "Usage: $0 <tracefile>"

**}**

**if** **[** -z $1 **]**; **then**

usage

exit 1

**fi**

**if** **[** ! -f $1 **]**; **then**

echo "Trace file '$1' not found"

exit 2

**fi**

**if** **[** -f trace.cap **]**; **then**

# Backup existing trace file so as not to overwrite

mv -v trace.cap .trace.cap~

**fi**

# Copy user trace file and simulate

cp $1 trace.cap

make clean sim view

Figure 1 runtrace.sh script for creating and viewing traces

## Button behaviour

*Give typical timescales for the buttons to settle as measured from your*

*waveforms with GTKWave. Calculate the average time it takes for a button to*

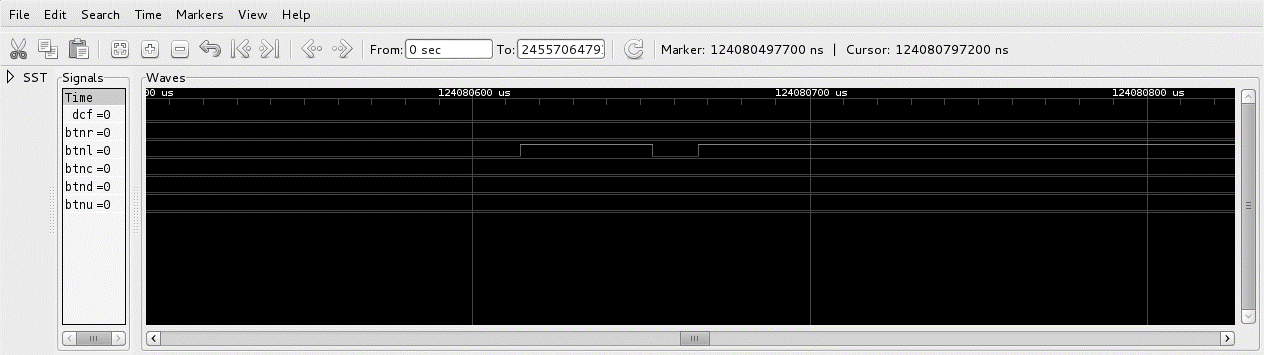
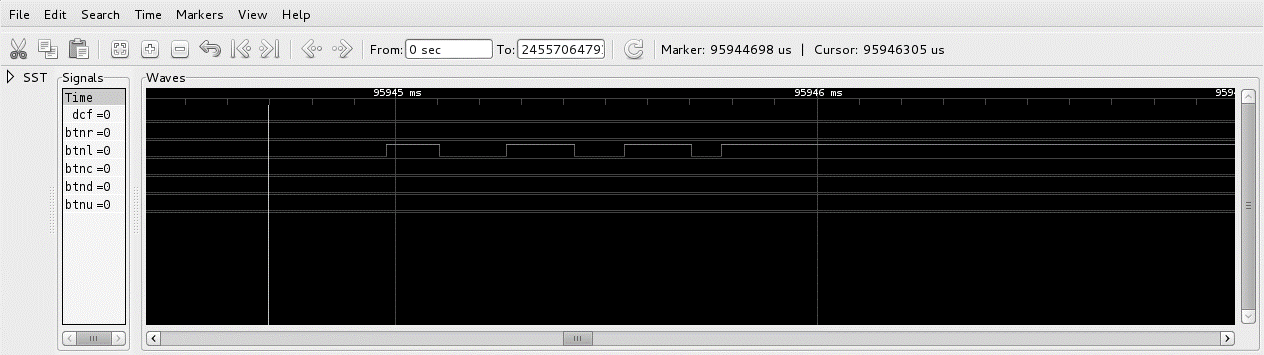
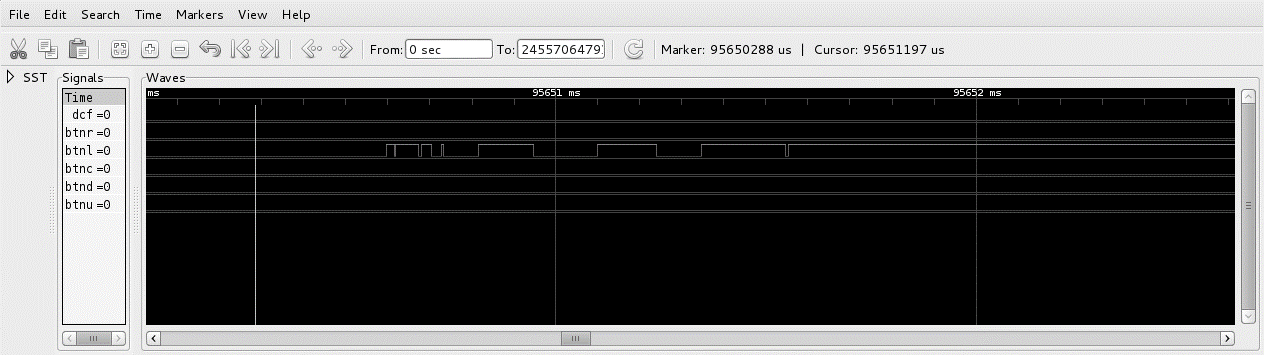
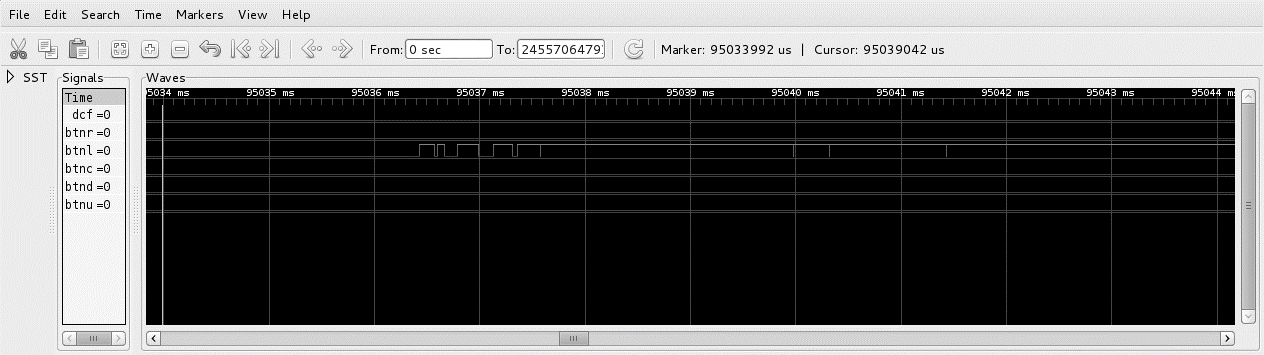
*settle with standard deviation plus minimum and maximum time. You need to*

*analyse at least 100 events to get reasonable statistics.*

## Button bouncing

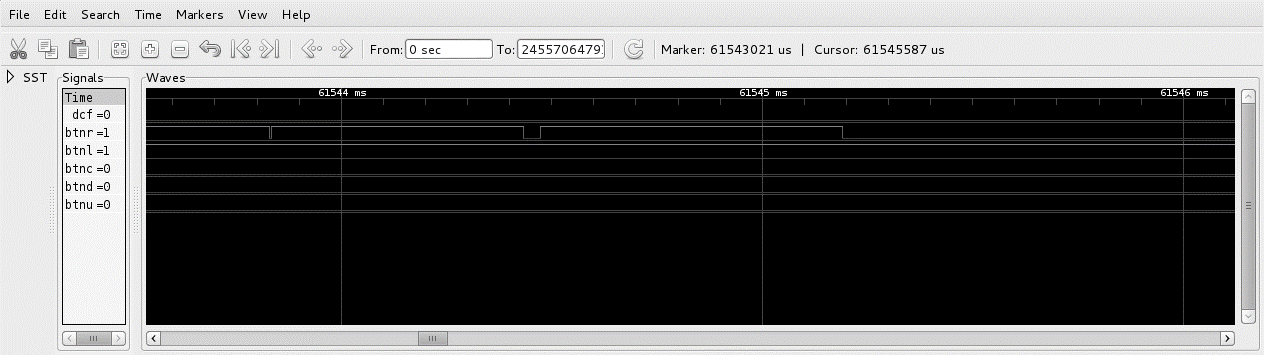
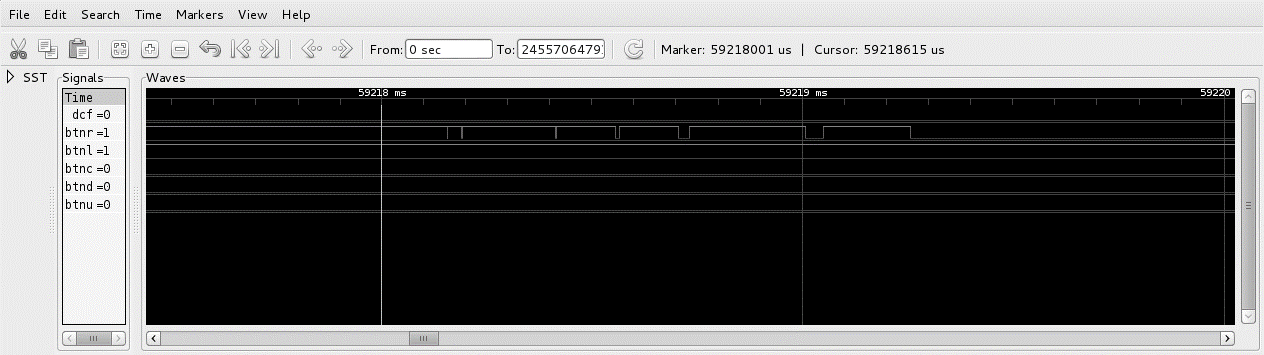
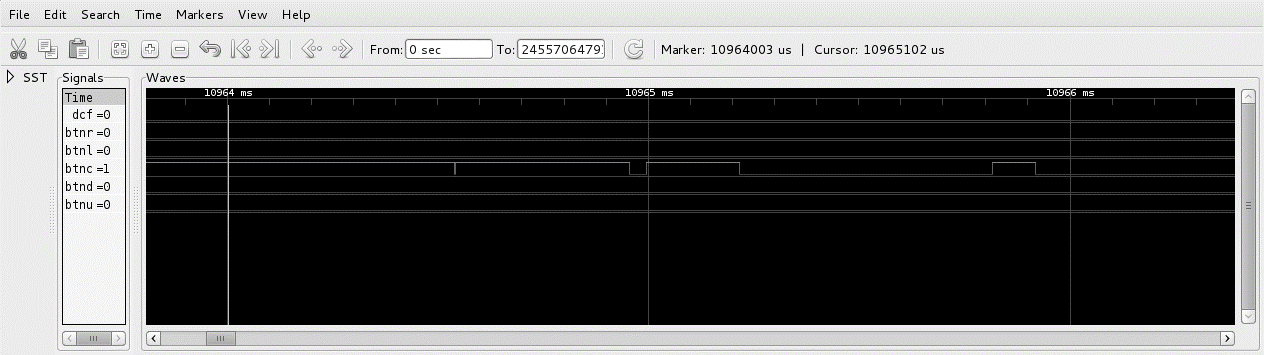
### Rising edge

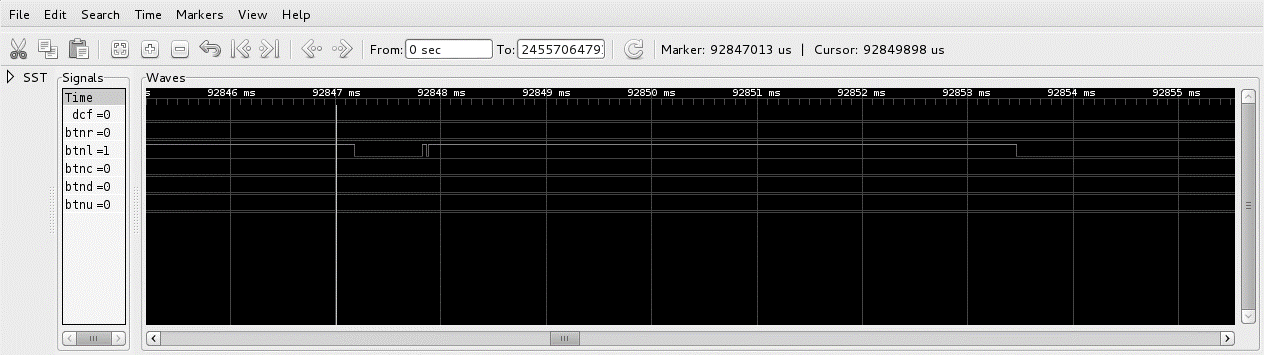
The following screenshots show four button bouncing events on the rising edge of the button press, i.e. as the button is pressed.



### Falling edge

The following screenshots show four button bouncing events on the falling edge of the button press, i.e. after the button has been released.





## DCF Signal

The DCF clock signal uses a 77.05 kHz carrier frequency and a simple pulse width encoding of binary digits, with a 100ms pulse to dictate a binary 0 and a 200ms pulse for binary 1. The signal consist of 59 bits with the last second of every minute containing no pulse modulation to mark the start of the next minute. The DCF signal contains the date, time (with time zone and leap second information), civil warning and weather information, with even parity bits to verify data.

To obtain a DCF trace the MSF data was filtered from the trace file, leaving 118 readings which covers a minute of DCF transmission (there are 2 readings per bit, one for the rising edge and the other for the falling). Figure 2 shows the full minute transmission, starting with the cursor on the 59th second of the previous minute.

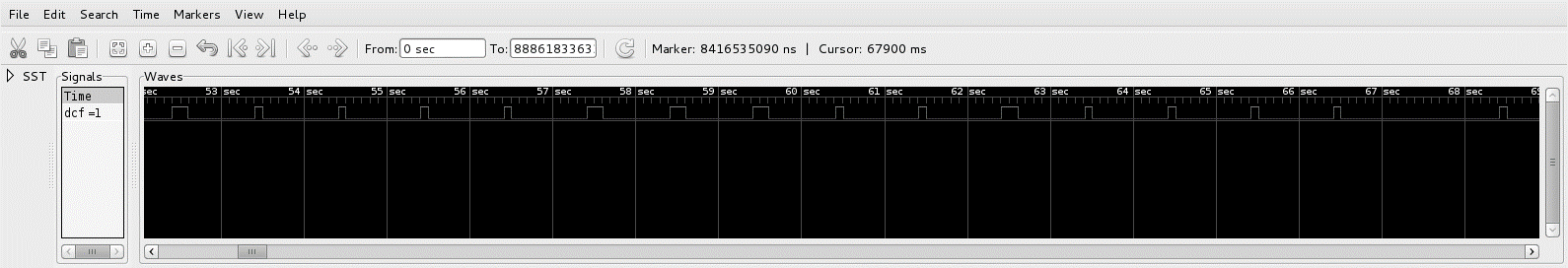
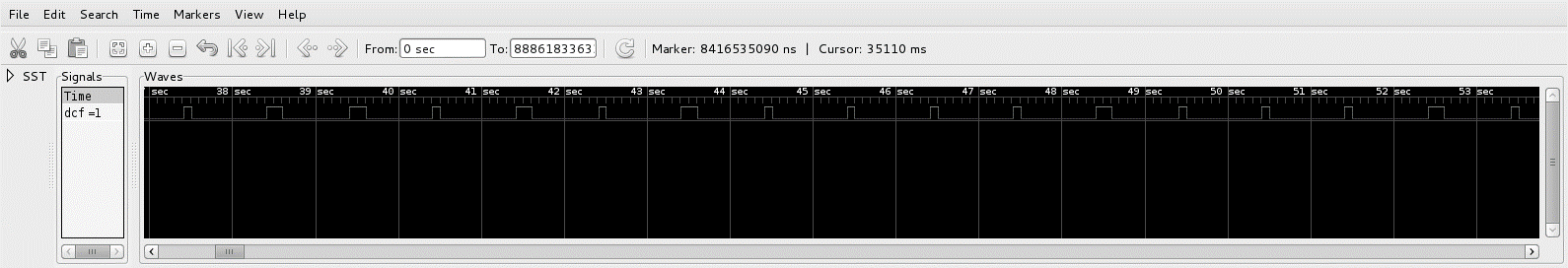
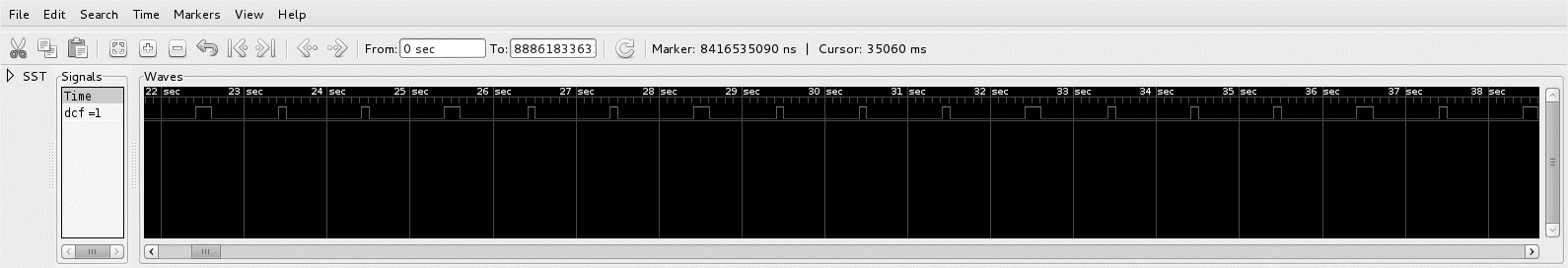
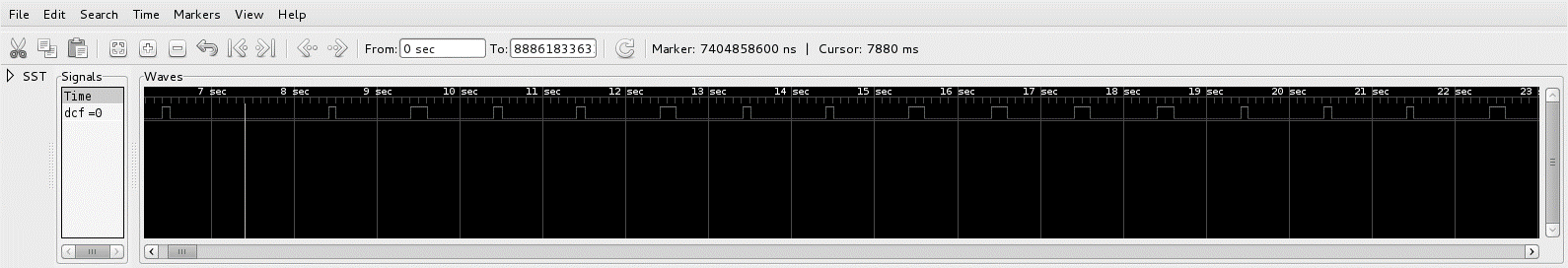


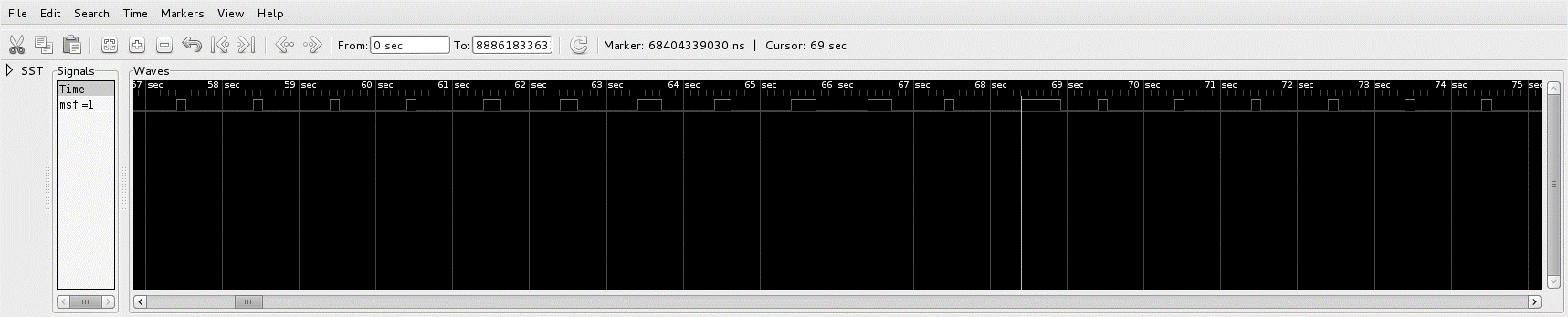
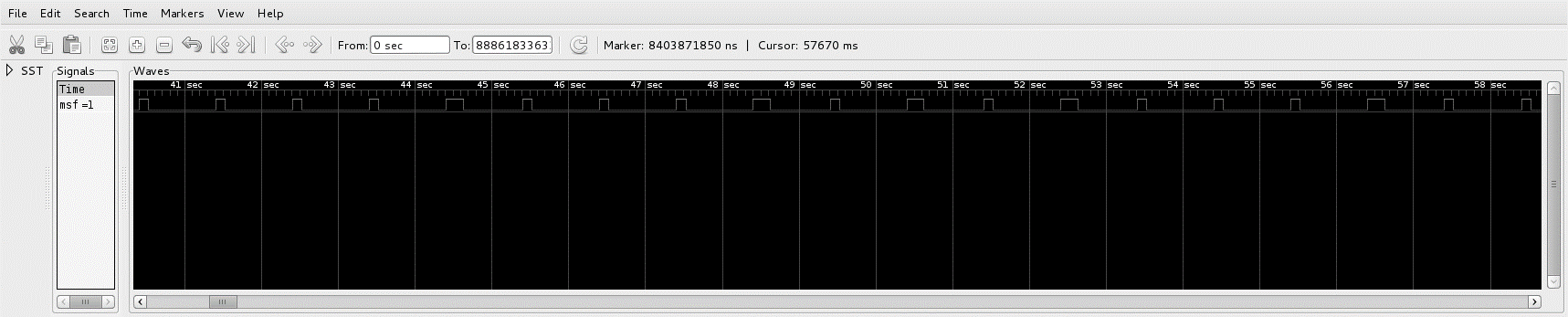
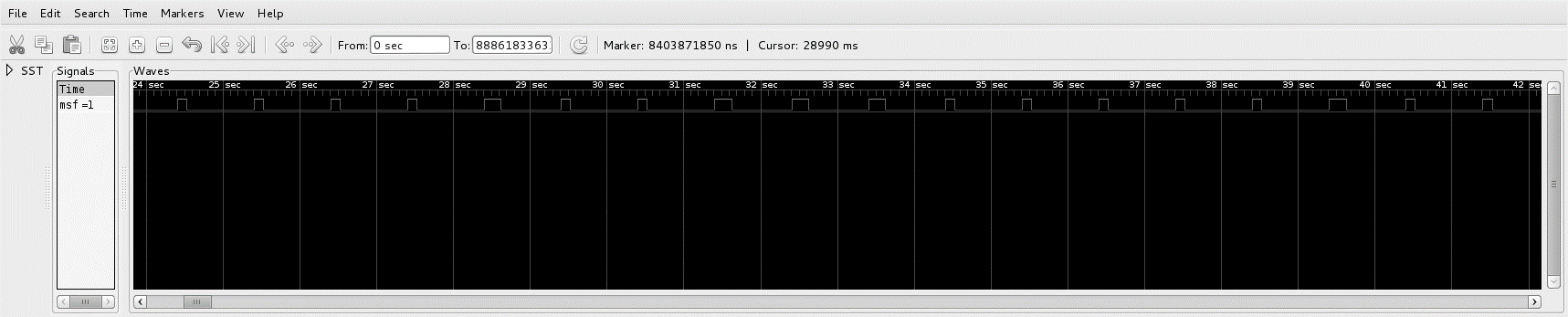
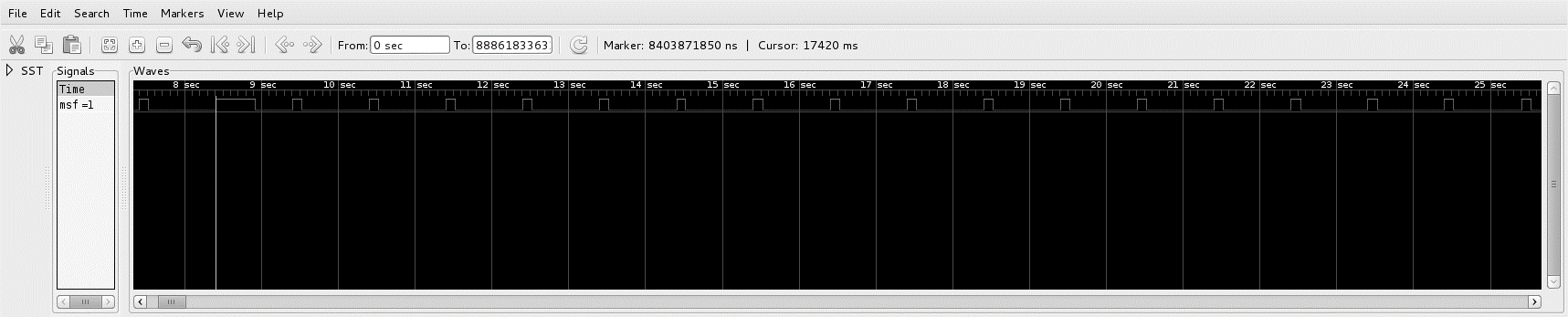
Figure 2 A sequential series of screenshots showing a full minute of DCF transmission.

The following table shows the trace file alongside information such as the bit number, the decoded value (based on the pulse length), and the purpose of each bit. The DCF transmission uses three even parity bits for the minutes, hours and date message components, with the recorded bit sequence decoding to the following message:

16:08 CEST (UTC+2), Thursday 10th October 13

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Bit** | **Value** | **Meaning** | **Weight** |
| 1 1 1 0 0 0 0 0 0 8416.53509 ms | :00 | **0** | Start of minute |  |
| 0 1 1 0 0 0 0 0 0 8506.42440 ms |
| 1 1 1 0 0 0 0 0 0 9410.87999 ms | :01 | **1** | Bundesamt für Bevölkerungsschutz und Katastrophenwarnung civil warning and weather bits. |  |
| 0 0 1 0 0 0 0 0 0 9606.97260 ms |
| 1 1 1 0 0 0 0 0 0 10409.72956 ms | :02 | **0** |
| 0 1 1 0 0 0 0 0 0 10506.94701 ms |
| 1 1 1 0 0 0 0 0 0 11408.11925 ms | :03 | **0** |
| 0 1 1 0 0 0 0 0 0 11505.66593 ms |
| 1 1 1 0 0 0 0 0 0 12412.53773 ms | :04 | **1** |
| 0 0 1 0 0 0 0 0 0 12606.91153 ms |
| 1 1 1 0 0 0 0 0 0 13413.35687 ms | :05 | **0** |
| 0 1 1 0 0 0 0 0 0 13507.81762 ms |
| 1 1 1 0 0 0 0 0 0 14416.62034 ms | :06 | **0** |
| 0 1 1 0 0 0 0 0 0 14507.73480 ms |
| 1 1 1 0 0 0 0 0 0 15409.88859 ms | :07 | **1** |
| 0 0 1 0 0 0 0 0 0 15602.11915 ms |
| 1 1 1 0 0 0 0 0 0 16411.74339 ms | :08 | **1** |
| 0 0 1 0 0 0 0 0 0 16601.28278 ms |
| 1 1 1 0 0 0 0 0 0 17411.81975 ms | :09 | **1** |
| 0 0 1 0 0 0 0 0 0 17601.90112 ms |
| 1 1 1 0 0 0 0 0 0 18409.60244 ms | :10 | **1** |
| 0 0 1 0 0 0 0 0 0 18604.48158 ms |
| 1 1 1 0 0 0 0 0 0 19415.78922 ms | :11 | **0** |
| 0 1 1 0 0 0 0 0 0 19504.81059 ms |
| 1 1 1 0 0 0 0 0 0 20415.81558 ms | :12 | **0** |
| 0 1 1 0 0 0 0 0 0 20507.40964 ms |
| 1 1 1 0 0 0 0 0 0 21414.51530 ms | :13 | **0** |
| 0 1 1 0 0 0 0 0 0 21504.40487 ms |
| 1 1 1 0 0 0 0 0 0 22415.59787 ms | :14 | **1** |
| 0 0 1 0 0 0 0 0 0 22599.88162 ms |
| 1 1 1 0 0 0 0 0 0 23414.60396 ms | :15 | **0** | Abnormal transmitter operation |  |
| 0 1 1 0 0 0 0 0 0 23504.56446 ms |
| 1 1 1 0 0 0 0 0 0 24412.62442 ms | :16 | **0** | Summer time announcement |  |
| 0 1 1 0 0 0 0 0 0 24504.82378 ms |
| 1 1 1 0 0 0 0 0 0 25410.82469 ms | :17 | **1** | CEST bit |  |
| 0 0 1 0 0 0 0 0 0 25600.05206 ms |
| 1 1 1 0 0 0 0 0 0 26417.90104 ms | :18 | **0** | CET bit |  |
| 0 1 1 0 0 0 0 0 0 26506.13445 ms |
| 1 1 1 0 0 0 0 0 0 27414.30934 ms | :19 | **0** | Leap second announcement |  |
| 0 1 1 0 0 0 0 0 0 27507.33158 ms |
| 1 1 1 0 0 0 0 0 0 28417.63158 ms | :20 | **1** | Start of encoded time |  |
| 0 1 1 0 0 0 0 0 0 28606.88466 ms |
| 1 1 1 0 0 0 0 0 0 29412.08879 ms | :21 | **0** | Minutes (0-59) | 1 |
| 0 1 1 0 0 0 0 0 0 29505.28061 ms |
| 1 1 1 0 0 0 0 0 0 30415.61355 ms | :22 | **0** | 2 |
| 0 1 1 0 0 0 0 0 0 30505.42330 ms |
| 1 1 1 0 0 0 0 0 0 31410.76013 ms | :23 | **0** | 4 |
| 0 1 1 0 0 0 0 0 0 31508.47938 ms |
| 1 1 1 0 0 0 0 0 0 32416.04544 ms | :24 | **1** | 8 |
| 0 1 1 0 0 0 0 0 0 32602.78078 ms |
| 1 1 1 0 0 0 0 0 0 33409.42868 ms | :25 | **0** | 10 |
| 0 1 1 0 0 0 0 0 0 33506.87336 ms |
| 1 1 1 0 0 0 0 0 0 34416.76350 ms | :26 | **0** | 20 |
| 0 1 1 0 0 0 0 0 0 34507.26182 ms |
| 1 1 1 0 0 0 0 0 0 35413.41920 ms | :27 | **0** | 40 |
| 0 1 1 0 0 0 0 0 0 35507.59860 ms |
| 1 1 1 0 0 0 0 0 0 36412.58461 ms | :28 | **1** | Parity bit for minutes |  |
| 0 0 1 0 0 0 0 0 0 36607.28515 ms |
| 1 1 1 0 0 0 0 0 0 37412.79020 ms | :29 | **0** | Hours (0-23) | 1 |
| 0 1 1 0 0 0 0 0 0 37506.37647 ms |
| 1 1 1 0 0 0 0 0 0 38414.68335 ms | :30 | **1** | 2 |
| 0 0 1 0 0 0 0 0 0 38602.50950 ms |
| 1 1 1 0 0 0 0 0 0 39412.98482 ms | :31 | **1** | 4 |
| 0 1 1 0 0 0 0 0 0 39608.47374 ms |
| 1 1 1 0 0 0 0 0 0 40411.07808 ms | :32 | **0** | 8 |
| 0 1 1 0 0 0 0 0 0 40503.44868 ms |
| 1 1 1 0 0 0 0 0 0 41414.51199 ms | :33 | **1** | 10 |
| 0 0 1 0 0 0 0 0 0 41603.81790 ms |
| 1 1 1 0 0 0 0 0 0 42411.98859 ms | :34 | **0** | 20 |
| 0 1 1 0 0 0 0 0 0 42504.74114 ms |
| 1 1 1 0 0 0 0 0 0 43409.60246 ms | :35 | **1** | Parity bit for hours |  |
| 0 0 1 0 0 0 0 0 0 43603.52495 ms |
| 1 1 1 0 0 0 0 0 0 44410.60012 ms | :36 | **0** | Day of month (1-31) | 1 |
| 0 1 1 0 0 0 0 0 0 44508.24911 ms |
| 1 1 1 0 0 0 0 0 0 45415.97966 ms | :37 | **0** | 2 |
| 0 1 1 0 0 0 0 0 0 45502.62891 ms |
| 1 1 1 0 0 0 0 0 0 46410.38667 ms | :38 | **0** | 4 |
| 0 1 1 0 0 0 0 0 0 46505.23869 ms |
| 1 1 1 0 0 0 0 0 0 47415.12294 ms | :39 | **0** | 8 |
| 0 1 1 0 0 0 0 0 0 47504.31203 ms |
| 1 1 1 0 0 0 0 0 0 48411.27513 ms | :40 | **1** | 10 |
| 0 1 1 0 0 0 0 0 0 48603.07266 ms |
| 1 1 1 0 0 0 0 0 0 49409.61938 ms | :41 | **0** | 20 |
| 0 1 1 0 0 0 0 0 0 49505.74470 ms |
| 1 1 1 0 0 0 0 0 0 50411.19757 ms | :42 | **0** | Day of week (Monday=1, Sunday=7) | 1 |
| 0 1 1 0 0 0 0 0 0 50505.94627 ms |
| 1 1 1 0 0 0 0 0 0 51412.42953 ms | :43 | **0** | 2 |
| 0 1 1 0 0 0 0 0 0 51503.34179 ms |
| 1 1 1 0 0 0 0 0 0 52412.19953 ms | :44 | **1** | 4 |
| 0 1 1 0 0 0 0 0 0 52604.17997 ms |
| 1 1 1 0 0 0 0 0 0 53411.11063 ms | :45 | **0** | Month (Junuary=1, December=12) | 1 |
| 0 1 1 0 0 0 0 0 0 53508.22833 ms |
| 1 1 1 0 0 0 0 0 0 54415.63883 ms | :46 | **0** | 2 |
| 0 1 1 0 0 0 0 0 0 54505.06983 ms |
| 1 1 1 0 0 0 0 0 0 55410.74412 ms | :47 | **0** | 4 |
| 0 1 1 0 0 0 0 0 0 55504.73368 ms |
| 1 1 1 0 0 0 0 0 0 56413.42473 ms | :48 | **0** | 8 |
| 0 1 1 0 0 0 0 0 0 56504.40834 ms |
| 1 1 1 0 0 0 0 0 0 57416.47699 ms | :49 | **1** | 10 |
| 0 0 1 0 0 0 0 0 0 57603.88238 ms |
| 1 1 1 0 0 0 0 0 0 58410.03573 ms | :50 | **1** | Year within century (0-99) | 1 |
| 0 0 1 0 0 0 0 0 0 58602.04190 ms |
| 1 1 1 0 0 0 0 0 0 59412.00920 ms | :51 | **1** | 2 |
| 0 0 1 0 0 0 0 0 0 59603.95935 ms |
| 1 1 1 0 0 0 0 0 0 60415.08350 ms | :52 | **0** | 4 |
| 0 1 1 0 0 0 0 0 0 60504.99266 ms |
| 1 1 1 0 0 0 0 0 0 61409.73421 ms | :53 | **0** | 8 |
| 0 1 1 0 0 0 0 0 0 61508.26582 ms |
|  |  |  |  |
| 1 1 1 0 0 0 0 0 0 62408.25061 ms | :54 | **1** | 10 |
| 0 1 1 0 0 0 0 0 0 62606.93558 ms |
| 1 1 1 0 0 0 0 0 0 63416.36916 ms | :55 | **0** | 20 |
| 0 1 1 0 0 0 0 0 0 63507.27450 ms |
| 1 1 1 0 0 0 0 0 0 64415.17233 ms | :56 | **0** | 40 |
| 0 1 1 0 0 0 0 0 0 64509.08096 ms |
| 1 1 1 0 0 0 0 0 0 65414.34857 ms | :57 | **0** | 80 |
| 0 1 1 0 0 0 0 0 0 65509.36495 ms |
| 1 1 1 0 0 0 0 0 0 66414.71985 ms | :58 | **0** | Parity bit for date |  |
| 0 1 1 0 0 0 0 0 0 66500.48195 ms |
|  | :59 |  | Minute mark (no transmission) |  |
|  |

## MSF Signal



*Screenshots of your sampled MSF signals over at least one full minute showing*

*the start of the minute and the start of the next minute. You need to zoom in*

*sufficiently to be able to tell the duration of the pulses and be able to*

*identify the information encoded on them. Make the screenshots overlap, e.g. the*

*end of one screenshot should be the start of the next, so that when you put all*

*screenshots next to each other you get the full minute with all details of the*

*encoded information clearly visible.*

*An annotated trace file of your MSF signals as described above, which*

*corresponds to the MSF screenshots in your report.*

*The decoded bits from second 0 to second 59 for the MSF signal the decoded time*

*and date information from the decoded bits including a description how you*

*decoded them including the parity checks.*

## Sampling accuracy

*An annotated trace file showing the differences in arrival times of the DCF and*

*MSF second markers from one second to the next and between MSF and DCF. An*

*analysis of these to show the mean difference and standard deviation between*

*consecutive seconds and the two radio clocks. An estimate of the frequency error*

*of the local crystal oscillator on the development board including error margins*

*based on your data.*

## Propagation times

The MSF signal is broadcast at 60kHz (1), while the DCF77 uses a 77.5kHz carrier signal (2), placing both signals in the Low Frequency (LF) spectrum of radio waves. At these frequencies, long wave radio propagate along the surface and sky between two points at the speed of light. At standard temperature and pressure, the speed of light is negligibly slower than in a vacuum, meaning that the propagation time can be calculated as the distance between the transmitter and receiver divided by 3 × 108 m/s.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Clock** | **Transmitter** | **Receiver** | **Distance (km)** | **Propagation Time (ms)** |
| MSF | 54° 54′ 36″ N, 03° 16′ 48″ W | 52° 28′ 59″ N, 01° 53′ 37″ W | 284.9 | 0.9497 |
| DCF | 50° 00′ 56″ N, 09° 00′ 39″ E | 52° 28′ 59″ N, 01° 53′ 37″ W | 806.1 | 2.6870 |

Table 1 Propagation times of the two clock signals (location coordinates sourced from Wikipedia)

From this we can derive an expected difference between propagation times of 1.7373 ms, or 1.7 × 108 samples on the Spartan-6 development board.

*A theoretical estimate of the expected time difference between DCF and MSF radio*

*clock signals and a comparison with your experimental results obtained plus*

*explanation of any differences.*

# References

1. **Various.** Time from NPL. *Wikipedia.* [Online] N.D. [Cited: 10th October 2013.] http://en.wikipedia.org/wiki/Time\_from\_NPL.

2. —. DCF77. *Wikipedia.* [Online] N.D. [Cited: 10th October 2013.] http://en.wikipedia.org/wiki/DCF77.