# EEEN3006J

# Wireless Systems

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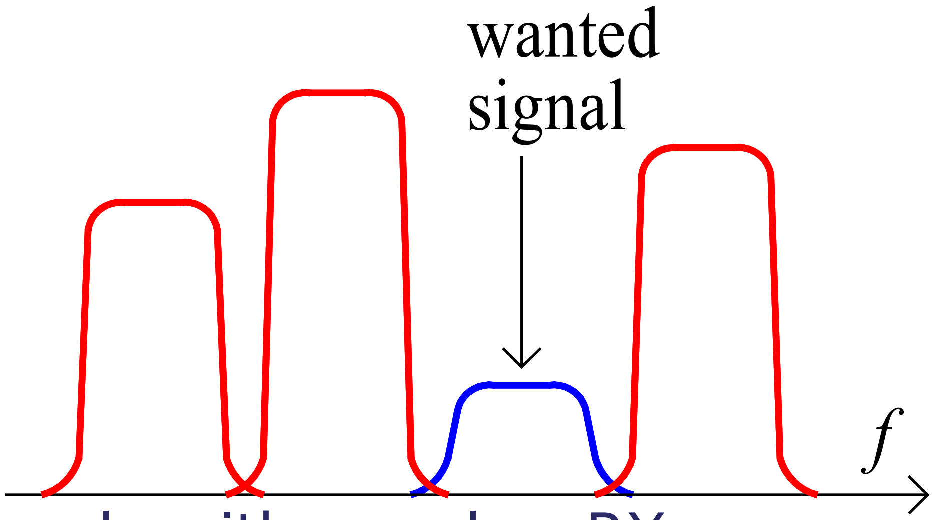
# What Do We Want from a Receiver?

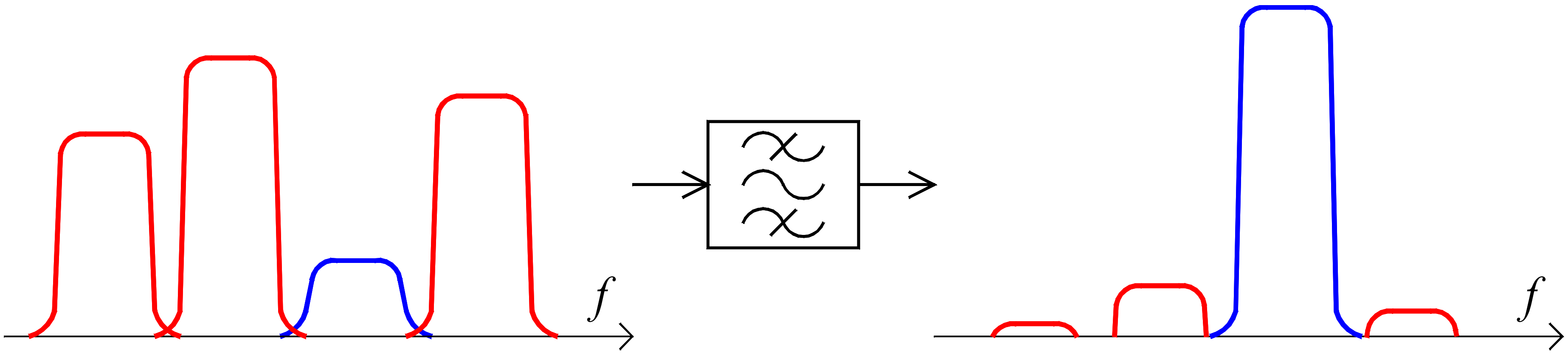



- Sensitivity
  - able to work properly with very low RX power
  - but must also work at much higher RX power
    - wanted signal can vary by 70 dB – 80 dB
    - *Dynamic Range*
- Selectivity
  - able to select the wanted signal
  - reject unwanted signals present at input
    - perhaps at much higher power
    - perhaps very close in frequency

# Selectivity – Background

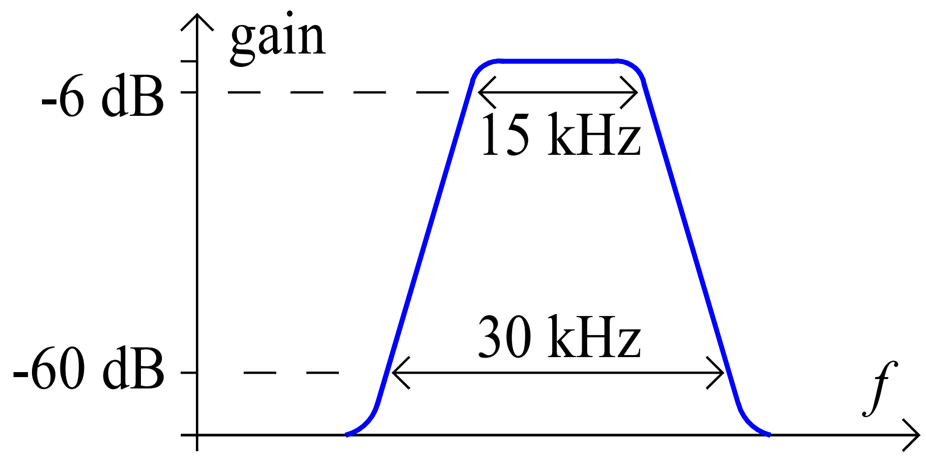
- Frequency spectrum – scarce resource
  - mostly controlled by (inter)national agencies
- Frequency band for specific purpose
  - e.g. FM radio broadcasting, 3G phones
  - allocated by regulatory agency
  - standards for transmissions within the band
  - so know something about neighbouring signals
- Band usually divided into channels
  - each transmission must fit in one channel
  - so receiver must be able to select one channel
  - channel bandwidth depends on system
    - 12.5 kHz, 25 kHz, up to 5 MHz, 10 MHz…

# Selectivity Depends on Filters



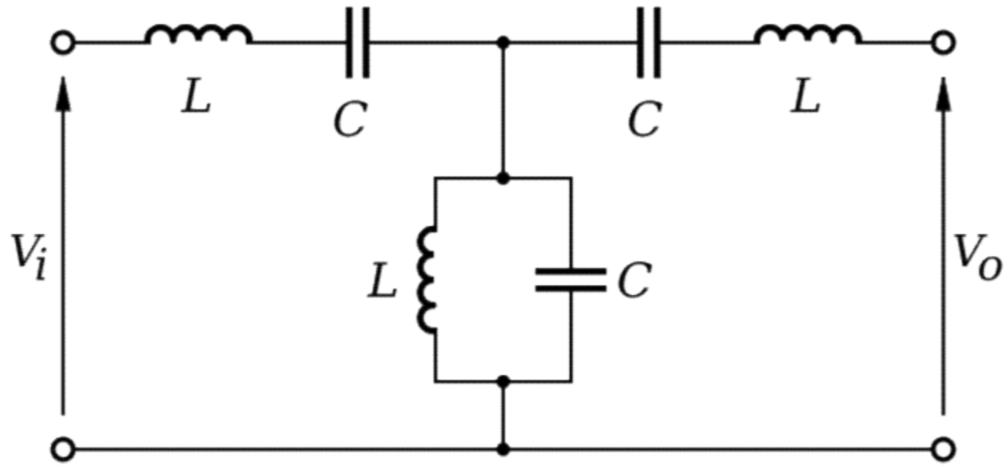

- Want to pass wanted signal
  - block unwanted signals at different frequencies
  - but “block” not possible – aim to attenuate
  - then amplify wanted signal
- Filters are critical part of radio receiver
  - often band-pass filters, low-pass possible
  - specifications can be challenging
  - especially if want narrow BW at high frequency
  - more difficult if want adjustable…

# Filter Specifications



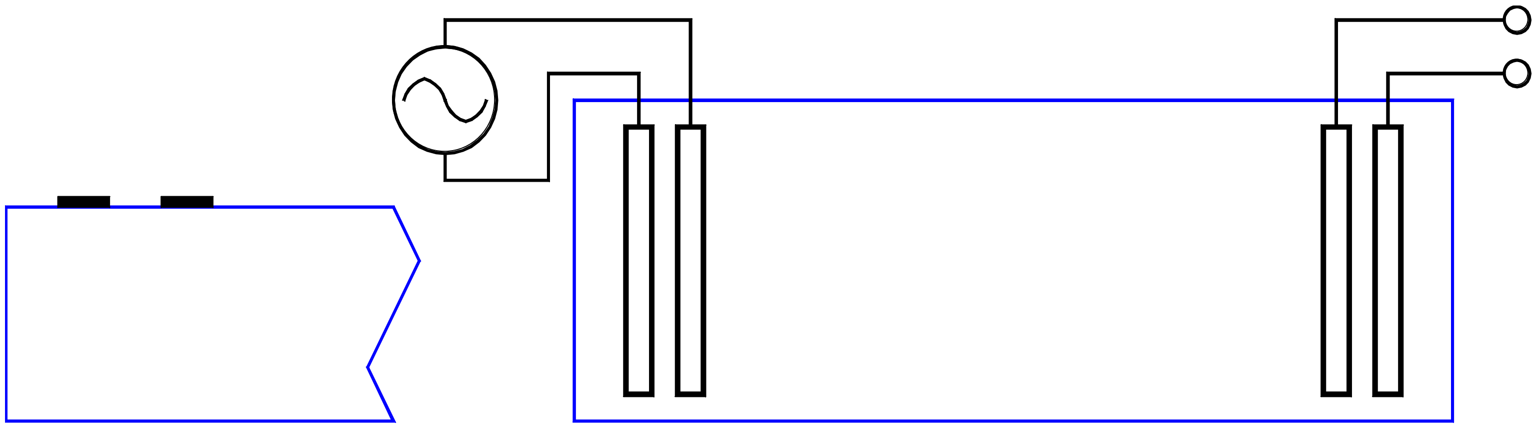

- Specify width of pass-band
  - to some acceptable level of attenuation
  - with some acceptable ripple (gain variation)
- Specify attenuation in stop-band(s)
  - at some specified frequency offset from centre
  - or specify bandwidth at some large attenuation
- Shape factor: ratio of bandwidths
  - specify two attenuation values: e.g. 30/3 dB
  - example has shape factor 2.0 at 60/6 dB

# Filters at RF



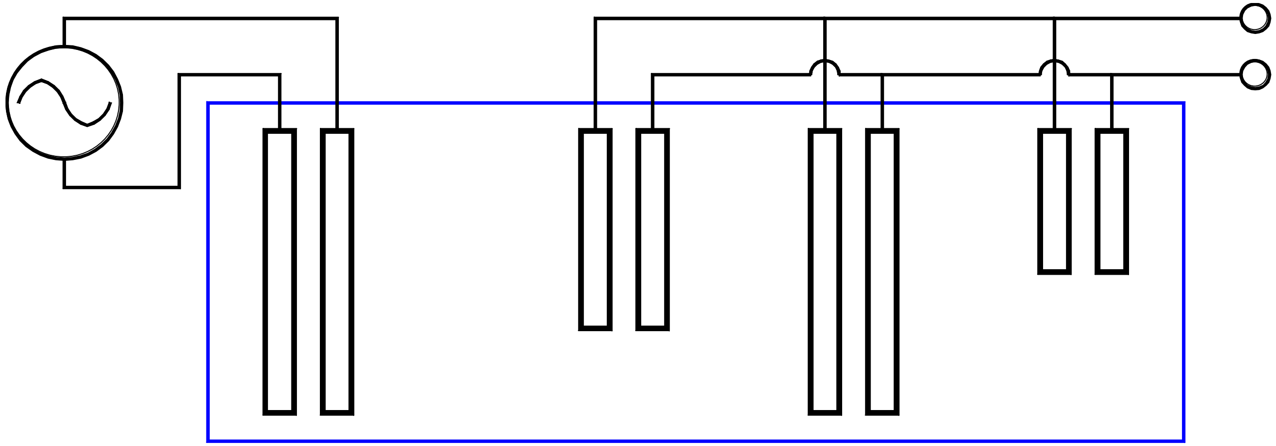

- Passive filters
  - no op-amps, just inductors, capacitors
  - or transmission-line segments (RF Electronics)
  - or mechanical resonators, SAW, etc.
- Demanding specification $\Rightarrow$ high order
  - high complexity, many components
  - so high insertion loss (pass-band attenuation)
  - cannot use at input to receiver
    - recall noise calculations – attenuator at input
    - increased receiver noise temperature, noise power
    - bad for sensitivity – need more signal power

# Surface Acoustic Wave - SAW



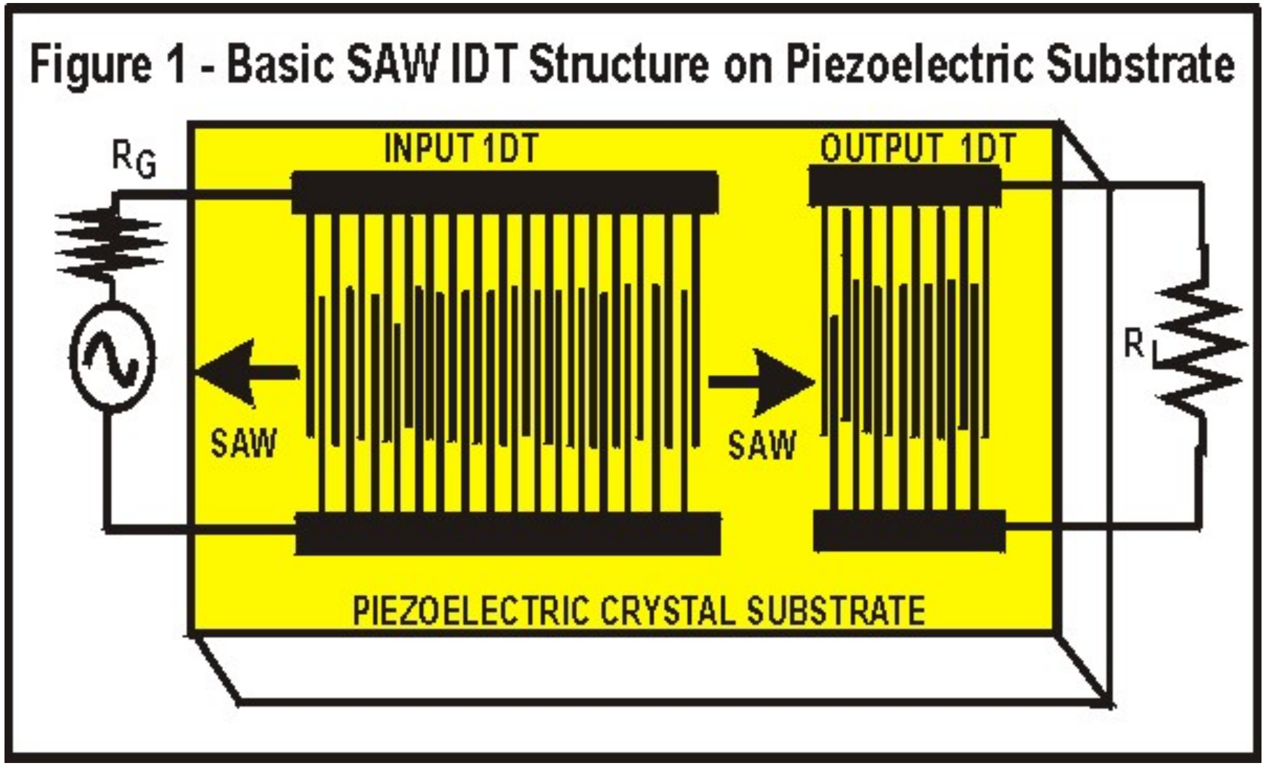
- Acoustic wave (like sound wave)
  - travelling on surface of slab of material
  - usually piezo-electric material:
    - e.g. quartz, Lithium Niobate ($LiNbO_3$), Lithium Tantalate ($LiTaO_3$)…
- Wave launched by electrodes on surface
  - using piezo-electric effect: voltage -> strain
- Wave received by electrodes – same or other
  - also piezo-electric effect: strain -> voltage

# SAW Filter Concept



- Simple application – acoustic delay line
  - acoustic velocity ~ 3000 m/s to 4000 m/s
  - so wavelength ~ 10 μm at 300 – 400 MHz
- Add more electrodes – tapped delay line
  - get copies of input, with different delays
  - output is weighted sum of these
  - analogue FIR filter…
  - not feasible with electrical signals – too fast

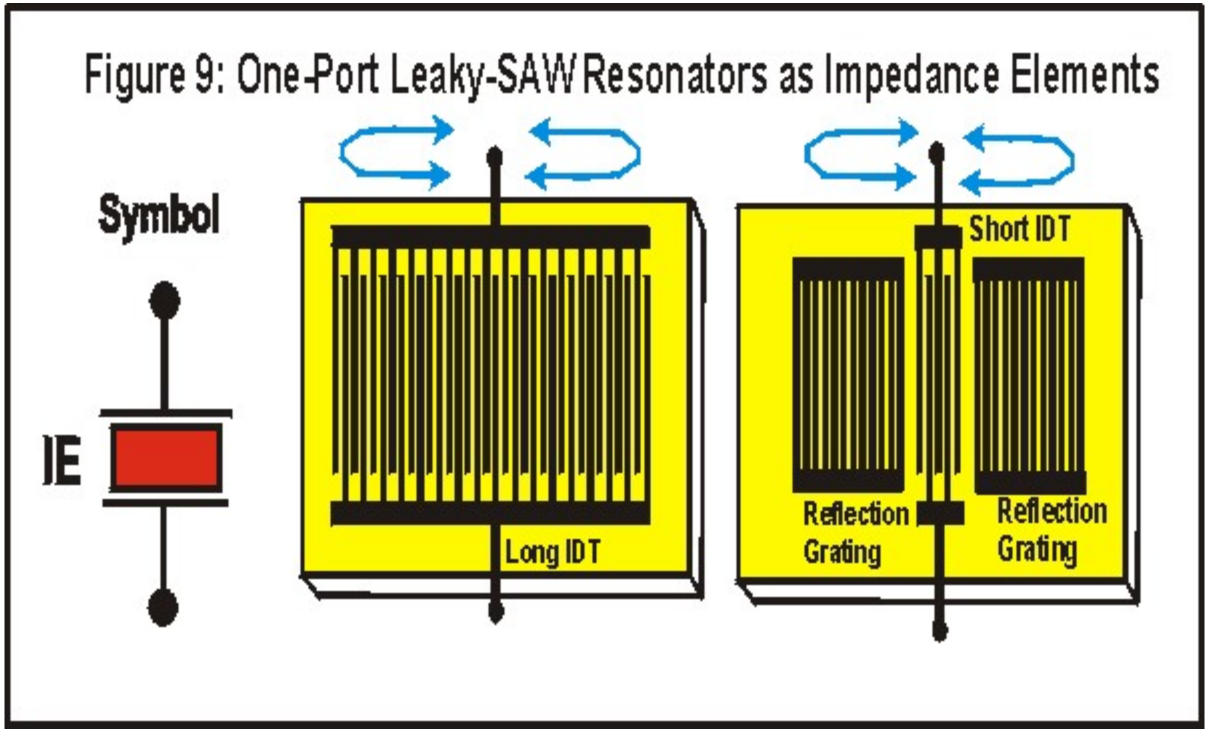
# SAW Filter - Transversal




C. K. Campbell

- Uses inter-digitated transducers (IDT)
  - launch and receive with separate IDTs
- This structure can give high performance:
  - BW < 1% of $f_{centre}$, high stop-band attenuation
  - but high loss in passband – 10 dB to 30 dB
  - not suitable for all applications…

# SAW Filter - Resonator

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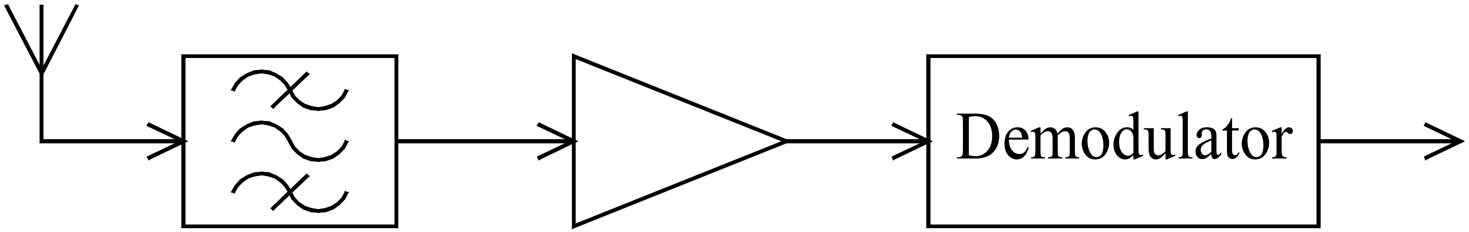
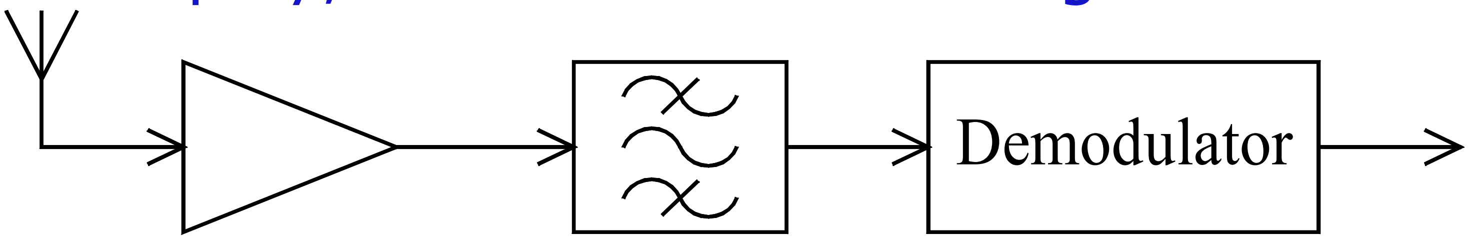
- One-port resonator – like crystal resonator
  - or LC resonant circuit, with very high Q factor
- Filter based on resonator – lower loss (<3 dB)
  - but often more ripple in passband
  - less stop-band attenuation, etc.
- Usable from ~ 10 MHz to GHz region
  - small size, easy to make, but not on silicon!

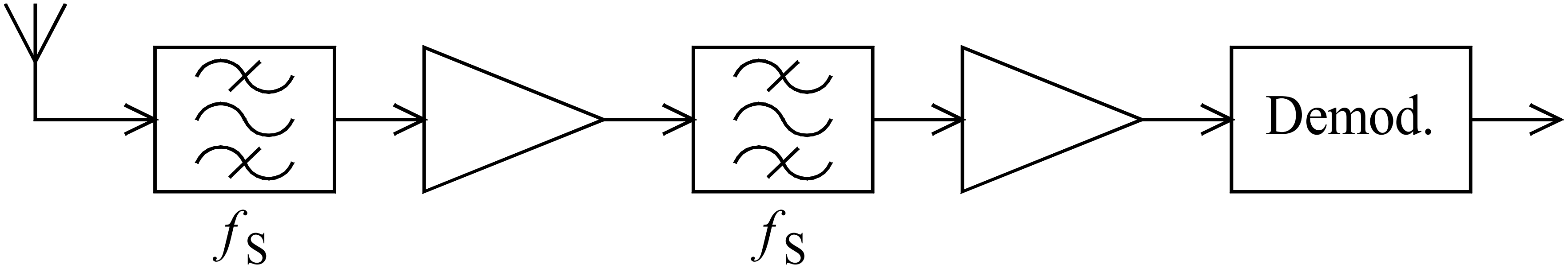
# Simple Receiver Structure




- This example works at fixed frequency
  - receive signal at that one frequency only
- Need amplification for sensitivity
  - RX signal v. small, demod. needs larger signal
- Need filter for selectivity
  - select wanted signal, attenuate all others
- Amplify, Filter – which should go first?

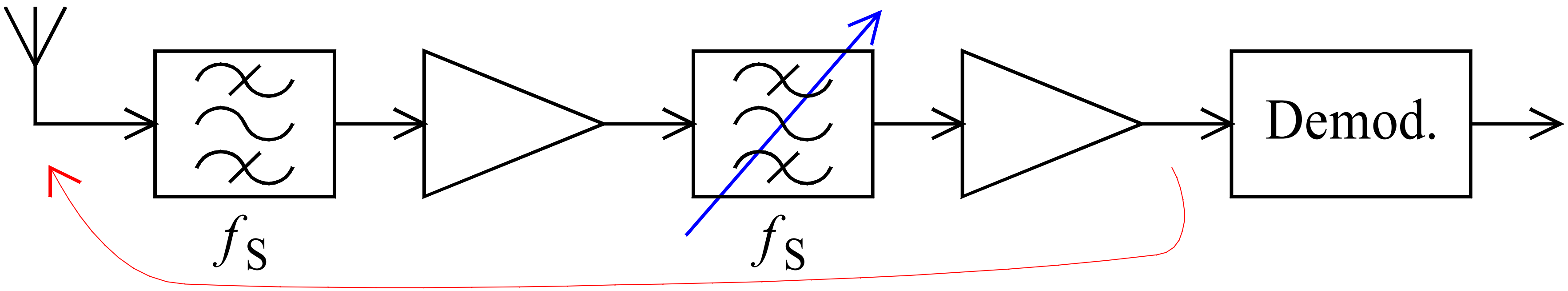


# More Practical Receiver



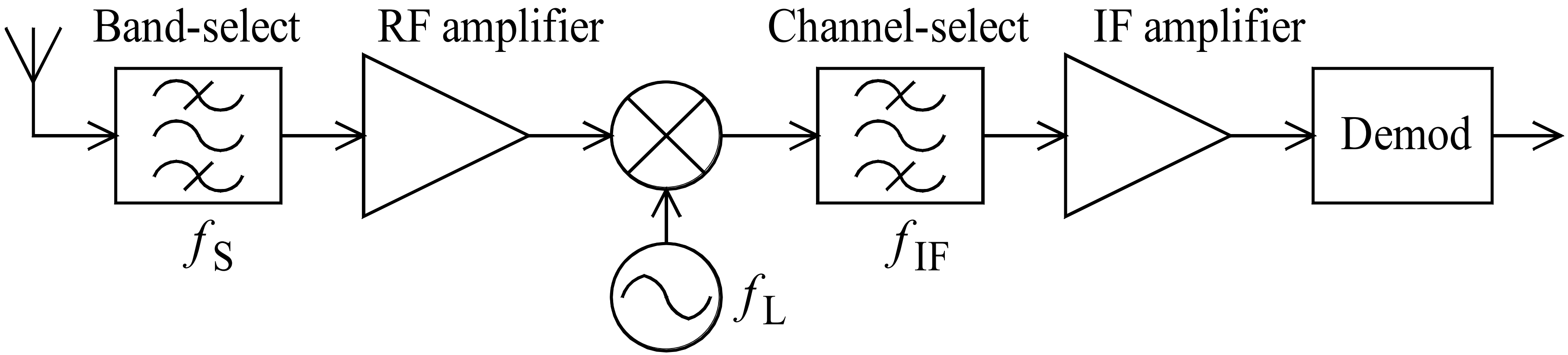

- Wide BW filter at start – simple, low loss
  - attenuates signals outside band of interest ?
  - gives some protection to first amplifier
- Amplify, but not too much
  - still many signals present, maybe strong signals
- Narrow BW filter – select desired signal
  - can afford higher loss after amplification
- Amplify more – only one signal now...
  - adjust gain (automatically) to suit signal

# Tuned Radio-Frequency (TRF) Receiver



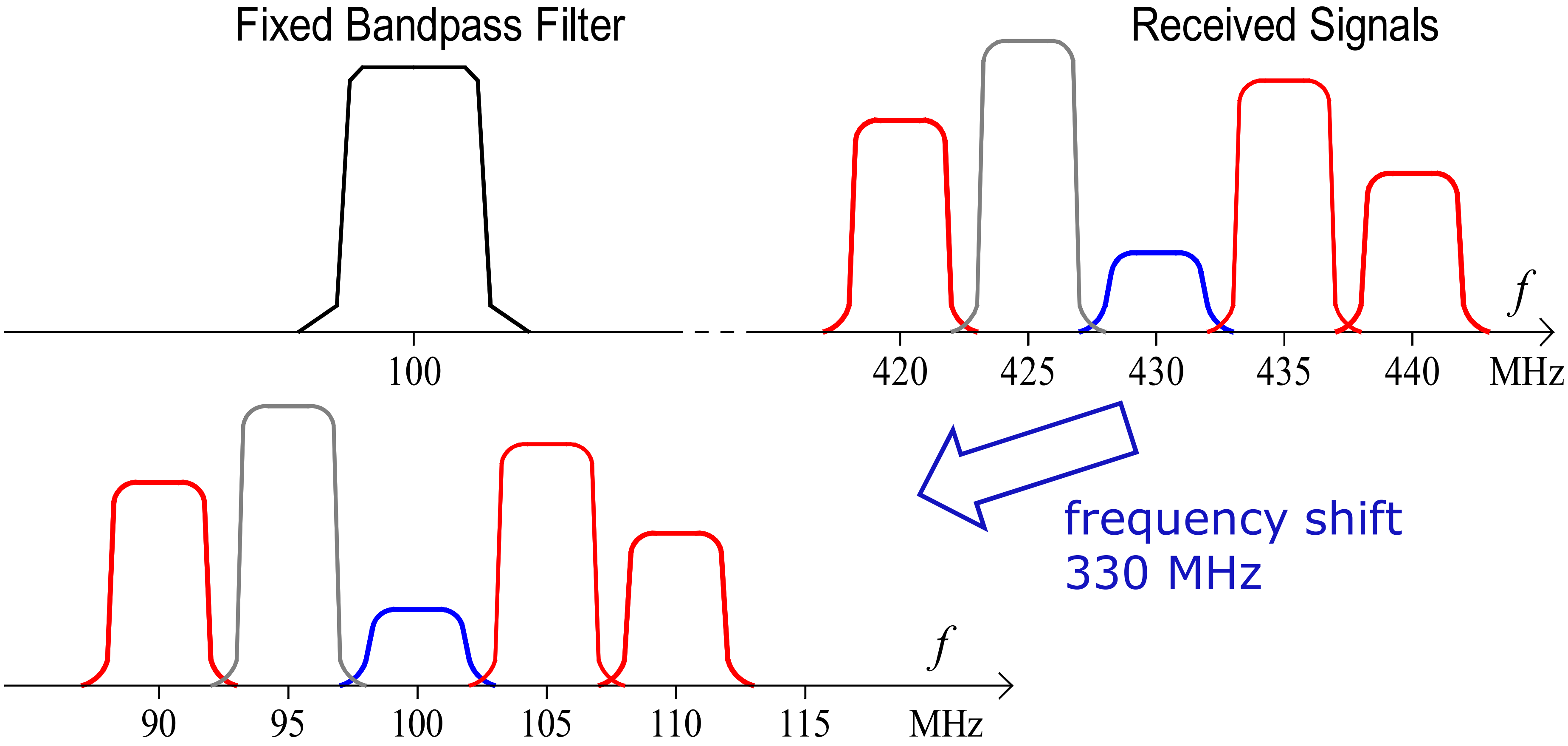

- All processing at frequency of RX signal, $f_s$
- With high gain, risk of instability
  - leakage of signal back to antenna...
- To vary frequency, need adjustable filter
  - not possible with SAW, transmission line
  - difficult with LC – limited Q factor
  - not suitable for narrow BW signal at high freq.
- Simple, but not best performance
  - use only for fixed-freq., low-spec receiver

# Superheterodyne Receiver



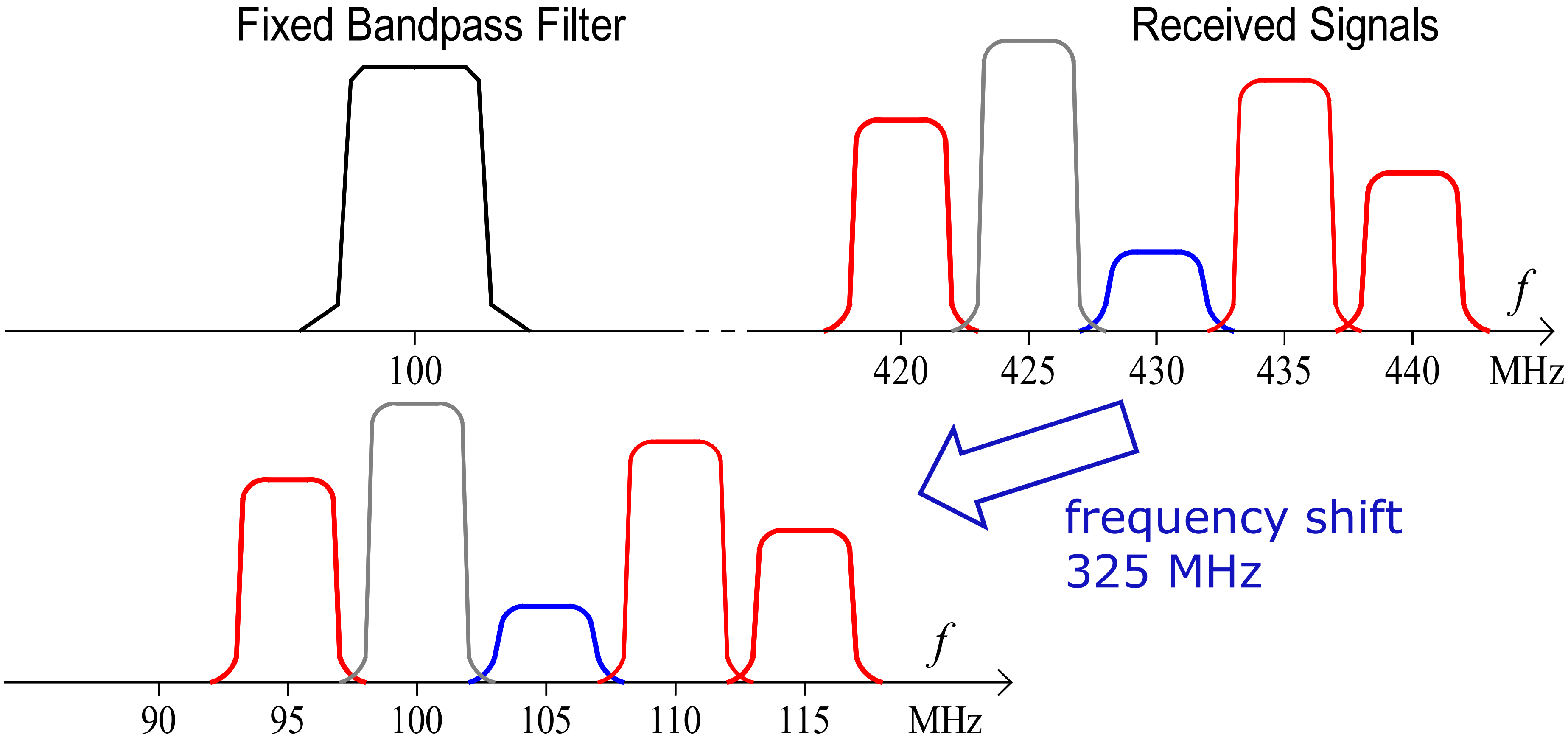

- How to select the wanted signal ?
  - at any frequency (or any channel) in band
  - using fixed-frequency filter (e.g. SAW)
- Frequency shifting
  - move the wanted signal to the filter frequency
  - most processing done at fixed frequency
  - called *intermediate frequency* (IF)
  - only early part of receiver has to work over the range of receive frequencies

# Shifting Signal…



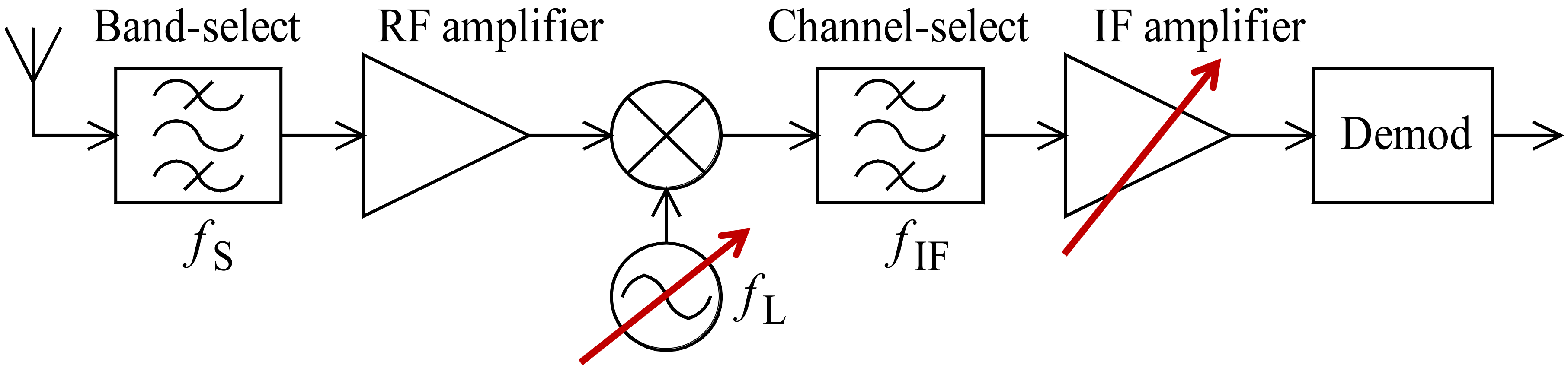

- Adjust frequency shift as required
  - to get wanted signal aligned with filter

# Shifting Signal…




- To receive a different signal
  - change frequency shift…

# Simple Heterodyne Receiver




- Band-select filter – pass entire RX band
  - all signals of interest (but must be low loss)
- Some amplification at RF (all signals in band)
- Frequency shift by adjustable amount
  - to get wanted signal to IF
- Channel selection – narrow, high-spec filter
  - selects wanted signal only
- Amplify – only one signal, adjustable gain

# Zero-IF systems (homodyne)

- Reduces circuit complexity (1 conversion) but problems, e.g. lower dynamic range.
- Software defined radio has given it new life.
- Self-Mixing of Reverse LO feed-through:
  - LO component in RF input can return through mixer and be modulated by the LO signal.
  - Components at DC and 2 $f_o$ at IF output.
- No consequence for a heterodyne system, but can cause problems for homodyne systems.

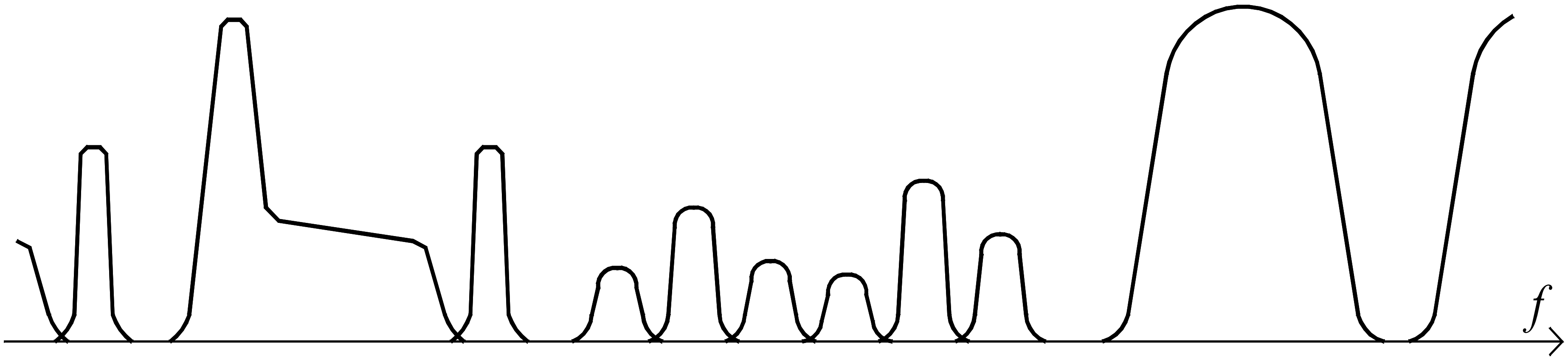
# Hetrodyne Receivers (Advantages)

- Channel-selection filter at fixed frequency
  - much easier to build high-spec filter at fixed $f_c$
  - can choose relatively low frequency
  - so fractional bandwidth higher, also easier
- Band-select filter can often be fixed also
  - change frequency by adjusting oscillator only
- Amplification mostly at IF
  - lower frequency, easier to build amplifier
- Demodulation at lower, fixed frequency
- Frequency shift good for stability
  - no very high gain at either frequency
  - large signals at demodulator not at same frequency as received signals…

# Disadvantages

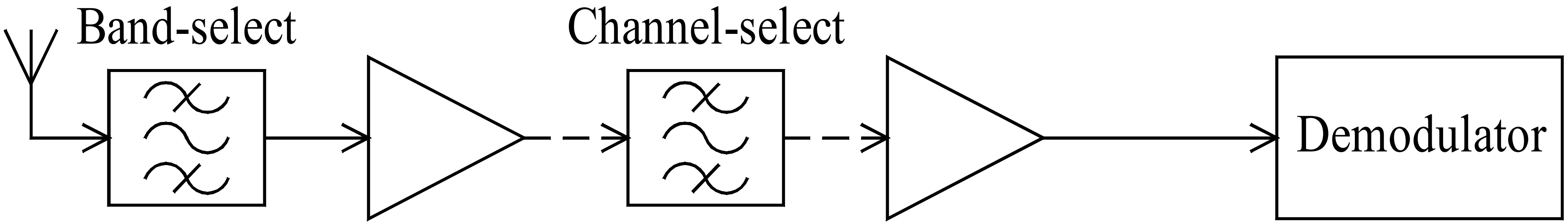
- Frequency shift brings new problem
  - vulnerable to interference at *image frequency*
  - can avoid with careful design
- Complexity – lots of analogue signal processing
  - most at relatively high frequencies
  - alternatives can get signal to baseband sooner
  - then sample and convert to digital
  - then process digital signals – DSP…
- Needs high-spec channel selection BPF
  - cannot be integrated onto IC
- But still widely used, for good performance
  - not usually cheapest solution…

# Sensitivity



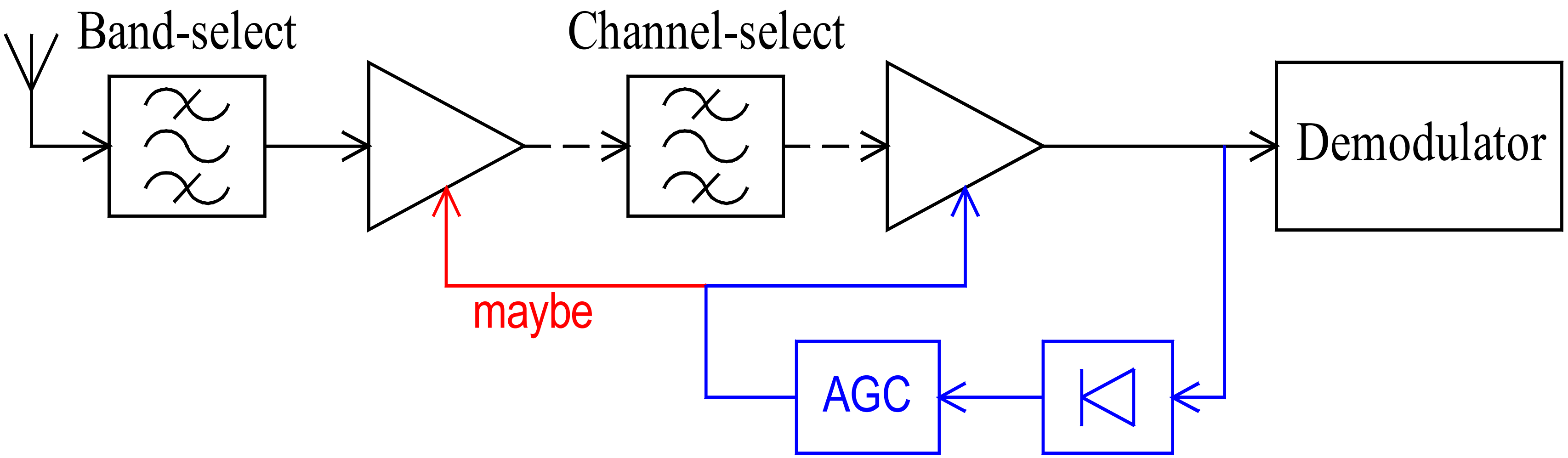

- For best sensitivity, minimise noise figure
  - so start with high-gain, low-noise amplifier?
- But entire RF spectrum is present at input
  - need filter before amplifier – some protection
  - but need low loss, so must be simple filter
- At amplifier, still many signals present
  - so moderate amplifier gain, maybe adjustable

# Dynamic Range




- For sensitivity, need high receiver gain
  - antenna input could be a few μV
  - demodulator typically needs few hundred mV
  - so need overall voltage gain ~$10^5$ or more
- But also have to handle larger signals
  - e.g. operating nearer to transmitter
    - reduce distance from 10 km to 10 m, 60 dB increase
  - with a few mV at antenna, same gain?
- Need adjustable gain, to avoid overload
  - automatic gain control - AGC

# Automatic Gain Control

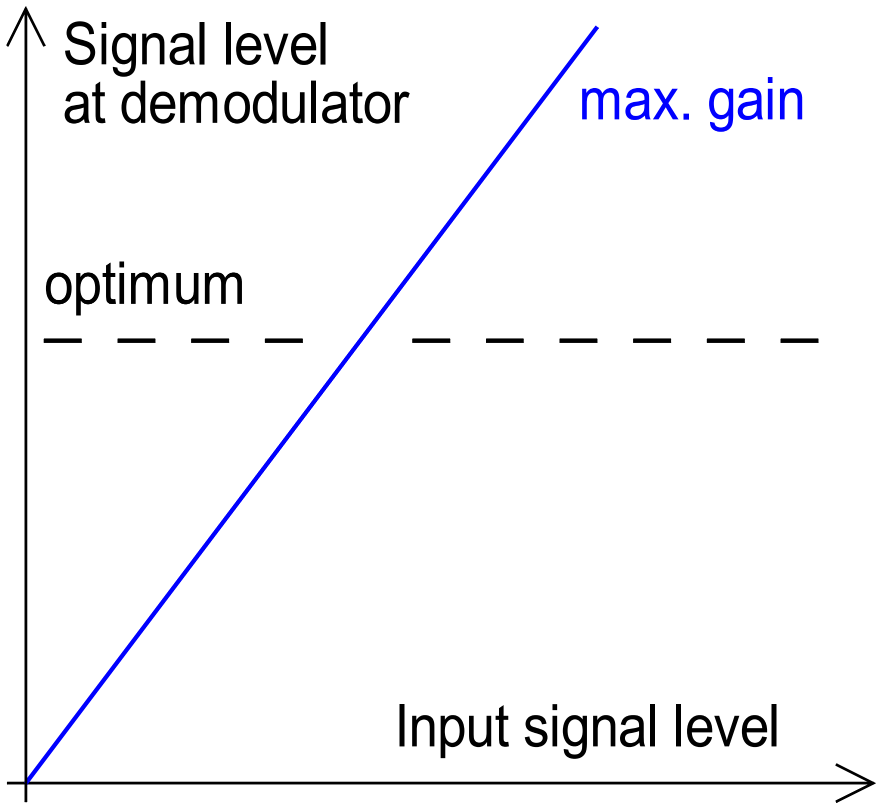



- Sense signal level at demodulator
  - adjust gain to keep near optimum level
  - only sensing wanted signal (not interferer)
  - often only changing gain after channel select…
  - if demodulation in DSP, sense there, feed back
- RF amplifier handles many signals
  - AGC may adjust its gain
  - but not usually sensing the problems here…

# AGC Behaviour

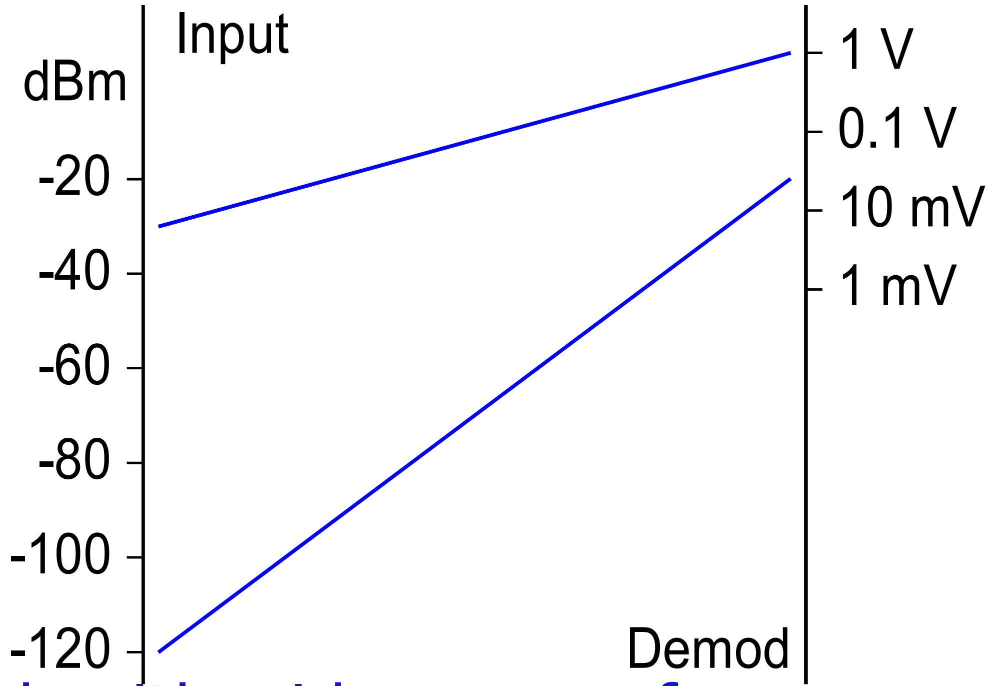
AGC usually acts slowly – responds to average signal level

Avoid reacting to any amplitude modulation of signal…




- AGC is feedback control system
  - use maximum gain for small input signals
  - as input signal increases, keep max. gain
  - until signal at demodulator is optimum
  - then reduce gain to keep at optimum level…

# Dynamic Range




AGC acts to compress the range of signal power variation

Expands dynamic range of receiver

- Receiver must work with wide range of power
  - dynamic range = ratio of max. to min.
  - often need 70 dB or more
- Dynamic range of demodulator limited
  - e.g. 10-bit A/D converter, only 1024 levels
  - if covers 1 V range, quantisation step ~1 mV
  - max signal 1 Vp-p, min ~20 mVp-p ?
  - dynamic range only 34 dB