What is “Digital Radio”

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Communications is …

- **A message**
  - That contains information
- **Sent by**
  - a person or a machine
- **At**
  - a moment in time
- **To be received**
  - other people or machines
- **Usually requiring a response**
  - From the receiver
- **Other considerations**
  - Was it an accurate message
  - Was it sent by an authentic sender
  - Was it received by the intended receiver(s)
  - Was the message was correctly understood by the receiver.
  - Was privacy and secrecy violated.
- **With Radio communications there are no guarantees!**

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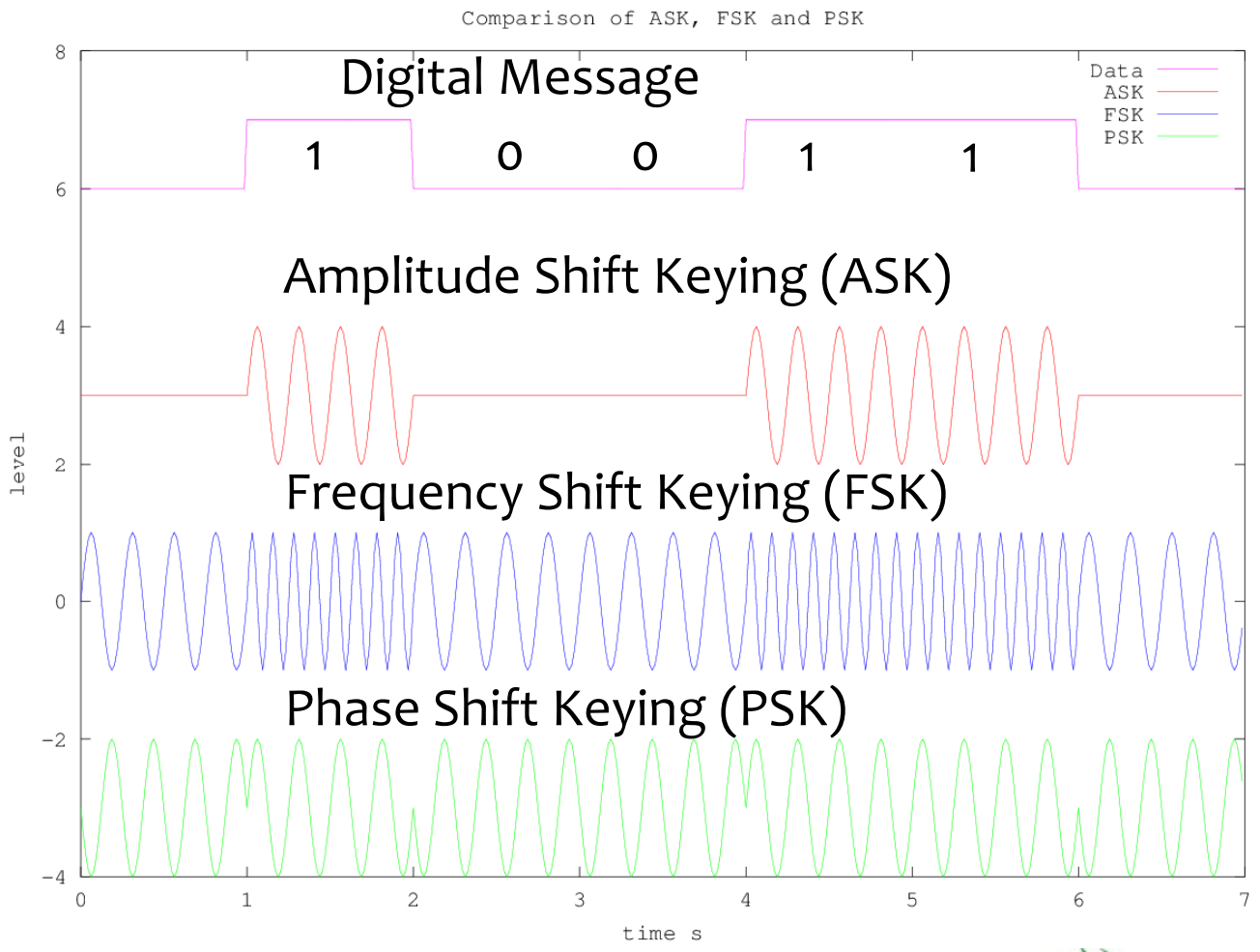
What is digital Radio?

- **Analogue Communication**
  - Use directly amplified electrical signals from a sensor.
    - E.g. Microphone.
  - Can use AM, FM and PM
- **Digital Communication**
  - Describe the information to be sent by a sequence of pulses.
    - E.g Morse Code
      - SOS . . . _ _ _ . . .
  - Can use ASK, FSK, and PSK
  - Amplitude shift keying etc.

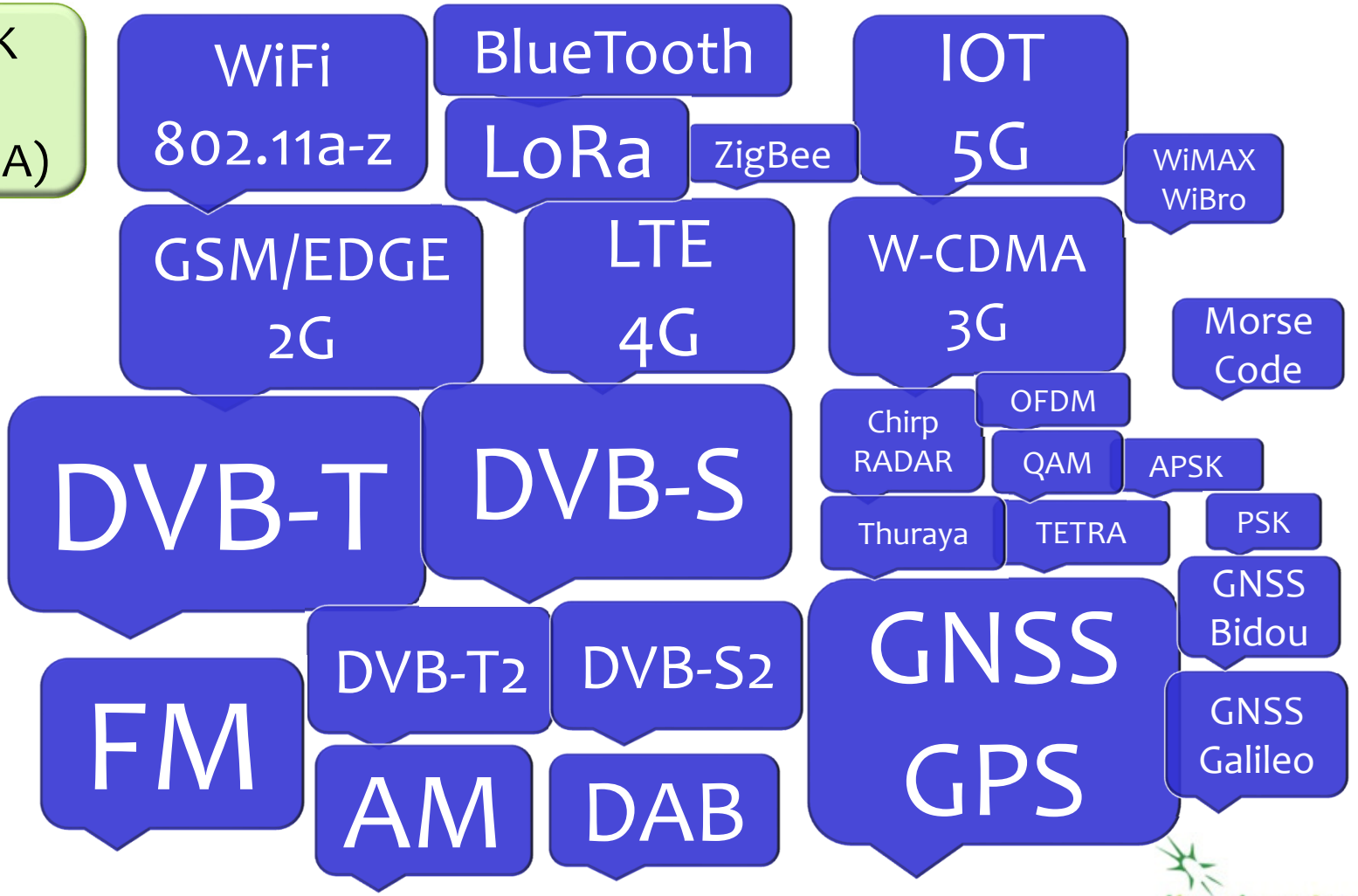


And then things got complicated…

<1940s Morse AM FSK
1950s FM appeared
1978 Military GPS (CDMA)

Since 1991, an explosion of Radio Standards, many are GMSK, CDMA and OFDM based

We need SDR!!!



What is software defined radio

- **Conceptual Definition**
  - The ability to make a radio that can do something entirely new which it did not do in the factory.
    - E.g. Using a Realtek DVB-T dongle receiver for SAT-NAV.
- **Engineering Definition**
  - A Radio whose behaviour can be dynamically redefined by software or firmware changes. (Field Programmable)
    - E.g. Has reprogrammable Microprocessors and FPGAs instead of hard wired parts.
- **Consumer Definition**
  - Can I watch live TV.
  - Can I watch a youtube video of my cat.
  - Can I use it as a "sat nav" down the motorway.

SDR – Partitioning for Low Cost

RF Parts

Antennas
SAW Filters
RF Switches
Power Amps

TRX RFIC

RF and DSP
Field Programmable

FPGA

Data link and
Extra DSP

PCIe Link

USB3 Link

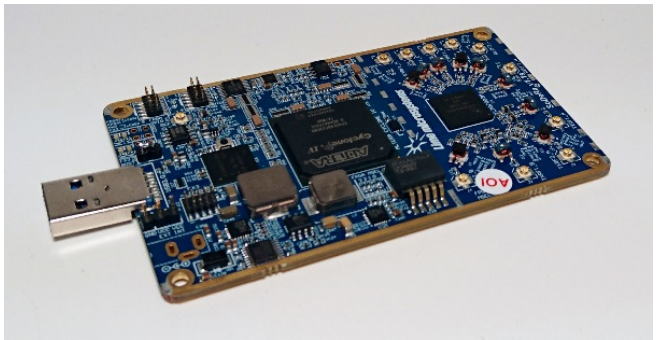
Open Source Software/Apps

COMPUTER

Multicore
GHz Processor
And Memory

WiFi/Ethernet/ ADSL Network

Optimal partitioning of the radio system leads to an easy to use low cost solution.



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LMS7002M FPRF Transceiver Block Diagram

High level of integration, including dual 12-bit ADC and DAC

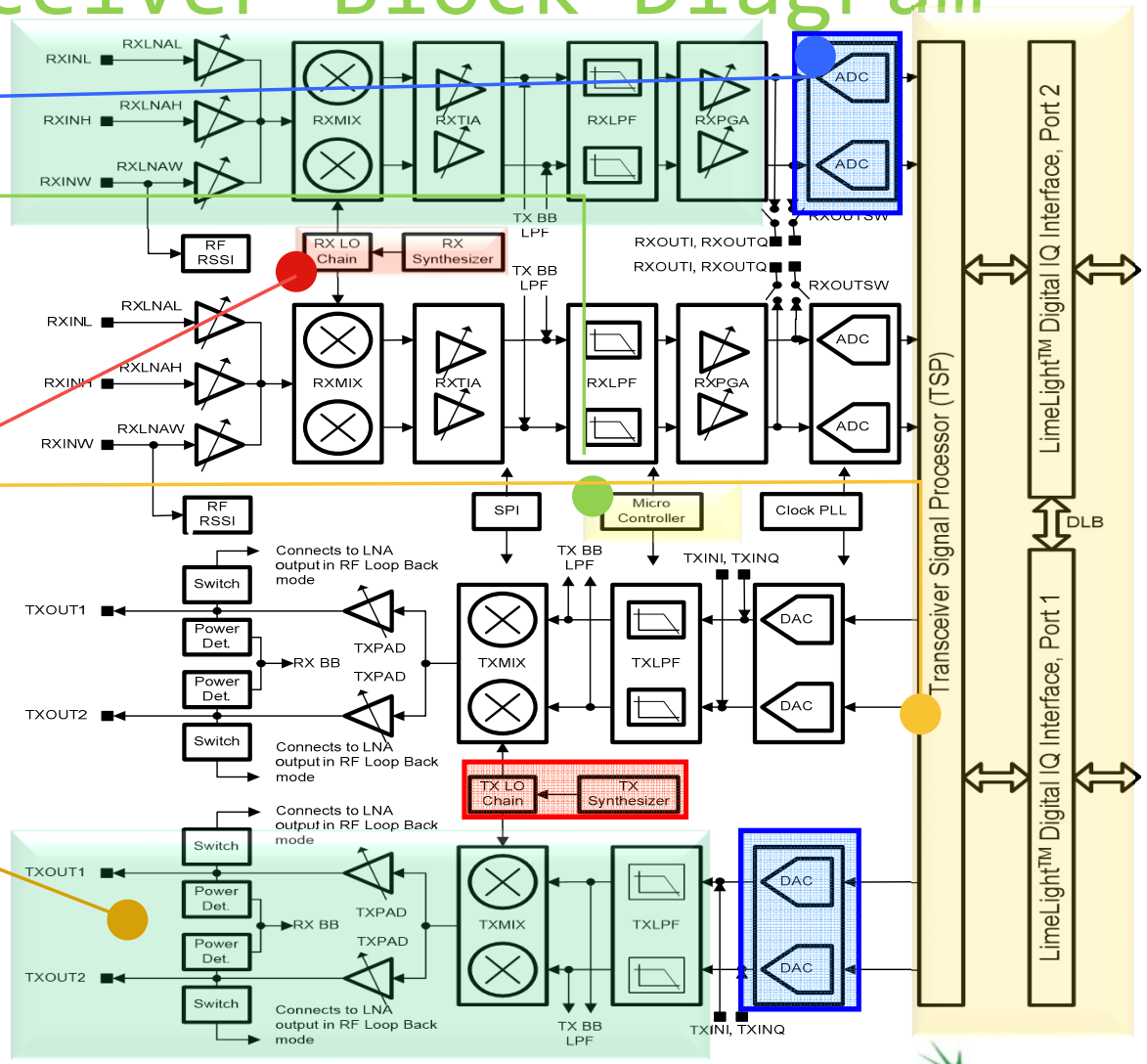
Integrated 8051 MCU

Transceiver Signal Processor block and LimeLight interface

Frequency

100KHz – 3.8GHz

Highly configurable RF gain and IF filter with numerous bypass options



LMS7002M

Field Programmable RF

LMS7002M is very complicated!!!!

- **Lets break it down a bit**
- **MIMO Transeiver**
  - Up to 2 TX channels can operate simultaneously
  - Up to 2 RX channels can operate simultaneously.
- **Each TX channel**
  - 2 outputs
  - Low band (for <2.5GHz)
  - High band
- **Each RX channel**
  - 3 Inputs
  - Low band (opt for 800MHz)
  - Wide band (general purpose)
  - High band (opt for 2-3.8 GHz)
- **Synthesisers x3**
  - SXT – TX Synthesiser
  - SXR – RX Synthesiser
  - CLKGEN – Digital Circuits

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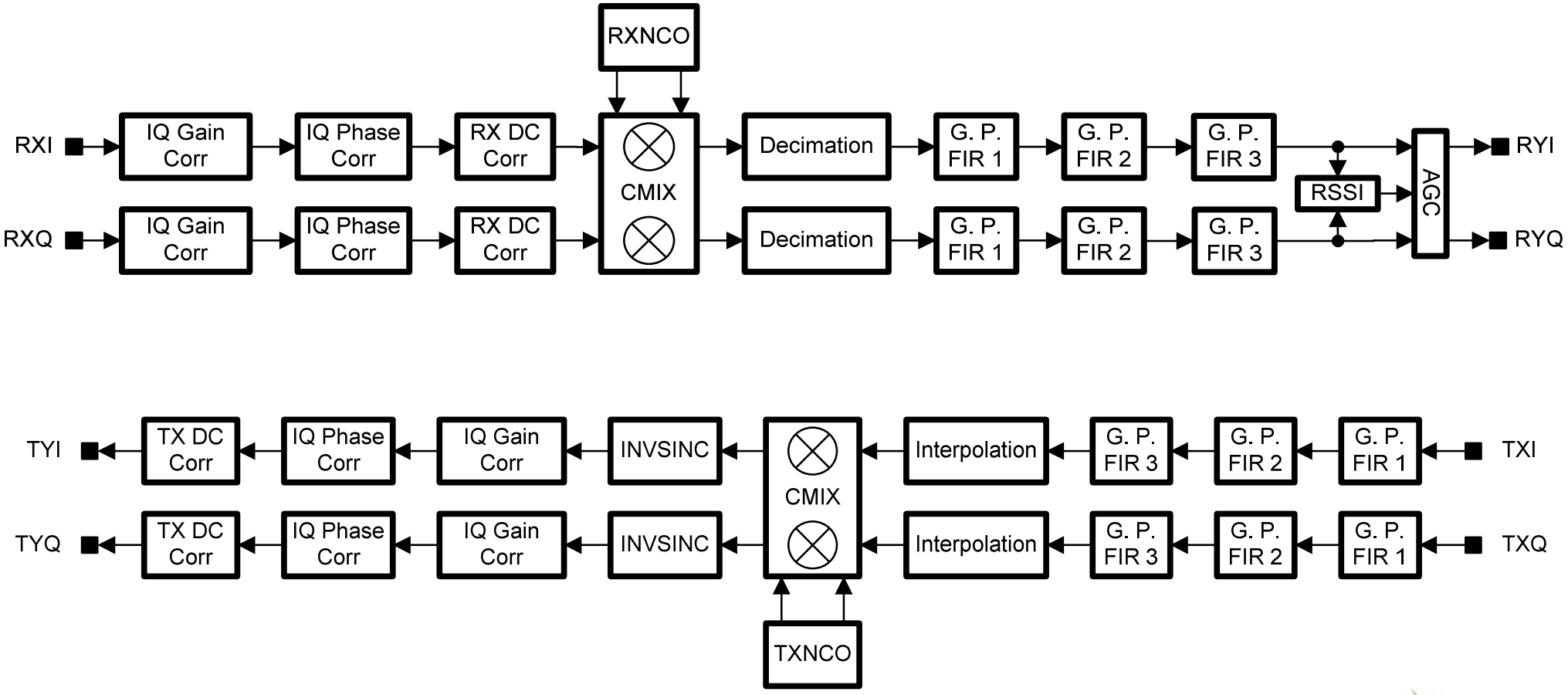
LMS7002M FPRF Transceiver Signal Processing TSP



What is the range of a LimeSDR

- **A very simple question…**
  - Without a simple answer…
- **Depends on many things…**
  - Distance between Tx and Rx
  - Frequency of Tx
  - Bandwidth of signal
  - Forward Error Correction coding
  - Height and gain of Tx and Rx antennas
  - Noise figure and RF matching of Rx
  - Does the signal have to pass through walls
  - Landscape and weather
- **Classic approach is the Link Budget**
  - Depends on…
- **Tx Output power**
- **Path Loss**
  - Distance and frequency
- **Antenna gains**
- **Rx Sensitivity**
  - Bandwidth, Forward Error correction and Receiver noise figure
- **Fading behaviour**
  - Probability depending on height, speed etc. Need some margin.

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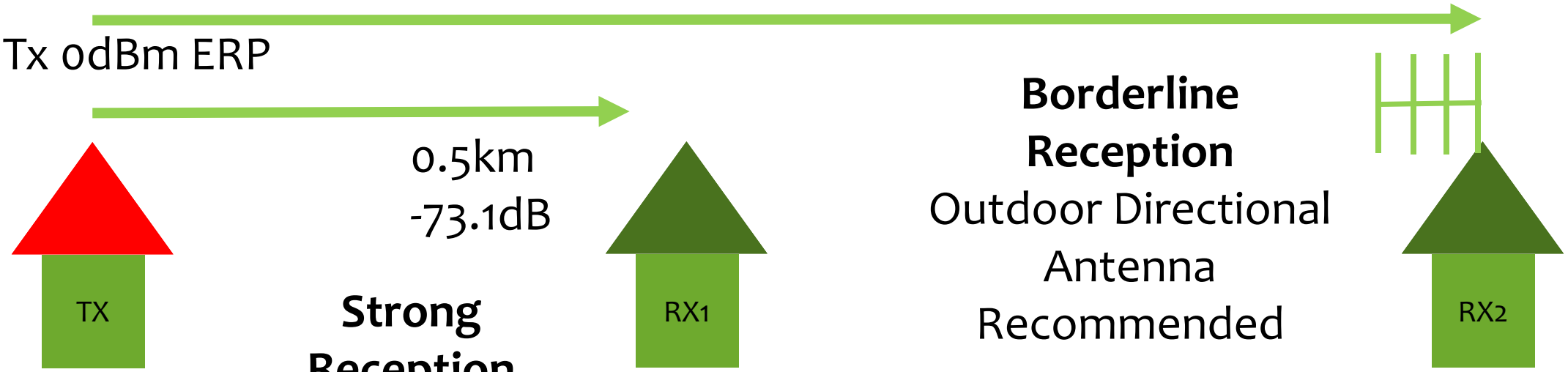
LimeSDR DAB Radio Link Budget Example

Range of a Radio is usually a probability not a certainty!



Upper Limit of Range for LimeSDR

30dB Margin Reliable Broadcast

10dB Margin Usable

	Range of LimeSDR without external amplification (Optimistic)									
LimeSDR	DAB	DVB-T2	GSM (2G)	W-CDMA UL (3G)	LTE (4G)	LTE (4G)	WiFi	BlueTooth	Zigbee	
	OFDM-PSK8	OFDM	GMSK	DSSS-BPSK	OFDM-QPSK	OFDM-QPSK	OFDM-QPSK	GMSK	DSSS-BPSK	
LO	215.00	480.00	870.00	870.00	870.00	870.00	2450.00	2450.00	2450.00	MHz
RF BW	1.50	7.77	0.18	3.84	20.00	1.40	20.00	1.00	0.25	MHz
Tx Level	**0.00**	**-6.00**	**4.00**	**3.00**	**-2.00**	**-2.00**	**-5.00**	**-5.00**	**-5.00**	**dBm**
Tx Filter loss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	dB
TxAe	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	dBi
RxAe	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	dBi
Dist	**7.00**	**0.73**	**8.30**	**25.50**	**0.50**	**1.90**	**0.12**	**0.40**	**4.80**	**km**
Loss	95.99	83.33	109.61	119.36	85.21	96.81	81.81	92.27	113.85	dB
Other Loss	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	dB
Rx Level	**-93.99**	**-87.33**	**-103.61**	**-114.36**	**-85.21**	**-96.81**	**-84.81**	**-95.27**	**-116.85**	**dBm**
Thermal	-112.07	-104.93	-121.28	-107.99	-100.82	-112.37	-100.82	-113.83	-119.85	dBm
Eb/No*	2.00	2.00	2.00	2.00	0.00	0.00	0.00	2.00	2.00	dB
Spread Factor	1	1	1	256	1	1	1	1	32	
CodeGain	0.00	0.00	0.00	24.08	0.00	0.00	0.00	0.00	15.05	dB
RF Switch	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	dB
RX Filter Loss	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50	dB
Rx NF	3.00	2.50	2.50	2.50	2.50	2.50	3.00	3.00	3.00	dB
Sensitivity	**-104.07**	**-97.43**	**-113.78**	**-124.57**	**-95.32**	**-106.87**	**-94.82**	**-105.83**	**-126.90**	**dBm**
Margin	**10.08**	**10.09**	**10.16**	**10.21**	**10.11**	**10.06**	**10.01**	**10.56**	**10.05**	**dB**

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Bad Neighbours

- **“No man is an island”**
  - John Donne 1624.
- **Especially true for Urban radio links.**
- **We are surrounded by radio links.**
  - UHF TV Transmission
  - VHF Radio Transmission
  - 2G/3G/4G Mobile Radio
  - Point to Point and Satellite links
  - WiFi and Bluetooth Devices
  - 5G Internet of Things
  - And many more…

- **How do we live with bad neighbours?**
  - SAW RF Band Select Filter
  - Directional antennas

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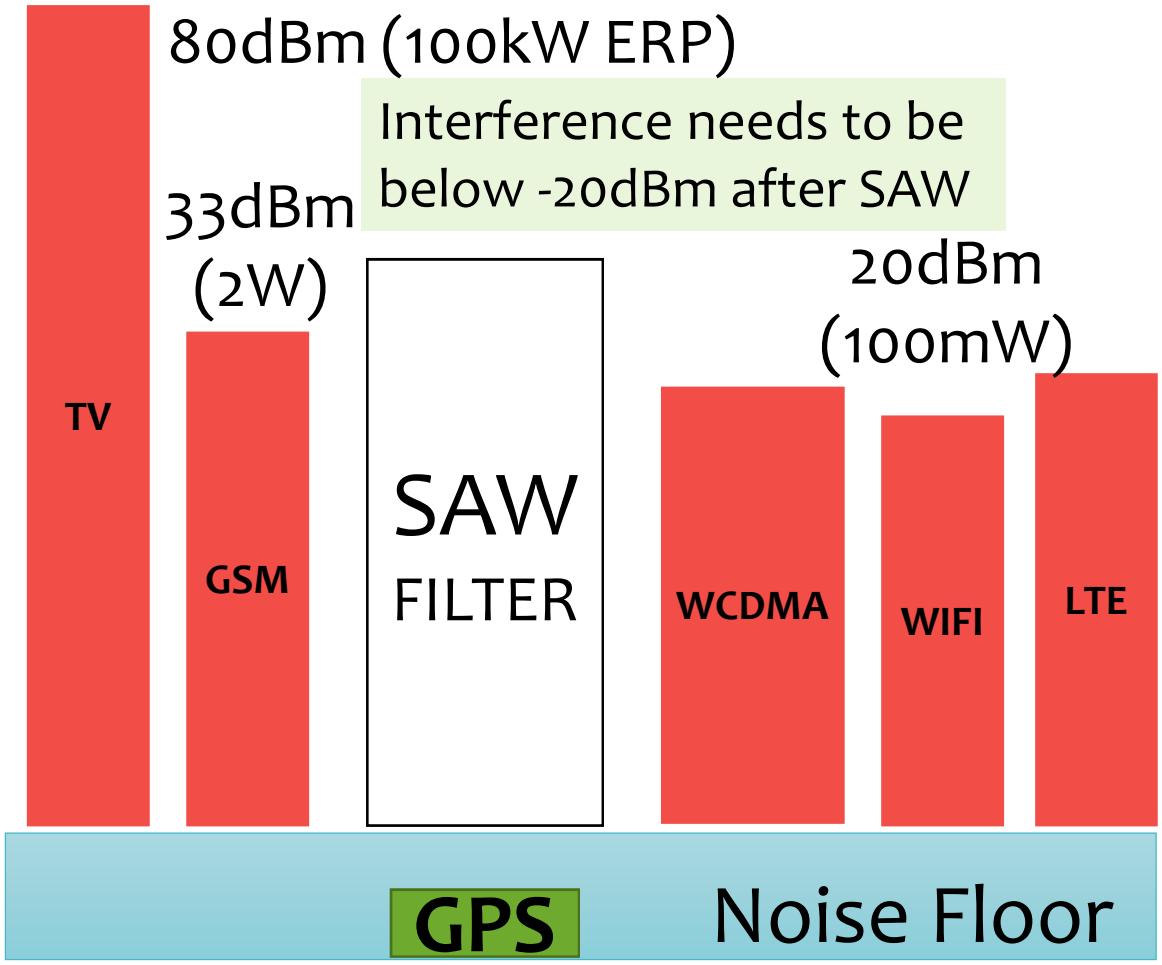
SDR GPS Receiver: Dynamic Range



Collocation of Broadcast, Mobile and WiFi With GNSS leads to challenges (Bad Neighbours!)

Receiver must be able to work with very low signals in the presence of strong interfering signals.

This simultaneously requires low NF, very low far out phase noise (-160dBc), high P1dB and good IIP2 and IIP3 and a good ADC.

Often your own TX is your worst interferer in collocated radios Need SAW filters in active antenna.

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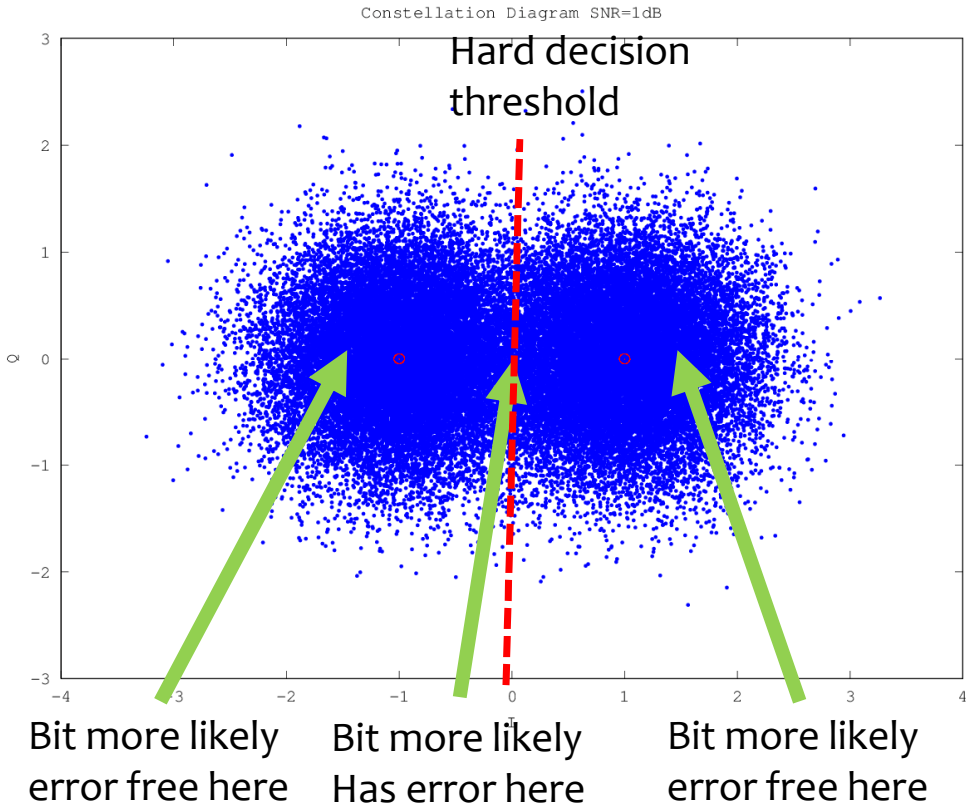
How NOT to be a Bad Neighbour!

- **Think about other radio users**
  - Spread spectrum signals?
- **Use RF Band Select Filter**
  - E.g. SAW
  - Removes harmonic responses and EMC spurs
- **Use Pulse Shaping Filter**
  - E.g. RRC or Gaussian FIR
  - Minimise Adjacent Channel interference
- **Consider Directional Antennas**
  - Direct Power to where you need it.
- **Only transmit with the power you need.**
  - OFCOM License regulations
- **Transmit within the band you are licensed.**
- **Some UK License Exempt Bands**
  - UK Frequency Allocation Table 2013
    - Annex B Table 1 Non-specific short range devices
  - VHF 138.32MHz (0.15MHz BW) 10dBm ERP
  - VHF 173.27MHz (0.14MHz BW) 0dBm ERP
  - UHF 433.9MHz (1.7MHz BW) 10dBm ERP
  - UHF 866MHz (6MHz BW) 13dBm ERP
  - WiFi 2442MHz (83MHz BW) 10dBm ERP
  - ERP=Tx Power+Tx Antenna Gain (dipole)

Noise and Symbol errors

- **Ideal digital systems have**
  - Precisely defined values,
  - Either 1 or -1
    - how can you mess it up?
- **Real systems have added noise.**
  - Random values defined by probability.
  - If noise too large, decision threshold crossed for some of the bits.
    - Data is partially damaged
    - Worse case half of bits are wrong!
    - What can we do?
  - Bit errors can be singular or in bursts.



Error Correction Coding

- **Hard Error Correction**
  - Bit Value depends on decision threshold only.
- **Soft Error Correction**
  - Probabilistic decision about which bits are more likely to contain errors.
  - Evaluate multiple possibilities and select the most likely.
- **Soft Error Correction improves performance of FEC codes.**
  - E.g. Hamming 4/7 code 1.3dB.
  - Turbo Code, LDPC and Viterbi widely used