

ECE 215/S – Principles of Electronic Cyber Warfare

Block 3: Communication Systems, Radar, and Electronic Warfare

Lesson 30: Demodulation

Department of Electrical and Computer Engineering
United States Air Force Academy

Fall 2026

Objective 3.2

I can design a demodulator given a modulated signal for envelope and synchronous detection.

- Lessons 28 and 29 put the message *onto* the carrier. Today we take it back *off*
- Which demodulator you can use is decided entirely by α
- Two loose ends from Lesson 29 land here: the power parked in the carrier, and the receiver's band-pass filter
- **Quiz 8** covers Objectives 3.1 and 3.2 — today is the last new material before it

Where We Are Going

By the end of this lesson, you will be able to:

- Compute the **modulation efficiency** η of an AM signal
- Describe how an **envelope detector** works and when it is valid
- Find the output of each block of a **synchronous detector**, and say why it always works
- **Design** either demodulator — every block, the oscillator, and every cutoff frequency

Modulation Efficiency

Lesson 29: an under-modulated signal parks power in the carrier, and the carrier carries no message. **Efficiency** is the useful share of the power, $\eta = (P_{\text{upper sideband}} + P_{\text{lower sideband}})/P_{\text{total}}$, and for AM it works out to

$$\eta = \frac{\alpha^2}{\alpha^2 + 2}$$

- **Exact for a single-tone message.** For any other message it is the estimate this course uses
- $\alpha = 1$ gives $\eta = 1/3 = 33.3\%$, the best an envelope-detectable signal can do. A smaller α wastes more; with no bias the carrier vanishes and $\eta \to 100\%$
- **So why does AM broadcast under-modulate?** Because the **receiver** is then a diode and a few resistors and capacitors — a crystal radio needs no power supply at all. One transmitter serves millions of receivers, so wasting power at the one expensive end to make the millions cheap is an engineering decision, not a mistake

Two Ways to Demodulate

	Envelope detector	Synchronous detector
Works on	$\alpha \leq 1$ only: under- or fully modulated	**every** AM signal: over-modulated, or with no carrier at all
Cost	cheap and easy to build	expensive and complex
Efficiency	transmit power wasted on the carrier	up to 100%
Used for	broadcast: one transmitter, many receivers	point-to-point and power-limited links (satellite, spacecraft)

Check α first. It tells you which detector is even an option.

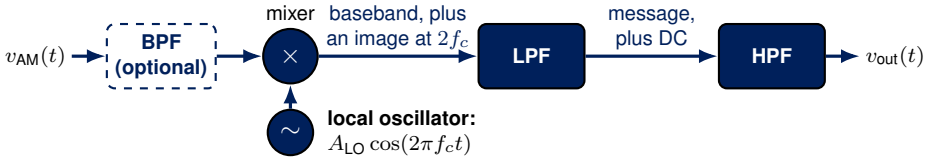
Envelope Detection

The envelope is $A_c[\,B + v_m(t)\,]$: the message, scaled and riding on a DC level. Trace it, then drop the DC.



- **Rectifier** — one diode. Lesson 10's rectifier folded the negative half up; this one simply drops it
- **LPF** removes everything from $f_c - f_{m,\max}$ up — the carrier-frequency content. What is left has the envelope's shape
- **HPF** strips the DC level (Lesson 15: an HPF always removes DC), leaving the message's shape
- If the envelope crossed zero ($\alpha > 1$), the rectified outline is *not* the message, and this fails
- The dashed **BPF** is Lesson 29's tuned filter: it goes first when other channels share the band

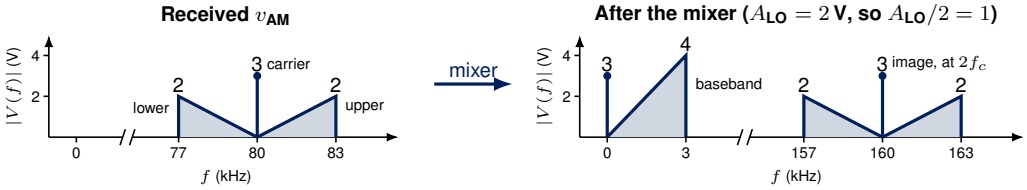
Synchronous Detection



- The **local oscillator** (LO) is a sinusoid the receiver makes itself, at **exactly** f_c, with its own amplitude A_{LO}. The circle-$\times$ is the **mixer** — Lesson 28's function multiplier
- Multiplying shifts the sidebands back down to **baseband** — the message's own band, from 0 Hz up — and makes a copy at $2f_c$, the **image**. The **LPF** discards the image; the **HPF** removes the DC the carrier leaves
- Nothing depends on the envelope's shape, so **over-modulation does not matter**. The cost is that "exactly f_c" — in frequency and in phase
- A quiz may call A_{LO} "the carrier signal amplitude, A_c": it means this *demodulating* carrier, not the transmitter's carrier

What the Mixer Does to the Spectrum

The mixer multiplies by $A_{\text{LO}} \cos(2\pi f_c t)$. Lesson 28's sum-and-difference rule, one component at a time: **a component of height H at f becomes two, each of height $H \cdot A_{\text{LO}}/2$, at $f - f_c$ and at $f + f_c$.**



- **Carrier** ($A_c B$ at f_c) $\rightarrow f_c - f_c = 0$: a **DC term**, $A_c A_{\text{LO}} B/2$. Here $3 \times 2/2 = 3$ V. It lands there once, so it does **not** double
- **Sidebands** $\rightarrow +f_m$ and $-f_m$. Since $\cos(-x) = \cos(x)$, $-f_m$ is the same tone as $+f_m$: fold it over and **add**. Here $2 + 2 = 4$ V at 3 kHz; for one message tone, $A_c A_{\text{LO}} A_m/2$
- The $f + f_c$ copies are the **image**: the received spectrum again, centered on $2f_c$

Choosing the Cutoffs

Block 2 shortened a cutoff to f_c. From Lesson 28 on, f_c is the **carrier**, so a cutoff is written out: f_{cutoff}, as on the equation sheet. Any f_{cutoff} inside the window is a correct design.

Filter	Must remove	Window for f_{cutoff}
LPF, envelope	carrier-frequency content, from $f_c - f_{m,\max}$ up	$f_{m,\max} \le f_{\text{cutoff}} < f_c - f_{m,\max}$
LPF, synchronous	the image, from $2f_c - f_{m,\max}$ up	$f_{m,\max} \le f_{\text{cutoff}} < 2f_c - f_{m,\max}$
HPF, both	DC, at 0 Hz	$0 < f_{\text{cutoff}} \le$ lowest message tone

- **The course's habit:** LPF **just above** $f_{m,\max}$, HPF at **10 Hz**. Both sit inside every window. A cutoff is inclusive (Lesson 15), so $f_{\text{cutoff}} = f_{m,\max}$ itself still passes the whole message
- **Other channels in the band (FDM)?** Put a **BPF** first, passing $f_c - f_{m,\max}$ to $f_c + f_{m,\max}$. An envelope detector must have it
- A synchronous detector may skip the BPF: the mixer drops a neighbor at carrier f_n to $|f_n - f_c|$, so the LPF window then ends below that neighbor's lowest product

Method: Designing a Demodulator

1. **Find** $\alpha = \max(\text{message})/B$, or $(\max - \min)/(\max + \min)$ from envelope limits
2. **Choose:** $\alpha \leq 1$, either detector (envelope is cheaper); $\alpha > 1$ or no carrier, synchronous
3. **Draw the chain:** rectifier, or mixer with oscillator $\rightarrow$ LPF $\rightarrow$ HPF. Shared band: BPF first
4. **Set every value:** oscillator f_c, A_{LO}; LPF just above $f_{m,\max}$; HPF 10 Hz; BPF $f_c \pm f_{m,\max}$
5. **Follow the spectrum** (synchronous): each component $\times A_{\text{LO}}/2$, at $f \pm f_c$; sidebands add
6. **Check:** the message passes the LPF and the HPF; DC and the lowest unwanted component do not

A design names every block and every value.

Worked Example

Two transmitters use the same carrier, $A_c = 1\,\text{V}$ at $f_c = 150\,\text{kHz}$, and send the same message, $v_m(t) = 4\cos(2\pi \cdot 8000t)\,\text{V}$. Only the bias differs:

	max(message)	**bias** B
Signal 1	$4\,\text{V}$	$6\,\text{V}$
Signal 2	$4\,\text{V}$	$3\,\text{V}$

For each signal, follow the Method. *Work it before the next slide.*

1. Find α, classify the signal, and find its modulation efficiency
2. State which detector(s) will work
3. Design one — name every block and every value. A synchronous detector uses $A_{\text{LO}} = 1\,\text{V}$
4. For Signal 2, draw the spectrum at the input, after the mixer, and at the output

Worked Example — Solution

Signal 1

$$\alpha = \frac{4}{6} = 0.667 \quad \text{(under-modulated)}$$

$$\eta = \frac{0.667^2}{0.667^2 + 2} = 18.2\%$$

Either detector works. Choose the cheap one.

Design (envelope):
rectifier $\rightarrow$ LPF, $f_{\text{cutoff}} = 10$ kHz $\rightarrow$ HPF, $f_{\text{cutoff}} = 10$ Hz

LPF window: 8 kHz to just below $150 - 8 = 142$ kHz, so 10 kHz is inside it.

Signal 2

$$\alpha = \frac{4}{3} = 1.333 \quad \text{(over-modulated)}$$

$$\eta = \frac{(4/3)^2}{(4/3)^2 + 2} = \frac{8}{17} = 47.1\%$$

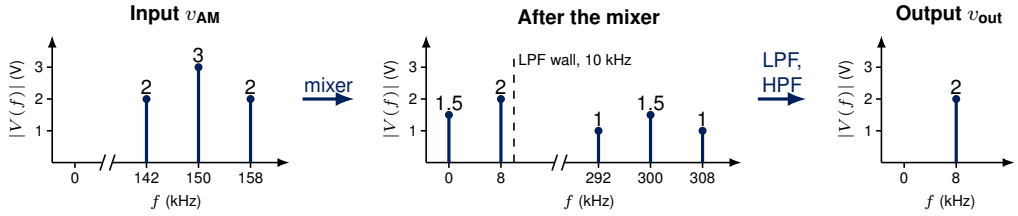
Synchronous only.

Design:
mixer with $1\cos(2\pi \cdot 150{,}000t)$ V $\rightarrow$ LPF, $f_{\text{cutoff}} = 10$ kHz $\rightarrow$ HPF, $f_{\text{cutoff}} = 10$ Hz

LPF window: 8 kHz to just below $2(150) - 8 = 292$ kHz, so 10 kHz is inside it.

Same message, same LPF: the cutoff follows $f_{m,\max} = 8$ kHz, not the detector.
Signal 2 is far more power-efficient, and requires the expensive receiver.

Worked Example — Signal 2, Block by Block



- **Input:** sidebands $A_c A_m/2 = (1)(4)/2 = 2$ V at 150 ± 8 kHz; carrier $A_c B = (1)(3) = 3$ V
- **Mixer** ($A_{LO}/2 = 1/2$): carrier $\rightarrow$ DC, $3/2 = 1.5$ V. Sidebands $\rightarrow 1 + 1 = 2$ V at 8 kHz. Image: 1, 1.5, 1 V at 292, 300, 308 kHz
- **LPF** removes the image and **HPF** the DC: $v_{out}(t) = 2\cos(2\pi \cdot 8000t)$ V, the message times $A_c A_{LO}/2 = 1/2$. A 2 V oscillator would return the full 4 V
- **Check:** 8 kHz passes the 10 kHz LPF and the 10 Hz HPF; 0 Hz and 292 kHz do not

Your Turn

A received AM signal has a carrier at $f_c = 80$ kHz. The message contains tones up to 12 kHz. The envelope swings between 2 V and 14 V.

1. Find α from the envelope limits, classify the signal, and find the modulation efficiency
2. Design an envelope detector: name every block and every value
3. Design a synchronous detector with $A_{\text{LO}} = 2$ V. Give its LPF window, and the DC term its HPF must remove
4. A second station starts up at 110 kHz with the same message band. What must each design add or change?

Wrap-Up

Key ideas:

- $\eta = \alpha^2/(\alpha^2+2)$ — only the sidebands carry the message
- **Envelope detection** is cheap but needs $\alpha \leq 1$. **Synchronous detection** works on anything, but must make f_c exactly
- The mixer scales every component by $A_{\text{LO}}/2$ and moves it by f_c: the sidebands **add** at baseband ($A_c A_{\text{LO}} A_m/2$ for a tone) and the carrier becomes **DC** ($A_c A_{\text{LO}} B/2$)
- A design names **every block and every value**: oscillator at f_c, LPF just above $f_{m,\max}$, HPF at 10 Hz, and a BPF first when channels share the band

Next lesson:

- **Lesson 31 — Objective 3.3: Antennas.** How the signal gets off the wire and into the air
- **Quiz 8** (Objectives 3.1–3.2) is due at **Lesson 32 (6/9 Nov)** — today is the **last new material before it**. Lesson 31's antennas are on Quiz 9