

History of Soft Switching

by Rudy Severns

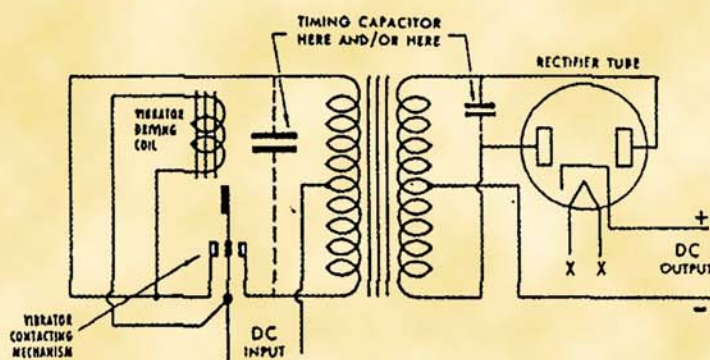


Fig. 1 1920s - 1930s Technology
Published in 1947, *Mallory Handbook*

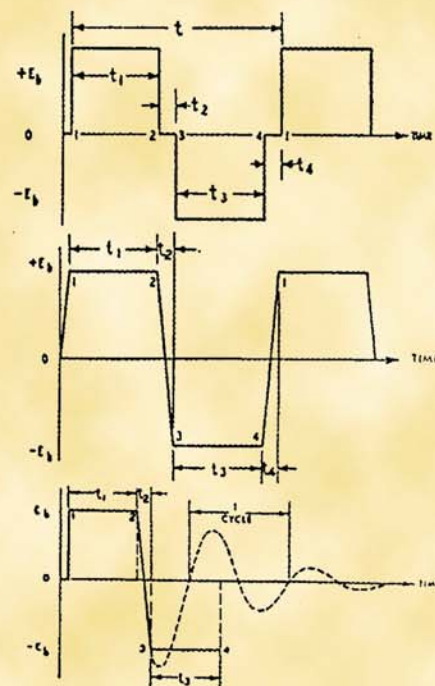


Fig. 2

Switches have been used for power conversion since the late 1800's, first with mechanical devices and later with electronic switches. The advantages of controlling or at least modifying the turn-on and turn-off voltage and/or current waveforms associated with a switch have been recognized from the beginning.

The capacitor turn-off snubber, for example, shows up as a capacitor across the contacts of the mechanical vibrator used by Heinrich Hertz to demonstrate the existence of electromagnetic waves. The idea was to retard the rate of rise of voltage across the switch as the switch opened, which in turn, suppressed arcing and limited the life of the contacts.

Because switching of inductive loads is intrinsic to most power conversion, a great many schemes have been advanced for "commutation aids"—circuits that reduce the loss or stress on a switch while turning on or off. These range from a wide variety of snubber circuits, soft switching using resonant transitions, zero current switching (ZCS) resonant converters to ZCS and zero voltage switching (ZVS) quasi-resonant circuits. There are many possible routes to achieve reduced switching stress and/or loss. In this discussion we will take a look at the history of one approach. We will cover other approaches in subsequent articles.

"ZVS using resonant transitions" is an active topic among design engineers. The latest round of interest is relatively recent, and many think the technique is something new. Yet, resonant transition switching is an idea with a long history in power conversion.

Radio equipment was widely used in vehicles beginning in the 1920's. Most of these early vehicles could only provide low voltage DC (6-24 V) power sources. Unfortunately, the vacuum tube technology of the day required the use of DC voltages of 100 V or more. A common way to provide high voltages was to employ a mechanical vibrator to chop the input DC to make AC, pass it through a step-up transformer, and then rectify and filter it on the secondary.

An example of a DC-DC converter is given in *figure 1*. This figure was taken from the 1947 Mallory Handbook^[1], but represents a technology that matured in the late 1920's and early 1930's. This circuit is the direct predecessor to the transistor squarewave inverters created in the 1950's. Much of the vibrator converter technology was incorporated into the

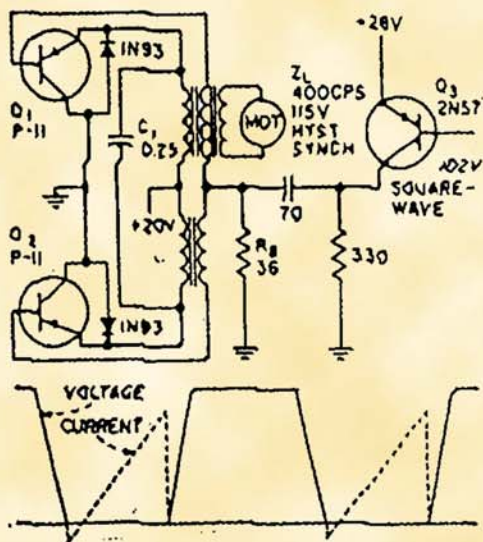


Fig. 3 Published in 1958

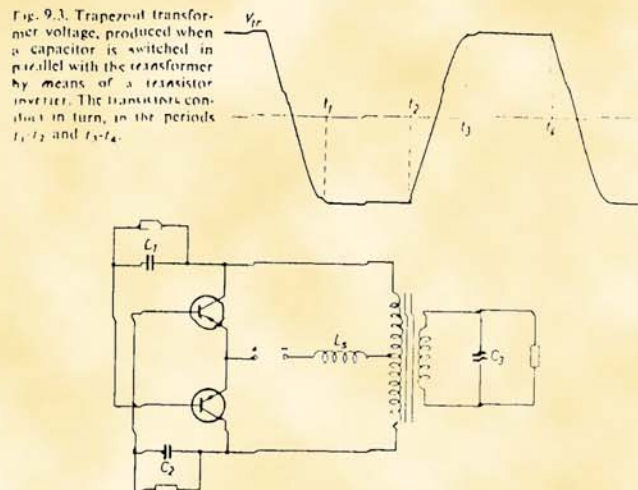


Fig. 4 Published in 1959

new transistor inverters. Vibrator inverters are one of the grandparents of modern DC-DC converters.

Notice that in *figure 1* there is a capacitor (referred to as the “timing” capacitor) placed across either the primary or the secondary windings of the transformer. This capacitor, along with transformer leakage and magnetizing inductances, provided resonant transition switching that greatly extended the vibrator contact life by suppressing arcing of the contacts. In *Figure 2*, typical circuit waveforms^[1] show that this example exactly reproduces modern resonant transition switching. *Figure 3* shows that the transition is the first part of a resonant ringing waveform. The fact that a deadtime (t_2 & t_4) was deliberately introduced to allow for resonant transition switching is clearly shown.

The discussion in the handbook goes on to point out the effects of deadtimes that are too small and too large. The length of the deadtime was controlled by the inertia of the reed, which had a small weight on it, and the spacing of the contacts. It becomes obvious that the concept of resonant transition switching was clearly understood 70 years ago.

Another set of contacts were provided to rectify the output in place a vacuum tube rectifier in some inverters. This is an early example of synchronous rectification, which is another hot topic today. Using vibrators in automobile radios persisted into the 1960's until all vacuum tubes were replaced with transistors operating directly from 12 V DC.

When power transistors became available in the mid-1950's, vibrators were replaced with transistors with anti-parallel diodes. *Figure 3* represents this with representative current and voltage waveforms. Note that the switch current was deliberately made negative at switch turn-on (inductive load), with the current flowing through the anti-parallel diode to provide zero-voltage turn-on. A capacitor was used along with the transformer inductances to provide resonant transition switching. These figures are taken from a 1958 Electronics magazine article^[2] that specifically addresses the issue of increasing switching efficiency by using what we now refer to as “soft-switching”.

Only Need One Topology?

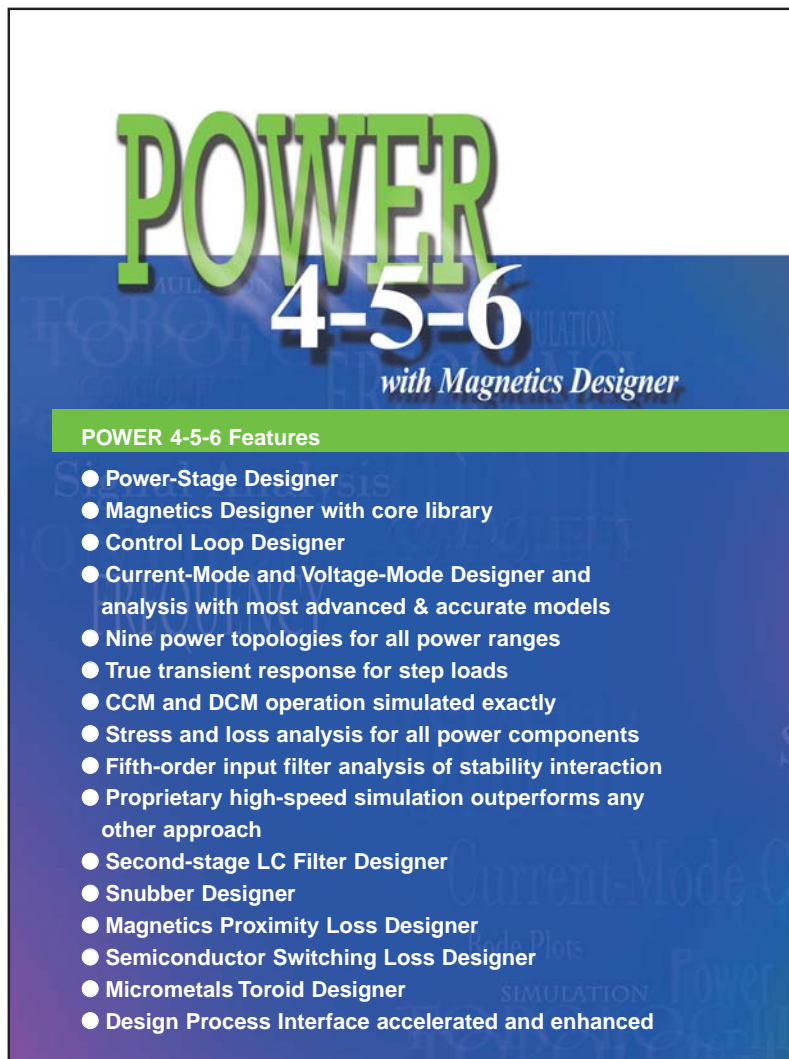
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The soft switching theme appears again in three editions (1959, 1962 & 1971) of the Philips Fluorescent Lamp book^[3]. Figure 4 shows an example of a fluorescent lamp ballast. In this example the resonant transition capacitors are connected across the transistors, as is present practice, and a dead-time is provided in switch conduction. There is also a separate series inductor and additional capacitance on the transformer secondary.

The present renaissance in soft switching for power converters appears in 1981. In April of that year, a paper by Goldfarb^[4] demonstrated the use of the transformer magnetizing inductance to “recover the charge on the snubber capacitors” in a full bridge switching converter. Dead-time for resonant transitions usage was shown. In September of 1981, Carsten^[5] presented a paper using an active clamp in a forward converter which used both the magnetizing and leakage inductances for soft switching. These papers seemed to spark interest in the technique. Since that time, there have been many, many more papers on the subject.

Vibrator and transistor inverters were not the only applications for soft switching. Beginning in the 1930's, inverters using thyratrons, grid controlled mercury arc tubes and ignitrons were in common use. These circuits all used switching commutation aids.

When thyristors become available in the late 1950's, the earlier technology for thyratrons, ignitrons and magnetic amplifiers was adapted for the new devices. Over a period of 50 years almost every conceivable commutation circuit was examined. Commutation using an auxiliary switch, of which much has recently been written, is a very old trick that has been well explored in an amazing variety of variations beginning more than 70 years ago.

The term “soft commutation” was used by Morgan^[6] in a 1966 IAS transactions paper. Morgan pointed out the advantages of reduced switching loss, di/dt , dv/dt and EMI associated with controlling the commutation transition time. Again, the use of resonant circuits for soft switching was demonstrated. He also pointed out that there were other circuits that performed similarly in addition to the one he was presenting.

We can extend the term “soft switching” to cover a wide variety of snubber circuits that are intended to reduce switching loss. For example, the conventional R-C-diode snubbers can be designed to provide very soft, low-loss turn off by selecting an appropriate capacitor value. An analysis of a typical soft switching circuit, such as the phase-shifted bridge circuit with a primary inductor, shows that at turn-off, the behavior is exactly the same as a normal R-C-diode snubber. The turn-off loss in the switches is described by the same equations as the R-C-diode snubber.

One small mystery remains in this historical survey. It has been difficult to pin down the early use of the phase-shifted full bridge. It was apparently used in the 1960's for sonar transducer drivers, but no confirmation of this has been found by this author. Anyone familiar with early references are invited to respond.

The need for commutation aids when using switches with inductive loads has been obvious from the beginning. If for no other purpose, the arcing of the contacts or the failure of the switches would bring this to the attention of the experimenter. This requirement drove the invention of most of the techniques we now implement. Resonant transition switching is certainly in that category.

References

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