# Teaching Math on an Oscilloscope, Part II: FFT of Non-Sinusoids

**By:** Marsh Faber
Agilent Technologies

### Purpose:

To show mathematical concepts in real time: integration, differentiation and FFT conversions. Note that this experiment is a way for the math, physics and engineering departments to work together to show students some "real" applications of math.

### Equipment:

- Agilent 33120A Synthesized Function/Arbitrary Waveform Generator
- Agilent 54600B 100 MHz Digital Oscilloscope with
- Agilent 54657A FFT and GPIB plug-on module

### Prerequisites:

A very basic understanding of calculus and Fourier Transforms. Math Functions on a Scope, Part I.

In part I of this experiment, we covered basic FFT functions of a sine wave, derivatives and integrals. Now let's do some more advanced FFT topics.

### FFT of a TWO SINE WAVEs:

The sine wave in PART I showed a single dominant signal at 1 kHz, as it should. If we insert a signal with two dominant sine waves, what will the FFT look like? Let's try it. The Agilent 33120A has a mode that can output a signal with two separate sine wave frequencies. [Default values are FSK FREQ 100Hz, FSK rate 10 Hz, main FSK freq. Is that shown on the front panel.] Turn CH 1 back on to look at the time domain representation, set its horizontal sweep speed to 10 ms/cm, and set up the Agilent 33120A as follows:

SHIFT FSK

The scope screen should look like FIG 10.

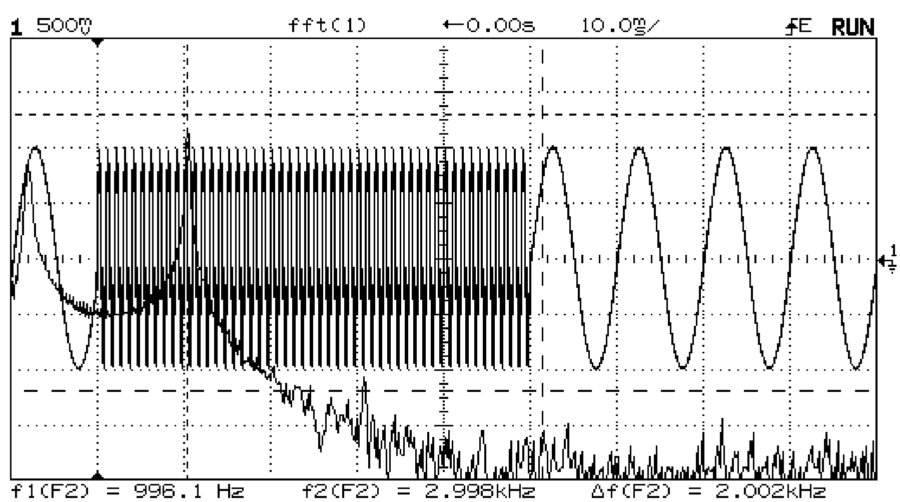


**FIG 10: FSK waveform and FFT.**

To look at just the FFT of the FSK waveform, toggle CH1 and hit FIND PEAKS:

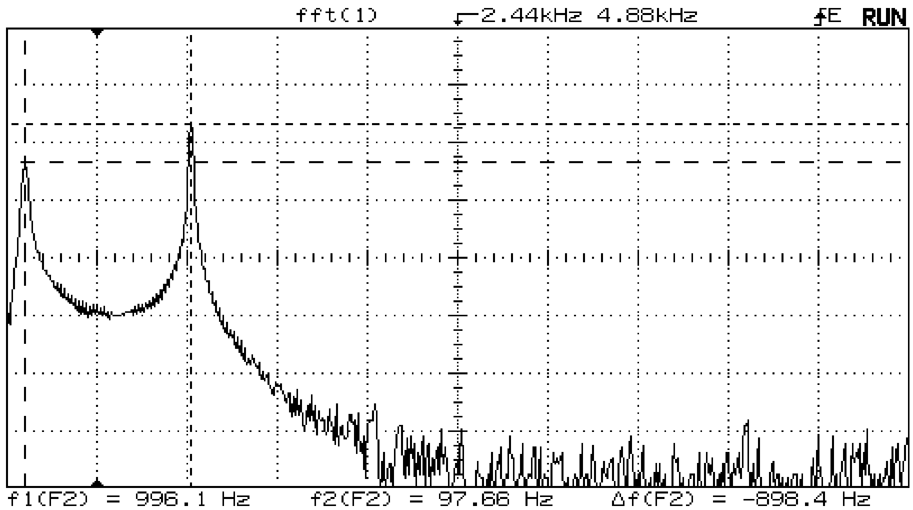


**FIG 11: FFT of FSK waveform: 100 Hz, 1 kHz**

The scope found both peaks. The FFT is a valuable tool to find all the spectral content of any signal, whether is electrical or mechanical. And it can find things that are not readily visible in the time domain.
This signal had two distinct sine waves, running sequentially. But the FFT can also help us find the sinusoidal components of non-sinusoids:

**FFT of a SQUARE WAVE:**
Let's try a square wave. First, exit FSK mode: SHIFT FSK, toggle CH1 button on the scope to see the waveform. On the Agilent 33120A: SQUARE WAVE. You should have a 1 kHz square wave. Set the scope time base to about 2 ms/cm. You'll see the FFT and the time domain waveforms. Toggle CH1 again to just look at the FFT, and hit CURSORS; FIND PEAKS to show the square wave transform:

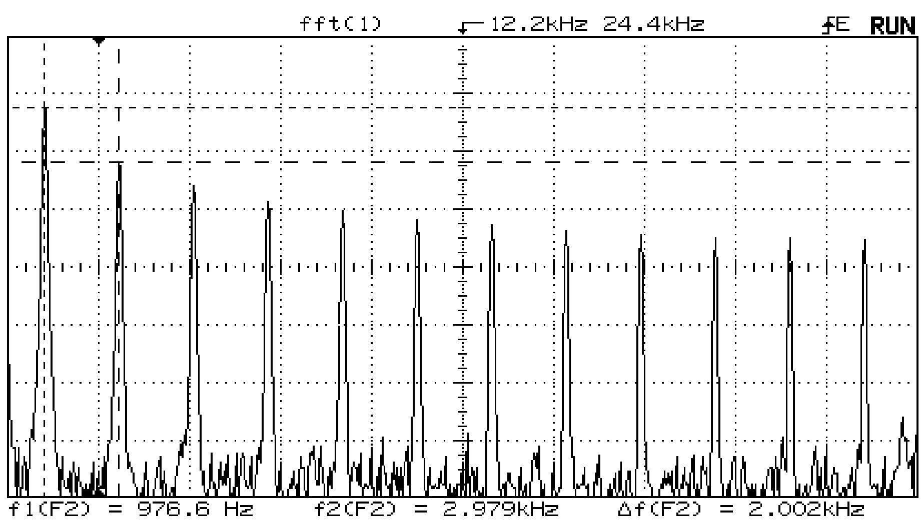


**FIG 12: FFT of a 1 kHz square wave**

Notice how rich the waveform is in harmonics. It takes a VERY wide bandwidth amplifier to pass all the harmonics of a square wave. **How does the amplitude of each peak correspond to Fourier coefficients?**

**FFT of a PULSE TRAIN:**

**What do you predict will happen if we changed the duty cycle of the square wave to make it more like a pulse train?** Let's find out. On the Agilent 33120A: SHIFT % DUTY. Use the knob to change the number from 50% to 20% and hit ENTER. The waveform is now a pulse train with 20% duty cycle. The FFT should look something like FIG 13.

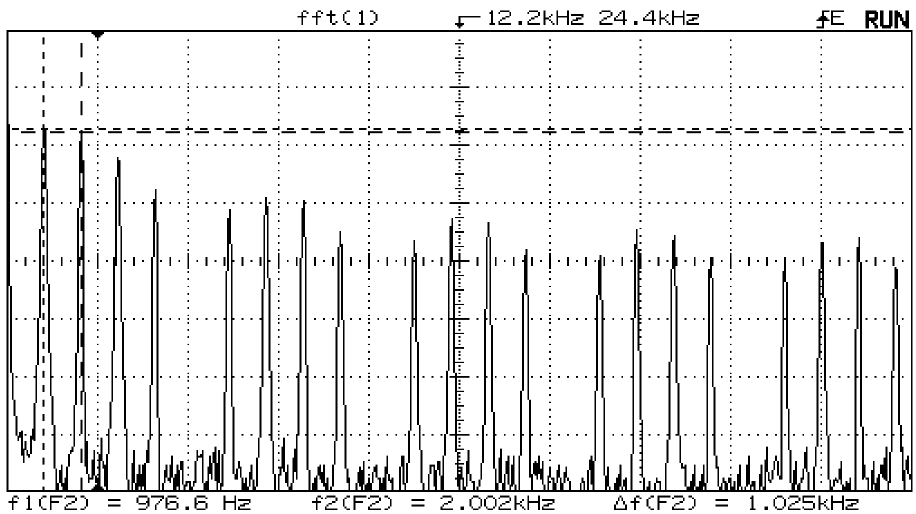


**FIG 13: FFT of a pulse train**

**Does the FFT in FIG 13 have the shape you would expect**?

**FFT of a SINC WAVE:**

Reset the duty cycle to 50%: SHIFT; DUTY %; set to 50 with the knob; ENTER.

Now select a different waveform: SHIFT ARB. Toggle the RIGHT ARROW until you see SINC on the Agilent 33120A display. Then ENTER. Set the time base for 100 us/cm and take the FFT. You should see:

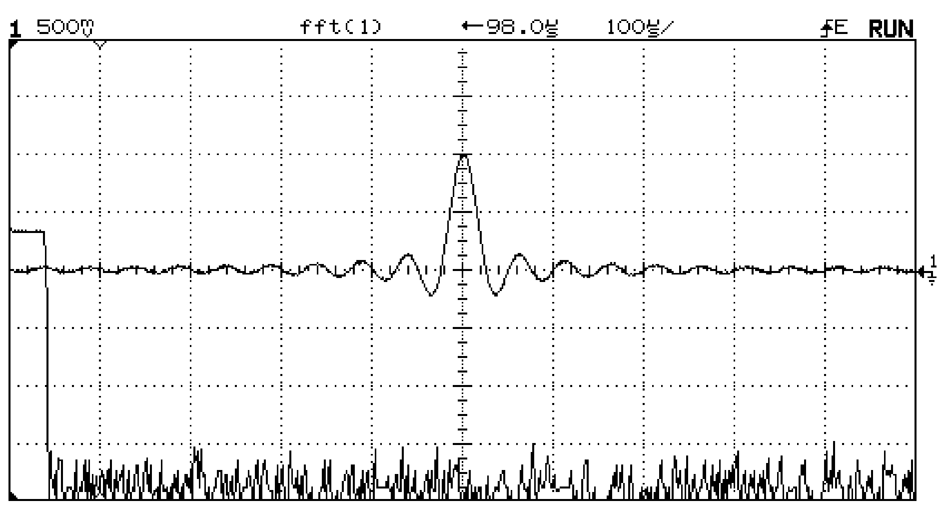


**FIG 14: FFT of a SINC waveform**

**How do you explain this one??? Is this the "dual" of anything you have seen before?**

**Harmonics:**

The next time you hear a fan turning, or an engine or a squeaky wheel, try to hear how many harmonics there are. What is the fundamental frequency? Is there more than one unrelated fundamental? Is there a beat frequency between two elements going at nearly the same rate, as in two airplane engines that aren't quite synchronized? How much acoustic energy is in the harmonics relative to the fundamental, in other words, does it sound like a siren or like noise?

One legendary helicopter designer used a broomstick (with no broom end) as his primary piece of audio analysis equipment. He simply put one end of the broomstick on the engine and placed his ear on the other end, and listened.

**This concludes Part II of Math Functions on a Scope** MLF 5/97