High voltage converters

High voltage converter—1000V\textsubscript{OUT}, nonisolated
Photomultiplier tubes, ion generators, gas-based detectors, image intensifiers and other applications need high voltages. Converters frequently supply these potentials. Generally, the limitation on high voltage is transformer insulation breakdown. A transformer is almost always used because a simple inductor forces excessive voltages on the semiconductor switch. Figure 4.49’s circuit, reminiscent of Figure 4.11’s basic flyback configuration, is a 15V to 1000V\textsubscript{OUT} converter. The LT1072 controls output by modulating the flyback energy into L1, forcing its feedback (FB) pin to 1.23V (the internal reference value). In this example loop compensation is heavily overdamped by the V\textsubscript{C} pin capacitor. L1’s damper network limits flyback spikes within the VSW pin’s 75V rating.

**Fully floating, 1000V\textsubscript{OUT} converter**

Figure 4.50 is similar to Figure 4.49 but features a fully floating output. This provision allows the output to be referenced off system ground, often desirable for noise or biasing reasons. Basic loop action is as before, except that the LT1072’s internal error amplifier and reference are replaced with galvanically isolated equivalents. Power for these components is bootstrapped from the output via source follower Q1 and its 2.2M ballast resistor. A1 and the LT1004, micropower components, minimize dissipation in Q1 and its ballast. Q1’s gate bias, tapped from the output divider string, produces about 15V at its source. A1 compares the scaled divider output with the LT1004 reference. The error signal, A1’s output, drives the optocoupler. Photocurrent is kept low to save power. The opto-coupler output pulls down on the pin, closing a loop. Frequency compensation at the V\textsubscript{C} pin and A1 stabilizes the loop.

![Figure 4.49 • Nonisolated 15V to 1000V Converter](image-url)
Figure 4.50 • Isolated Output 15V to 1000V Converter

The transformers isolated secondary and optical feedback produce a regulated, fully galvanically floating output. Common mode voltages of 2000V are acceptable.

**20,000V\text{CMV}** breakdown converter

Figure 4.50’s common mode breakdown limits are imposed by transformer and opto-coupler restrictions. Isolation amplifiers, transducer measurement at high common mode voltages (e.g., winding temperature of a utility company transformer and ESD sensitive applications) require high breakdowns. Additionally, very precise floating measurements, such as signal conditioning for high impedance bridges, can require extremely low leakage to ground.

Achieving high common mode voltage capability with minimal leakage requires a different approach. Magnetics is usually considered the only approach for isolated transfer of appreciable amounts of electrical energy. Transformer action is, however, achievable in the acoustic domain. Some ceramic materials will transfer electrical energy with galvanic isolation. Conventional magnetic transformers work on an electrical-magnetic-electrical basis using the magnetic domain for electrical isolation. The acoustic transformer uses an acoustic path to get isolation. The high voltage breakdown and low electrical conductance associated with ceramics surpasses isolation characteristics of magnetic approaches. Additionally, the acoustic transformer is simple. A pair of leads bonded to each end of the ceramic material forms the device. Insulation resistance exceeds $10^{12}\Omega$, with primary-secondary
capacitances of 1pF to 2pF. The material and its physical configuration determine its resonant frequency. The device may be considered as a high Q resonator, similar to a quartz crystal. As such, drive circuitry excites the device in the positive feedback path of a wideband gain element. Unlike a crystal, drive circuitry is arranged to pass substantial current through the ceramic, maximizing power into the transformer.

In Figure 4.51, the piezo-ceramic transformer is in the LT1011 comparators positive feedback loop. Q1 is an active pull-up for the LT1011, an open-collector device. The 2k-0.002µF path biases the negative input. Positive feedback occurs at the transformers resonance, and oscillation commences (Trace A, Figure 4.52 is Q1’s emitter). Similar to quartz crystals, the transformer has significant harmonic and overtone modes. The 100Ω-470pF damper suppresses spurious oscillations and “mode hopping.” Drive current (Trace B) approximates a sine wave, with peaking at the transitions. The transformer looks like a highly resonant filter to the resultant acoustic wave propagated in it. The secondary voltage (Trace C) is sinusoidal. Additionally, the transformer has voltage gain. The diode and 10µF capacitor convert the secondary voltage to DC. The LT1020 low quiescent current regulator gives a stabilized 10V output. Output current for the circuit is a few milliamperes. Higher currents are possible with attention to transformer design.

Figure 4.51 • 15V to 10V Converter with 20,000V Isolation
Inductors are used in converters because they can store energy. This stored magnetic energy, released and expressed in electrical terms, is the basis of converter operation. Inductors are not the only way to store energy with efficient release expressed in electrical terms. Capacitors store charge (already an electrical quantity) and as such, can be used as the basis for DC/DC conversion. Figure 4.53 shows how simple a switched-capacitor based converter can be (the fundamentals of switched-capacitor based conversion are presented in Appendix B, “Switched-Capacitor Voltage Converters—How They Work”). The LT1054 provides clocked drive to charge C1. A second clock phase discharges C1 into C2. The internal switching is arranged so C1 is “flipped” during the discharge interval, producing a negative output at C2. Continuous clocking allows C2 to charge to the same absolute value as C1. Junction and other losses preclude ideal results, but performance is quite good. This circuit will convert $V_{IN}$ to $-V_{OUT}$ with losses shown in Figure 4.54. Adding an external resistive divider allows regulated output (see Appendix B).
With some additional steering diodes this configuration can effectively run “backwards” (Figure 4.55), converting a negative input to a positive output. Figure 4.56’s variant gives low dropout linear regulation for 5V and -5V outputs from 6V IN. The LT1020-based dual output regulation scheme is adapted from Figure 4.8. Figure 4.57 uses diode steering to get voltage boost, providing ≈2V IN. Bootstrapping this configuration with Figure 4.54’s basic circuit leads to Figure 4.58, which converts a 5V input to 12V and -12V outputs. As might be expected output current capacity is traded for the voltage gain, although 25mA is still available. Figure 4.59, another boost converter, employs a dedicated version of Figure 4.58 (the LT1026) to get regulated ±7V from a 6V input. The LT1026 generates unregulated ±11V rails from the 6V input with the LT1020 and associated components (again, purloined from Figure 4.8) producing regulation. Current and boost capacity are reduced from Figure 4.58’s levels, but the regulation and simplicity are noteworthy. Figure 4.60 combines the LT1054’s clocked switched-capacitor charging with classical diode voltage multiplication, producing positive and negative outputs. At no load ±13V is available, falling to ±10V with each side supplying 10mA.
Figure 4.55 • Switched-Capacitor -VIN to +VOUT Converter

Figure 4.56 • High Current Switched-Capacitor 6V to ±5V Converter

Figure 4.57 • Voltage Boost Switched-Capacitor Converter
Figure 4.58 • Switched-Capacitor 5V to ±12V Converter

Figure 4.59 • Switched-Capacitor Based 6V to ±7V Converter

Figure 4.60 • Switched-Capacitor Charge Pump Based Voltage Multiplier
High power switched-capacitor converter

Figure 4.61 shows a high power switched-capacitor converter with a 1A output capacity. Discrete devices permit high power operation.

The LTC1043 switched-capacitor building block provides non-overlapping complementary drive to the Q1-Q4 power MOSFETs. The MOSFETs are arranged so that C1 and C2 are alternately placed in series and then in parallel. During the series phase, the 12V supply current flows through both capacitors, charging them and furnishing load current. During the parallel phase, both capacitors deliver current to the load. Traces A and B, Figure 4.62, are the LTC1043-supplied drives to Q3 and Q4, respectively. Q1 and Q2 receive similar drive from Pins 3 and 11. The diode-resistor networks provide additional non-overlapping drive characteristics, preventing simultaneous drive to the series-parallel phase switches. Normally, the output would be one-half of the supply voltage, but C1 and its associated components close a feedback loop, forcing the output to 5V. With the circuit in the series phase, the output (Trace C) heads rapidly positive. When the output exceeds 5V, C1 trips, forcing the LTC1043 oscillator pin (Trace D) high. This truncates the LTC1043’s triangle wave oscillator cycle. The circuit is forced into the parallel phase and the output coasts down slowly until the next LTC1043 clock cycle begins. C1’s output diode prevents the triangle down-slope from being
affected and the 100pF capacitor provides sharp transitions. The loop regulates the output to 5V by feedback controlling the turn-off point of the series phase. The circuit constitutes a large scale switched-capacitor voltage divider which is never allowed to complete a full cycle. The high transient currents are easily handled by the power MOSFETs and overall efficiency is 83%.

![Figure 4.62 • Waveforms for Figure 4.61](image)

**References**


5. Williams, J., “Power Conditioning Techniques for Batteries,” Linear Technology Corporation, Application Note 8

6. Tektronix, Inc., CRT Circuit, Type 453 Operating Manual, p. 3-16

