Receiver architectures

APERTIF (DIGESTIF) as a design example

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outline

- APERTIF specifications
- System partitioning
- RFI environment at Westerbork
- Receiver architectures
- Some first receiver specifications for APERTIF
- DIGESTIF as a first step

Some basic parameters

- APERTIF stands for APERture Tile In Focus
- Target frequency range 850-1750MHz
- Target Instantaneous bandwidth is 300MHz
- FoV of 8 sq. degrees
  - 220 active elements required
  - 25 dual polarized beams (50 beams total)
- Aeff/Tsys>100m^2/K (all telescopes)
  - Tsys <50K
- Beamforming is performed all digital
- 1m^2 available at focal point telescope for FPA
- Should be installed on the WSRT in 2010
  - Uses existing mechanical infrastructure

Resulting order magnitude numbers

- Total datarate with 8 bits digitization is ~1.4Tb/s
  - Sampling at 800MHz
- After beamforming this reduces to 120Gb/s (4 bits)
- Required processing (rough estimate):
  - Subband partitioning one element (polyphase filtering):
    - Prefilter:16 MAC/sample
    - FFT: 3* log(nr_subbands)/log(4)=3*log(64)/log(4)=9 MAC/sample
    - Total MAC/element: 25MAC/sample*sampling_clock=20GMAC
  - Beamforming (all elements used for all beams):
    - Nr_beams*nr_elements*4MAC/sample*2*bandwidth=26400GMAC
- Total required processing : 220*20GMAC+26400GMAC=30800GMAC
- ~0.5 of the largest FPGA /element currently available (early 2007) when running at full speed

System partitioning

Main drivers

- Max 375kg in prime focus of telescope
- Max $1m^3$ in prime focus of telescope
  - Puts restriction on size of electronics
  - Puts restriction on power consumption (cooling)
- Cost
  - The main variable for partitioning are the signal transport cost and cost associated to mounting/shielding
  - Antenna cost, receiver cost and digital processing cost determined by requirements (FOV, BW, freq. range)
- Five main architectures were considered

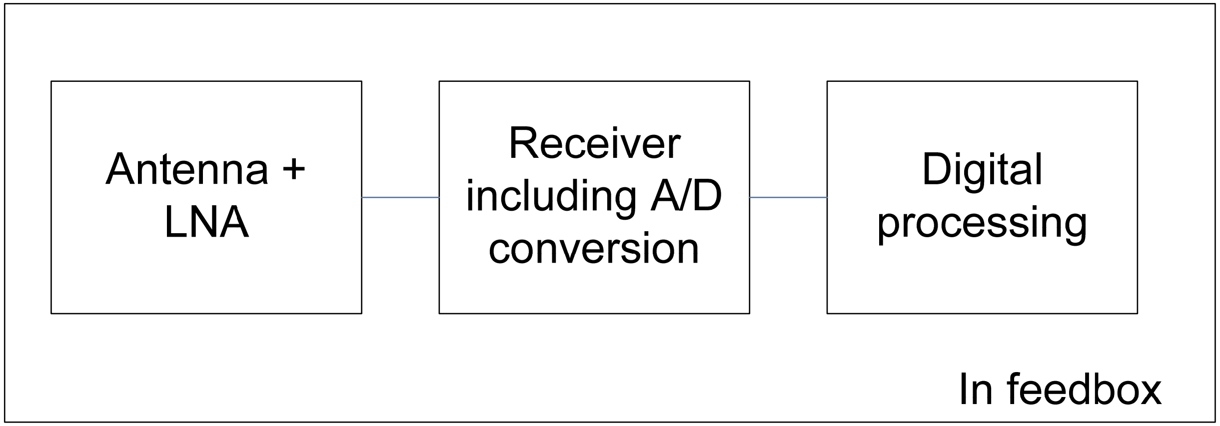
Westerbork telescope

feedbox

Cable jumper

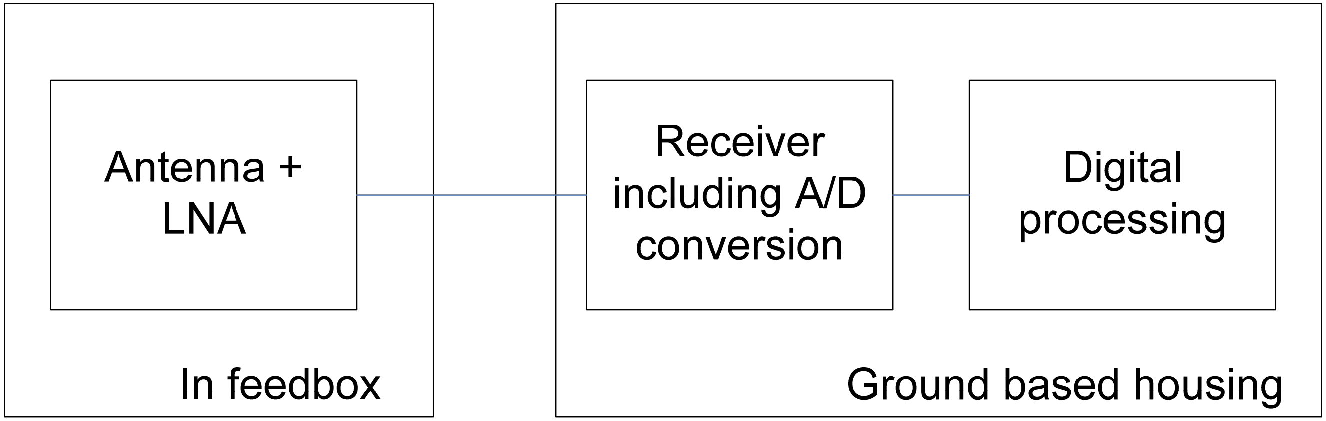
Ground based house

Everything in feedbox



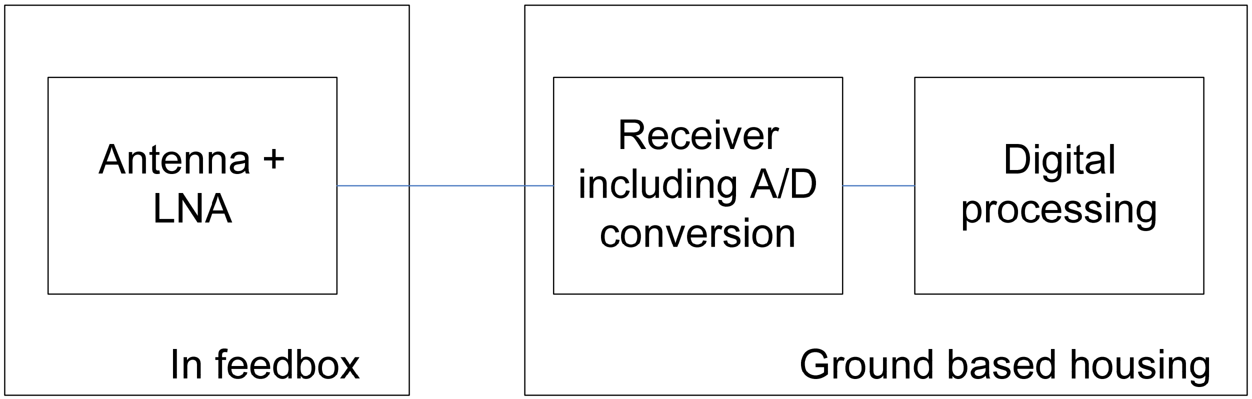
- Results in potentially the lowest cost solution
  - No signal transportation costs
- Available space will be limiting factor
  - Large level of integration required
- Cooling will become problematic
  - Some 6kW of power consumption in $1m^3$
- Self generated RFI of major concern

Coax to ground based house



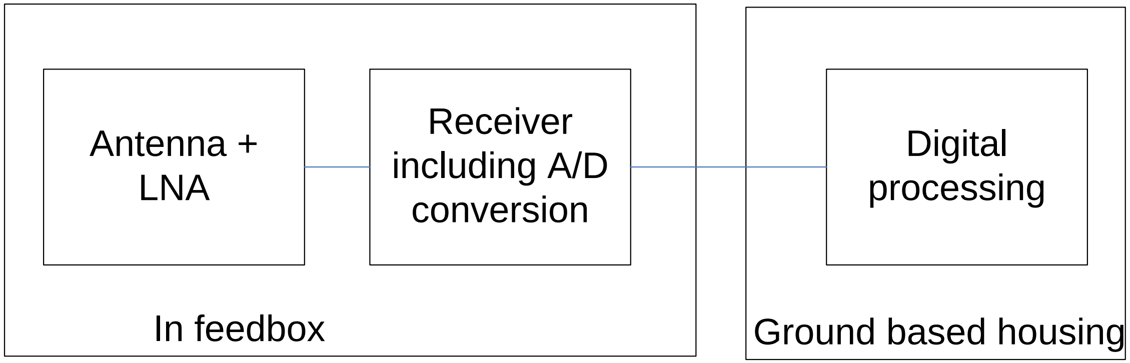
- Coax all the way to ground based house (20-50Euro element)
- Size, weight, power consumption no major concern
- Digital processing at ground
- Major issue is getting the cable all the way to the ground
  - Difficult for large amount of cables (>100)

Analog fiber link to ground based house



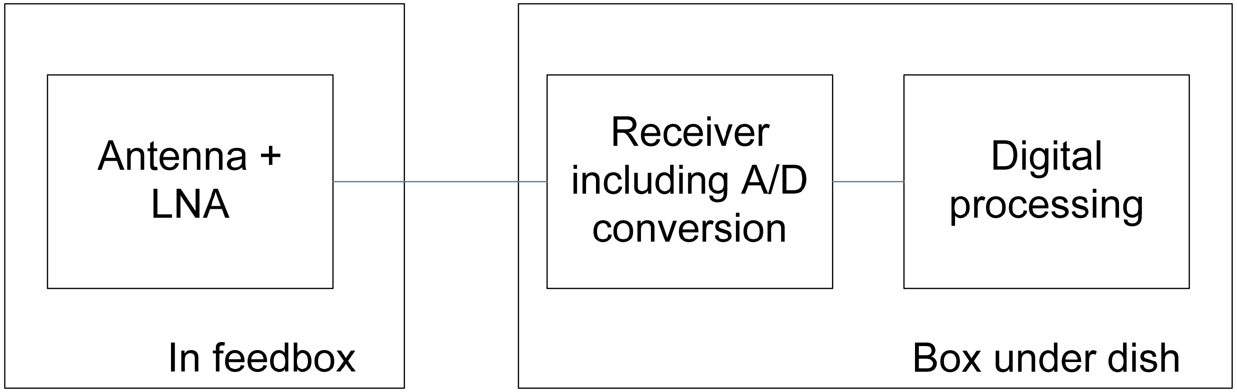
- Solves problem of large bundle of coax across jumper
- Digital processing at the ground
- Increase in cost compared to coax cable (500-1000Euro/element)
- Development of low cost analog optical link required

Digital fiber link to ground based house



- No problem with analog cables all the way to the ground
- Processing at ground
- Self generated RFI of concern
- Technical proven technology; COTS
- High cost solution (700-1500Euro/element for transport)

New box under reflector



- Coax cables to new box under reflector (10-30Euro/element)
- Solves space/thermal problem in feedbox
- Avoids cables all the way down
- Question mark if it is possible to mount the box
- Box might introduce maintenance issues
- Seems most attractive, if mechanical feasible

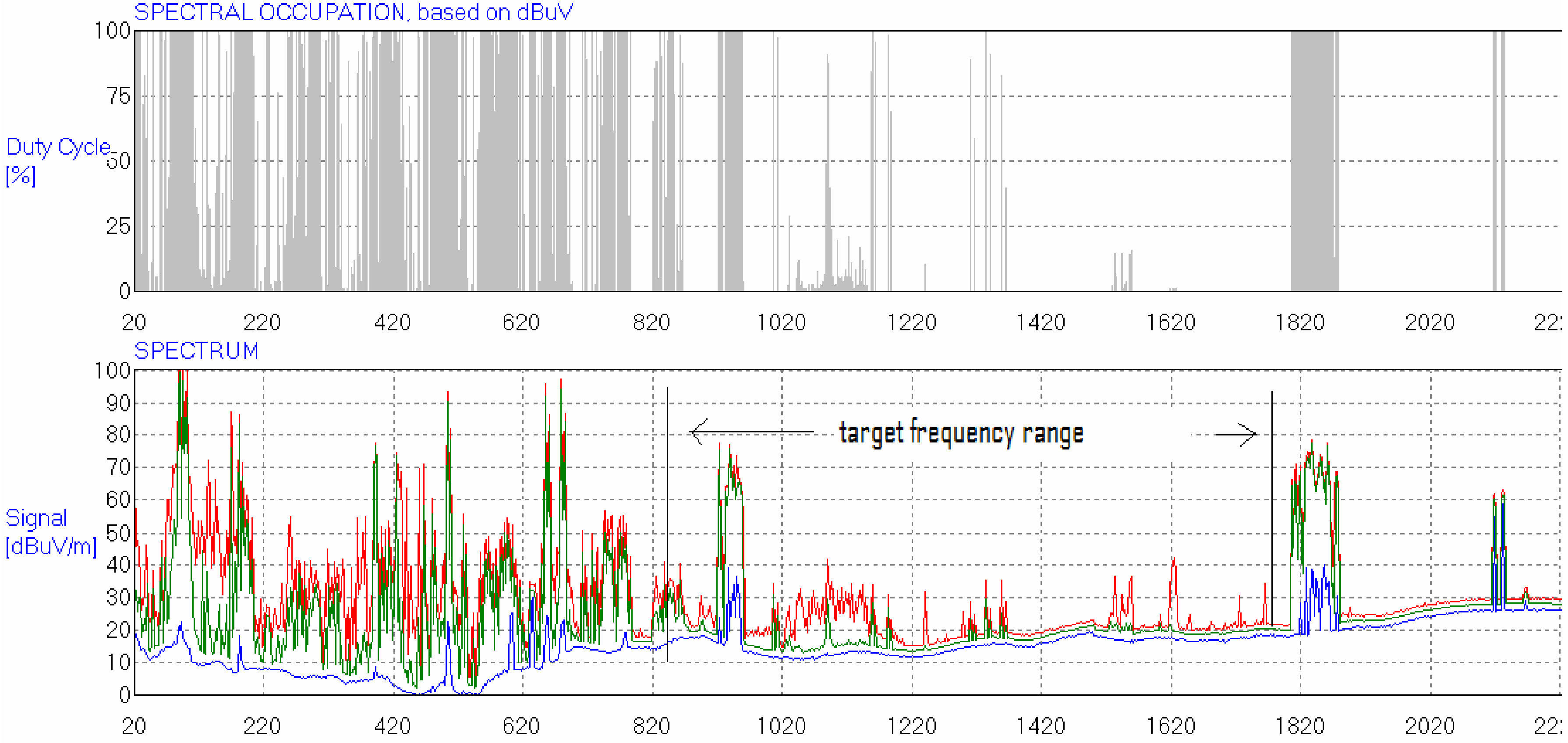
Westerbork telescope

New box

Conclusion on system partitioning

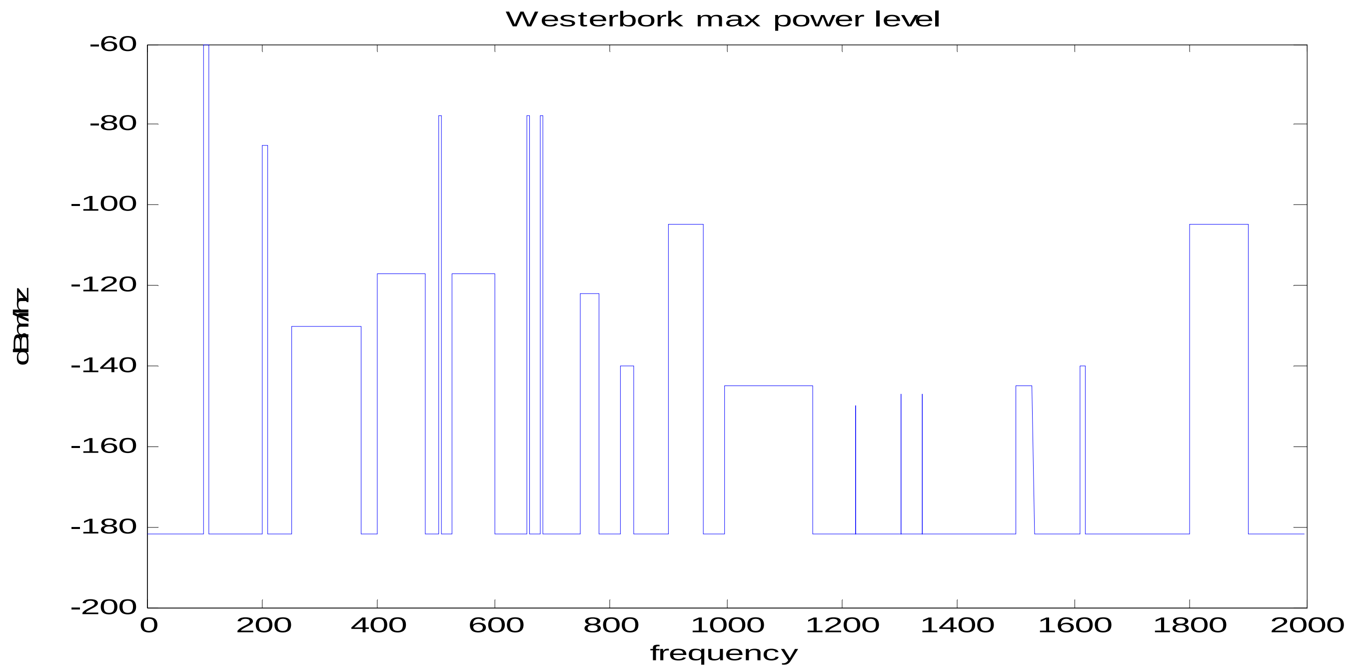
- Processing should be located as close as possible to antennas to limit signal transportation cost
- Locating everything in the feedbox is hard to realize
  - Size
  - Power consuption / cooling
  - Self generate RFI
- Digitization and processing should be co-located
- RF signal transport over coax cable seems most suitable
- New box under telescope seems most promising
  - No integration of all RF functions in one chip

RFI at Westerbork



- •Measurements with WSRT monitoring station (30m height)
- •TV channels (highest peaks) are out of band. Signals turned off recently

Translation to dBm/Hz



using

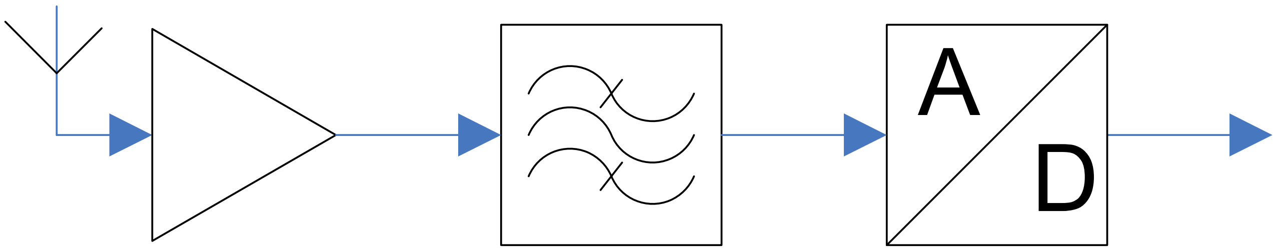
$$P_{re} = \frac{\lambda^2 E^2}{480\pi^2}$$

- Worst case analysis (max power)
- Integrate over required band and compare with KTB noise
- 8 bits are insufficient to handle GSM
- 8 bits sufficient for other parts of required frequency range

Conclusion on RFI/nr. of bits

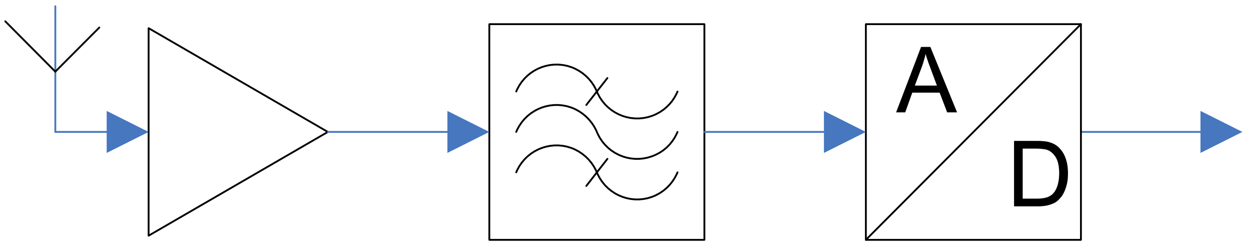
- GSM from 900-960MHz can not be sampled with 8 bits
- 8 bits OK for other part of frequency range
- Limit required number of bits -> exclude 900-960MHz
- When digitizing with 8 bits, 0.85-1GHz not useable
- The antennas will be designed for 0.85-1.75GHz
- The RF system will be designed for 0.85-1.75GHz
  - GSM band will determine linearity requirements after LNA

Direct sampling



- High speed sampling at 3.5GHz
- High resulting data rate
- Large digital processing power required
- With RFI environment at Westerbork bandpass filter required
- Quality of the A/D clock will be an issue
- Required A/D converter currently not commercially available

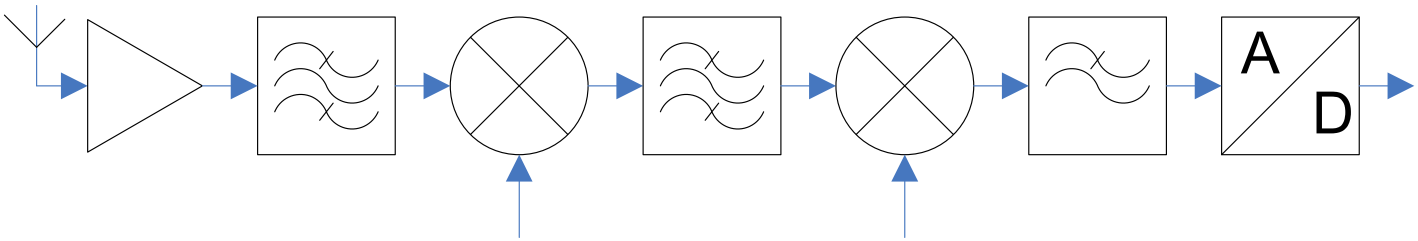
Undersampling



- Reduction of required sampling rate compared to direct sampling
- Analog input bandwidth of A/D should be sufficient
- A switchable bank of bandpass filters is required
  - High cost
  - Difficult to integrate
- Use only 1 filter and sample at 1750MHz
  - For reduced frequency range from 1000-1750MHz

Superheterodyne receiver

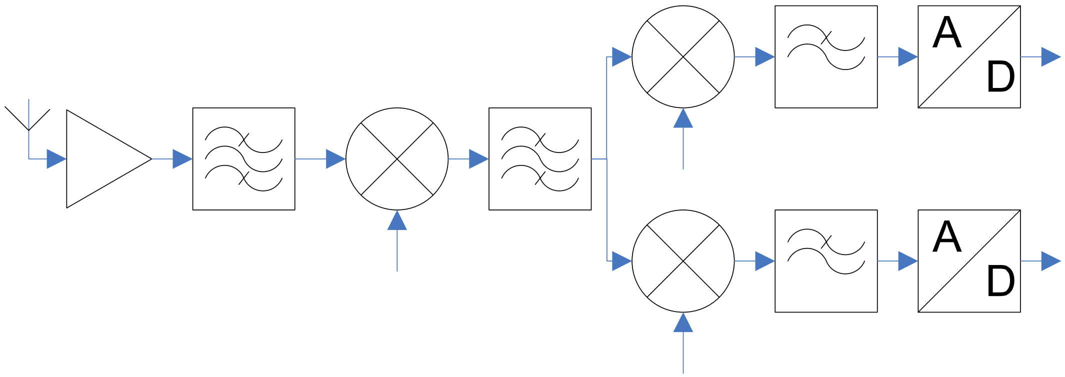
without IQ sampling



- Good handling of RFI
- Only band of interest converted and processed
- Several filters-> hard to integrate
- 2 Local oscillators
- Sampling at 800MHz (depending on quality of BP filter)
- Can be built with “discrete” components
- No large technical risks foreseen
- No large potential for cost reduction !!???

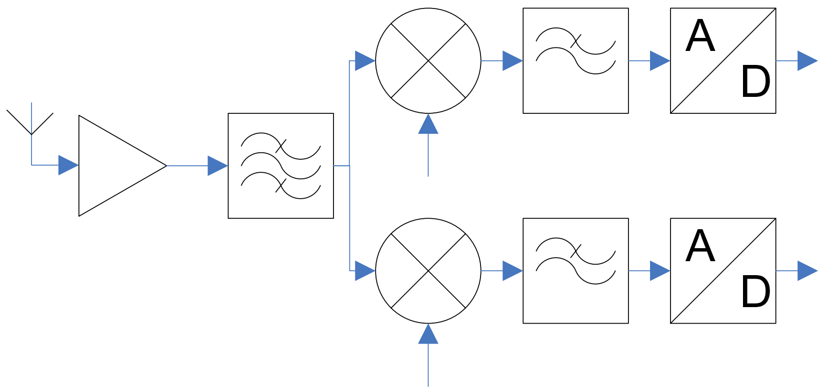
Superheterodyne receiver

with IQ sampling



- Relaxed requirements on second filter
- “Low” speed A/D converters (400MHz, 2 required)
- Only band of interest converted and processed
- Still 2 Local oscillators
- IQ balance will be biggest challenge
  - Only at one frequency required
- Better potential for integration
  - Integration is likely required in order for this receiver to be feasible

Zero-IF receiver



- Good potential for integration
- Only one Local oscillator required
- “low” speed A/D converter (400MHz, 2 required)
- IQ balance over large frequency range
- Only band of interest converted an processed
- Integration is required
  - Potential for low cost solution

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Rx specification from antenna to A/D converter

- 66dB of net gain required between antenna and A/D
  - for 8 bits A/D, input 0.5V and 100ohm input impedance
- T_{sys} <50K
- Second and third order distortion set 10dB below noise level
- For LNA TV-channels Smilde important
  - Analog signals Smilde recently turned off but now digital
- other components IP2 and IP3 requirements can be reduced significantly by sufficient filtering

LNA requirements

- Spillover=15K
- Noise coupling =5K
- Tsky = 5K
- Loss between antenna and LNA 0.1dB
- Means T_{lna} needs to be 18K (0.25dB) in order to achieve Tsys

- Cooling might be needed achieve the required Tsys
- With 1m^2 of antenna-elements opening of cooler very large and/or long cables
  - Likely unrealistic for 1m^2 of antenna-elements
- Local cooling ??

Preliminary Rx specifications

Passband>0.85GHz

Stopband <0.8GHz

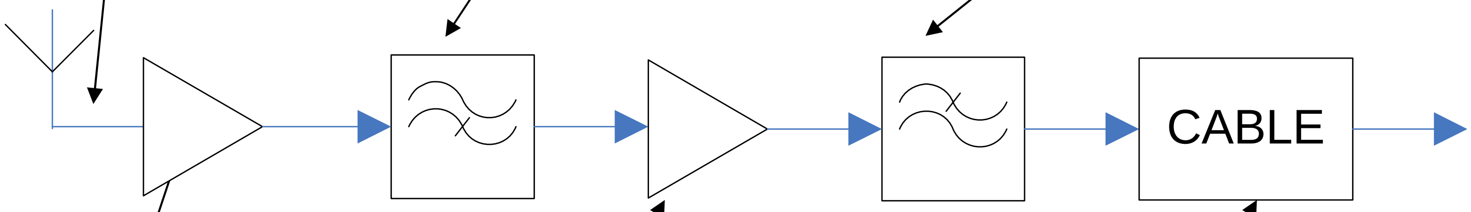
Stopband att.>25dB

Passband>1.8GHz

Stopband >2.2GHz

Stopband att.>20dB

Loss<0.1dB



0.85-1.75GHz

Gain=25dB

OIP2=50dBm

OIP3=15dBm

NF_{LNA}=0.2dB

0.85-1.75GHz

Gain=20dB

OIP2=20dBm

OIP3=-2dBm

NF=1dB

Loss<8dB

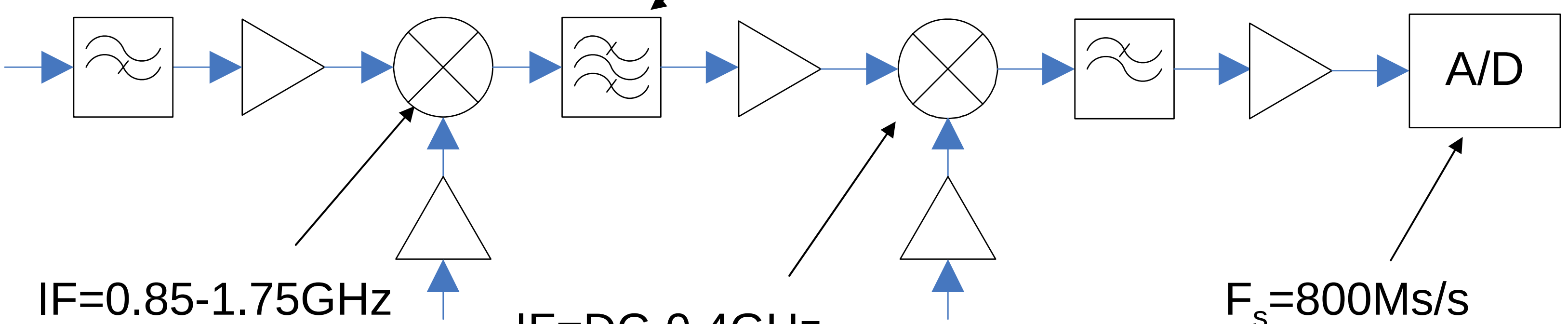
Slope <2dB

Preliminary Rx specifications(2)

Passband 2.4-2.7GHz

Stopband 2.35-2.75GHz

Att. at 2.35 and 2.75GHz>24dB



IF=0.85-1.75GHz

RF=2.4-2.7GHz

LO=3.55-4.15GHz

IF=DC-0.4GHz

RF=2.4-2.7GHz

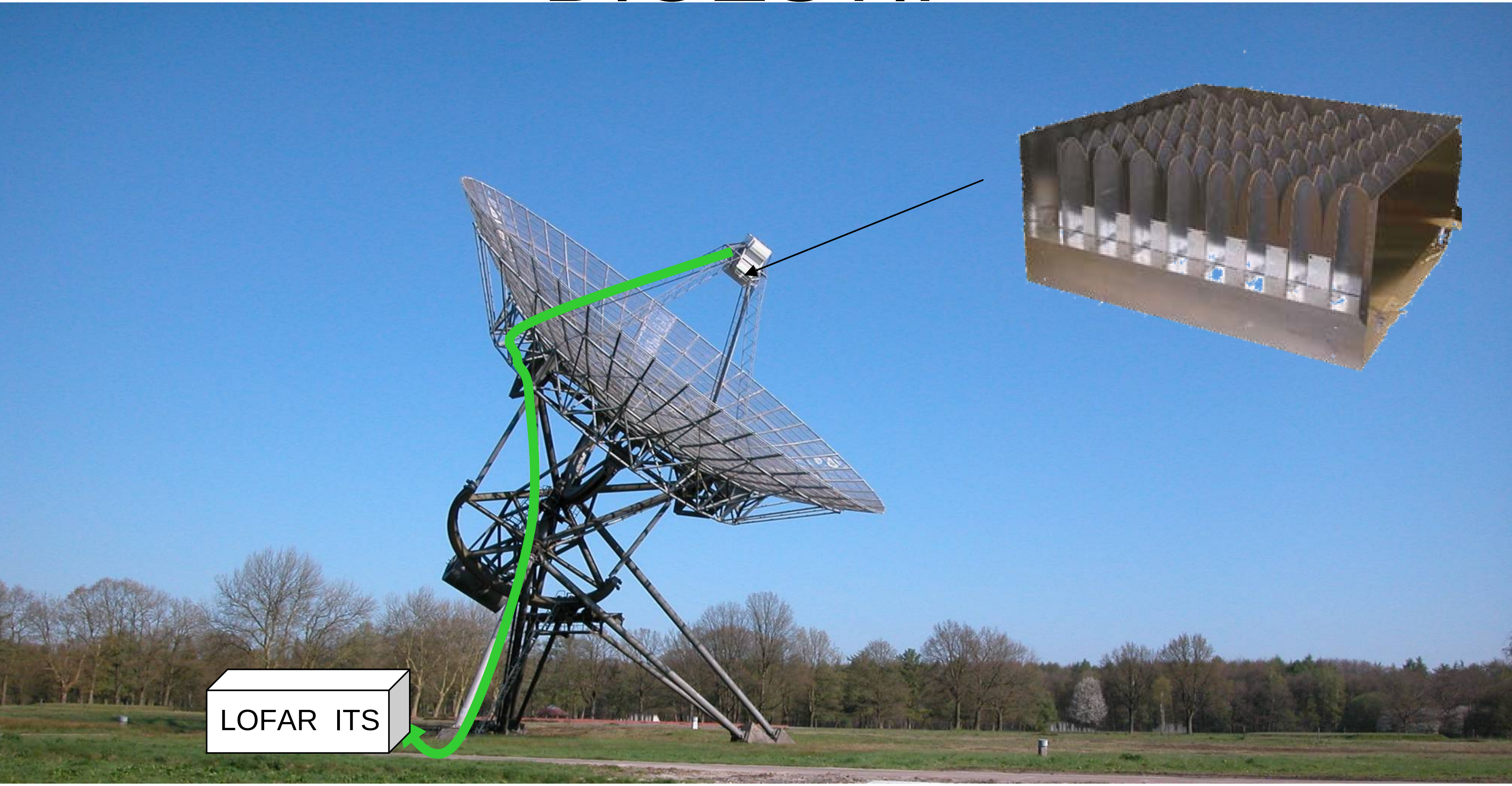
LO=2.75GHz

F_s=800Ms/s

Signal gain complete receiver ~30dB

All specifications to be checked with DIGESTIF

DIGESTIF



DIGESTIF specifications

• Frequency range	**1.0** – 1.7 GHz
• Array size	80 x 80 cm
• Dual linear polarization	(vivaldi elements)
• Number of elements	8 x 7 x 2 = 112
• Instantaneous bandwidth	30 MHz
• Number of receivers	60
• Data storage	max 6.7 seconds per measurement
• System temperature	100 K
• Dish diameter	25 m

- Additional requirement : no structural changes to WSRT

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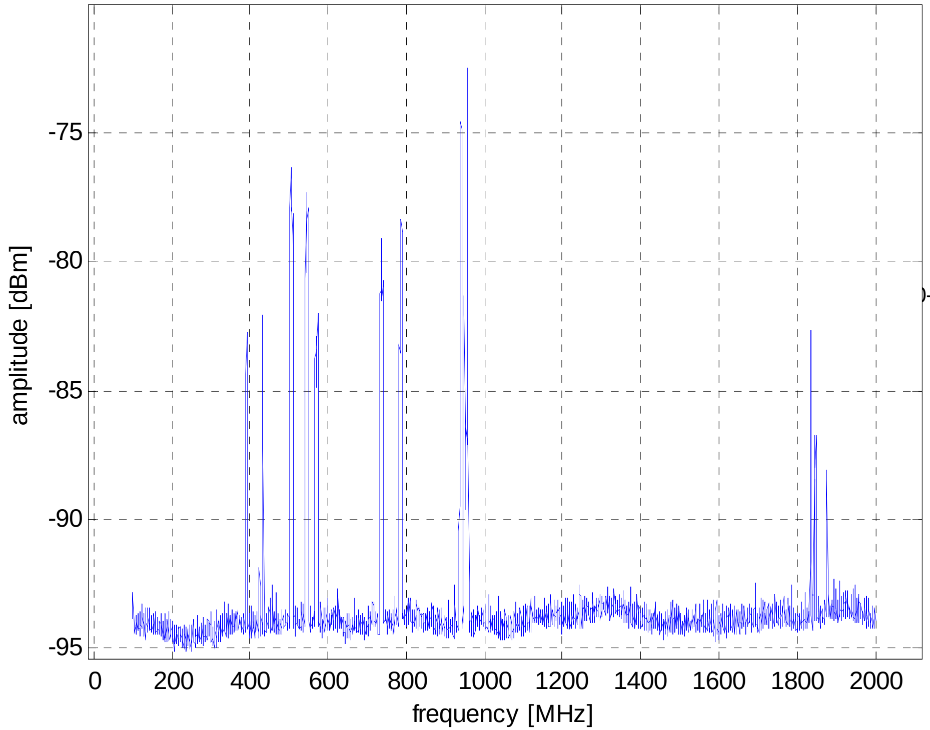
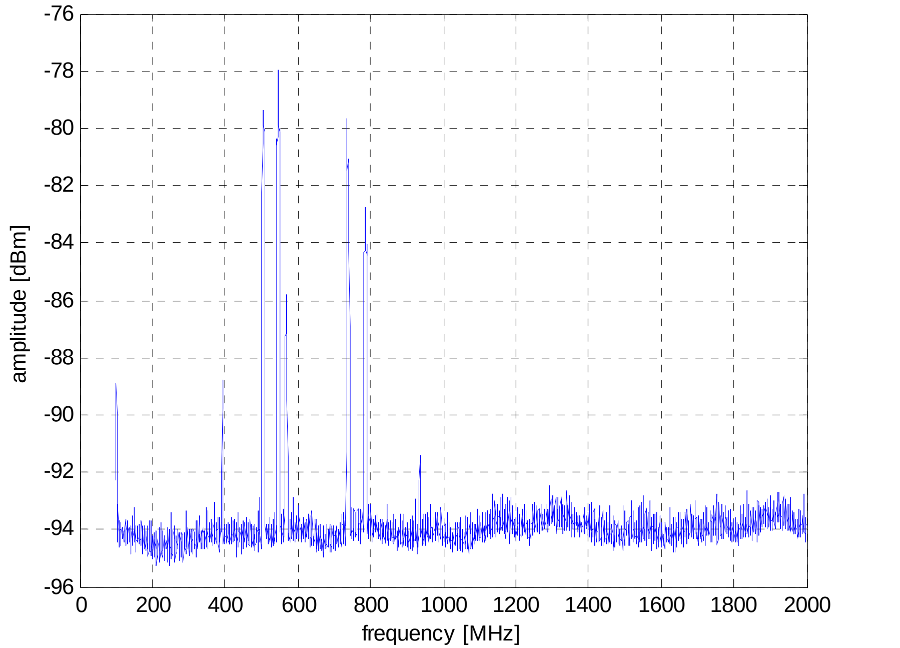
Measurement RFI with antenna

0-37.DAT 30.Jul 07 rbw:1000000 vbw:30000 swt:6.50e-002 det:MAXPEAK Att:0 dB P_{tot}:-58.6 dB

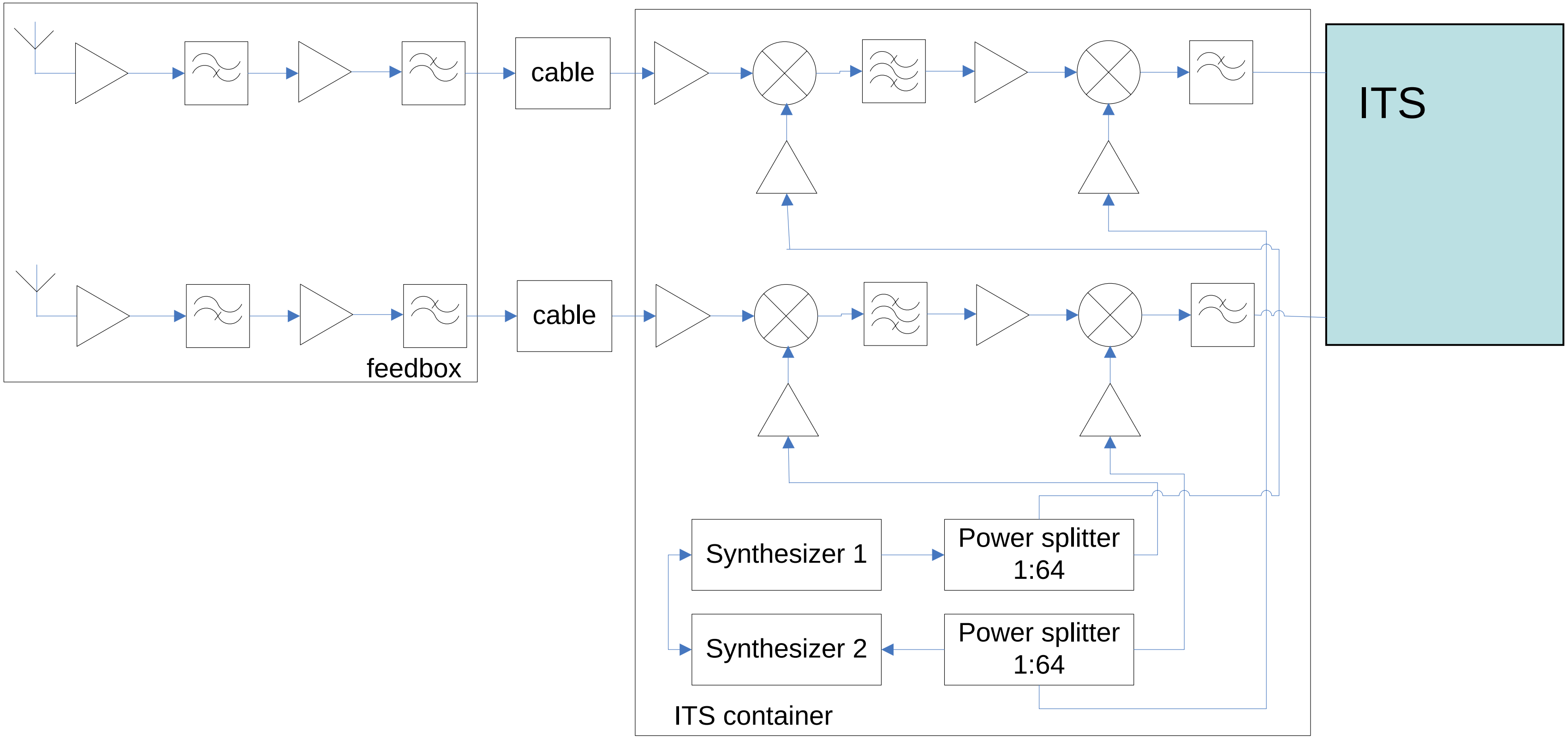


)-20.DAT 30.Jul 07 rbw:1000000 vbw:30000 swt:6.50e-002 det:MAXPEAK Att:0 dB P_{tot}:-60 dBn



Measured in container (add ~20dB for cable loss and 50-75ohm transformers)

DIGESTIF schematic



•No control outside ITS container

•Uses as much as possible APERTIF architecture

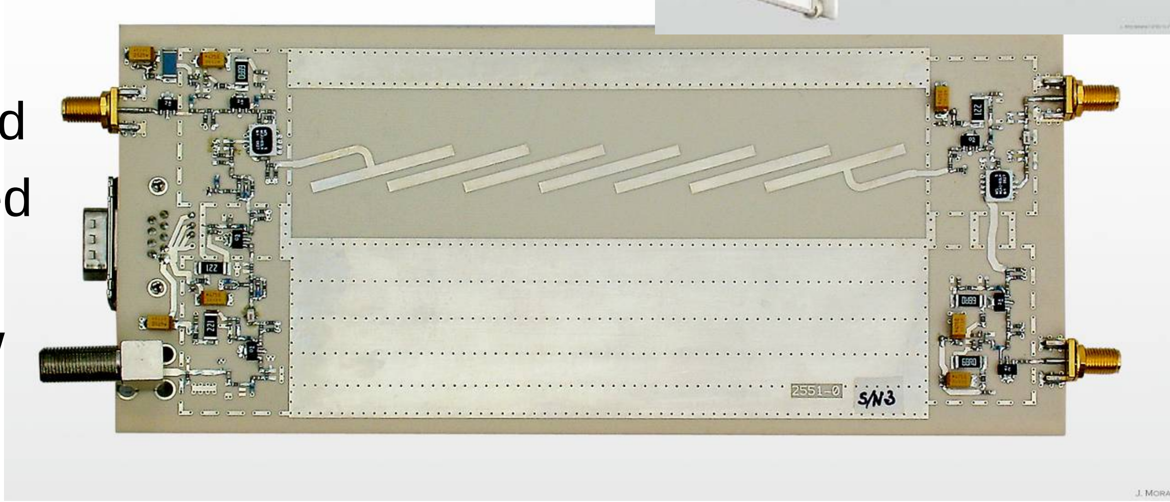
LNA and cable

- Design for 50ohm input impedance
- 40 dB gain (flat)
- HPF with 30dB attenuation at 800MHz
- 3 stages, with filtering after first stage
- T_{LNA} =65 K (over entire band, measured)
  - With reasonable S11 (-7.5dB worst case)
- IP2 first stage ~40dBm
- Sma input connector (50ohm)
- F-connector output (75 ohm)

- Cable loss at 1.7Ghz 15 dB
- Gain slope from 1 GHz to 1.7 Ghz 5 dB
- Corrected in Down Conversion Unit (DCU)
- Cables are tuned to <100ps

Down Conversion Unit

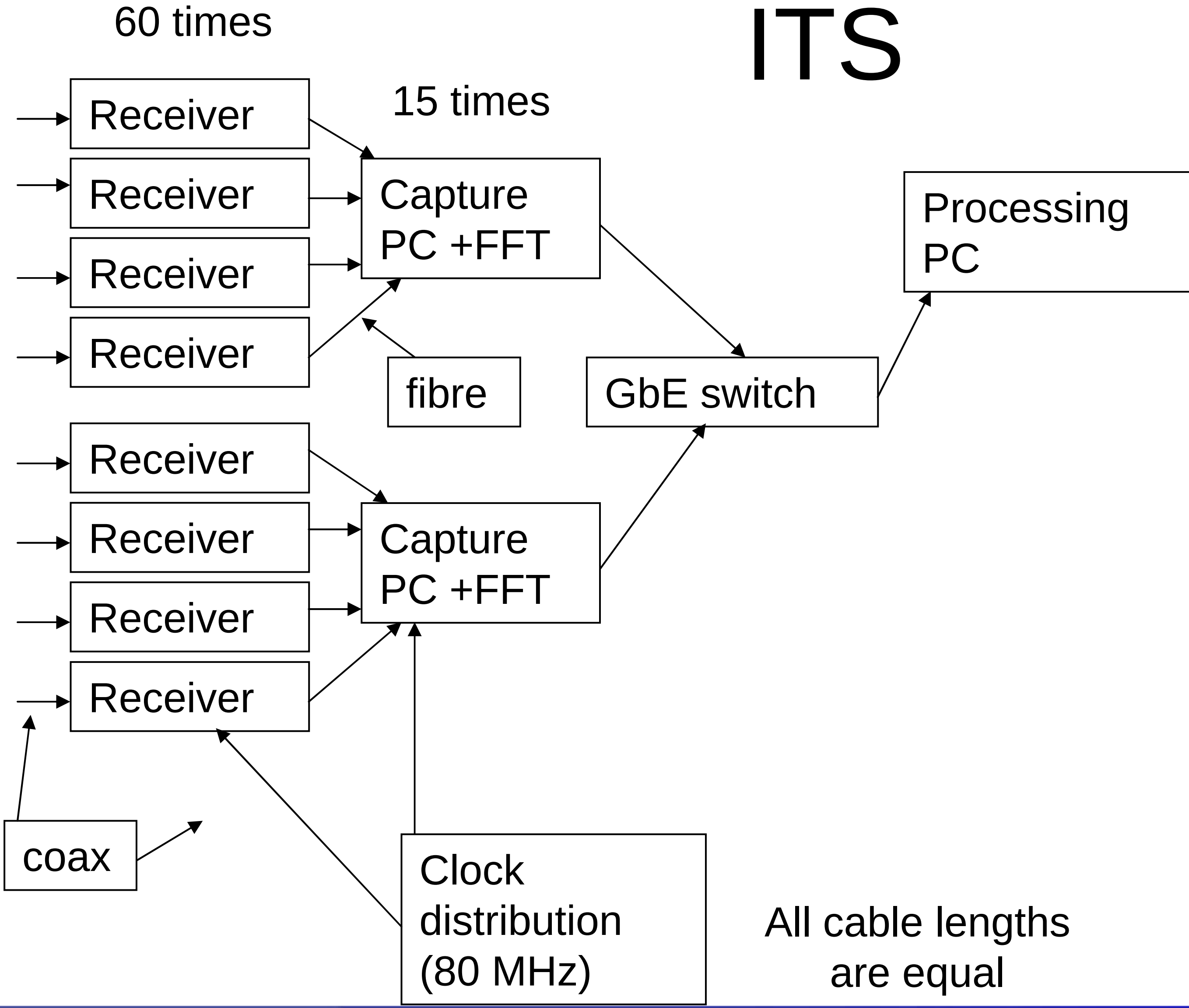
- Input band 1-1.7GHz
- Bandpass filter 2.5GHz center, 80 MHz BW, 60dB down for $|f_c - f| > 100$MHz, one steep slope required
- Convert to 40-80 MHz band
- 13 dB gain from input to output (1.4GHz input)
- LO1 3.5-4.1 GHz, input level >-13dBm
- LO2 fixed at 2.56 GHz, input level >-13dBm
- 10dBm mixers
- Cable equalizer included
- Additional shielding used
- Single supply voltage
- Power consumption 5W



Receiver unit (ITS)

- Sampling at 80 MHz
- 12 bits (10 effective)
- Sampling in second nyquist zone
- 40-80MHz bandpass filter
  - >60dB down at 38 and 82MHz
- Signal gain receiver 25dB
- High Speed Optical Link to computer

ITS



All cable lengths are equal

Conclusions

- A new box under dish seems best solution
- 0.85-1GHz can likely not be used because of RFI
  - For a limited scan range of telescope this frequency range can be used, but then more stringent requirements on filtering
- A super-heterodyne receiver will be used
- T_{sys} (not T_{lna}) of 50K will be challenging to achieve
- DIGESTIF:
  - 4 channels are currently operational (one with good LNA, 4 next week)
  - 32 channels will become operational in the next couple of weeks
  - Full system operational next couple of months
- First results with DIGESTIF ->presentation of Wim