COMP3310/6331 – #1-2

Overview, introduction

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It’s a new-ish course

- Recently reviewed after 20+ years
  - Lots of feedback from students, assessors, externals

- New lecturer, restructured content and flow, broader assessment, …

- I will be using Wattle, including discussion forum
  - Slides posted there (just) before the lecture

- I want to focus less on ‘what’, more on ‘how’ and ‘why’
  - Having said that…

- Seeking more feedback for further tuning

CECS Class Representatives

Why become a Class Rep?

- **Develop skills sought by employers**, including interpersonal, dispute resolution, leadership and communication skills.
- **Become empowered**. Play an active role in determining the direction of your education.
- **Become more aware of issues influencing your University** and current issues in higher education.
- **Ensure students have a voice** to their course convener, lecturer, tutors, and college.

Roles and Responsibilities:

- Act as the official liaison between your peers, convenors and lecturers.
- Be creative, available and proactive in gathering feedback from your classmates.
- Attend regular meetings, and provide reports on course feedback to your course convenor and the Associate Director (Education).
- Close the feedback loop by reporting back to the class the outcomes of your meetings.

CECS Class Representatives

Want to be a Class Rep? Nominate today!

To nominate yourself as a Class Representative, email the Convenor (Eric.McCreath@anu.edu.au) by **4 March**:

- Your name;
- Your student ID;
- The course code (e.g. COMP3310/6331) of the course you'd like to represent: and
- The reason that you would like to be a Class Rep.

ANUSA and PARSA offer Class Representative training on **12 March** to give you skills to be an effective Class Rep.

Contact ANUSA/PARSA Presidents for more information: sa.president@anu.edu.au and parsa.president@anu.edu.au

Structure of this course

- **Lectures**: 26-30, 3hr/week, tapering towards the end of the course.

- **Labs**: 8 2hr labs, every week (#2 onwards, skip wk6, 7,12)

- Assessment:
  - **3 assignments**, 10% each
    - Deadlines are real.
    - Writing, Reading, Coding, Analysing, ...
  - **1 mid-semester exam,** 20%
  - **1 final exam**, 50%

Resources

- Text books
  - Tanenbaum, Stevens, others
  - Open source textbooks
- Google and Youtube and Wikipedia and MOOCs and …
- Network Organisations with online training
  - learn.NSRC.org, academy.APNIC.net, …
- Fellow students, tutors, lecturer(s)

Why bother?

1. Why do we care?
    1. Client/server/cloud, consumer/content, peer2peer, M2M, IoE, …
    2. What's the "stuff" connecting everything?
    3. Three components wrapped for a purpose

Distributed systems (applications)
Networks (messages)
Communications (bits)

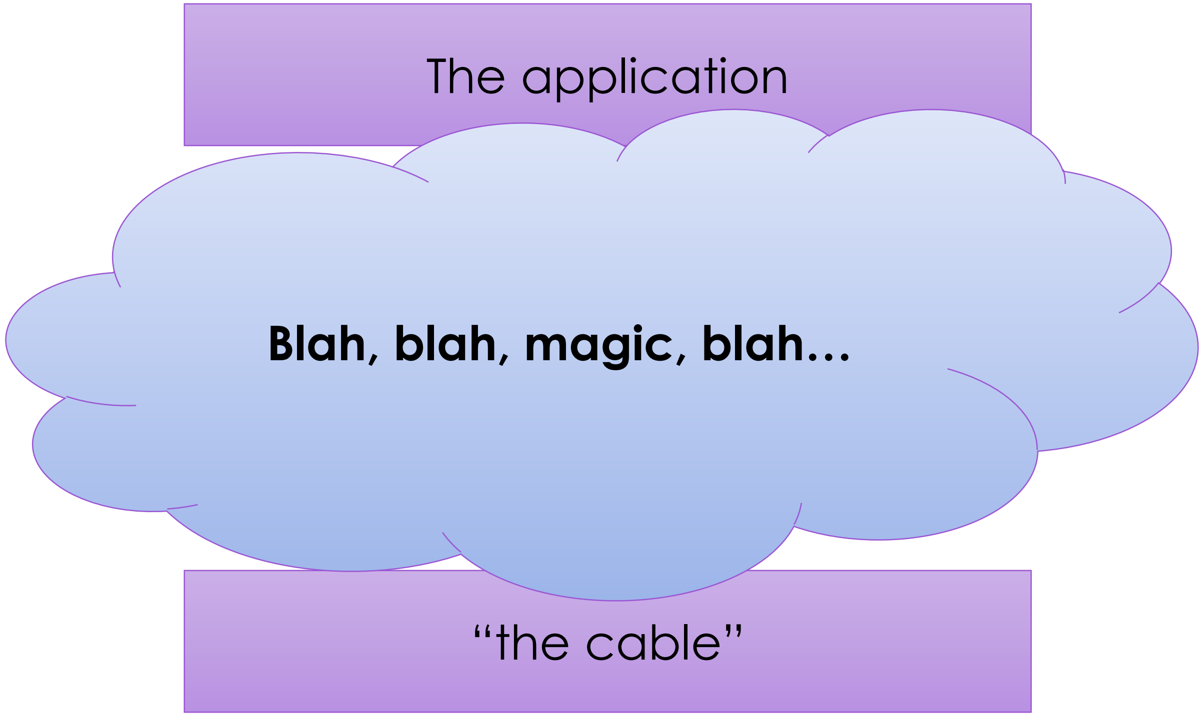
2. Define computer networking;
    1. What's a computer? (at either end?)
    2. What's a communications link? [A to B]
    3. What's a network? [many to many, sharing]

An aid to navigation…

An application talks to an operating system

- which talks to the computer hardware
- which talks to a “cable”
- which talks to another computer’s hardware
- which talks to that operating system
- which talks to an application over there

Or another way



Which will become

The application

“Communication stuff”

“Network stuff”

“the cable”

Topic schedule – (indicative…)

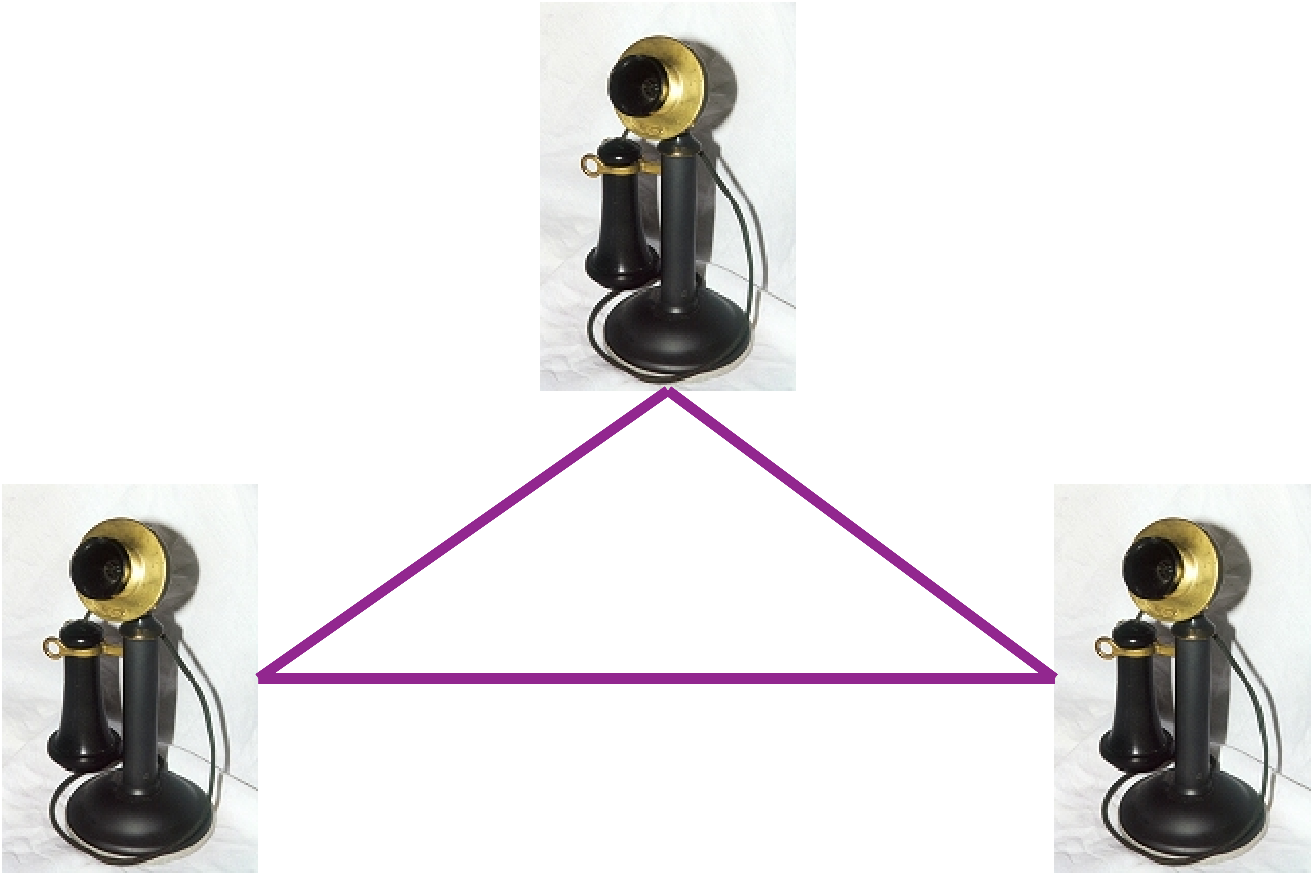
Topic		Topic	
1-2	Information Transmission	15-17	Web, Realtime Comms, IoT
3-5	Physical: Copper, Fibre, Wireless	18	Routing
6-8	LANs; Ethernet and WiFi	19	Flows and Congestion
9	WANs: Layers	20	Monitoring Networks
10-11	IPv4, IPv6	21	Security
12	UDP, TCP	22	Real world networks
13-14	Applications, DHCP, DNS,		

Isn't it all the Internet ?

- Internet dominance and why it works
  - Globally agreed standard(s)
  - Globally trusted governance
  - Abstract multiple link-types
  - Copes with all sorts of topologies
  - Connectionless – mostly

- And yet – it's not the only network technology
  - Serious overheads (inefficient)
  - Performance issues (ineffective)
  - Trust issues (insecure)

Some basics: an early network… (~1876)

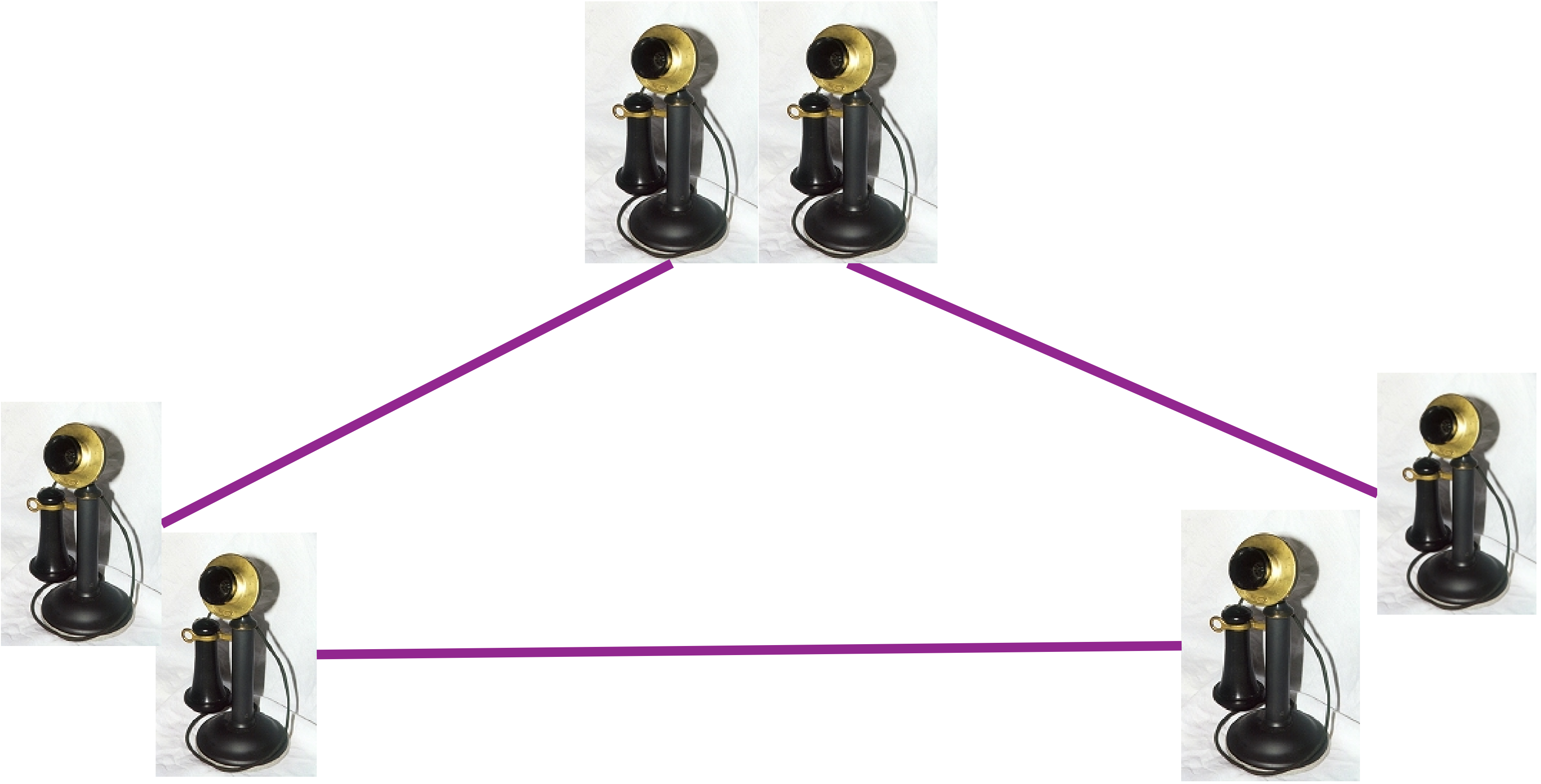


- Fully meshed
- Cable congestion

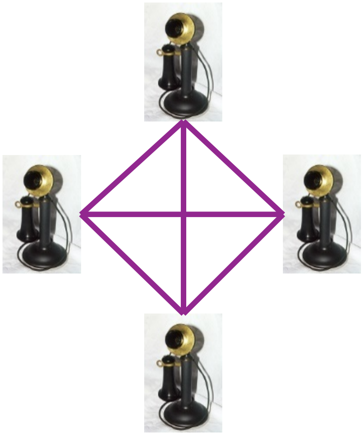
A “key” problem

Can only call one other phone?!

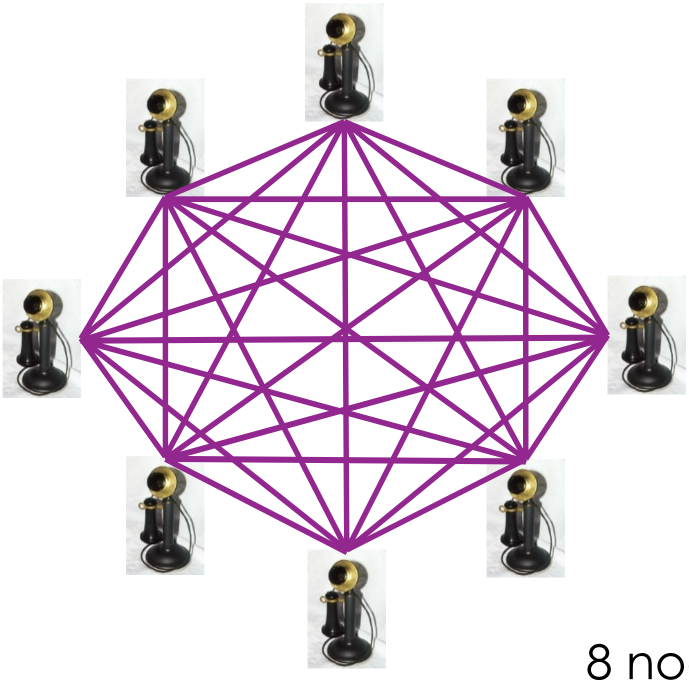
This does not scale well!



Network topology: Fully meshed



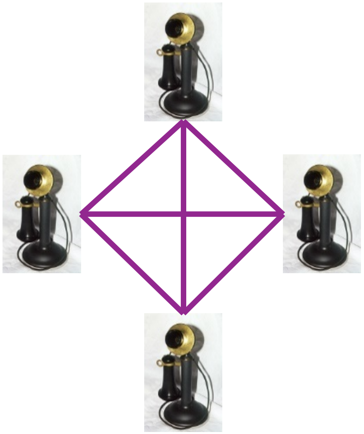
4 nodes
- 12 phones
- 6 links

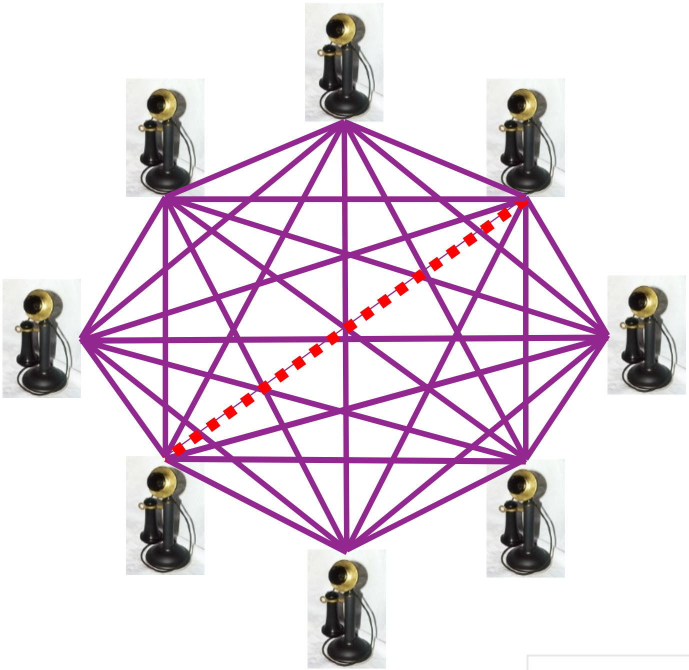


8 nodes
- 56 phones
- 28 links

Metcalfe: Value of a network goes up as N^2

Network topology: Fully meshed

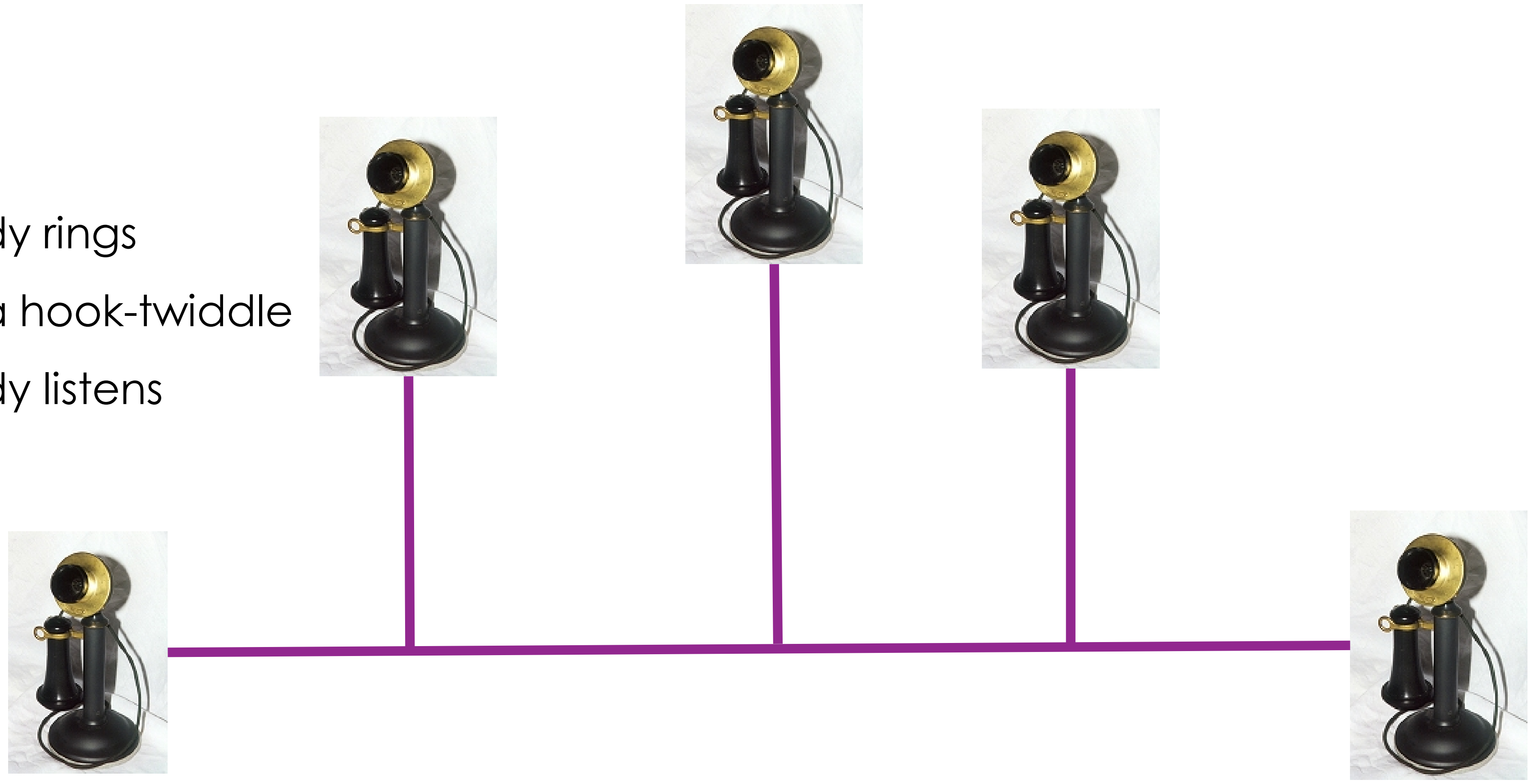




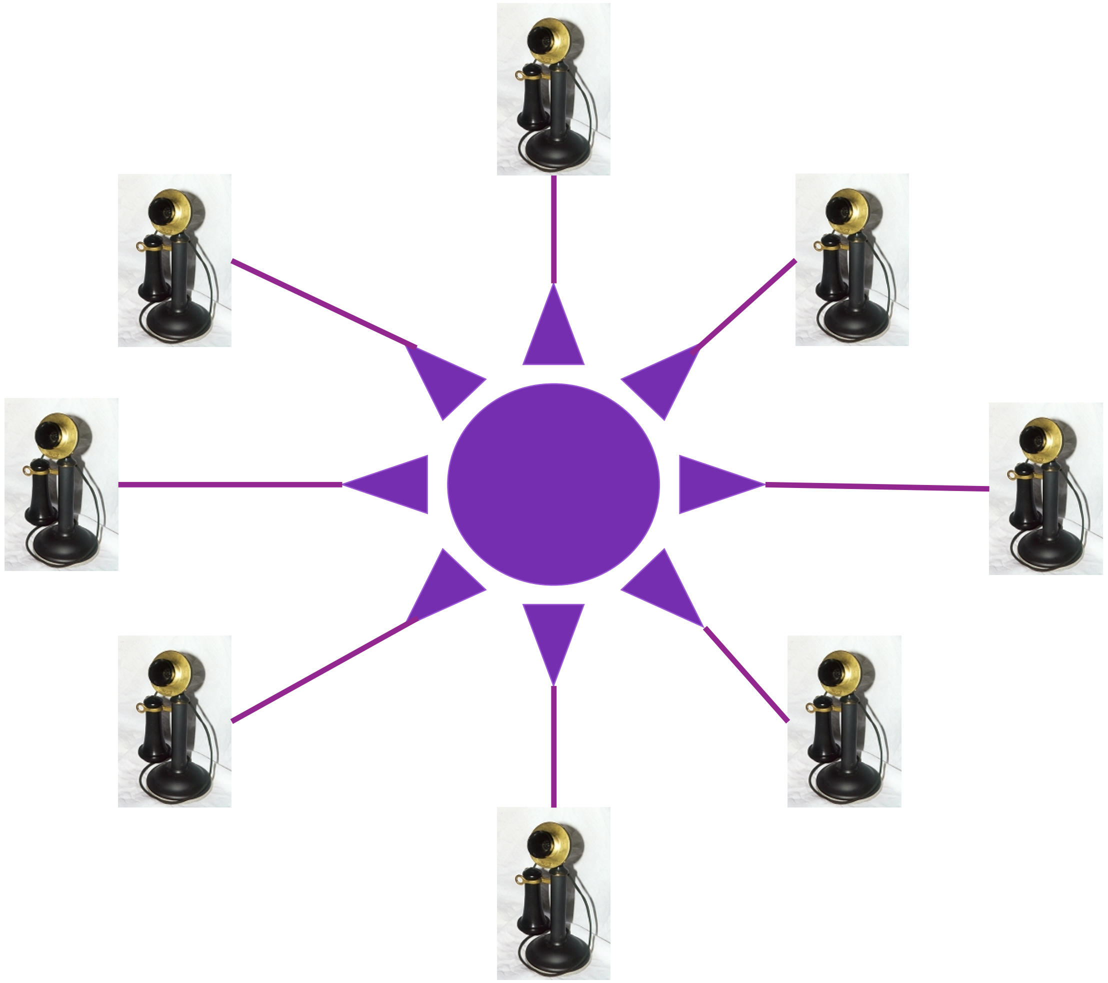
But no redundancy

Another approach – the party line (“bus”)

- Everybody rings
- Signal via hook-twiddle
- Everybody listens

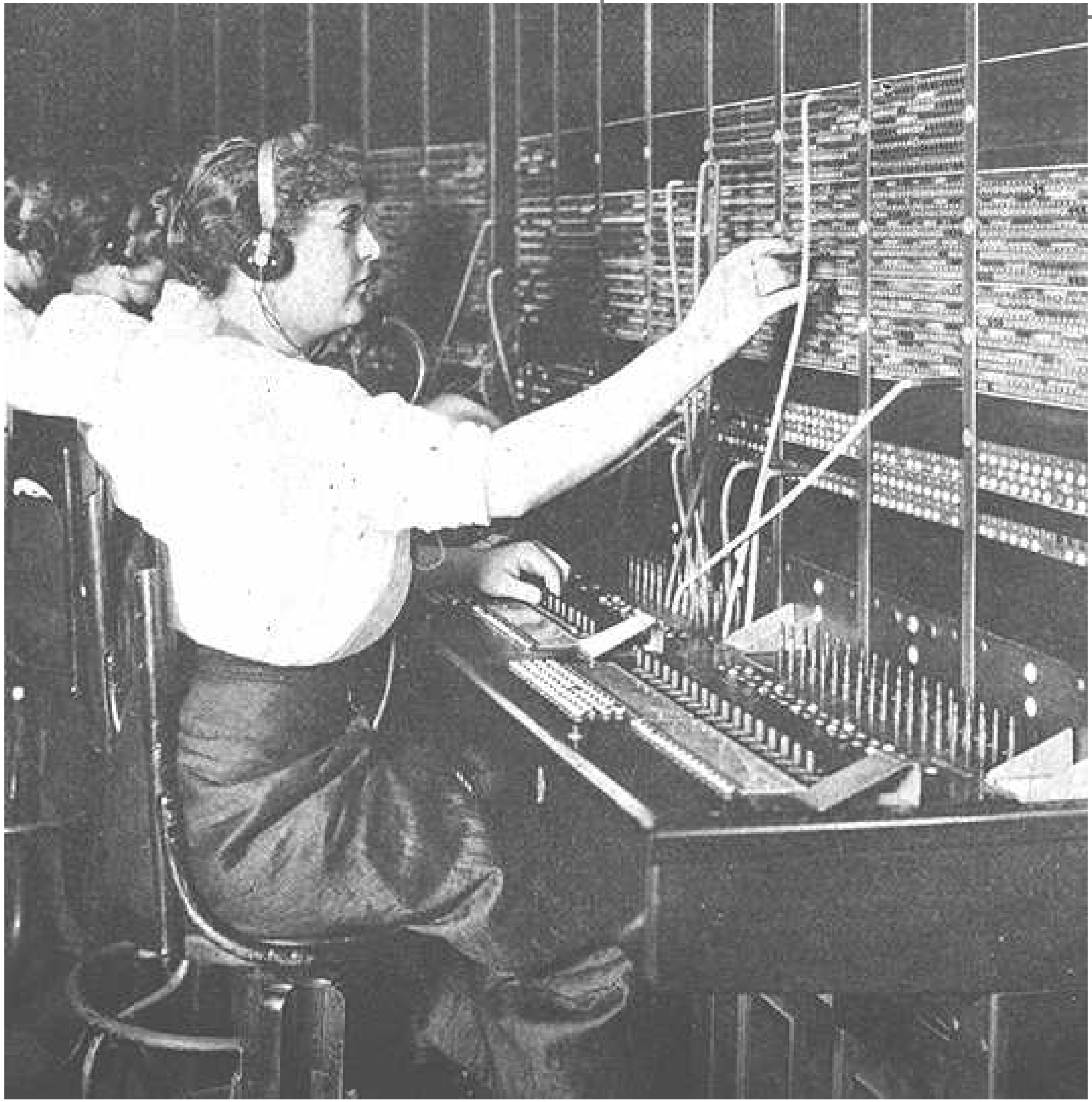


Or a star ("hub-and-spoke" - ~1877)

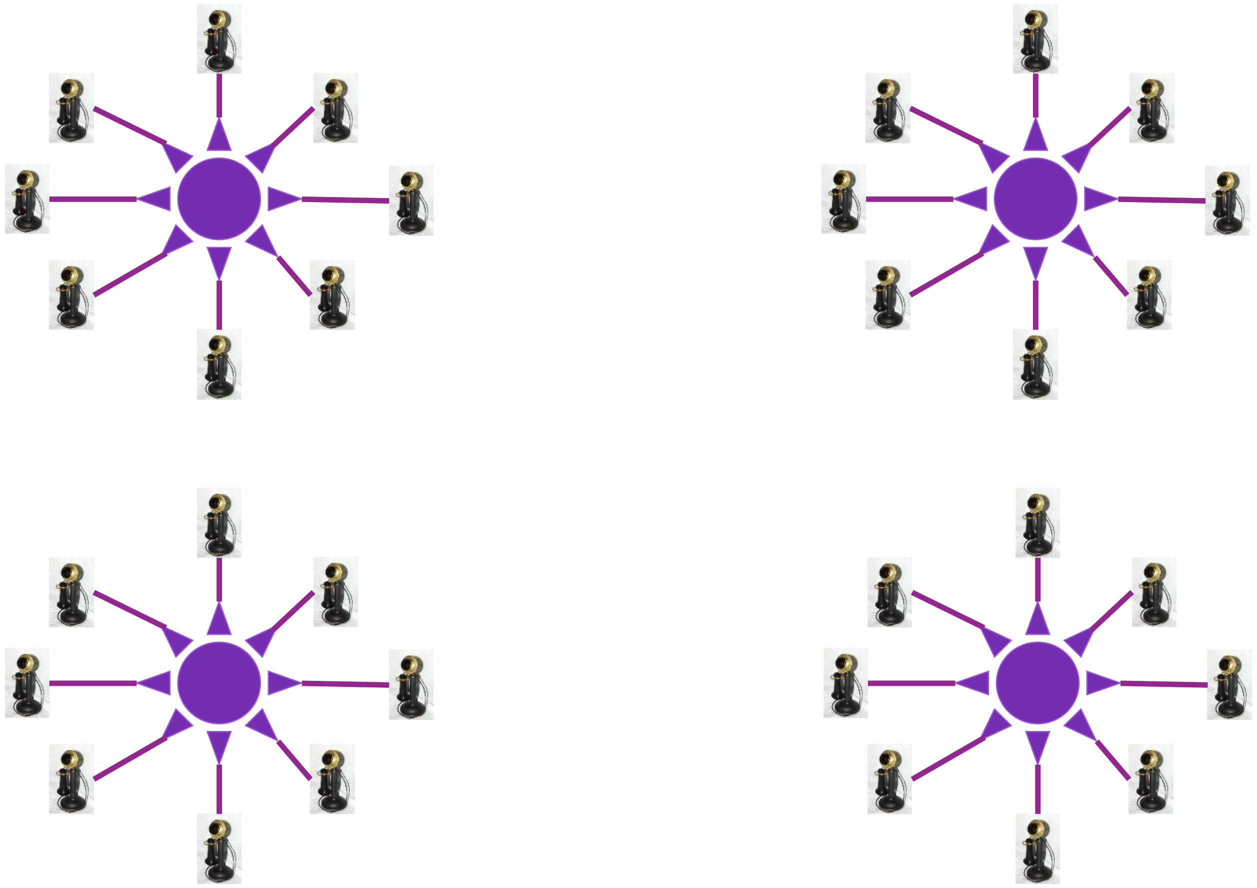


What/who is the star?

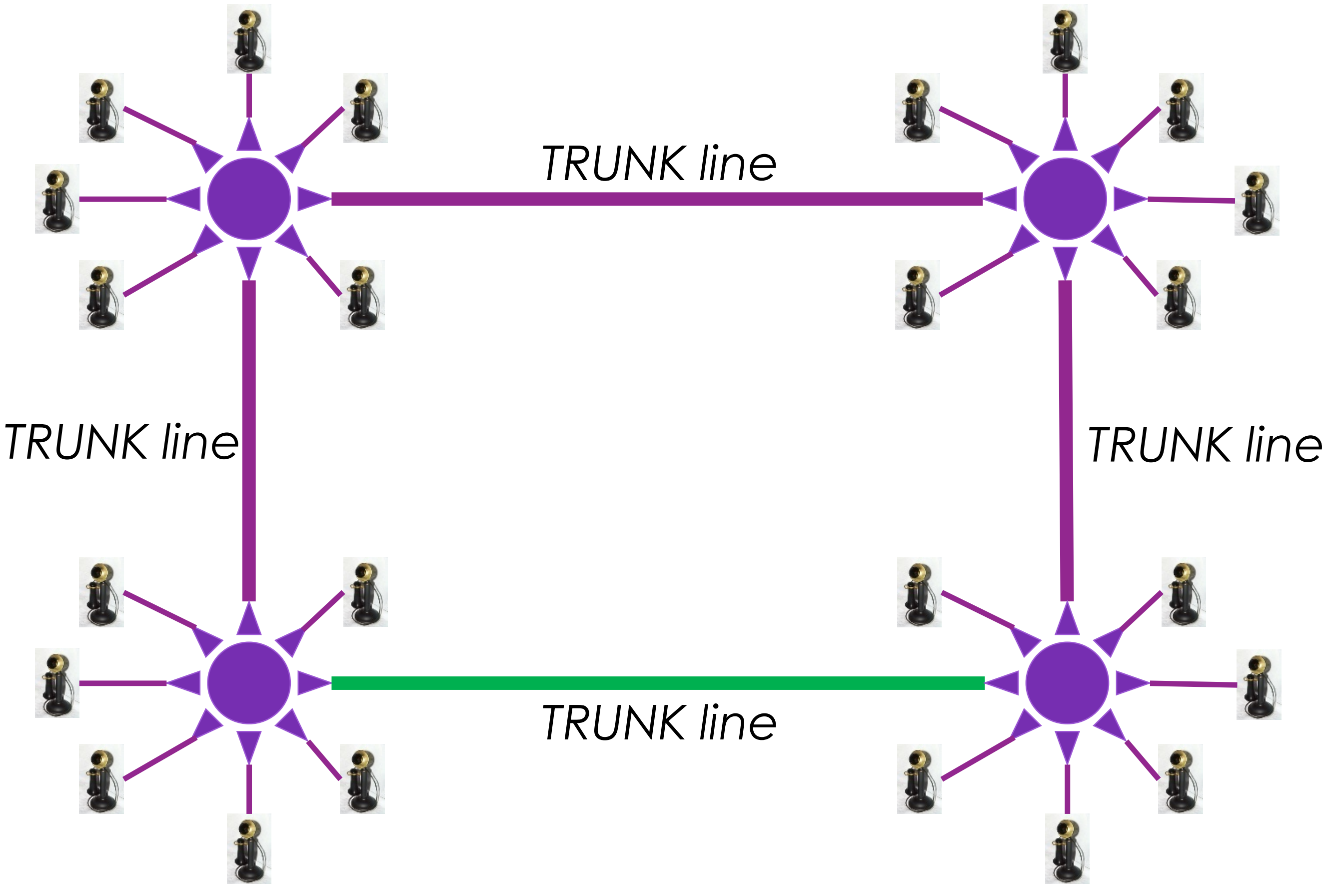
A crossbar switch, any-to-any connectivity



Islands of connectivity

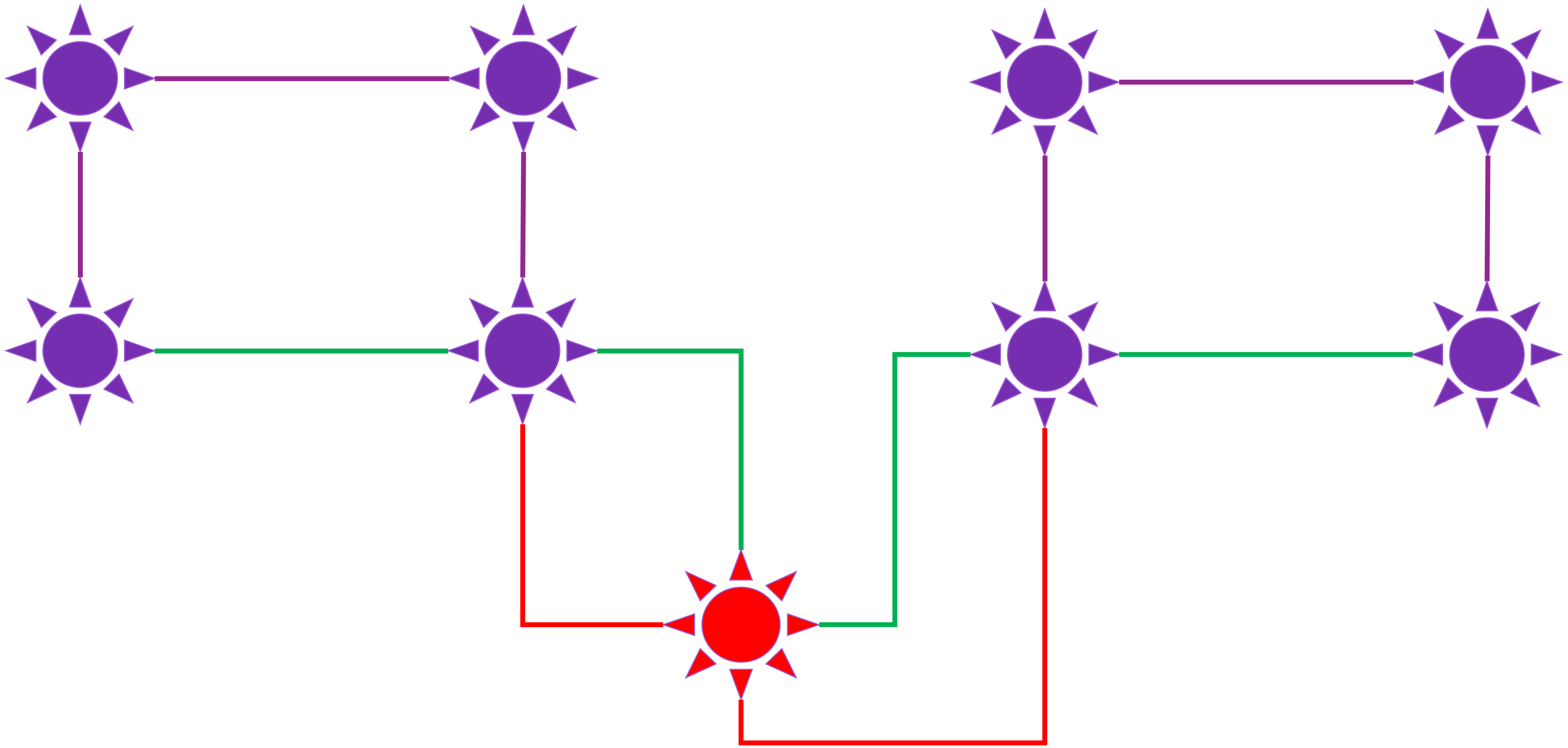


Meshing islands with trunks



- **Multiple paths**
- **Lose capacity**

Regional exchanges



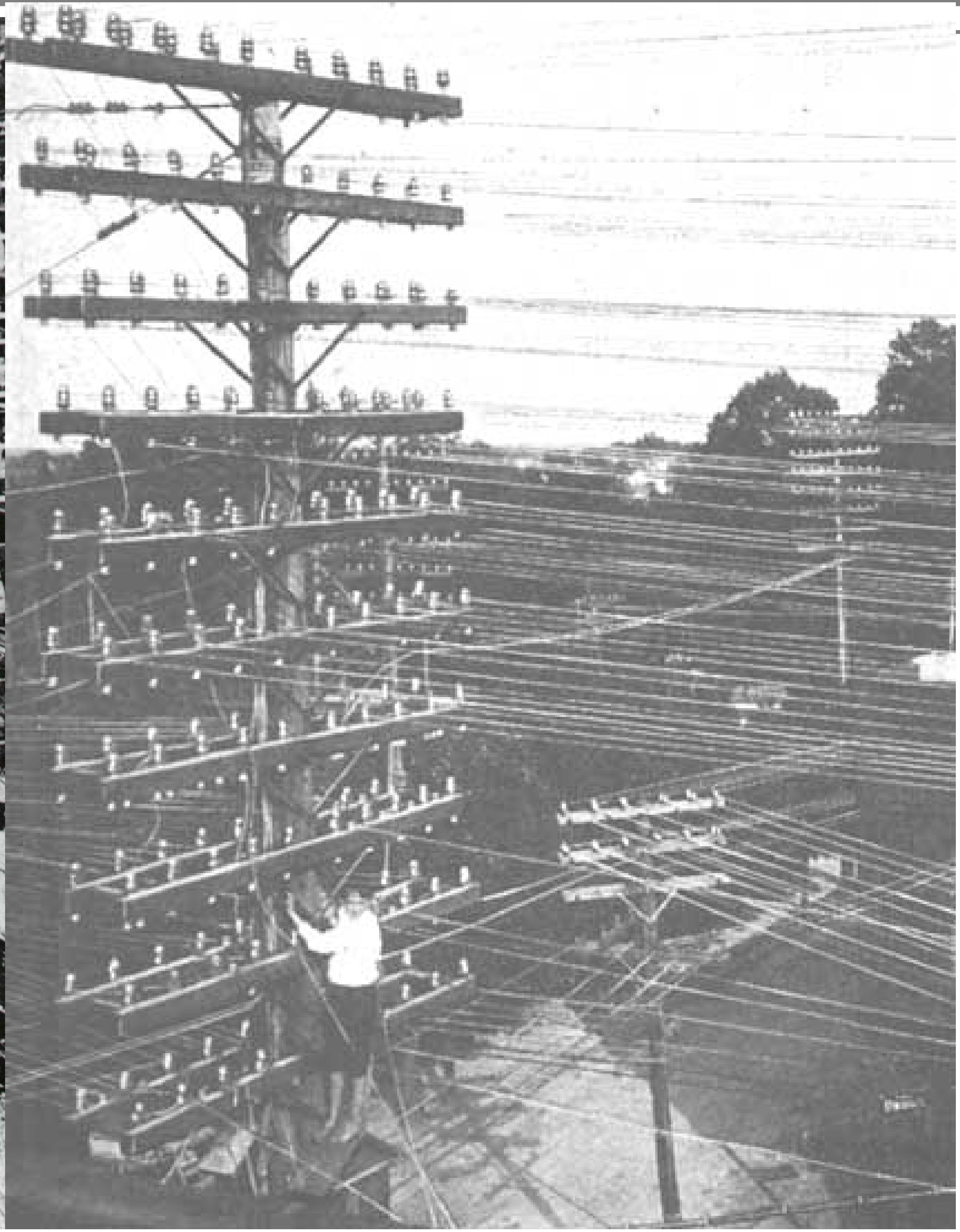
Back to "nearly fully meshed"…

- Keep adding another hierarchy of exchanges
  - Regional exchanges just link exchanges to each other

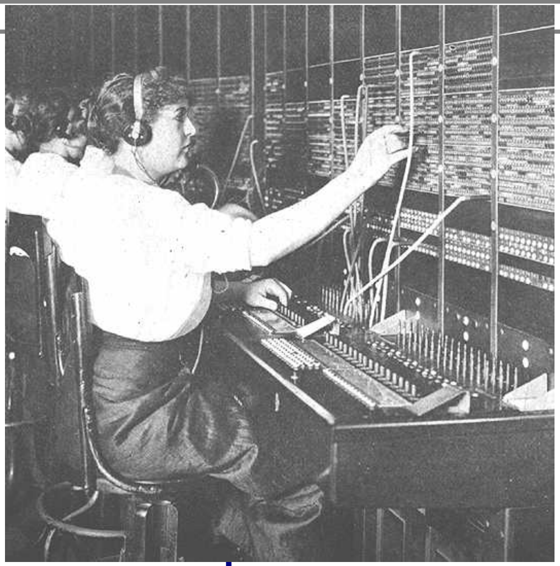
- Rely on probability to keep inter-exchange (trunk) links from saturation
  - Not everyone wants to make a call at the same time

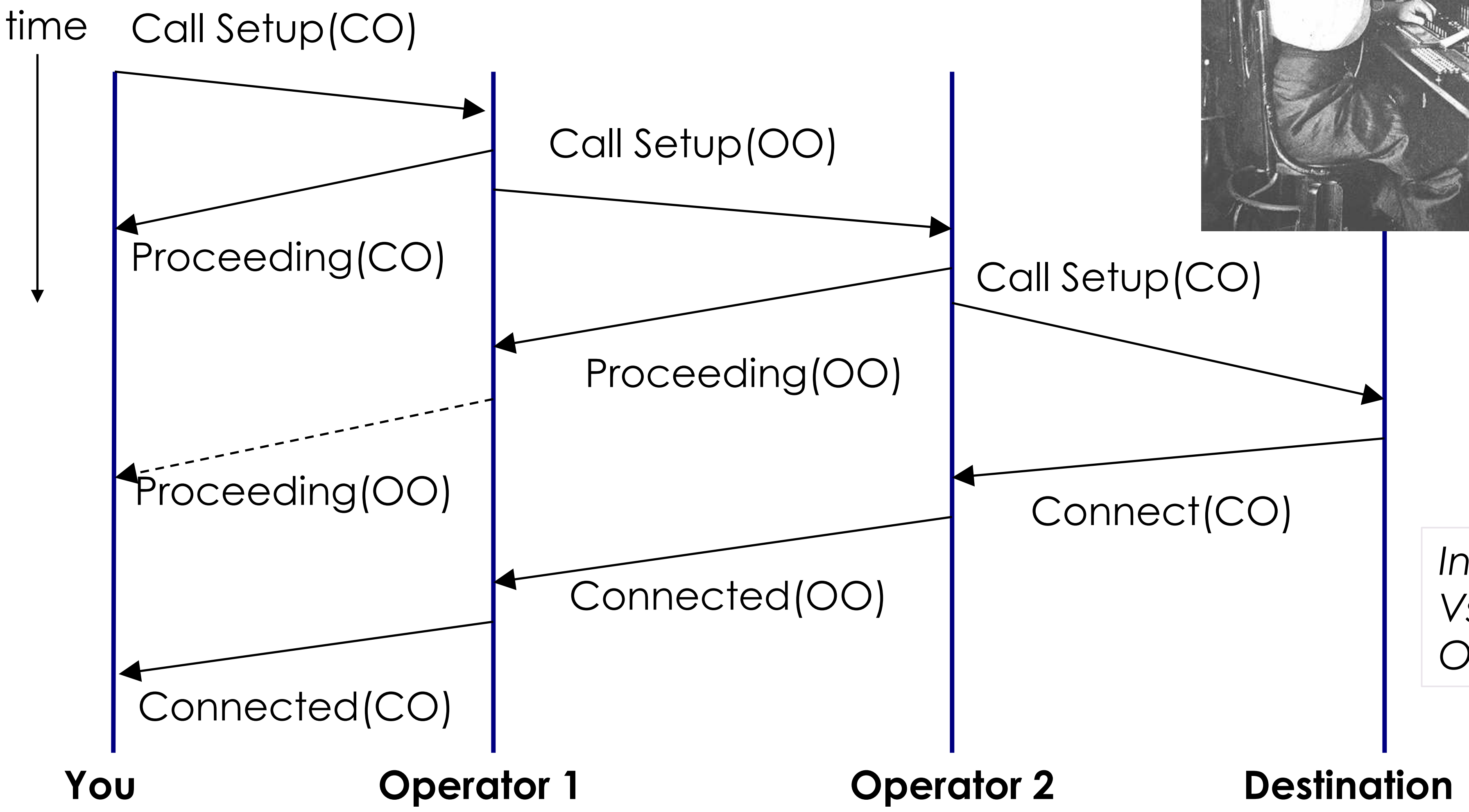
- No requirement for "direct" (one exchange) connectivity
- Provide multiple (backup) paths

- But ever more cables (or "circuits")…



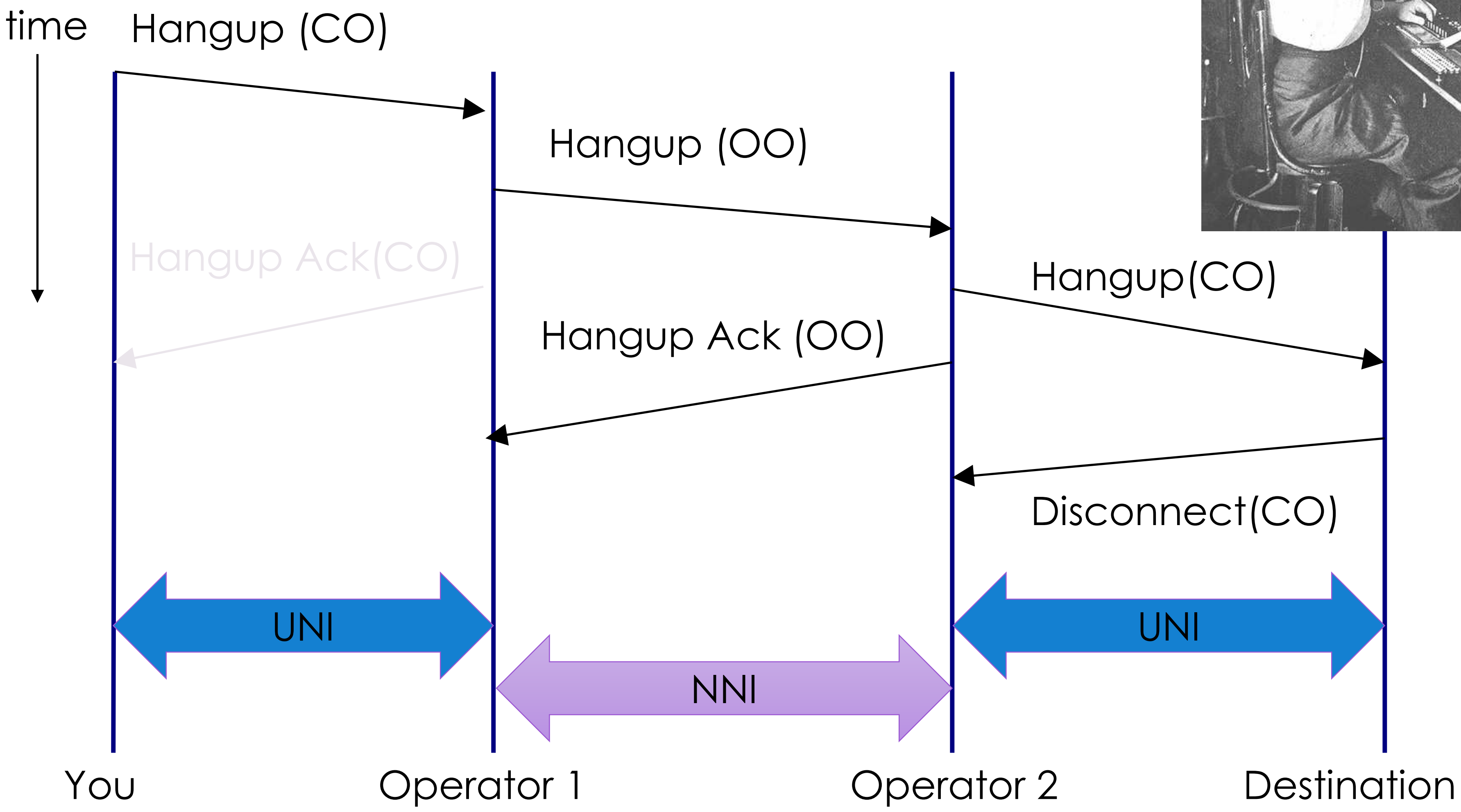
Call Signalling - Establishment

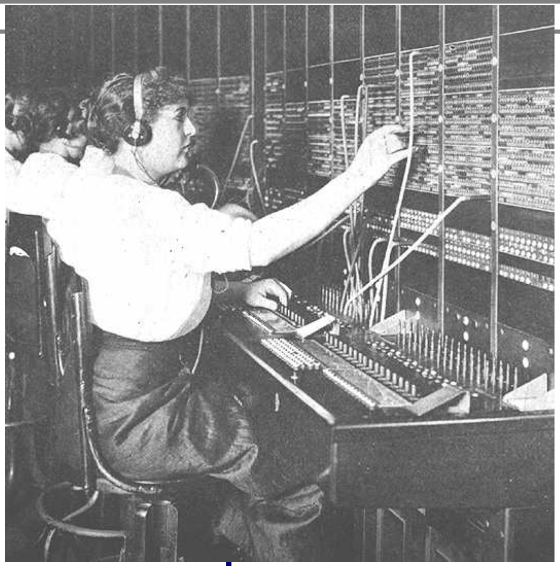




In-band
Vs
Out-of-band

Call - Tear Down (required!)





Circuit Switching

- Circuit setup
  - Is hop-by-hop
  - Can be signalled in-band or out-of-band
- Defines
  - User-Network Interface (UNI)
  - Network-Network Interface (NNI)
- Guarantees fixed (reliable) quality during call

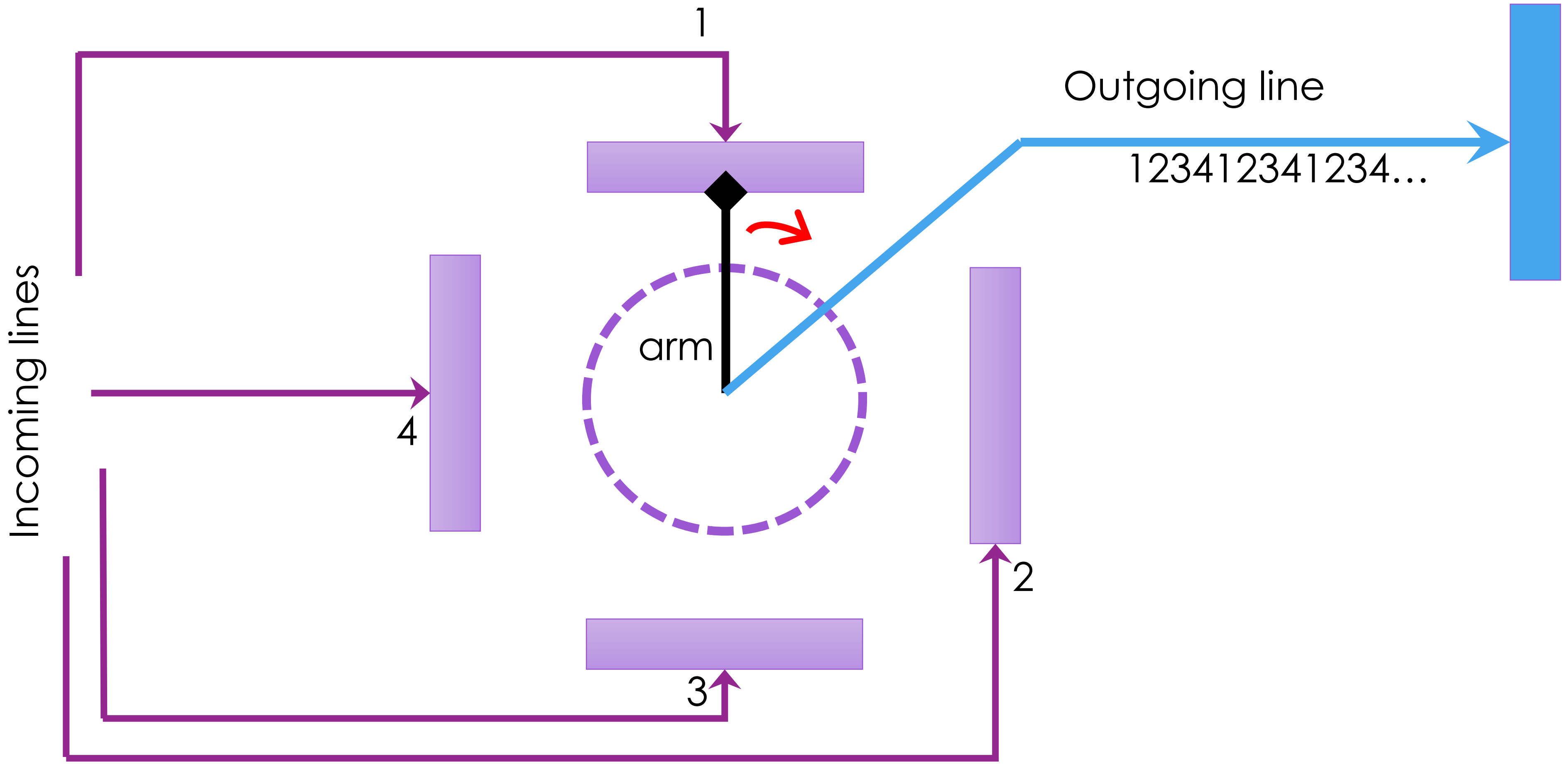
- Expensive to scale
  - Lots of wasted capacity
  - Explicit resource allocation/release
  - Trunks become major congestion points
- Multiple single-points of failure
  - Network stores end-to-end state
  - Call failure requires a new call to be set up

"Connection Oriented"

When your trunk is full…

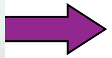
- Buy more links, or look to share it better
- Sharing = *Multiplexing* (Muxing and DeMuxing) = ‘multiple’ + ‘parts’
  - **Spatial Division Multiplexing** vs **Time Division Multiplexing** (vs …)
- Compare:
  - Circuits (it’s all yours)
  - Cells (take equal turns)
  - *(and Frames (take turns as you need to))*

Analogue TDM



Trust and Automation!

- Automated exchanges (Almon Strowger, 1888)
  - https://www.youtube.com/watch?v=xZePwin92cI
  - Pulse dialling – mimics hook twiddle
  - *Smart clients, dumb network*
    - Public Switched Telephone Network (PSTN) or
    - Plain Ol' Telephone System (POTS)



- Number (address) allocation and distribution
  - By geography, not identity
  - Scalable: Authoritative, directories, processes

Communications = Information Transmission

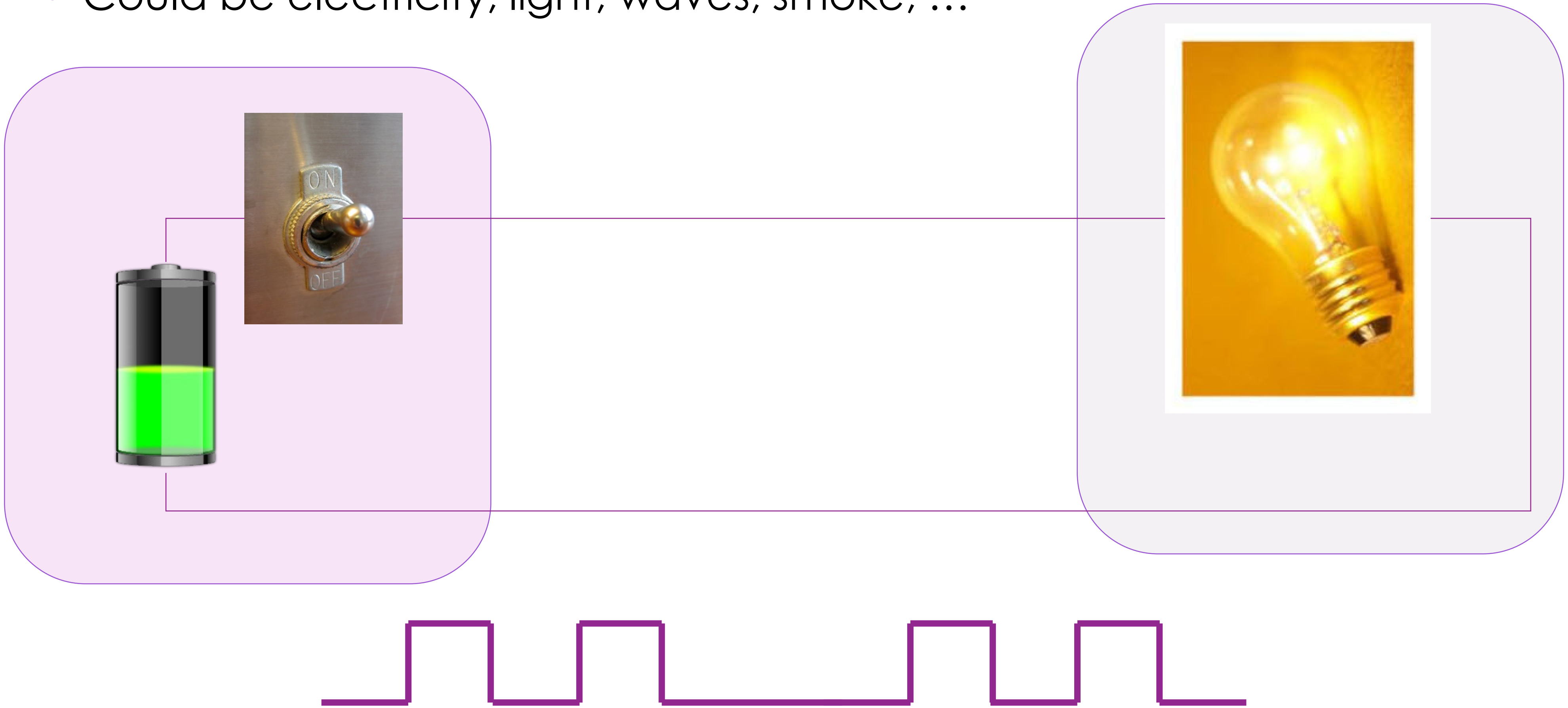
- And Transmission over a link faces many problems

  - Attenuation (loss of energy)
  - Noise (gain of energy)
  - Delay distortion (smearing)
  - Frequency cut-offs (loss of information)
  - Frequency-specific attenuation
  - …

- What the…?

A simple on-off transmission of information

- Could be electricity, light, waves, smoke, …



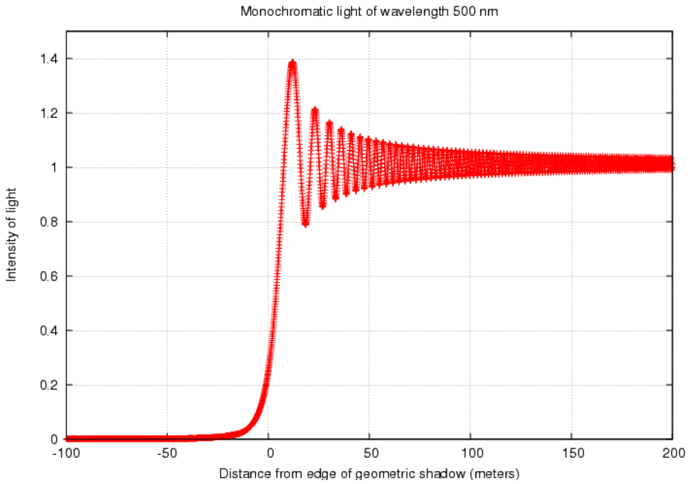
Problem: make it faster

- Smaller, faster, narrower pulses
  - But this breaks down
  - Too small (too faint)
  - Too narrow (too brief)

- Real world:
  - lightbulbs brighten and dim, not on/off
  - Switches are not instant, nor consistent

Analogue/digital

- Digital is powerful, easy to replicate, regenerate, manipulate – but is artificial
- **Nature is analogue**, it abhors a sharp (digital) edge
  - Knife-edge experiment
  - ElectroMagnetic radiation at high (harmonic) frequencies, electricity inverters
  - Nature loves sine waves – EM, sound, fluids, …
- You need to think in frequency-space



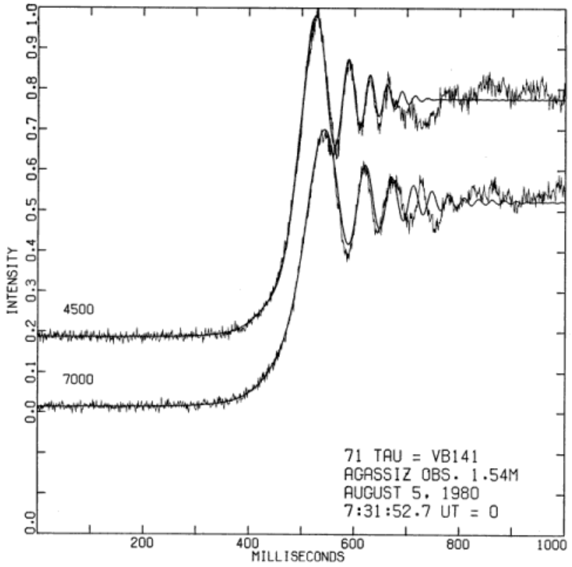


FIG. 1(a). The emersion of 71 Tau observed at Agassiz. The two curves are labeled by the approximate filter wavelenths. This figure shows the fit with both secondary and primary objects. Note the limb distortion effects at 700 ms.

Maths alert!

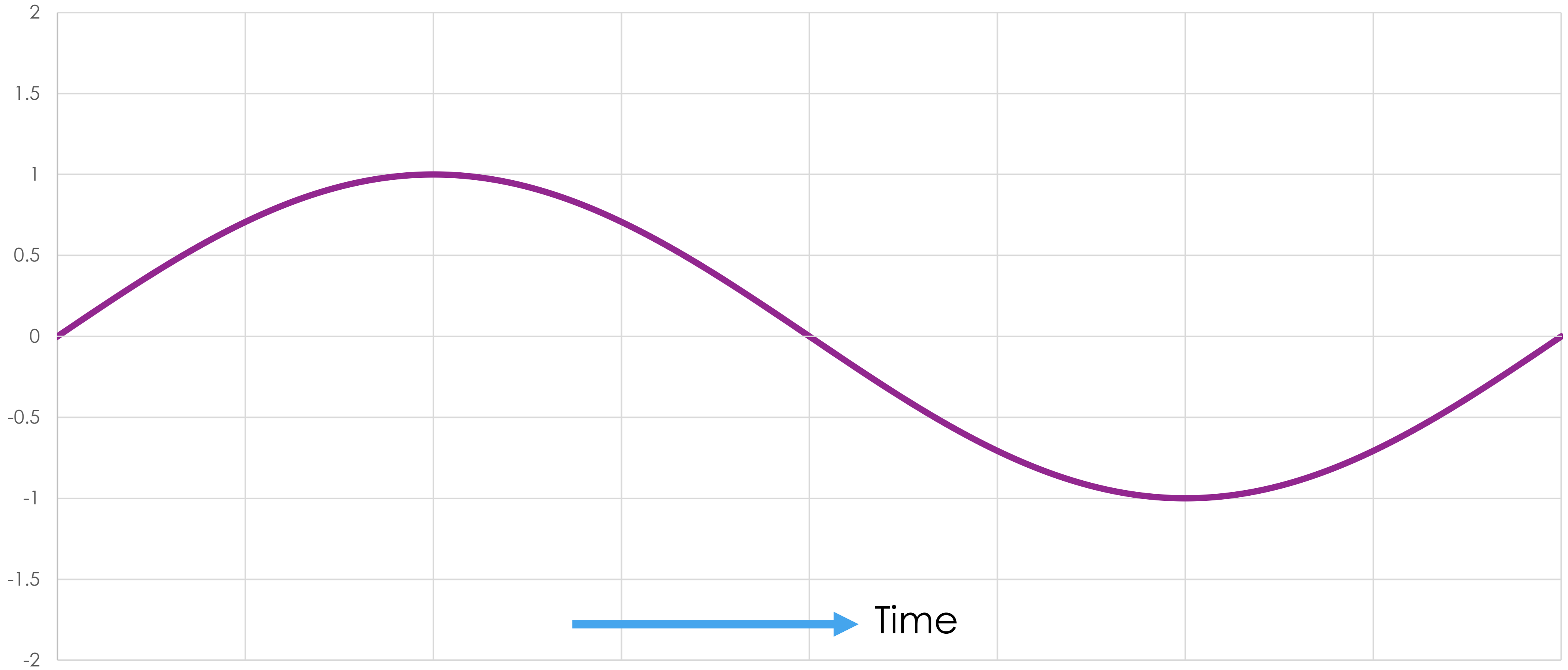
- Concept of Fourier transformation/calculation
  - Fundamental frequency, harmonics

  - *Any reasonably well behaved function* ***g(t)*** *with frequency* ***f*** *can be written as*

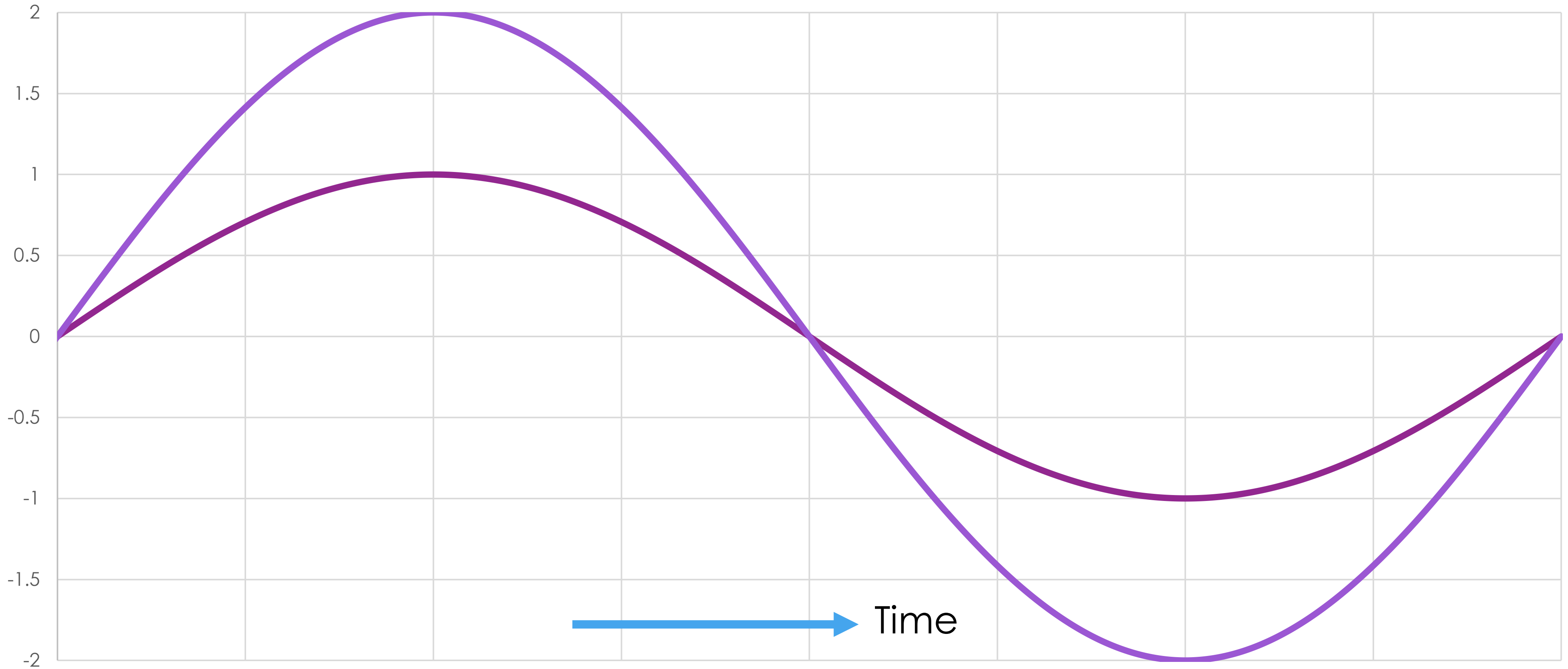
$$g(t) = \tfrac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

  - Or: Give me <u>any</u> reasonable curve, and I can draw it by adding up a bunch of sine waves…

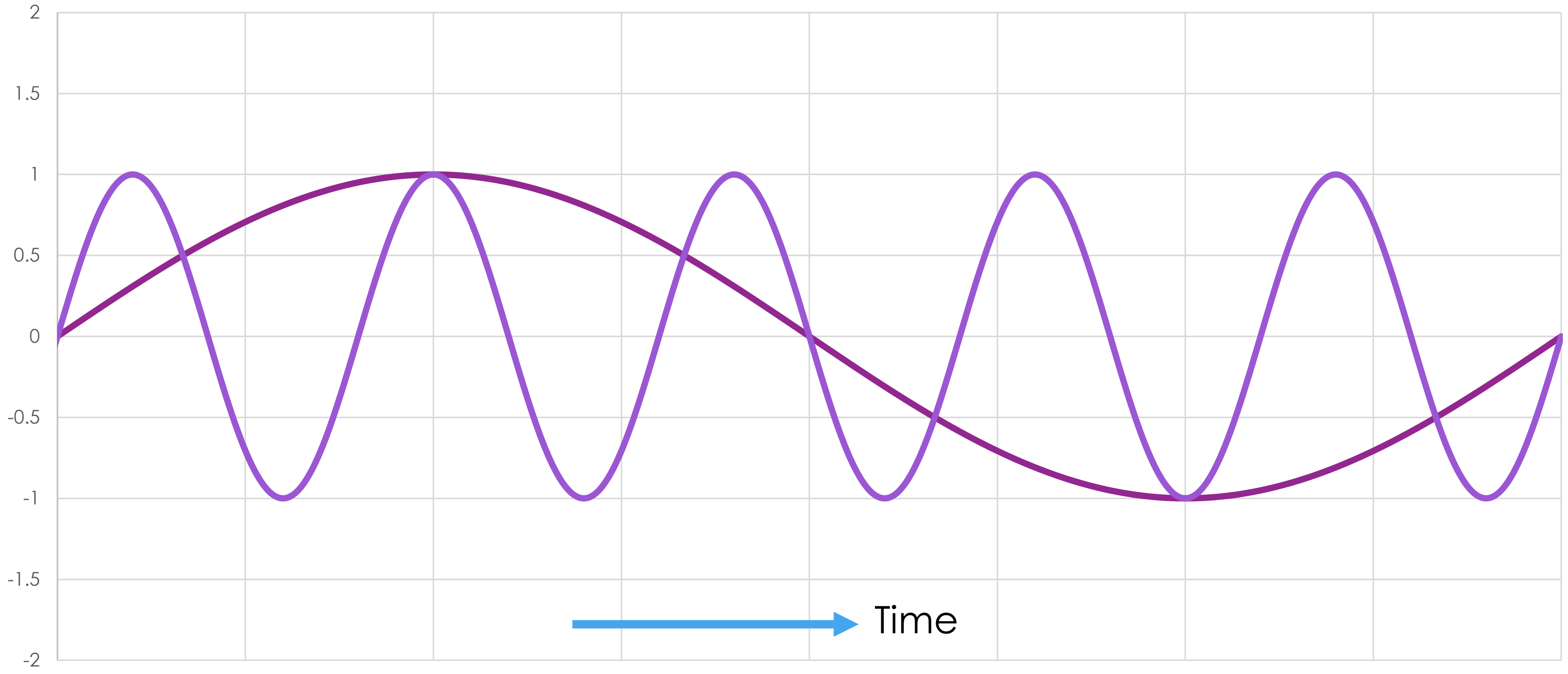
Simple sine wave



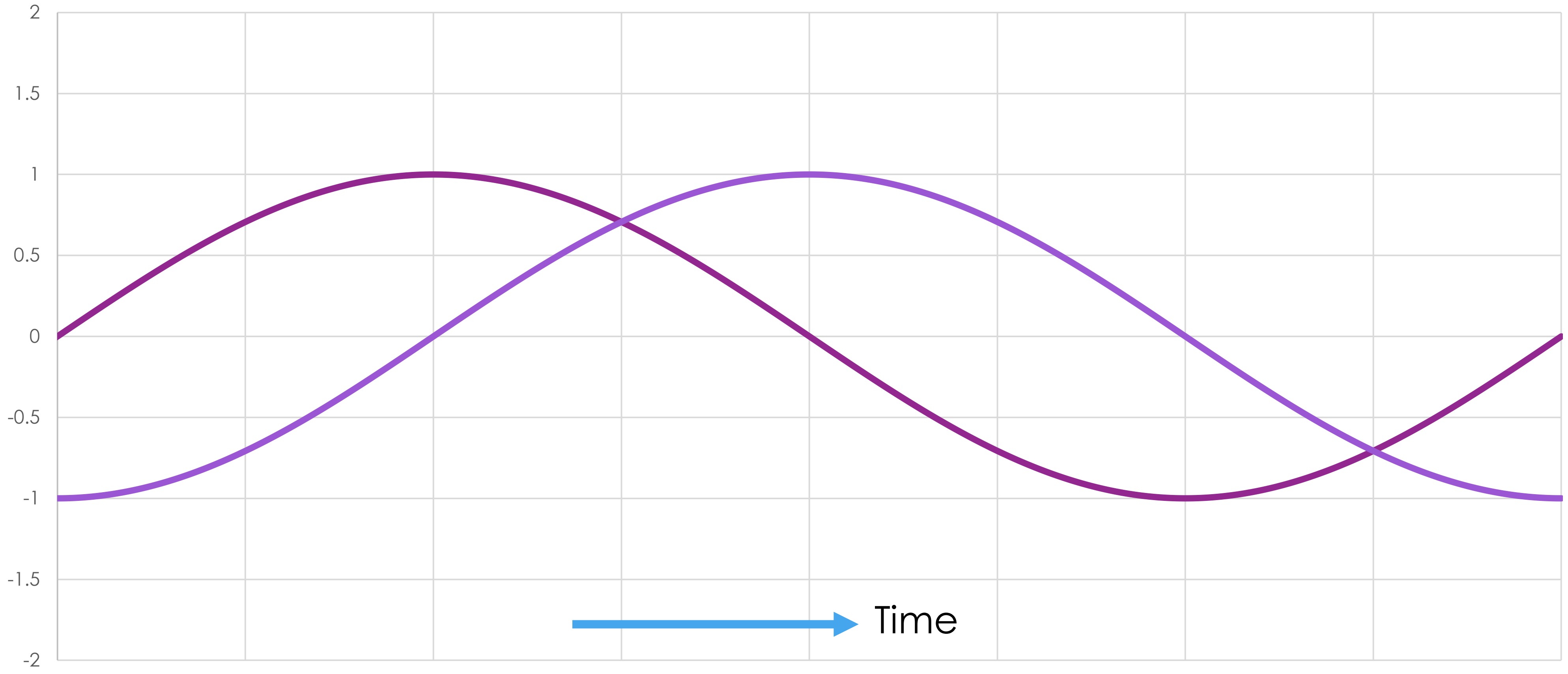
Amplitude change



Frequency change



Phase shift



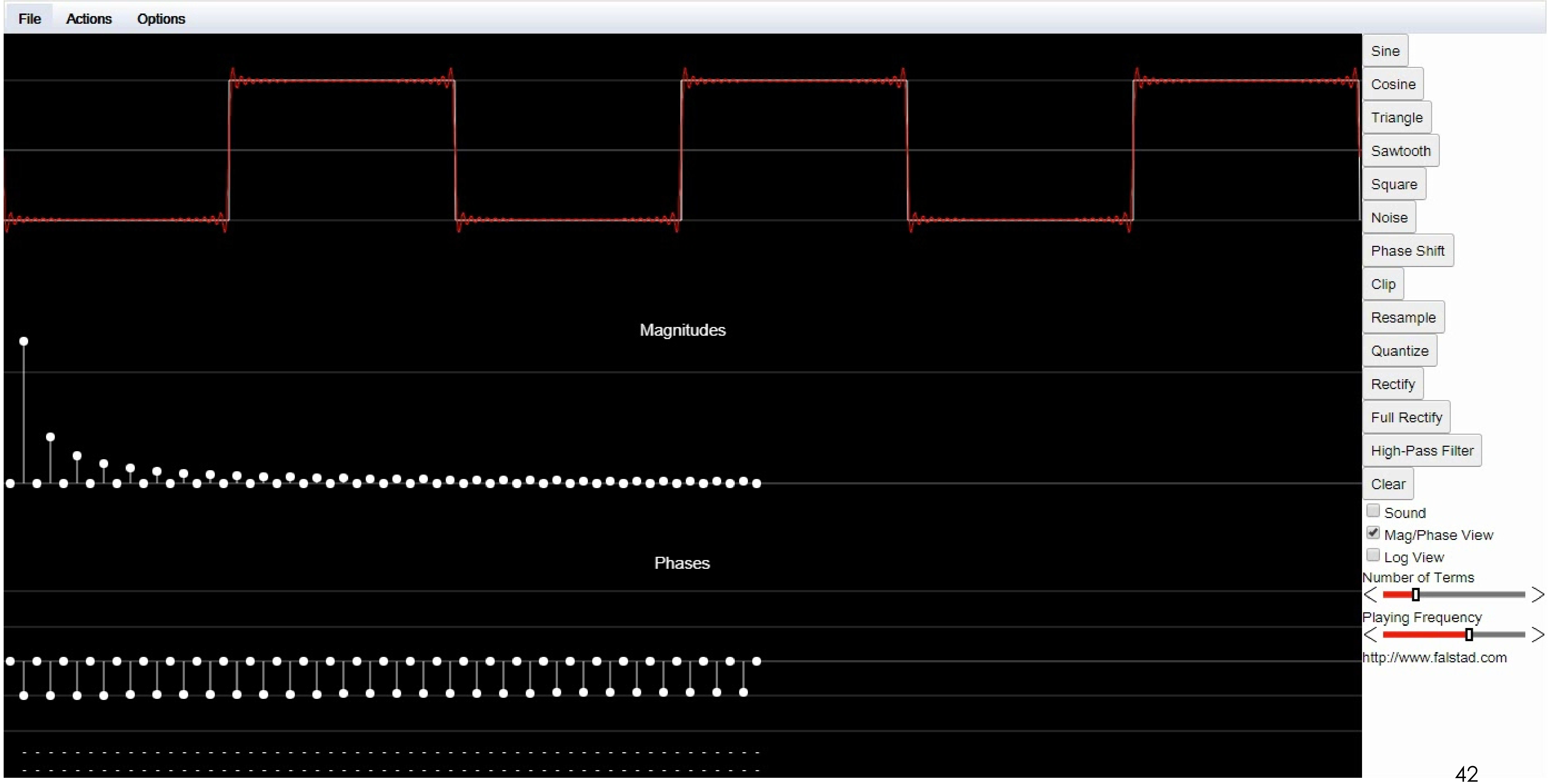
Turning functions into component waves

Fourier transforms

http://www.falstad.com/fourier/Fourier.html

- Sine waves -> Triangular waves, sawtooth waves, square waves
- Frequency cutoffs
  - High-pass/low-pass filters – nature doesn’t like high frequencies
  - Attenuation windows
  - Frequency-specific distortion

Component waves

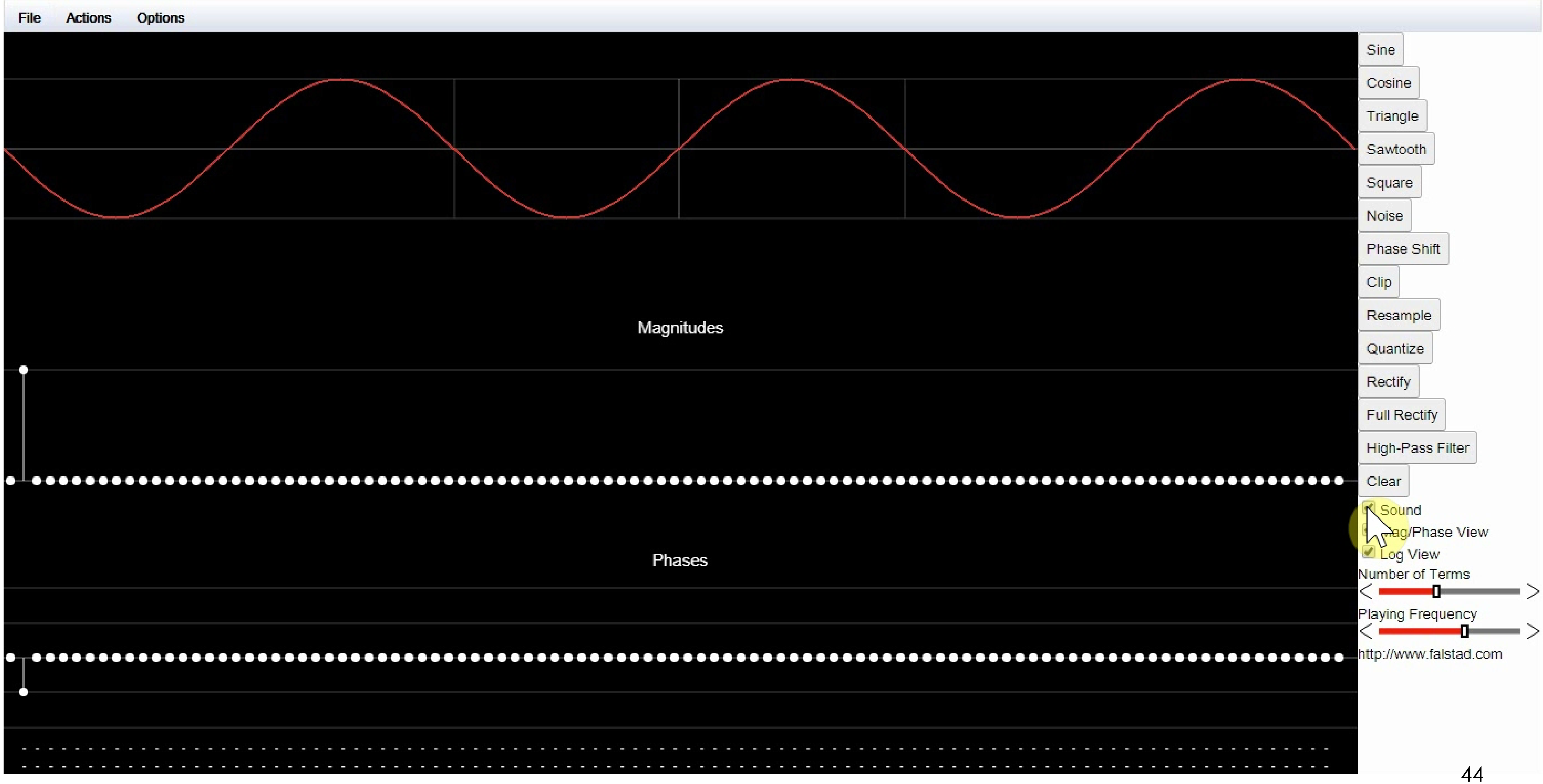


Turning functions into component waves

Any curve?
https://youtu.be/QVuU2YCwHjw

- Also used in image/video, audio compression
- Frequency separation by eye, by ear?

Visual, aural separation



So how does this help?

- Electronics is *really* good at <u>creating</u> and <u>measuring</u> sine waves
  - Can modify amplitude, frequency and phase of a signal very efficiently
  - And extract that information at the other end

- Encode information

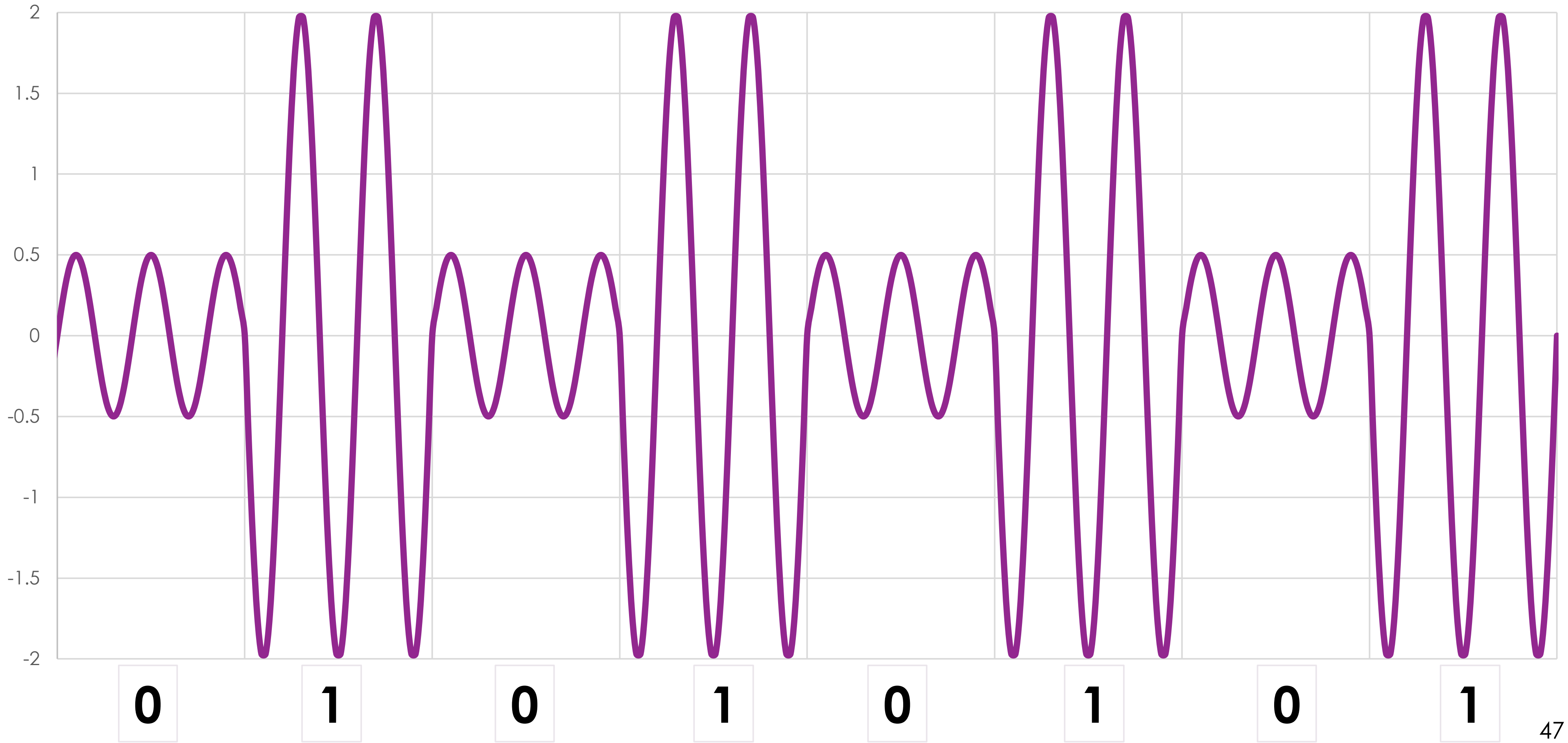
  into changes (**modulation**)

  of a basic (**carrier**) signal, or wave

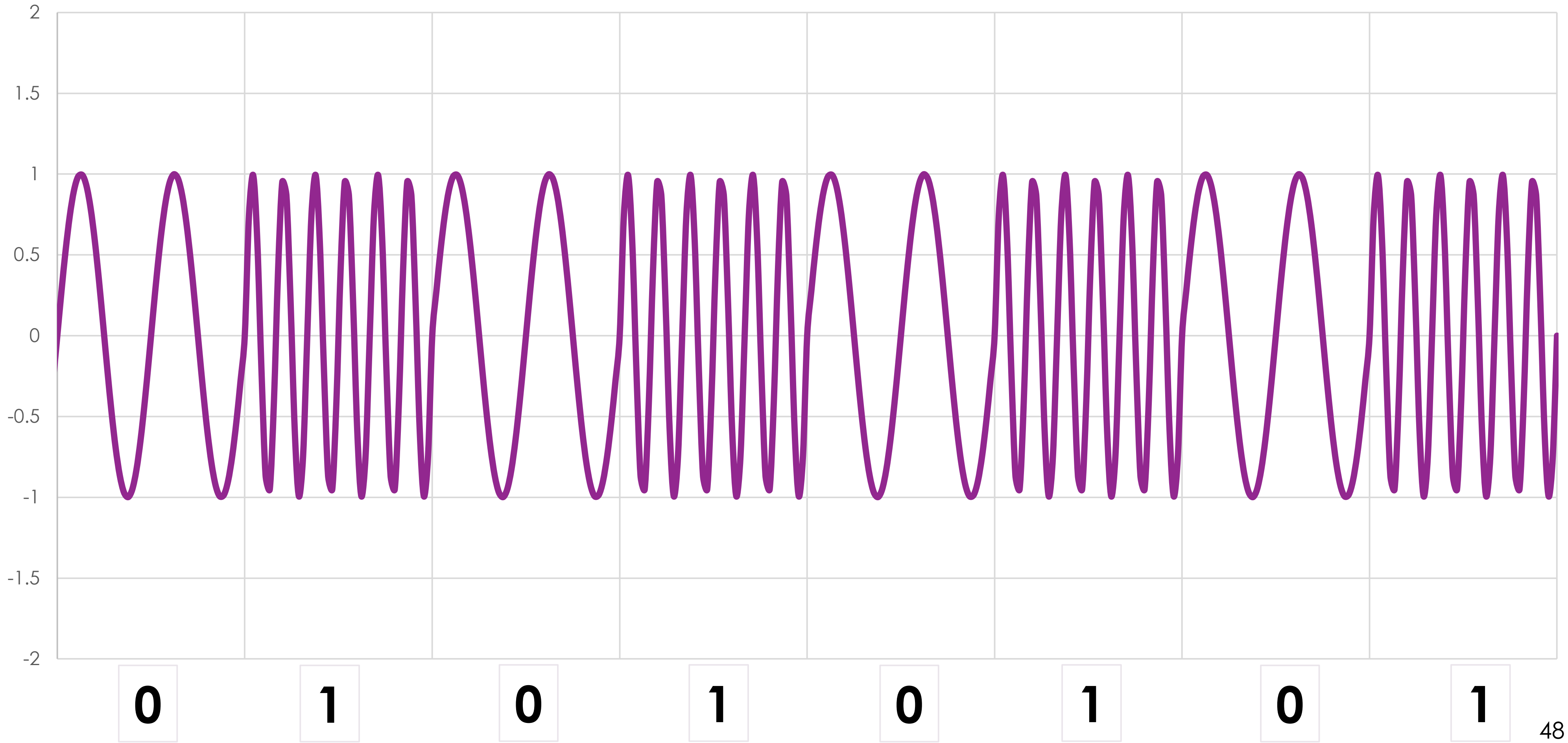
Modulation

1. Modulation - Turning information (bits) into analogue signals
2. Demodulation – Turning analogue signals into information (bits)
    1. Mo-dems do both.
3. Given a nice sine wave, how do we encode information in it?
    1. Take its fundamental waveform and tweak
        1. Its amplitude
        2. Its frequency
        3. Its phase
        4. Or a combination

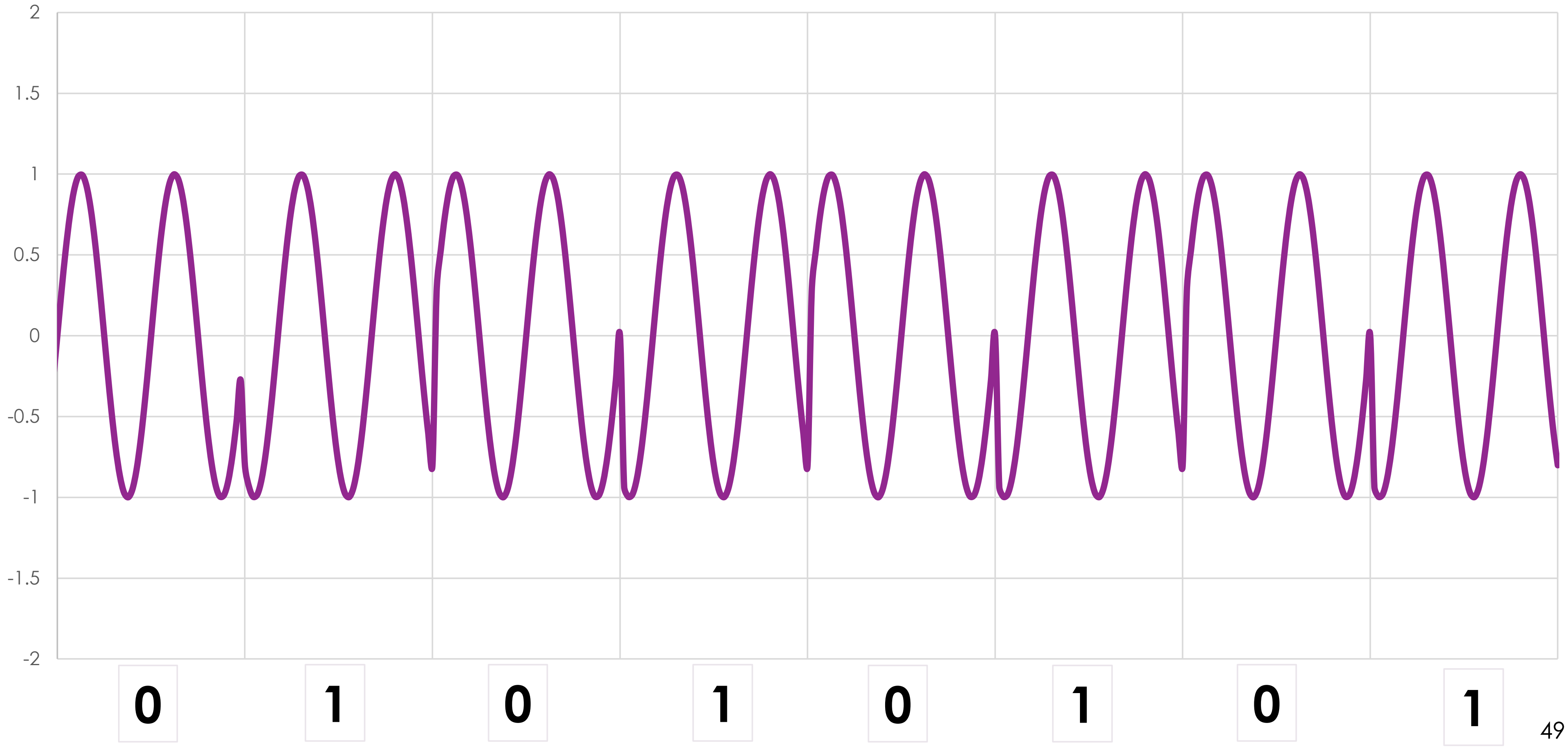
Amplitude Modulation



Frequency Modulation



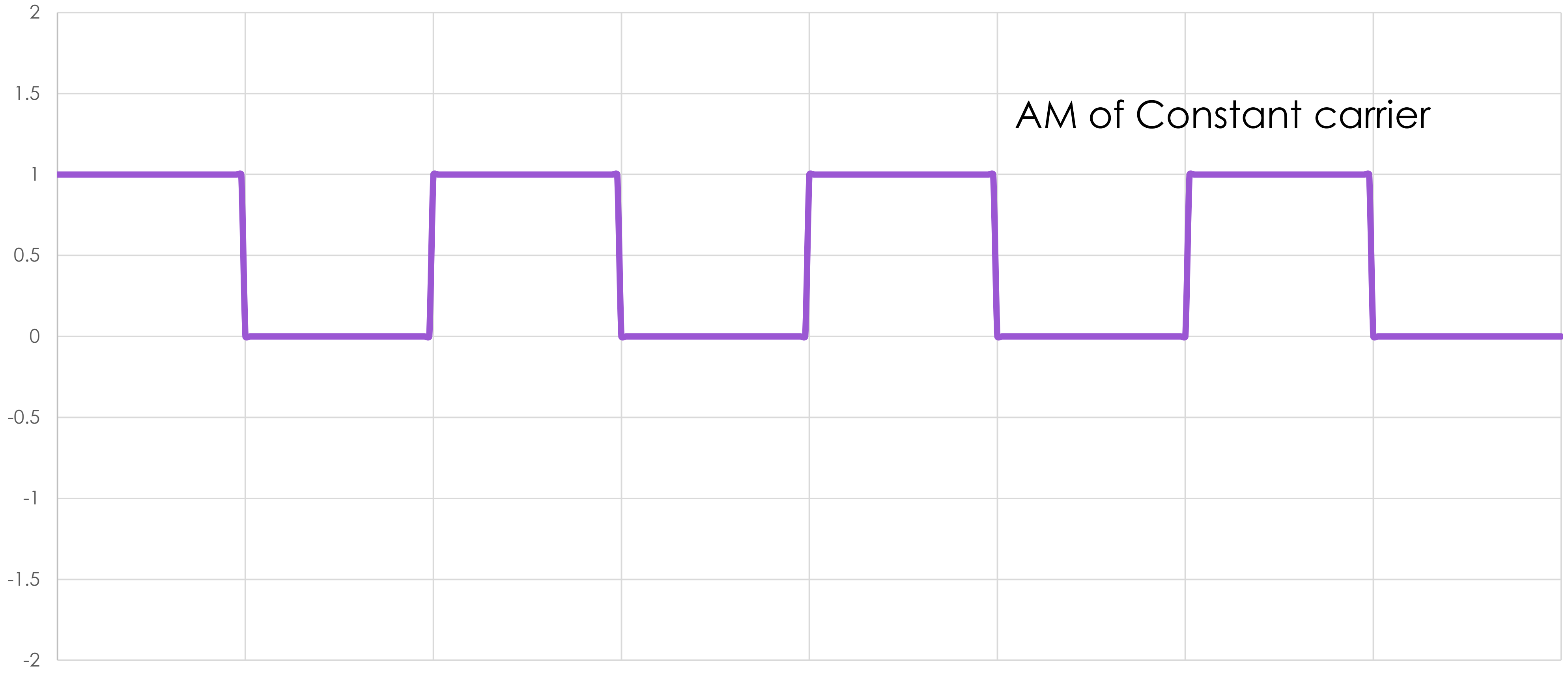
Phase Modulation



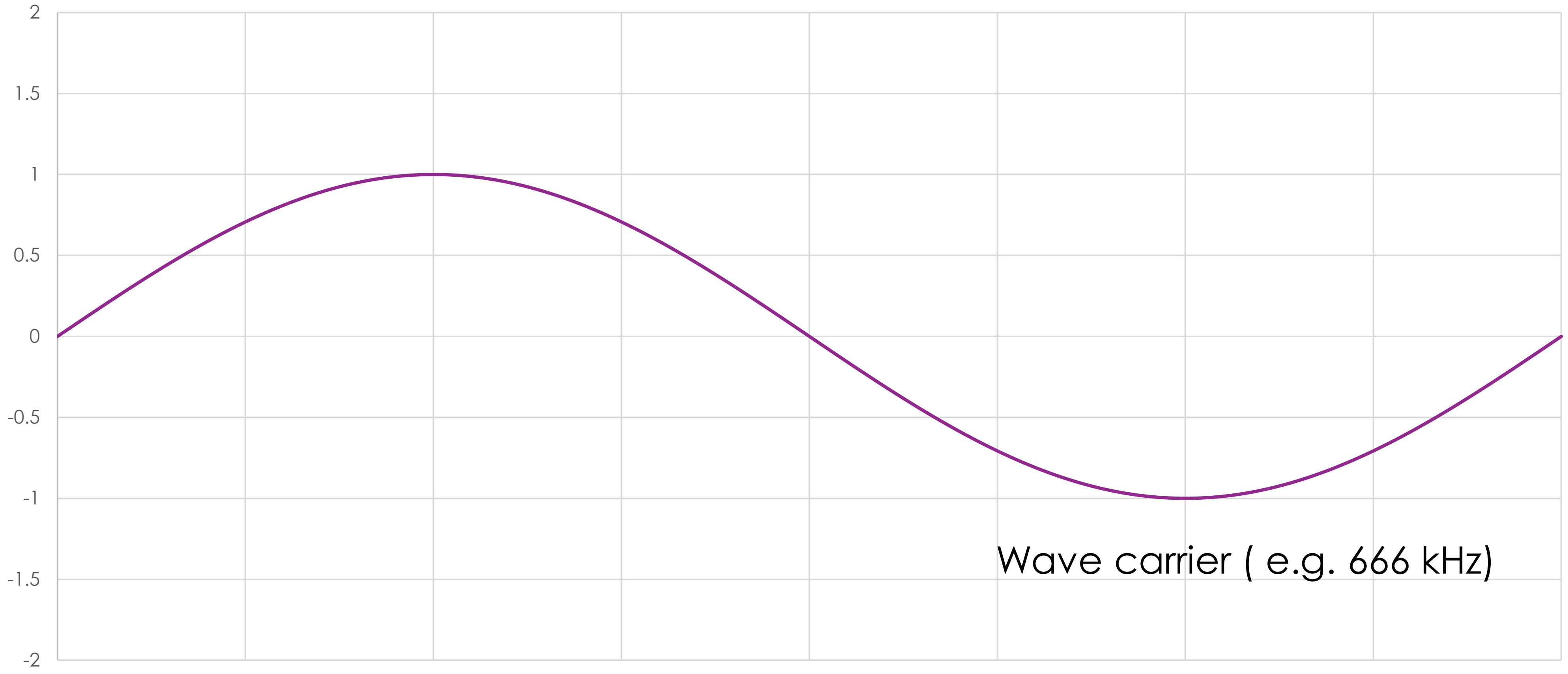
Modulating a carrier

- The “carrier” is the underlying transport “wave”
- Can be a constant (DC) “voltage”
  - Up/down or just On/Off
- Can be a wave (AC) to tune into

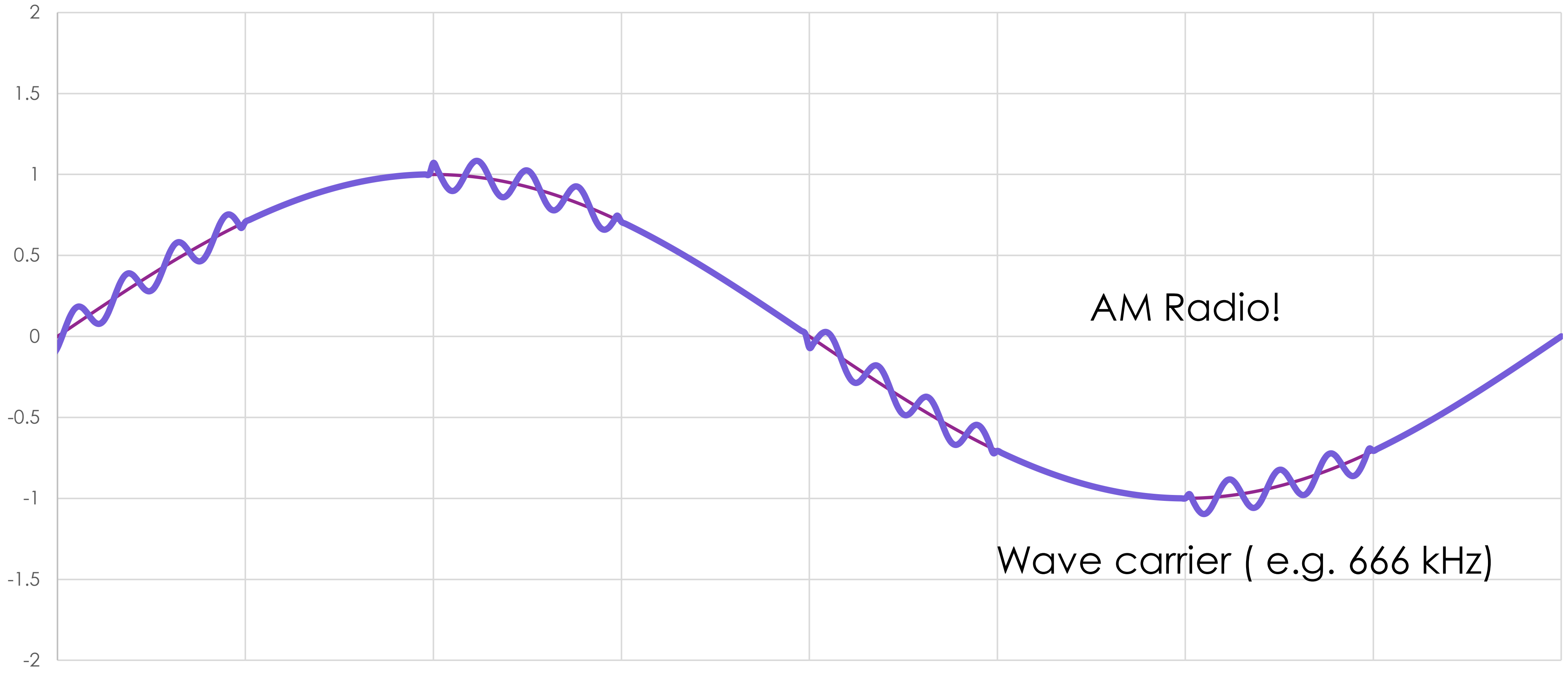
AC/DC signalling (baseband)



AC/DC signalling (passband)



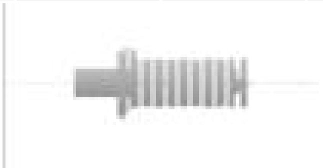
AC/DC signalling (passband)



Combining AM/FM/PM

- Dual-Tone Multi-Frequency (DTMF)
- Dial-up Modem

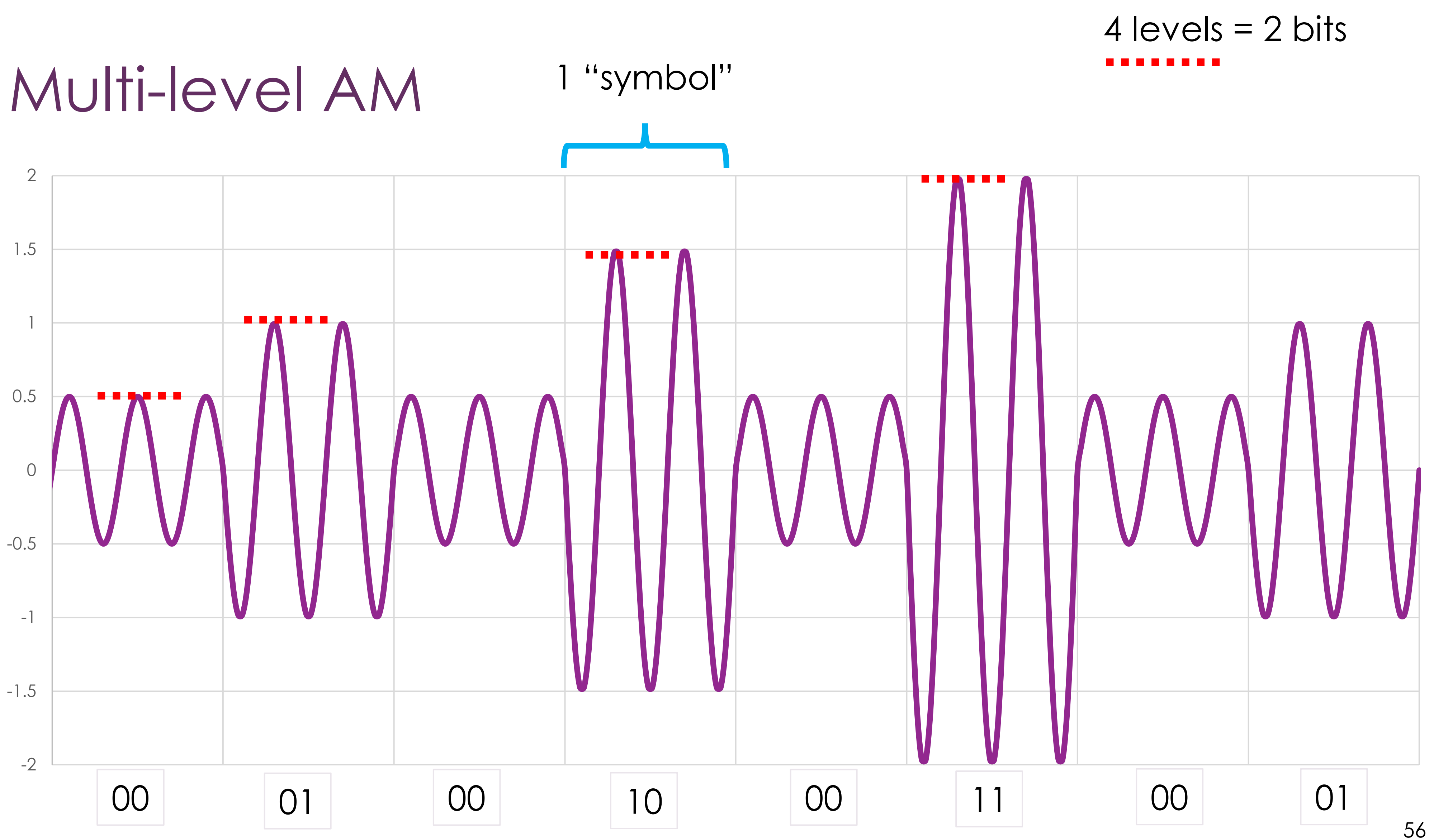
Hz	1209	1336	1477
697	1	2	3
770	4	5	6
852	7	8	9
941	*	0	#



Faster/more efficient Transmission

- More data per “cycle” – more 0/1’s in the same time
  - Multi-level AM = Amplitude Shift **Keying** (ASK)
  - Multi-level FM = Frequency Shift **Keying** (FSK)
  - Multi-level PM = Phase Shift **Keying** (PSK)

Multi-level AM

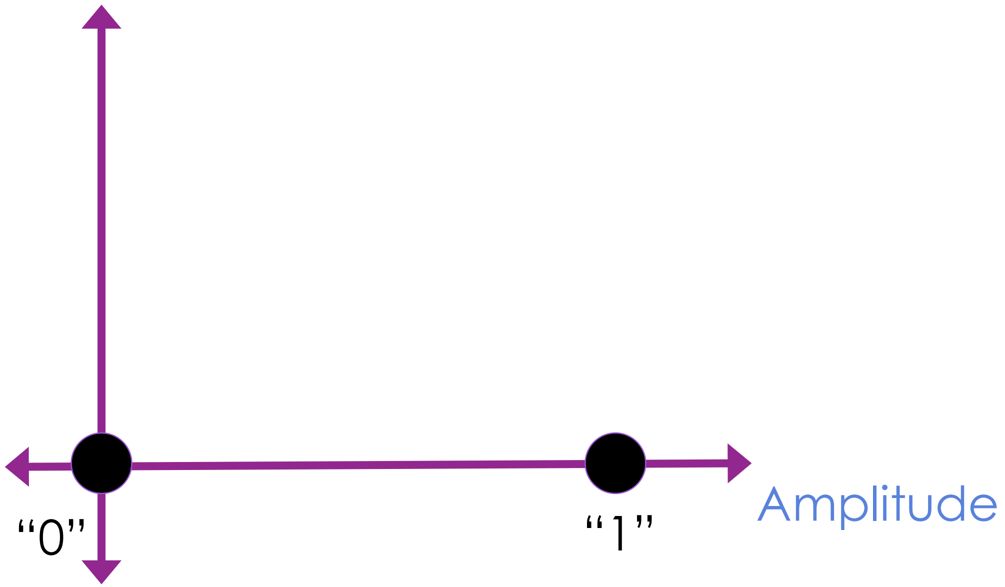


Faster/more efficient Transmission

- Symbol (baud) rate != bitrate
  - *Baud: Binary Analogue Units of Data – minimum "chunk" of data*
  - 1 symbol/second >> 1 bit/second

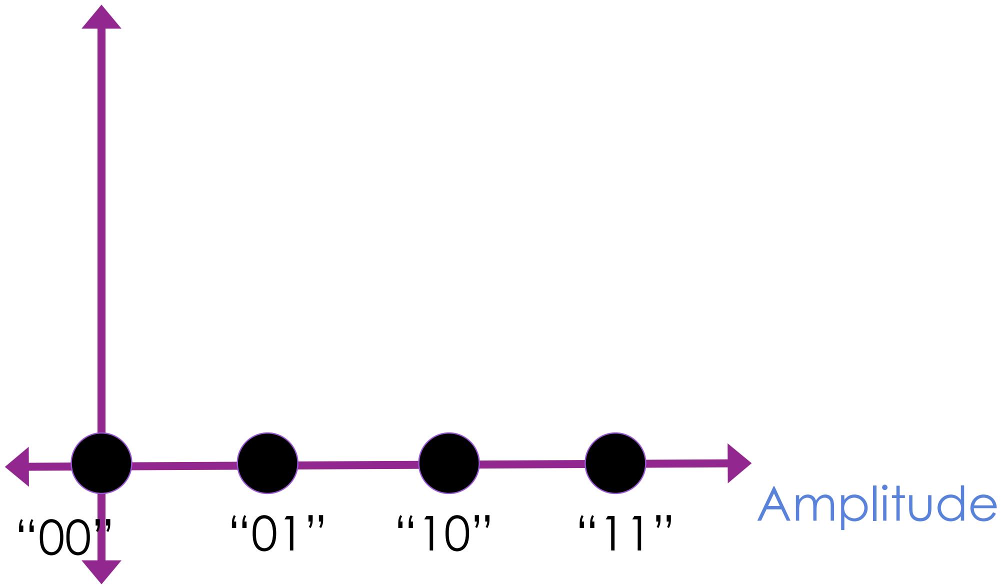
- Combine ASK and PSK to get even more bits/symbol

Constellation diagrams

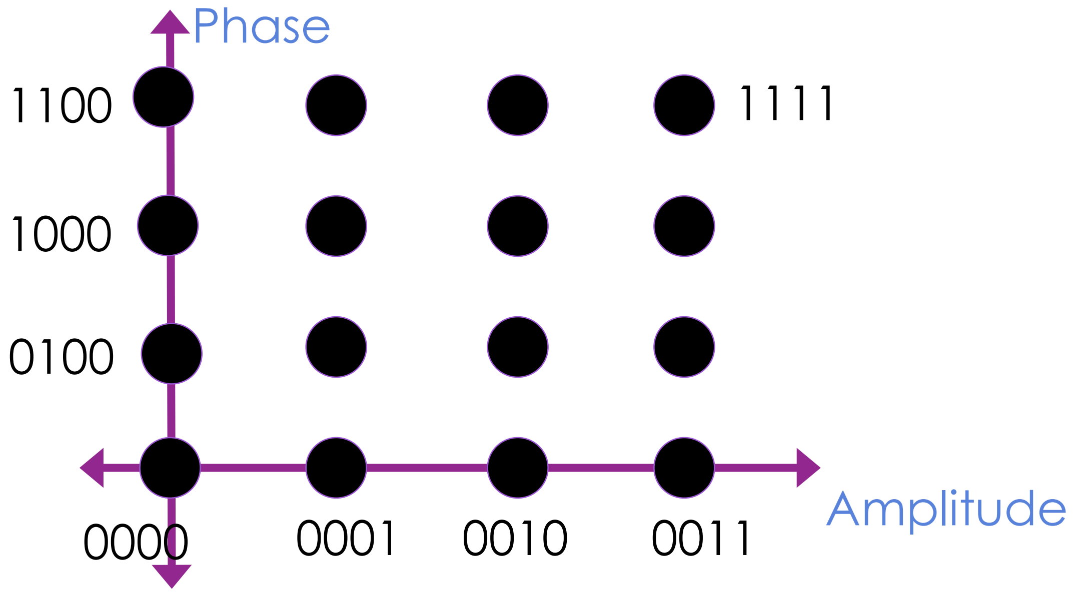


This is OOK!

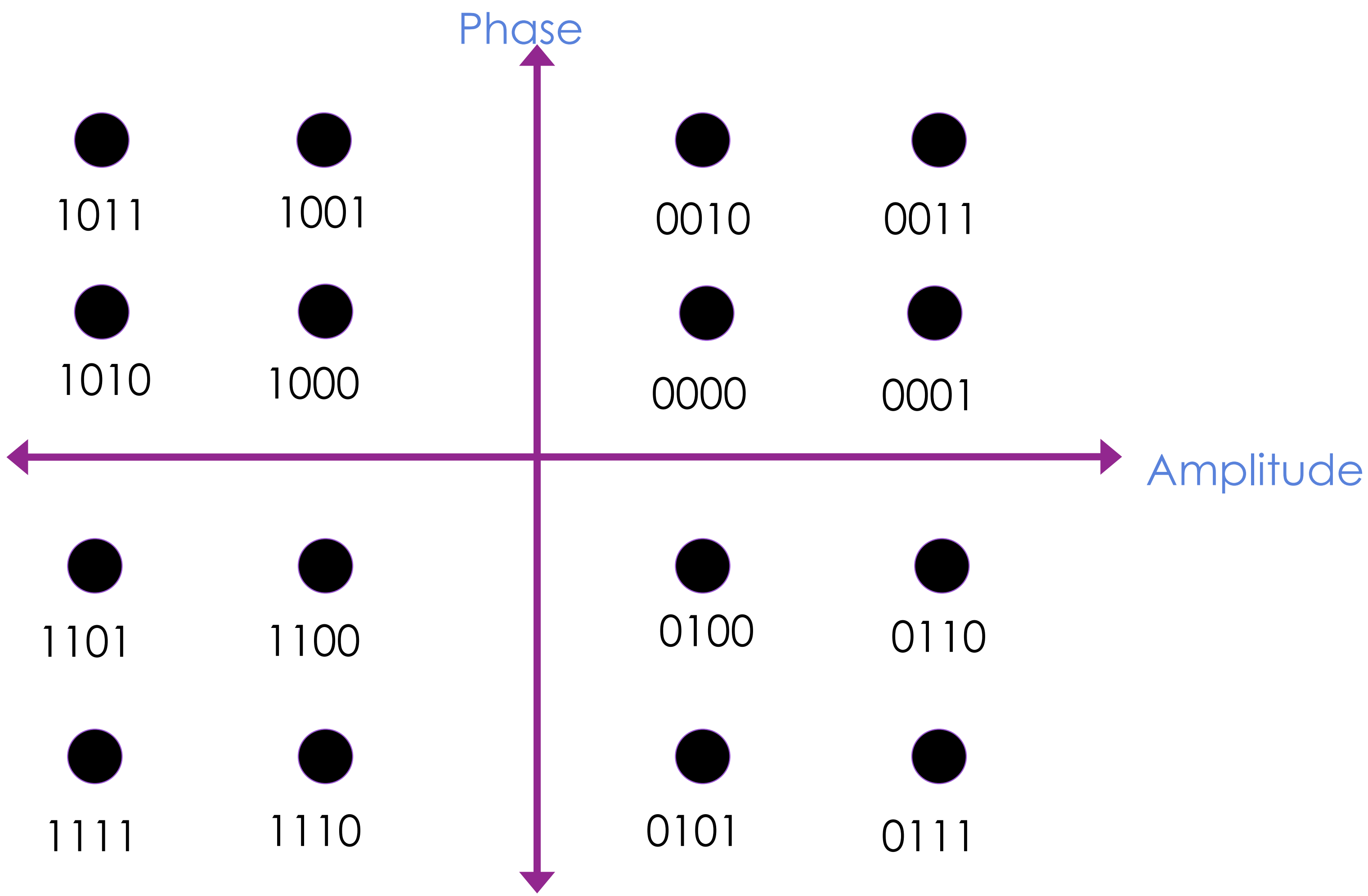
Constellation diagrams



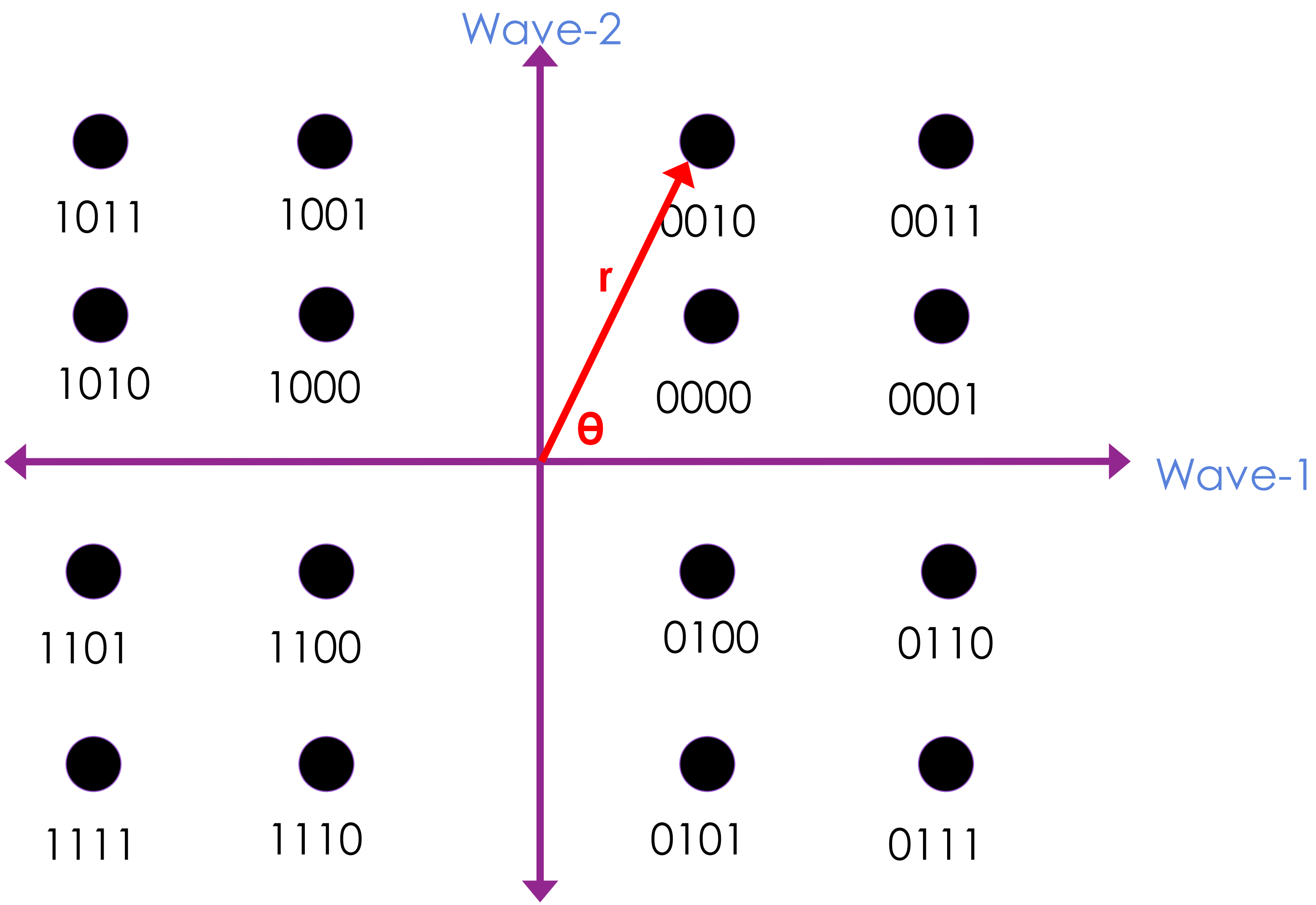
Constellation diagrams



Or drawn another way



Quadrature Amplitude Modulation



Add two waves in “quadrature”

Example of

16-QAM

r =amplitude
θ =phase

16 QAM and beyond!

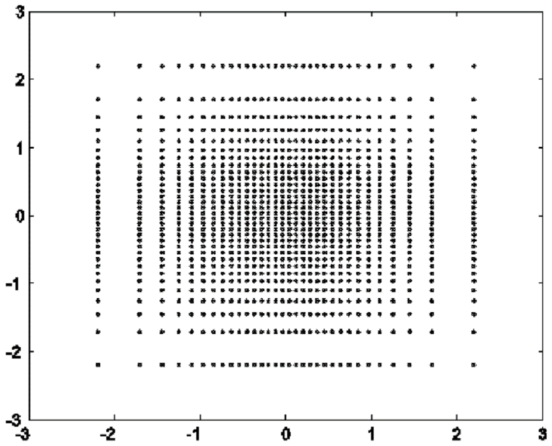
- Below 16QAM (4 bits) tend to use Binary PSK, QPSK, 8PSK
  - at constant Amplitude

- Above 16QAM: how high can we go?
  - CableTV systems: 256 QAM
  - Powerline data: 4096 QAM
  - ADSL: 65536 QAM (=16-bit/symbol)

- Very sensitive to noise! So what else can we do?

- Choices, choices, choices…
  - ASK – easy, but sensitive to attenuation and noise (energy gain/loss)
  - PSK – hard, but more robust to noise

FIG. 4

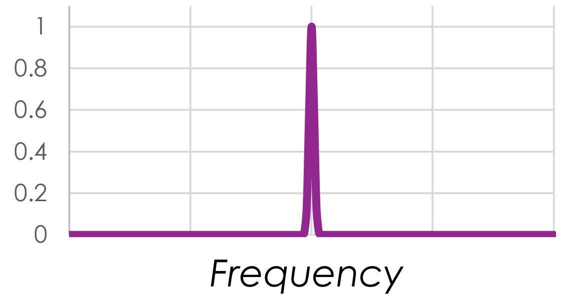


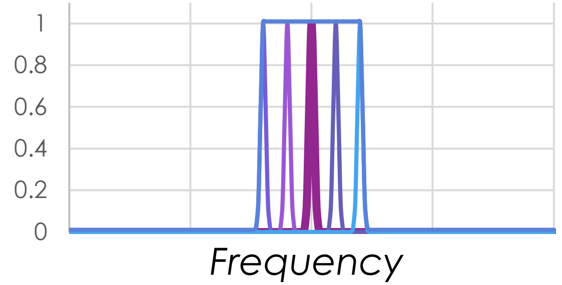
non-uniform 1024-QAM

Bands

- *FSK – easy, but uses a <u>band</u> of frequencies*
- Base-**band** – a single (constant) carrier
  - ASK (OOK = 2 levels = 1bit)
- Pass-**band*** – a single frequency carrier
  - ASK, PSK
- Broad-**band** – effectively multiple frequency carriers across a range
  - ASK, PSK, <u>**FSK**</u>
- **Band**-width – a specific range of frequencies
  - Or a data-rate?

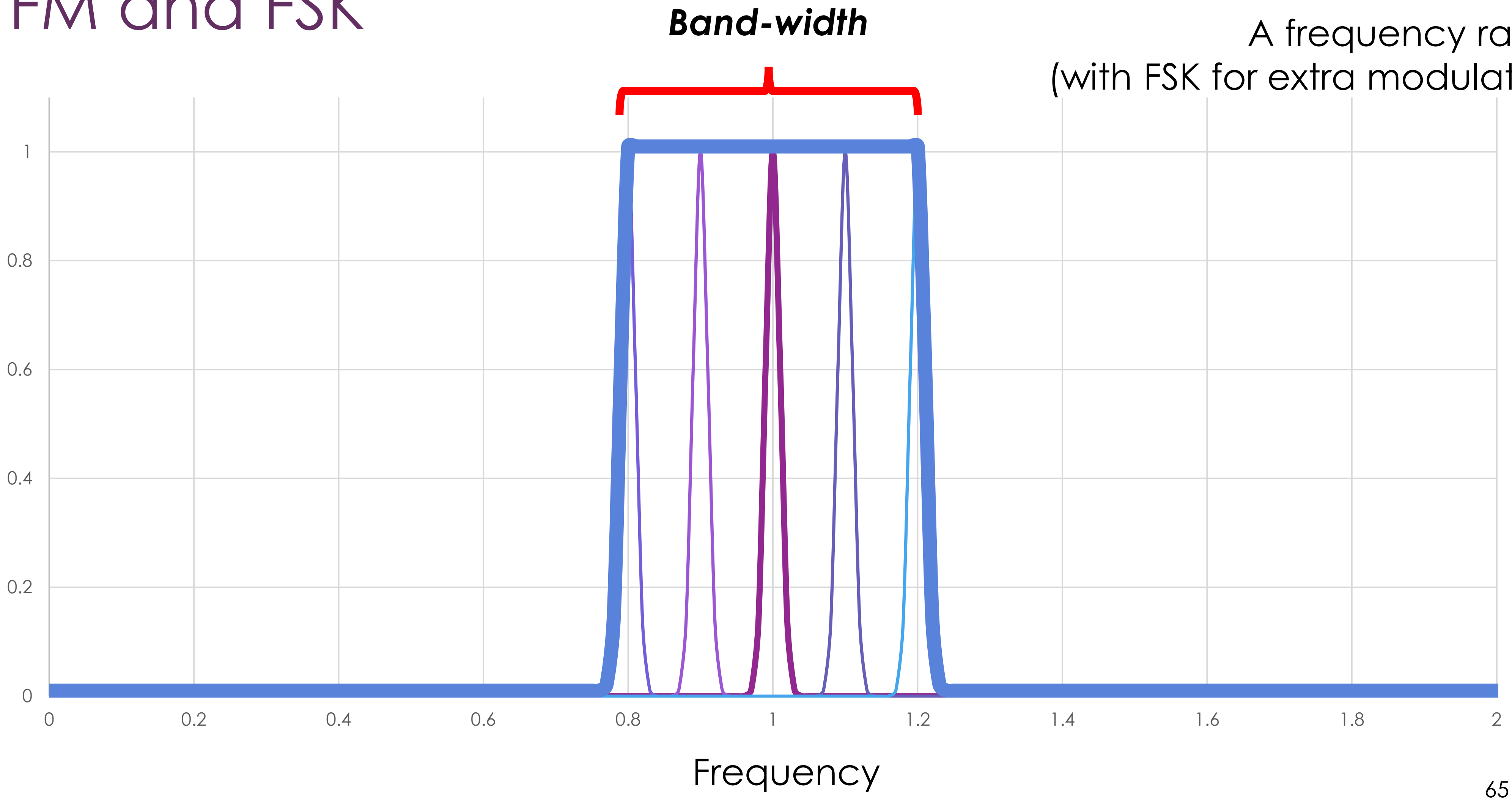
End-on-view of a wave





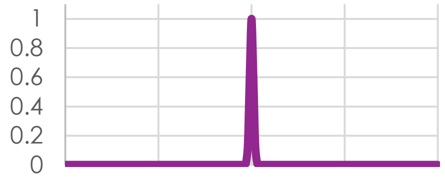
FM and FSK

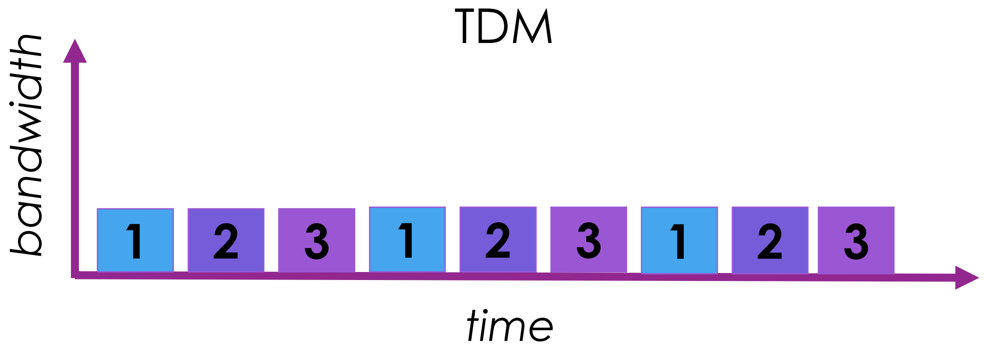
Multiple separate carriers/"cables"
(each carrying ASK/PSK data independently)
or
A frequency range
(with FSK for extra modulation)

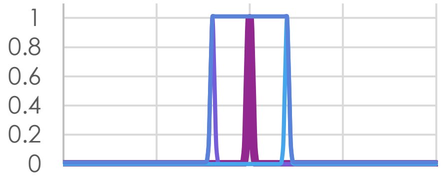


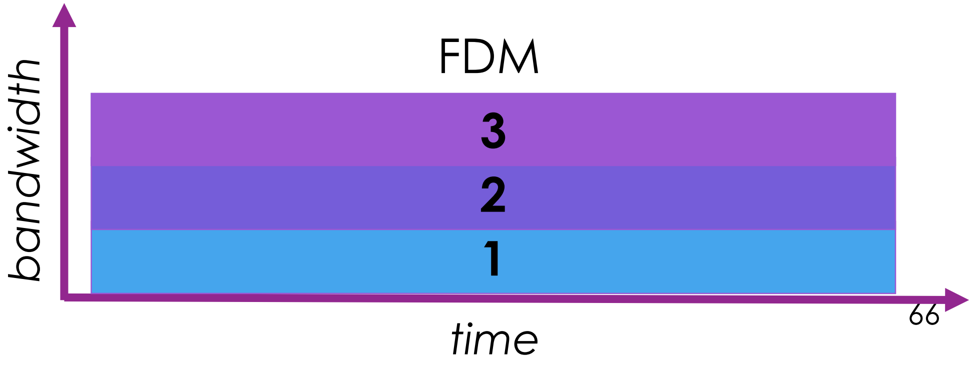
Back to Multiplexing

- Spatial Division Multiplexing
  - More paths (wires)
- Time Division Multiplexing
  - Take turns
    - Get it all, briefly
      - People, computers, …
- Frequency Division Multiplexing
  - Dedicate different channels/carriers
    - Get a share, all the time
      - TV, Radio, …
    - By expending extra energy
    - Use multiple tones/colours





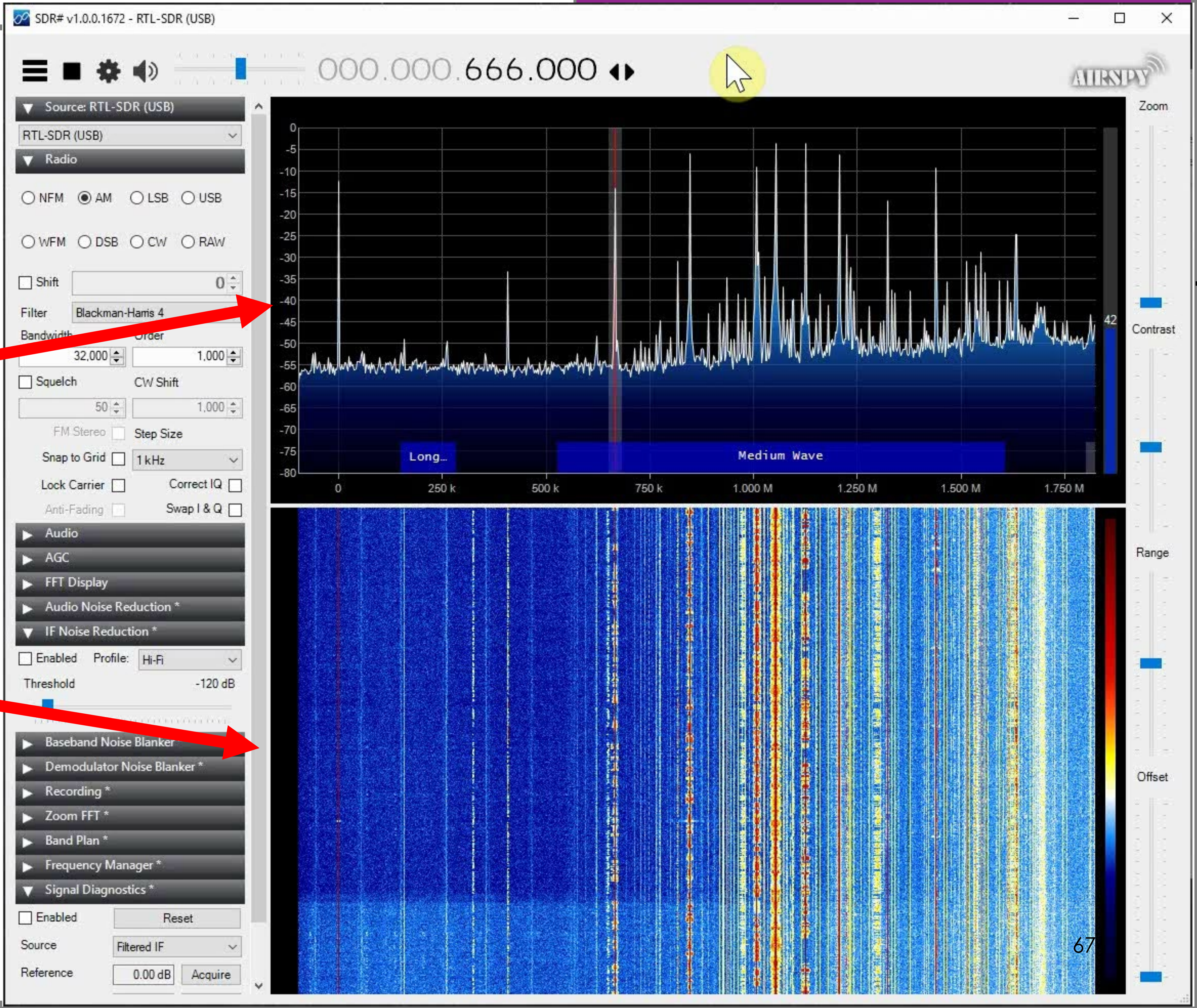




AM radio stations

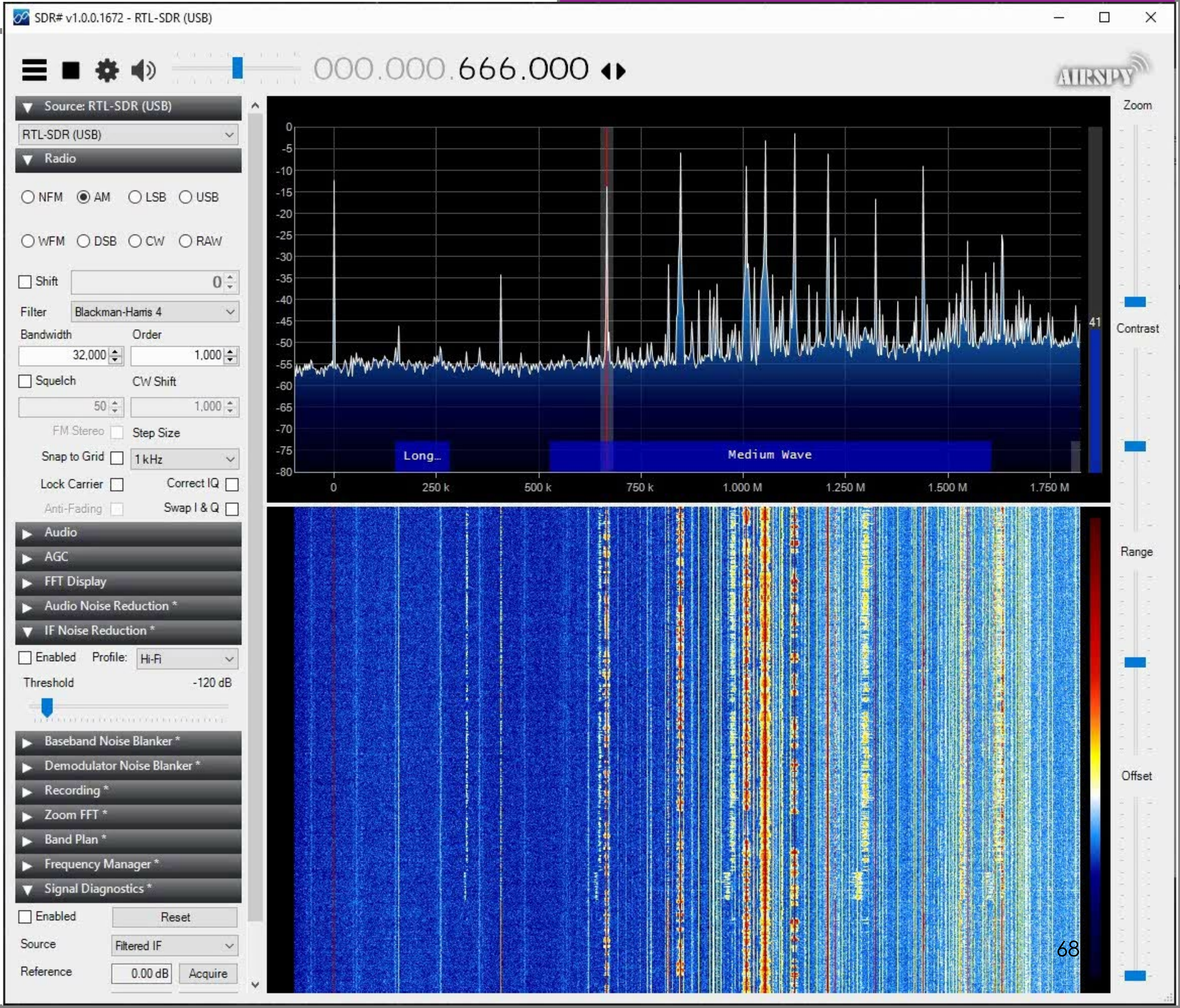
Realtime Frequency scanner

"Waterfall" chart (view over time)



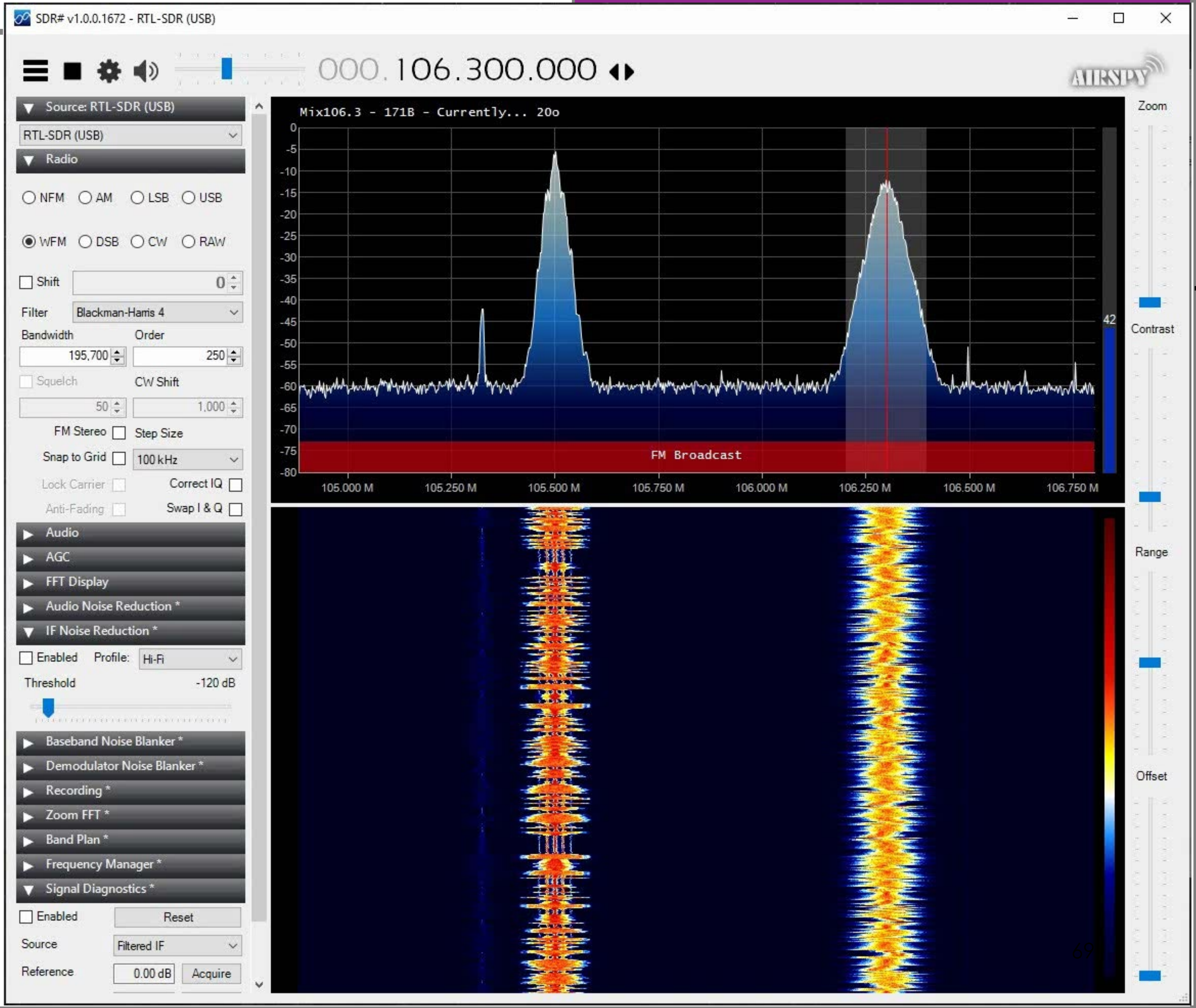
One station

Pick one and zoom in close



FM radio

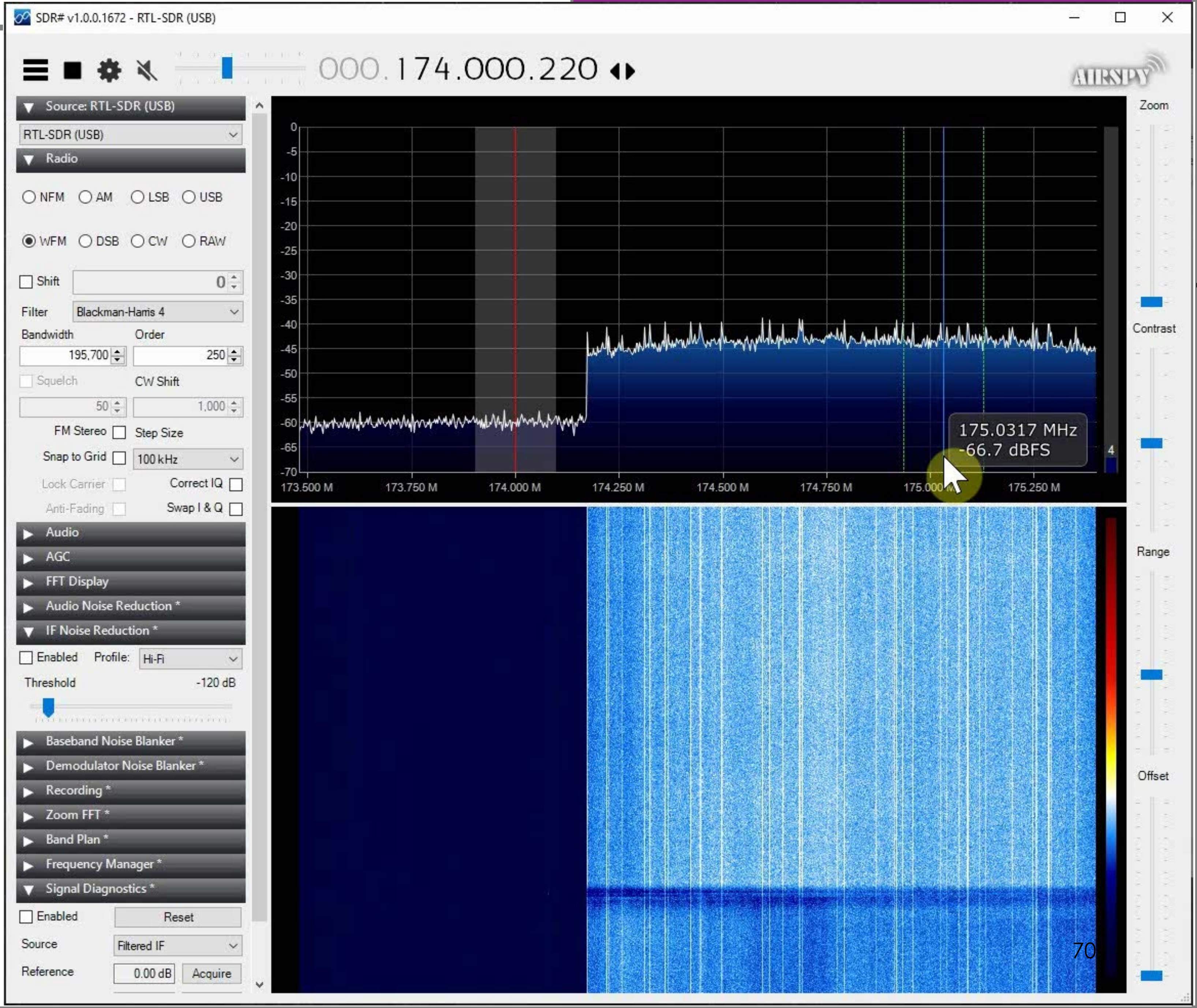
Same zoom level as all the AM stations



Mystery signal?

Very wide:
lots of information

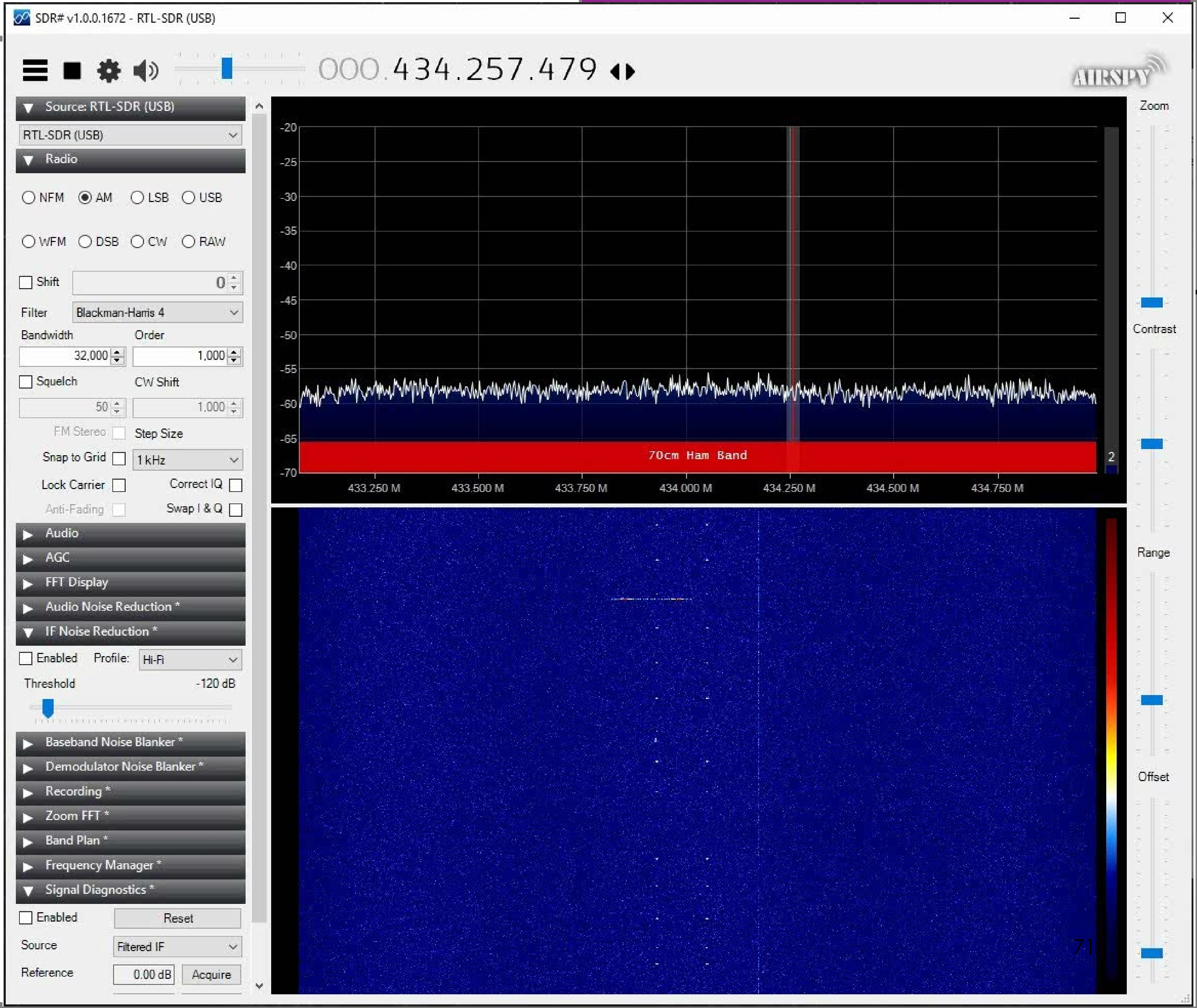
~Constant levels:
not analogue but
compressed digital



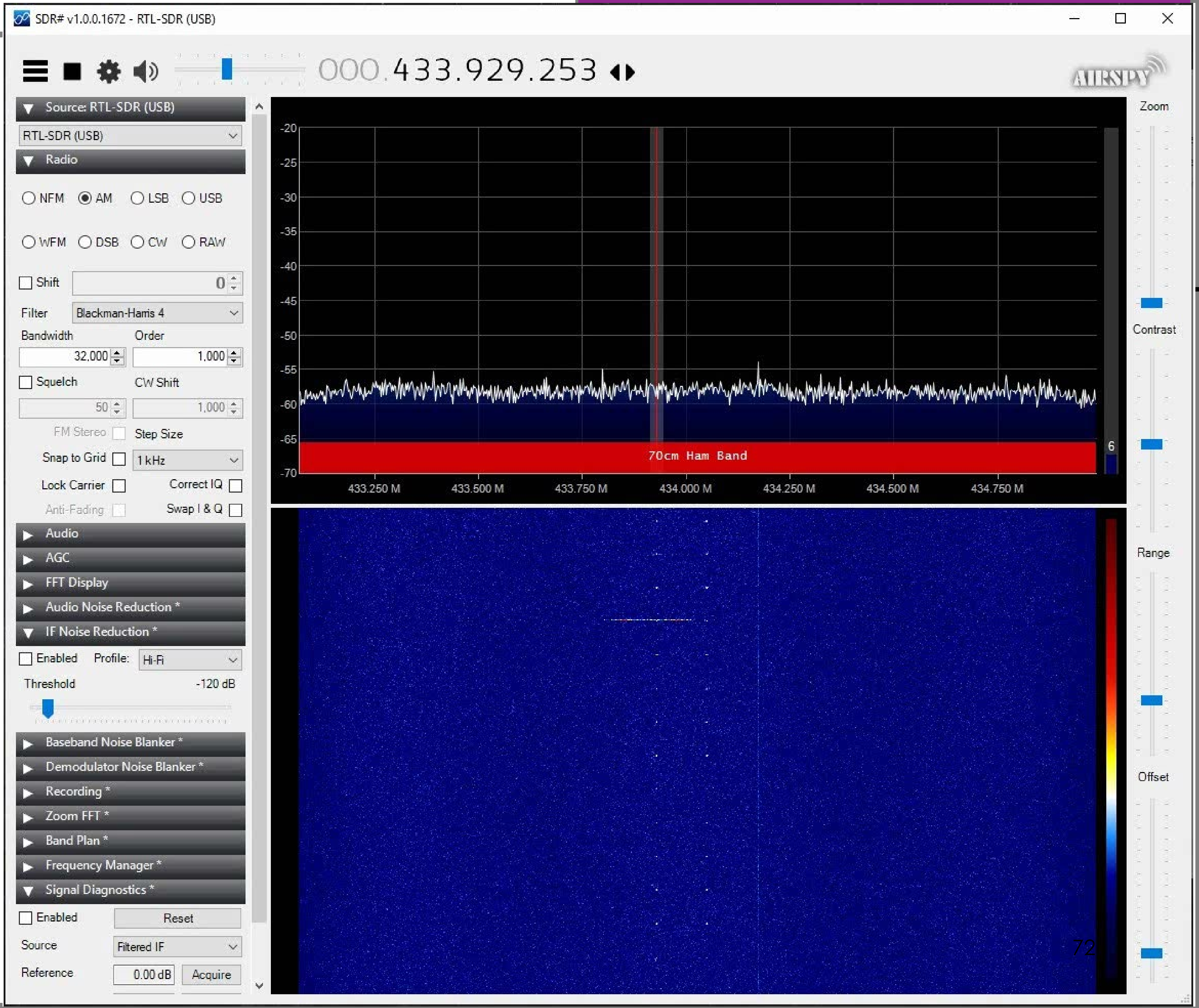
Ticks and blats

Something narrow ticks
Like a heartbeat…

Something then blats
A lot of information



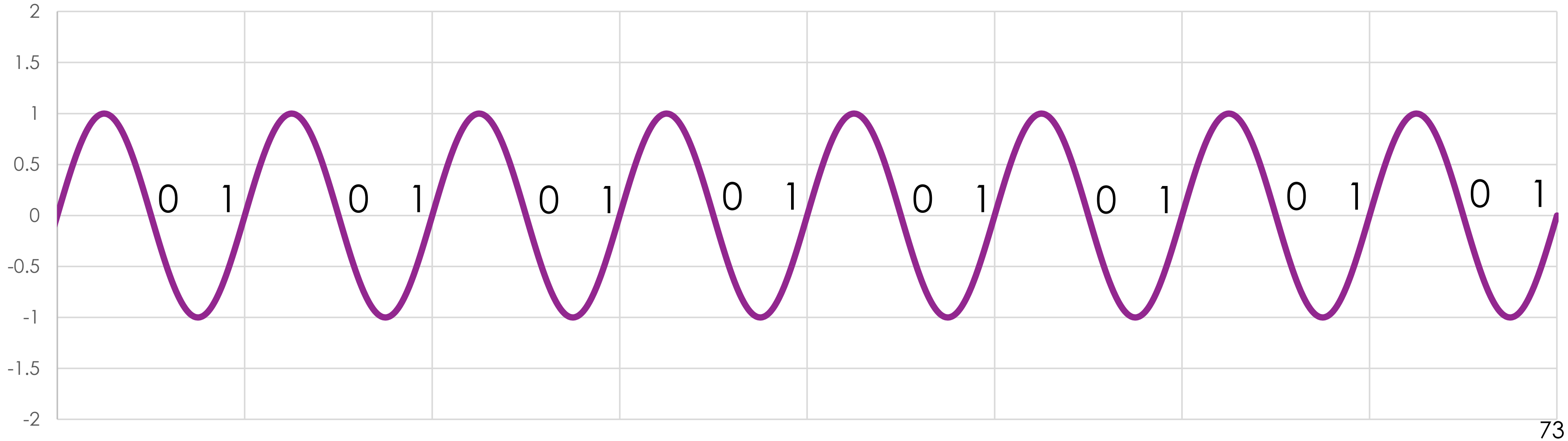
Special broadcasts



Harry Nyquist (1924):
"Certain factors affecting telegraph speed"

Throughput limits

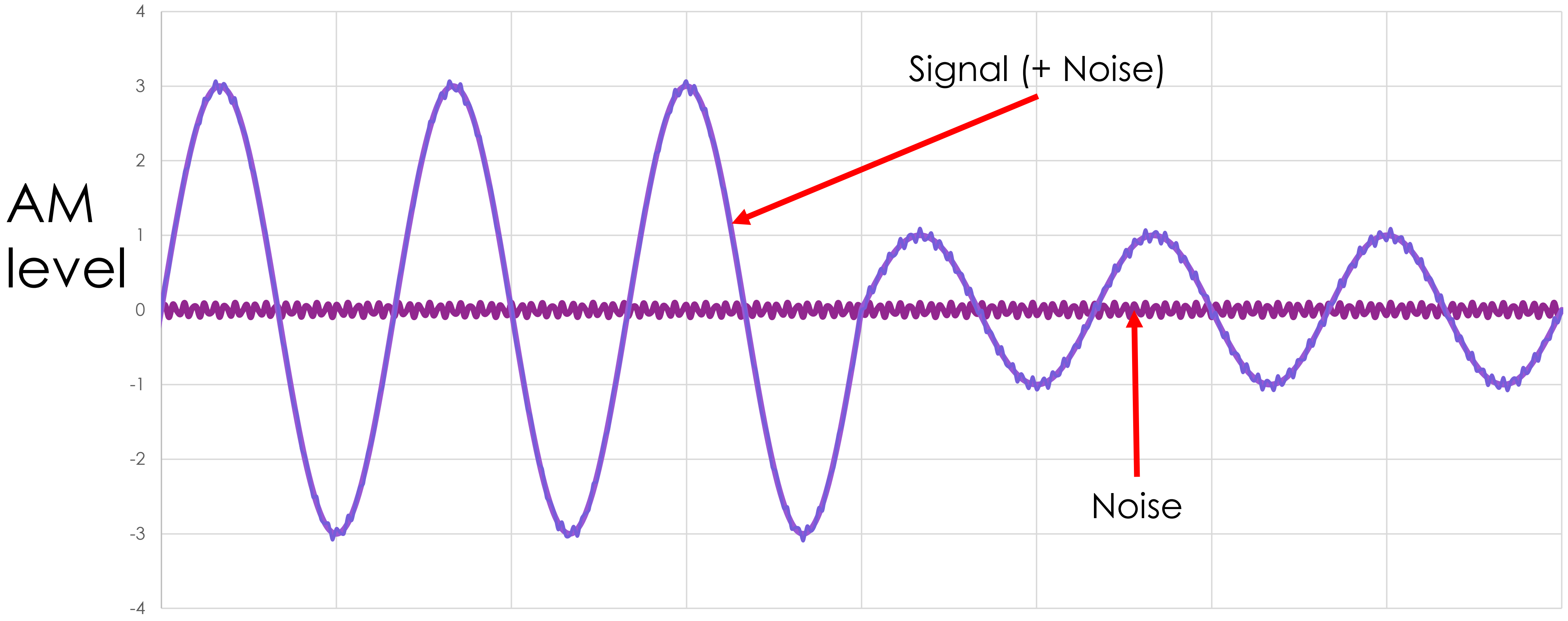
- How much can we squeeze into a carrier? (without noise)
  - Simplest wave carries 2 bits/cycle *(down=0, up=1) [psk]*
  - Can have V levels in a symbol *[ask]*
  - **Nyquist limit = 2 * Frequency * $\log_2$ (V) bits/s**



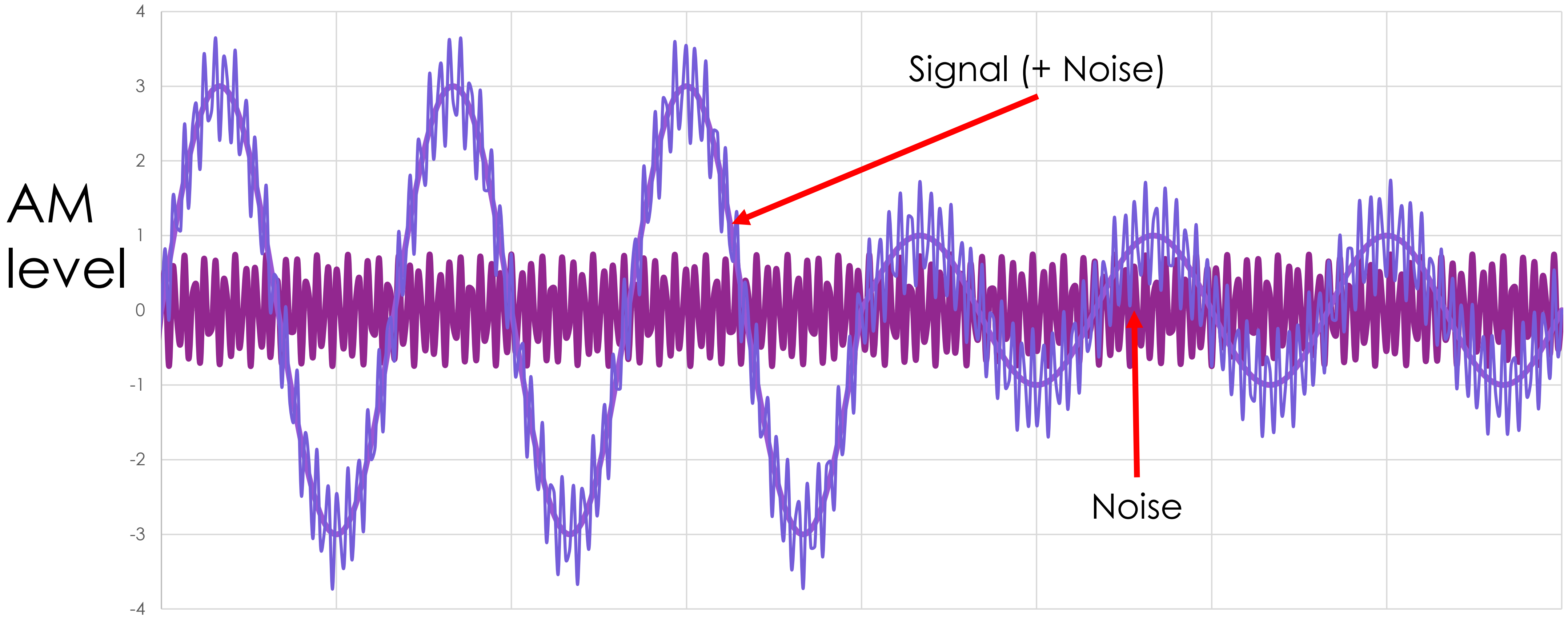
Robust Transmission

- Given **noise**, how much can we squeeze through?
- Noise is energy added/subtracted from the signal
  - Mainly modifies its **amplitude**
    - Also increases uncertainty around phase and frequency
  - Introduces errors in the level of a symbol
    - Note: White noise vs pink noise vs …

High-signal : Low-noise (30:1)



High-signal : Higher-noise (4:1)



Shannon "Capacity Limit"

- *Claude Shannon, 1948: A Mathematical Theory of Communication*
  - *"Father of information theory"*

- **Reliable Capacity = Baudrate * $\log_2$ (1+Signal/Noise)**

- We define a Signal:Noise ratio (SNR) based on the relative energy
  - Big factors, so $\log_{10}$ scale = 'Bels'
  - Too coarse, so multiply by 10 = 'deciBels'

- SNR in deciBels = 10*$\log_{10}$(Signal/Noise)

100:1 = 20dB
10:1 = 10dB
2:1 = 3dB
0.1:1 = -10dB

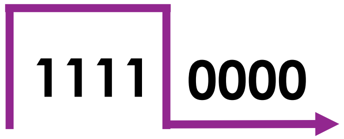
Cool, we're done!? No… sorry…

- **ENCODING**
- When transmitting a sequence of bits from A to B

  (regardless of modulation)

  A and B need to be 'in sync'
- Synchronising sender and receiver
  - where is the bit boundary? Have you stopped, or are you sending zeroes?

- Is that a very slow "10" or fast "11110000"?



Encoding

- The Clock Recovery problem (et al…)
- Allow receiver to keep in synch by making transitions frequently
  - Bonus: can be less sensitive to noise
    - Easier to detect a change up/down than a fixed signal
- Two key concepts:
  1. Map bit patterns to reduce repetition (increase variation)
  2. Signal **each** bit with a transition
- Feels like 100+ schemes have been developed.

Mapping bit patterns

- <u>4b/5b</u>, 6b/8b, 8b/10b, 8b/6t, … *Run-Length-Limited coding (vs bit-stuffing)*

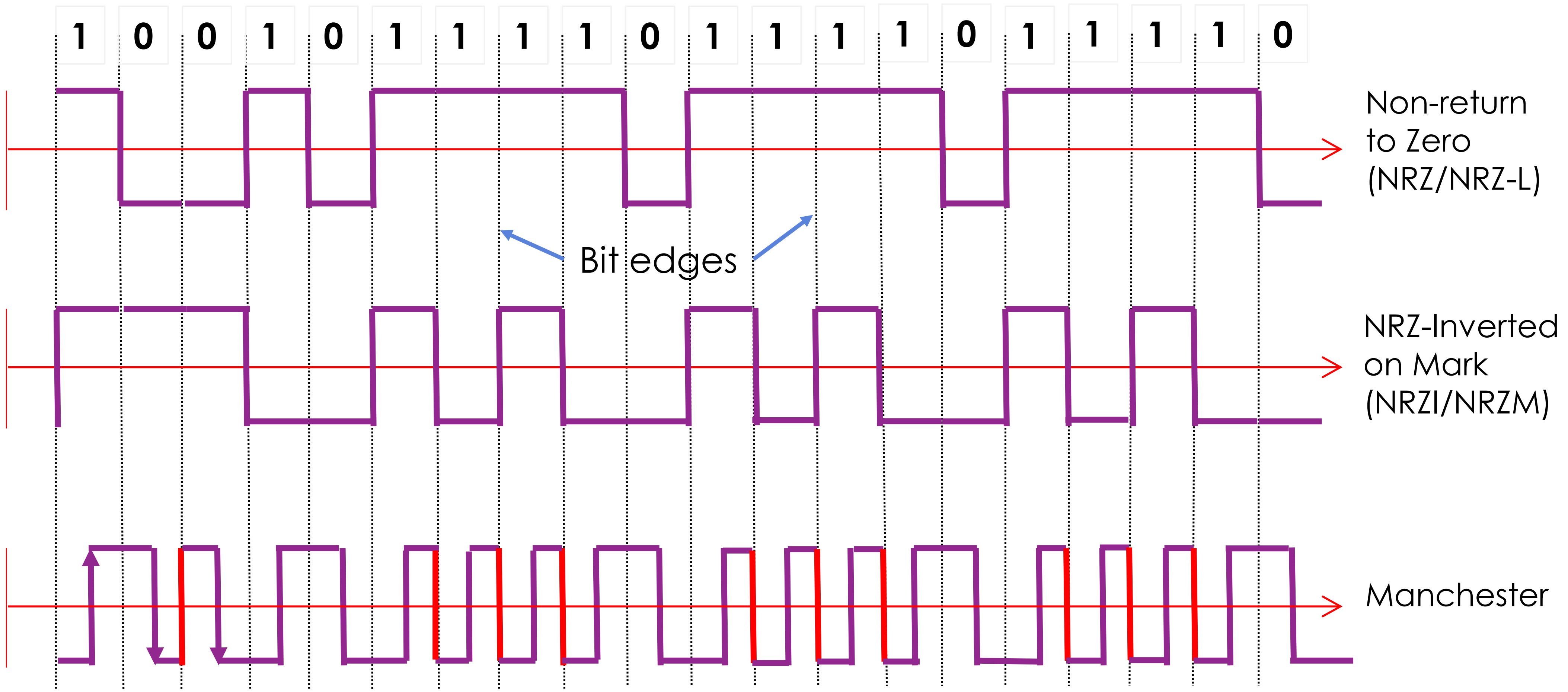
- Given 4 bits, rewrite as 5 bits
  - Avoid runs of zeroes
  - Trade bandwidth for reliability

- Get 1-4 bit changes every 5 bits sent

Given	Send	Given	Send
0000	**11110**	0100	**01010**
0001	**01001**	1000	**10010**
0010	**10100**	1101	**11011**
0011	**10101**	1111	**11101**

- So 1000 0000 0000…. becomes 10010 11110 11110 11110….
  - *No more than 3 zeroes in a row – but 6 ones?!*

Signalling bits with transitions



Lots of overhead

- What's your actual throughput?
  - 4b/5b costs you
  - Manchester costs you
  - Noise costs you
  - …

- Be careful when people talk about data rates – what do they mean?

A quick word about Standards

- Basically: None.

- Multiplexing, modulation, encoding schemes are established through
  - Publications
  - Patents
  - Implementations

Now we're done?

Yes!

Now let's put these signals over some media…