THE GURU'S LAIR

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Steplocked Magic Sinewaves

Optimize power efficiency.

Don drives the Cheby to the Leby with his potent new scheme to digitally synthesize high efficiency power sinewaves.

What is the most efficient possible method to synthesize precision low distortion power sinewaves?

The crucial answer to this big bucks question is obviously a major concern to the designers of electric autos, industrial ac motor controls, telephone ringer circuitry, for solar power conversion, aerospace power aps, electric utilities, robotics, or for UPS, PFC, and their associated power quality conditioners.

I've recently been exploring what I have been calling *steplocked magic sinewaves*. Which apply *Chebyshev Polynominals* and a few other arcane math tricks to synthesize ultra low distortion sinewaves. With precisely defined amplitudes and frequencies. All done through use of an amazingly low number of low energy switching events. For exceptional efficiency.

The key feature of steplocking is that *any number of low harmonics can in theory be forced to zero.* And, with care, to darn little in the real world. Often *n* pulses per quadrant can be chosen to force an astonishing 4*n* low order harmonics to zero!

Compared against current PWM schemes, steplocking could offer you these compelling advantages:

- Vastly fewer switching events for dramatic efficiency improvement.
- Low energy "single side" switching for further efficiency gains.
- Reduced high frequency energy can simplify heatsinking.
- Critical harmonic energy is less than the fundamental, even at very low amplitudes
- Any number of low harmonics can be forced to or very near zero.
- Offers nearly unlimited choice of precision amplitude increments.
- Switching pulses are locked to the chosen fundamental.
- No modulation or demodulation is used. Load integration is optional.
- Extremely low end microcomputer friendly. Nothing analog.
- Very low storage needs, typically only seven bytes per amplitude.
- Can safely be made totally three phase delta friendly.
- Per-cycle switching events often independent of speed or frequency.

And, over on the dark side, we do have these limitations:

- *The first pair of uncontrolled odd harmonics are often fairly strong and may even be comparable in strength to the fundamental.*
- *Lowpass filtering may be needed, provided by motor inductance and the load interia.*
- *Highly precise timing is required, to 1 part in 30,000 or better.*
- *Speed or frequency may have to be set by a second PLL circuit.*
- *Best suited for power and lower audio frequencies.*
- *Reasonably wide speed/frequency range does not go down to dc.*

A First Look

Figure one shows us some steplocked sinewave variations. You have a few exactly spaced pulses that thicken as you near the sinewave crests. Higher amplitudes are gotten by thickening and then repositioning slightly.

You will often be working in the first quadrant only. This is mirrored for the second. The pair then can get flipped for the remaining bottom half of the waveform.

Using one quadrant guarantees no dc term, no even harmonics, and no Fourier cosine terms for any of your odd harmonics. It also requires only one-fourth the storage for your table lookup listing of pulse start and pulse width values.

Each pulse is output to connect a dc power supply to your load. Two half-bridge drivers are often used for single phase apps. Unlike PWM, *only one driver is normally switched at a time*. Which might give you a further efficiency improvement.

The spectrum for any steplocked magic sinewave typically consists of a fundamental, zero even harmonics and no dc term. A chosen number of low odd harmonics are also forced to zero or approximately zero.

The higher the number of pulses, the more odd harmonics you are able to force to zero. But the worse your efficiency because of the increase in switching events.

The lowest two *unsuppressed* odd harmonics will often be quite strong and might even approach (but never exceed) the fundamental amplitude. These unsupressed harmonics can be minimized by low pass filtering.

To have deep harmonic nulls, the pulse positions and widths must be *exactly* specified. A one microsecond timing accuracy is neither excessive nor unreasonable at 60 Hertz.

It is convenient to number your sequences by the total pulses. Thus, a seven pulse-per-quadrant solution can be called a Steplock-28 and have 56 half-bridge switching events.

Steplock Synthesis

Figure two shows how to synthesize a very efficient controlled amplitude steplocked magic sinewave. One that has zero low harmonics through the sixteenth. Similar techniques can be used on other sequences to force any number of low harmonics to zero.

Some knowledge of *Fourier Series* would be quite helpful here. You can find this in any intro circuits book. I also now have a ***MUSE90.PSL*** tutorial up on my website.

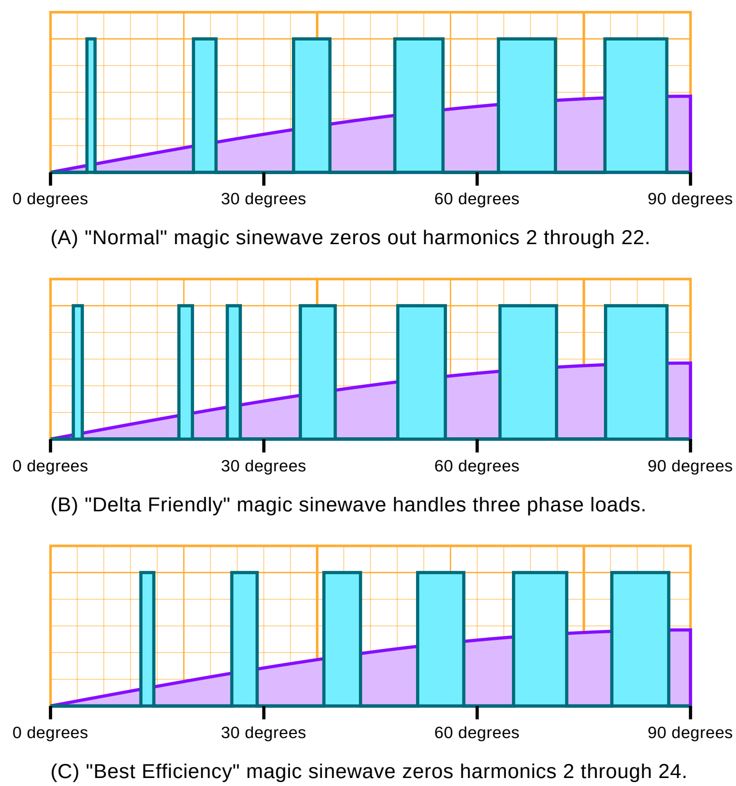

Figure 1 – *Three variations on steplocked magic sinewaves.*

The key secret behind a steplock synthesis is...

each pulse edge
controls something

..."Something" will typically be an odd harmonic. But might set your fundamental amplitude or may force some useful sequence property.

As mentioned. we should work in the first quadrant to eliminate even harmonics and pick up some other benefits. We will need one pulse edge to set our fundamental amplitude, an edge to zero out our third harmonic, and six more to zero out harmonics 5, 7, 9, 11, 13, and 15. Eight edges for four pulses per quadrant.

This gives us eight rather messy equations in eight unknowns. Which could get solved for the precise pulse positions and widths. From previous brute force testing, I already do know that at least one useful and unique solution can often be found.

A simple Calculus 101 integation tells us that any first quadrant unity height pulse adds to the fundamental amplitude using this formula...

$$\text{amplitude} = (4/\pi)\,[\cos(\alpha) - \cos(\beta)]$$

...where α is your start angle in degrees and β will be the end angle in degrees. Our first equation should then simply sum the four pulses to give our fundamental amplitude.

There are similar four-pulse start and end equations easily written and set to zero for each harmonic to get controlled. Use terms such as $\cos(3\alpha)$ for your third harmonic, $\cos(5\alpha)$ for the fifth, and so on as needed.

As written, these eight equations are rather ugly. We may want to play with them to make them friendlier. Firstoff, we'll want to get rid of those nasty multiple angles. You'd suspect that useful identities are buried in a trig book somewhere...

$$\cos(3\theta) = 4\cos(\theta)^3 - 3\cos(\theta)$$

$$\cos(5\theta) = 16\cos(\theta)^5 - 20\cos(\theta)^3 + 5\cos(\theta)$$

... and as many more as we need.

PROBLEM:

Create a minimal pulse steplock sequence that generates a fundamental sinewave of 0.53 amplitude but has zero harmonics through the sixteenth.

SOLUTION:

By working in quadrants, all even harmonics will automatically be forced to zero. Eight pulse edges will be needed to control the fundamental and the first seven odd harmonics (3, 5, 7, 9, 11, 13, 15). For eight equations in eight unknowns.

Write the eight harmonic equations using Chebyshev polynominals…

$$\begin{aligned} T_1(P1S) - T_1(P1E) + ... + T_1(P4S) - T_1(P4E) &= 0.53 * \pi/4 \\ T_3(P1S) - T_3(P1E) + ... + T_3(P4S) - T_3(P4E) &= 0 \\ T_5(P1S) - T_5(P1E) + ... + T_5(P4S) - T_5(P4E) &= 0 \\ .... \quad .... \quad .... & \\ T_{15}(P1S) - T_{15}(P1E) + ... + T_{15}(P4S) - T_{15}(P4E) &= 0 \end{aligned}$$

EQNS I

Where P1S is the cosine of the first pulse start angle, P1E is the cosine of the first pulse end angle, T_1 is a first order Chebyshev polynomial (used to define the fundamental), T_3 is a third order Chebyshev Polynomial (used to define the third harmonic), etc… That $\pi/4$ is a Fourier Series scaling factor.

By adding or subtracting previous line multiples, the equations can be reduced to this elegantly simple form…

$$\begin{aligned} (P1S)^1 - (P1E)^1 + ... + (P4S)^1 - (P4E)^1 &= 0.53 * \pi/4 \\ (P1S)^3 - (P1E)^3 + ... + (P4S)^3 - (P4E)^3 &= 0.53 * 3\pi/16 \\ (P1S)^5 - (P1E)^5 + ... + (P4S)^5 - (P4E)^5 &= 0.53 * 5\pi/32 \\ .... \quad .... \quad .... \quad & .... \end{aligned}$$

EQNS II

Successive vertical amplitude values are scaled by the bizarre power sequence (3/4)(5/6)(7/8)(9/10)... Solution of these equations using my fast and simple PostScript iterative approximation procs gives you these values…

P1 start: 17.9125	P1 end: 21.4007
P2 start: 36.1121	P2 end: 42.7902
P3 start: 54.8818	P3 end: 64.1028
P4 start: 74.4503	P4 end: 85.1345

Figure 2 – *The math behind steplock synthesis.*

After using these identities, all that's left are zeros, constants, or powers of primary angle cosines. We can now substitute...

$$x = \cos(\theta)$$

...and similar terms to get rid of all of the nasty trig and leave us with eight plain old algebraic equations in eight unknowns. Before we solve these, though, let's drive the...

Cheby to the Leby

Those multiple angle substitutions are *polynominals*. Or just summed powers of a variable. This particular sequence of polynominals are called first kind *Chebyshev Polynominals*. You can verify this by digging deep enough into any thick enough math handbook to find this rare gem...

$$\mathbf{T}_n(\cos(\theta)) = \cos(n\theta)$$

...where $\mathbf{T}_n$ is the appropriate Chebyshev Polynominal of the order you need. As you may already know, these polynominals have all sorts of other uses including filters and curve fitting. More details in ***MUSE152.PDF*** and in my ***Active Filter Cookbook***.

A curious Cheby property is that when it is good at something, it may end up being the *best possible* you can do. So, until proven otherwise, I'll claim that *the steplock synthesis shown here is the best possible you can do in terms of the maximum harmonic cancellation for minimum pulse edges and switching events.*

And thus is potentially the most efficient. It flat out ain't gonna get any better than this.

We really need to know very little about Chebychev Polynominals. $\mathbf{T}_0$ is defined as 1 and $\mathbf{T}_1$ is defined as x. The rest of the terms can be found by using this cute recursive formula...

$$(\text{next term}) = 2x(\text{current term}) - (\text{previous term})$$

In steplock magic sinewaves, we are usually only interested in the odd Cheby terms because we are seeking odd harmonic control. Substituting Chebyshev for the angle reductions gives us the superbly compact EQNS I you'll find in figure two.

Many fancy PC math packages do provide Chebyshev capabilities and work directly with equations of this type. But we can further reduce our equations down into an astoundingly and elegantly simple format. It turns out that any time you have a pile of equations, you can add or subtract multiples of the individual equation lines to each other without changing their validity.

Doing so leads to the stunningly simple plain old power expressions of EQNS II in figure two.

Elegant simplicity at its finest.

Equations like this are often best solved by starting with a good guess and then incrementally "shaking the box" to get a closer answer.

Because a fundamental amplitude error is very much a different animal than a harmonic zero error, I find it best to minimize all harmonics first and then try again.

Ferinstance, suppose I am after an 0.4000 amplitude and get a harmonic zeroed 0.4004, I ask for a 0.3996 and retry. This ploy rapidly converges.

Calculators and catalogs for many thousands of magic sinewaves are up at ***www.tinaja.com/magsn01.html***

Variations on a Theme

Since "real" sinewaves do not have a hole near their crest, you could also force an *odd* number of edges per quadrant. The two leftover edges can form a (usually) wider pulse bridging 90 or 270 degrees. To do so, you end your final pulse at 90 degrees and let the adjacent quadrant pulse abut.

A few normalized 0.57 amplitude examples for four different types of my steplocked magic sinewaves can be found in the nearby sidebars. Full catalogs are now available online. A steplock-24 solution of figure two for

"NORMAL" MAGIC SINEWAVE **ANXC24 - 57/100**

SUMMARY: This steplock-24 "constant amplitude increments" magic sinewave is not delta friendly. Harmonics 2 through 22 are virtually zero. The first major harmonics are the 23rd and 25th. Harmonic amplitudes are relative to the fundamental. Filtered "f" harmonics assume a filter of an "integrating" or 1/H or 1/f response. An 0.001 degree or better timing accuracy is required.

Desired Amplitude:	0.57
Actual Amplitude:	0.569999
Actual Power:	0.324899
Distortion 2H-22H:	0.00096016%
First strong harmonics:	23 and 25
Pulses per sine cycle:	24
Total switching events:	48
Delta Friendly:	No

P1 start: 5.1278	end: 6.2655	delta: 1.1377
P2 start: 20.1049	end: 23.2776	delta: 3.1727
P3 start: 34.1831	end: 39.2932	delta: 5.1101
P4 start: 48.423	end: 55.1945	delta: 6.7715
P5 start: 62.9925	end: 71.0116	delta: 8.0191
P6 start: 77.9668	end: 86.6674	delta: 8.7006

H3: -7.10092e-07	H21: -3.80407e-06	H21f: -1.81146e-07	c1sd = 0.0
H5: -3.6481e-06	H23: 0.803194	H23f: 0.0349215	c1ed = 0.0
H7: -5.7061e-08	H25: -0.440767	H25f: -0.0176307	c2sd = 0.0
H9: 4.65998e-06	H27: -0.169326	H27f: -0.00627134	c2ed = 0.0
H11: 4.11531e-07	H29: -0.0100077	H29f: -0.000345094	c3sd = 0.0
H13: 5.11062e-06	H31: 0.0125276	H31f: 0.000404115	c3ed = 0.0
H15: -2.63622e-06	H33: 0.0149846	H33f: 0.00045408	c4sd = 0.0
H17: 2.2086e-06	H35: 0.0162002	H35f: 0.000462862	c4ed = 0.0
H19: 2.01816e-06	H37: 0.0174321	H37f: 0.000471138	varx = 2.2243%.

"POWER" MAGIC SINEWAVE **PNXC24 - 57/100**

SUMMARY: This steplock-24 "constant power increments" magic sinewave is not delta friendly. Harmonics 2 through 22 are virtually zero. The first major harmonics are the 23rd and 25th. Harmonic amplitudes are relative to the fundamental. Filtered "f" harmonics assume a filter of an "integrating" or 1/H or 1/f response. An 0.001 degree or better timing accuracy is required.

Desired Power:	0.57
Actual Power:	0.570004
Actual Amplitude:	0.754986
Distortion 2H-22H:	0.00280368%
First strong harmonics:	23 and 25
Pulses per sine cycle:	24
Total switching events:	48
Delta Friendly:	No

P1 start: 6.5807	end: 7.9501	delta: 1.3694
P2 start: 19.7636	end: 23.8198	delta: 4.0562
P3 start: 33.1612	end: 39.748	delta: 6.5868
P4 start: 46.9206	end: 55.7708	delta: 8.8502
P5 start: 61.2185	end: 71.9104	delta: 10.6919
P6 start: 76.226	end: 88.0418	delta: 11.8158

H3: 4.12131e-06	H21: 1.2991e-05	H21f: 6.18618e-07	c1sd = 0.0
H5: -1.16603e-05	H23: 0.566697	H23f: 0.024639	c1ed = 0.0
H7: -3.73359e-07	H25: -0.223865	H25f: -0.0089546	c2sd = 0.0
H9: 1.10683e-05	H27: -0.265764	H27f: -0.0098431	c2ed = 0.0
H11: -7.84968e-06	H29: -0.0699187	H29f: -0.00241099	c3sd = 0.0
H13: -1.2681e-06	H31: -0.00842073	H31f: -0.000271637	c3ed = 0.0
H15: 1.40929e-05	H33: -0.000586764	H33f: -1.77807e-05	c4sd = 0.0
H17: -3.21663e-06	H35: 5.63657e-05	H35f: 1.61045e-06	c4ed = 0.0
H19: -8.33785e-06	H37: -0.000374254	H37f: -1.0115e-05	varx = 1.5721%.

six pulses per quadrant results in the "best efficiency" listing shown.

The best efficiency solutions have a "missing" pulse of zero energy at each zero crossing. You can instead create steplocked magic sinewaves whose pulses end up more evenly spaced. Which costs you control of one odd harmonic, but can help us in developing our upcoming three phase delta friendly solutions. Which gives the "normal" example shown.

Useful choices for your amplitude increments could be 100 or 256 steps, but nearly any amplitude set can get used. You can also work in constant power increments by selecting the *square root* of your desired power.

The "power" example shown here is a "normal" magic sinewave which has been suitably scaled.

Special table lookup amplitudes can also be chosen to let you correct illumination nonlinearity or adapt to a motor's torque variations.

Given sufffficient math accuracy, selected magic sinewave harmonics get forced arbitrarily close to zero. Newer ***JavaScript calculators*** let you force dozens or even *hundreds* of low harmonics very near zero. They also reveal the quantized storage accuracy you will need.

Becoming Delta Friendly

The real world may place a further limit on steplocked magic sineaves: Most larger industrial motors will be three phase. We sure would not want to have to rewire existing motors or use six power half bridge drivers if three are all we really need.

I'll define a *delta friendly* magic sinewave as one that lets us control unmodified three phase motors.

Most steplock sequences are *not* delta friendly!

Becoming delta friendly involves some horribly off-the-wall concepts, but the bottom line is that it can be done using a few carefully selected steplock sequences. The usual price is your ability to control a few less harmonics than optimal.

Specifically, *3n + 1* harmonics get zeroed rather than your full *4n*. But only *one half* the storage is needed.

I've covered delta friendliness in depth elsewhere. But let's briefly review: Connect a three phase motor to three SPDT switches and you only have *eight* switch states.

For a given winding, the possible combinations can only result in your forcing the individual [ABC] winding currents of [000], [0+-], [0-+], [+0-], [+-0], [-0+], [-+0], or [000] again. Now, phases A, B, and C will be *spatially* 120 degrees apart. But B is also what A should end up *in time* 120 degrees later. And C is now what A will be in time 240 degrees later.

From which we can conclude that *the third harmonic of any narrow sample of a delta friendly waveform must ~always~ be zero.*

Note that this rule is *vastly* more restrictive than simply generating a waveform whose third harmonic just averages to zero over a cycle. You cannot rob Peter to pay Paul.

Reflecting this need back into the first quadrant should give us these two wondrously obtuse rules...

- *If there is zero energy in any narrow sample x in the 60 to 90 degree range, there must also be zero energy in samples (x-60) and (120-x).*
- *If there is one energy in any narrow sample x in the 60 to 90 degree range, there must also be one energy in one but not both samples (x-60) and (120-x).*

The reasoning behind these rules becomes obvious when you draw the first quadrant of a waveform's third harmonic. If no negative 3H energy is present, there should be no positive energy either. If there is something negative, it must be cancelled by an equal positive that can lie in either but not both of two positions either side of the first 3H crest.

One way to gain delta friendliness is to start with a "normal" or equally spaced pulse sequence. Then you can carefully shift and sometimes split the narrowest and middle pulses so you obey the above rule. To visualize this, you can copy figure 1b and fold it forward at 60 degrees. Then fold back again at 30. Then hold it up to a strong light and look through it.

Note how the pulses on the first and second folds will exactly sum to match the pulses on the third fold.

Once again, if you have energy on

"DELTA FRIENDLY" SINEWAVE — ANDC28 - 57/100

SUMMARY: This steplock-24 "constant amplitude increments" magic sinewave is fully delta friendly. Harmonics 2 through 22 are virtually zero. The first major harmonics are the 23rd and 25th. Harmonic amplitudes are relative to the fundamental. Filtered "f" harmonics assume a filter of an "integrating" or 1/H or 1/f response. An 0.001 degree or better timing accuracy is required.

Desired Amplitude:	0.57
Actual Amplitude:	0.569998
Actual Power:	0.324897
Distortion 2H-22H:	0.000823799%
First strong harmonics:	23 and 25
Pulses per sine cycle:	28
Total switching events:	56
Delta Friendly:	Yes

P1 start: 3.2089	end: 4.4724	delta: 1.2635
P2 start: 18.0554	end: 19.96	delta: 1.9046
P3 start: 24.8653	end: 26.6919	delta: 1.8266
P4 start: 35.1347	end: 40.04	delta: 4.9053
P5 start: 48.8375	end: 55.5276	delta: 6.6901
P6 start: 63.2089	end: 71.1625	delta: 7.9536
P7 start: 78.0554	end: 86.6919	delta: 8.6365

H3: -2.66285e-07	H19: 1.26135e-06	H19f: 6.63869e-08	c2sd = 0.0
H5: 5.51211e-06	H21: 3.80408e-08	H21f: 1.81146e-09	c2ed = 0.0
H7: 5.19256e-06	H23: 0.69968	H23f: 0.0304209	c3sd = 0.0
H9: 2.21904e-07	H25: -0.49741	H25f: -0.0198964	c3ed = 0.0
H11: 2.14239e-06	H27: -2.36698e-07	H27f: -8.76659e-09	c4sd = 0.0
H13: 4.0967e-08	H29: 0.213105	H29f: 0.00734844	c4ed = 0.0
H15: 6.21332e-08	H31: 0.140614	H31f: 0.00453593	c5sd = 0.0
H17: -2.05196e-06	H33: 1.69454e-07	H33f: 5.13498e-09	c5ed = 0.0
			varx = 3.635%.

"BEST EFFICIENCY" SINEWAVE — AEXC24 - 57/100

SUMMARY: This steplock-24 carrier suppressed "constant amplitude increments" magic sinewave is not delta friendly. Harmonics 2 through 24 are virtually zero. The first major harmonics are the 25th and 27th. Harmonic amplitudes are relative to the fundamental. Filtered "f" harmonics assume a filter of an "integrating" or 1/H or 1/f response. An 0.001 degree or better timing accuracy is required.

Desired Amplitude:	0.57
Actual Amplitude:	0.569999
Actual Power:	0.324899
Distortion 2H-24H:	0.0016277%
First strong harmonics:	25 and 27
Pulses per sine cycle:	24
Total switching events:	48
Delta Friendly:	No

P1 start: 12.7084	end: 14.5303	delta: 1.8219
P2 start: 25.4965	end: 29.0625	delta: 3.566
P3 start: 38.4459	end: 43.5967	delta: 5.1508
P4 start: 51.6323	end: 58.1195	delta: 6.4872
P5 start: 65.1187	end: 72.5928	delta: 7.4741
P6 start: 78.9357	end: 86.9411	delta: 8.0054

H3: -4.83751e-06	H19: -3.61587e-06	H19f: -1.90309e-07	c2sd = 0.0
H5: -4.52684e-07	H21: -2.90377e-06	H21f: -1.38275e-07	c2ed = 0.0
H7: -3.48072e-06	H23: -1.94504e-06	H23f: -8.45668e-08	c3sd = 0.0
H9: -6.0062e-06	H25: -0.74578	H25f: -0.0298312	c3ed = 0.0
H11: -5.11993e-06	H27: 0.519984	H27f: 0.0192587	c4sd = 0.0
H13: -9.73988e-06	H29: 0.199263	H29f: 0.00687113	c4ed = 0.0
H15: -6.38196e-06	H31: 0.0249853	H31f: 0.000805979	c5sd = 0.0
H17: -2.45922e-06	H33: 0.00155691	H33f: 4.71791e-05	c5ed = 0.0
			varx = 3.6166%.

fold three, you must have energy on only one of the first two folds.

From this visualization, you can easily derive which edges will have to "track" each other to pick up delta friendliness. Note particularly that your first fold pulses should track in the *same* direction as the third, and your second fold pulses track in the *opposite* direction.

Mathematically, to create a delta friendly steplock-28, you could start off by using fourteen edges. You then *lock* seven of these edges so your tracking pulses automatically force the above rules. For instance, the start of your first pulse would get locked to the start of the sixth pulse minus 60 degrees.

To force delta friendliness, you apparently have to "waste" seven of your available edges and seven of your equation variables. But these same seven edges also conveniently zero out all triad harmonics of 3, 9, 15, 21, 27, 33... In our steplock-28 example, this leaves us with seven edges. You use one edge to set your fundamental, and six to zero out the remaining odd harmonics 5, 7, 11, 13, 17, and 19.

You still have fourteen equations in fourteen unknowns, and the usual "guess and shake the box" solution approach will still apply. Half of the equations are now a lot simpler.

A "delta friendly" seven pulse per quadrant example is shown nearby. All harmonics should be very nearly zero through the 22nd. Its complete 100 amplitude catalog is online.

In this example, a normal-24 has had its first pulse adjusted and its second pulse split out and shifted to form a delta-28 and meet the needed delta friendly rules.

Certain delta friendly solutions can introduce other subtle problems. The "best" catalogs I've found would appear to demand 3, 7, 11, 15, 19... pulses per quadrant. And the "best" all-around magic sinewaves so far are ***steplock28Q*** variations. Which can need as few as seven bytes stored.

Some More Help

PIC microcomputers seem ideal for steplock magic synthesis. You store the start and length of each pulse in an internal table. Table needs can be quite modest. They can be further reduced by ***Quadratic Interpolation*** or a group of similar techniques. One quadrant worth of pulses might get generated by suitable switching and time delay routines. That quadrant is mirrored for the second, and the pair is flipped for the third and fourth.

For single phase uses, you would output to a pair of half bridge power drivers. Making the left driver high and your right one low should force positive current into the load for all pulses in the first 180 degrees.

Making the right driver high and the left low forces negative current into the load for the other half cycle.

You can set both drivers high or both low to get a zero current. Your choice depends on what has and will happen. Pick the one giving you the fewest total switching events.

The timing needed to exactly zero out harmonics has to be surprisingly precise. I'd recommend an accuracy of at least one part in 30,000. You can use the ***JavaScript Calculators*** to evaluate needed accuracy. Eight-bit lookups often "just barely miss".

Frequency or speed is set by your overall delay times. To allow sane clock frequencies, magic sinewaves appear to be restricted primarily to power and low audio frequencies.

I'd also recommend setting any variable speed or frequency *external* to your generating PIC. Perhaps by phaselocking the clock.

As previously noted, catalogs of steplock magic sinewaves are up at ***www.tinaja.com/magsn01.html***

My additional support, software, sourcecode, and consulting services are found via ***don@tinaja.com***.

Many thanks to mathematician Jim Fitzsimmons for all his valuable contributions to this concept.

Microcomputer pioneer and guru Don Lancaster is now the author of 35 books and countless articles. Don maintains his US technical helpline you'll find at (520) 428-4073, besides offering all his own ***books***, ***reprints*** *and* ***consulting services***.

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