GNSS – eLoran combined receiver

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benefits for the mass market

Motivation for adding eLoran to GNSS Receiver

- Backup for GNSS is great….but NOT the motivation
- Motive is GNSS indoor sensitivity.

- LORAN signals at 100kHz penetrate buildings
  - But note local electrical interference problems

- GNSS sensitivity limits driven by data download and time
  - Data download solved by self-assistance [2]
  - Time in steps
    - 30 mins, seconds, 10ms, 2ms, 0.5ms, microseconds
    - Each brings a new, improved, sensitivity level

Benefits of Time to GNSS acquisition

- 30 mins accuracy to determine satellites in view
- Few seconds accuracy to determine relative doppler shift and relative codephase predictions
  - Relative to the first satellite found… need one strong sat
- 10 millisecond accuracy to remove 20ms bit edge ambiguity
  - Removes need to read true data,
  - only statistical edge detect needed
  - About 6dB benefit
- 0.5 milliseconds to determine 20ms databit period
  - When it is too weak to detect directly
  - Allows 20ms coherent integration, about 6dB benefit
- Microseconds (ie precise time assistance) to reduce code phase search from 1ms to microseconds
  - Statistical, less candidates, another 6dB benefit

Time sensitivity benefits (2)

- Gains cannot be directly added, thresholds overlap
  - Data -146 dBm
  - 1ms/20ms integration handover -144dBm
  - Bit Edge 20ms ambiguity -150dBm
- Position ambiguity maps onto time (300km = 1ms)

Galileo

- 4ms code epoch – more sensitive than GPS 1ms
  - much longer search to acquire
- 4ms symbol period
  - Less sensitive than GPS 20ms period
  - No ambiguity problem as epoch = symbol
- More sensitive due to pilot code
  - Pilot destroyed by secondary code
  - Solved by time assistance eg eLoran.
  - Knowing time, secondary code can be wiped, allowing long coherent integration
  - 2ms accuracy required

Deja-vu

- Combined LORAN/GPS receiver proposed in 1992
  - WGA 1992 conference in Birmingham [1]

- Motivation then was to stimulate LORAN market
  - Dying due to “threat” of GPS
  - Improved performance available
    - Hardware costs paid by GPS ASP
      - Precise clock
      - Powerful CPU

1992

AN ECONOMIC IMPLEMENTATION OF A COMBINED LORAN/GPS RECEIVER

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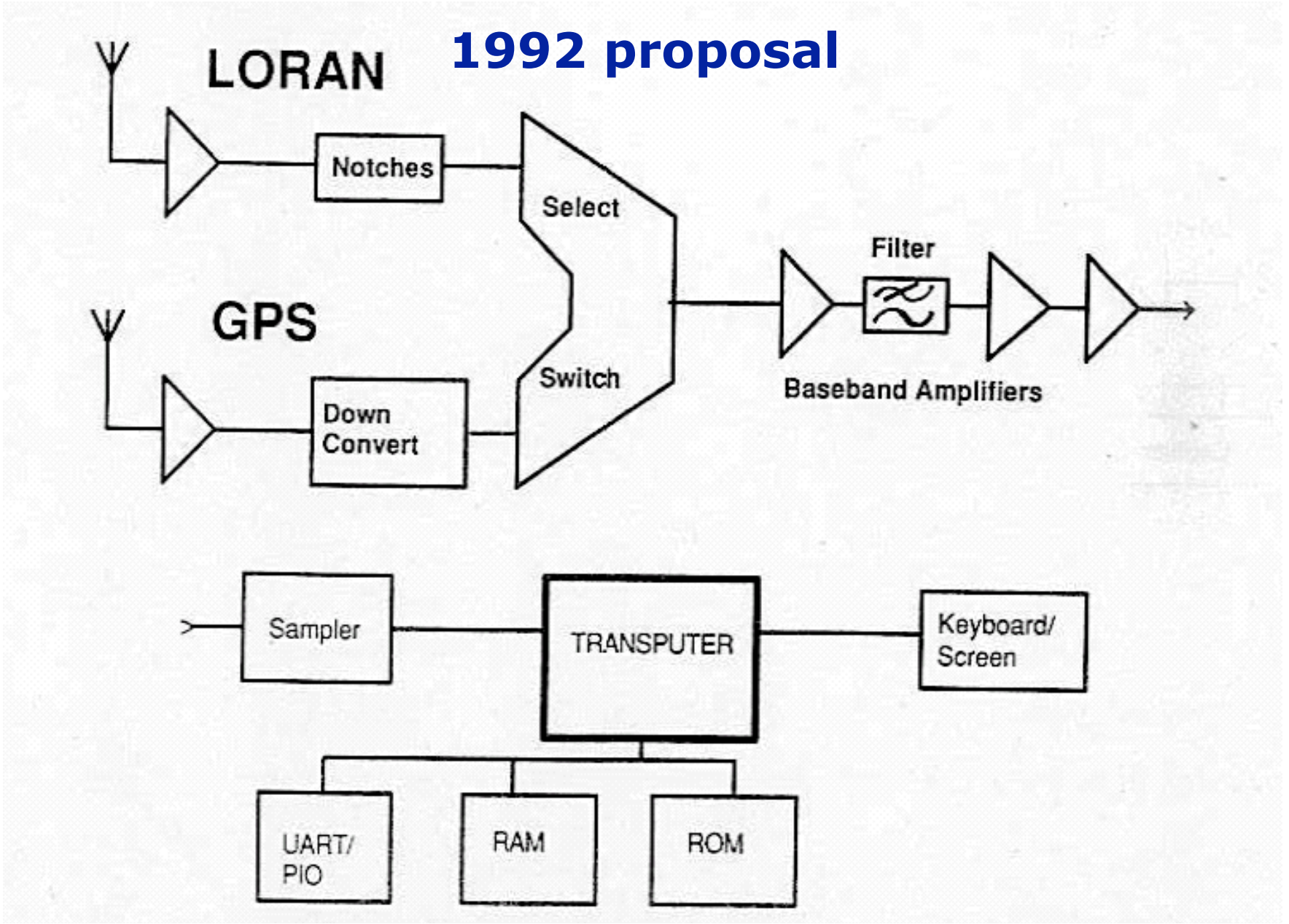
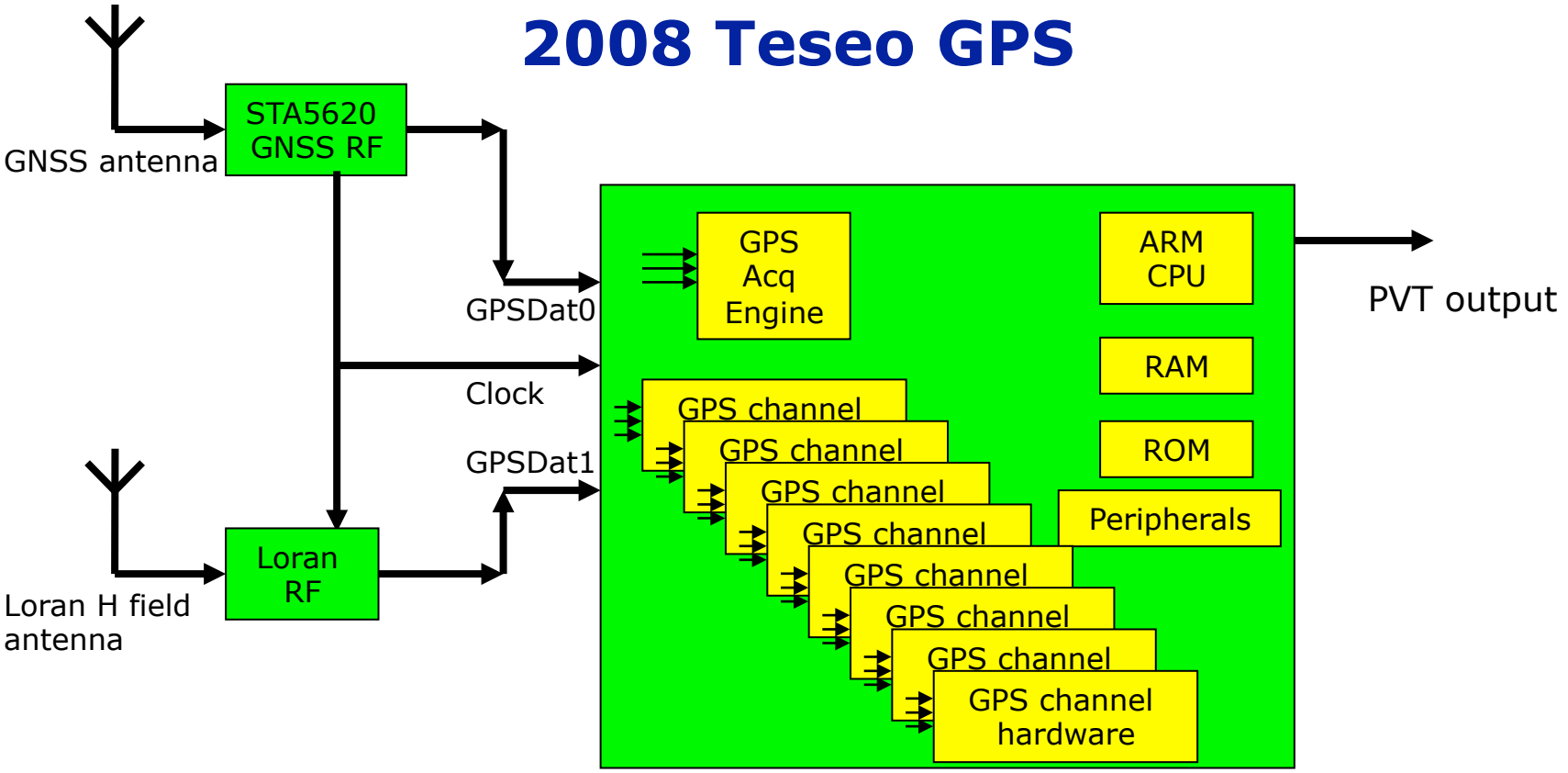
1992 proposal



What's new ?

- GPS is one chip
  - Or two chips RF, Baseband
  - Or hosted, RF/Tracker plus positioning software in host
  - Or SW GPS… RF only plus dsp and positioning sw in host
- LORAN proposal applies to all the above
- Needs 100KHz antenna and RF only.
- Example used here is Teseo standalone GPS
  - Available as single chip STA8058, includes GPS RF
  - Available as dual chip STA5620 RF + STA2058 Baseband

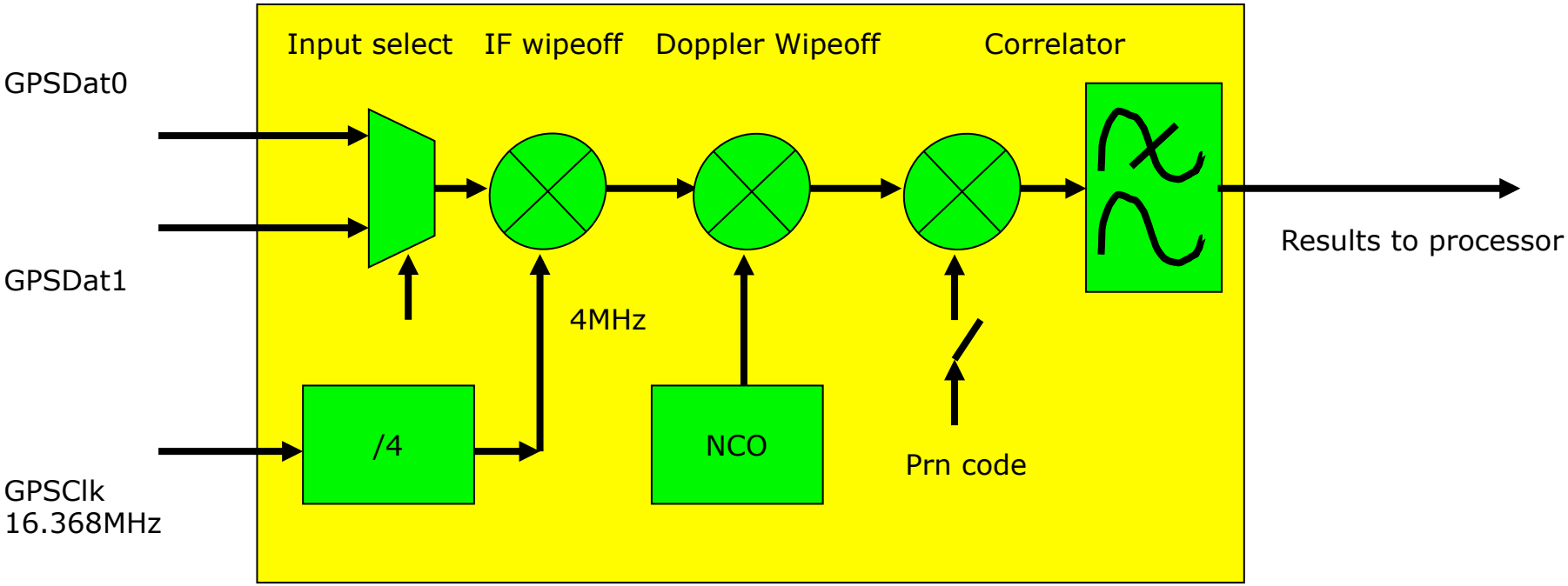
2008 Teseo GPS



Teseo STA2058 GPS processor (2006/2007)

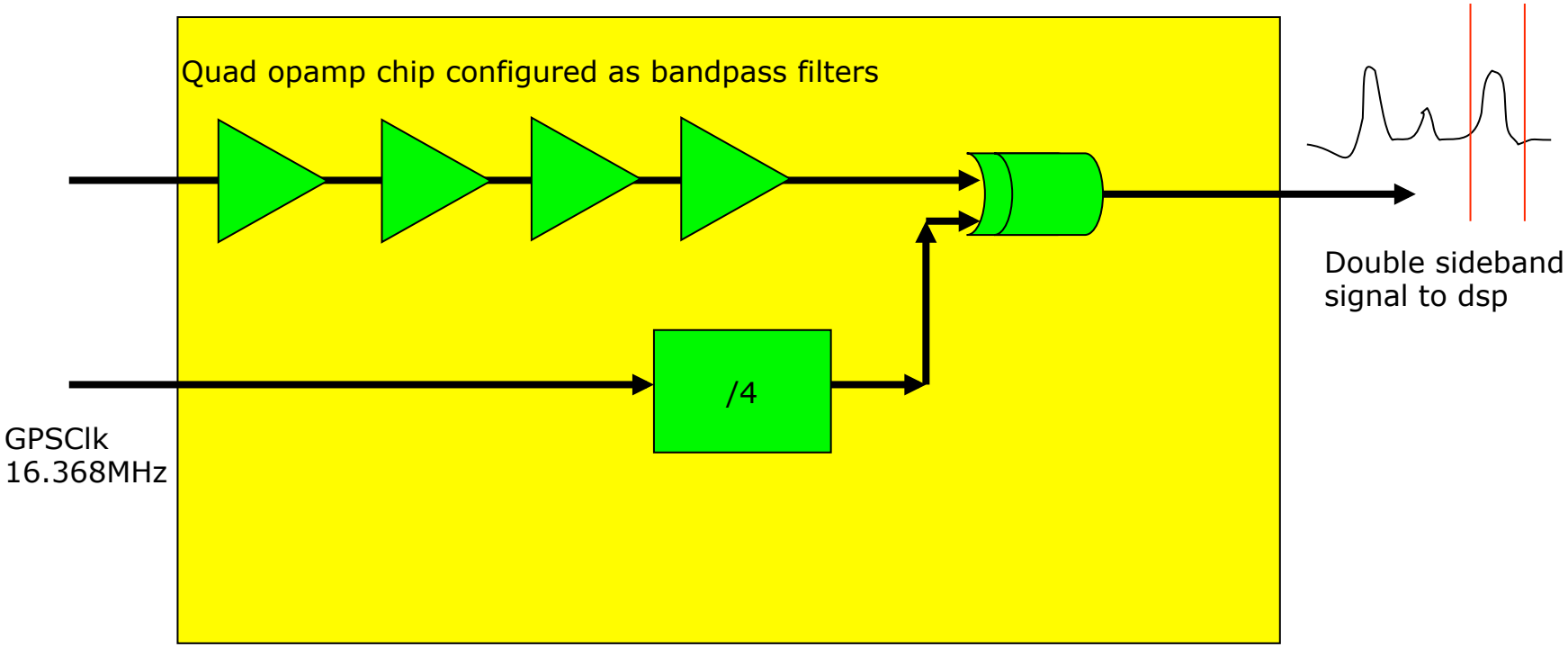
- 2 Radios can be connected
- 2 Data inputs supported
- Common clock and timebase from 0.5ppm TCXO
- Dual input also available on Cartesio STA2062 Multimedia/GPS Processor for PNDs

Teseo GPS Correlators



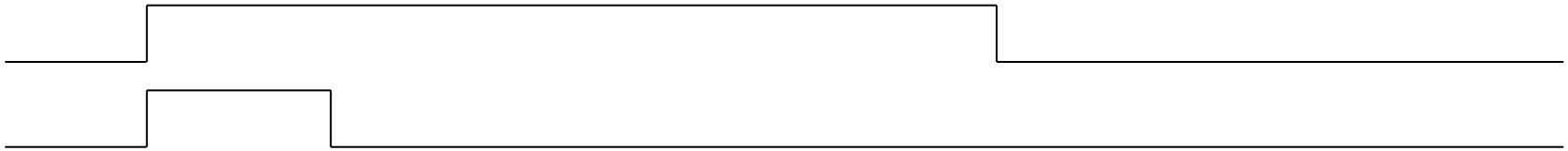
- Multiplexer exists for antenna diversity in GPS
  - One channel can select LORAN input
- NCO can be set to 100000 Hz
- PRN code can be switched off
- Accumulator integrates LORAN energy, I/Q
- Problem :- 4.092 MHz IF required.

Loran RF



- XOR of 1 bit signal with 4.092MHz derived from same TCXO
- Double sideband created….baseband extracts USB only
- 4 stage Sallen-Key Bandpass filters
- Low Q / wide bandwidth

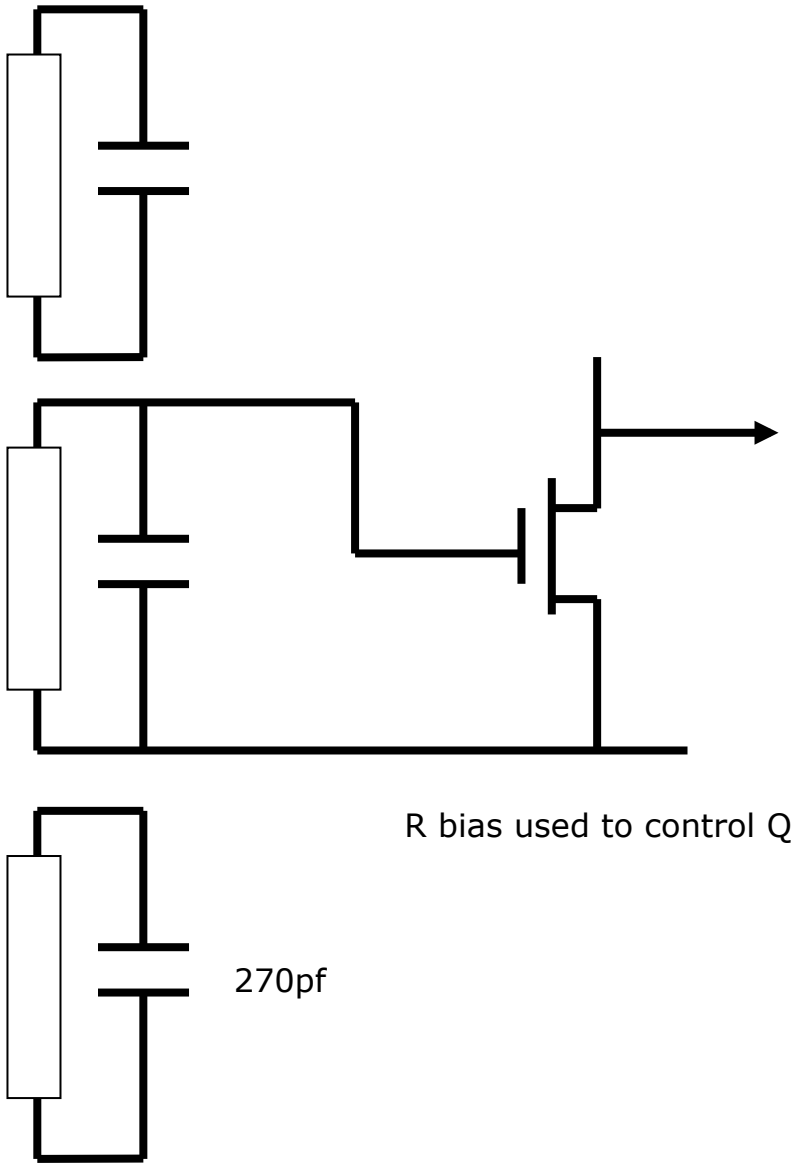
Galileo processor – memory codes



- Write code as a gating window
- Set window to enable first 3 cycles for tracking
- Set window to enable 10 cycles for acquisition
  - (skywave no issue)
- Check also with 1 cycle advance
  - Ratio ensures first cycle.
- Precise measurement from carrier phase (Q/I)
- All LORAN signals in same channel, same NCO
  - 4 MHz converter phase ambiguity +/- 125ns
  - Common mode for all LORAN signals.
- Time domain version also possible
  - Switch off NCO
  - Write windowed 100kHz waveform into prn code memory.

H field antenna

- Space limitations
- Inductor/Capacitor LC tuned with FET LNA
- Helper LC pairs to increase antenna aperture when space allows
- Q must be controlled due to wide bandwidth of pulsed signal

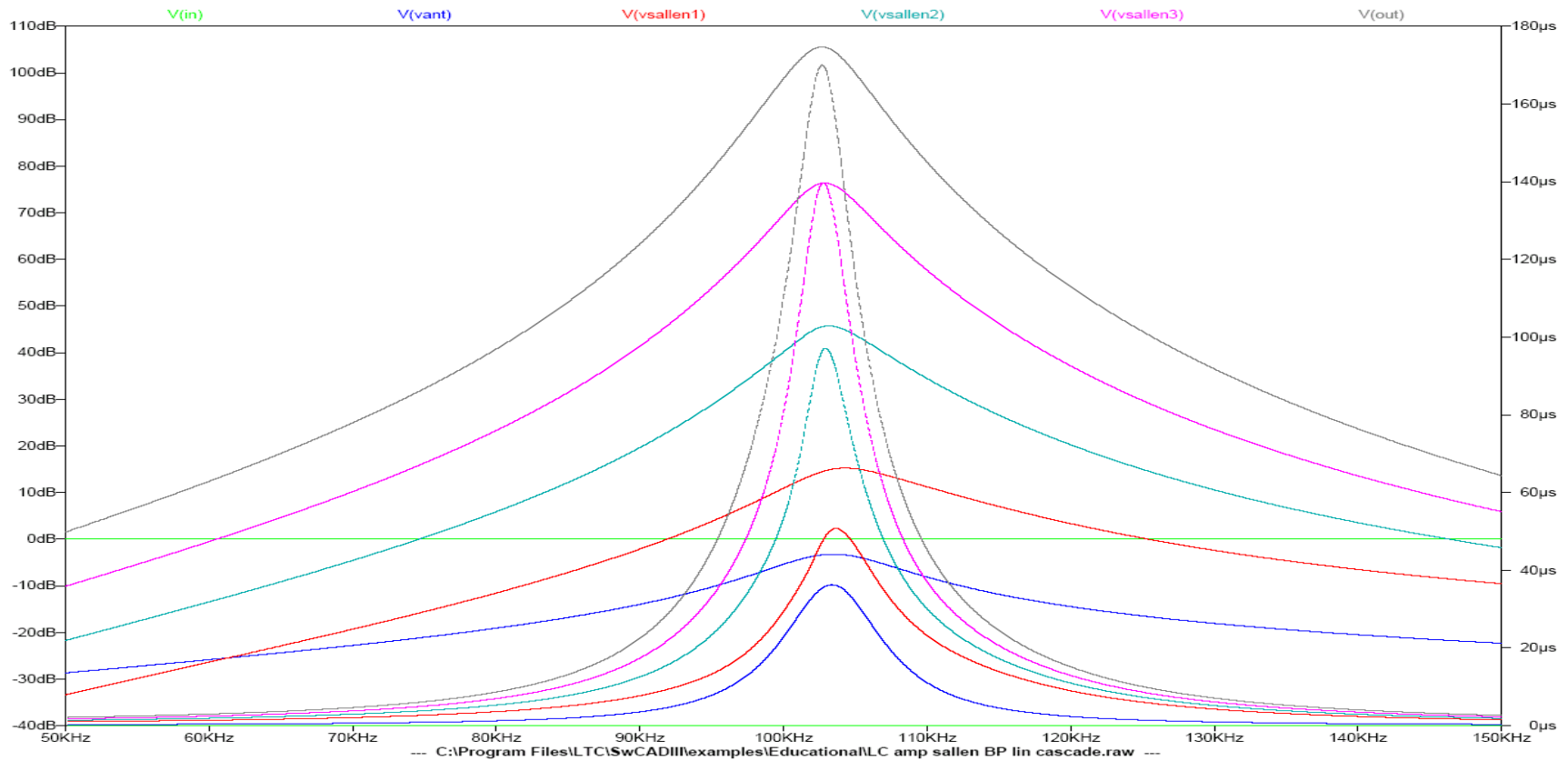


R bias used to control Q

Coilcraft Antenna coil
4308RV-905
9 milliHenries

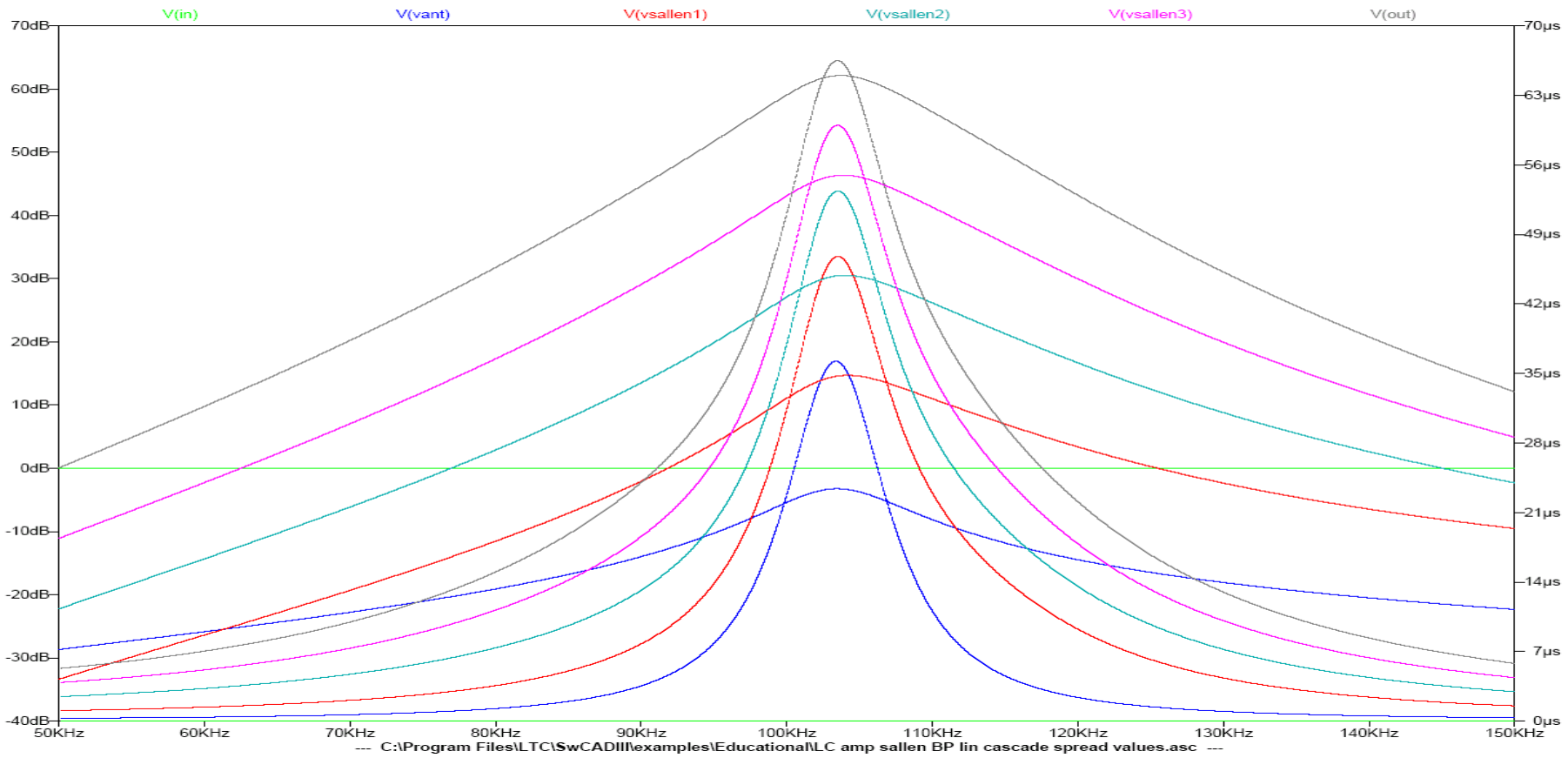
270pf

100KHz RF chain response (1)



- Antenna minimal loading
- All poles tuned identically
- 110db gain
- 170us delay
- 150us dispersion 90/110kHz

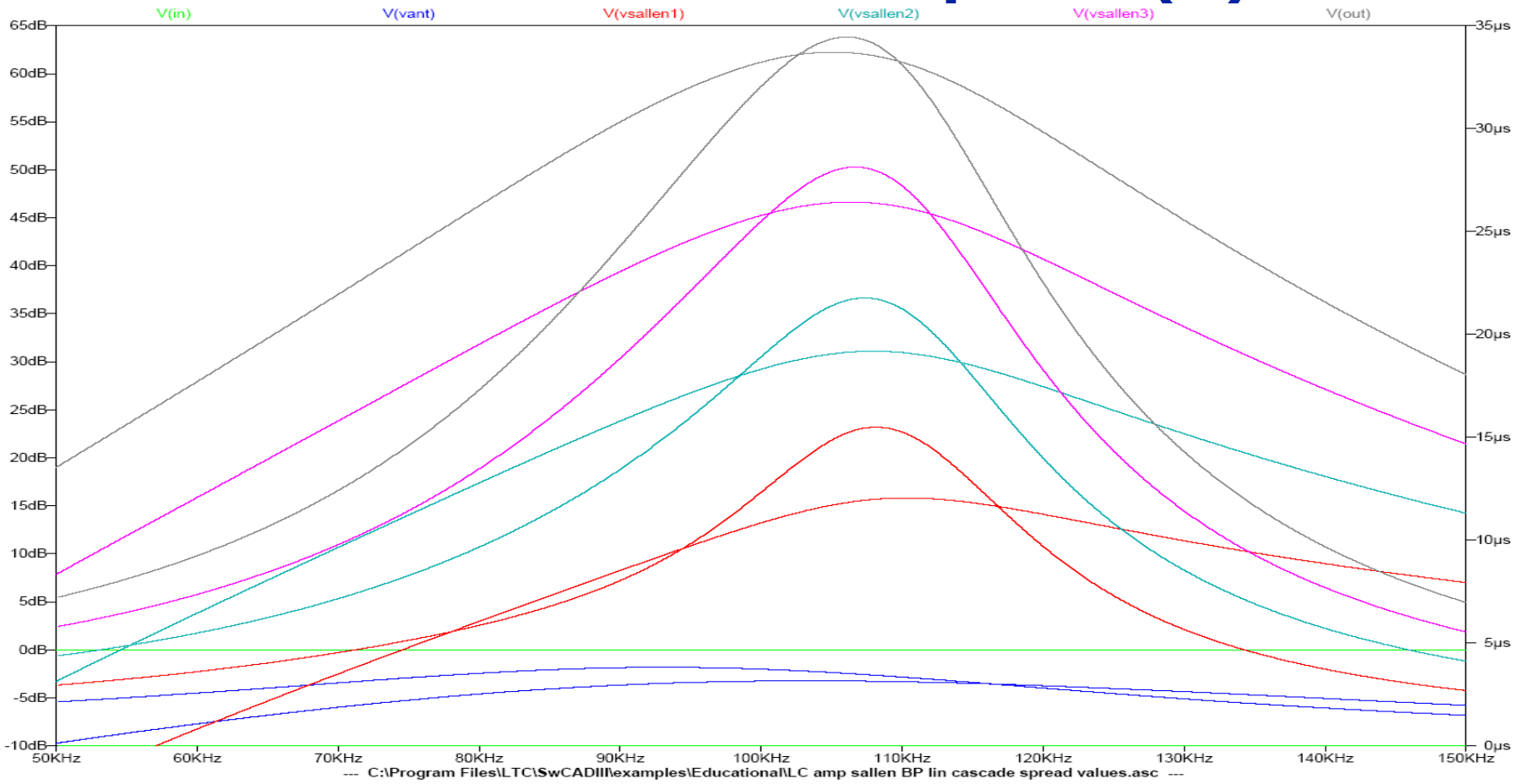
100KHz RF chain response (2)



- Antenna minimal loading
- Pole tuning spread

- 70db gain
- 65us delay
- 40us dispersion 90/110kHz

100KHz RF chain response (3)



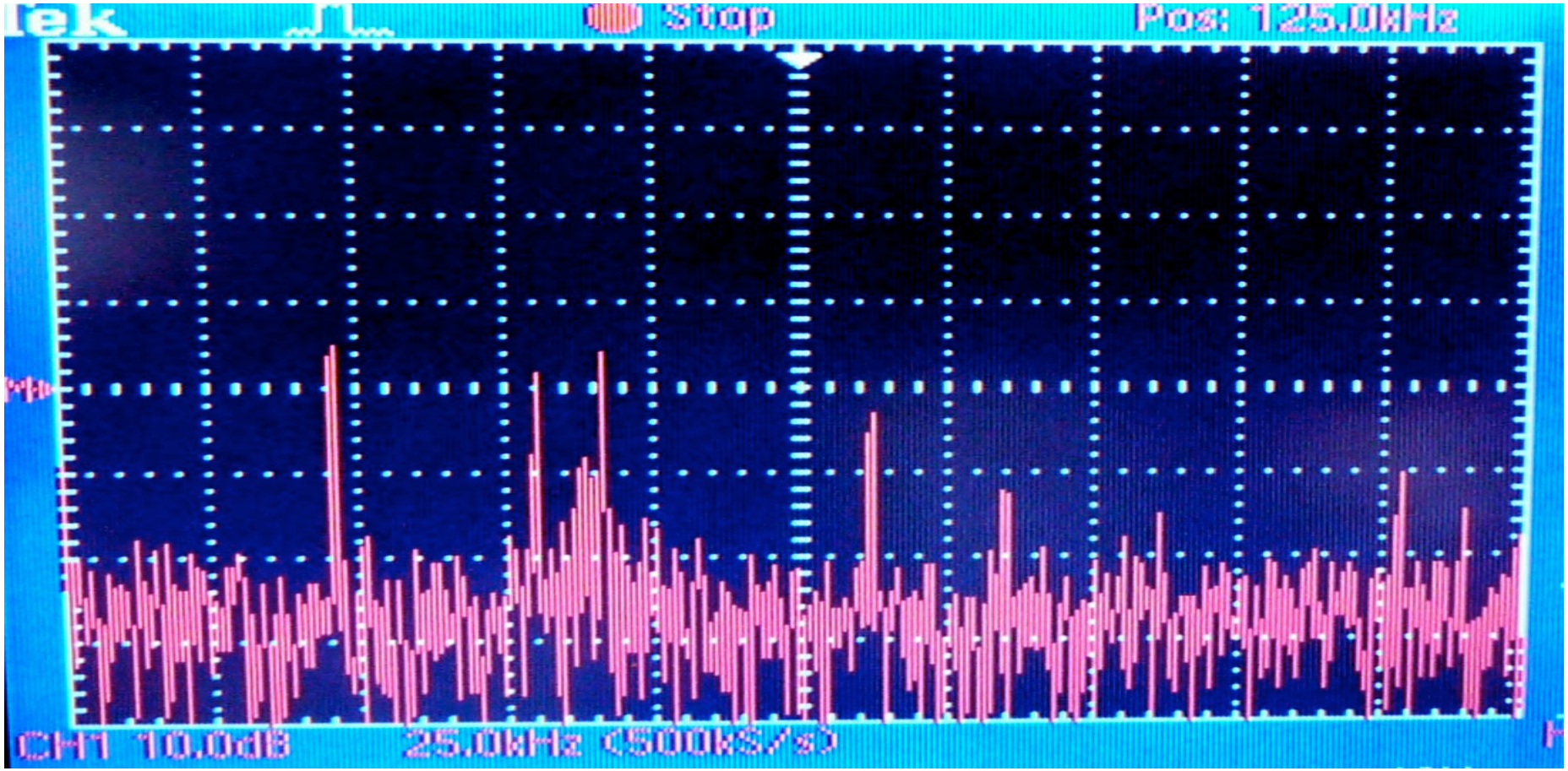
- Antenna 10kohm load
- Pole tuning spread more

- 65db gain
- 35us delay
- 8us dispersion 90/110kHz

Difficulties

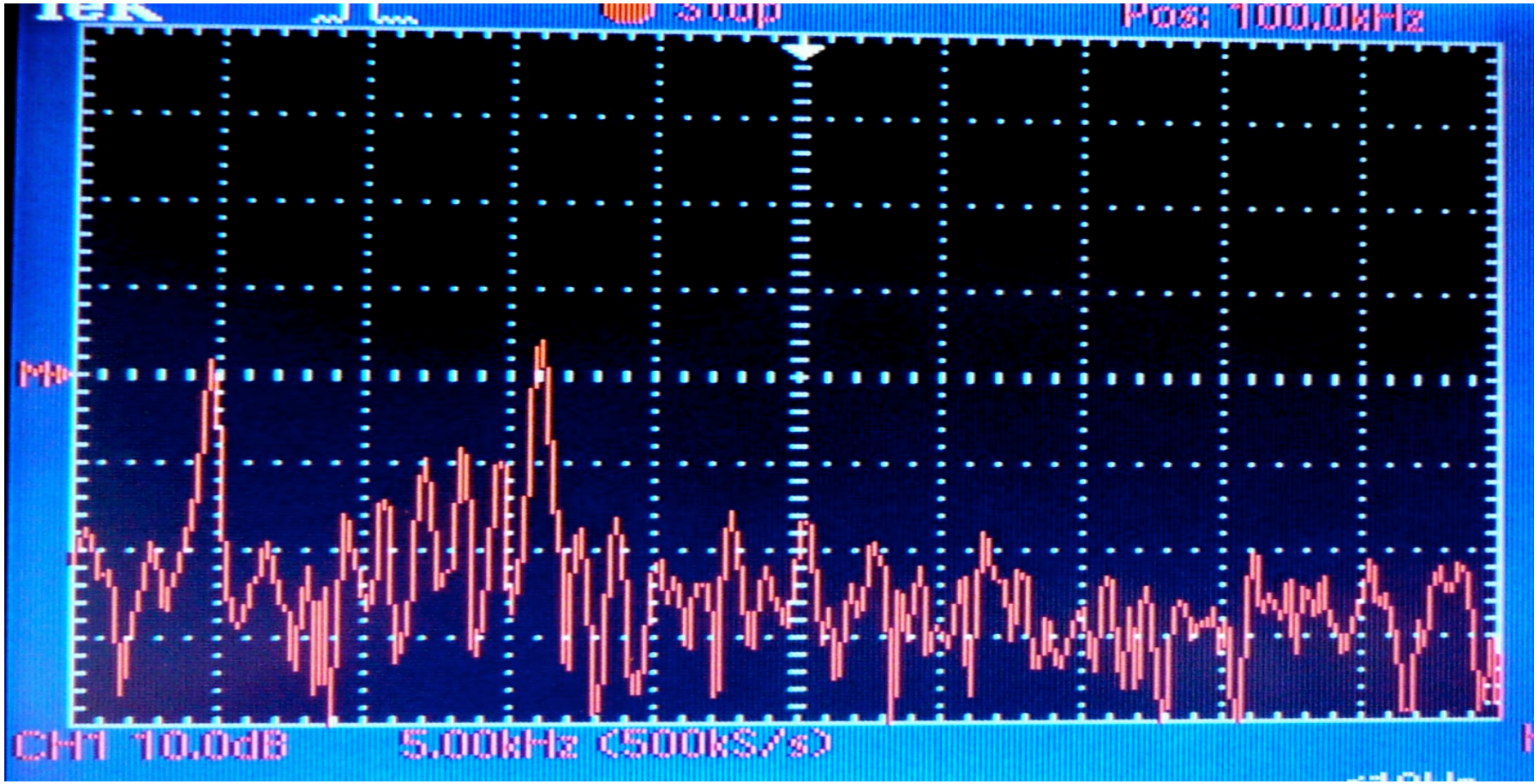
- Space limitations for H-field antenna
- Sensitivity of H-field antenna
- Electrical interference
  - Fluorescent lights
  - Neon signs
  - Energy-efficient bulbs (CFL)
  - RF-ID tag readers….security badge readers !
- Eloran rollout schedule
- Southern Europe coverage

Noise, Office environment (1)



- FFT 0-250kHz
- Peaks at 50kHz(lighting), 80KHz, 91kHz, 137kHz

Noise, Office environment (2)



- FFT 75-125kHz
- Peak at 80KHz is 'scope LCD, 91kHz is PC LCD

Time targets

- Realistic targets allowing for position movement
- GPS 0.5 milliseconds
- Galileo 2 milliseconds
- 100 microseconds easily achievable with LORAN, even indoors

Before eLORAN rollout

- All LORAN transmissions are time locked
  - Allows TOA working
  - Allows cross-chain working
- Access to signals from two chains with relatively co-prime GRI's allows absolute time resolution
- If only slave received, not master, difficulties of identification (X/Y/Z)
  - Prior knowledge of user position may identify slave.
- Most of Europe receives 2 masters
  - Lessay(6731), Sylt(7499)
- (with apologies to Spain, Portugal, Italy, Greece etc)

LORAN chains

Lessay*	6731	M	49,14867 N	1,50473 W	
Soustons	6731	X	43,73975 N	1,38044 W	13000.0
Anthorn	6731	Y	54,91083 N	3,28717 W	27300.0
Sylt	6731	Z	54,80833 N	8,29357 E	42100.0
Bo	7001	M	68,63506 N	14,46315 E	
Jan Mayen	7001	X	70,9143 N	8,73237 W	14100.0
Berlevag	7001	Y	70,84528 N	29,20444 E	29100.0
Sylt*	7499	M	54,80833 N	8,29357 E	
Lessay	7499	X	49,14867 N	1,50473 W	14100.0
Vaerlandet	7499	Y	61,29707 N	4,69628 E	29500.0

- * Dual rated, useful for absolute time even before eLoran

Conclusions

- Indoor GNSS performance improved by over 10dB
  - Phone networks rarely have 3GPP precise time (10us)
- 0.5ms for GPS, 2 ms for Galileo sufficient
- Easily achieved with eLoran
- Minimal extra electronics
  - Though price pressure in mobile phone is intense
- Antenna size and interference problems
  - H-field antenna sensitivity
  - Try Loop antenna conformal to case