A degree makes you smart? I don't think so Tim!

By Dan P. Bullard

False facts are highly injurious to the progress of science, for they often endure long

Charles Darwin, The Descent Of Man

"I don't think so Tim" was the phrase uttered on every single episode of the 1990s TV show, *Home Improvement* when the self absorbed "expert" in home renovation and improvement, Tim Taylor invariably got something completely wrong in the middle of the project, usually on-air in front of his studio audience. The show was clearly mocking Bob Villa's show on PBS, *This Old House* where Bob would spend fantastic sums of money (the property owner's, aka Someone Else's Money) fixing up old homes. Villa's show imploded when he talked the owner of a Craftsman home into upgrading to a second story only to be flooded out when a weekend rainstorm came after the roof was removed in preparation for the addition.

Experts are funny people. They think they know so many indisputable facts that make them irreplaceable, and yet, as DeGaul once said, "the graveyards are full of indispensable men." A college degree cements this hubris in place, making these people almost impossible to work with for anyone who questions their expertise or opinion. I saw this in the US Navy when an officer, freshly commissioned with his shiny gold braid and brand new diploma in Basket Weaving 101 would be roundly browbeaten into submission by a Chief Petty Officer who had seen more blue water than the officer would ever see. Officers with their shiny new degree know nothing about the way things really work on a ship. The professors in their ivory towers had never been to sea, and had lots of theories but no real understanding of shipboard life, and it was the professors who determined who would get a degree and who wouldn't.

As a self-taught engineer I have the same problem. I have worked with many degreed engineers, from BSEEs to PhDs and have watched them flail until I came on the scene and found their "little problem" for them, much to their chagrin. This has happened way too many times for me to recount here, but let me focus on just a few of the most egregious errors made in mixed signal technology.

M must be a prime number – I don't think so Tim! When sampling, the formula M/N = Ft/Fs defines how to set your sampling frequency. Normally you pick a radix 2 number for N so the FFT runs quickly and then *some of you* go find a table of primes to pick your M that will make your formula fit the Test Frequency, Ft that you are looking to use. The problem is, M need not be a prime number. The real rule is that M and N must be mutually prime, orthogonal for those of you in Rio Linda (h/t Rush).

I have heard this for decades, from CEOs to colleagues to customers. "I can't get the test frequency in the specification because I need to use a Prime for M!" Once I was giving a sales demo at 7AM and the customer was so impressed with my mixed signal knowledge that he started teasing my boss by claiming he could offer me twice what my boss was paying me at the time. But then he mentioned that M must be prime, a discussion ensued. He claimed that if M is not prime, harmonics will fall on top of the fundamental corrupting the amplitude. At the time I couldn't prove he was wrong and not only did I lose the sale, but I lost the job offer as well!

But where did he hear this? His college professor of course. It was on the test and he answered the question to the professor's satisfaction (the wrong answer) and passed, and hence got his diploma.

Let's look at an example with an N of 32, so we get 16 unique bins (plus Nyquist which some guys from MIT use [shudder]) and an M of 10. Because 10 and 32 share the common factor, 2, the actual sampling solution is reduced to 10/32 = 5/16. So now the *effective* N is 16, so the number of unique bins is now 16/2 + 1 or 9. Notice in the table below I show where the harmonics will fall after obeying Dan's Rules to deal with

Where do the harmonics fall with M = 10?

Harm	Bin	Rule 1	Rule 2
F_T	10	10	10
2nd	20	20	12
3rd	30	30	2
4th	40	8	8
5th	50	18	14
6th	60	28	4
7th	70	6	6
8th	80	16	16

Harm	Bin	Rule 1	Rule 2
9th	90	26	6
10th	100	4	4
11th	110	14	14
12th	120	24	8
13th	130	2	2
14th	140	12	12
15th	150	22	10
16th	160	0	0

the aliasing of the harmonics that will necessarily happen with an M of 10 and an N of 32. (If you don't believe in aliasing because your professor told you it was bad, wait for point #2 coming up.) Notice that the first eight harmonics fall into unique bins, although the fact that every bin is even should be a clue that something is wrong. The second eight harmonics fall into the **same bins** (denoted by the color coding of the bins). This is what the above unnamed engineer tried to convey to me, and I agree that this happens if M and N share common factors.

However, let's see what happens when I use a non-prime odd number like 9. Even though 9 is not a prime number, just being odd means that it has no common factors with N which again is 32. With an M of 9, all of the first 16 harmonics fall into unique bins. This is guaranteed when M and N share no common factors. M does not need to be prime, the **real** rule is that M and N must share no common factors. But that's not what the professors are teaching, because they learned from their professors, who learned from their professors, ad infinitum.

It takes an outsider who didn't have to take a test on a topic, he had to actually do the experiments himself and learn it the way that Ohm learned Ohm's Law. The guy

Where do the harmonics fall with M = 9?

Harm	Bin	Rule 1	Rule 2
F_T	9	9	9
2nd	18	18	14
3rd	27	27	5
4th	36	4	4
5th	45	13	13
6th	54	22	10
7th	63	31	1
8th	72	8	8

Harm	Bin	Rule 1	Rule 2
9th	81	17	15
10th	90	26	6
11th	99	3	3
12th	108	12	12
13th	117	21	11
14th	126	30	2
15th	135	7	7
16th	144	16	16

without a degree doesn't wait to be taught something, he takes the initiative and figures it out for himself. The guy with the degree just recites some vague memory of a test item he remembers from a class that came between drinking and carousing with co-eds.

Aliasing is bad – I don't think so Tim! A few months back I was watching an MIT video on sampling and my jaw dropped when the professor told his students that aliasing occurred when you didn't obey Nyquist and that aliasing was **bad**! That's like saying that dynamite is bad. Sure, in the wrong hands, explosives are bad, but in the right hands explosives can do wonderful things, like bore tunnels, blow tree stumps apart or open up veins full of precious minerals.

Aliasing is a wonderful thing, if you understand it. I've been using aliasing for decades to sample waveforms faster than the slow A/D convertors that were available at the time. I used aliasing in the extreme to measure frequencies into the hundreds of megahertz using a 33MHz sampler in the form of a single digital pin comparator and got the technique published in the now defunct Test and Measurement World. But, like dynamite, in the wrong hands it can be a nightmare.

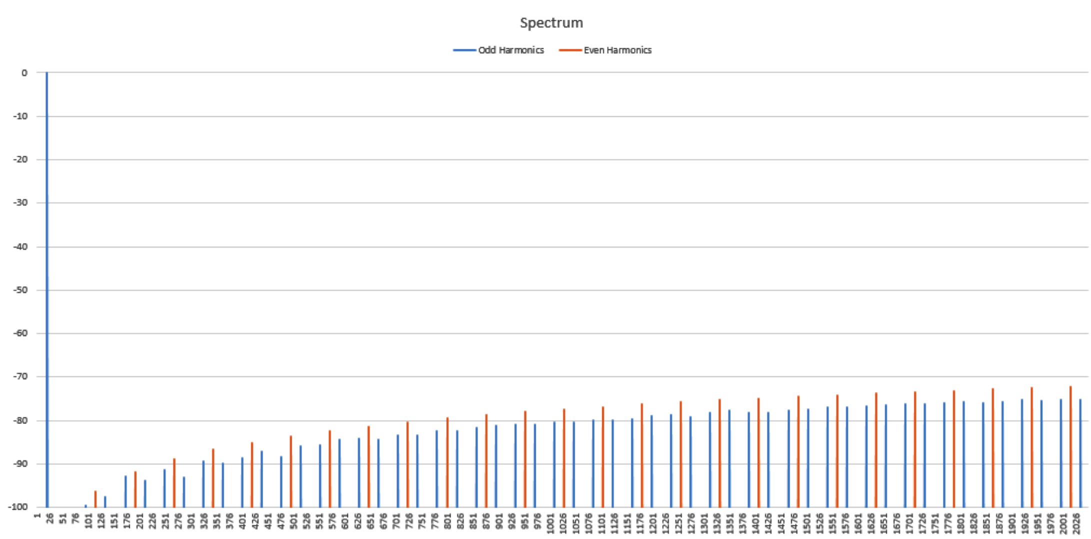
I once made a sale to a test house in Taiwan and handed the project over to a degreed engineer who had coded for mixed signal products before, but had never worked with a test frequency that was so high up in the spectrum. We had to test ENOB with a 10MHz tone using a 65MHz sampler and the customer wanted to go up to 80MHz. I worked out the math and chose a sample rate of 26.666MHz so that everything from the 2nd harmonic to the 8th harmonic would be aliasing. This poor guy worked for months on this project and the customer got very upset. The engineer would not let me help him and so he flailed away in complete frustration and eventually gave up. I had to go over to Taiwan to troubleshoot the problem, and, using a technique I invented that re-orders the samples so that M becomes 1, I found that the digital tester timing was all screwed up. It seems that another degreed engineer back at the factory hard-coded a value of 10ns into the timing API and when we used a non-standard clock frequency, the drive and strobe timing could end up being off by as much as 5 nanoseconds. Another degreed engineer tried to figure out a way to blame me for the screwup, but alas, he could not. The error was in the code long before I joined the company.

Because of the months-long delay the customer lost confidence in my aliasing technique and went with a competitor who had moved to a higher sample rate convertor for their capture instrument. Lesson learned: aliasing is bad if you don't get it, in other words, aliasing is bad if you have a degree, otherwise you are probably fine because you'll prove to yourself that it works.

Total Harmonic Distortion is the best way to test analog circuits – I don't think so Tim! There is a whole lot of voodoo and false facts when it comes to harmonics. Anyone who has ever had to get a THD test to correlate from one ATE tester platform to another knows what a frustrating experience this can be. In some cases it can be almost impossible to get correlation because some smarty-pants degreed engineer took advantage of symmetry to reduce the even harmonics to almost nothing to make the THD look better than it should be. It turns out that THD is a lie no matter how you look at it.

It's not that asymmetry causes even harmonics as your professor told you, it's that symmetry **cancels** even harmonics *hiding flaws in the device that the user would much rather know about*. If you can't replicate the exact conditions that Mr. Smart E. Pants BSEE used to implement his test, you are going to spend a lot of time on the test floor beating your head against the tester.

THD is a lie because of the way that harmonics actually work. The harmonic signature of an INL failure is wholly different from what you get from a DNL failure. In fact, it's quite likely that THD won't notice even a very large DNL failure because of the way that sine waves miss so many points along a device's transfer function and because the harmonic signature of a DNL failure doesn't even create any harmonics near the fundamental.



Spectrum of a DNL failure

Depending where in the transfer function the DNL failure occurs, the harmonics might not start to appear until the 10th harmonic or even much higher. Now maybe you don’t think anything higher than the 9th harmonic will cause your users grief, but then again, what’s the 10th harmonic of 1KHz in an audio circuit? Yeah, 10KHz, still very audible to anyone under the age of 90 or so. Are you looking to tell customers how good your products are, or are you trying to hide the flaws of a crappy part so your stock options can finally surface from their current underwater cruise aboard the *Seaview*.

You need a degree to be a good engineer – *I don’t think so Tim*! As a degreed engineer you have made a lot of assumptions in your career, they were all based on things that your professors jammed down your throat and forced you to chant in unison, “M must be prime, aliasing is bad, THD is good”, as well as many, many other nonsensical tidbits that you were forced to buy into. But then along comes a guy without a degree who shows you that what you know is just a load of dingo’s kidneys and your ego takes a serious bruising.

Keep an open mind and don’t look down your nose at those who didn’t waste their money to learn the chant. We are doing just fine. I would say that every single company should employ a number of self-taught engineers because these people are the ones who can find the truth without being force-fed false facts that, as Darwin noted, can linger for years and as Mark Twain noted, you get into trouble over things you know for sure *that just ain’t so*.

Dan P. Bullard is a proud self-taught electronics engineer who has solved insoluble problems all over the world. Specializing in mixed signal test, but also fluent in wireless, MEMS, digital, memory, processors and analog. Dan owns the domain www.danbullard.com, has a YouTube channel that specializes in electronic topics and has recently published a book on mixed signal test; Distortion: The Cause Of Harmonics And The Lie Of THD available in paperback or Kindle on Amazon.com.