An Open and Free ISDB-T full_seg Receiver Implemented in GNU Radio

Federico Larroca, Pablo Flores Guridi, Gabriel Gómez Sena, Víctor González-Barbone and Pablo Belzarena

{flarroca, pablof, ggomez, vagonbar, belza}@fing.edu.uy

Instituto de Ingeniería Eléctrica, Facultad de Ingeniería, Universidad de la República
Uruguay

Wireless Innovation Forum Conference on Wireless Communications Technologies and Software Defined Radio (WInnComm '16)
Reston, Virginia

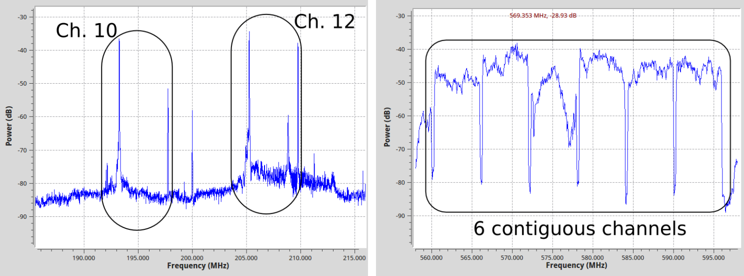
March 17th 2016

Background

- A daunting task has been undertaken in several countries: DTV Transition

Background

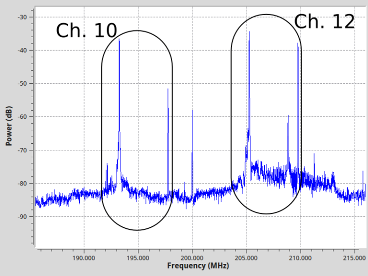
- A daunting task has been undertaken in several countries: DTV Transition
  - Increased spectral efficiency



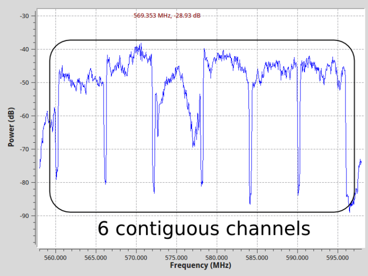
(a) PAL (b) ISDB-T

Background

- A daunting task has been undertaken in several countries: DTV Transition
    - Increased spectral efficiency
    - ⇒ Improved audio/video quality
    - ⇒ $$$(Digital Dividend)



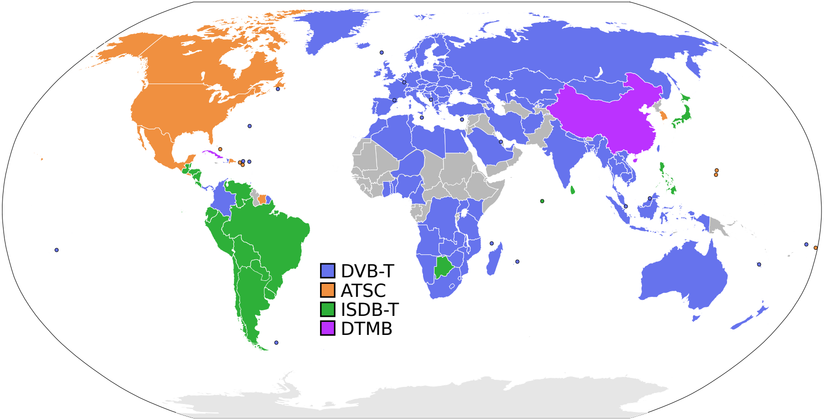
(a) PAL



(b) ISDB-T

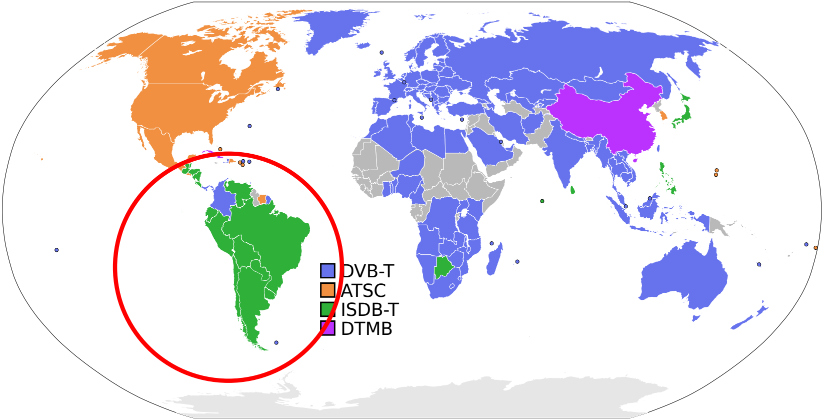
Background

- Plenty of standards: ATSC, DTMB, DVB-T, ISDB-T



Background

- Plenty of standards: ATSC, DTMB, DVB-T, ISDB-T
- ISDB-T $\rightarrow$ ISDB-T International (ISDB-Tb)



Background

Key elements in this transition:

- Deep understanding of the chosen technology
    - No true expertise can be achieved without dealing with actual implementations
- DTV service as good as current analog one
    - Measurements campaigns are necessary

Background

Key elements in this transition:

- Deep understanding of the chosen technology
  - No true expertise can be achieved without dealing with actual implementations
  - We don't manufacture receivers or transmitters
- DTV service as good as current analog one
  - Measurements campaigns are necessary
  - DTV measurement equipment is very costly

Background

Key elements in this transition:

- Deep understanding of the chosen technology
  - No true expertise can be achieved without dealing with actual implementations
  - We don't manufacture receivers or transmitters
- DTV service as good as current analog one
  - Measurements campaigns are necessary
  - DTV measurement equipment is very costly

Software Defined Radio: an excellent alternative!

Background

Key elements in this transition:

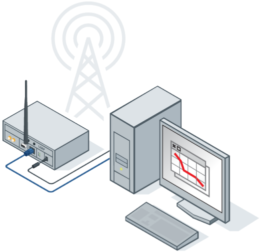
- Deep understanding of the chosen technology
  - No true expertise can be achieved without dealing with actual implementations
  - We don't manufacture receivers or transmitters
- DTV service as good as current analog one
  - Measurements campaigns are necessary
  - DTV measurement equipment is very costly

Software Defined Radio: an excellent alternative!

- We present `gr-isdbt`, an open and free receiver for ISDB-T:
  - Measurement campaigns (access to the full receiving chain)
  - Evaluation of possible improvements
  - Getting to know how things work
  - ...

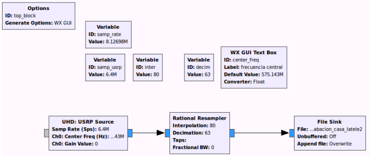
Software Defined Radio (SDR)

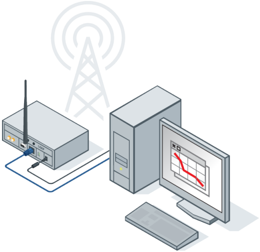
- Basic idea: implement as much as possible of receiver and/or transmitter in software
- We focused on PC-based SDRs: enough sampling rate ($\geq 6\,\mathrm{MHz}$) + some hundreds dollars



Software Defined Radio (SDR)

- Basic idea: implement as much as possible of receiver and/or transmitter in software
- We focused on PC-based SDRs: enough sampling rate ($\geq 6\,\text{MHz}$) + some hundreds dollars
- Software: GNU Radio
  - Free and open-source SDR development toolkit
    - Provides framework to implement and interconnect blocks
  - Extremely popular
    - Supports most (if not all) SDR hardware
    - Growing base of already-implemented blocks



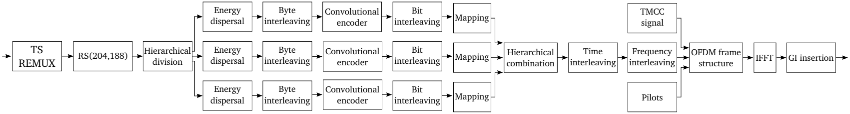


Agenda

ISDB-T, introduction

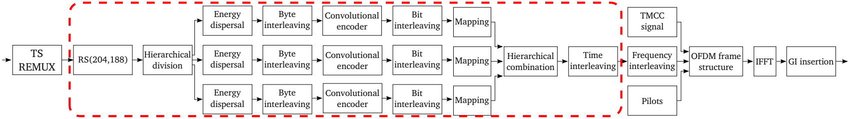
- Stands for Integrated Services Digital Broadcasting - Terrestrial
- Japanese digital and terrestrial television standard, based on DVB-T
- Adopted and adapted by Brazil:
    - Ginga instead of BML for interactivity
    - MPEG-4 instead of MPEG-2 for source coding
- New version of the standard was named ISDB-Tb
- ISDB-Tb was lated adopted by most of South American countries

ISDB-T, briefly described



Parameters	Values
Modulation	BST-OFDM, with CP
Total Bandwidth	6 MHz
Number of segments	13
Segments bandwidth	$6000/14 \approx 428.57\ kHz$
Number of carriers	8192, active: 5617 (mode 3) 4096, active: 2809 (mode 2) 2048, active: 1405 (mode 1)
Sampling rate	$512/63 \approx 8.126MHz$
Cyclic Prefix duration	1/4, 1/8, 1/16, 1/32 (of active symbol duration)
Active symbol duration	252 μs (mode 1) 504 μs (mode 2) 1004 μs (mode 3)
Convolutional Code Rate	1/2, 2/3, 3/4, 5/6, 7/8
Time interleaving parameter	0, 1, 2, 4 (mode 1) 0, 2, 4, 8 (mode 2) 0, 4, 8, 16 (mode 3)
Modulation schemes	DQPSK, QPSK, 16QAM, 64 QAM

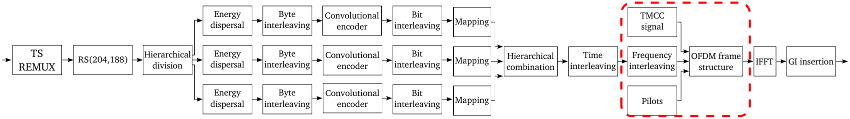
ISDB-T, briefly described



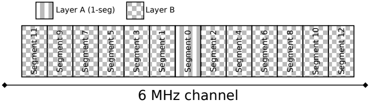
- (up to) three Transport Streams (**Layers** in ISDB-T lingo) transmitted at the same time
- Each Layer may use its own set of transmission parameters

Parameters	**Values**
Modulation	BST-OFDM, with CP
Total Bandwidth	6 MHz
Number of segments	13
Segments bandwidth	$6000/14 \approx 428.57\ kHz$
Number of carriers	8192, active: 5617 (mode 3) 4096, active: 2809 (mode 2) 2048, active: 1405 (mode 1)
Sampling rate	$512/63 \approx 8.126 MHz$
Cyclic Prefix duration	1/4, 1/8, 1/16, 1/32 (of active symbol duration)
Active symbol duration	252 μs (mode 1) 504 μs (mode 2) 1004 μs (mode 3)
Convolutional Code Rate	1/2, 2/3, 3/4, 5/6, 7/8
Time interleaving parameter	0, 1, 2, 4 (mode 1) 0, 2, 4, 8 (mode 2) 0, 4, 8, 16 (mode 3)
Modulation schemes	DQPSK, QPSK, 16QAM, 64 QAM

ISDB-T, briefly described

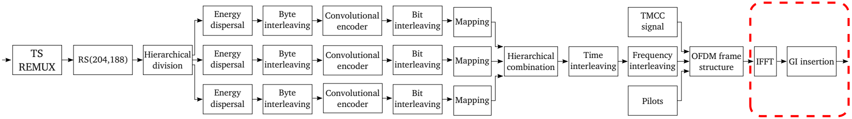


- OFDM with configurable number of carriers
- Each Layer is sent over a set of particular carriers
- Carriers are partitioned into **Segments**



Parameters	Values
Modulation	BST-OFDM, with CP
Total Bandwidth	6 MHz
Number of segments	13
Segments bandwidth	$6000/14 \approx 428.57\ kHz$
Number of carriers	8192, active: 5617 (mode 3) 4096, active: 2809 (mode 2) 2048, active: 1405 (mode 1)
Sampling rate	$512/63 \approx 8.126MHz$
Cyclic Prefix duration	1/4, 1/8, 1/16, 1/32 (of active symbol duration)
Active symbol duration	252 μs (mode 1) 504 μs (mode 2) 1004 μs (mode 3)
Convolutional Code Rate	1/2, 2/3, 3/4, 5/6, 7/8
Time interleaving parameter	0, 1, 2, 4 (mode 1) 0, 2, 4, 8 (mode 2) 0, 4, 8, 16 (mode 3)
Modulation schemes	DQPSK, QPSK, 16QAM, 64 QAM

ISDB-T, briefly described

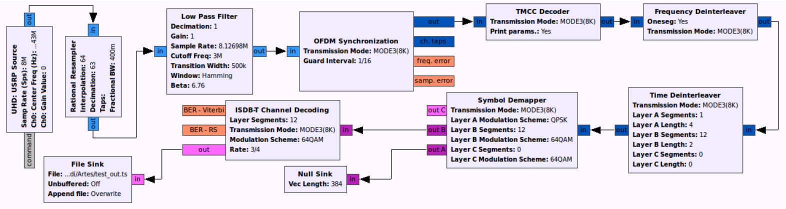


- Sampling rate is fixed
- Cyclic prefix is configurable

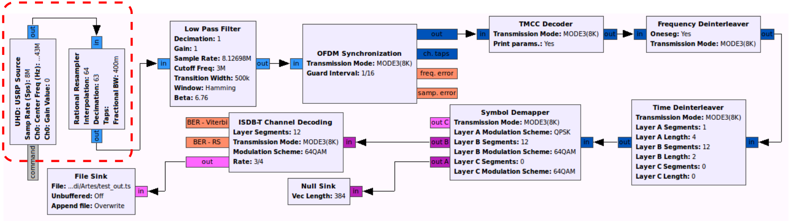
Parameters	**Values**
Modulation	BST-OFDM, with CP
Total Bandwidth	6 MHz
Number of segments	13
Segments bandwidth	$6000/14 \approx 428.57\ kHz$
Number of carriers	8192, active: 5617 (mode 3) 4096, active: 2809 (mode 2) 2048, active: 1405 (mode 1)
Sampling rate	$512/63 \approx 8.126 MHz$
Cyclic Prefix duration	1/4, 1/8, 1/16, 1/32 (of active symbol duration)
Active symbol duration	252 μs (mode 1) 504 μs (mode 2) 1004 μs (mode 3)
Convolutional Code Rate	1/2, 2/3, 3/4, 5/6, 7/8
Time interleaving parameter	0, 1, 2, 4 (mode 1) 0, 2, 4, 8 (mode 2) 0, 4, 8, 16 (mode 3)
Modulation schemes	DQPSK, QPSK, 16QAM, 64 QAM

Agenda

Our Implementation



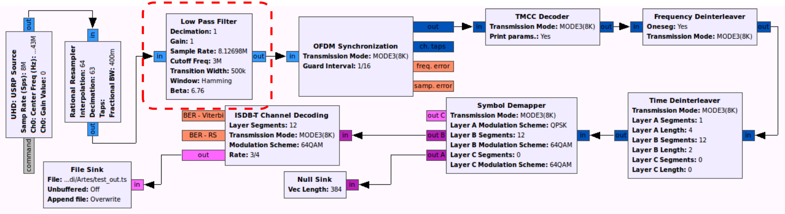
Our Implementation



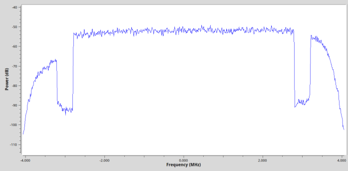
Critical: sample at **precisely** 512/63 MS/s

- USRP does not support this rate

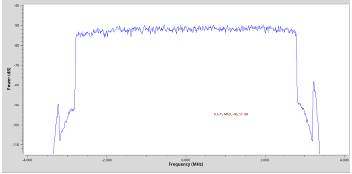
⇒ Sample at 8 MS/s followed by a 64/63 rational resampler



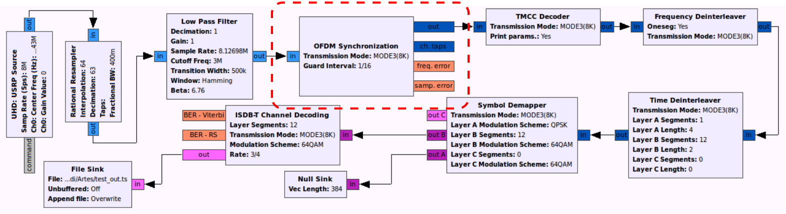
Remove adjacent channel



$\Rightarrow$



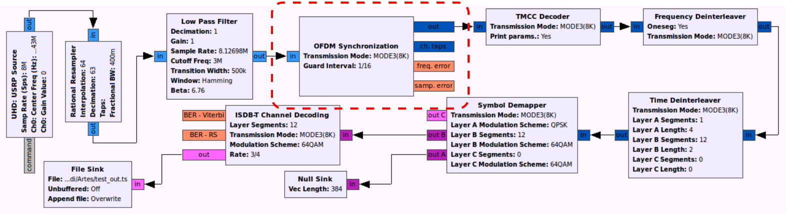
Our Implementation



Two phase OFDM synchronization:

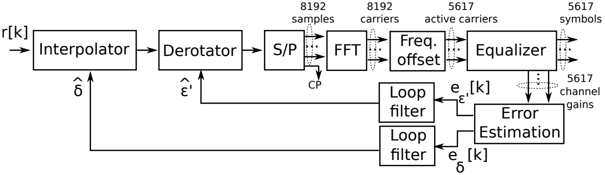
1. Acquisition: symbol alignment and coarse frequency correction
2. Tracking: fine frequency and sampling clock correction

Our Implementation



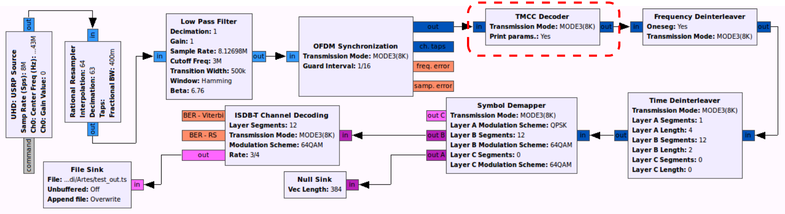
Two phase OFDM synchronization:

1. Acquisition: symbol alignment and coarse frequency correction
2. Tracking: fine frequency and sampling clock correction
    - Performs equalization too since correction requires channel estimates



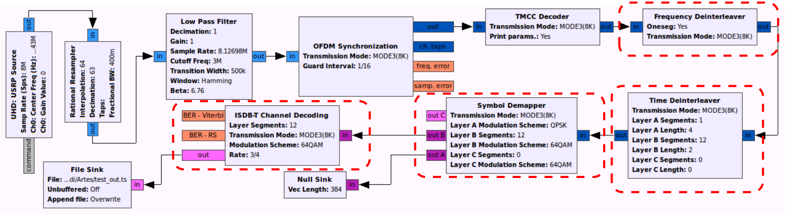
(One-shot synchronization blocks are available too)

Our Implementation



- Certain carriers include the transmission parameters of each Layer
- Decode them and (optionally) print them
  - First print and then configure blocks manually

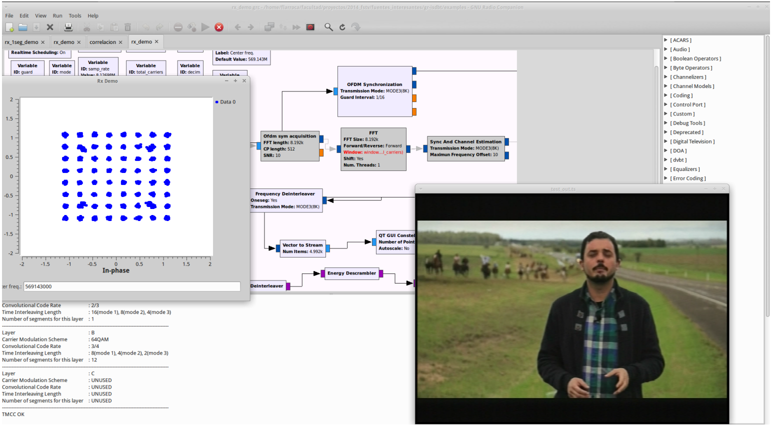
Our Implementation



Relatively standard blocks:

- Frequency deinterleaver
- Time deinterleaver
- Symbol demapper
- Viterbi and Reed-Solomon decoding
  - We used Bogdan Diaconescu's very fast implementation (see `https://github.com/BogdanDIA/gr-dvbt`), now part of GNU Radio

Demo Time!


File Edit View Run Tools Help
rx_1seg_demo × rx_demo × correlacion × rx_demo ×
Rx Demo
Data 0
In-phase
569143000
OFDM Synchronization
Transmission Mode: MODE3(8K)
Guard Interval: 1/16
Ofdm sym acquisition
FFT length: 8.192k
CP length: 512
SNR: 10
FFT
FFT Size: 8.192k
Forward/Reverse: Forward
Shift: Yes
Num. Threads: 1
Sync And Channel Estimation
Transmission Mode: MODE3(8K)
Maximun Frequency Offset: 10
Frequency Deinterleaver
Oneseg: Yes
Transmission Mode: MODE3(8K)
Vector to Stream
Num Items: 4.992k
Energy Descrambler
Deinterleaver
Convolutional Code Rate : 2/3
Time Interleaving Length : 16(mode 1), 8(mode 2), 4(mode 3)
Number of segments for this layer : 1
Layer : B
Carrier Modulation Scheme : 64QAM
Convolutional Code Rate : 3/4
Time Interleaving Length : 8(mode 1), 4(mode 2), 2(mode 3)
Number of segments for this layer : 12
Layer : C
Carrier Modulation Scheme : UNUSED
Convolutional Code Rate : UNUSED
Time Interleaving Length : UNUSED
Number of segments for this layer : UNUSED
TMCC OK
[ACARS]
[Audio]
[Boolean Operators]
[Byte Operators]
[Channelizers]
[Channel Models]
[Coding]
[Control Port]
[Custom]
[Debug Tools]
[Deprecated]
[Digital Television]
[DOA]
[dvbt]
[Equalizers]
[Error Coding]

Agenda

Conclusions and further developments

- We have presented `gr-isdbt`, the first **full_seg** software-based, free and open ISDB-T receiver
- Currently, the one_seg receiver is already implemented and can be downloaded (tested with NooElec R820T-based NESDR Nano SDR)
- We consider this work to be a further step in the appropriation that the region is performing regarding digital television
- The block-based architecture of GNU Radio offers the possibility to replace particular blocks or simulate channel conditions, in order to test different algorithms and implementations
- There is plenty room for improvement, you are welcome to contribute!

Thanks for your time!

Any questions?

Federico "Larroca" La Rocca - flarroca@fing.edu.uy
https://github.com/git-artes/gr-isdbt

OFDM Synchronization, Acquisition phase

- Model of the received signal:

$$r[k] = s[k-\theta]e^{j2\pi\frac{\epsilon k}{N}} + n[k]$$

- We used a classic algorithm to estimate both, θ and ϵ: "Maximum Estimation of Time and Frequency Offset in OFDM Systems", Beek et al.

OFDM Synchronization, Acquisition phase

Symbol alignment and coarse frequency correction

- Consider the observation interval $2N + L$

OFDM Synchronization, Acquisition phase

Symbol alignment and coarse frequency correction

- Consider the observation interval $2N + L$
- Consider the set of points

$$\mathcal{I} = \{\theta, \ldots, \theta + L - 1\},$$

- See that

$$\forall k \in \mathcal{I} : E\{r[k]r^*[k+m]\} = \begin{cases} \sigma_s^2 + \sigma_n^2 & m = 0, \\ \sigma_s^2 e^{-j2\pi\epsilon} & m = N, \\ 0 & \text{otherwise.} \end{cases}$$

OFDM Synchronization, Acquisition phase

Symbol alignment and coarse frequency correction

- Consider the observation interval $2N + L$
- Consider the set of points

$$\mathcal{I} = \{\theta, \ldots, \theta + L - 1\},$$

- See that

$$\forall k \in \mathcal{I} : E\{r[k]r^*[k+m]\} = \begin{cases} \sigma_s^2 + \sigma_n^2 & m = 0, \\ \sigma_s^2 e^{-j2\pi\epsilon} & m = N, \\ 0 & \text{otherwise.} \end{cases}$$

- Find the sample that maximizes

$$\gamma(m) = \sum_{k=m}^{m+L-1} r[k]r^*[k+N]$$

in the observation interval

OFDM Synchronization, Acquisition phase

Symbol alignment and coarse frequency correction

- Consider the observation interval $2N + L$
- Consider the set of points

$$\mathcal{I} = \{\theta, \dots, \theta + L - 1\},$$

- See that

$$\forall k \in \mathcal{I} : E\{r[k]r^*[k+m]\} = \begin{cases} \sigma_s^2 + \sigma_n^2 & m = 0, \\ \sigma_s^2 e^{-j2\pi\epsilon} & m = N, \\ 0 & \text{otherwise.} \end{cases}$$

- Find the sample that maximizes

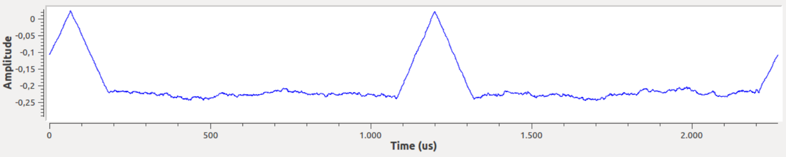
$$\gamma(m) = \sum_{k=m}^{m+L-1} r[k]r^*[k+N]$$

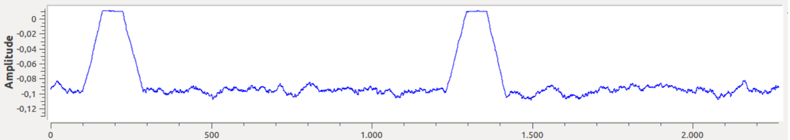
in the observation interval

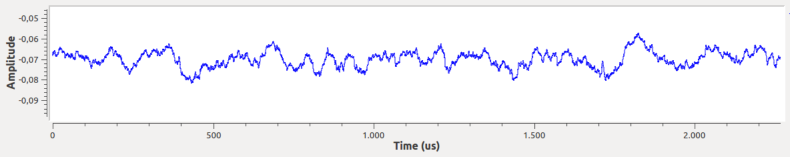
- Finally

$$\hat{\epsilon} = -\frac{1}{2\pi}\angle\gamma(\hat{\theta})$$

OFDM Synchronization, Acquisition







OFDM Synchronization, Acquisition

Frequency offset estimation

- For large frequency offsets

$$\Delta f = \Delta f_I + \Delta f_f \tag{1}$$

with Δf_I multiple of subcarrier spacing $1/T_s$ and Δf_I the fractional frequency offset ϵ

OFDM Synchronization, Acquisition

Frequency offset estimation

- For large frequency offsets

$$\Delta f = \Delta f_I + \Delta f_f \tag{1}$$

  with Δf_I multiple of subcarrier spacing $1/T_s$ and Δf_I the fractional frequency offset ϵ
- ISDB-T does not have continual pilots as DVB-T, TMCC carriers should be used
- We don't know their information, but we know they all transmit the same
- DBPSK is used and the initial value of every carrier depends on its position $T[i]$, with $i \in [0, M-1]$ the number of TMCC carrier

Frequency offset estimation

- For large frequency offsets

$$\Delta f = \Delta f_I + \Delta f_f \qquad (1)$$

  with Δf_I multiple of subcarrier spacing $1/T_s$ and Δf_I the fractional frequency offset ϵ
- ISDB-T does not have continual pilots as DVB-T, TMCC carriers should be used
- We don't know their information, but we know they all transmit the same
- DBPSK is used and the initial value of every carrier depends on its position $T[i]$, with $i \in [0, M-1]$ the number of TMCC carrier
- Being $W(T[i])$ this initial value, and $Y[k]$ the output of the FFT, $m = \Delta f_I$ maximizes

$$\Gamma[m] = \sum_{i=0}^{M-2} w(T[i])Y[T[i]+m].w(T[i+1])Y^*[T[i+1]+m]$$

OFDM Synchronization, Tracking

Channel estimation and equalization

- If $X[i]$ is transmitted in the i-th carrier, then

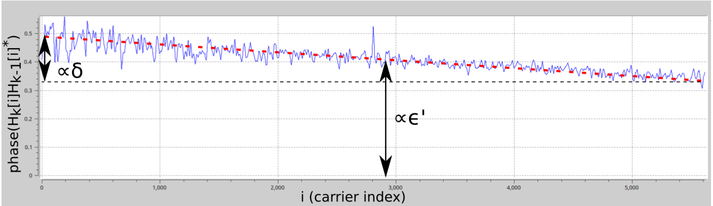
  $$Y[i] = X[i].H[i]$$

  with $H[i]$ the channel gain in the corresponding frequency
- For estimating the channel gain SP are used, as we know their values and positions
- With linear interpolation we can estimate the channel in the other carriers
- As there are four possible SP configurations, a very similar algorithm to the one just discussed was applied to SPs

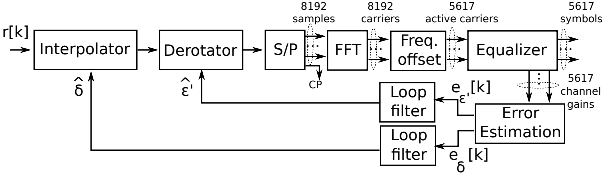
OFDM Synchronization, Tracking

Fine frequency and sampling correction

- The lingering frequency error $\hat{\epsilon}$ plus the sampling error δ produces the following effect:



- Which suggests a PLL-like structure to correct it:



See "Optimum Receiver Design for OFDM-Based Broadband Transmission-Part II: A Case Study" by Speth et al.

TMCC Decoder

- For reading the TMCC data, frame synchronization is needed
- The TMCC carrier starts with a 16 bits synchronization word
- The last 204 bits of the carrier are stored and the first 16 bits continually compared to this sync word
- When matched, the BCH code parity check code syndrome is computed
- It no errors were found, the TMCC is decoded
- Finally, all control pilots are removed, only data symbols are output