Magic Sinewave Demo Hardware

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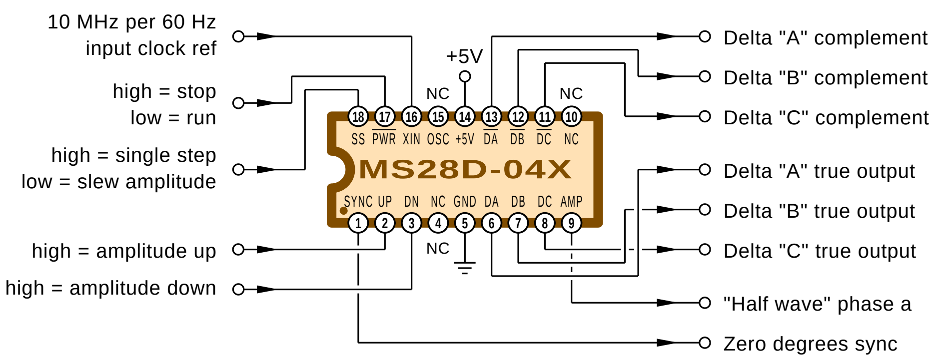
A new class of **math functions** called **Magic Sinewaves** lets you efficiently produce power sinewaves that can have **any** chosen number of low harmonics forced very near **zero**. And do so using the fewest possible switching events for the highest possible energy efficiency. Two new intros appear **here** and **here**, along with a development proposal **here**, a tutorial **here**, visualizations **here** , jitter and distortion analysis **here**, lots of calculators **here**, and seminars and workshops **here**.

I've managed to finally create some actual demo and test hardware, centered on the **PIC 16F628A** and **16F648A** chips, and working with the **Oshensoft** simulator and **Pocket Programmer II**. Our first commercial offering is the **MS28D-04X**. This is a fully populated and **delta friendly** magic sinewave generator that outputs single or **three phase** logic level signals that can produce nearly **one hundred** amplitude levels of digitally synthesized variable frequency sinewaves. All of the harmonics through the **twenty second** are very nearly zero. Per this **theoretical distortion analysis**.

Units are **commercially available** for immediate delivery. As are sourcecode and **custom variations**. Here is the schematic of the stock MS28D-04X…



The 18 pin **DIP** chip is powered from a conventional +5 volt dc source and draws less than ten milliamperes. An external clock input reference of approximately **six Hertz per Megahertz** is required to set your output speed or frequency. A **ten MegaHertz** reference input thus becomes a **sixty Hertz** output frequency.

The exact number of clock cycles per output cycle is presently set to **12*4*3472 = 166656**. Thus a **10.000** MHz clock currently produces a **60.00384}** Hertz output frequency.

Your clock normally will come from an externally provided digital or analog reference, a voltage-to-frequency converter, or a frequency setting phase lock loop. Other magic sinewave chips are also available that allow a crystal oscillator, internal timing, or local RC timing. These options require a **PIC** configuration change at programming time.

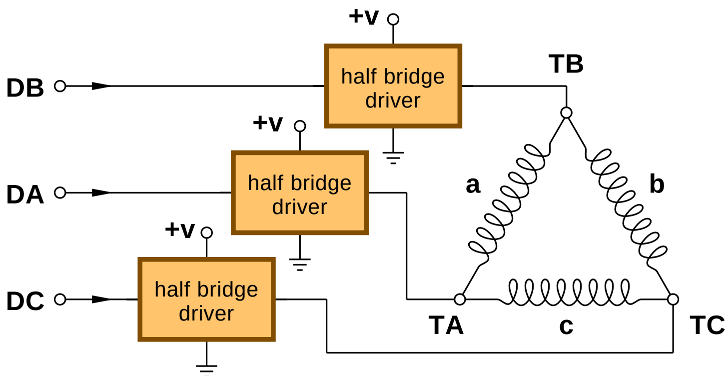
Here is what the pins do...

pin 1 - SYNC	Outputs a sync pulse whose **leading edge** occurs a small fraction of a degree **before** the Phase A **positive going** zero crossing. Pulse width varies somewhat with amplitude. Use as an optional output frequency reference and scope sync for testing. Also very useful for synchronous inverter locking.
pin 2 - UP	In single step mode, high **increases** amplitude by one count when input. Unless at 100. In slew mode, high **increases** the amplitude **continuously** at a preset slew rate of 120 levels per second. Unless already at 100.
pin 3 - DC	In single step mode, high **decreases** amplitude by one count when input. Unless at 0. In slew mode, high **decreases** the amplitude **continuously** at a preset slew rate of 120 levels per second. Unless already at 0.
pin 4 - NC	Input **reserved** for future feature.
pin 5 - GND	System **ground** pin.
pin 6 - DA	Terminal "**A**" **delta output**. Normally routed to a half bridge driver. Phase A is **clockwise** from this output. Phase C is **counterclockwise**.

pin 7 - DB	Terminal "**B**" **delta output**. Normally routed to a half bridge driver. Phase B is **clockwise** from this output. Phase A is **counterclockwise**.
pin 8 - DC	Terminal "**C**" **delta output**. Normally routed to a half bridge driver. Phase C is **clockwise** from this output. Phase B is **counterclockwise**.
pin 9 - AMP	Optional **"half wave" phase A output**. Externally **RC** low pass filtered dc output will equal **0.4405** of the **rms** amplitude. A two pole 0.1 second filter is recommended. Also useful to scope verify chip operation.
pin 10 - NC	**Reserved** by PIC for low voltage programming.
pin 11 - $\overline{\textbf{DC}}$	**Complement** of **DC** output may be needed by certain half bridge drivers. May be resistively summed with **DB** for analog phase **B** output.
pin 12 - $\overline{\textbf{DB}}$	**Complement** of **DB** output may be needed by certain half bridge drivers. May be resistively summed with **DA** for analog phase **A** output.
pin 13 - $\overline{\textbf{DA}}$	**Complement** of **DA** output may be needed by certain half bridge drivers. May be resistively summed with **DC** for analog phase **C** output.
pin 14 - +5V	**+5 VDC supply**. Typical current is under 10 milliamperes and depends on frequency and port loading. Bypassed using at least two 0.05 microfarad capacitors as close as practical.
pin 15 - NC	**Reserved** for future use. Presently a **clock/4** output. Required for feedback if crystal is used.
pin 16 - XIN	**Reference frequency clock input**. Scale factor is **Six Hertz per MegaHertz**. Or **10 MHZ** in for **60 Hertz** output.
pin 17 - $\overline{\textbf{PWR}}$	**Output power disable**. High = stop, low = run. Presently returns to **previous** amplitude.
pin 18 - SS	**Update mode select**. High = **one** single step per **UP** or **DN** pulse. Low = slew at preprogrammed 120 levels per second rate.

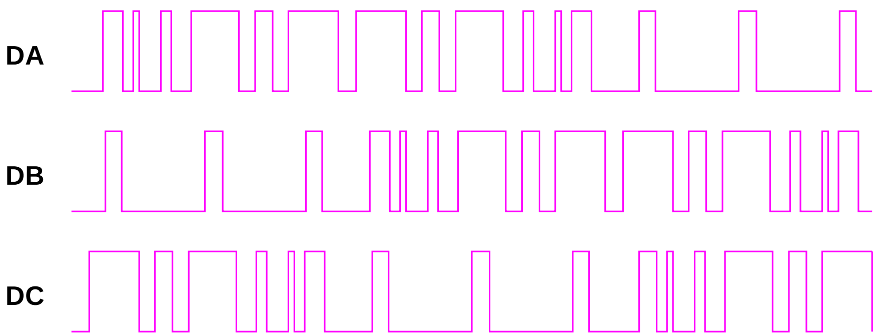
Typical Waveforms

Here is how the **MS28D-04X** normally gets connected to a three phase motor…



This assumes **non-inverting** half bridge drivers. Otherwise, the corresponding **$\overline{\text{DA}}$**, **$\overline{\text{DB}}$**, and **$\overline{\text{DC}}$** lines are used. The half bridge supply voltage determines the **peak** of the output sinewave voltage for Amplitude 100. Minus on-state conduction drops.

The delta terminal waveforms are not intuitively obvious…

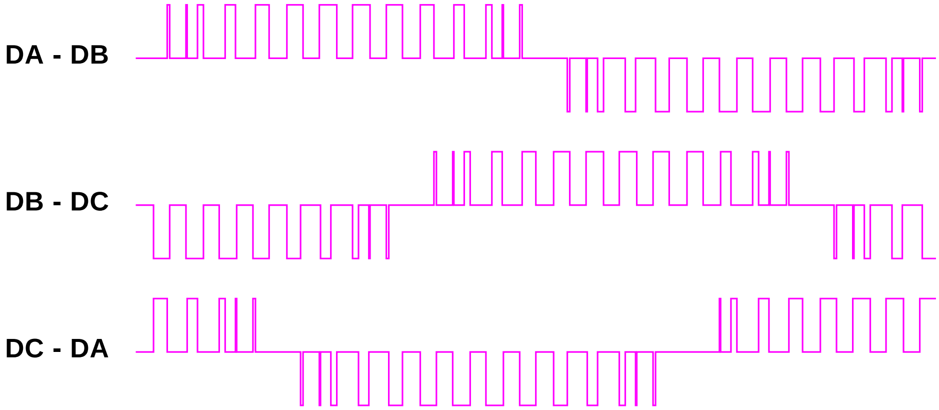


We see that the waveforms are forward and reverse symmetric. And are identical except for phase shifts of **120** and **240** degrees.

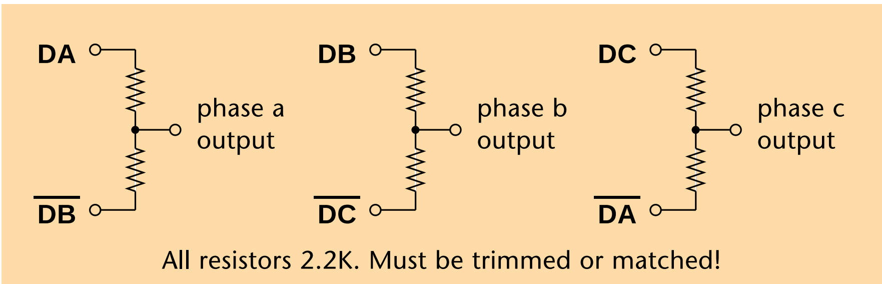
Any actual motor or other load phase responds to the **difference** between adjacent Delta terminals. For instance **DA** drives the left end of phase a above, while **DB** drives the right end of phase a. If **DA** is high and **DB** is low, a **clockwise** current results in phase a. If **DA** is low and **DB** is high, a **counterclockwise** current results in phase a.

Should **DA** and **DB** both be either low or high, then **zero** current results in phase a. Thus, any phase responds to the **difference** of its two drive waveshapes.

Which gives us these expected phase waveforms…



The bridge drivers will automatically take care of these subtractions for you. You also can **digitally subtract by ADDING one complement**. Which is quite handy to generate these bipolar analog test outputs…



You can use similar resistive adding with opamps or filters. If not already provided, add a series 100 microfarad output coupling capacitor to block the 2.5 volt dc offset. Loading the ac output with a 1K resistor to ground will drop the output values to about a 0 DBM peak level.

Getting Started

Evaluation chips are presently provided in 18 pin DIP packages. You can use most any breadboarding or test system that is 20 MHz friendly. Those new **PIC Mockup breadboards** from **Technical Works** are especially handy and well suited for this task. But even an older Heath ET3200 logic breadboard or similar can be used.

Your regulated +5 volt DC power supply has to be able to provide ten mils and must be properly bypassed with at least two 0.05 microfarad capacitors as close to the **MS28D-04X** as practical.

An external CMOS compatible clock of **6 Hertz per Megahertz** must be input. A **10 MHz clock will produce a 60 Hertz** output frequency.

Ultimately, this clock will come from the rest of your system and will provide your frequency or speed reference. Initially, though, you could use most any old hf function generator or a three-cascaded-inverter oscillator built from a **74HCT14** hex CMOS Schmidt trigger, a resistor, and a capacitor. The **Linear Technology LTC1799**, **LTC6903**, or **LTC6904** also look very interesting as clock sources.

Two normally low slide switches are recommended as **SS** and **$\overline{\text{RUN}}$** inputs. Similarly, two normally low pushbuttons are recommended as **UP** and **DN** inputs.

As shown above, your **DA**, **DB**, and **DC** outputs are routed to three half bridge drivers to power your load. Should your half bridge drivers be inverting, you can use the **$\overline{\text{DA}}$**, **$\overline{\text{DB}}$**, and **$\overline{\text{DC}}$** complementary outputs instead. Optical isolation may be required for wye connected loads or for loads that must remain ground balanced.

Your **SYNC** output can be routed to an electronic counter to verify your output frequency. This line is also useful for unambiguous scope sync or to provide a locking for on-grid synchronous inverters. Use only the **leading edge**.

The **AMP** output with its **"half wave" phase a** output can be scope viewed for a quick operation check. It can also be lowpass filtered to give you a DC output level that is proportional to **0.4405** of the rms output amplitude. Two stage **RC** filtering with a time constant of **0.2** seconds is recommended.

Note that this AMP dc level is referenced to the MS29D-04X +5vdc supply and not to your half bridge output voltage!

As shown above, your **DA** and **$\overline{\text{DB}}$** lines can be summed to provide a convenient bipolar analog output for distortion and spectrum measurements. A classic analog audio spectrum analyzer and a frequency selective voltmeter is recommended for most accurate results. As is a **Direct Fourier Transform** rather than a **FFT**.

Note that a typical computer sound card will sample a **60** Hertz waveform only around **400** times or roughly once per degree. This is far too low a sample rate to give you accurate **Magic Sinewave** distortion figures. Similarly, real time spectrum analysis software often will use a **Fast Fourier Transform** or **FFT** that may add windowing artifacts and sampling restrictions to your analysis.

Regardless...

> **Be sure your distortion and spectrum testing is actually and accurately measuring the magic sinewave and NOT viewing its own sampling or windowing artifacts!**

Accurate predictions of **Magic Sinewave** performance can be found by using these **Magic Sinewave Calculators** and this **Quantization Analysis Tutorial**.

The **SigView** shareware software might also be of some assistance here.

Some Options

There are all sorts of different **Magic Sinewave** chip options available. Some other devices in the series are planned that would provide maximum efficiency **single phase operation**. Or would zero out **three phase** delta harmonics up through the **34th** or the **46th**. Or possibly higher. Additional switching transitions do have to be one-on-one traded off per phase for any extra harmonics zeroed.

Changing a config bit during programming can allow stand-alone **10 MHz crystal** use for a fixed 60 Hertz output. This can be useful for simple inverters, but may not be suitable to synchronous on-grid feeder apps. Lower reference frequencies such as **6 MHz/MHz** may be possible, as would **400 Hertz** aerospace apps.

The slew rate and initial starting amplitude can also be preprogrammed. The number of available amplitudes could be increased or decreased. Amplitude steps could be made nonlinear for such effects as constant power increments, for any **low-medium-high** steps, incandescent lamp brightness linearization, other load nonlinearity correction, or even random candle flame effects.

At present, the phase output sequence can be reversed by swapping the **DB** and **DC** delta lines. This can easily and cheaply be done using config jumpers, a **DPDT** manual switch or an external dual data selector. While an internal reversal feature is possible, doing so may end up resource intensive.

Restart or rerun behavior can be altered. Restarting from zero amplitude might be best for motor apps, while restarting from last amplitude could better serve preset theater lighting users.

Present maximum frequency is beyond **120** Hertz, set by the **20** MHz spec limit of the **PIC** being used. The lower frequency limit and the frequency delta or speed spread is determined by your lowpass filtering and your ability to properly deal with the strong harmonics **23** and **25**.

Code modifications could allow external slew rate setting or a programmable soft start. Amplitude updates faster than six per cycle would appear possible but may require extensive new development.

Amplitude input via seven parallel lines is also a mode option. But this might introduce **severe** transient load problems. Unless the sequential input amplitude words were carefully and externally controlled.

Consulting Services and **Custom Programming** are available on these and other options. As are **training seminars**.

You can also **email** me for further assistance.

Transient Considerations

The **MS28D-04X** has been designed to be extremely "load gentle". Outputs start at zero phase of an initial amplitude and can theoretically increase or decrease at a **maximum speed of six one-level increments per cycle**.

Stock chips are slew rate limited to a slower **120** amplitude changes per second. Thus "off" to "full" will presently take a minimum of **0.833** seconds. Amplitudes can only synchronously change with all three delta outputs at zero. This should be ideal for motor starting or gentle long-life incandescent lamp startups.

Stopping also always takes place with all three delta outputs at zero. **Stopping or shutdown may need up to sixty degrees of latency**. If this is unacceptable, an external "emergency stop" could be provided for.

An important rule…

> **You should carefully evaluate the dynamics of your intended use to make certain the available slew rates and latency times are compatible with your system stability!**

Filter Requirements

As with any pulse sinewave synthesis system, **Magic Sinewaves** output a mix of a desirable clean sinewave and considerable high frequency noise components. In particular, the **MS28D-28X** outputs strong amplitude dependent **23rd** and **25th** harmonics that may end up a significant fraction of the fundamental.

There are also some much higher frequency harmonics present, but these usually will completely disappear when you properly deal with the **23rd** and **25th**.

Typically, a motor’s inductance usually does a one pole low pass filter, while its load intrtia adds a second. Often, this will be more than enough filtering.

Regardless…

> **A minimum of 30 decibels of low pass filter rejection should be provided for your 23rd and higher harmonics!**

Your filtering and your intended load will determine the frequency or speed range you have available. Other **Magic Sinewave** chips can be made available that zero additional harmonics. These will trade off additional switching transitions for additional zeros rejected, easier filtering, and wider speed ranges. But all will give you the maximum possible number of harmonics zeroed for a given choice of pulses per cycle.

Single Phase Use

Note that those **DA**, **DB**, and **DC** unipolar delta drive waveforms are **not** stand alone magic sinewaves in and of themselves. In particular, any single output by itself will include **strong** triad harmonics. Especially the ninth. It is only when **pairs** of unipolar outputs are **subtracted** from each other that you get a low distortion and high efficiency bipolar magic sinewave.

Since the triad harmonics are identical in all three waveforms, any two outputs should automatically **cancel** their triads when they are subtracted.

Any **pair** of outputs can be used as a standalone single phase source. But specific use of outputs **DA** and **DB** is recommended for zero starting phase.

For More Help

The MS28D-04X chips are available at $19.63 each plus shipping. Sourcecode and one hour of consulting is separately available for $89 additional.

You can order your samples and sourcecode **here**. They should also be shortly available on **eBay**.

Licensing arrangements for your own chip production using our sourcecode or any of its derivatives or variants are available and are quite reasonably priced. You can **email me** for further details.

Additional **Magic Sinewave** services, programming, seminars, training and project development is available **here** and **here**.

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