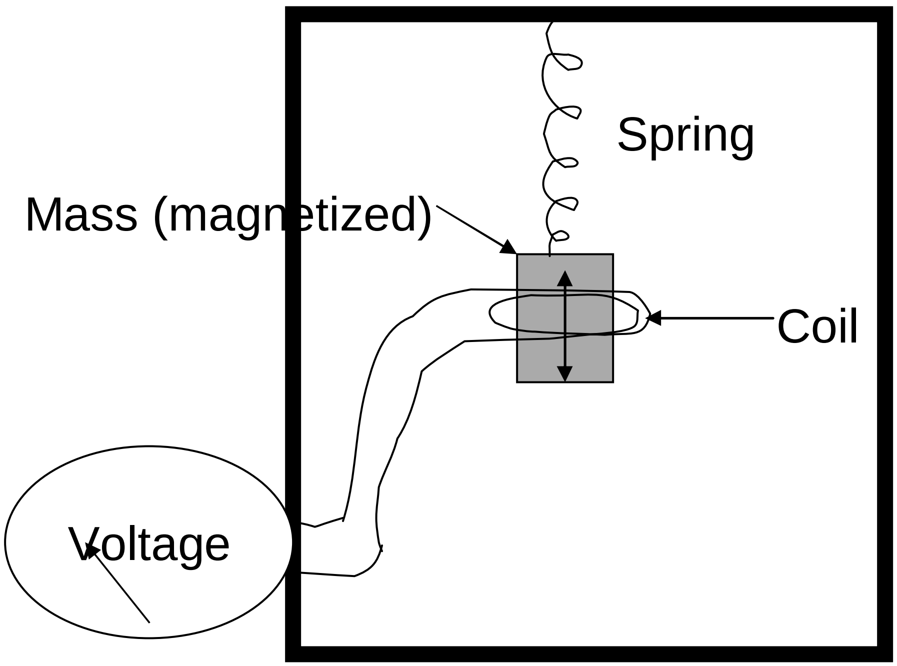
What are we recording?

- First, exactly what are those geophones recording?



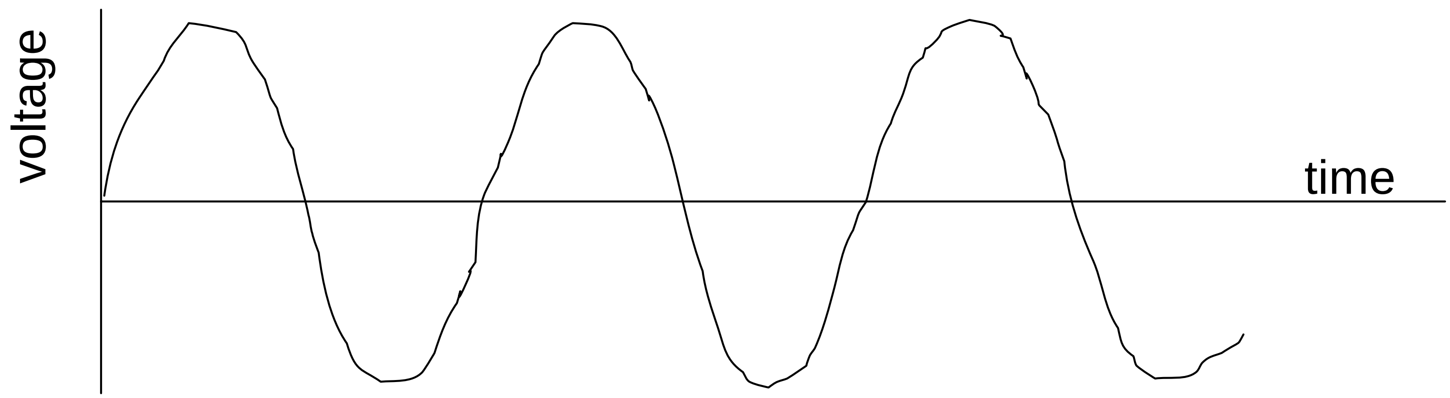
The oscillating mass is magnetized and produces a voltage in the coil. The voltage is proportional to the speed of the mass.

So we are actually measuring the speed of the oscillating mass.

How does this relate to earth movement?

Wave frequency

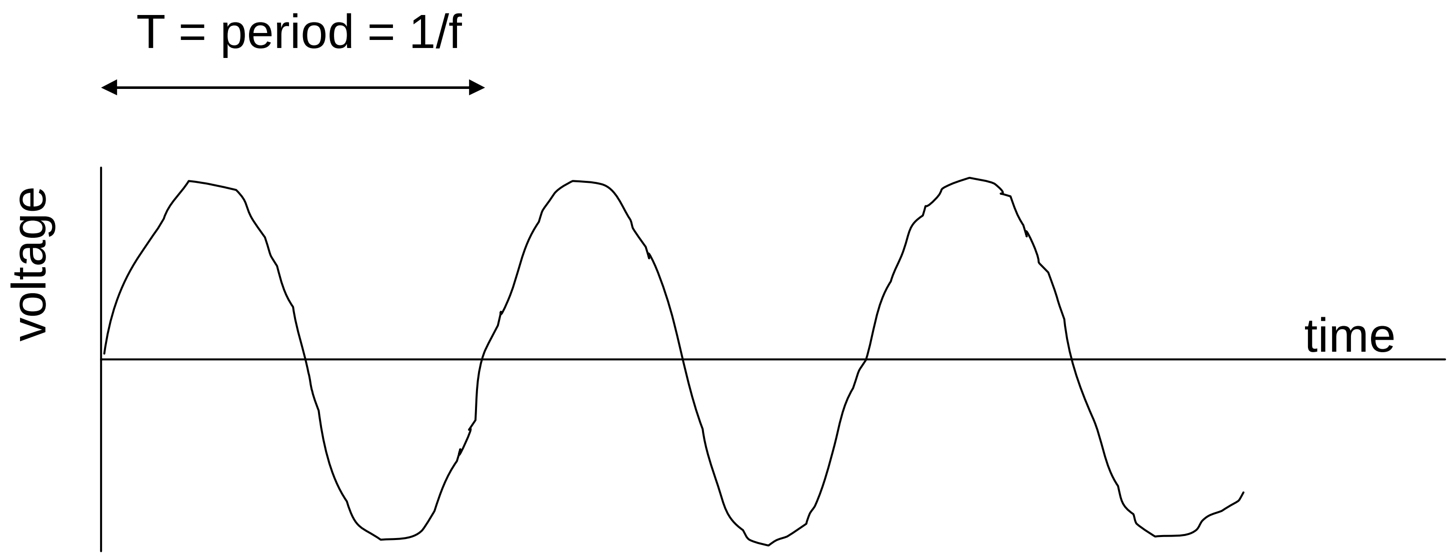
- The simplest wave we can record is an sinusoidal wave:



Voltage = cos (2πft), where f=frequency and t=time

Wave frequency

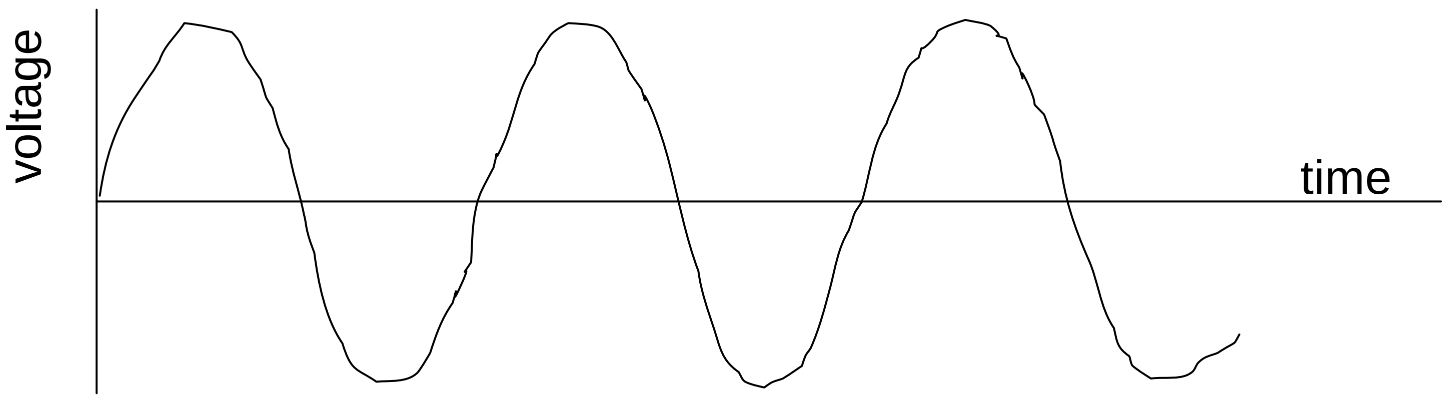
f in cycles/second
T in seconds/cycle



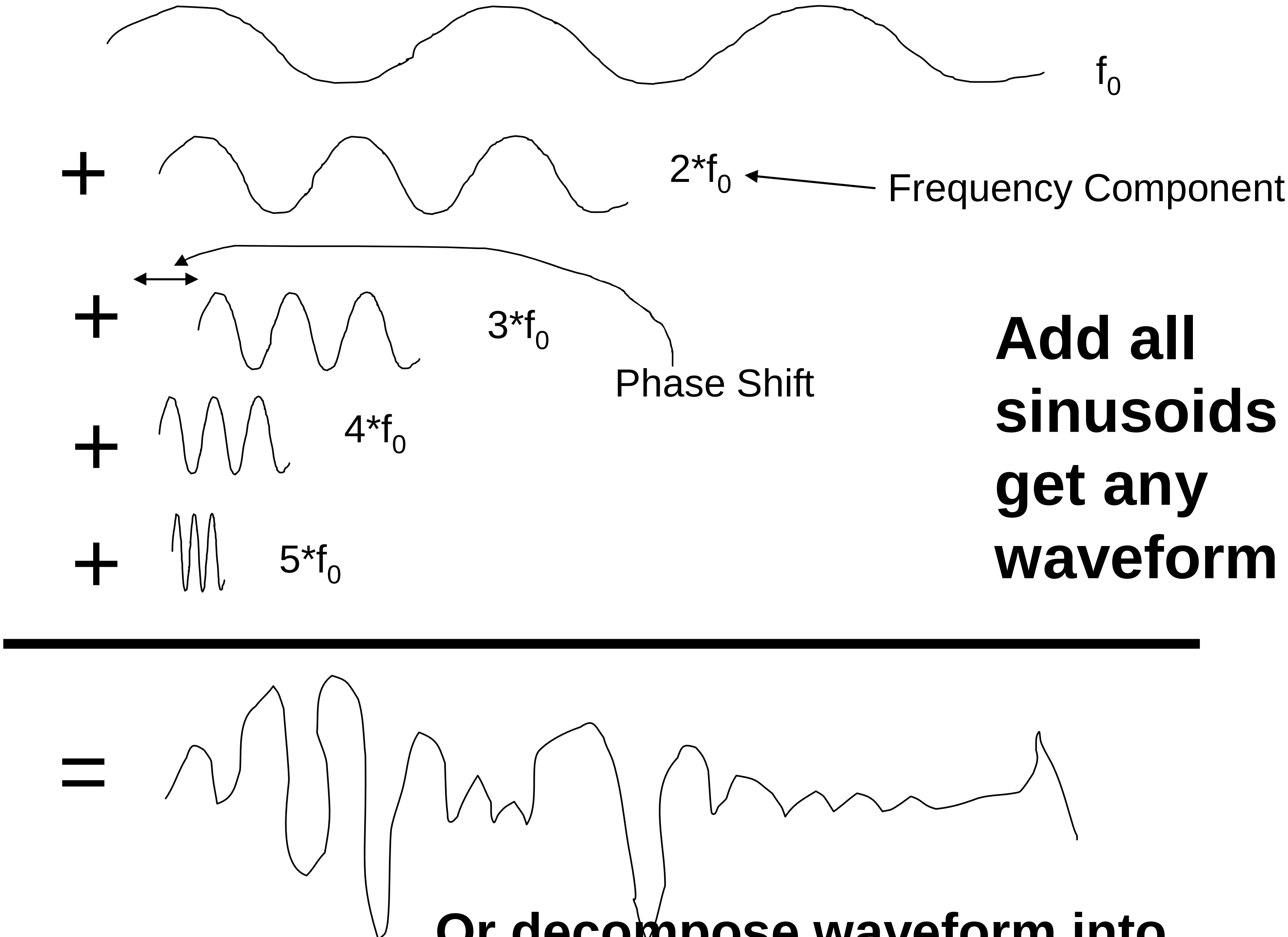
Voltage = cos (2πft), where f=frequency and t=time

Adding up the sinusoids

We can produce any general wave by adding up the sinusoids of differing frequencies and phase shifts:



Voltage = cos ($2\pi ft$), where f=frequency and t=time

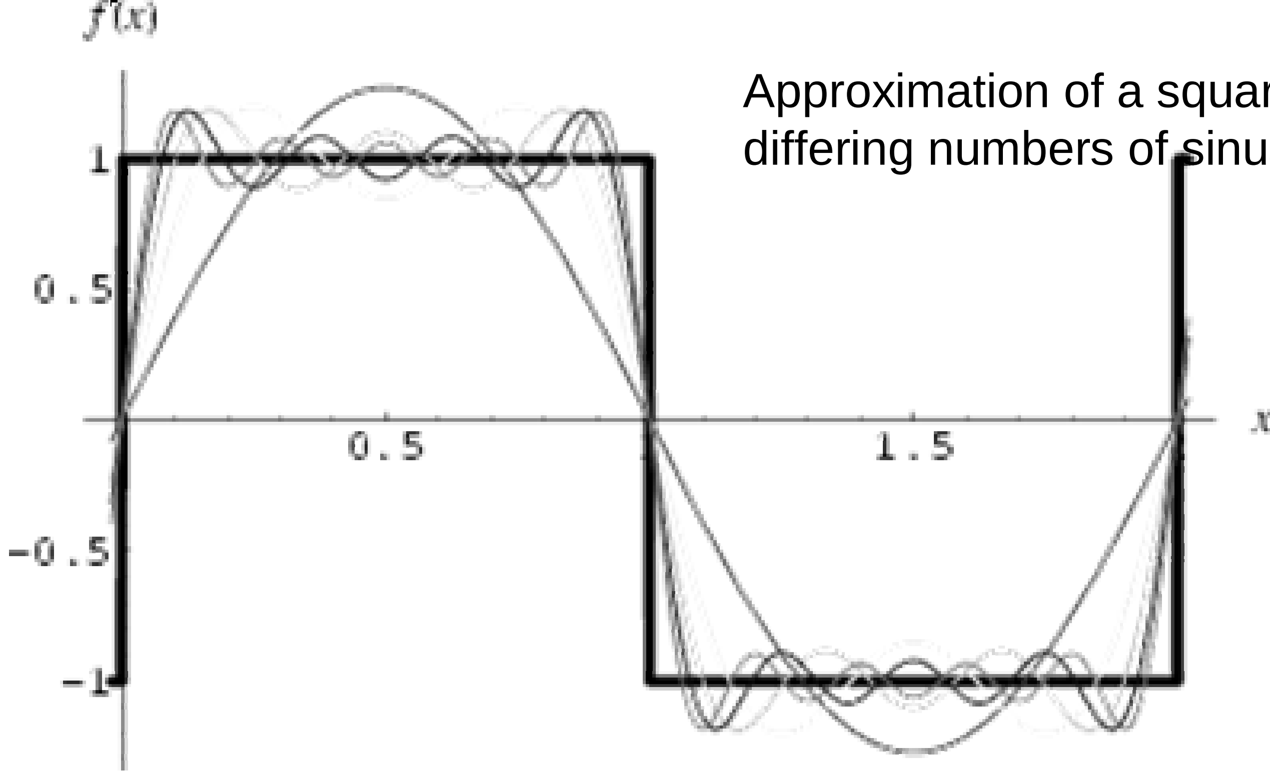


Add all sinusoids up to get any waveform

Or decompose waveform into component sinusoids (each with a different amplitude and phase shift)

Adding up the sinusoids

- Any wave can be thought of as a sum of sinusoids with different frequencies, amplitudes, and shifts.



Approximation of a square wave with differing numbers of sinusoids in it

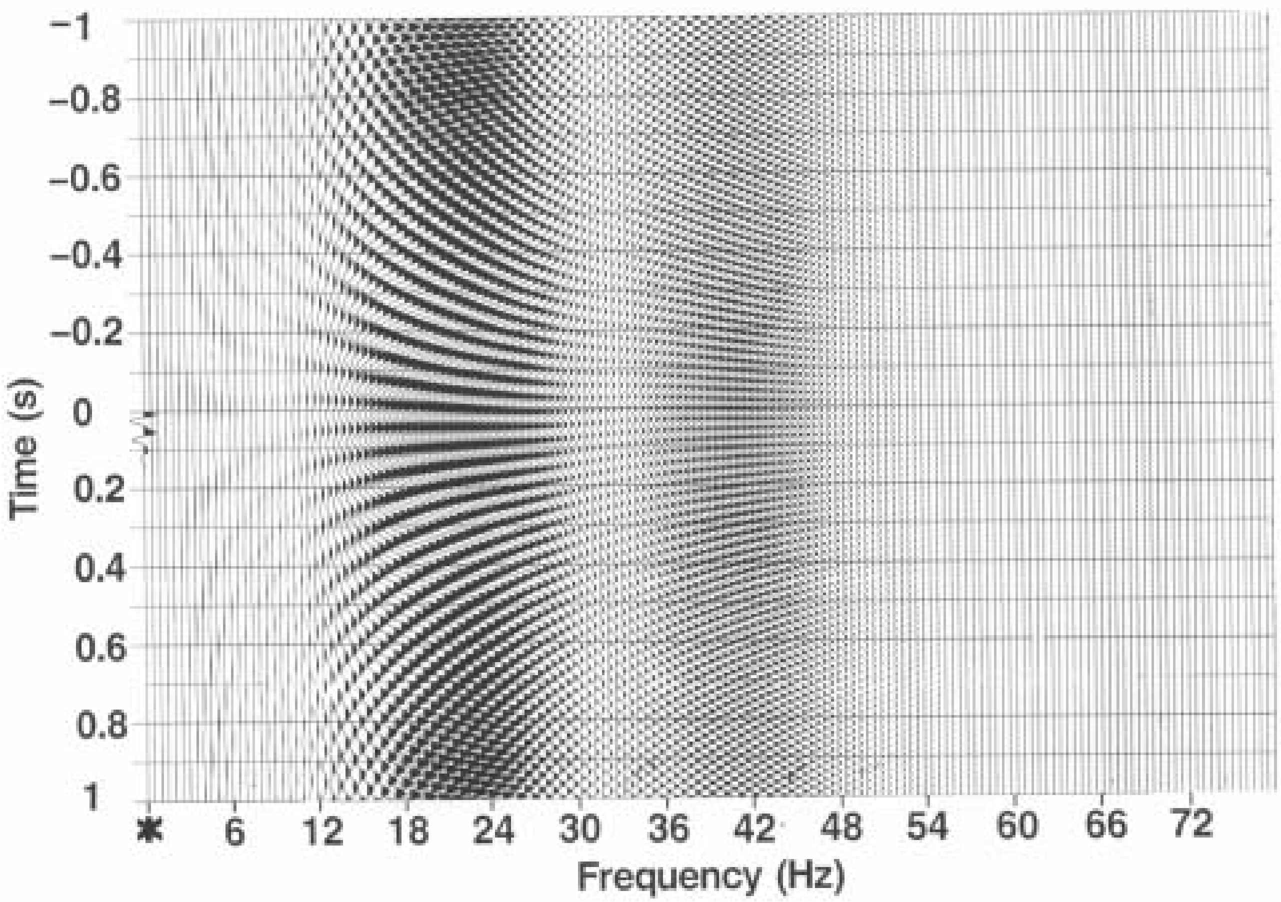
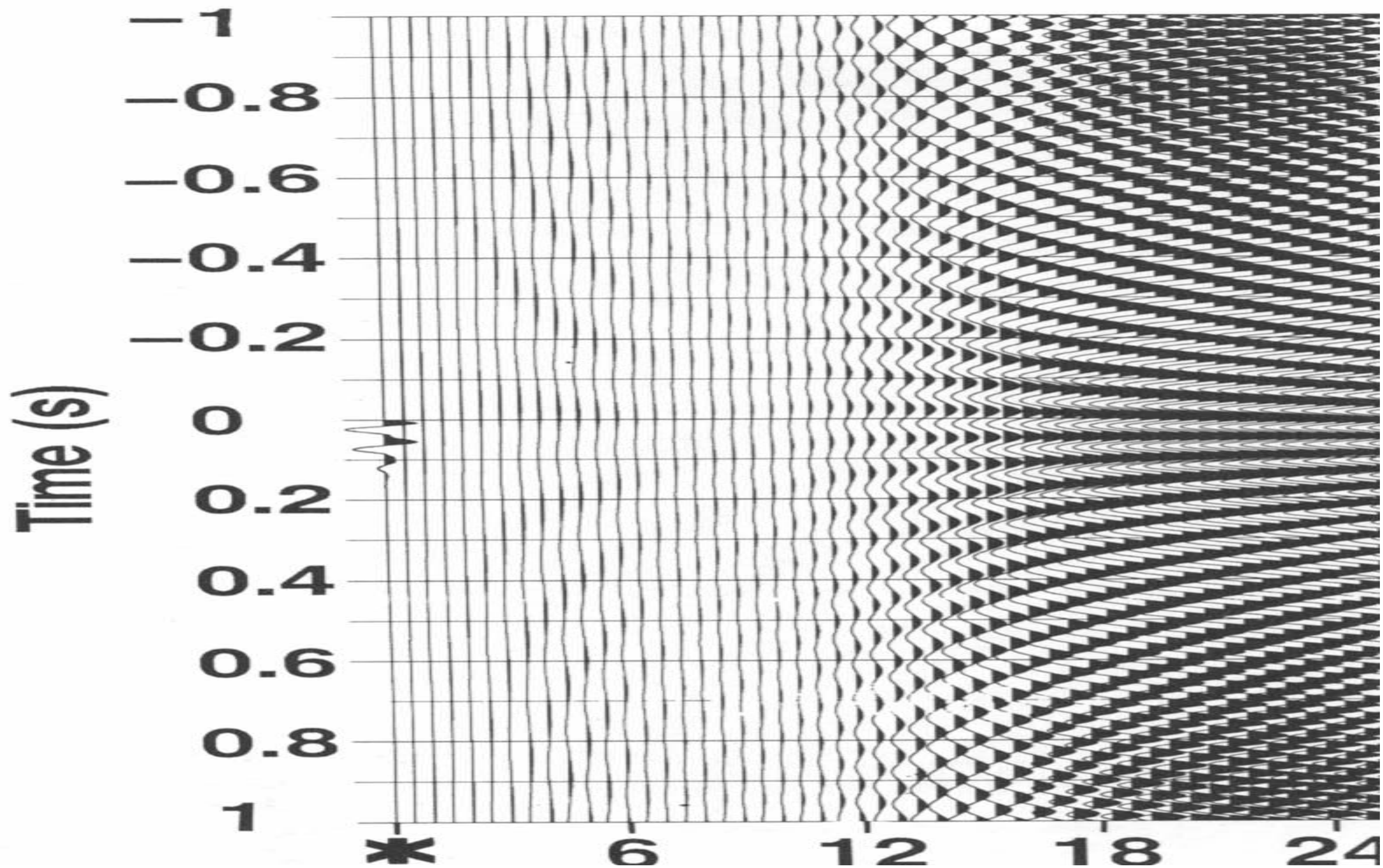


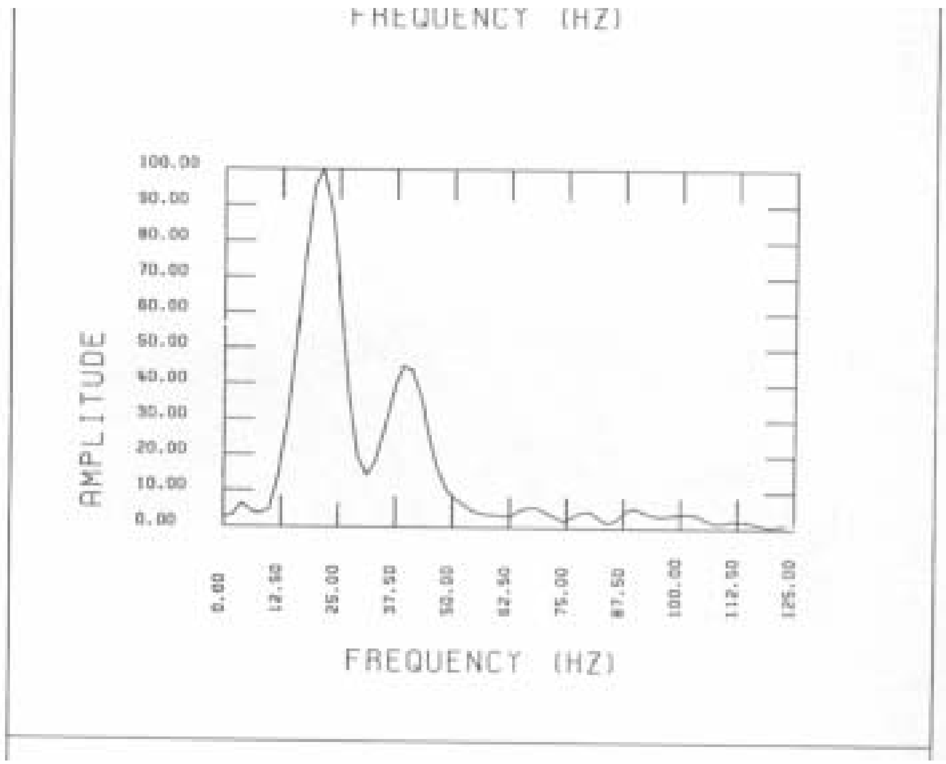
FIG. 1-2. An ensemble of sinusoidal motions with different frequency, peak amplitude, and phase-lag can be superimposed to synthesize a time-dependent waveform on the trace as indicated by the asterisk.

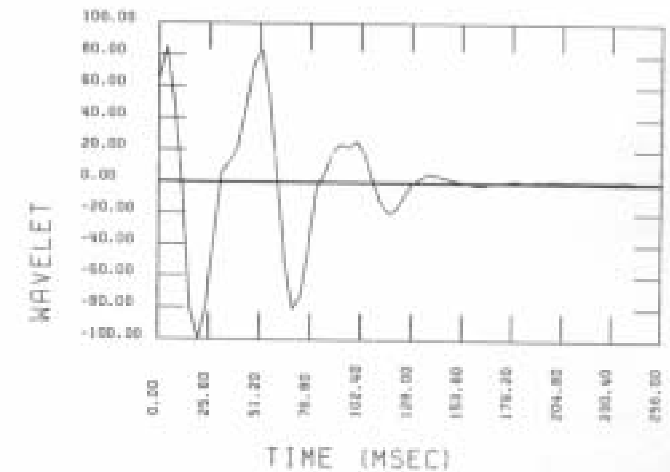


−1
−0.8
−0.6
−0.4
−0.2
Time (s)
0
0.2
0.4
0.6
0.8
1
*
6
12
18
24

Amplitude spectrum

- The amplitude spectrum of the wave shows the amplitudes of the different frequency components of the wave.





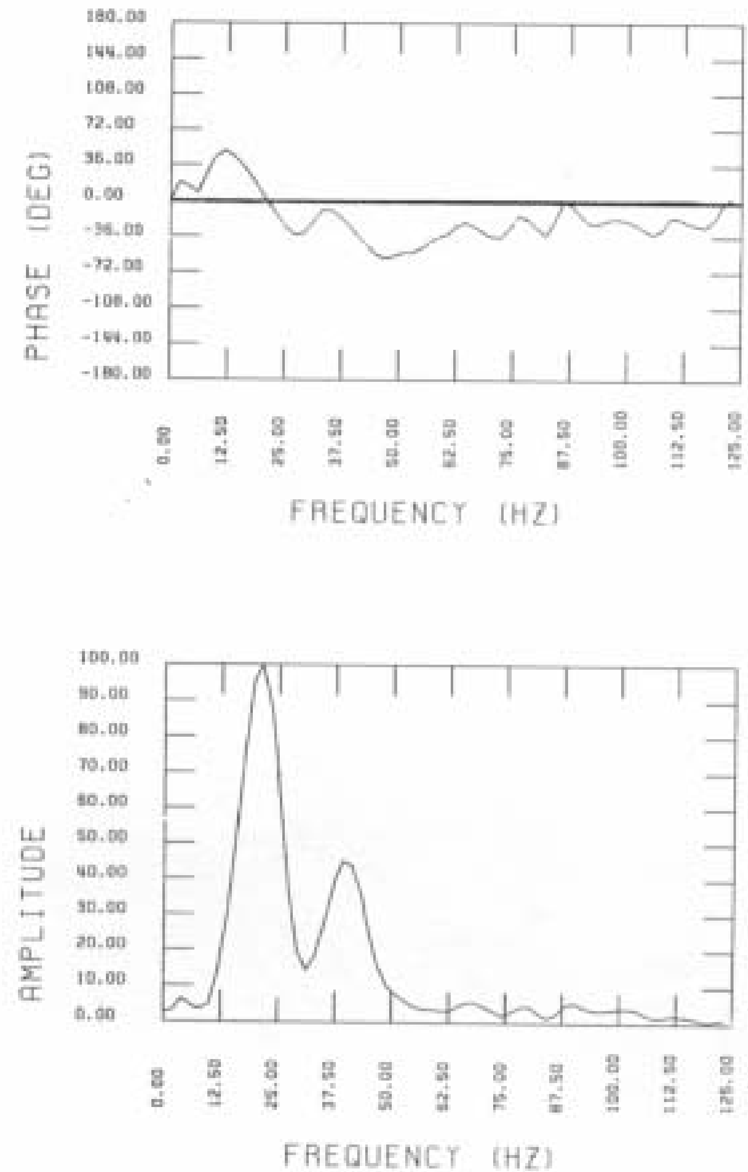
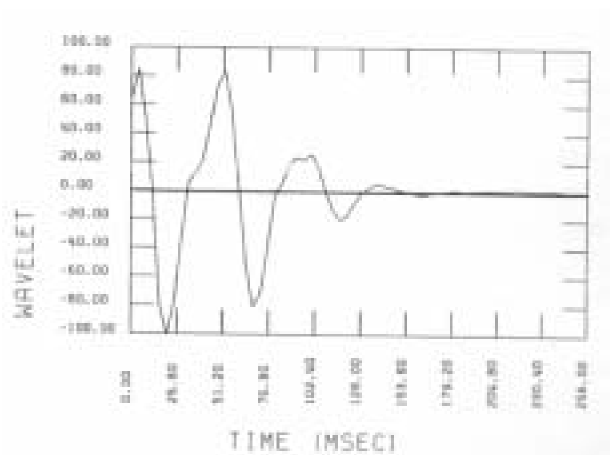


FIG. 1-3. The information from Figure 1-2 can be condensed into amplitude and phase spectra. Each point along the amplitude spectrum curve corresponds to the peak amplitude of the sinusoid at that frequency plotted as a trace in Figure 1-2. Note the equivalence of the two peaks in the amplitude spectrum with the two high-amplitude zones in Figure 1-2. Each point along the phase spectrum corresponds to the time delay of a peak or trough along the sinusoid at that frequency with respect to the timing line at $t = 0$. Note the equivalence of the phase curve with the trend of a positive peak from trace to trace in Figure 1-4.

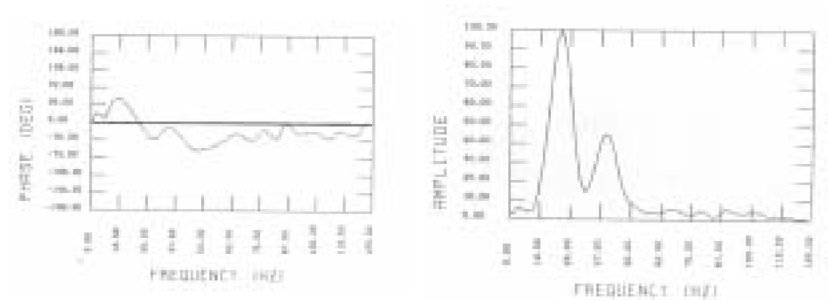
Fourier Transform

- Converting the signal from time to frequency is called the Fourier Transform
- It is sometimes referred to as the "frequency domain"

Time Domain



Frequency domain (frequency and phase)

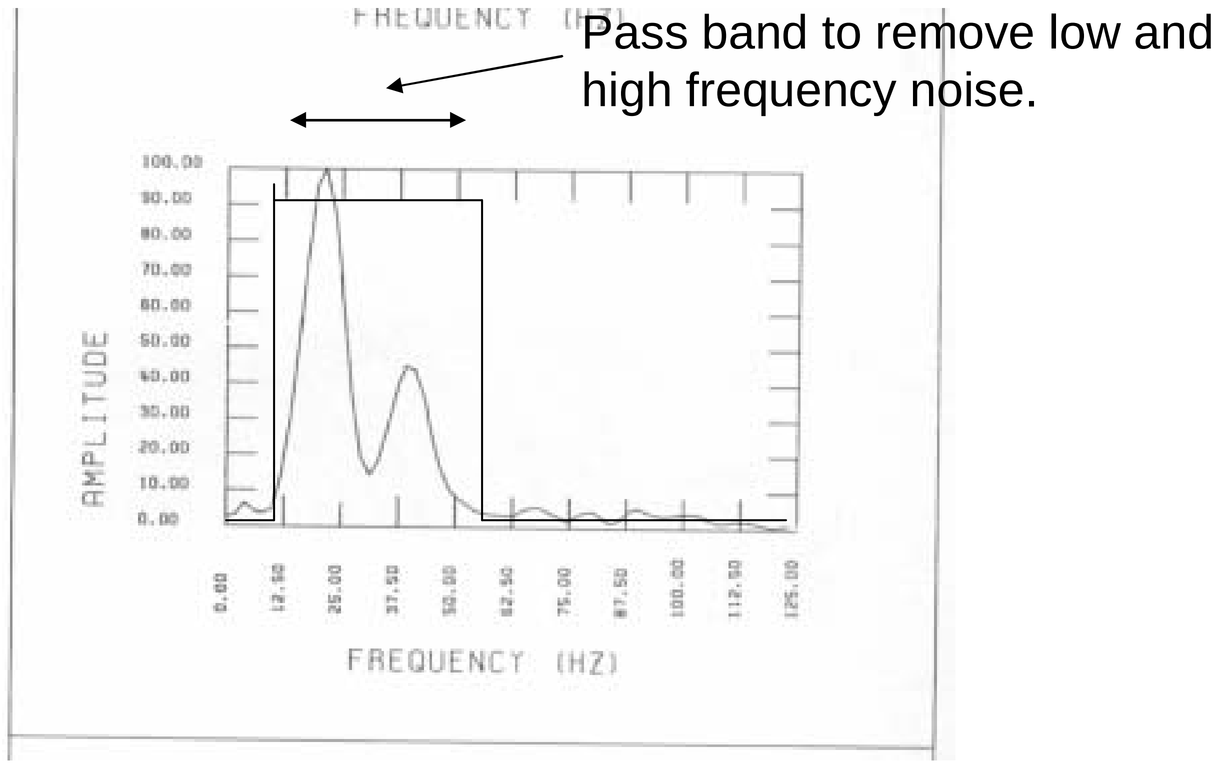


Filtering

- We can use the amplitude spectrum to filter
  - Low-pass filter removes high frequencies (cars, wind noise)
  - High-pass filter removes low frequencies (cars, trucks, pumps, surface waves)
  - Notch filter removes noise at a set frequency (pumps, 60hz noise)

Applying the filter

- To apply a filter we simply modify the shape of the amplitude spectrum to remove frequencies from the signal

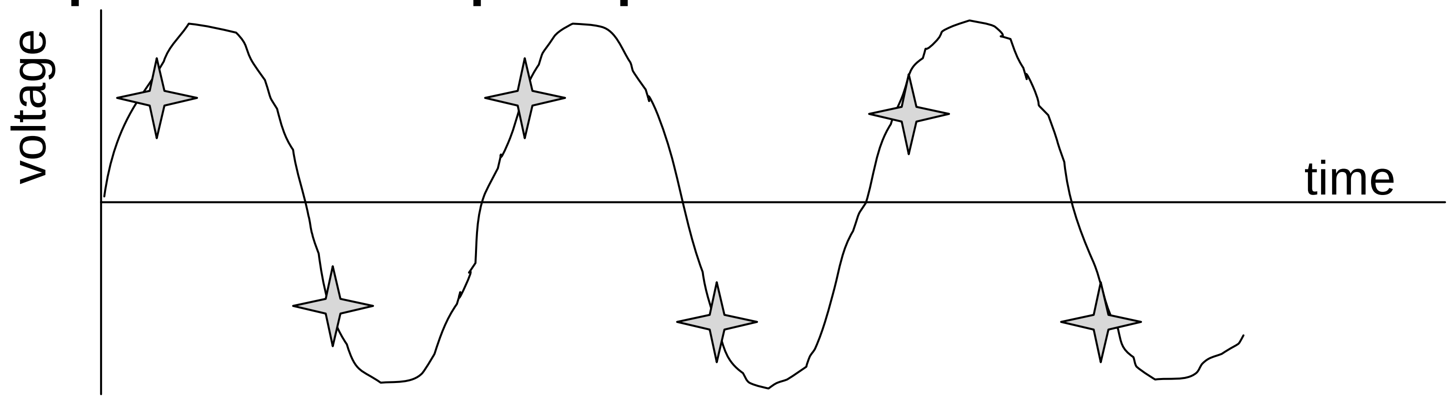


Digital recording

- When we record digitally (not analog) we sample the data at time samples separated by Δt
- For seismic data
  - Δt is about 0.004s or 4 ms (milliseconds)
- What is the highest frequency we can record?

Aliasing Frequency

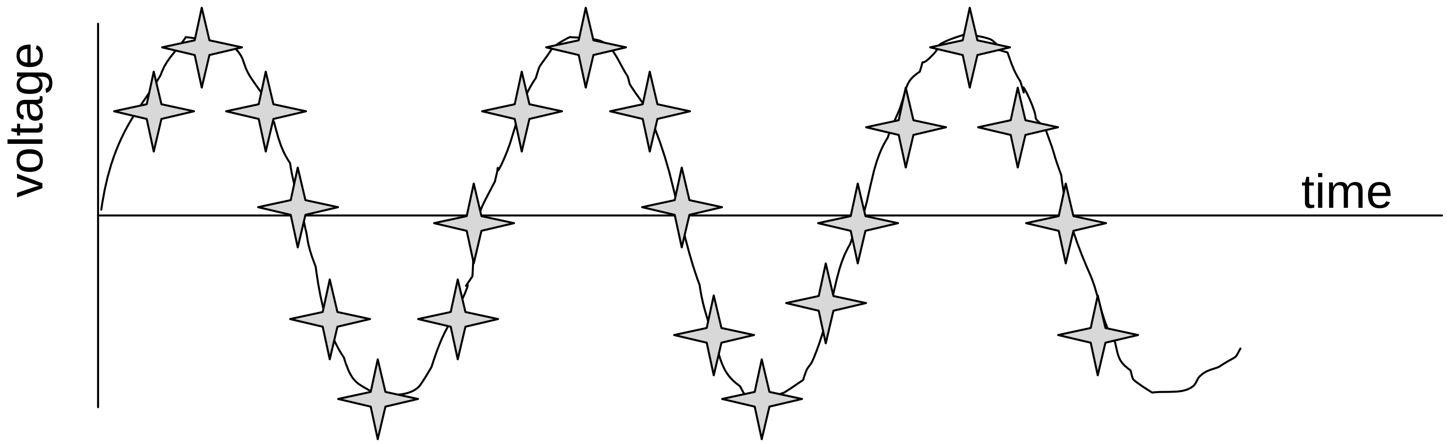
- The highest frequency we can record is called the aliasing frequency or the Nyquist frequency.
- It is the frequency for which each is sampled twice per period



Voltage = cos (2πft), where f=frequency and t=time

Aliasing Frequency

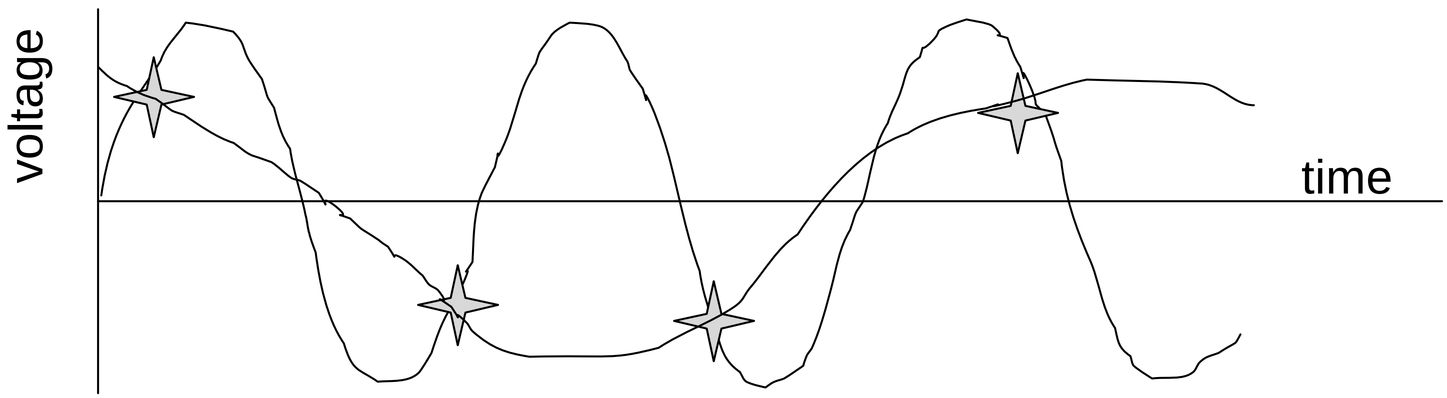
- If I record more often than twice per cycle, all is fine



Voltage = cos (2πft), where f=frequency and t=time

Aliasing Frequency

- If I record less often than twice per cycle, a longer period signal results, this is bad.



Voltage = cos (2πft), where f=frequency and t=time

Aliasing frequency

- So if I record at interval Δt and I need two samples per cycle to record a frequency

the period will be $T_{alias}=2^* \Delta t$

And the frequency will be $f_{alias}=1/T=1/(2^* \Delta t)$

If we have samples/second instead of Δt we use samples/second = $1/\Delta t$ so that

f_{alias} = (samples/sec)/2

Aliasing frequency

- Frequencies below the alias frequency are recorded.
- Frequencies above the alias frequency are mapped (or “aliased”) back into the lower frequencies. This is bad.

Wagon wheels and aliasing

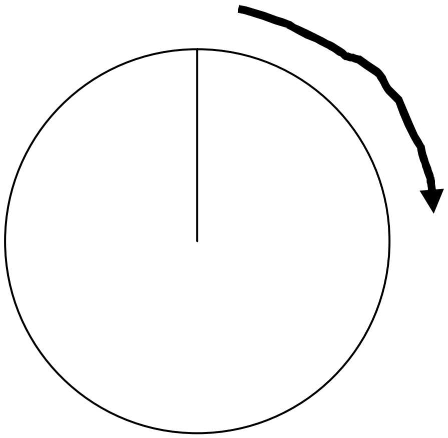
- Ever notice how the wagon wheels in old movies look like they're going backwards?
- Does this happen in real life?

Wagon wheels and aliasing

- Ever notice how the wagon wheels in old movies look like they're going backwards?
- Does this happen in real life?

- No it doesn't!
  - It looks like the wheel goes forward, stops, then starts going backwards, and then stops and goes forwards, and repeats this until it blurs.
  - It is because the movie is taking discrete still pictures.

Wagon wheels

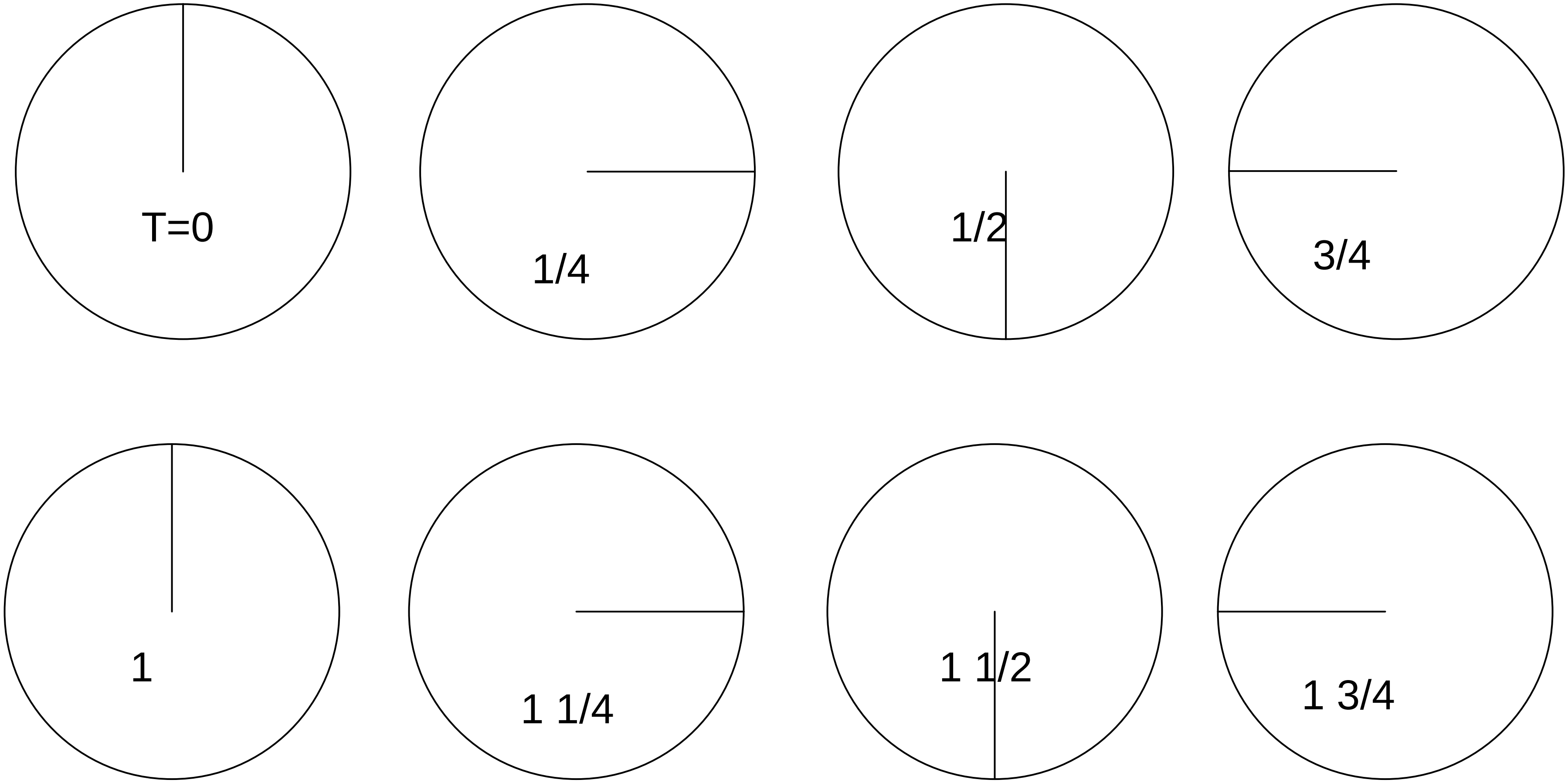


Consider a wheel rotating
once per second clockwise

f = 1 cycle / second
T = 1/f = 1 second/cycle

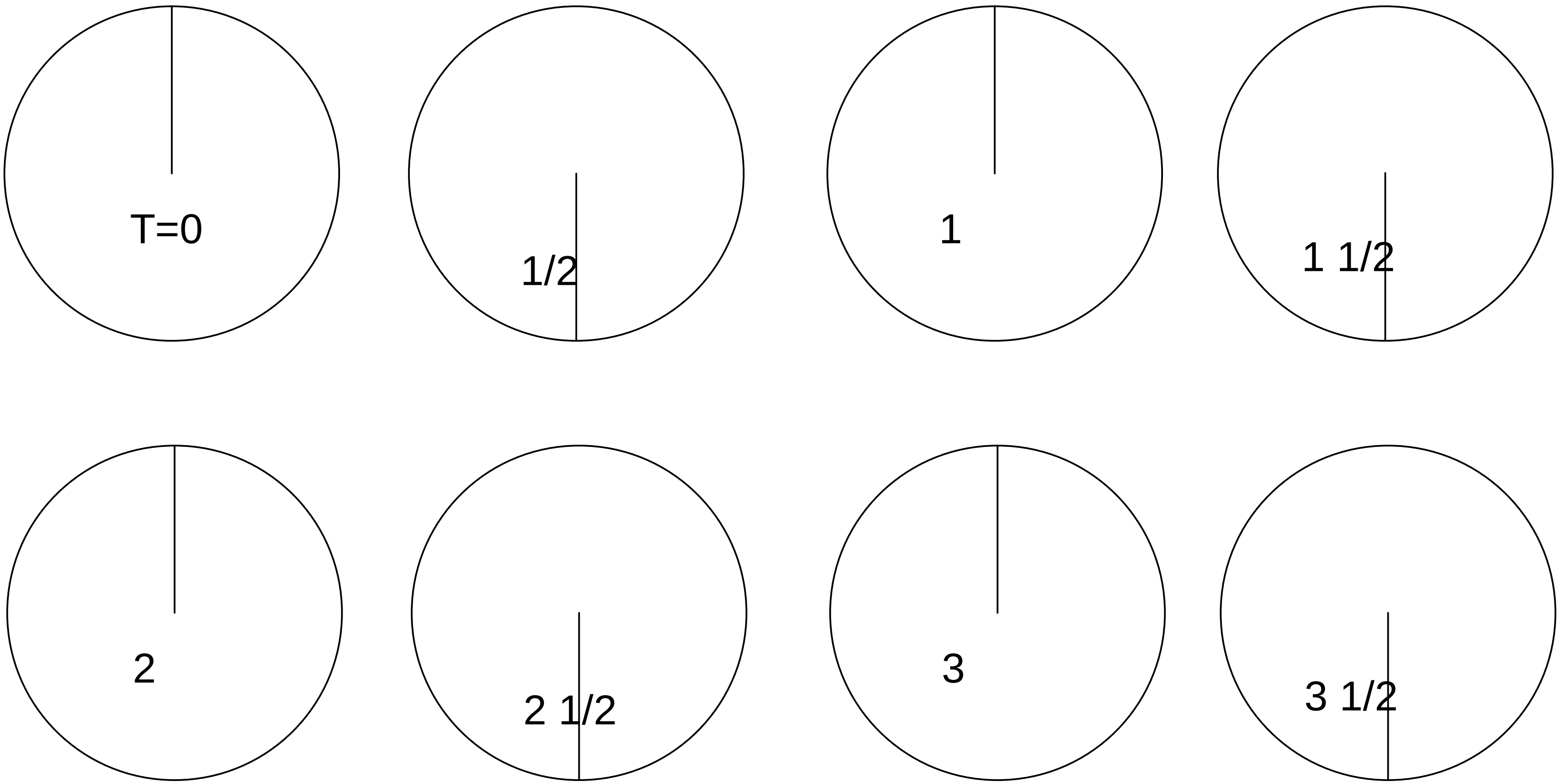
Now, if we take a movie of this at a fixed sampling rate, what will it look like?
Let’s try 4 samples/second, 2 samples/second, and 4/3 samples/second

Sample at 4 times per second (4Hz)



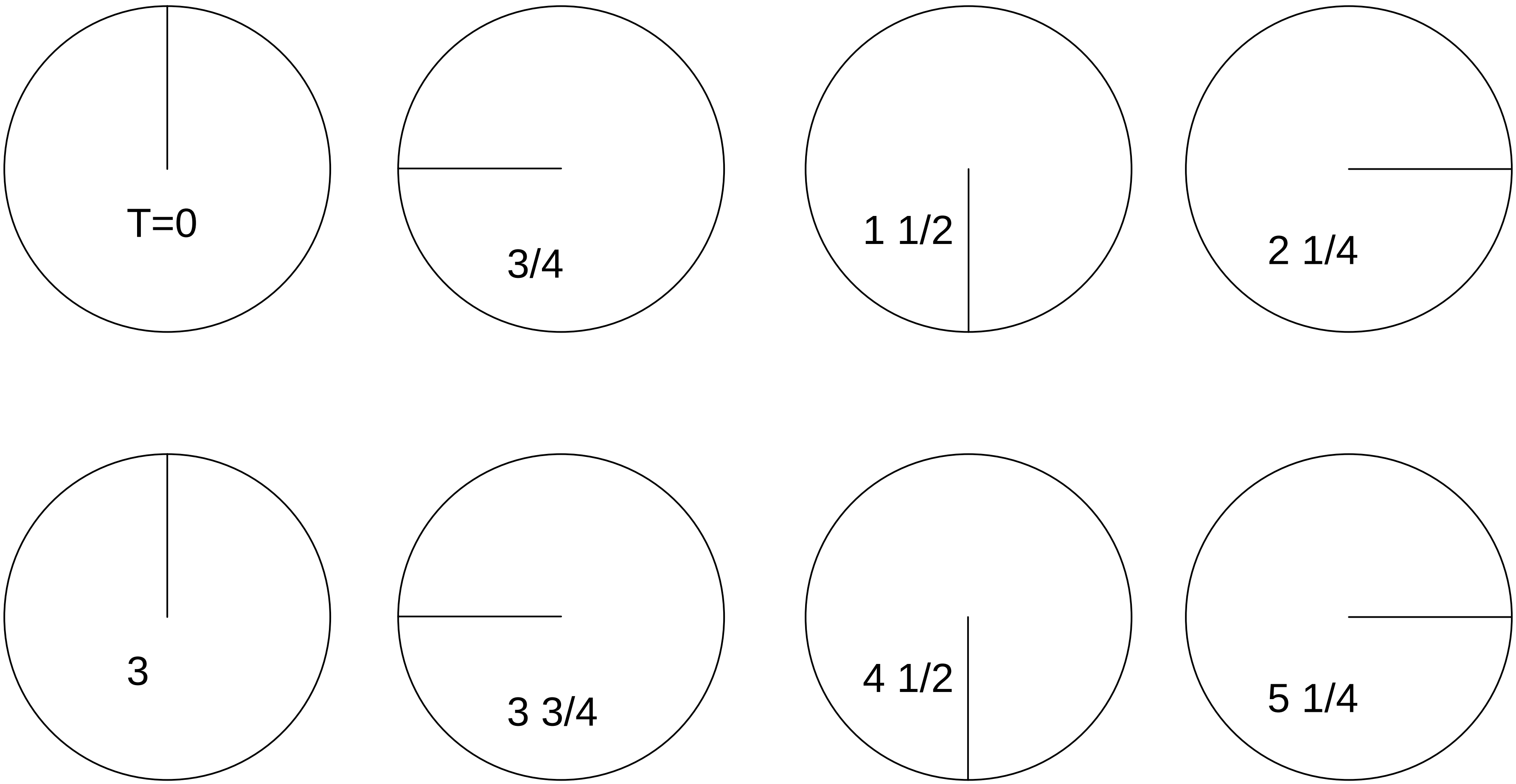
It’s moving clockwise at 1 cycle/second. Everything’s fine!

Sample at 2 times per second (2 hz, ½ second period)



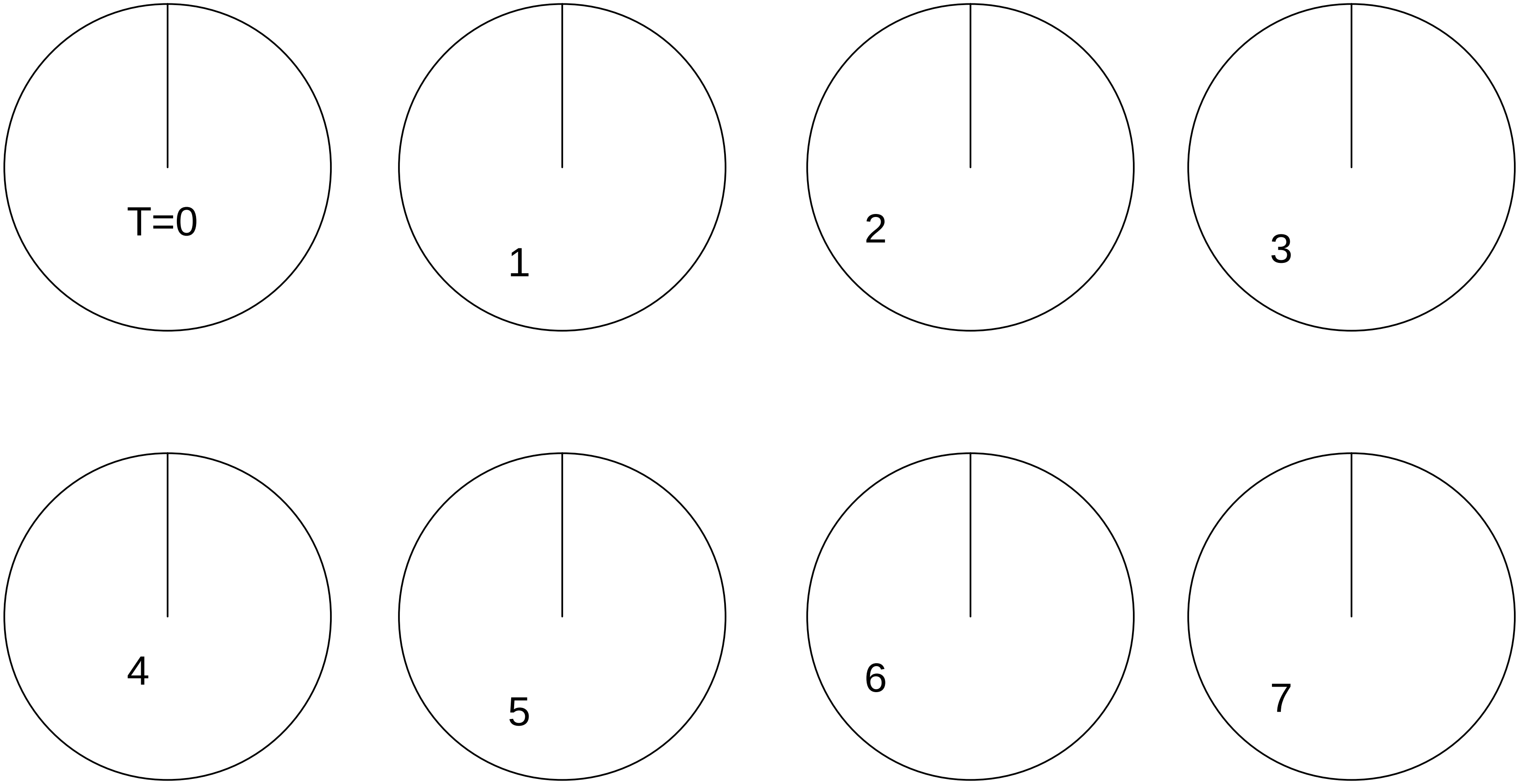
Not clear which way it is going!
This is the “aliasing” frequency!

Sample at ¾ second period (4/3 Hz)



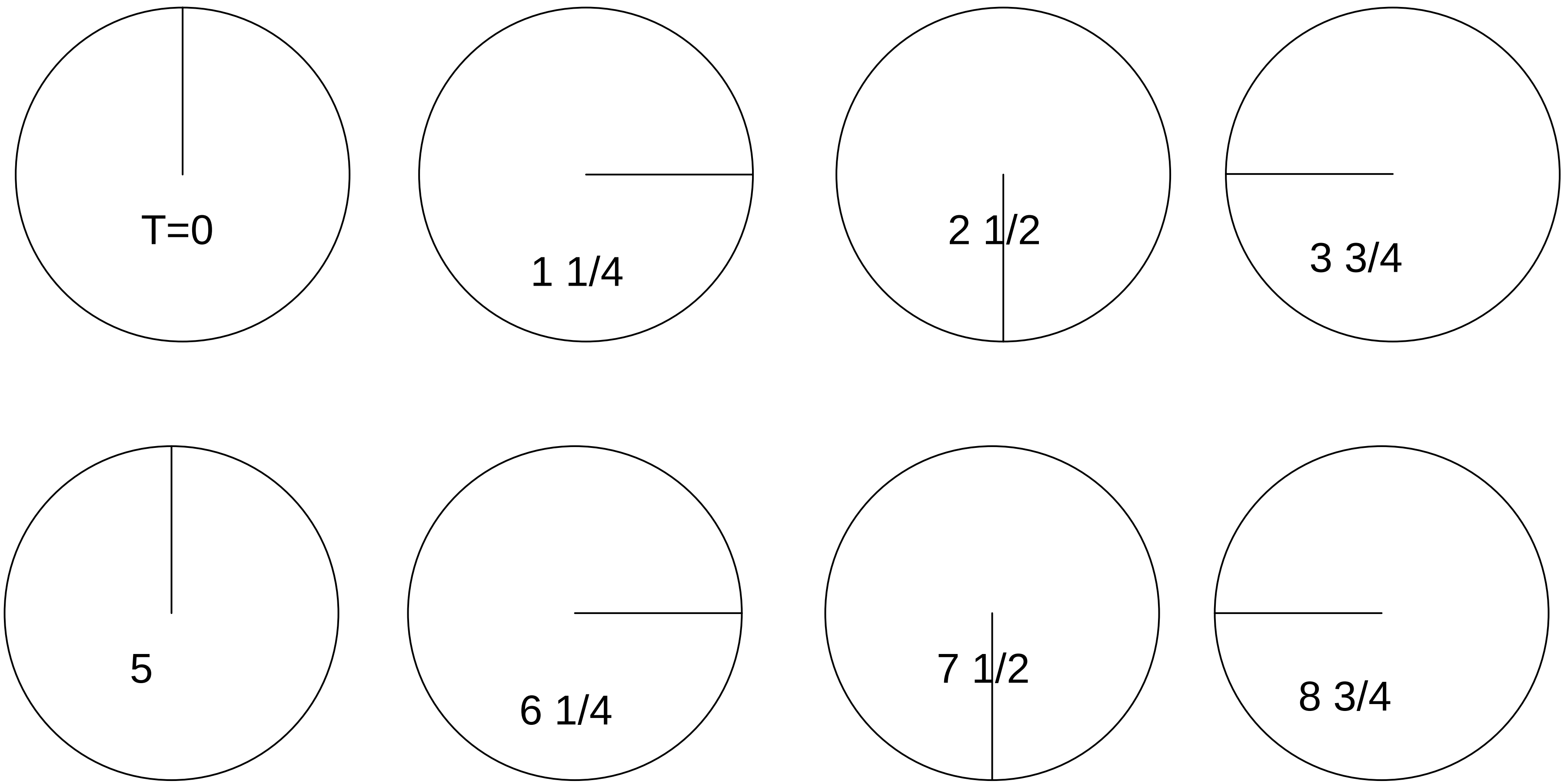
Now it looks like it's moving backwards (counterclockwise) at 1cycle/3seconds = 1/3 Hz. It has been "aliased" to lower frequency! (1cy/s – 4/3 cy/s = -1/3 cy/s)

Sample at 1 second (1 Hz)



Now it looks like it's stopped again!. It has been "aliased" to lower frequency! (1cy/s – 1 cy/s = 0 cy/s)

Sample at 1 1/4 seconds (4/5 Hz)



It's moving clockwise at 1 cycle/ 5 second or .2 cycles/second.
1cy/sec – 4/5 cy/sec = +1/5 cy/sec. So the 1Hz has been aliased to 0.2Hz!

CD recorders and aliasing

A CD player records at

– 44,100 samples/channel/second x 2 bytes/sample x 2 channels x 74 minutes x 60 seconds/minute = 783,216,000 bytes

So its aliasing frequency is

44,100/2 = 22,050 hz

This is ok, since your hearing only goes to about 20,000 hz at most.

CD players and aliasing

- What about the frequencies higher than 22 kHz?
  - If we attempt to digitally record them (either live or from analog tape) they will be aliased back into the low frequencies and distort the music.
  - To cure this an “anti-aliasing filter” is applied before recording (it’s really just a low-pass filter).