A Review of Inverter Design and Topologies

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Electronic Switch Types

This section will examine the types of switches that have been used and are currently being used in inverter designs. The purpose of the switches in an inverter is to break up the direct current (DC) into pulses that may then be applied to a transformer or filter system to produce higher voltage alternating current (AC).

As switch design and performance continues to improve, inverter efficiency is on the rise, sizes are decreasing, and power levels are going up. Semi-conductor type switches have changed greatly with time due to manufacturing processes and new materials. Losses caused by poor quality switches have been greatly reduced already, and every day further improvements are made. Let's examine several different switch types beginning with the earliest.

Vibrator Switches

The first inverters, from companies such as **Tripplite**™**,** made use of a mechanical vibrator to perform the switching functions in the inverter. This type of switch was essentially an oscillating relay. The vibrator performed well in its ability to conduct high currents and had very low resistive losses.

Overall the vibrator posed more problems than solutions. However since semiconductors didn't exist, vibrators had to be the solution. Although vacuum tubes were available they were inefficient and required high voltages to operate. Vacuum tubes were self-defeating in inverter design.

The down side to vibrators was the fact that they were a mechanical device and subject to poor reliability. The contacts suffered from arcing and would in some cases weld together allowing high continuous current flow. The advent of semiconductors completely displaced the vibrator type switch.

Silicon Controlled Rectifier Switches (SCR's)

Silicon Controlled Rectifier type switches (called SCR's) replaced the mechanical vibrator switches. These switches are completely solid state and current flow is controlled by a "gate". When the gate current reaches a certain threshold, the SCR will turn on, and will not turn off until the gate current falls below its turn-off threshold. Think of it as a latching type electronic relay.

The SCR's strong points are ability to handle high current (1000 amps for some types), and operate well at high voltages. The drawbacks are high on state voltage drop (typically more than 1.0 volt) and slow switching speed (making them unsuitable for high frequency applications). Another problem with SCR's is the possibility of "latch up", a situation where the SCR will not turn off.

SCR's still enjoy usage in high power inverter applications where idle losses are a very small percentage of total power output (example: a 20kW inverter).

Darlington Transistors

Darlington paired transistors were the next step in switch types used in inverters. The germanium transistors that were available simply did not have enough current gain to operate efficiently. Typical gain of germaniums was about ten. This meant that six amps had to be provided to the base to get a sixty amp current through the transistor, not very efficient!!

Darlington transistor switches came along and solved the problem with high gains (Typically greater than 100). This type of transistor operates well, but has a couple of pitfalls that make it unsuitable for some types of inverters. Darlington transistors have high on resistance meaning low efficiency. Also, slow switching speed means they are inadequate for high frequency inverter applications.

MOSFET's (Metal Oxide Semiconducting Field Effect Transistor)

The latest and greatest switching technology is the MOSFET or FET. In some ways the FET is the answer to all problems encountered with inverter designs. A FET is essentially a variable resistor. The "on" resistance is very low, and FET's are easy to drive (easy to connect in circuit). They are low cost, and handle high currents well (60-100 amps). Probably one of the few shortcomings of a FET is they do not operate well at high voltages, and still cannot handle the extreme currents that an SCR is capable of. However, FET's lend themselves well to parallel connection, which allows not only more current carrying ability, but also lower on resistance.

FETs are ideal for medium power applications and due to their ruggedness, the FET has proven to be an outstanding switch for inverters, whether high or low frequency.

IGBT's (Insulated Gate Bipolar Transistor)

IGBT's are like a bipolar transistor with a FET type control gate. Like a FET, IGBT's are easy to drive, but unlike a FET have a high on state voltage drop (typically more than 1.5-2.0 volts). IGBT's do combine some of the qualities of SCR's such as excellent high voltage operation and high current handling ability. Downfalls such as slow switching speed make using an IGBT in a high frequency circuit a complex task.

In certain high frequency applications this type of switch has benefits, but at the expense of cost and complexity of design to make it operate reliably and efficiently. Additionally, high idle losses in the switch make it more suitable for high power high voltage applications.

Inverter Topologies and Design Practices

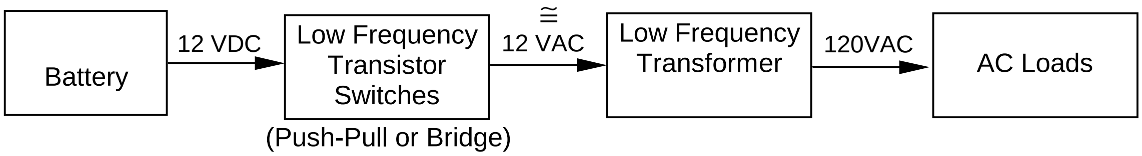
Many topologies, or circuit designs, have evolved in the quest for creating higher power AC from low voltage DC sources. This section will examine the design techniques of the past, present, and future of power inverters.

Square Wave and Modified Square Wave Inverters

Low Frequency Transformer Based Inverters

The following topologies are based on low frequency switching of the low voltage DC side, applying the resulting DC pulses to a step-up transformer. Two common topologies are the **push-pull**, and the **H-Bridge**. The push-pull topology is suitable for production of square and modified square output waveforms, while the H-Bridge is useful for producing modified square wave and sine wave outputs.

The general flow of a low frequency transformer based inverter is shown by the figure below.



Square Wave Inverters

The **Square Wave Inverter** derives its name from the shape of the output waveform (See Figure 1).

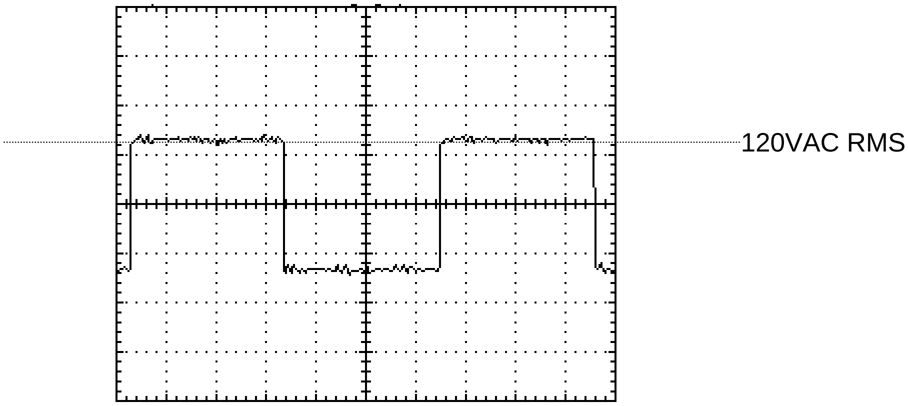


Figure 1, Square Wave Output Wave

Square wave inverters were the original "electronic" inverter. The first versions, such as Tripplite™, use a mechanical vibrator type switch to break up the low voltage DC into pulses. These pulses are then applied to a transformer where they are stepped up. With the advent of semiconductor switches the mechanical vibrator was replaced with "solid state" transistor switches.

A common circuit topology referred to as “push-pull” is used to produce a square wave output (See Figure 2).

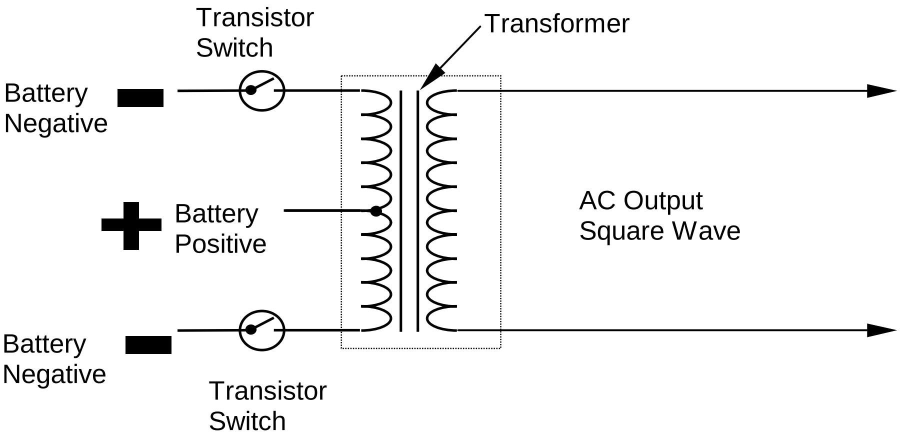


Figure 2, Push-Pull Topology - Square Wave Output

The basic theory of operation behind a push-pull design is as follows:

The top transistor switch closes and causes current to flow from the battery negative through the transformer primary to the battery positive. This induces a voltage in the secondary side of the transformer that is equal to the battery voltage times the turns ratio of the transformer. Note: Only one switch at a time is closed. (See state Figure 4A below).

After a period of approximately 8ms (one-half of a 60hz AC cycle), the switches flip-flop. The top switch opens and then the bottom switch closes allowing current to flow in the opposite direction (See state Figure 4B below). This cycle continues and higher voltage AC power is the result.

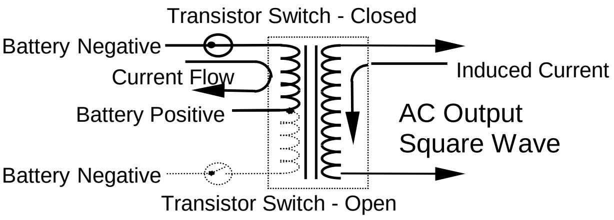


Figure 4A

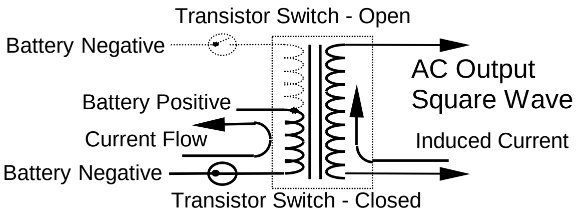


Figure 4B

The major problem with the push-pull approach is that the current in the transformer has to suddenly reverse directions. This would be like shifting your car into reverse at fifty miles per hour. This causes a large reduction in efficiency as well as potential for large transients, thus degrading the waveform. Another drawback is the transformer required for a push-pull design must have two primaries. This is a complex task to design a transformer meeting this requirement and increases cost and bulkiness.

Square wave inverters are still produced but have several major drawbacks. The output waveform has high total harmonic distortion (THD). It does work okay for powering motors although the motor will generate excess heat. Most electronic equipment will not operate well (if at all) from a square wave. This is due to waveform characteristics, and lack of voltage regulation. The peak voltage of the output pulse is directly related to battery voltage. Since the transformer ratio is fixed, any change in battery voltage will affect the peak output voltage. For a square wave, RMS voltage is equal to peak voltage and as a result power output is dependent on battery voltage.

Finally, most square wave inverters have mediocre efficiency (typically about 80%), and the idle power draw is relatively high.

Modified Square Wave Inverters

The addition of an extra winding in the transformer along with a few other parts allows output of a **Modified Square Wave** (often referred to as a modified sine wave by marketing types) while still utilizing a push-pull topology (Figure 5).

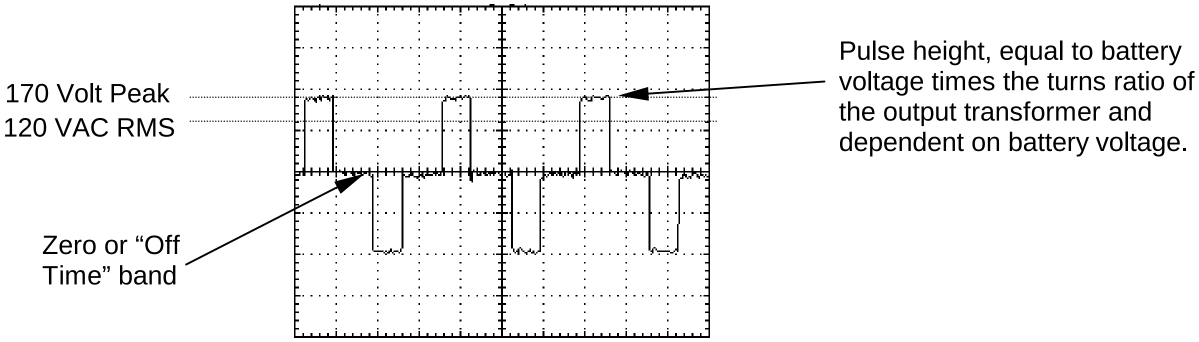


Figure 5, Modified Square Wave, and Off-Time

The switching cycle is identical to that described in the section on square wave inverters, except for one additional step. In the switching cycle, another step is added which “clears” out the transformer reducing the problems associated with the sudden change in current direction. This is accomplished by the **off time shorting winding** shown in figure 6. As one switch opens and before the second switch closes, the switch across the shorting winding closes, effectively removing the current from the transformer. This would be like slowing a car to a stop and then shifting to reverse, much better than the situation mentioned previously. Off-time shorting provides a better zero crossing of the waveform, which equates to better ability to operate electronic devices. Improved efficiency and lower total harmonic distortion of the waveform are other benefits.

Several manufacturers accomplish off-time shorting by placing a solid-state switch directly across the AC output lines. This approach works, however the switch is not isolated from the AC line, and as a result it is subject to abuse from transients, which can be caused by reactive loads (i.e.- electric motors). Utilizing a shorting winding in the transformer is preferable due to the isolation provided from the AC output.

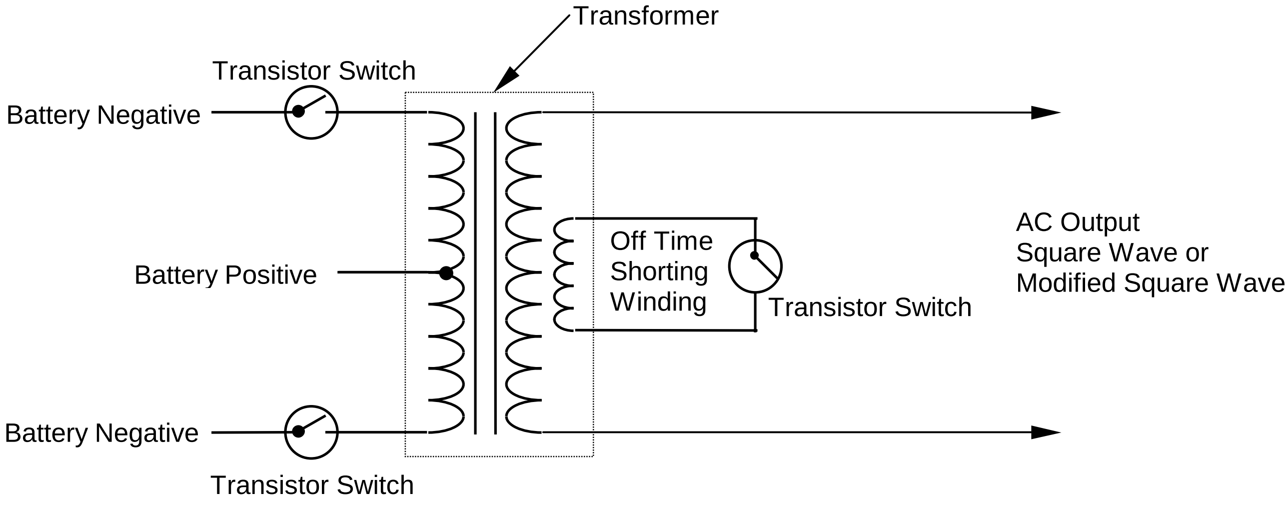
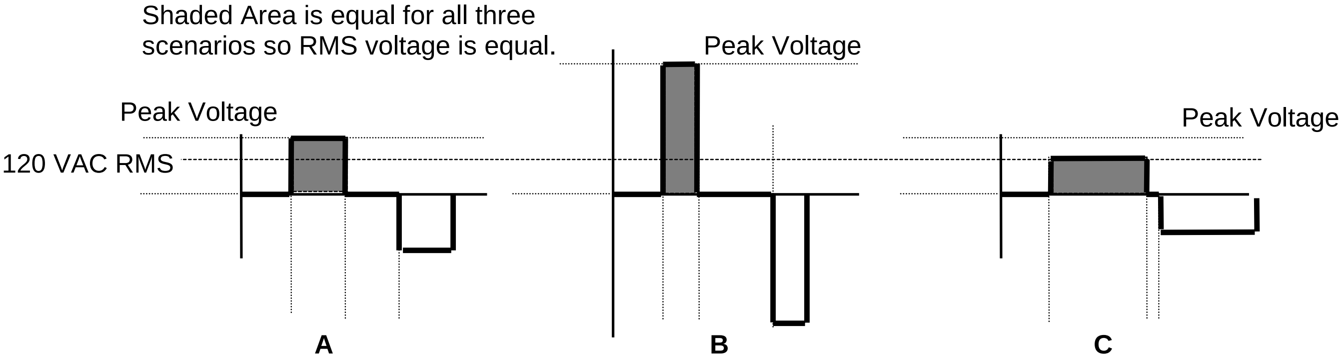


Figure 6, Push-Pull Topology with Shorting Winding

The major advantage to a modified square wave is the ability to regulate RMS voltage by means of varying the **pulse width**, and **off time** periods. The pulse width variation method of regulation is referred to as **pulse width modulation** or **PWM**.

The idea behind RMS regulation is to keep the area inside the waveform equal at all times (Figure 7A). Since the peak voltage, or pulse height, is a product of battery voltage and transformer ratio (as we learned previously), when the peak voltage increases the area inside the pulse will increase if the pulse width remains the same. With a square wave inverter nothing can be done about this RMS voltage increase, but PWM control allows the width of the pulse to be narrowed, thus maintaining a constant area inside the waveform (Figure 7B).



A
Nominal Battery Voltage

B
High Battery Voltage

C
Low Battery Voltage

Figure 7, RMS Voltage Regulation Using PWM

Conversely, if the battery voltage decreases the RMS voltage will also decrease if the pulse width remains the same. In this situation, RMS voltage regulation may be achieved by increasing the pulse width (Figure 7C).

Increase and decrease of pulse width is accomplished by controlling the on and off time of the transistor switches. Realistically, there is a point where the zero time is no longer present as the pulse width is increased, and essentially a square wave is present. Beyond this point the RMS voltage becomes unregulated.

Modified square wave inverters are a great improvement over square wave types. They offer good voltage regulation, lower total harmonic distortion and better overall efficiency. Electric motors operate much better from a modified square wave and most electronic equipment will operate without problems.

Summary of Push-Pull Topology

The push-pull topology was the first step in “electronic” inverter technology. Some major disadvantages are complexity of the transformer design and higher transformer losses in a square wave design.

The Advantage is the simplicity of the overall circuit design, and opportunity for cost effective manufacturing.

There are still many manufacturers utilizing the push-pull circuit topology for power inverters.

H-Bridge Inverters

The H-Bridge topology accomplishes its task in much the same manner as a push-pull topology. The main advantage of this design is the simplicity of needing only one primary winding on the transformer. H-Bridge inverters have evolved with improvement in transistor characteristics. Since current flows through two transistor switches in series, instead of one as in the push-pull design, older more inefficient transistors meant twice the losses in the inverter. This kept push-pull topologies as the primary means of producing square and modified square waveforms. The advent of FET’s (Field Effect Transistors) allows the H-Bridge design to be easily utilized.

Shown in figure 8 is an H-Bridge switch arrangement. The transistors are divided into four groups or “corners” with the transformer primary connected across the middle of the “bridge” thus forming an “H” pattern. In practice each transistor switch is made up of multiple transistors in parallel allowing higher current handling and lower resistance when the switches turn on (called “on resistance” of the transistor). Notice also that there is no off time shorting winding in the H-Bridge transformer. The current flow still reverses direction but now the shorting is accomplished by closing the bottom two switch groups at the same time. This effectively shorts the transformer primary removing residual current flow after the upper set of switches turn off.

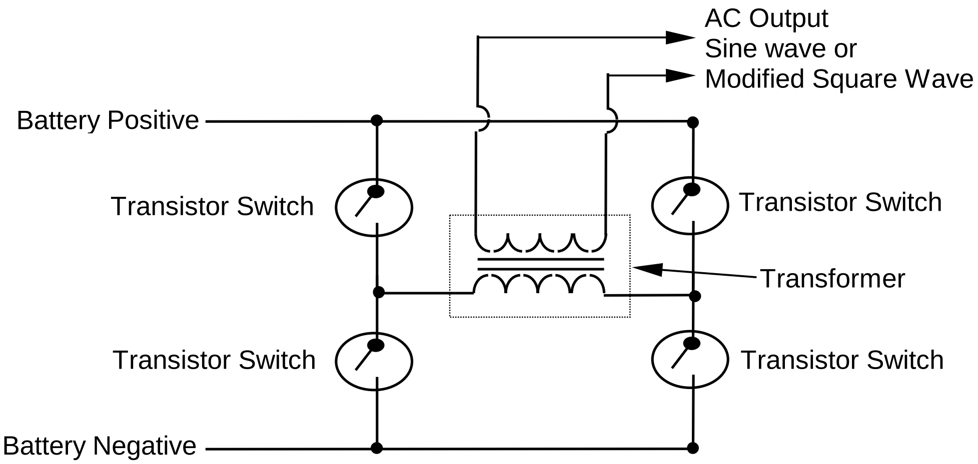


Figure 8, H-Bridge Topology

Just as in a push-pull circuit, the transistors are switched on and off in a specific pattern to produce each part of the waveform. The pattern is as follows:

Two opposite corners of the bridge are closed, allowing current to flow from the battery negative through the transformer primary to the positive terminal of the battery (Figure 9A). This current induces a current flow in the secondary of the transformer, which has a peak voltage equal to the battery voltage times the turns ratio of the transformer.

After a period of time (variable according to pulse width modulation for voltage regulation) the switches that were closed open, and the bottom two transistor switches close providing off-time shorting (Figure 9B). The length of the on and off-time is determined according to the PWM controller.

Next the two corners opposite step A, close and allow current flow through the transformer in a direction opposite to the current flow in figure A (Figure 9C). After this cycle is completed, the bottom switches close for off-time shorting and then the cycle repeats. In this way AC is produced.

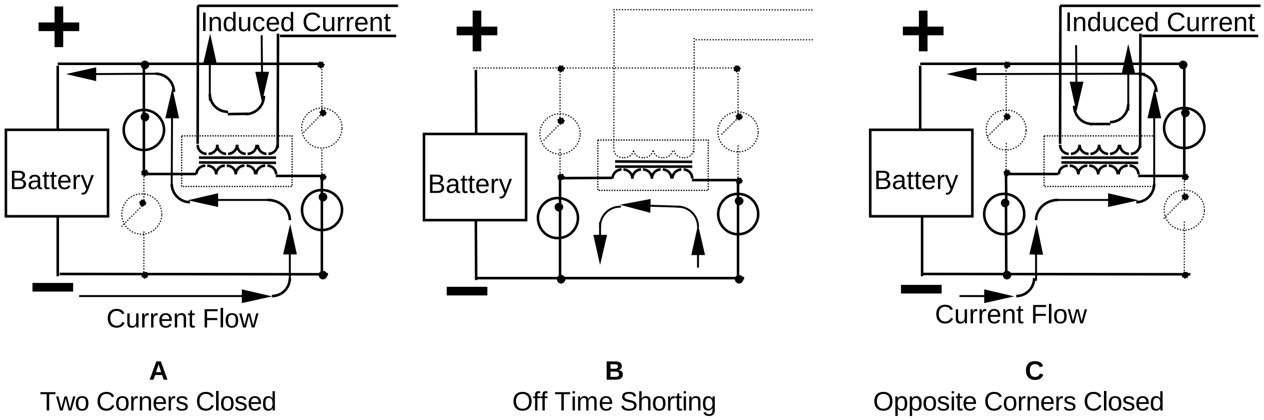


Figure 9, H-Bridge State Diagram

The H-Bridge design efficiency is dependent mostly upon the quality of the transistors used and the number of transistors in parallel. Most of the losses in this design take place in the transistor switches, so as transistors improve and become available the performance of H-Bridge based inverters will improve also. Examples of inverters that utilize the H-Bridge design are the Trace Engineering DR and SW series inverters.

Dual Transformer Low Frequency Inverter

The dual transformer approach to creating a modified square wave is equivalent to two push-pull inverters (low frequency) with square wave outputs and their transformers secondaries tied together in series (Figure 10). By timing the switching of the two inverters so that they are out of phase with one another, the resultant waveform is a modified square wave. **Heliotrope** inverters utilize the dual transformer design.

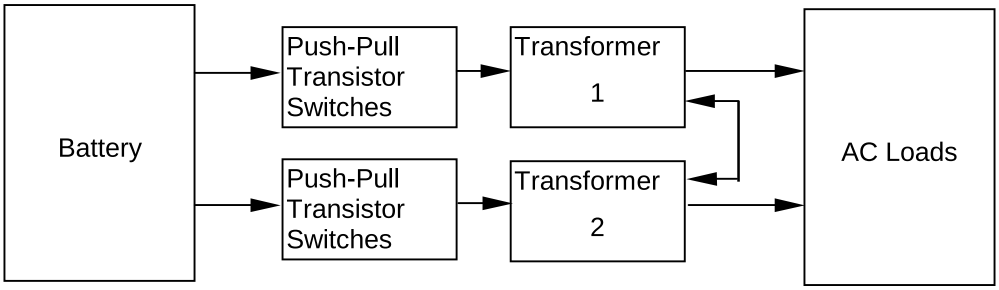


Figure 10, Dual Transformer - Modified Square Wave Only

The switches in this type of inverter operate in the same manner as described in the previous section on push-pull inverters. Shown in figure 11 are the output waveforms of each transformer, and the resultant inverter output. It is possible to pulse width modulate the final output by changing the phasing between the square waves.

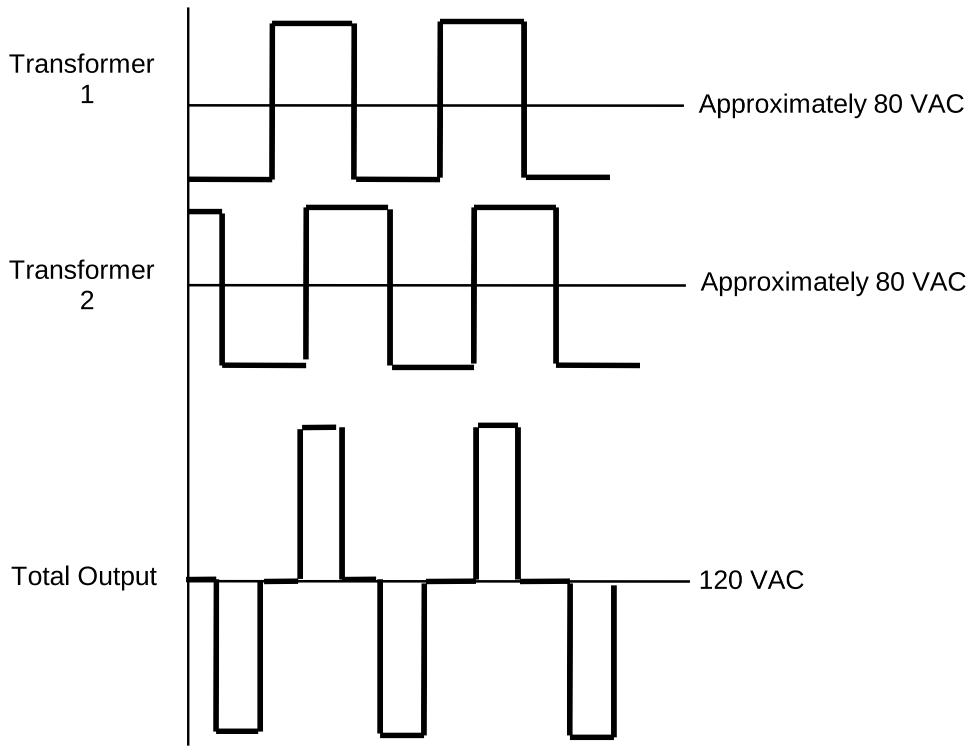


Figure 11, Dual Transformer Output Waveforms

High Frequency Inverters

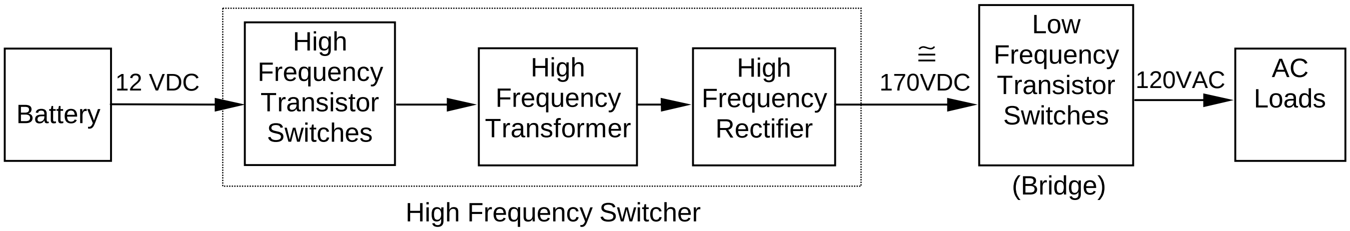
High frequency inverters are another approach to creating higher power AC from low voltage DC. The name, high frequency, refers to the speed at which the transistors switch on and off. This type of inverter creates low voltage AC from battery power, and applies it to a high frequency transformer, which creates high voltage AC. The high voltage AC is then rectified (changed back to DC) to high voltage DC and then a low frequency switcher (an H-Bridge) creates utility power AC.

High frequency inverters may be either modified square or sine wave outputs.

Drawbacks to the high frequency approach are poor surge ability for starting motors and other reactive loads, and the fact that there are transistor switches on the AC output which are not isolated from the AC loads. Transients, which may be created by reactive loads, can cause failure in the output transistors. Additionally in general the battery negative is not isolated from the AC out neutral in a HF inverter.

Shown below is a flow figure for a high frequency modified square wave output inverter.

High Frequency Inverter Flow Schematic



The transistor switching configuration is an H-Bridge switch layout with the transformer replaced by a high voltage power supply, often utilizing a flyback configuration (Figure 12). The high voltage switcher takes a low voltage DC input and produces a higher voltage DC output. The positive and negative ends of the high voltage supply are then alternately connected to the AC output lines by the bridge and output is pulse width modulated. This provides excellent voltage regulation.

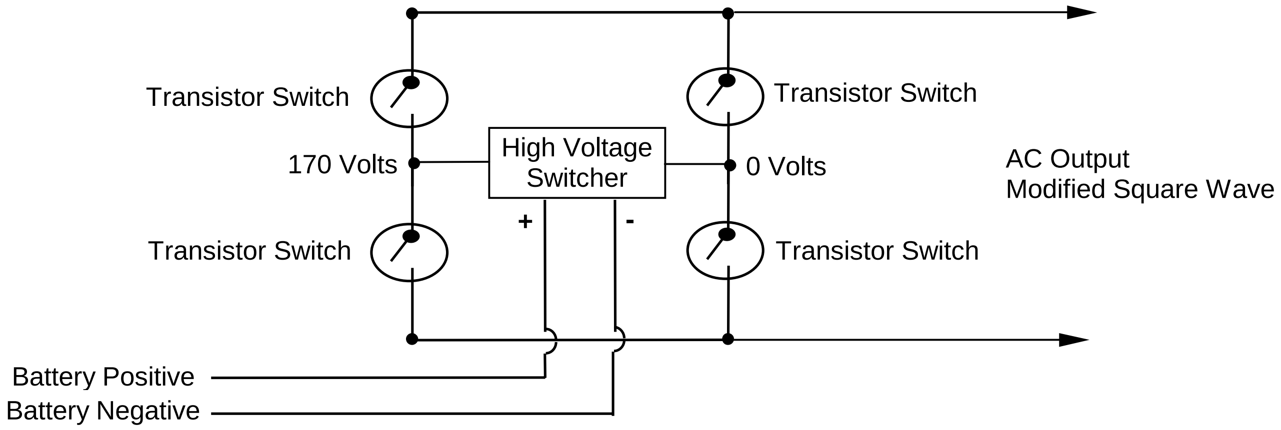
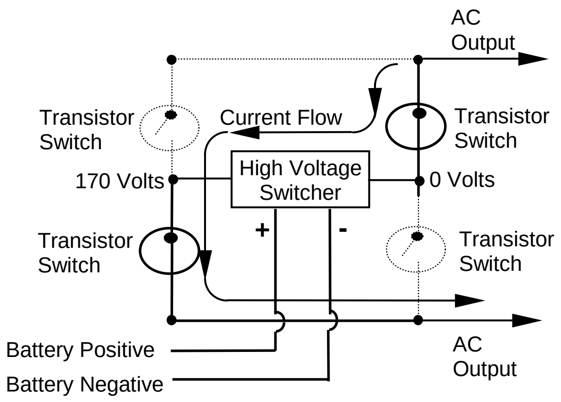


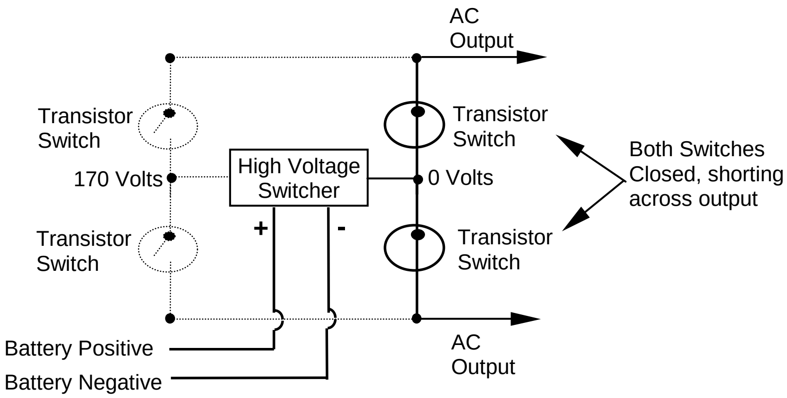
Figure 12, High Frequency Inverter with H-Bridge Topology

The voltage being switched in an HF inverter is the high voltage DC. In a low frequency transformer based H-Bridge, the low voltage DC from the battery was switched through a transformer. Off-time shorting is provided in the high frequency approach by closing the two transistors across the AC output on the zero volt side of the high voltage switcher. Remember, the switcher must off-time short between switch changes!

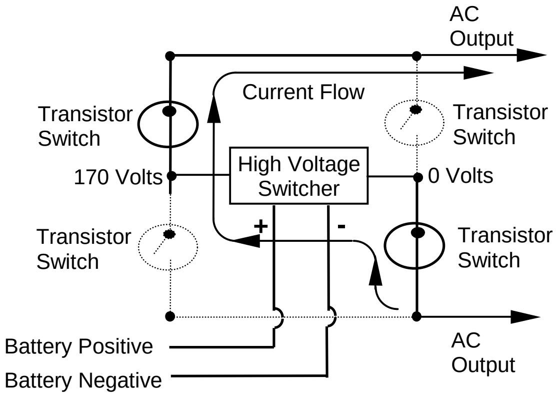
The three figures below show the states of the switches in one cycle of a high frequency inverter. Since the H-Bridge switcher has already been discussed, only a graphic depiction of the output switch states and current flow is shown.



13A, Two Opposite Corners Closed



13B, Off-time Shorting



13C, Other Two Corners Closed

Figure 13, H-Bridge Switch State Figure for High Frequency Inverter

The main advantage behind high frequency switchers is the very lightweight and physical size. Most HF inverters are low cost for the smaller sized units (less than about 300W).

Disadvantages of HF inverters are poor surge ability due to the characteristics of the switching power section supplying the bridge (limits their usage to motor loads). Lack of isolation between the transistors and AC loads makes them very vulnerable to transients caused by reactive loads since there is no transformer to isolate and act as a “flywheel” to oppose fast changes in output current. HF inverters exhibit high idle current because the high voltage switcher runs constantly, and this also often causes interference with TV’s, radios, etc.

Sine Wave Output Inverters

Just as with modified square wave and square wave output inverters, multiple approaches and topologies have developed to produce sine wave output inverters. These inverters are desirable in that they will run loads more like the utility grid. The downfall is complexity and expense in building some types of this inverter. A sine wave is shown in figure 14 along with several key points of the waveform.

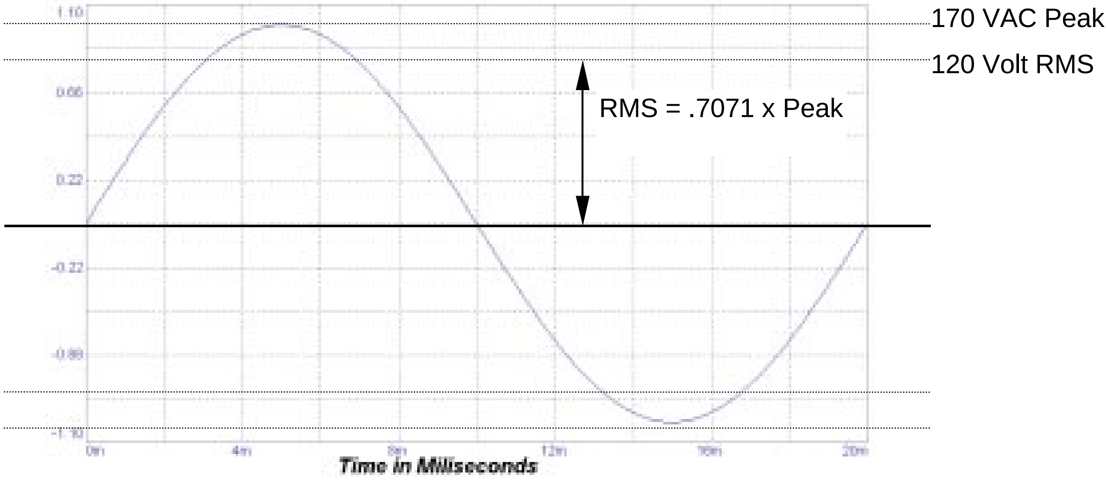


Figure 14, "Pure" Sine Wave Form (50 Hz Frequency)

Rotary Inverters

The earliest type of DC to AC inverters was the **Rotary Inverter**. Essentially this piece of equipment was a DC motor that turned an AC generator (See Figure 15). The rotary inverter had the advantage of producing a very nice sine wave output, at the expense of low efficiency (typically 60%) and very high idle power consumption.

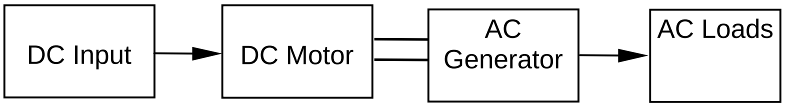


Figure 15, Rotary Inverter System Block Figure

Redi-Line still produces rotary inverters, and they are still in use today in service trucks and aircraft applications, although newer more efficient technology has, for the most part, made them obsolete.

The reliability of a rotary inverter is quite good, but further drawbacks such as poor surge ability for starting motors, heavy, bulky design, and noisy operation have pushed this type of inverter into the background but not completely out of the picture.

Ferro-Resonant Transformer Inverters

The Ferro Resonant sine wave output inverter takes advantage of the inductive characteristics of certain transformers. An inductor is a coil of wire that has the ability to store energy and to oppose changes in current within a circuit. An inductor acts like a magnetic "flywheel". In other words, if voltage is suddenly applied to an inductor, the inductor will react by attempting to slow down the resulting current rise. Conversely, if current is already flowing through the inductor and is suddenly removed, the inductor will react by releasing its stored current and attempt to stop the current from going to zero. As a result the fall time of the current is prolonged. This reaction acts to impede the changes in current. Unfortunately, inductance causes the transformer to have a relatively low efficiency (typically about 50%) and the waveform is very load sensitive.

A Ferro resonant transformer is designed to have a high inductance, which when placed as a filter in the output of a low frequency square wave or modified sine wave inverter creates a crude sine wave. Shown below is a flow figure of a basic Ferro resonant transformer.

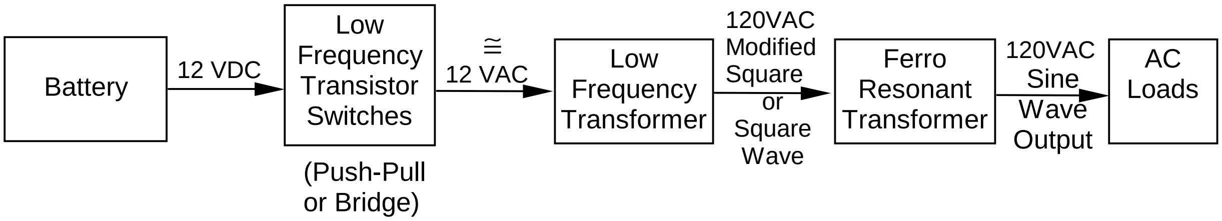
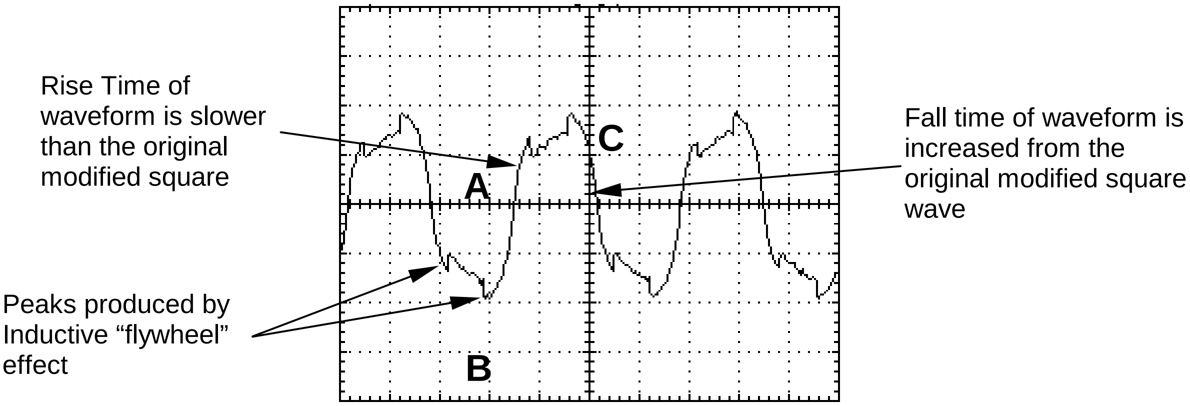


Figure 16 shows a Ferro resonant transformer at work. As the wave begins its first rise, the Ferro resonant transformer opposes the sudden change in current and slows down the rise time of the wave (Figure 16A). As the wave form stops rising and tries to flatten out, the transformer see this as a decrease in current change and so releases its energy thus causing the top of the waveform to "spike" upwards (Figure 16B). Next, the waveform begins to fall as the transistor switches open, and so the inductor attempts to hold the current up, thus slowing down the fall time of the waveform (Figure 16C). The process then continues through the negative pulse as current reverses directions in the transformer.



Rise Time of waveform is slower than the original modified square

Fall time of waveform is increased from the original modified square wave

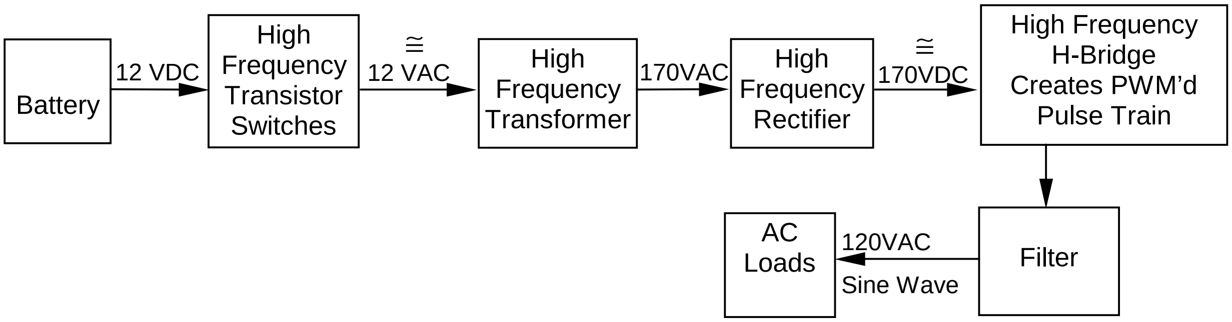
Peaks produced by Inductive "flywheel" effect

Figure 16, Actual Waveform produced by a Modified Square Wave fed through a Ferro Resonant Transformer, driving a 75W incandescent light bulb

Ferro Resonant transformers are still available in inverter form, or as a filter for protection against output spikes. Two companies currently utilizing Ferro resonant filters are **Topaz** and **Line Tamer**™.

High Frequency Sine Wave Output Inverters

A high frequency sine wave output inverter works in an almost identical manner to a high frequency modified square wave inverter. Shown below is the flow figure for the system.



The main difference between a high frequency modified square wave inverter, and a high frequency sine wave output inverter is in the final switching stage and the addition of a filter before the AC loads. The H-Bridge, which does the final switching of the rectified high voltage DC, operates at high frequency. This is different from the low frequency H-Bridge modified square wave version that produces one pulse for each half cycle. The high frequency H-Bridge sine wave type uses many positive high voltage DC pulses with varying pulse widths (PWM), then negative high voltage DC pulses (also PWM'd). The output filter smoothes out these pulses into a sine wave before powering the AC loads.

The transistor switches in the sine wave type HF inverter still close in the same pattern, but with a small difference. As two opposite corners close, one of the closed switches is opened and closed at high frequency for a time determined by the pulse width modulation clock. This produces the pulse train shown in figure 16. After a specified number of pulses the switches off-time short in the same manner as the modified square wave HF inverter. The bridge then switches to the two corners opposite from the first and the PWM cycling of one transistor of the conducting pair repeats.

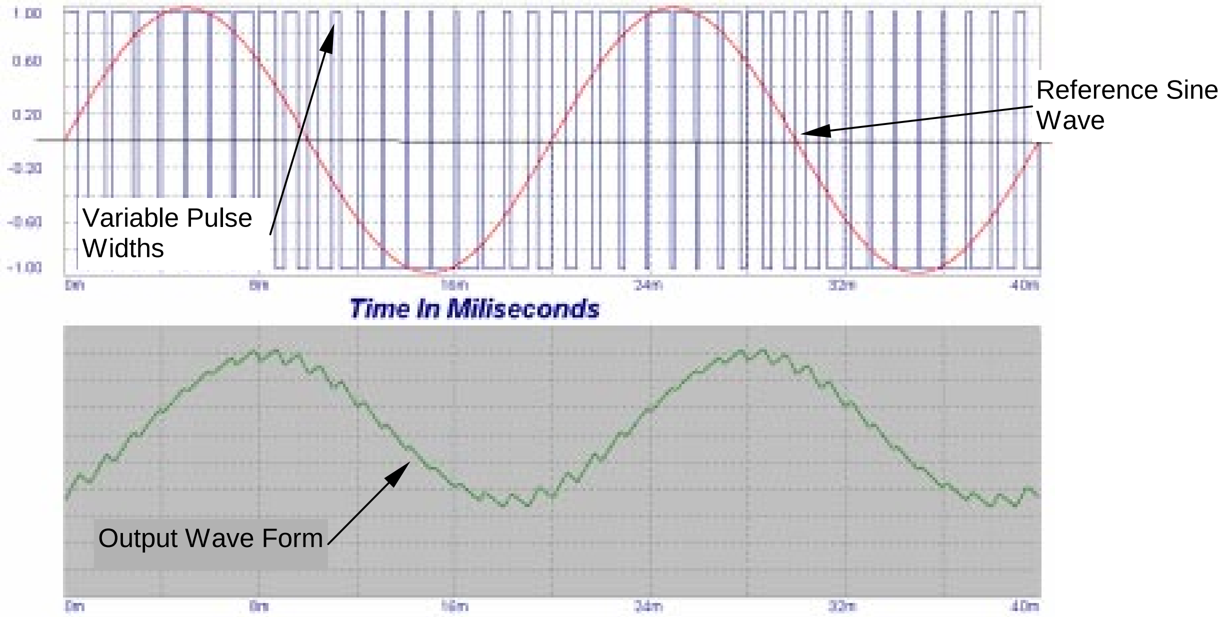


Figure 17

The output filter is generally an inductive type filter which smoothes the output from the HF transistor bridge to produce a sine wave output. **ExcelTech**™ uses this topology in their HF inverter designs.

The high frequency approach to creating a sine wave output inverter works well but still suffers from the anomalies mentioned earlier for high frequency modified square wave inverters. This includes no output isolation for the transistors, low surge capability, and high idle currents. Also, as mentioned previously, interference from the high frequency switcher may be a problem.

Low Frequency Sine Wave Inverters

An interesting approach to producing a sine wave output from a low frequency inverter was developed and patented by Trace Engineering of Washington State. The Trace **SW series** uses a combination of three transformers, each with its own low frequency switcher, coupled together in series and driven by separate interconnected micro-controllers. In essence it is three inverters linked together by their transformers. By mixing the outputs from the different transformers, a **stepped approximation of a sine wave** is produced. Shown in figure 18 is the output waveform from a Trace SineWave series inverter. Notice the "steps" form a staircase that is shaped like a sine wave. The total harmonic distortion in the Trace Engineering SineWave approach is typically 3-5%.

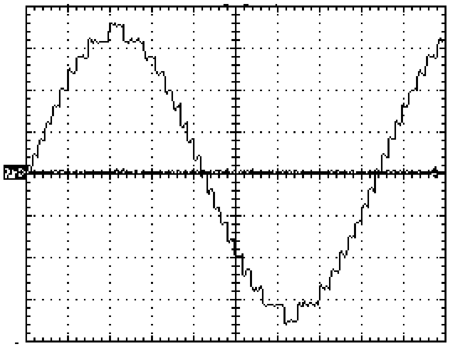
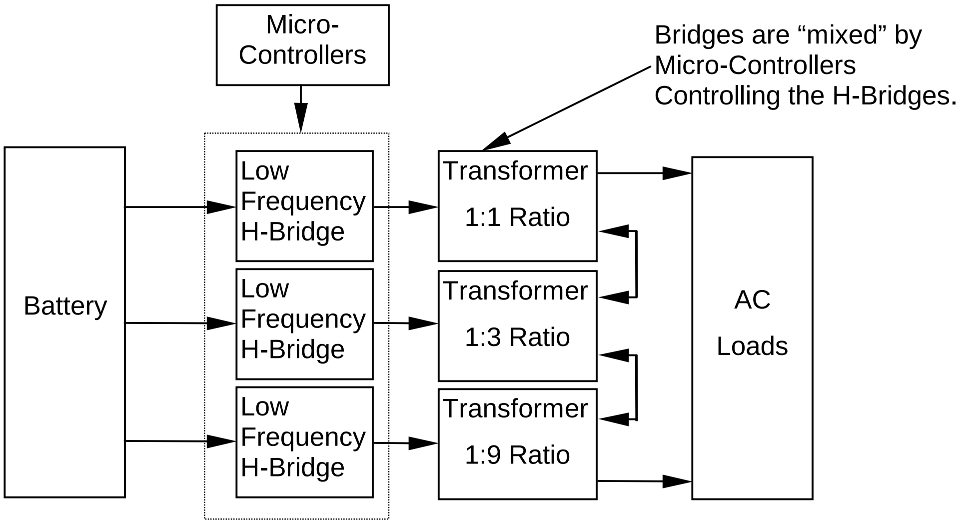


Figure 18, Trace SW Series Inverter Output

The multi-stepped output is formed by modulation of the voltage through mixing of the three transformers in a specific order. Anywhere from 34-52 "steps" per AC cycle may be present in the waveform. The heavier the load or lower DC input voltage the more steps there are in the waveform.

The main disadvantage to this type of approach is the complexity of accomplishing the task. The complex design requirements directly relate to the cost of the inverter, so in general this type of inverter, even though better, is usually more pricey. However, once designed, this type of inverter solves a lot of the problems present in the high frequency and Ferro resonant approaches to creating a sine wave. The low frequency method described, has excellent surge ability, high efficiency (typically 85 to 90%), good voltage and frequency regulation, and low total harmonic distortion.



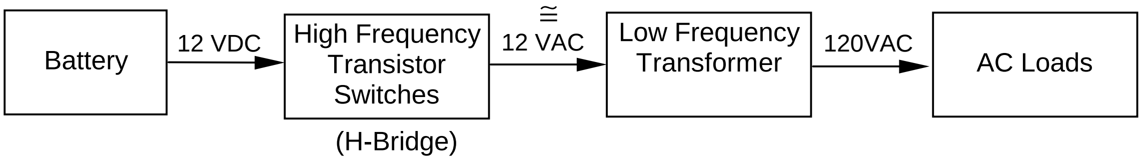
Hybrid High/Low Frequency Sine Wave Inverters

Tucked away between high frequency and low frequency inverters the **Hybrid** or **High/Low** sine wave output inverter. The name is derived from the mix of high frequency and low frequency inverter design methods.

The topology for a hybrid inverter is the same as an H-Bridge modified sine wave inverter, except the transistors are switched at a high frequency. This is similar to the previous high frequency sine wave inverter's design. Examples of this design are the **Dynamote Brutus** and the **Kenetech** inverters.

A plus with the hybrid topology is that it is inherently bi-directional, allowing the inverter to also act as a battery charger. The output waveform amplitude of a hybrid is easily controlled allowing the inverter to operate in parallel to a utility or generator.

Below is a flow schematic for a hybrid inverter.



Hybrid inverters offer a solution to the problems with both high and low frequency inverter designs. They allow good surge power, DC-AC isolation (via the transformer), good efficiency (typical 85-95%), low distortion (typically 1-5%) with an excellent sine wave output. The design is very rugged and reliable.

Conclusion

Many different approaches to inverter design have been attempted. As discussed, all have strong points as well as weaknesses. The "perfect" inverter has yet to be invented, but if it were it would be 100% efficient with infinite power and a sine wave output. However, since nothing is free in life, we must continue to make due with present technology and move forward as semiconductors become better and better.

Table 1 on the next page shows a tabular comparison of the different inverter types discussed. It is meant to be a guideline and does not necessarily represent every inverter built.

Table 1
Comparison of Inverter Types

Topology	Switch Type	Switch Frequency	Waveform Type	Total Harmonic Distortion	Typical Efficiency	Idle Power Consumption	Surge Ability	Interference	DC-AC Isolation	Reliability
Vibrator	Mechanical	Low	Square	High (≈50%)	60-80%	High	Poor	Medium	Yes	Poor
Push-Pull	SCR	Low	Square	High (≈50%)	80%	High	Good	Low	Yes	Good
Push-Pull	MOSFET	Low	Modified Square	Medium (≈15-35%)	80-90%	Low	Very Good	Low	Yes	Good
H-Bridge Low Freq.	MOSFET	Low	Modified Square	Medium (≈15-35%)	85-95%	Low	Very Good	Low	Yes	Good
H-Bridge High Freq.	MOSFET	High	Modified Square	Medium (≈15-35%)	85-90%	Medium	Poor to Good	High	No	Poor
Dual Xfrmr	MOSFET	Low	Modified Square	Medium (≈15-35%)	80-90%	Medium	Good	Low	Yes	Good
Rotary	Mechanical	Low	Sine wave	Low	50-70%	High	Poor	Low	Yes	Poor
Ferro Resonant	MOSFET	Low	Semi-Sine wave	Medium (≈15-35%)	50-70%	High	Poor	Low	Yes	Good
High Frequency	MOSFET	High	Sine wave	Very Good (1-5%)	70-90%	High	Poor	High	Yes	Poor
Low Frequency Multi-Step	MOSFET	Medium-low	Sine wave	Very Good (3-5%)	85-95%	Low	Very Good	Low	Yes	Very Good
Hybrid High/Low	MOSFET	High	Sine wave	Very Good (1-5%)	85-95%	Medium	Good	Low	Yes	Very Good