Additional modulation variations:

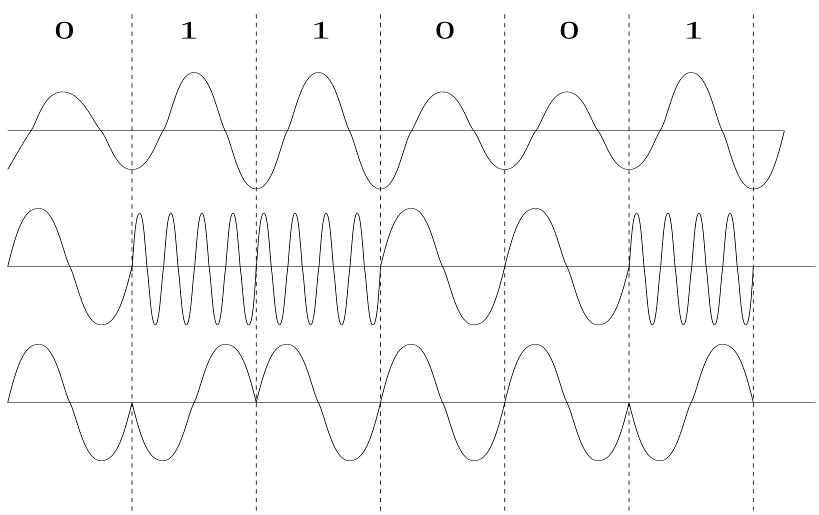
- Amplitude modulation (AM): encode bits using amplitude levels

  → use multiple magnitude levels

  → 8 levels: 3 bits per clock tick (called baud)

- Frequency modulation (FM): encode bits using frequency changes

- Phase modulation (PM): encode bits using phase shifts



Terminology: AM, FM, PM are also called amplitude, frequence, phase shift keying (ASK, FSK, PSK)

→ e.g., BPSK: binary PSK; QPSK (4 phases)

→ or their combination: amplitude and phase

→ QAM (quadrature amplitude modulation): amplitude and phase

→ e.g., 16-QAM: 4 amplitudes, 4 phases; 64-QAM

→ e.g., WiFi, DVB

But ASK and PSK can increase bit rate only so much.

Same with increasing frequency.

$\rightarrow$ esp. wireless due to LOS constraint above 10 GHz

What's left?

Back to 100 MHz–102 MHz example.

→ bandwidth: 2 MHz

→ how many carrier frequencies can we squeeze in?

→ recall: with 100.0, 100.1, 100.2, . . ., 101.8, 101.9, 102.0 MHz could support 31 simultaneous users

→ what about: 100.00, 100.01, 100.02, . . ., 101.98, 101.99, 102.00 MHz

→ how many parallel bit streams possible?

There must be a catch.

→ what is it?

Bits on one carrier frequency may interfere with bits on another carrier frequency.

→ e.g., bits carried on 100 MHz frequency distort bits carried on 101 MHz frequency

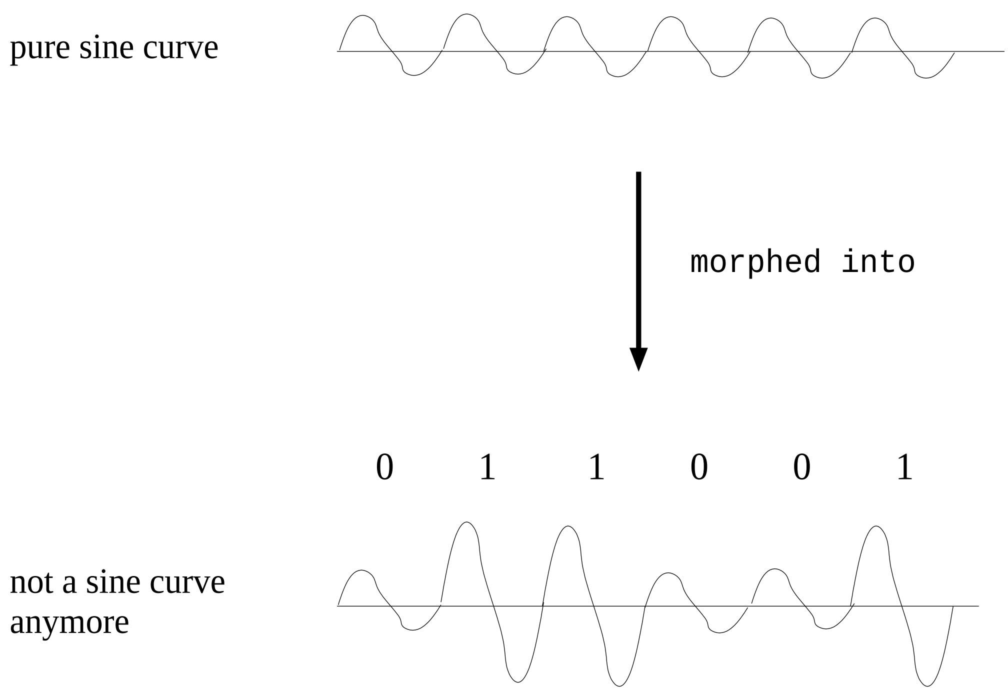
→ and vice versa

→ called inter-channel interference (ICI)

→ why does this happen?

We start out with pure sine curve.

→ e.g., frequency $f = 100$ MHz



To carry bits, it gets morphed by AM into something else.

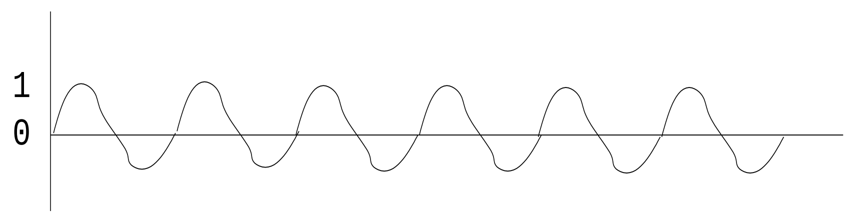
→ a beast! (think of movie "The Fly")

→ a good beast

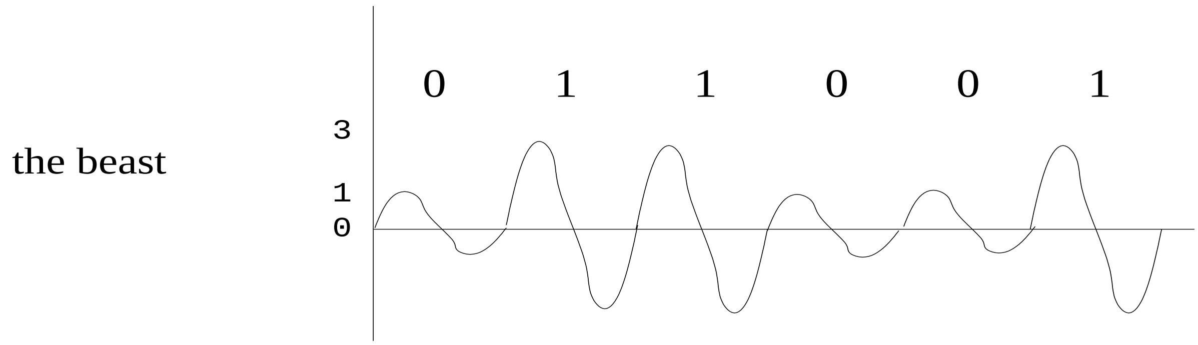
Let's look at DNA of "the beast."

First, what's the "DNA" of pure sine curve?

pure sine curve



"DNA" of good beast carrying bits 0 1 1 0 0 1



→ DNA from parent: pure sine curve (100 MHz)

→ but will also carry mutant DNA: from 101 MHz, 102 MHz

→ also how much of each mutant DNA (i.e., magnitude)

→ ex.: magnitude 1 from 100 MHz, 2 from 101 MHz, 0.03 from 102 MHz

How to create beast from parent and mutant DNAs:

→ just add

→ beast = $1 \times$ sine(100 MHz) + $2 \times$ sine(101 MHz) + $0.03 \times$ sine(102 MHz)

Will adding the three sine curves above create the morphed curve carrying bits 0 1 1 0 0 1 ?

For any morphed curve (aka " signal") carrying bits, it is difficult to find by visual inspection what the component DNAs (i.e., pure sine curves) are.

→ also how do we know that adding sine curves will give us the beast?

First, why do we care?

→ recall motivation: inter-channel interference

→ bits carried on frequency 100 MHz distorts bits carried on 101 MHz

→ how?

Intuition: performing AM modulation on pure sine curve 100 MHz to ship bits 0 1 1 0 0 1 has a side effect

→ creates mutant DNA: 101 MHz sine curve of amplitude 2

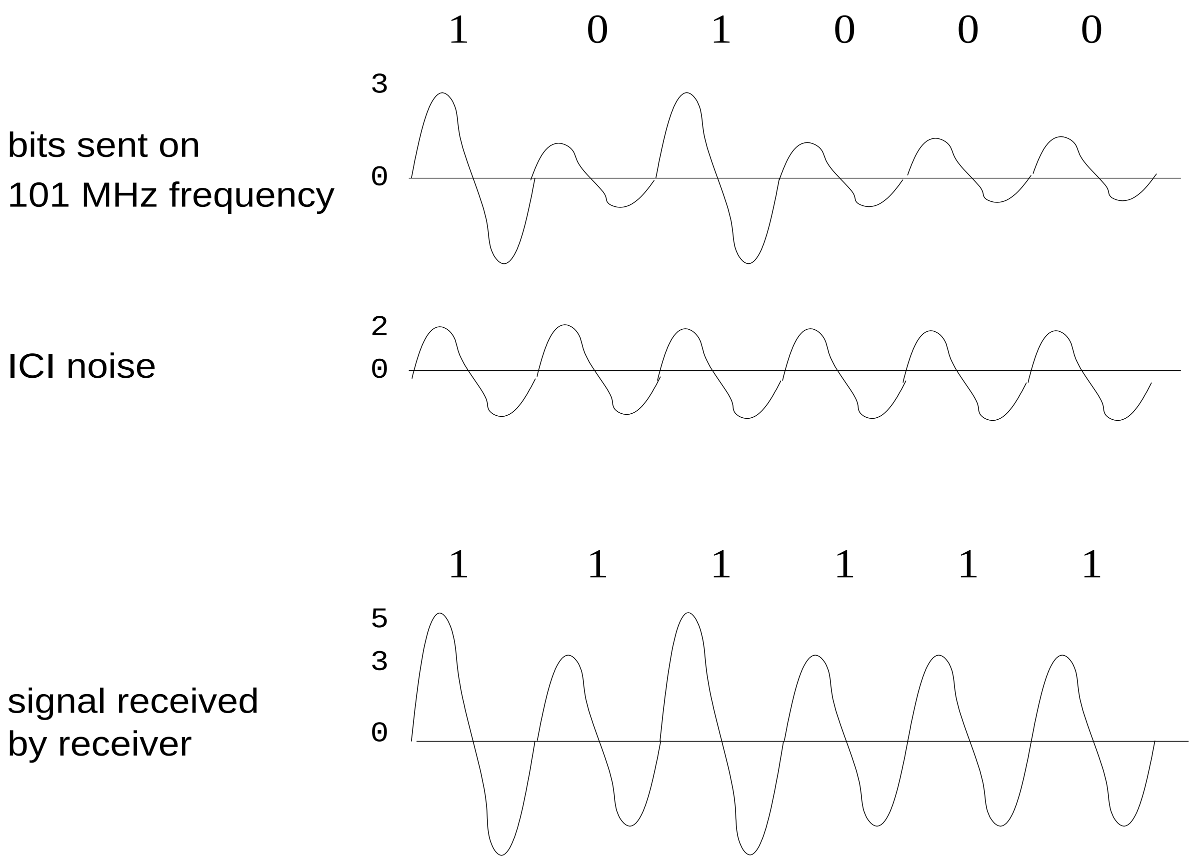
When a receiver wants to know what bits are carried on frequency 101 MHz, it "tunes into" frequency 101 MHz and checks how the amplitude varies every clock tick

→ say bits 1 0 1 0 0 0 were sent on frequency 101 MHz

→ but noise on 101 MHz with amplitude 2 mixes with the original signal

What bits will be receiver think have been transmitted?

Inter-channel interference (ICI) in action:



Key observations:

1. Sending parallel bit streams using multiple carrier frequencies only works if we can keep inter-channel interference (ICI) under control.

$\rightarrow$ else receiver gets corrupted bits

2. How do we know that a morphed sine curve carrying bits is just the sum of sine curves with different amplitudes?

$\rightarrow$ not obvious: J. F. made important contribution during Napoleon's time

3. How do we know what sine curves to add and what amplitude each should get to create beast?

$\rightarrow$ J. F. gives a simple formula