Alternative inverter drive

Linear power output stages are at their most efficient when driving a rail-to-rail square wave. Conventional motors on the other hand prefer a sine-wave drive. Irving Gottlieb describes how to get the best of both worlds in an unconventional way.

For some applications, a sine-wave is preferable to the square-wave output delivered by most dc-to-ac inverters. Among other things, square waves can roughen the torque characteristics of motors and they increase hysteresis and eddy-current losses. Also, the harmonic content of the square-wave format tends to agitate electromagnetic and radio-frequency interference problems

On the other hand, a switching circuit generating square wave power is noted for high efficiency, since it allows the switching transistors to operate with minimal thermal stress. Obviously it would be nice to retain the square-wave switcher, but at the same time obtain sinusoidal output.

In Fig. **1a)** is a basic saturable-core oscillator. This particular circuit makes use of an auto-transformer winding, and the switching transistors operate in the common-collector mode. Any of the other saturable-core oscillator circuits would be equally satisfactory for our purposes In Fig. **1b)**, a band-pass filter is associated with the output winding to produce a sine-wave. Sometimes, a simpler low-pass filter is similarly used, but it is then more difficult to get a good quality sine-wave.

A further technique is depicted in Fig **1c)**. The inclusion of the large inductor, *L*, enables the output winding to be resonated. Although the transistors still operate as a square-wave switching circuit, the desired sine-wave output is obtained. Noted that it would not be feasible to tune the output winding of the basic inverter circuit of Fig. **1a**.

The driven inverter of Fig. **1d** is a class-B amplifier This has fairly-good possibilities, but you should be prepared to cope with crossover distortion and with higher transistor dissipation than in the self-excited switching circuits

A different approach

Yet another approach to the problem makes use of parametric phenomena in magnetic cores. Briefly stated, voltage can be induced in the secondary of a transformer via variation in inductance, as well as variation in flux linkage.

You won't find much mention of this in traditional engineering texts though. This is because it is usually assumed that transformers are designed and operated to function over the essentially linear region of their magnetisation curves. Such operation minimises hysteresis loss and maximises efficiency.

You know, however, that violent non-linearity is to be found in saturable-core inverter transformers. As magnetic saturation approaches in these cores, permeability rapidly decreases, as does the inductance of associated windings

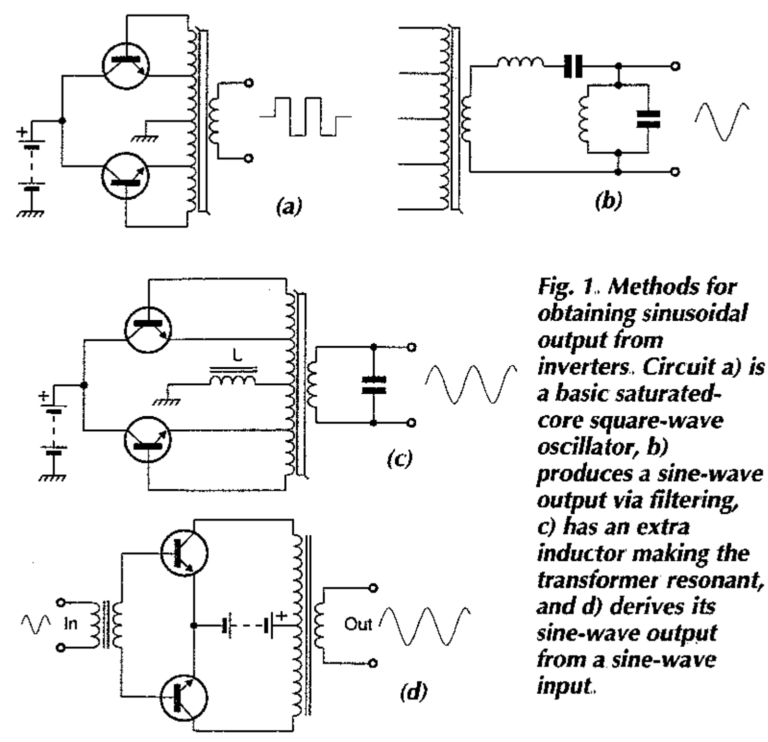

Fig. 1. Methods for obtaining sinusoidal output from inverters. Circuit a) is a basic saturated-core square-wave oscillator, b) produces a sine-wave output via filtering, c) has an extra inductor making the transformer resonant, and d) derives its sine-wave output from a sine-wave input.

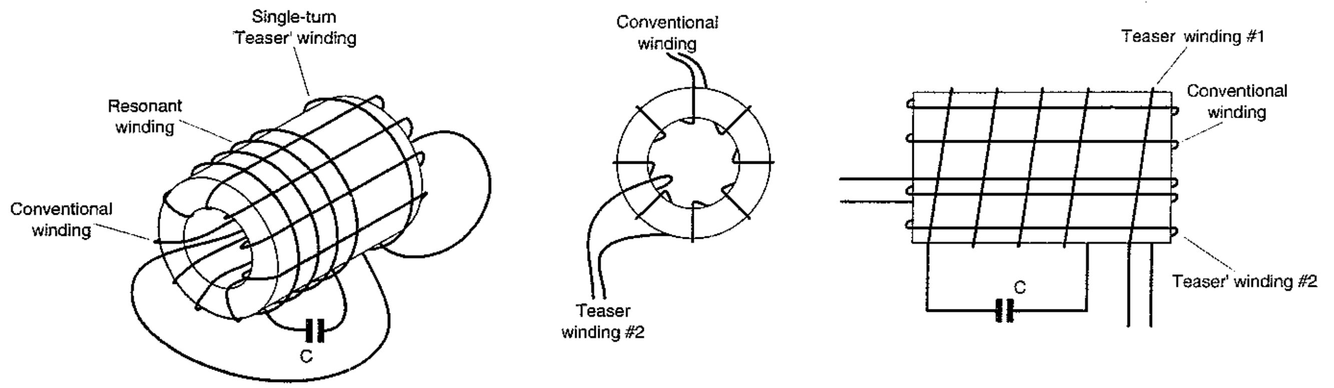

Fig. 2. Modified toroidal transformer for producing sine-waves. You start with a conventional winding, as used in saturable-core oscillators, then add windings as shown. a) is a perspective view, b) is the front view showing how one lead of the 'teaser' winding goes through the solenoid and c) is the side view.

Can this relationship be put to practical use?

In the sketches of **Fig. 2**, the salient feature of the modified oroidal transformer is the introduction of a resonant secondary winding Note that this winding is placed *over* the outer rim of the toroid.

The spatial relationship is such that no ordinary mutual flux linkage exists between the conventional primary winding and this unconventional secondary winding. Rather, the new winding senses the changing inductance of the core. This results in the parametrically induced emf. You can also think of this resonant winding as a shock-excited oscillator

As you can see, the modification involves a bit more than just the resonant winding. Additionally, two single-turn links are used to couple the primary and secondaries by ordinary electromagnetic means This enhances energy transfer. Overall then, the modified transformer uses both flux-cutting and inductance change to transfer energy. The links are the so-called 'teaser' windings A single pass through the hole of the toroid comprises a single turn

Does this idea worry you?

The unorthodox configuration of the modified transformer could, understandably, upset those of you used to more conventional formats.

The schematic diagram of **Fig. 3** should help clarify matters Here the X between the conventionally wound primary winding and the added resonant winding symbolises the lack of ordinary electromagnetic coupling between these windings.

As I pointed out, the absence of such flux-cutting energy transfer is brought about by the spatial orientation of these two windings. This brings us to the single-turn teaser windings which are geometrically arranged so as to promote some coupling via ordinary mutual induction. Thus, input and output windings are also link-coupled

To many practitioners, an interesting aspect of this scheme is that it calls for a bit of experimentation. Clearly, some kind of average value of inductance must be involved in the tuned output circuit. And although the Q of this resonant tank must necessarily impact both energy transfer and wave purity, it is not easy to quantify things for general applications.

I conducted investigations with a nominally 20W inverter at several tens of kilohertz; I obtained a very good sinusoidal output and I felt that the use of appropriate scaling factors should enable operation at other power levels and at other frequencies

It may be wise first to get the feel of this unusual circuitry and then proceed empirically in tailoring the resonant winding and the *L/C* ratio to conform to your specific needs. Also, if you already have an operational inverter using a saturating toroidal output transformer, much time and effort can be saved by placing the new winding(s) on this toroid

At first attempt, about the same number of turns should be used for the resonant winding as the total number of turns on the primary winding. Then, one or two decade capacitor boxes will facilitate search for resonance An oscilloscope is particularly useful in as much as one can observe both magnitude and waveshape.

Several things should be born in mind in interpreting results You may encounter sub-multiple resonances, but none of these will compare in magnitude and wave-purity with the true resonance of the fundamental oscillation frequency.

To a considerable extent, energy transfer will improve with the Q of the resonant windings. This in turn corresponds to a high ratio of C to L. Resonant impedance of a parallel-resonant LC tank is given in ohms by $\sqrt{(L/C)}$ with L expressed in henries and C in farads; high Q implies low impedance

A load resistor connected across the resonant output winding of such value that its presence reduces the amplitude of the sine-wave to half its unloaded value establishes the output impedance. Initially, at least, you should aim for an output impedance of about 250Ω.

To secure the output voltage you need, experimental flexibility is well served by employing either taps or an auto-transformer addition of a few turns. Clearly, Q, energy transfer, voltage, and output impedance are all interrelated and that optimisation for the requirements of a particular application can be an experimenter's delight At the same time, the basic operation is readily forthcoming, being neither elusive nor critical.

Once optimised, this scheme is likely to compel selection over the other techniques in matters of cost, board surface area, and wave-purity. ■

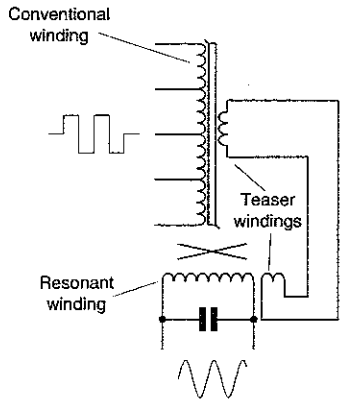

Fig. 3. Schematic of the modified toroidal transformer. The resonant winding is wound around the outer rim of the toroid. One 'teaser' winding is a single-turn link adjacent to, or over, the resonant winding. The other teaser winding is a single turn link formed by a single pass through the hole of the toroid. The conventional winding is the commonly used toroidal winding arranged for operation with push-pull switching transistors.