Analog and Telecommunication Electronics

C5 - Synchronous demodulation

» AM and FM demodulation
» Coherent demodulation
» Tone decoders

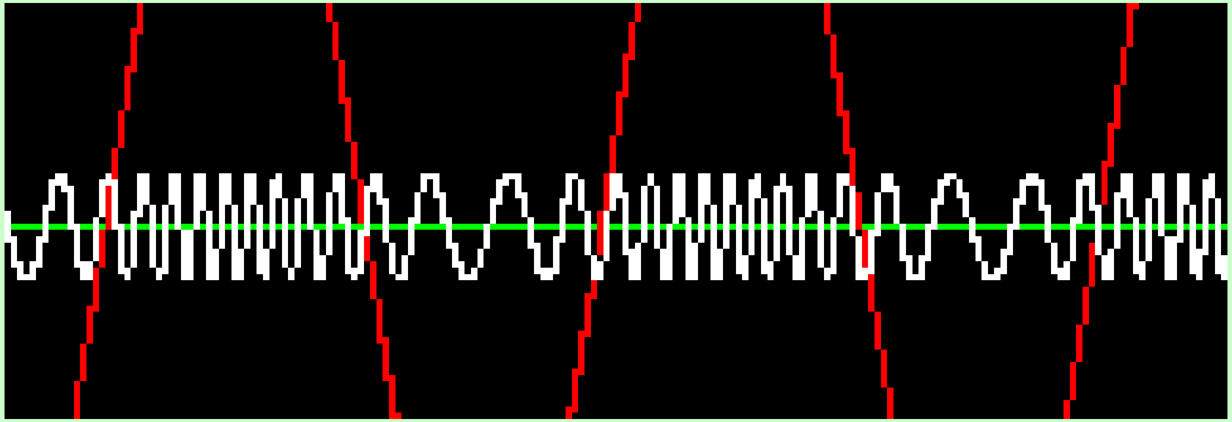
Lesson C5: synchronous demod.

- FM demodulators
- AM demodulators
  - Envelope and
  - Synchronous demodulators
- Digital modulations
  - FSK, PSK, ASK and others
- Tone decoders
  - NE 567 block diagram and parameters
- References sect. 3.7.1, 3.7.2

FM mo-demodulation

- Carrier frequency Fp, modulating signal M(t)
  - Fp = Fpo + K M(t)
  - Actual spectrum related with K
- Demodulation:
  - Techniques derived from AM
    - » Change FM into AM
    - » Use AM demodulator
  - PLL-based technique
    - » Fp must be in the lock range
    - » M(t) proportional to Vc(t)

Analog FM example

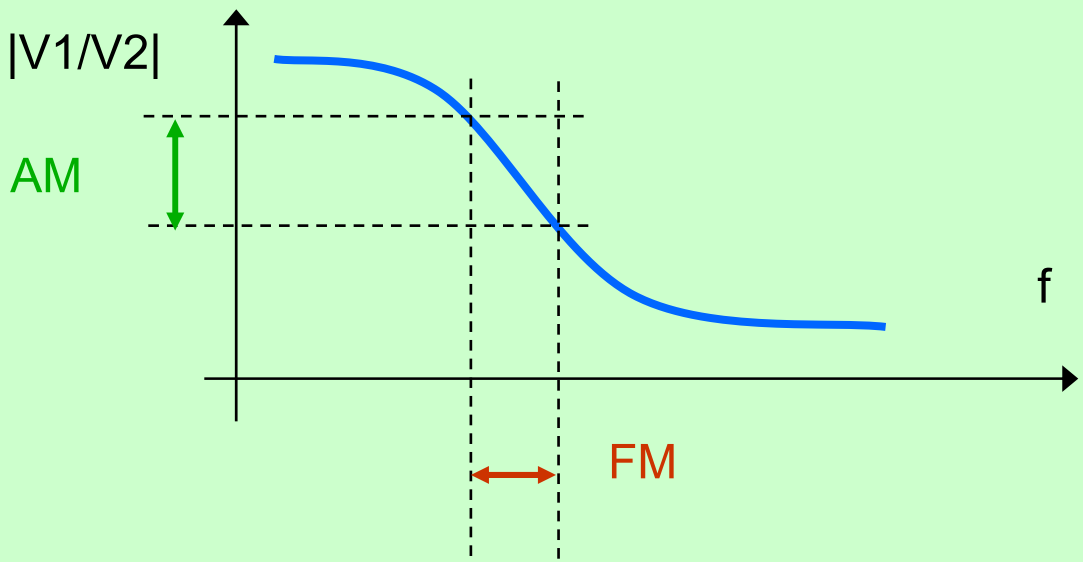


- Red: modulating signal
- White: FM signal

Add spectrum

FM →AM demodulation

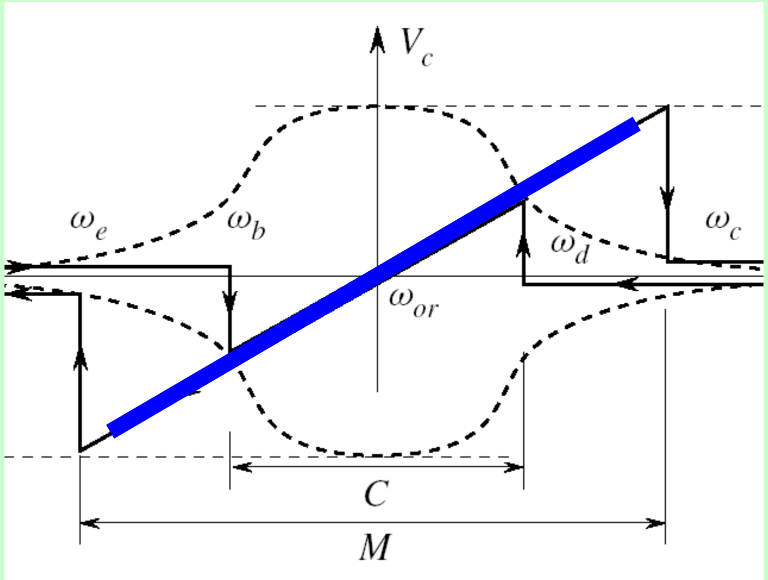
- Exploit the transition region of a steep filter
  - Frequency changes become amplitude changes



FM PLL demodulation

- Fp = Fpo + K M(t)

- PLL locked
  - Full Fp spectrum in the lock range
  - Vc(t) proportional to M(t)



Lesson B5: synchronous demod.

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AM signals

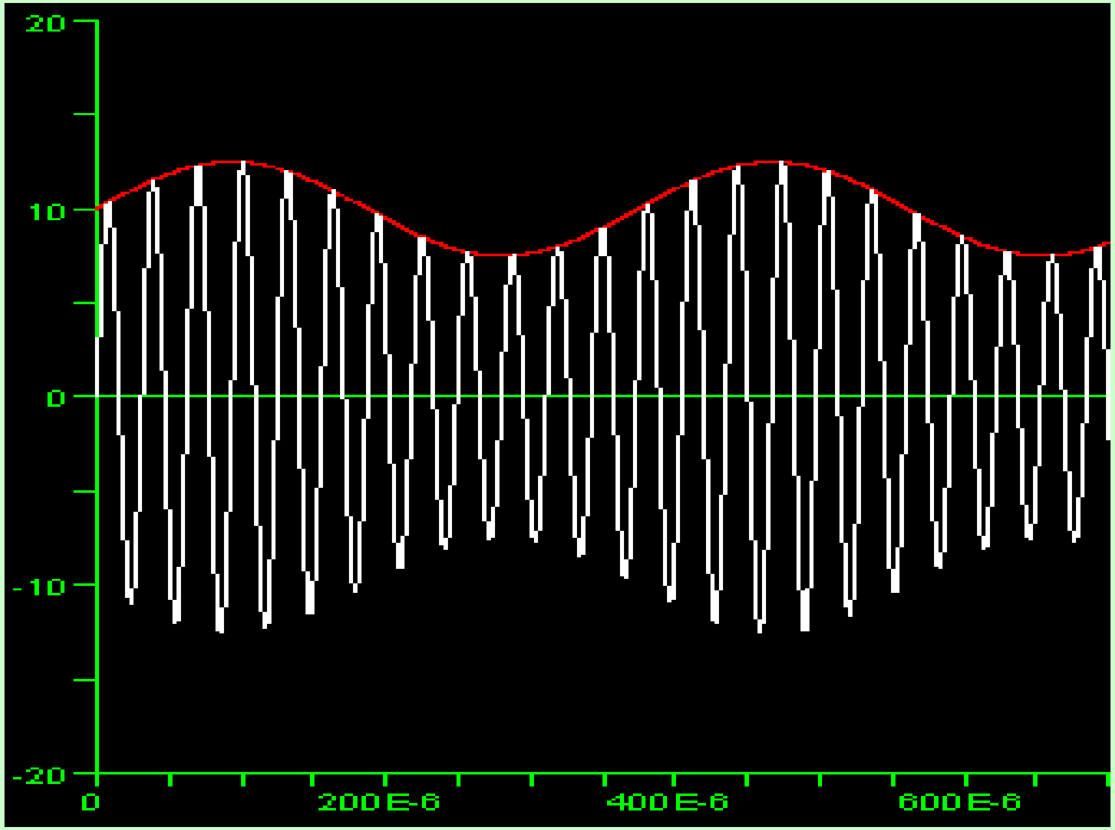
- Modulation:
  - Multiplication of carrier P(Fp) by modulating signal M
    - » S = Fp x M
    - » Time domain: M is the envelope of S(t)
    - » Frequency domain: M spectrum M(0) translated to M(Fp)
- Demodulation
  - Obtain envelope:
    - » Half- or full-wave rectifier + LPF
  - Move S to baseband (spectral translation)
    - » Coherent demodulation
    - » Needs reference signal: PLL

Examples of AM signals

- AM modulation
  - Modulating signal: A sin ωt + B
    - » max: A+B, min: B-A
    - » Modulation index m
      m = (max-min)/(max+min) = A/B
    - » m = 1: A = B (DC = Vp)
  - Examples with simulator
    - » AM 25% (m = 0,25)
    - » AM 50% (m = 0,5)
    - » AM 100% (m = 1)
    - » AM 200% (PSK-180°, DSB – suppressed carrier)

AM modulation: m = 0,25

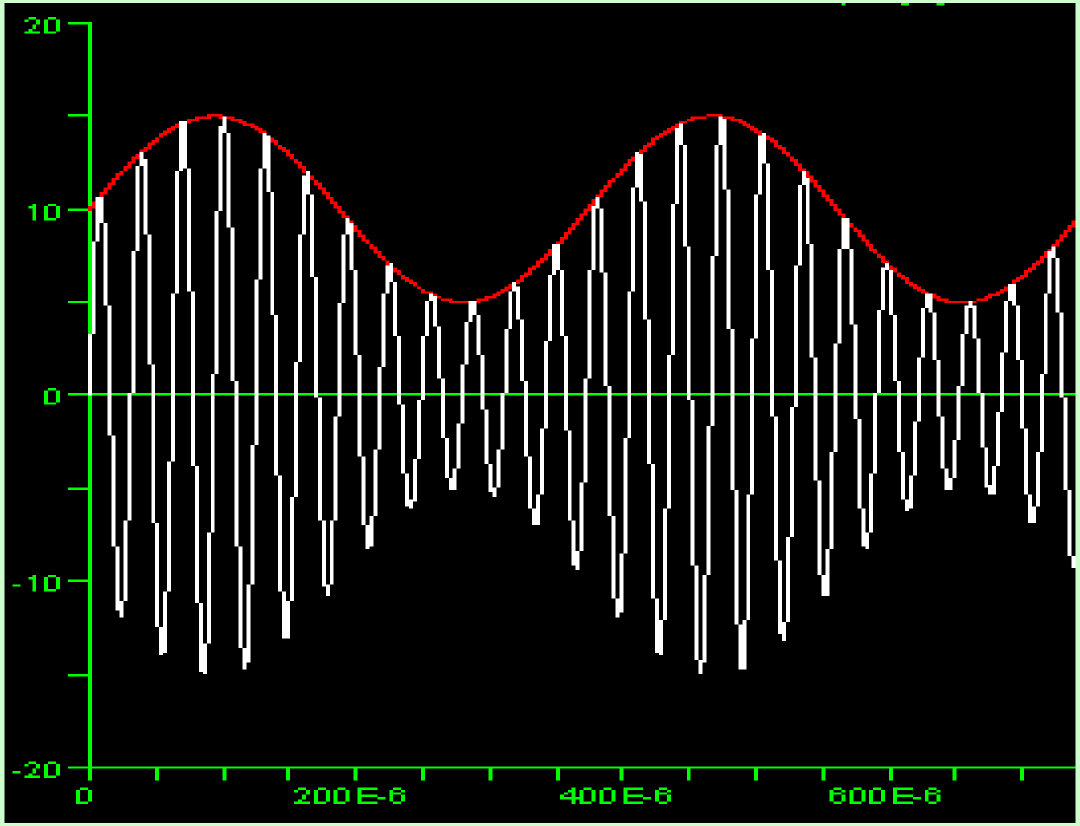
- A = 2,5V, B = 10 V, m = 0,25 (25%)



spectrum

AM modulation: m = 0,5

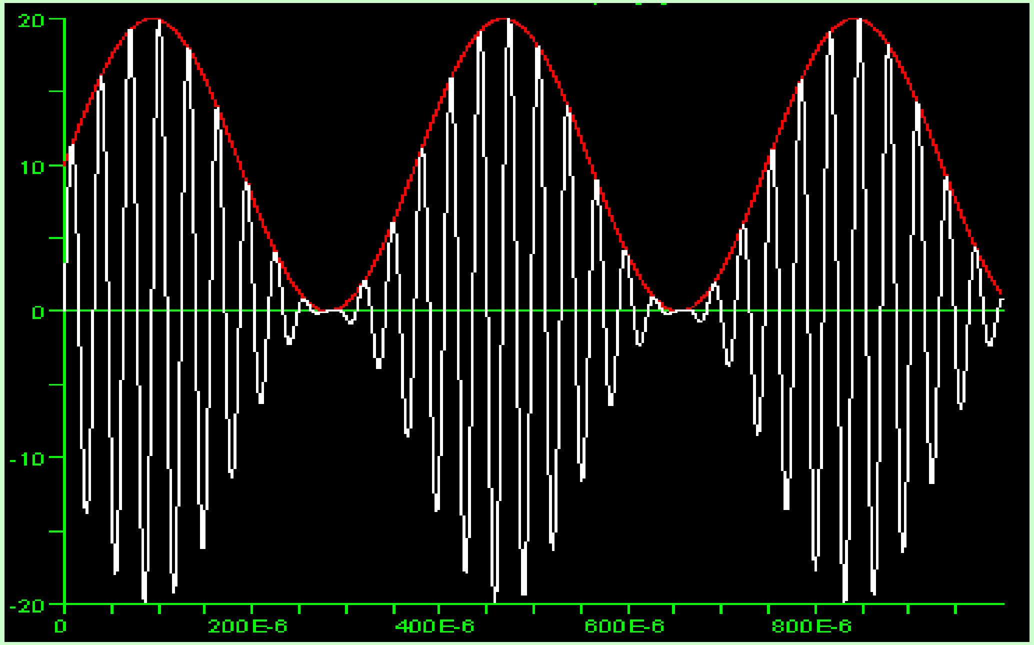
- A = 5V, B = 10 V, m = 0,5 (50%)

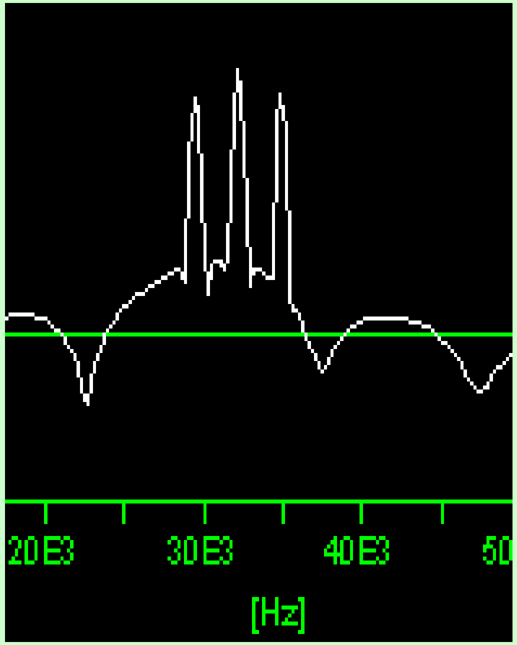


spectrum

AM modulation; m = 1

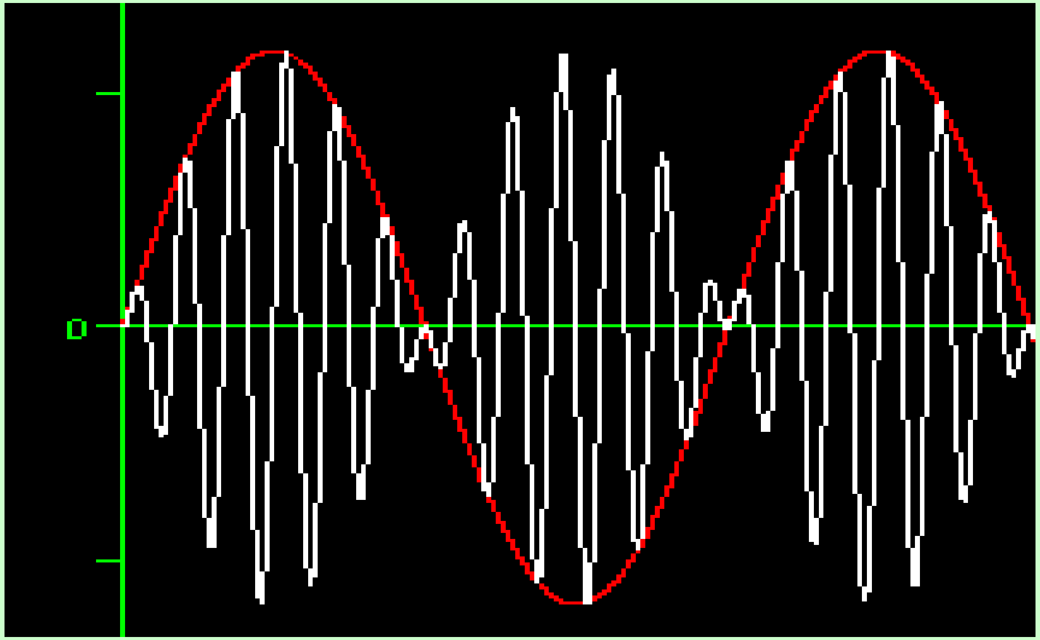
- A = 10V, B = 10V, m = 1 (100%)
  - the spectrum shows the carrier
  - Modulation signal → envelope (red)

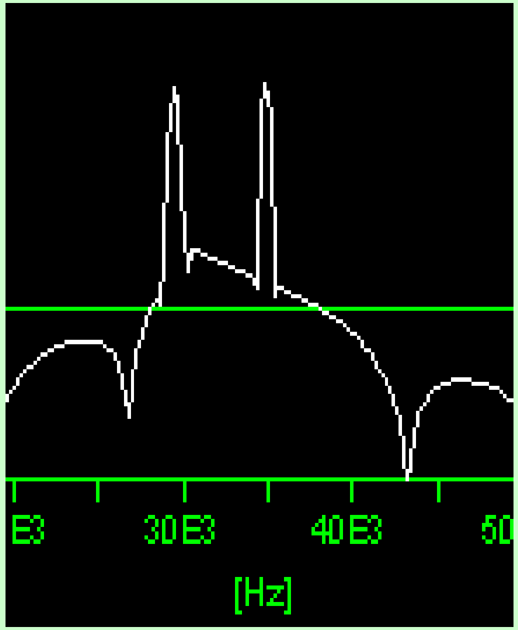




AM modulation - PSK

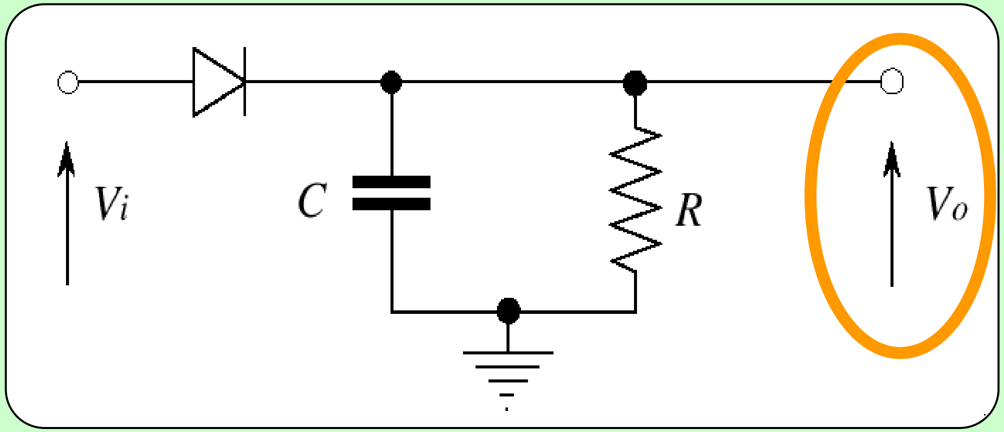
- A = 10V, B = 0V (suppressed carrier, PSK/180°)
  - the carrier does not appear in the spectrum
  - Modulation signal → envelope (red)

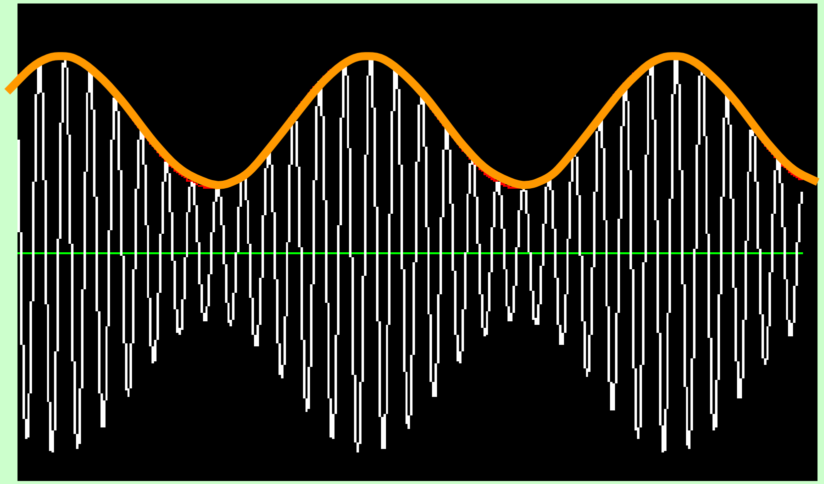




Envelope demodulator

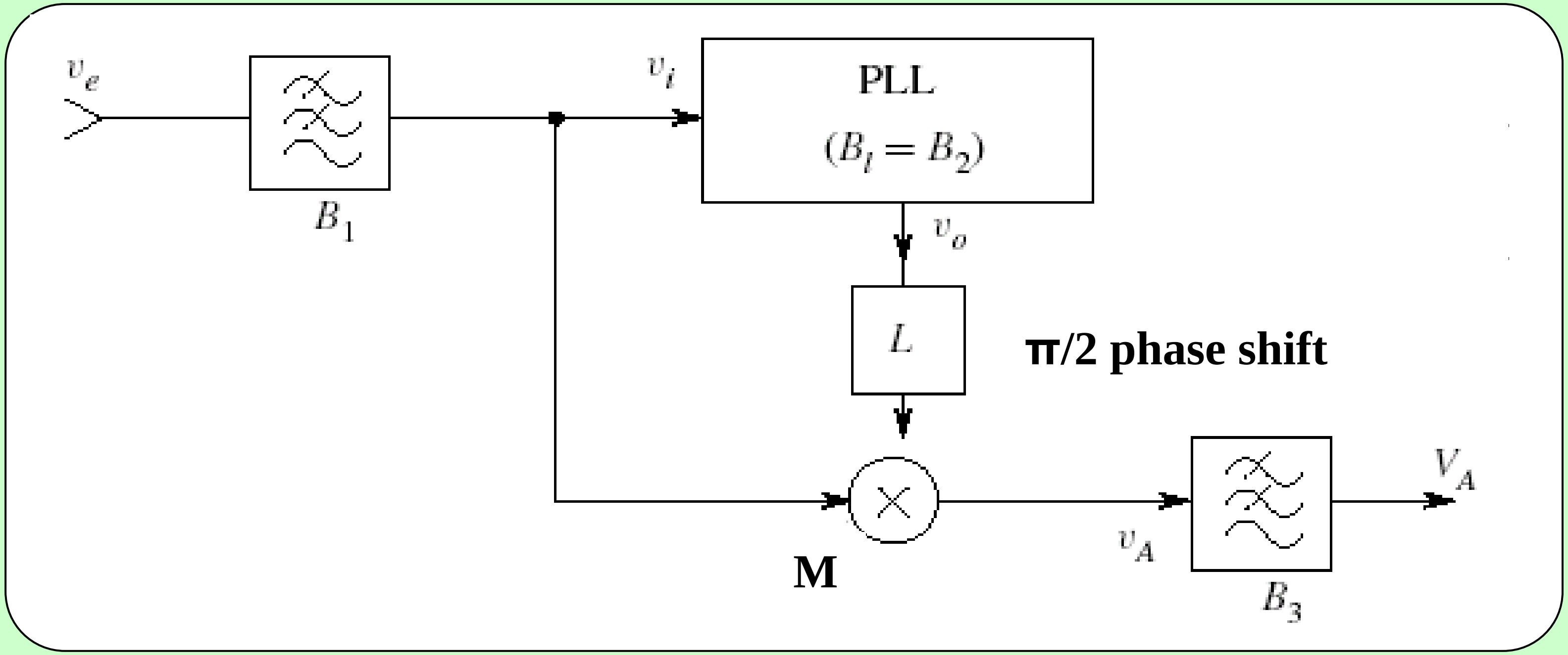
- Peak detector with loss
  - C charged to + peaks, discharged through R
- Problems:
  - Diode threshold
  - Noise sensitivity
  - Not for M > 1
- Improvements
  - Active diode
  - Full wave rectifier





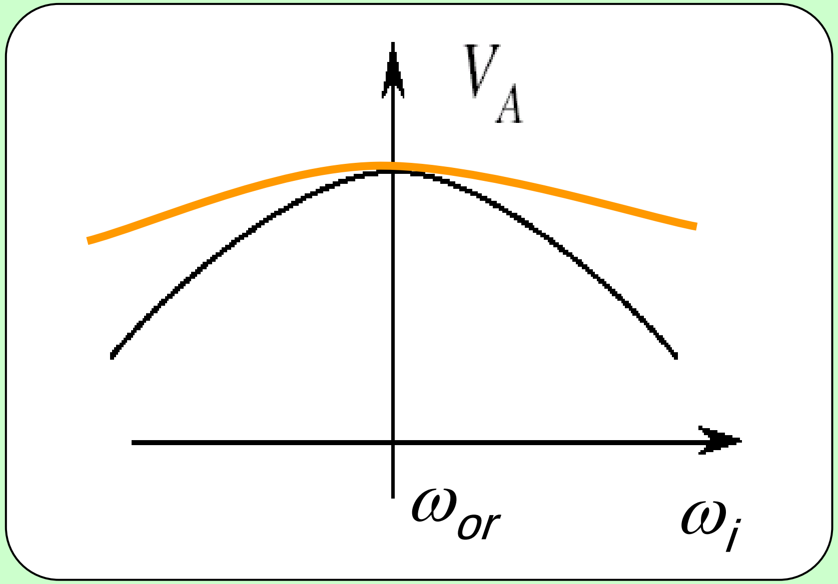
Coherent demodulation

- B1 cuts outband noise
- The PLL generates the reference signal
- The multiplier M moves Vi to baseband
- B3 isolates baseband signal



Effect of frequency drift

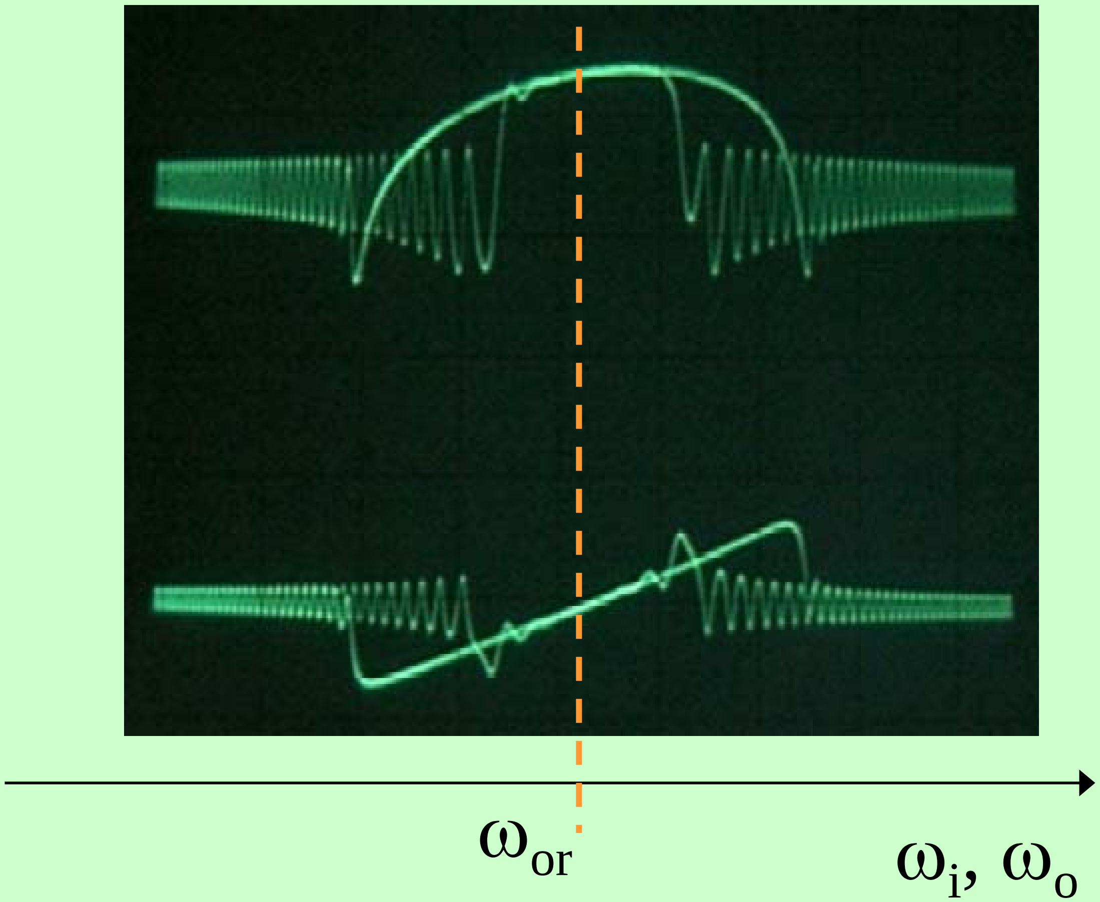
- Changes in Fi cause phase error in the PLL
  - To move the VCO: Vc ≠ 0
  - To get Vc ≠ 0: θe ≠ 0
  - Output error related with cos θe
  - Cross-demodulation (from FM to AM)
- To reduce the error
  - Increase loop gain
  - I/Q demodulator



AM demodulator output vs frequency

AM demod output

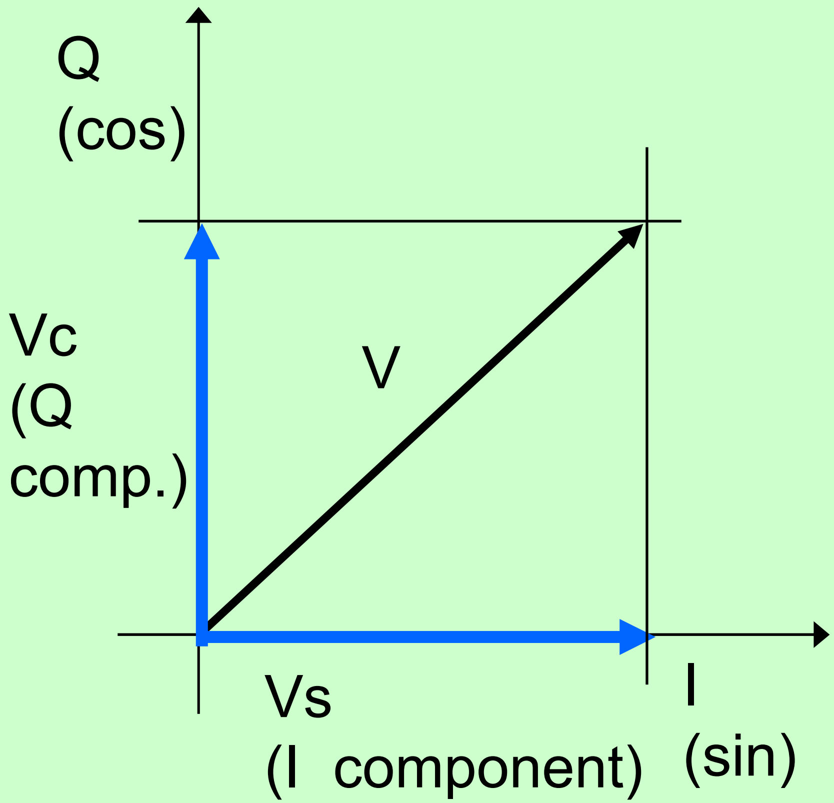
VCO control (Vc)



I-Q demodulation

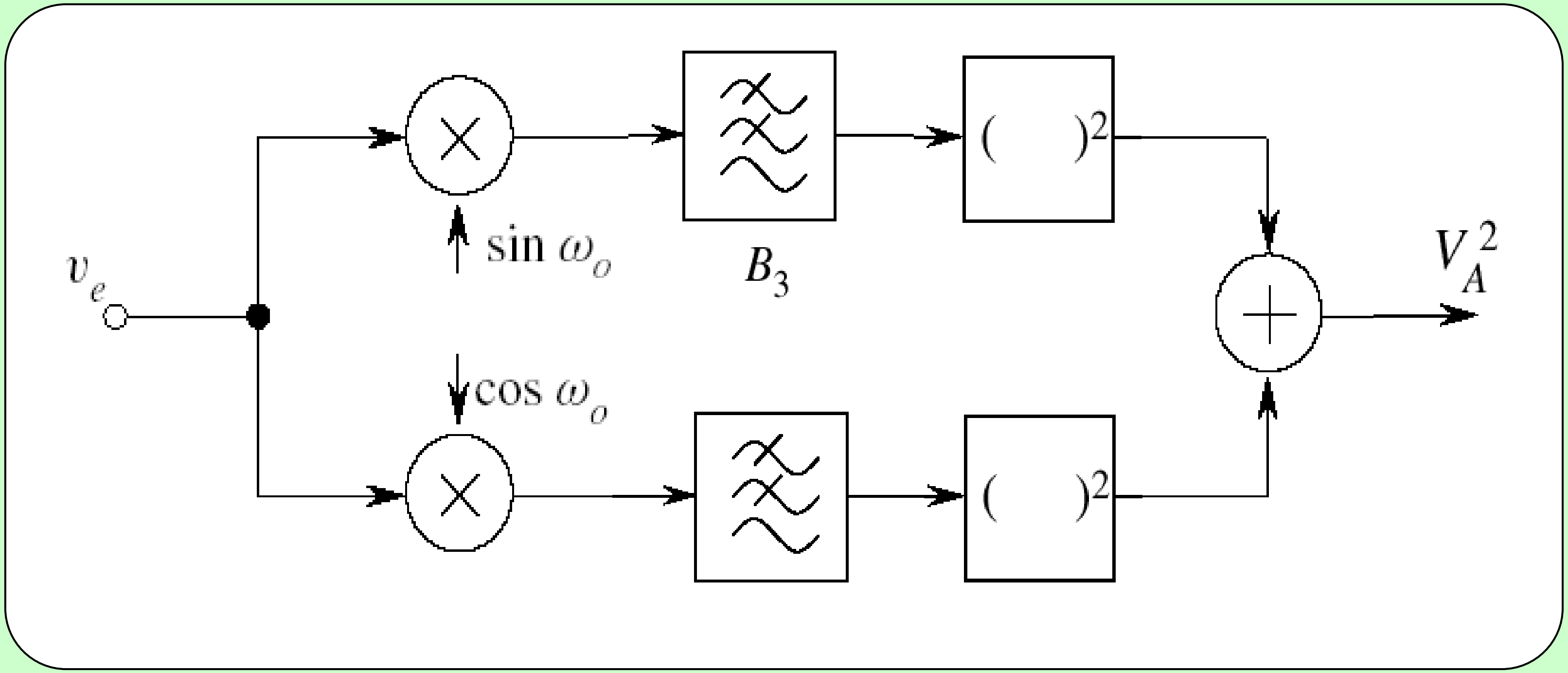
$$\begin{cases} V_C = \vec{V} \times \cos \omega t \\ V_S = \vec{V} \times \sin \omega t \end{cases}$$

$$\left|\vec{V}\right| = \sqrt{V_C{}^2 + V_S{}^2}$$



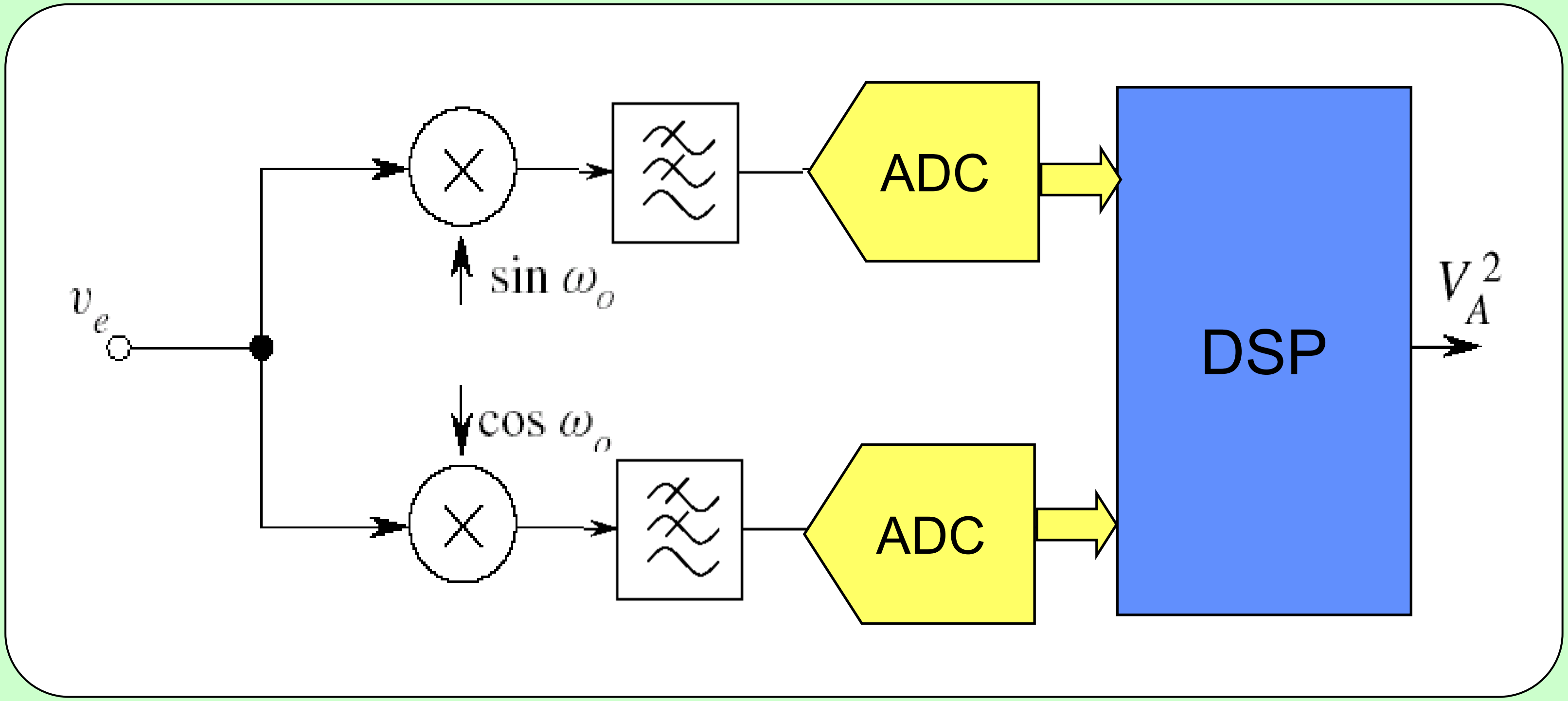
Analog I-Q demodulation

- Independent I-Q amplitude demodulation
- Va independent from Ve – Vo phase relation



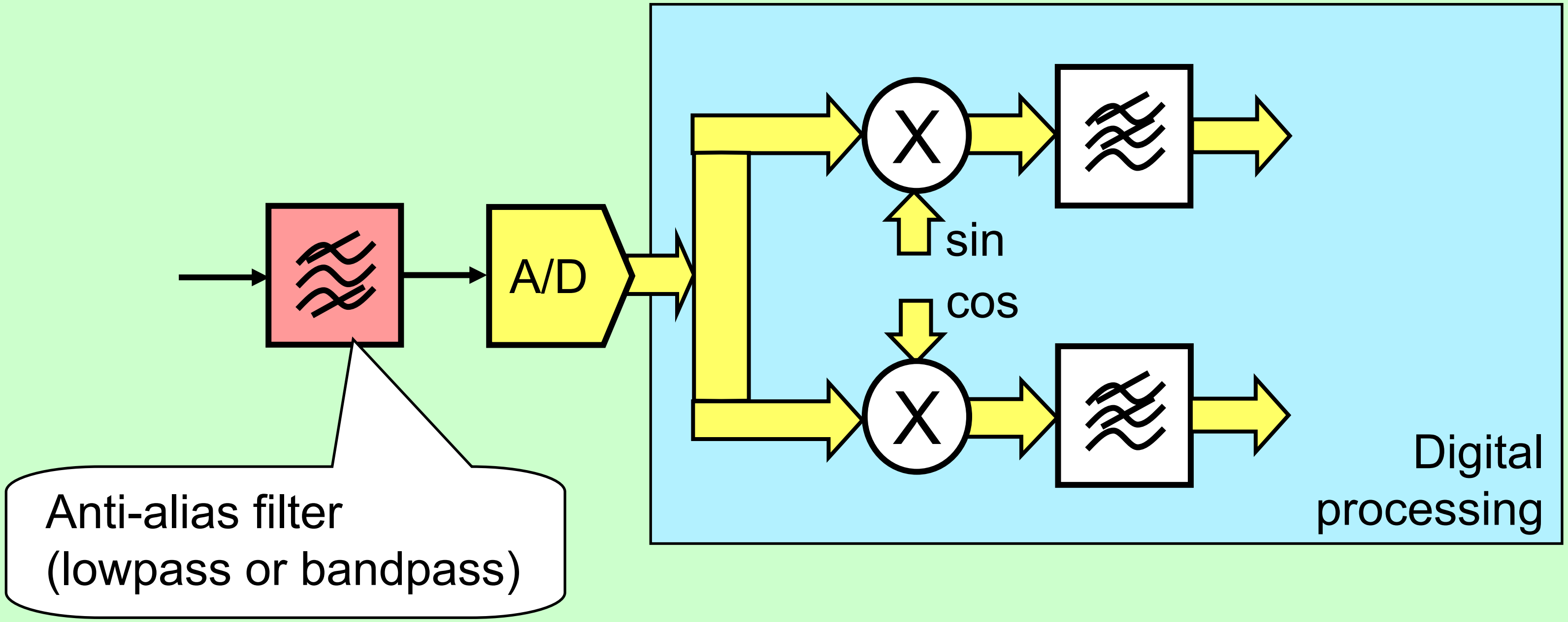
Digital I-Q demodulation

- A/D conversion after the multiplier (baseband)
- Digital processing



RF I-Q demodulation

- Direct A/D conversion of RF signal
- Digital I/Q demodulation
- Digital processing



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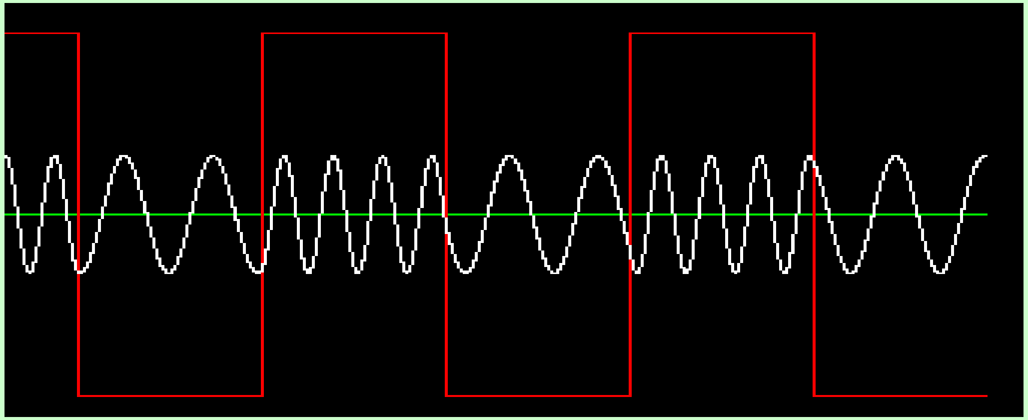
  - Tone decoder parameters
- Lab experiment 5: tone decoder behavior

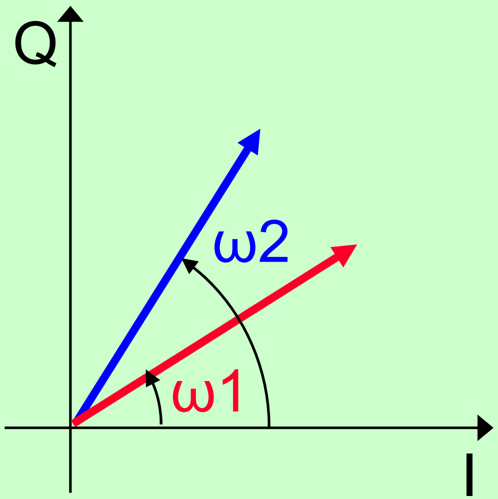
Digital modulations

- ASK, PAM
  - Amplitude Shift Keyed
    Pulse Amplitude Modulation
- FSK
  - Frequency Shift Keyed, FM to 2, …N frequencies
- PSK
  - Phase Shift Keyed, PM to 2, …N phases
- Mixed, QAM
  - …

FSK signal

- FSK
  frequency
  shift keyed





Digital FM → FSK

- Same techniques as analog FM
  - The transient response depends on loop parameters
- Separate AM channels for each carrier
  - Tone decoders with WTA

FSK Demodulators

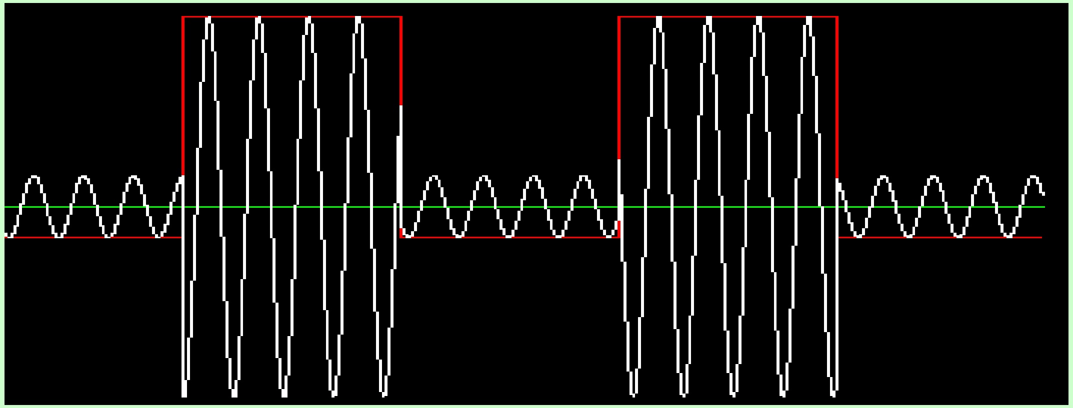
- Frequency Shift Keyed: FM to 2, …N frequencies
- Demodulation techniques
  – Single PLL, always locked → output = Vc
  – Multiple coherent AM detector
    » For each frequency PLL + AM coherent demodulators
    » output comparison (WTA)
  – Multiple envelope detector
    » Passband filter bank + envelope demodulators
    » output comparison (WTA)
- Tradeoff for all circuits (symbol passband filters)
  – Wideband: fast response, noise-sensitive
  – Narrowband: slow response (good if Bitrate < carrier/10)

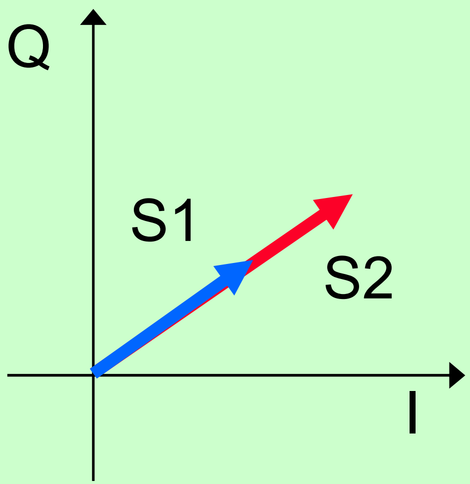
PAM/ASK demodulators

- Pulse Amplitude Modulation (PAM) or Amplitude Shift Keyed (ASK)
  - Discrete AM (2, …N levels)
- Demodulation techniques
  - Envelope detector
  - Coherent demodulation (PLL)
  - + output comparison (WTA)
- Tradeoff for all circuits: post-detection filter
  - Wideband : fast response, noise-sensitive
  - Narrowband: slow response

ASK signal

- ASK (PAM) discrete amplitude change

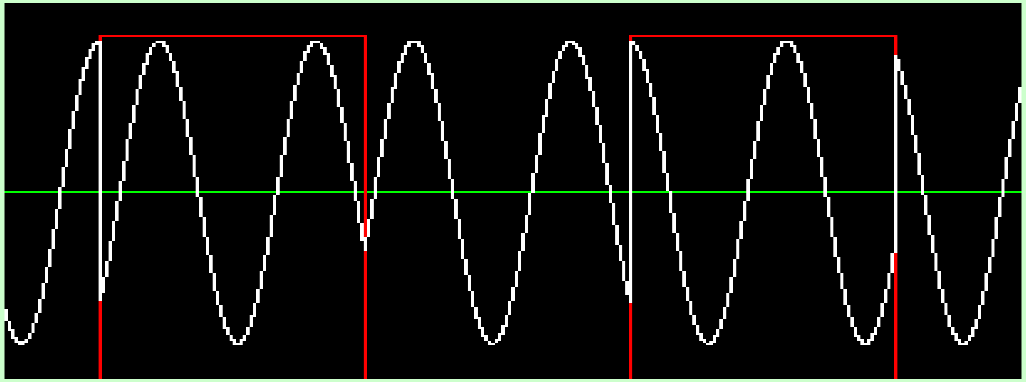


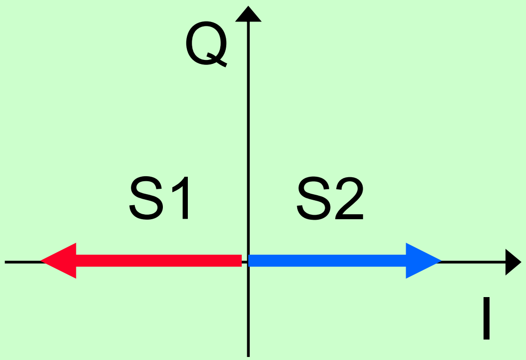


2-level ASK

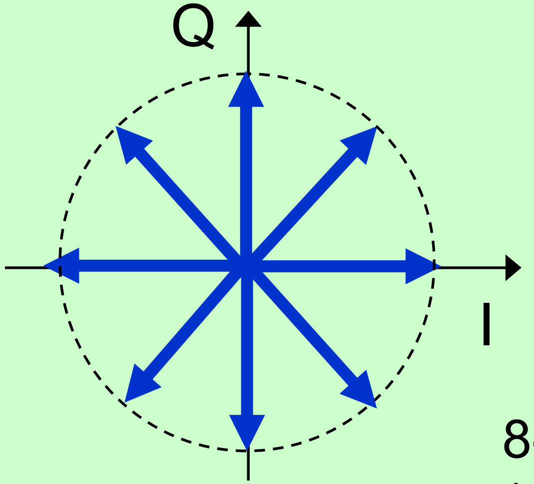
PSK signal

- PSK
  phase shift





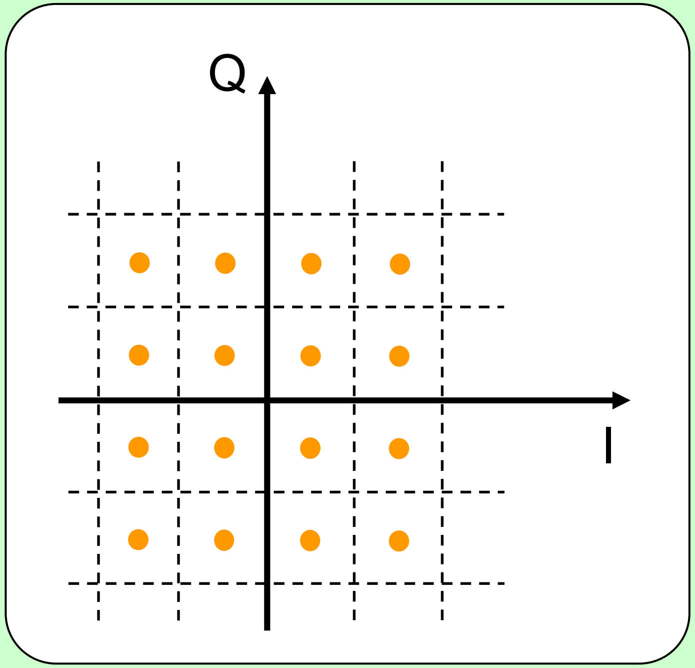
2-phase
(rotation π)



8-phase
(rotation π/4)

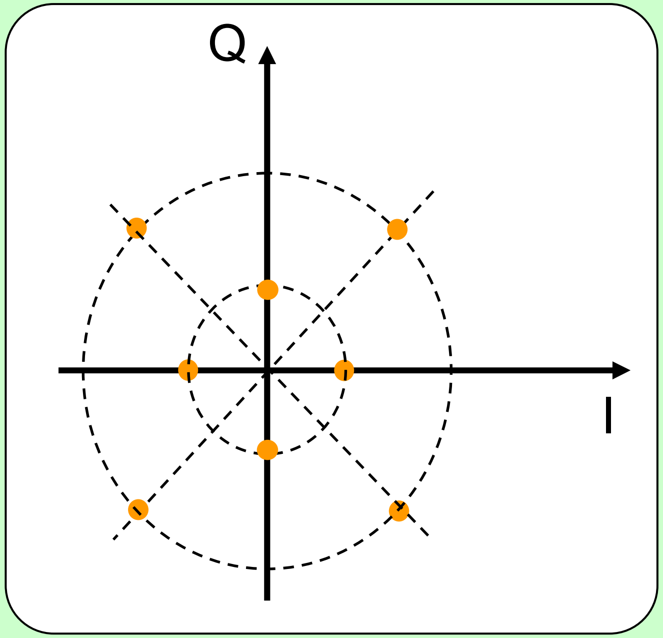
Complex signal (ASK+PSK)

- Amplitude and phase discrete changes
  - QAM
  - Signal constellation
- Example with 16 symbols
  - In the I/Q plane can be seen as combinations of
  - 4 possible I values
  - 4 possible Q values

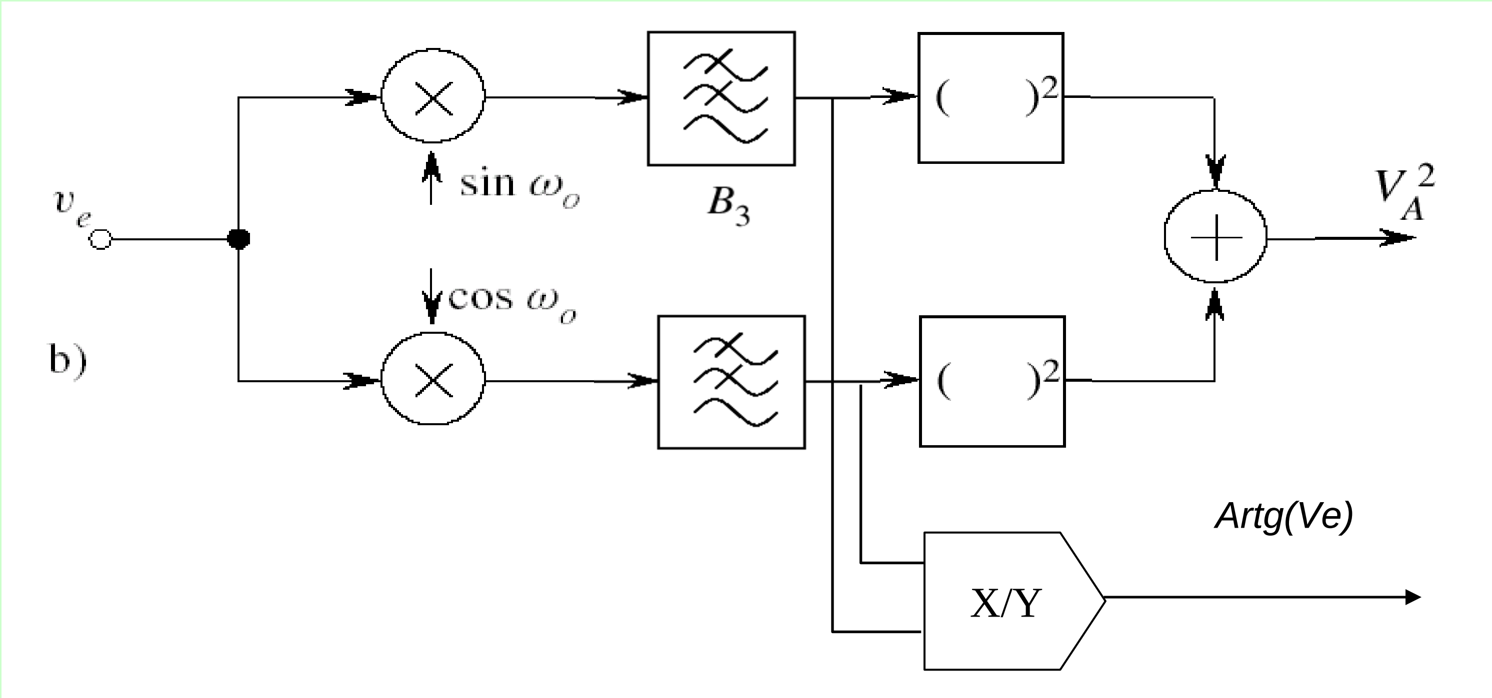


Complex signals demodulation

- Example 2
  - Phase shift: π/2 (4 states)
  - Amplitude levels 2
  - 3 bit/symbol
- In both cases:
- I/Q demodulation
- The I/Q components are obtained by coherent demodulation



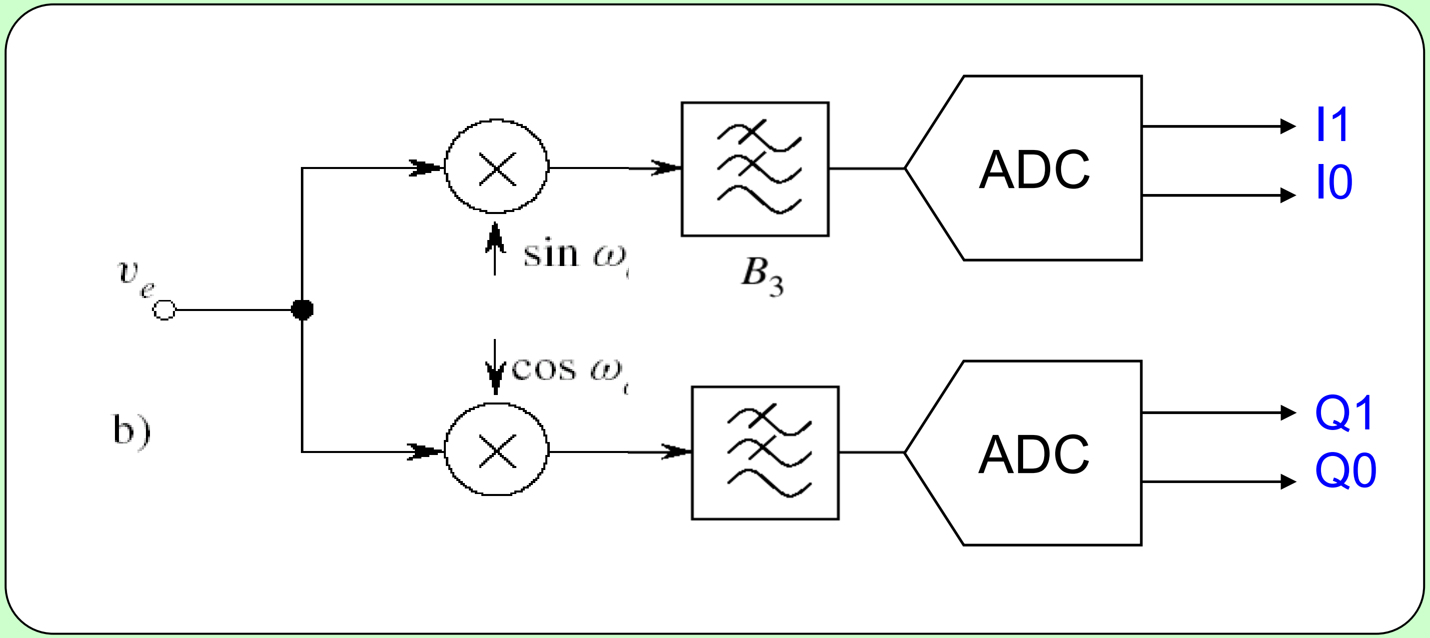
I/Q demodulation: A/P components



$$\begin{cases} V_C = \vec{V} \times \cos \omega t \\ V_S = \vec{V} \times \sin \omega t \end{cases}$$

$$\begin{cases} \left|\vec{V}\right| = \sqrt{V_C^{\,2} + V_S^{\,2}} \\ \angle \vec{V} = \operatorname{arctg} \dfrac{V_S}{V_C} \end{cases}$$

I/Q demodulation: I/Q components



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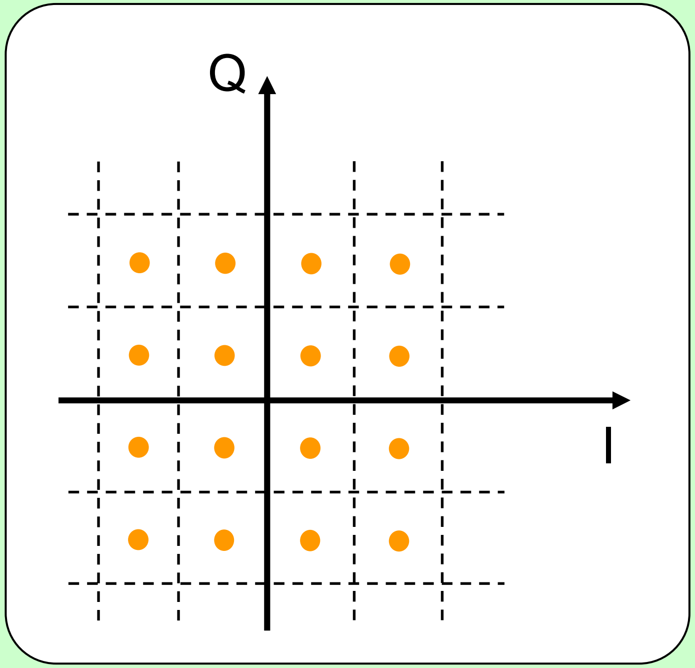
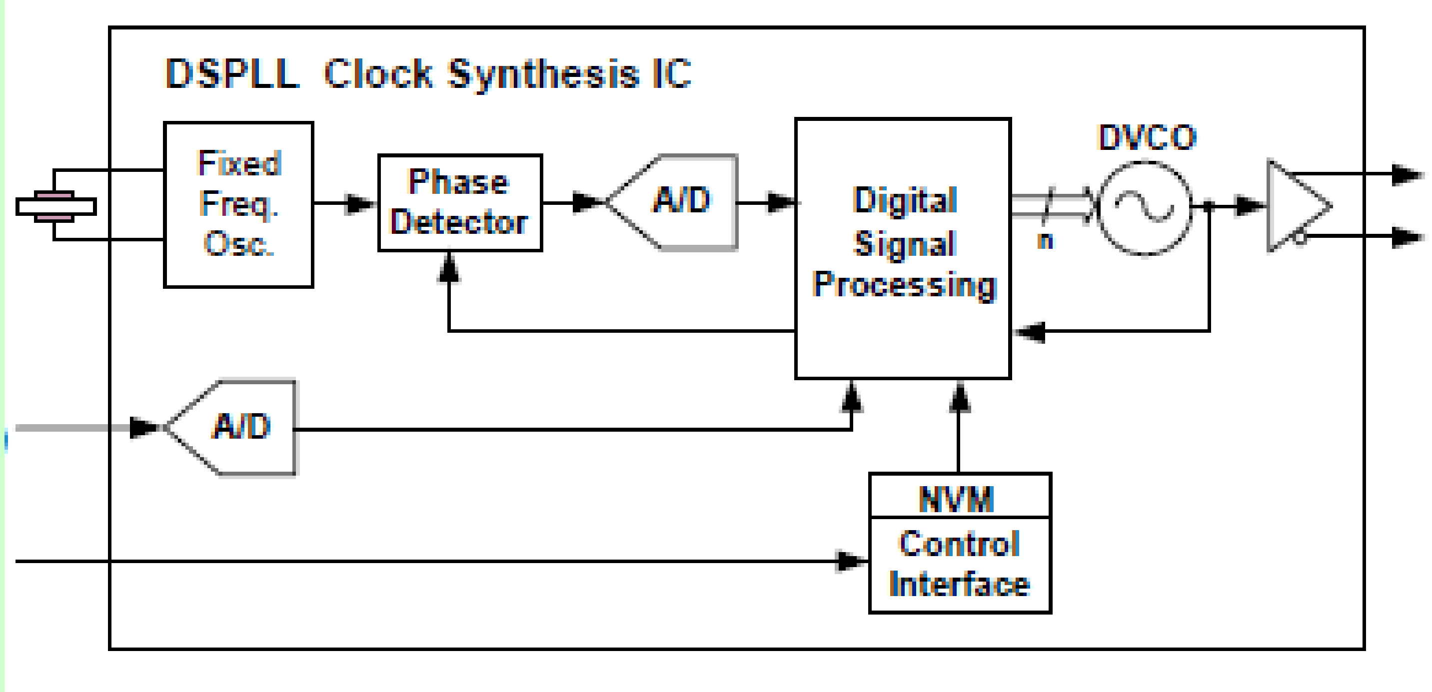


The ADPLL

- PLL based on digital circuits
  - Wired logic
  - Programmable logic
  - Processor + SW → DSPLL
- Programmable parameters, with better control
- Digital Vi → ADC on Vd
  - Digital loop filter + Numeric Controlled Oscillator
- Analog Vi → ADC on Vi
  - Digital PD + Digital loop filter + NCO

Example of DSP-PLL: Si550

- Variable frequency clock generator
  - Analog PD, then ADC
  - 10 MHz – 1,4 GHz range (Si550)



From https://www.silabs.com

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Integrated Tone Decoder

- NE567, LM576, …: bipolar / LMC567: CMOS
  - Same function, sligthly different structures
- Tone decoder operation:
  - Recognize a carrier (tone) within a frequency interval, even with strong interferences by noise and other signals
  - Used to recognize commands, numbers (phone), signalling overlapped with other signals
- Structure
  - PLL for analog signals + AM synchronous demodulator
- Features
  - Very narrow bandwidth
  - ON/OFF output + intermediate analog output

Tone decoder: specs

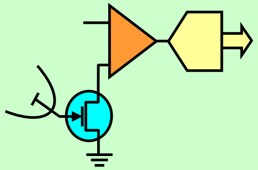
- Frequency range
  - Allowed values for the tome to be recognized
- Bandwidth
  - Frequency window for deconding of the tone
- Input amplitude range
  - Maximum in-band input signal which is not recognized
  - Minimum in-band input signal which is recognized
- Noise and interferers
  - Allowed wideband noise
  - Allowes narroband interferers (other tones)

Tone decoder: bandwidth

- The device id designed to recognize a specific frequency, with minimum change
  - The PLL can lock only to a narrow frequency range
  - The possible shift of the VCO is minimum
- Detection bandwidth: about 15% of central frequency

Largest detection bandwidth	$f_O = 100kHz = \frac{1}{1.1R_1C_1}$

10	14	18	% of f_O



Tone decoder: input range

- Amplitude range for tone recognition

Smallest detectable input voltage[4]		20	25	mV_{RMS}
Largest no-output input voltage[4]	10	15		mV_{RMS}

- Guaranteed minimum input level which is definitely recognized by the tone decoder (max of the min levels among several devices)
- Guaranteed maximum input level which is NOT recognized by the tone decoder (min of max levels)
- Same kind of specs as Vih/Vil for logic circuits

Tone decoder: noise and interferers

- Noise immunity

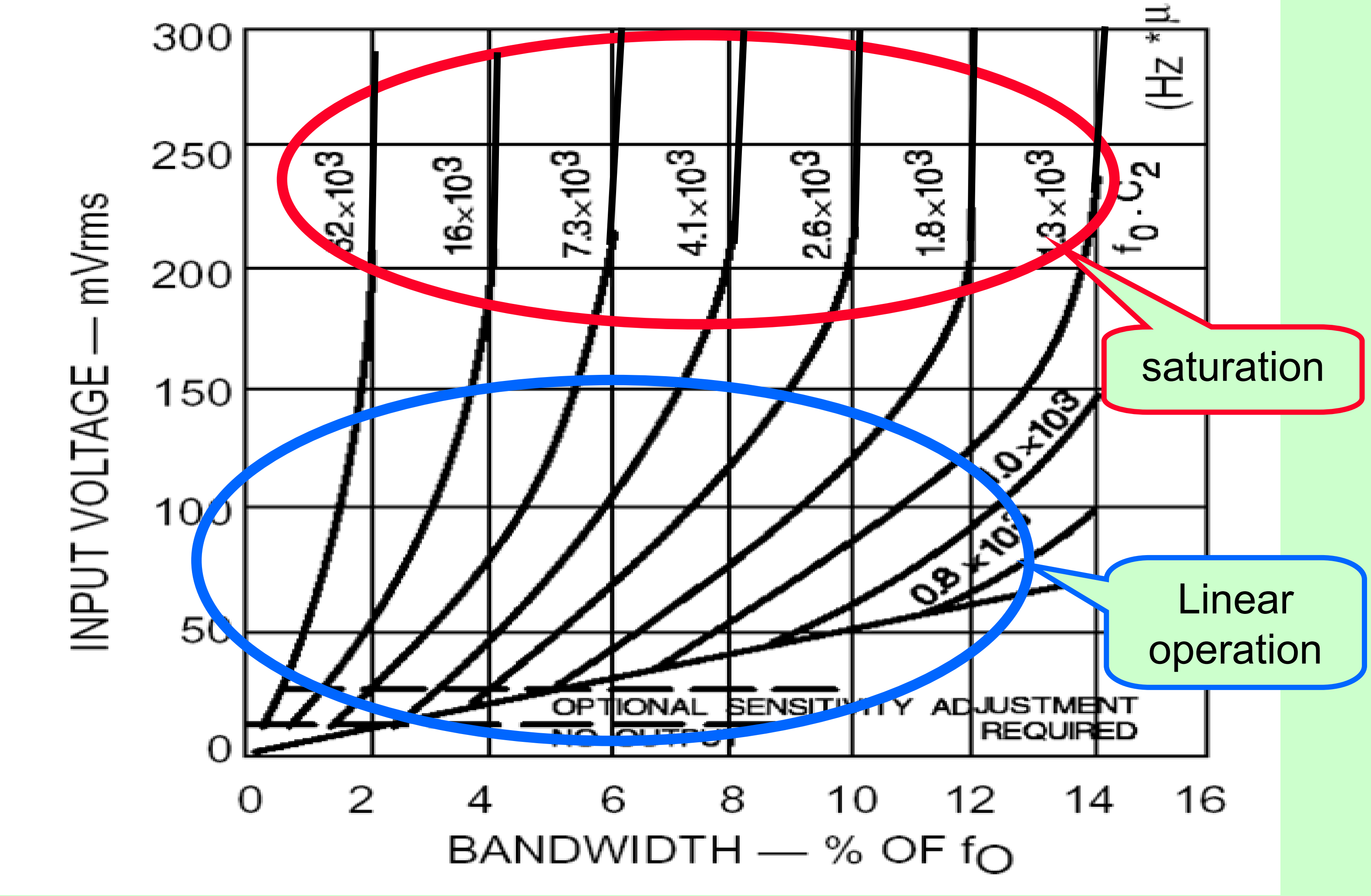
- Tone detection capability with noise or interferer stronger than the tone itself
  - (Outband signal)/(inband tone): + 6 dB
  - signal(tone)/(wideband noise): - 6 dB

Greatest simultaneous out-band signal-to-in-band signal ratio		+6		dB
Minimum input signal to wide-band noise ratio		-6		dB

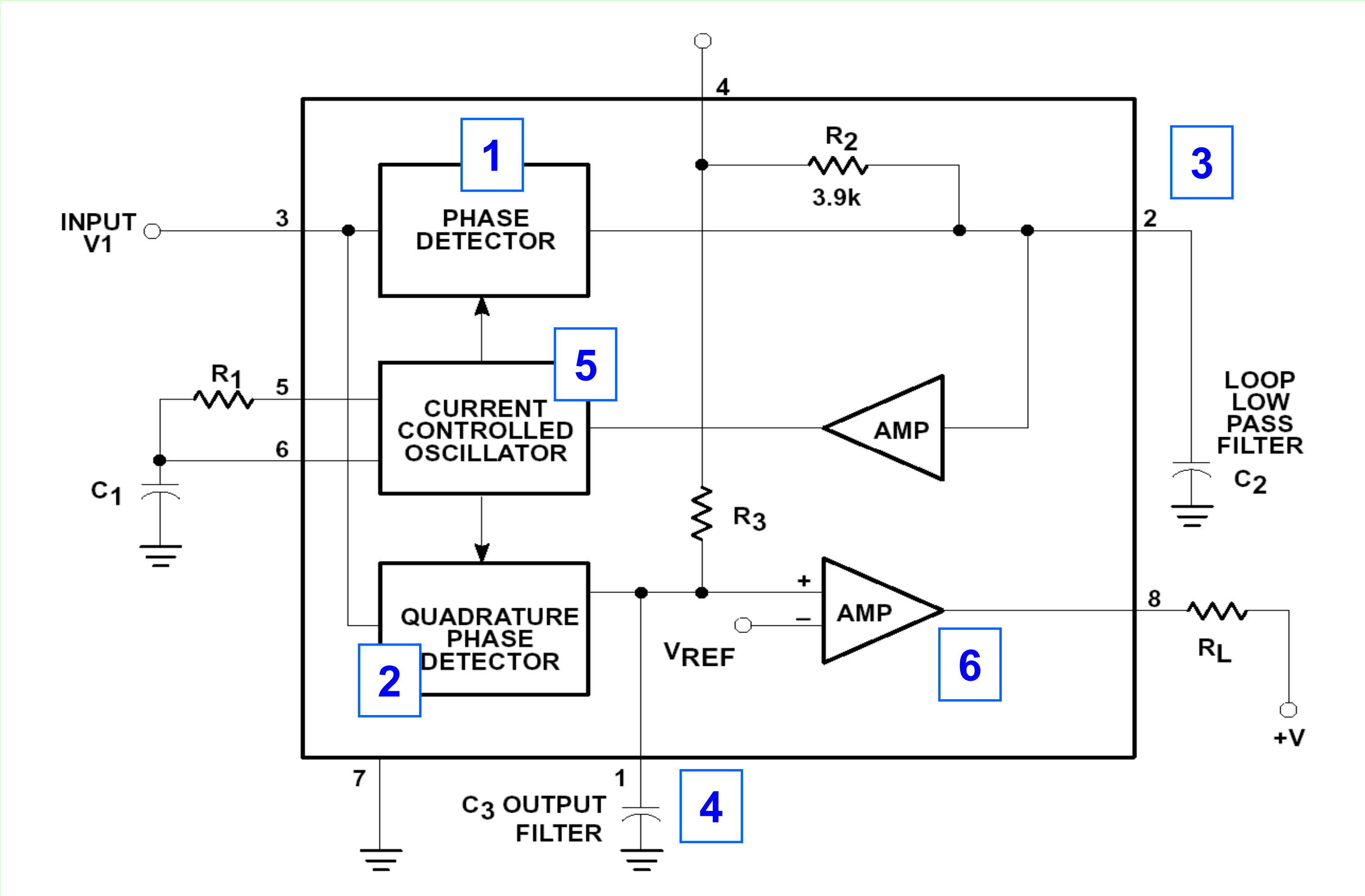
Tone decoder: bandwidth and F(s)

- The next diagram plots the capture range vs VI and filter parameters
- Detection bandwidth (capture range) depends on:
  - Input level
  - Loop filter F(s)
- Linear area
  - Vi < 100 mV
  - Capture range depends on Vi
- Saturation area
  - Vi > 200 mV
  - Capture range does not depend on Vi

Linear and saturating input levels



Tone decoder A: block diagram

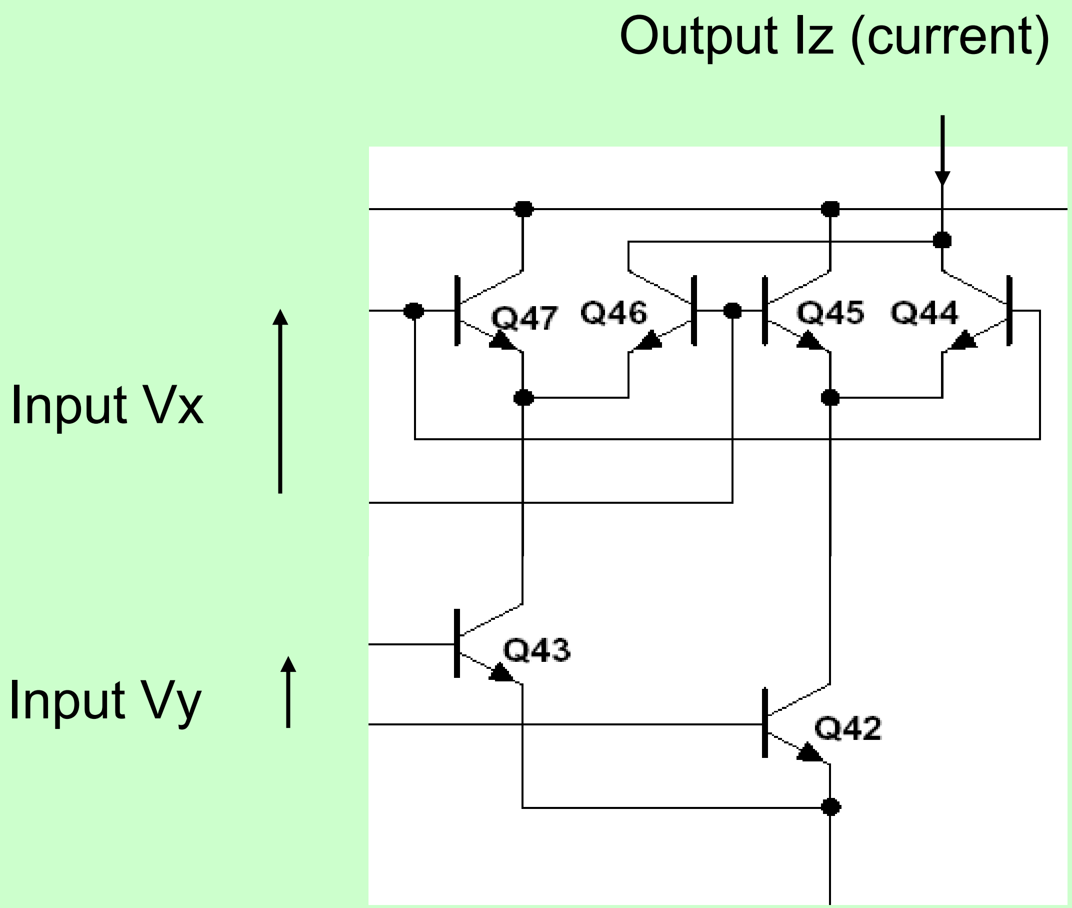


Tone decoder functional units

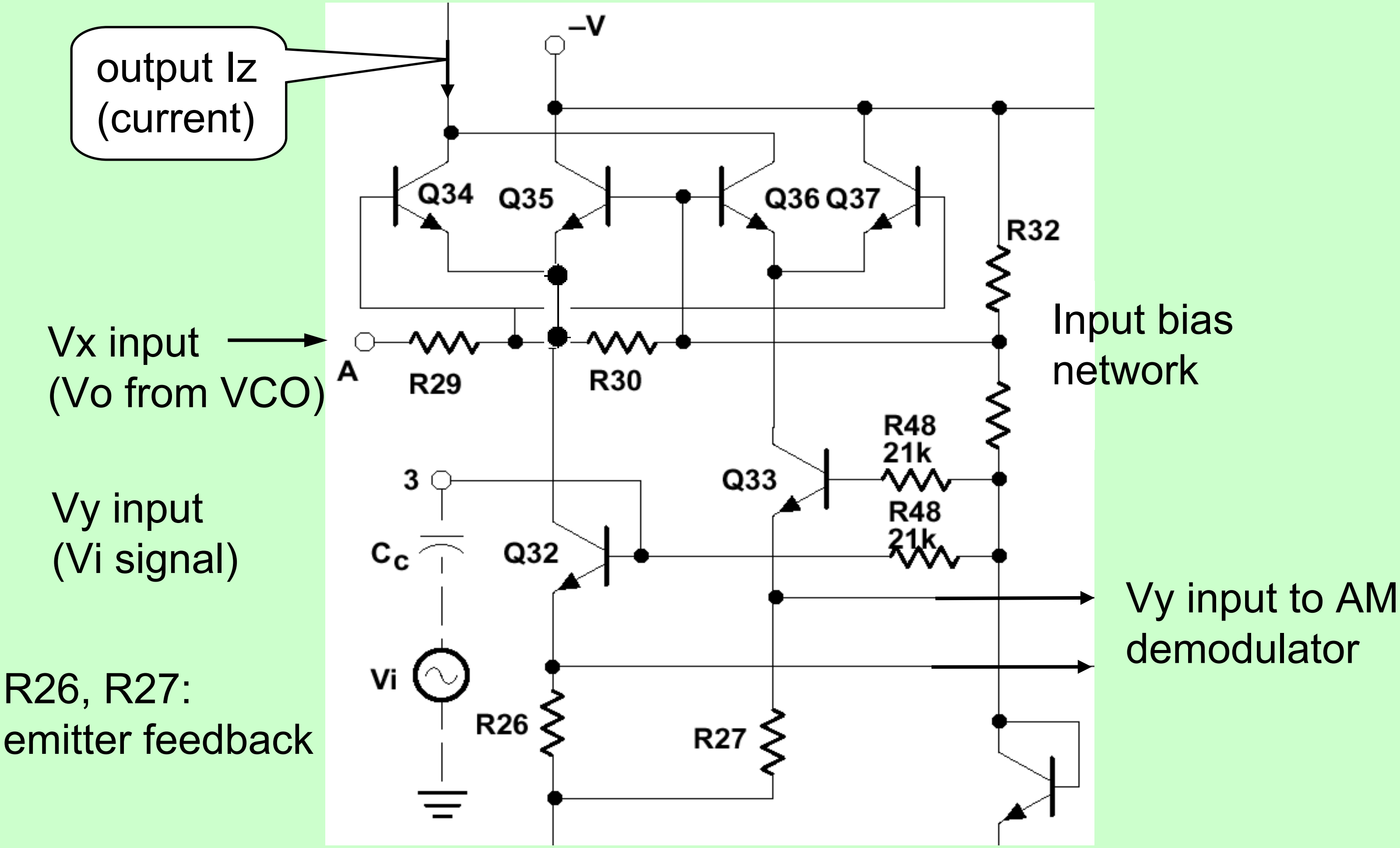
1. Phase detector
2. Amplitude demodulator
   - Gilbert cell multiplier
3. Loop filter
4. AM filter
   - Single pole (RC), Internal R, external capacitor
5. VCO and I/Q outputs
   - C charge/discharge, threshold control
   - Third comparator or double frequency VCO
6. Output stage
   - open collector, high current capability (150 mA)

PD and AM demodulators

- Gilbert cell multipliers

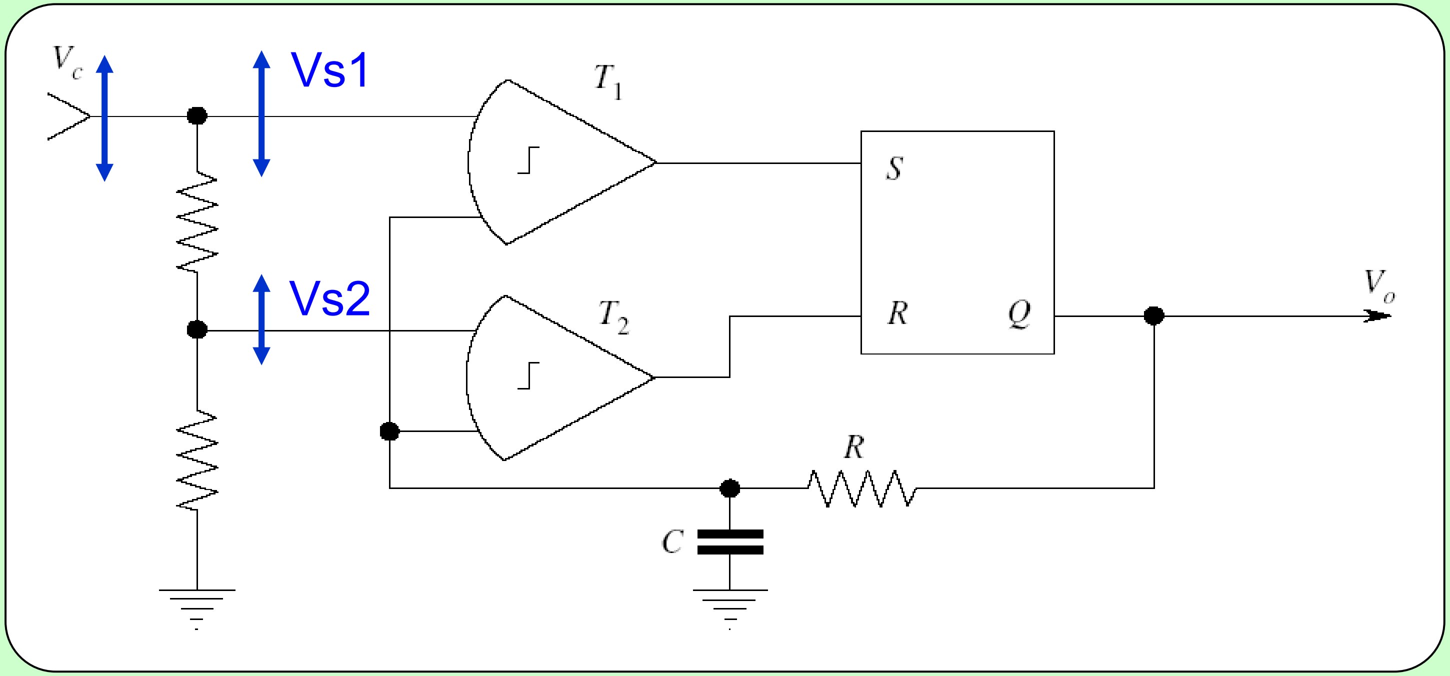


Linearization of differential stage



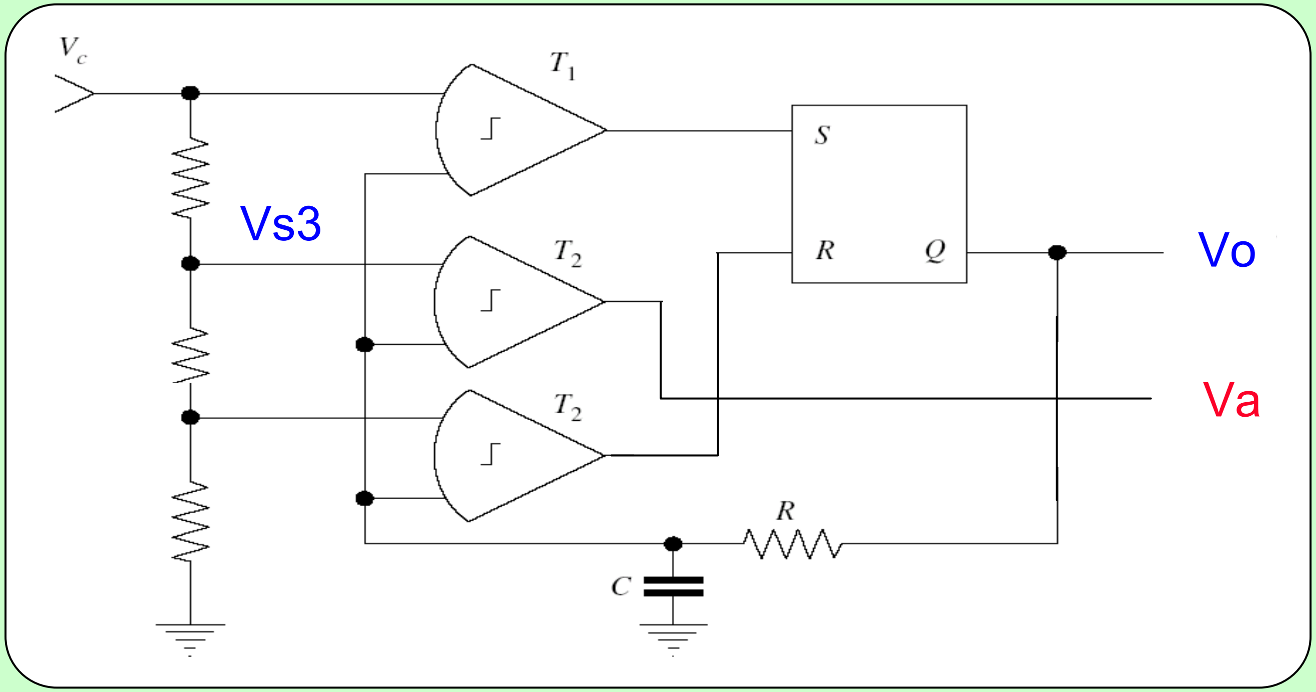
I-C fixed τ VCO

- Unique time constant (τ = RC)
- Frequency control by variable thresholds (Vs1, Vs2)
  - Limited frequency change



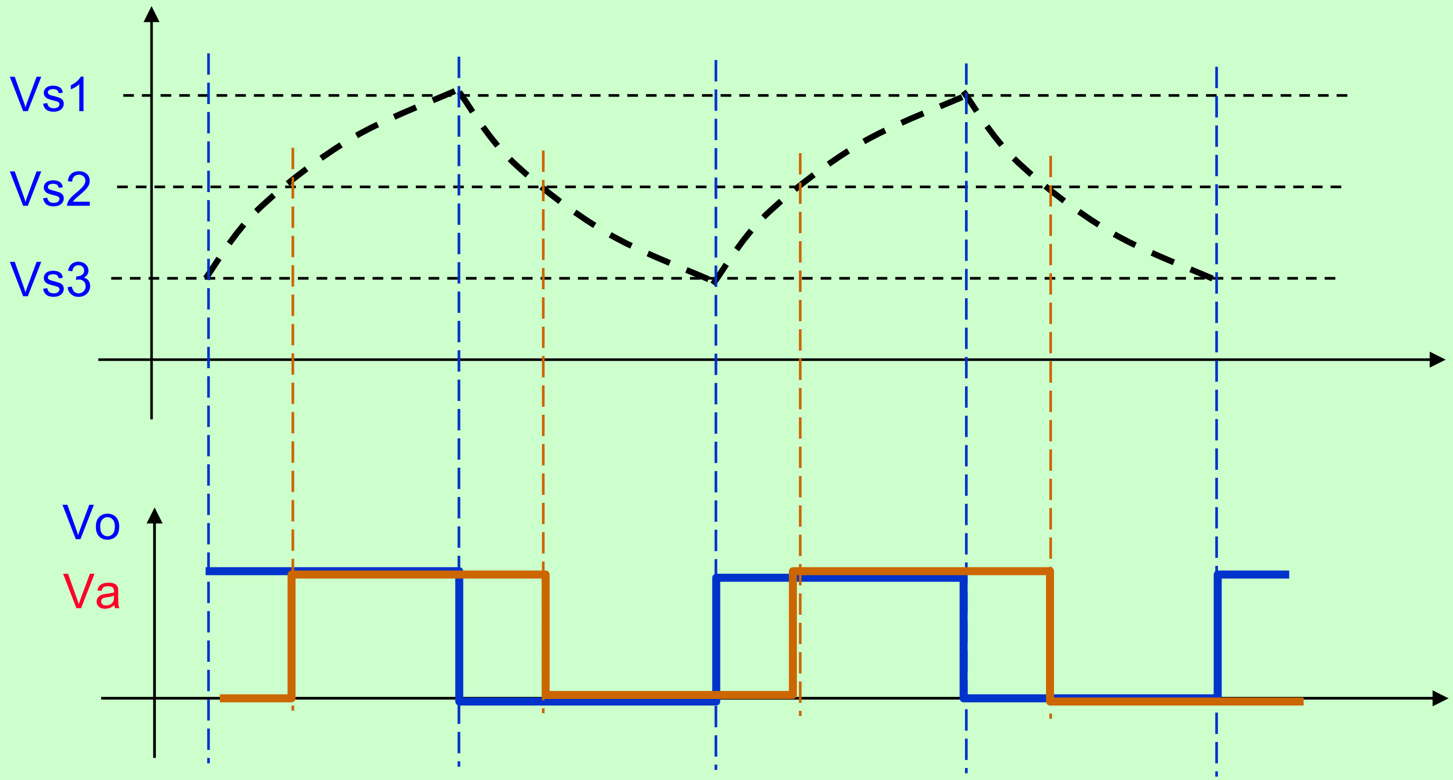
I/Q VCO outputs

- Additional comparator on the capacitor voltage
  - Almost triangular waveform on C
  - Intermediate threshold Vs3



VCO waveforms

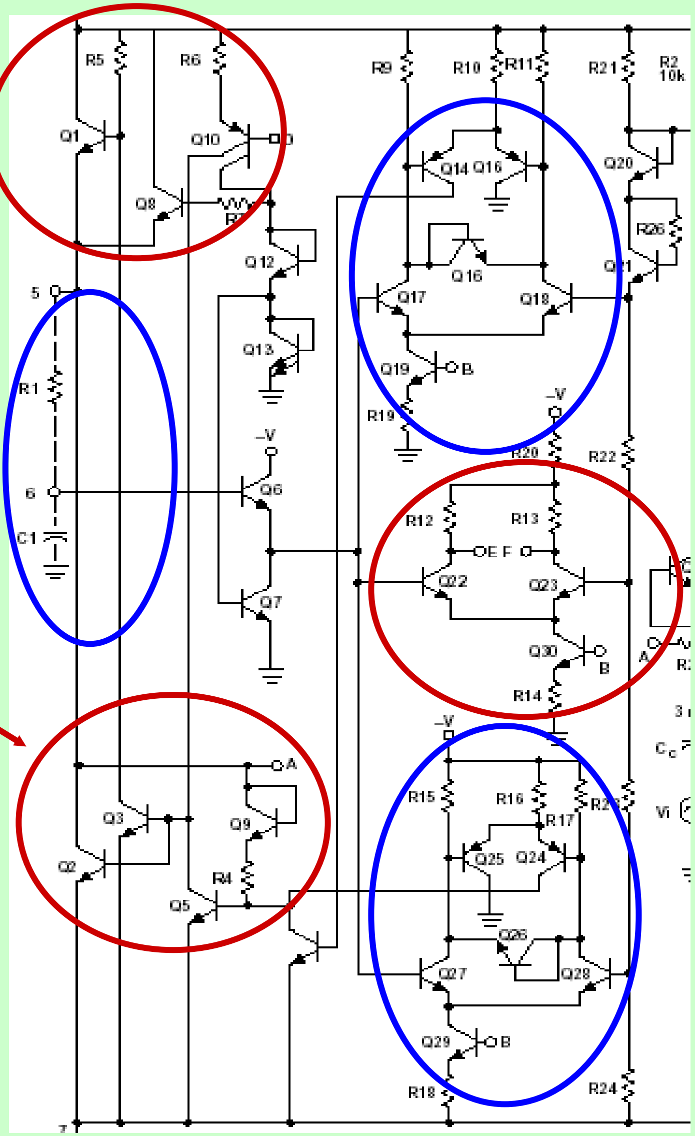
- Additional comparator on the capacitor voltage
  - Almost triangular waveform



Tone decoder: VCO circuit

C charge/discharge switches

RC timing group



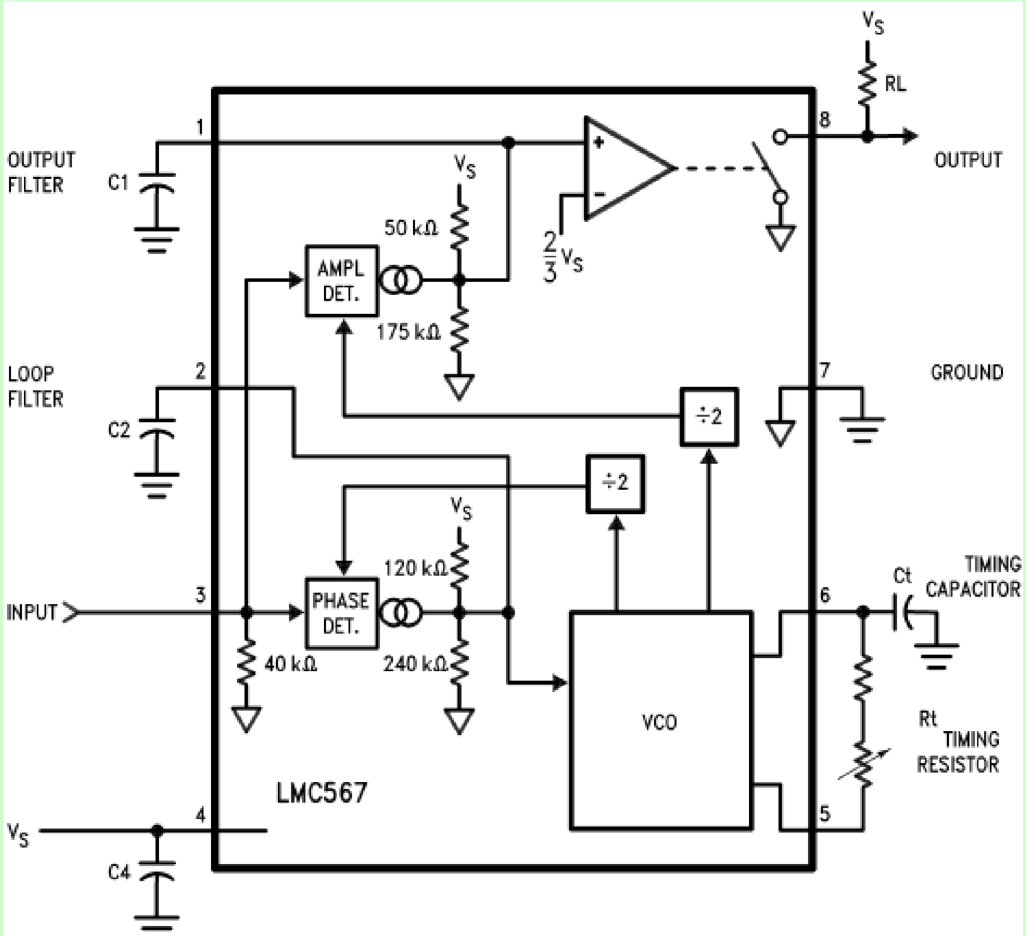
VCO Vs1 comparator

Q-oputput Comparator (Vs3)

VCO Vs2 comparator

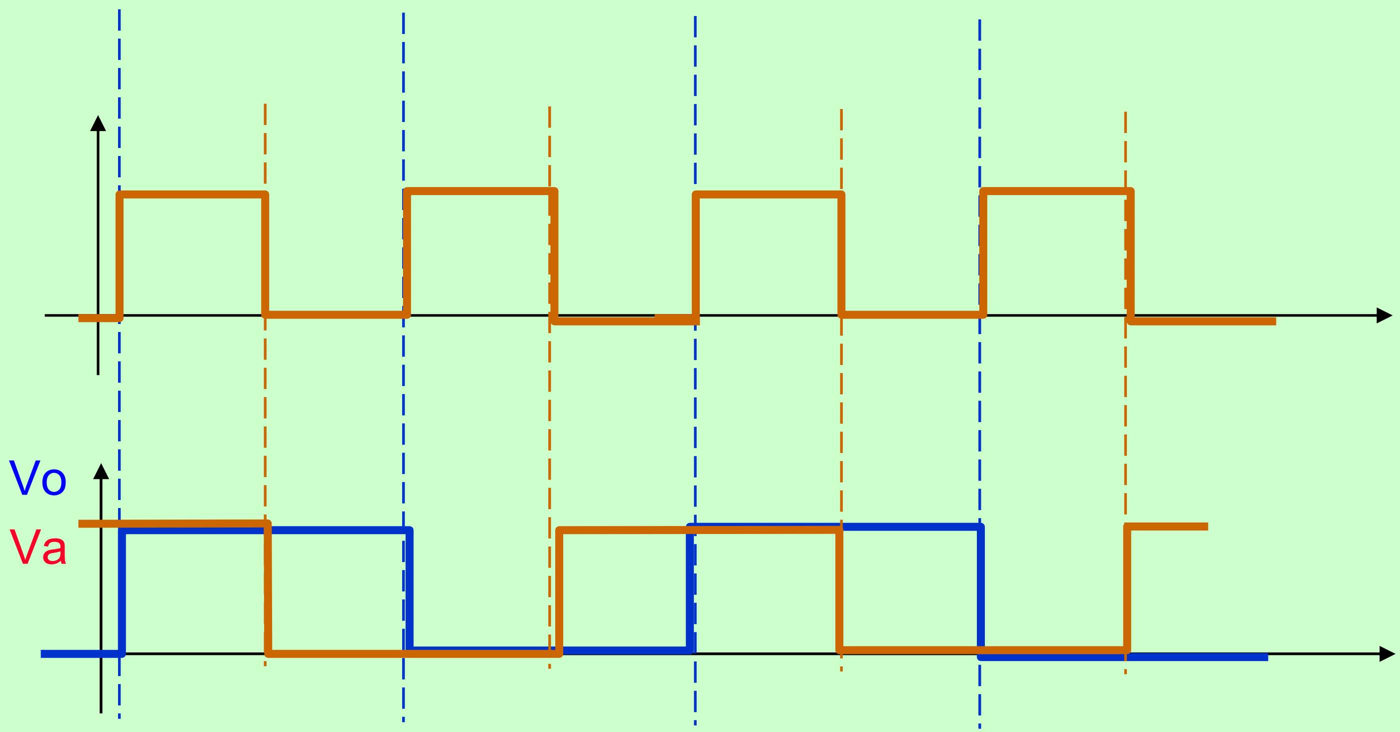
Tone decoder B: block diagram

- CMOS features
  - Higher R/Z
  - Lower current
  - Better I/Q VCO



Double VCO frequency I/Q

- VCO operates at double frequency
  - I/Q signals by Mod2 dividers on complementary edges



Lab experiment 4

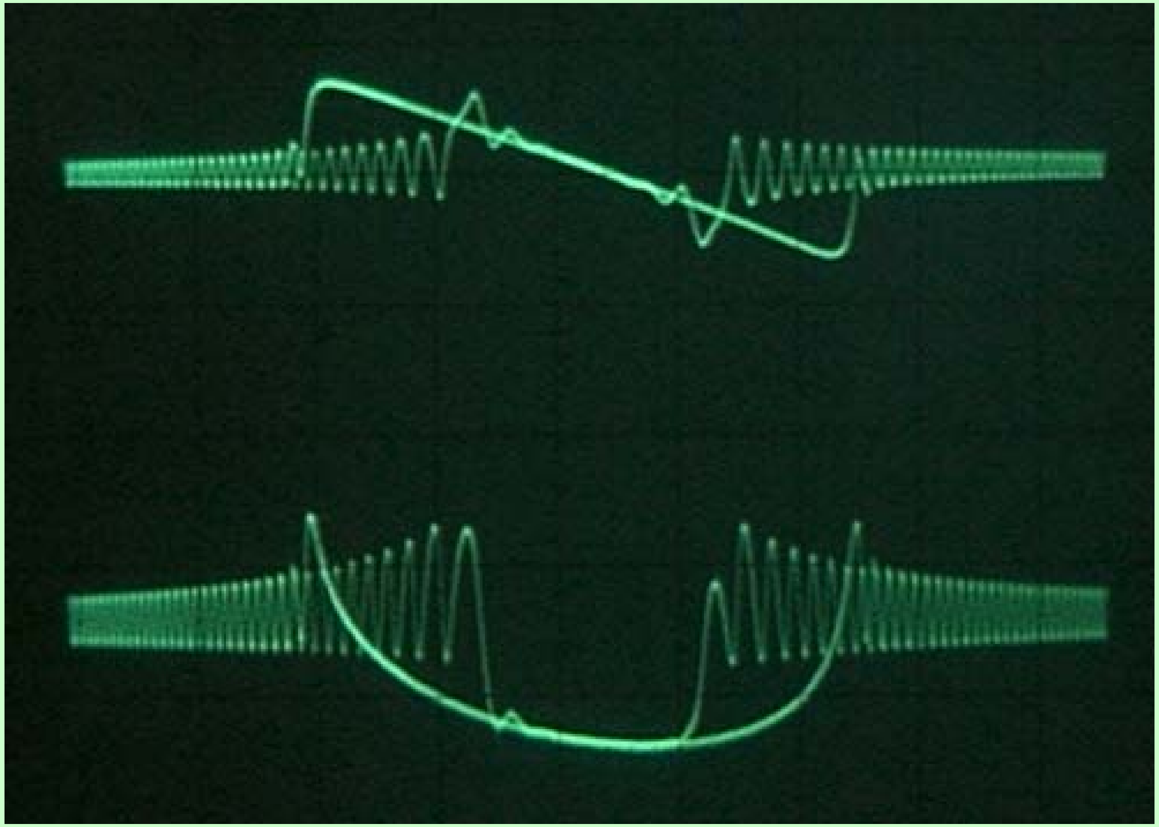
- Design a circuit using the NE567 IC, to obtain a tone decoder with detection range centered on 25 kHz, and the maximum bandwidth allowed by the device.
- Build the circuit
- Verify the tone decoder parameters
  - Measure capture and lock ranges
  - Find the amplitude threshold (at central frequency)
  - Plot the VCO characteristic: Fo(Vc)
  - Plot the Va(Fi) and Va(Vi) characteristic
  - Verify the behaviour with noise and interferers at the input

NE 576 – PD and AM demodulator

- PD and AM demodulator outputs vs input signal frequency.

VCO control voltage (butterfly plot)

Coherent AM demodulator output (cosine shape)



Lesson C5

- Describe the techniques for FM demodulation, with and without PLL.
- Define the criteria to select R and C in the AM envelope detector.
- Which are the benefits of coherent AM demodulation vs envelope demodulation?
- How to reduce the FM sensitivity of an AM coherent demodulator ?
- List the parameters which describe the performance of a tone decoder.
- Propose some circuits to generate I/Q signals from a single VCO.