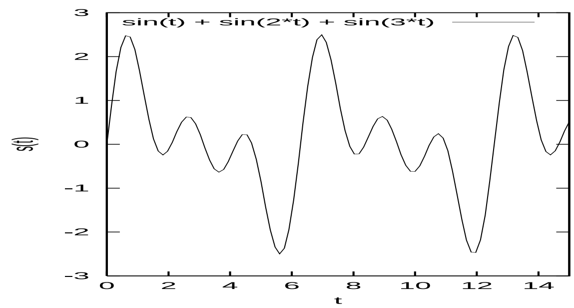
Joseph Fourier's claim: "all" signals are sums of sinusoids of different frequencies.

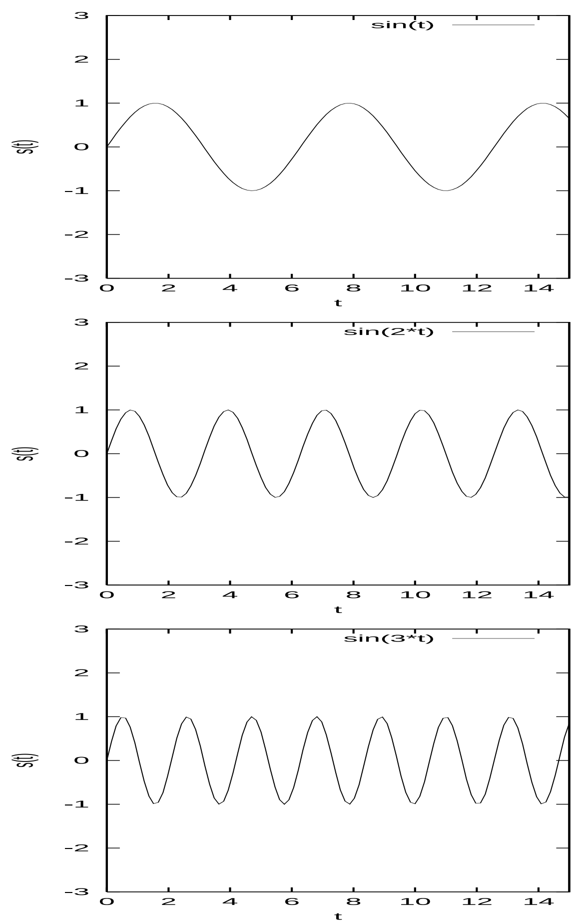
→ weighted sine curves

→ weight: amplitude of sine curve

→ "all": not exactly but doesn't matter for us in practice

# Example:



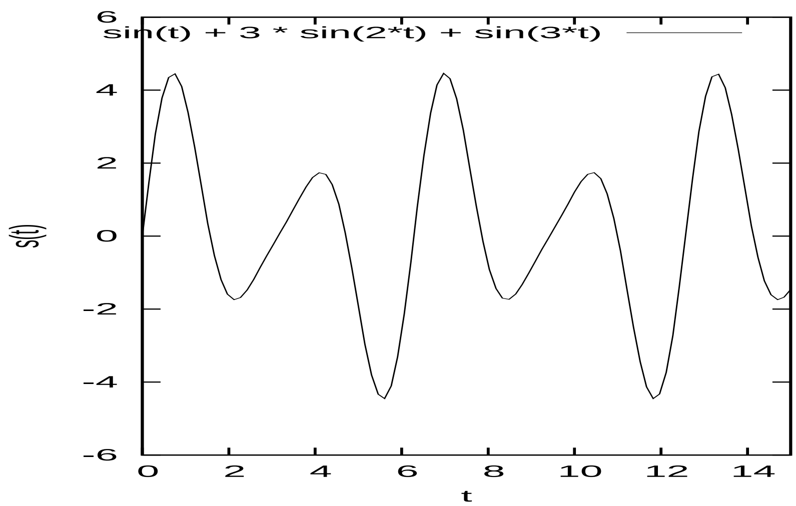
Top signal equals $\sin t + \sin 2t + \sin 3t$

$\rightarrow$ frequencies 1 Hz, 2 Hz, and 3 Hz

$\rightarrow$ weight?

Another example: signal created by

$\rightarrow \sin t + 3 \sin 2t + \sin 3t$




$\rightarrow$ frequency 1 Hz: weight 1

$\rightarrow$ frequency 2 Hz: weight 3

$\rightarrow$ frequency 3 Hz: weight 1

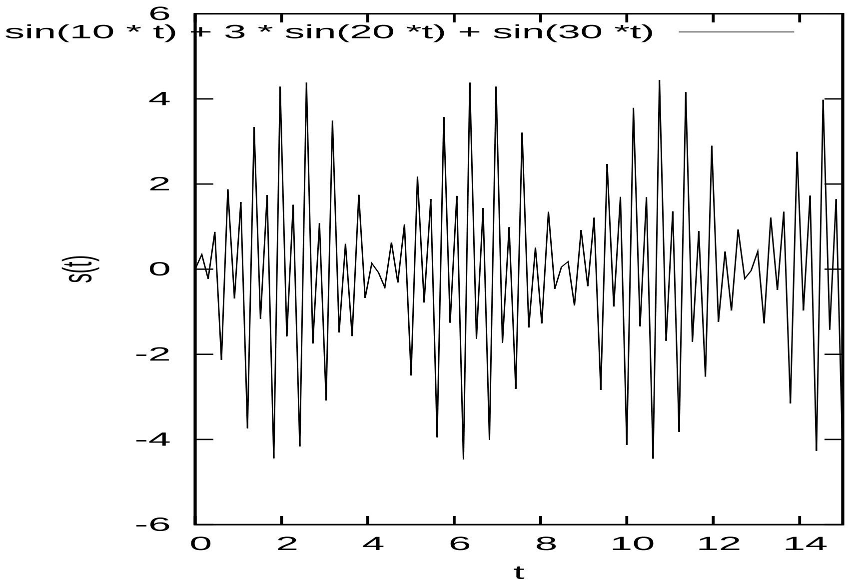
Weights of sine curves are called spectrum of the signal they create.

$\rightarrow$ spectrum: a list or table of weights

$\rightarrow$ like DNA (or fingerprint/signature) of signal

Yet another example: signal created by

$\rightarrow \sin 10t + 3\,\sin 20t + \sin 30t$



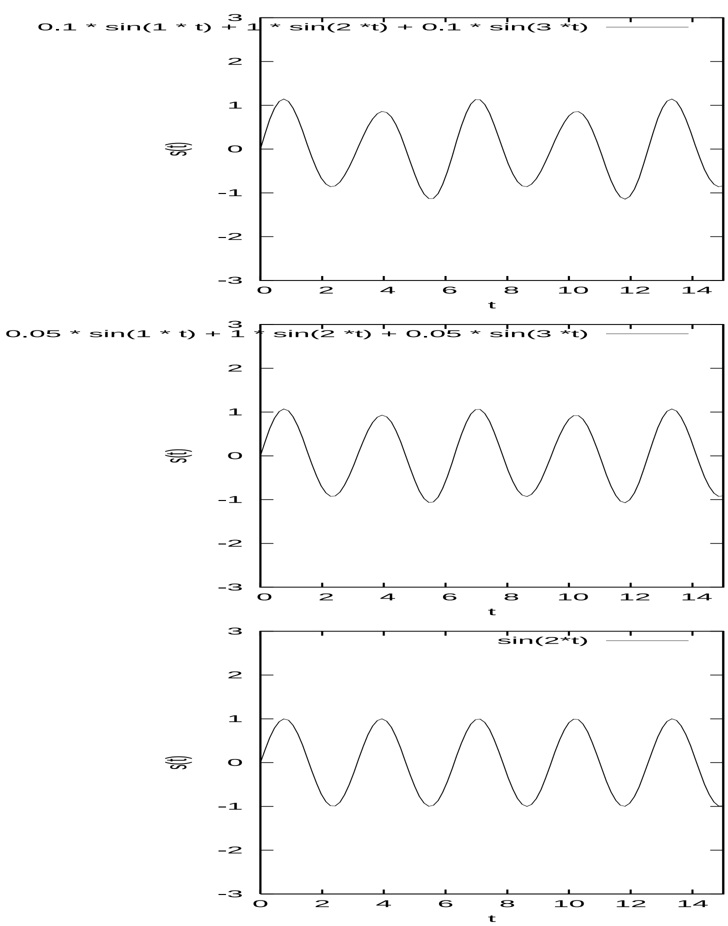

$\rightarrow$ spectrum of signal?

Another view of spectra: signals created by

$\rightarrow 0.1 \sin 1t + \sin 2t + 0.1 \sin 3t$

$\rightarrow 0.05 \sin 1t + \sin 2t + 0.05 \sin 3t$

$\rightarrow \sin 2t$



Sine curves with small weights in a spectrum don't contribute much

$\rightarrow$ may be ignored

$\rightarrow$ treat as if weights were zero

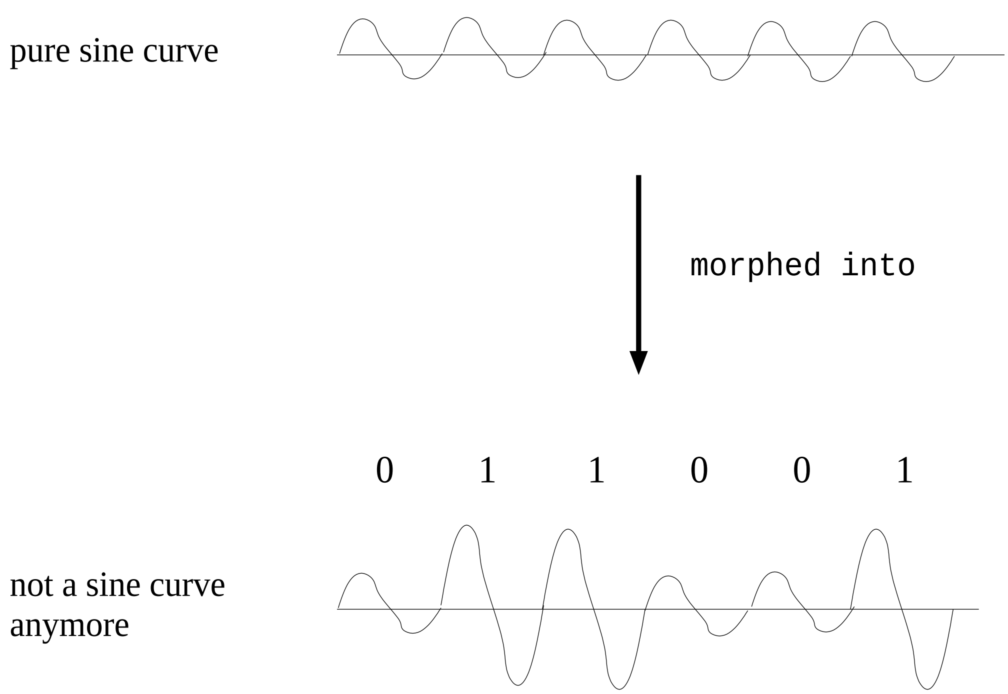
$\rightarrow$ same attitude as compression (video, image, audio)

$\rightarrow$ called lossy compression

$\rightarrow$ lossless compression?

Back to networking:

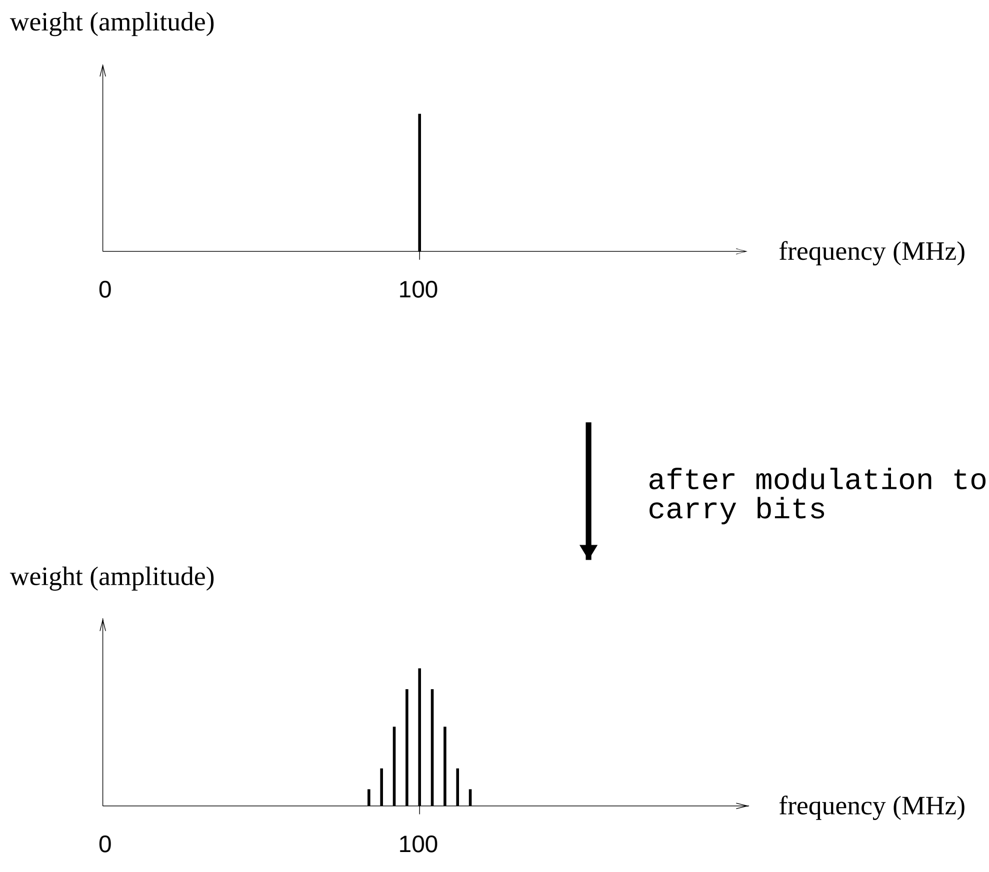
$\rightarrow$ pure sine curve of frequency $f = 100$ MHz




$\rightarrow$ spectrum before amplitude modulation?

$\rightarrow$ spectrum afterwards?

Spectrum before and after amplitude modulation to transmit bits:




Act of morphing sine curve to carry bits introduces energy around carrier frequency.

$\rightarrow$ amount of spreading: called "bandwidth" of signal

If spreading is limited: zero or near zero beyond a certain point

→ signal is called bandlimited

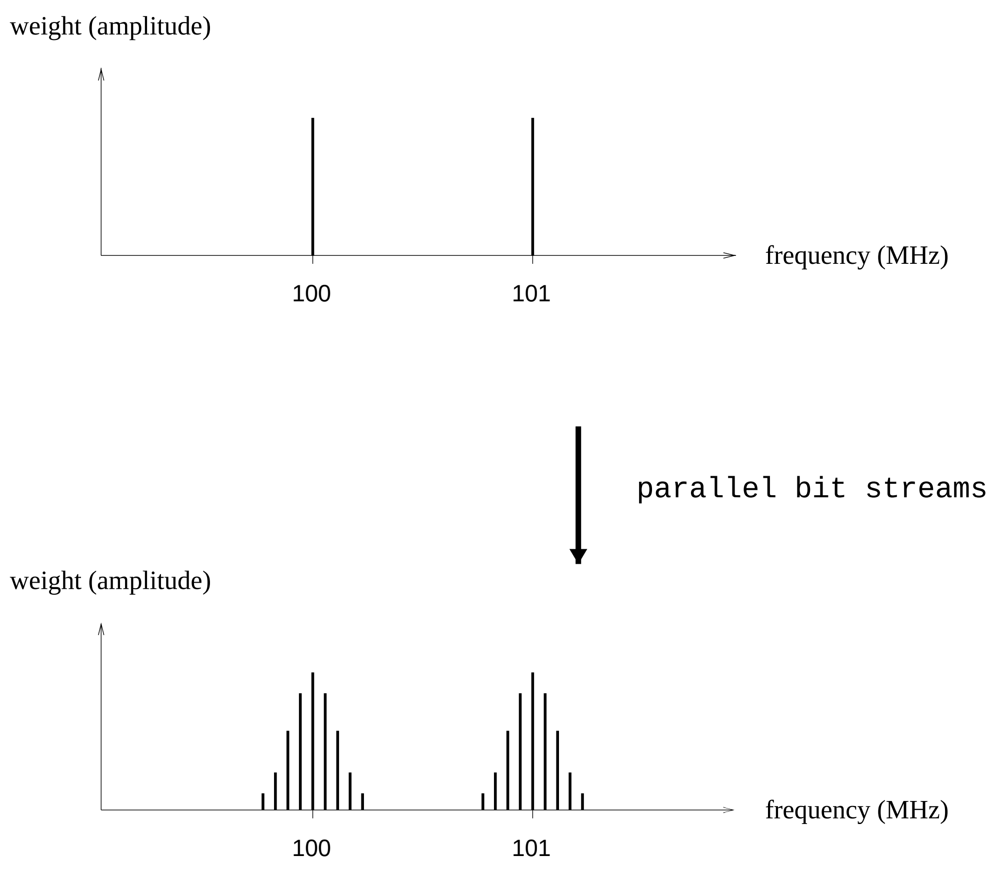
→ much of communication engineering deals with bandlimited signals

Question: can the amount of spreading depend on the data (i.e., bit pattern) being carried by a carrier frequency?

Question: what is the negative impact of spreading?

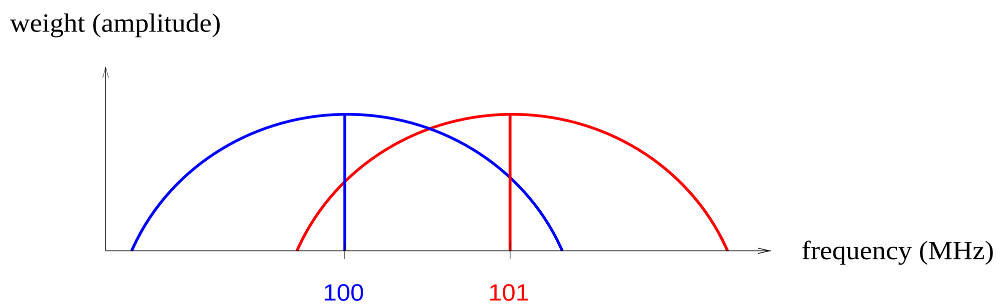
Inter-channel interference (ICI): two parallel bit streams carried on two carrier frequencies 100 MHz and 101 MHz

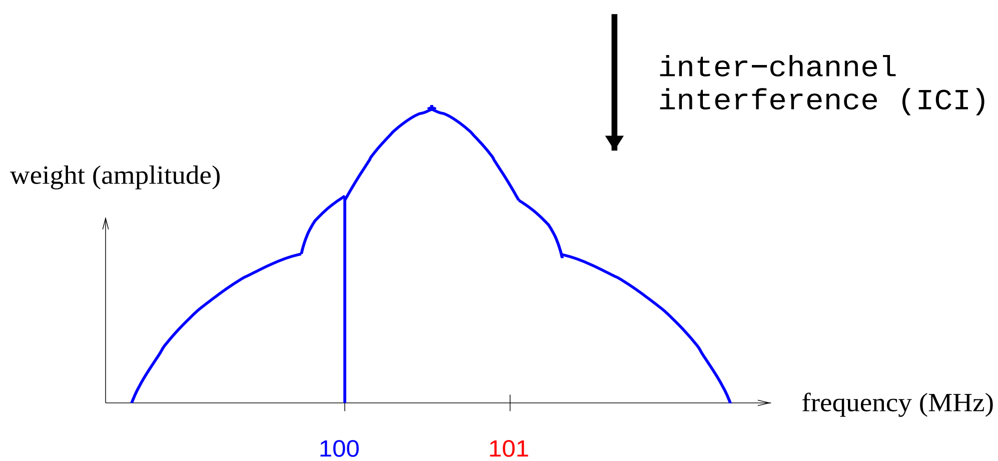
Good case:




→ signal bandwidths around 100 MHz and 101 MHz don't overlap: no ICI

Bad case:




→ signal bandwidths around 100 MHz and 101 MHz overlap

→ amplitude detected by receiver is distorted

→ ICI resulting in bit flips

Overlap (i.e., interference) causes weights from the two spectra to be added

→ distortion of original weight values

→ bit flips likely

→ bit value 1 or 0 is represented by weight (amplitude)

How to prevent ICI?

Allocate sufficient spacing—guardband—between adjacent carrier frequencies.

Drawback: limits how many carrier frequencies can be squeezed in a given frequency range.

→ e.g., 100 MHz–102 MHz

→ estimating guardband is part of hardcore radio engineering

→ limitation of traditional FDM

Recent advance: actually a "small revolution"

→ orthogonal FDM (OFDM)

→ used in high-speed wired and wireless systems (e.g., ADSL, WiFi, cellular)

→ the state-of-the-art

→ using carrier sine curves that are orthogonal to each other, can overcome traditional guardband requirement

→ orthogonal: at right angles

Similar idea also used in CDMA wireless networks (e.g., Verizon, Sprint)

→ what remains: CDMA followed by OFDM

→ covers state-of-the-art

→ hopefully will last a few decades

Question before moving on:

→ modulation that spreads signal spectrum is not good

→ can cause ICI

→ however: are there scenarios where spreading is a good thing?

Guardband example: IEEE 802.11 WLAN

→ U.S.: 11 channels for 2.4 GHz systems

→ channel: analogous to carrier frequency

→ 2.412, 2.417, 2.422, 2.427, 2.432, 2.437, 2.442, 2.447, 2.452, 2.457, 2.462 GHz

→ channel separation must be at least by 5 channels to avoid inter-channel interference (ICI)

→ otherwise bleeding over and bit flips

→ three hot spots in neighboring coffee houses: 1, 6, 11

→ same in office buildings, residential areas