Spread Spectrum Carrier Suppression SSCS Techniques for Magic Sinewaves

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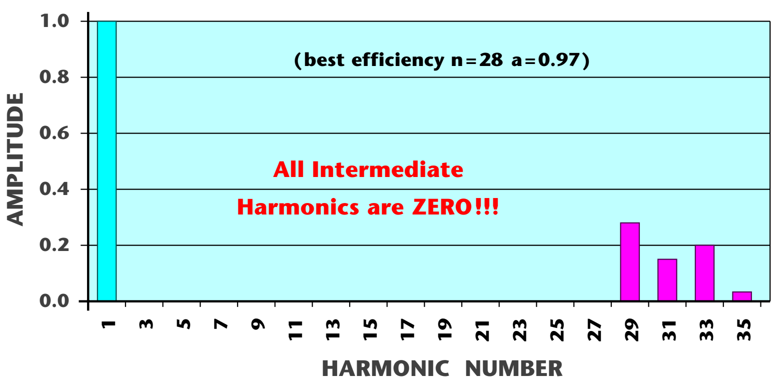
Magic Sinewaves are a newly discovered class of mathematical functions that hold significant potential to dramatically improve the efficiency and power quality of solar energy synchronous inverters, electric hybrid automobiles, and industrial motor controls, among many others. An executive summary can be found **here**, a slideshow type intro presentation **here**, a development proposal **here**, the latest calculator **here** with its tutorial **here**, demo chips **here**, and more info **here**.

Major goals of such digital sinewave generation including offering the **maximum possible efficiency** by using the fewest of simplest possible switching transitions; offering the **lowest possible distortion** by zeroing out a maximum number of low harmonics that impact power quality, whine, vibration, and circulating currents; and by using **all digital techniques** that are extremely low end micro friendly.

Magic sinewaves have two remarkable properties: **Any number of desired low harmonics can be forced exactly to zero** in theory, and to astonishingly low levels when quantized to 8-bit compatible levels. And magic sinewaves use the **absolute minimum possible and simplest energy-robbing transitions** to achieve such harmonic suppression.

The spectrum of a typical **magic sinewave** might look something like this...



Although any chosen number of the **Magic Sinewave** lower harmonics could be forced exactly to zero in theory, the first two or higher **unsuppressed** harmonics will remain of significant size. These will typically range from **one fifth** the size of the fundamental for high amplitudes up to **matching** the size of the fundamental for very low amplitudes.

Unlike conventional PWM with that has a far higher number of efficiency robbing transitions, **any one unsuppressed harmonic will never significantly exceed the strength of the fundamental**. Typically, the unwanted harmonic will be a lot less. At worse, it will barely exceed the fundamental by one or two percent at most.

As with most digital sinewave generators, higher harmonics are dealt with by **low pass filtering** or integration. **Magic sinewaves** in general have a lot less unwanted energy that is mostly quite high in frequency and thus is fairly easy to deal with. Filtering can often include the inductance of a motor being controlled along with its load inertia.

Nonetheless, it sure would be nice to be able to help the filtering process along by further reducing any unwanted harmonic energy. It turns out that there are some **spread spectrum** techniques that can lower uncontrolled harmonics by values from **6** to as much as **24** decibels. And that would be **before** any filtering. Unwanted higher frequency energy is also significantly reduced.

These concepts are quite similar to those used for EMI reduction in system clocks. In addition, they explore a quirk or two peculiar to magic sinewaves.

There are several manageable downsides to spread spectrum techniques. These include needing a lot **more memory** for both program and data storage; the somewhat **reduced efficiency** because of a few extra switching transitions; being **less useful** for higher amplitudes; probably **not being delta friendly**; and often demanding **more complex initial programming** and debug.

A simulation **demo** of what follows can be found **here**.

Uncontrolled Harmonic Amplitude "n" Independence

Our latest expanded **Magic Sinewave Calculator** and its **Tutorial** provides us with a rather astonishing result.

Consider a **BEF8 best efficiency magic sinewave** that has **n=8** pulses per quadrant and an amplitude of **0.53**...

h31 = 0.00000000000 (and all lower)
h33 = -0.77885548201
h35 = 0.57886655491
h37 = 0.17991844863

Next, compare it against this **0.53** amplitude **BBE23 bridged best efficiency magic sinewave**...

h89 = 0.00000000000 (and all lower)
h91 = -0.77885548201
h93 = 0.57886655491
h95 = 0.17991844863

We see that the first unwanted harmonics for a given amplitude are **identical** for both best efficiency and bridged best efficiency magic sinewaves. And that (for most values) are **independent of the number of pulses per quadrant**! Identical results **beyond ten decimal places** are usually gotten for wildly differing guesses and totally different repeated approximation routes.

Each sequential magic sinewave route suppresses one new odd harmonic. For instance, the first problem harmonic on a BBE8 will be the 27th. The first on a BEF8 will be the 29th. The first on a BBE9 will be the 31st, and the first on a BEF9 will be the 33rd, and so on.

Which leads to these obsrvations...

> **The strength of low unwanted harmonics of a magic sinewave are exactly determined by the fundamental amplitude. They are often fully independent the number of pulses per quadrant!**
>
> **BEF types and BBE types "take turns" zeroing out progressively higher low odd harmonics.**

I am not sure of the explanation for this "**n independence**" **phenomena**. I do suspect it has something to do with digital "distortionless modulation" of a carrier. It is still pretty amazing to see repeated and unrelated calculations converging on identical results, though.

Another curious quirk of many magic sinewaves can prove even more useful for spread spectrum harmonic reduction...

> **The first two uncontrolled low harmonics in most magic sinewave often alternate sign.**

Which suggests that some sneaky cancellations should be possible if we combine a certain magic sinewave for one quadrant with its neighbor for the next one.

Predicting Possibilities

Let's try to predict what the potential for this method is. Then we can go on to create actual plots of the possible improvements. All will make use of our spread spectrum techniques that combine one magic sinewave on the first quadrant with one or more of its neighbors on succeeding quadrants.

The need for carrier reduction is clearly greatest at low amplitudes. And this is precisely where the best performance of this SSCS approach will lie. At very low amplitudes, the unwanted coefficients of a **BBE8** can be approximated by...

27	29	31	33	35	37	39	41	43
0	1	-1	~0	~0	~0	~0	~0	~0

Here we've shown the harmonic numbers on the top row and their amplitudes on the bottom one. Our original **Magic Sinewave** math forces harmonics **3** to **27** to precisely zero in theory. Our first two uncontrolled harmonics will end up near plus and minus unity. And the next series of odd harmonics will be very nearly zero clear up through the **61st**. We can ignore anything higher in frequency here because they also will get significantly reduced by what follows.

The rms value of our unwanted low harmonics will be the sum of their squares. Or **1.4142** in this case. We can use this as our baseline reference.

Now consider using a BBE8 for the first quadrant and a BEF8 for the second...

27	29	31	33	35	37	39	41	43
0	1	-1	~0	~0	~0	~0	~0	~0
0	0	1	-1	~0	~0	~0	~0	~0
=========								
0	0.5	0	-0.5	~0	~0	~0	~0	~0

Here we've shown the **average** of the amplitudes below the line. We are usually permitted to average with the **Fourier Math** because of the **phase coherence** of any one summed harmonic. The rms amplitude of our three unwanted harmonics will be **0.707**. And we have achieved a modest but possibly useful **six decibels** of unwanted carrier rejection.

More has to be better, right? Well, maybe. Let's try alternating **four** progressive magic sinewaves over an entire cycle. One per quadrant. Ultimately, we'll put the BBE's back to back for best efficiency. The performance now looks like this...

27	29	31	33	35	37	39	41	43
0	1	-1	~0	~0	~0	~0	~0	~0
0	0	1	-1	~0	~0	~0	~0	~0
0	0	0	1	-1	~0	~0	~0	~0
0	0	0	0	1	-1	~0	~0	~0
=========								
0	0.25	0	0	0	-0.25	~0	~0	~0

This time, our rms unwanted harmonics will get suppressed to **0.3545** of the fundamental, or **twelve decibels of suppression** from our original. SSCS averaging of four magic sinewaves over a full cycle is probably optimal. Going to eight magic sinewaves over two cycles instead gives us...

27	29	31	33	35	37	39	41	43	45	47
0	1	-1	~0	~0	~0	~0	~0	~0	~0	~0
0	0	1	-1	~0	~0	~0	~0	~0	~0	~0
0	0	0	1	-1	~0	~0	~0	~0	~0	~0
0	0	0	0	1	-1	~0	~0	~0	~0	~0
0	0	0	0	0	1	-1	~0	~0	~0	~0
0	0	0	0	0	0	1	-1	~0	~0	~0
0	0	0	0	0	0	0	1	-1	~0	~0
0	0	0	0	0	0	0	0	1	-1	~0
=====	=====	=====	=====	=====	=====	=====	=====	=====	=====	=====
0	+.12	0	0	0	0	0	0	0	-.12	~0

Our rms error is now down to **0.176** and we have **eighteen decibels** of low amplitude suppression. But we now need **eight times** the memory for data storage and program length. And averaging harmonic energy over two fundamental cycles may be stretching things somewhat.

Thus, **you probably might want to think twice over 8:1 spectrum spreading**.

Yes, you can continue the process indefinitely, but at some point the process gets ridiculous. For **16:1** spectrum spreading, you would use sixteen magic sinewaves. One for each quadrant averaged over four consecutive fundamental cycles. Extending the above math tells us your rms unwanted low harmonics will be clear down at **0.0883** or a full **twenty four decibels attenuated**. But new our system requirements would seem clearly excessive.

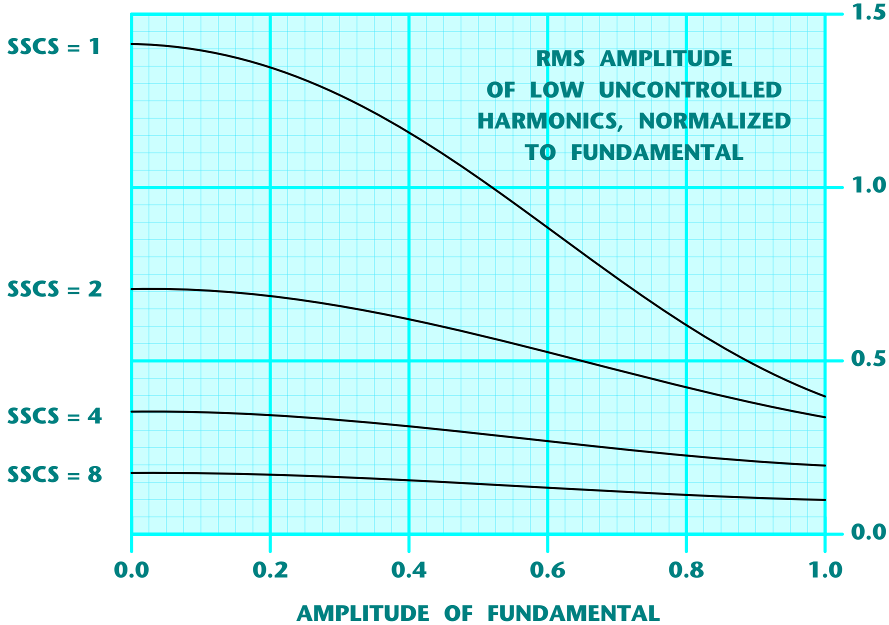
Thus, **sscs = 4** or **sscs = 8** would likely end up your best choices here.

Plotting the Full Response

A math checking simulator appears as **DEMOSSCS.PSL**. This is an in-house doc, so I left it somewhat rough around the edges. It is written in **PostScript** using my **Gonzo Utilities** and is sent to **Acrobat Distiller** which is used as a **Host Based PostScript Interpreter**.

We'll insert our usual note here that versions of Acrobat Distiller newer than **8.1** default to preventing disk access. The workaround is to run Distiller from the command line using an **Acrodist -F**.

The simulator creates **1:1**, **2:1**, **4:1**, and **8:1** spread spectrum magic sinewaves and then does a **Fourier Analysis** on them. Interpreting the results can give us this response plot what we can expect from spread spectrum techniques...



Another obvious benefit from spectrum spreading is that the filtering used should end up a lot more independent of amplitude. Thus further easing the filter needs.

For More Help

Further **Magic Sinewave** explorations require your participation as a Synergetics **partner** or **associate**.

To proceed, view the many **Magic Sinewave** tutorial files and JavaScript calculators you'll find at **http://www.tinaja.com/magsn01.asp**.

Full **consulting services**, custom designs, **seminars**, and workshops are available. Or you can email **don@tinaja.com**. Or call **(928) 428-4073**.