Some surface-mount capacitors exhibit acoustic noise when operated at frequencies in the audio range. A recent design uses 10-μF, 35V X5R 1206 ceramic capacitors that produce noticeable acoustic noise. To quiet such a board, you can use acoustically quiet capacitors from manufacturers such as Murata (www.murata.com) and Kemet (www.kemet.com). Unfortunately, they tend to cost more than standard parts. Another option is to use capacitors with a higher voltage rating, which could reduce the noise. Those parts may also be more expensive than standard capacitors. A third path is to make a physical change to the PCB (printed-circuit board).

A ceramic capacitor expands when you apply a voltage and contracts when you reduce the voltage. The PCB flexes as the capacitor changes size because the ends of the capacitor mechanically couple to the PCB through solder (Reference 1).

Figure 1a shows a capacitor with no applied voltage, and Figure 1b shows an exaggerated condition of PCB flexing when you apply voltage to a capacitor. Applying the voltage makes the PCB operate as a speaker. Keeping that fact in mind, consider two methods for improving the situation. The first technique is relatively simple: If your circuit uses one capacitor, replace it with two in parallel, each with half the capacitance of the noisy capacitor. This approach lets you place a capacitor on top of the board and the other on the bottom of the board; the capacitors lie directly above each other, and their orientations are the same. As the upper capacitor tries to flex the board down, the lower capacitor tries to flex the board up. These two stresses tend to cancel each other, and the PCB generates little sound.

Adding a second capacitor increases cost but not as much as replacing the noisy capacitor with one that might not create noise. A ceramic capacitor from Digi-Key (www.digikey.com) sells for approximately 27 cents (1000). A quieter KPS-series part from Kemet costs approximately $1.50. The second method involves making a slot in the PCB near each end of the capacitor (Figure 2). When the capacitor expands and contracts, it flexes only a small portion of the PCB, which should reduce the noise.

A test with five 10-μF, 25V ceramic capacitors connected in parallel showed that putting three capacitors on top of the PCB and two on the bottom reduces the noise by 14 dBA (acoustic decibels). Routing a slot on both sides of the five capacitors reduces the noise by 15 dBA. Both are substantial noise reductions. A Murata JG8-series capacitor reduces the noise by 9.5 dBA. Combining these techniques should further reduce the noise.

**REFERENCE**

Function generator has variable frequency

Adolfo Mondragon, Electrolux Products, Juarez, Mexico

The Exar (www.exar.com) XR-2206 function-generator IC can generate square, triangular, and sinusoidal signals with low distortion. Its output frequency is inversely proportional to the components in an RC network, according to the formula $F = 1/RC$.

Use a potentiometer as the resistor component to provide a frequency variation similar to a logarithmic scale. To change this behavior, the manufacturer’s data sheet recommends connecting a resistor network to a variable external voltage source. The voltage should be stable and vary from 0 to almost 3V.

Instead of using an external voltage, the circuit described here uses an internal reference voltage of approximately 3V at Pin 7 of the XR-2206. With this internal reference, the circuit requires no voltage regulators—not even in the power supply. The circuit requires a power supply with only a 12V, 500-mA center-tapped transformer, a bridge rectifier, and two filter capacitors (Figure 1). You can define the frequency equations using Figure 2 as a reference.

When $V_x$ is 0V, you determine the frequency using $F = 1/RC$. The current trough, $I_R$, equals $3/R$, where 3 is the voltage reference in Pin 7. From this equation and resolving the recipro-

Figure 1 The waveform-generation circuit has a frequency of 1 Hz to 100 kHz in five scales.
Power supply accepts wide input-voltage range

Jim Windgassen, Northrop Grumman Undersea Systems, Annapolis, MD

The switching power supply in Figure 1 produces 3.3V dc from an input voltage of 2.5 to 20V dc with high efficiency. The circuit operates at an input voltage as low as 1.5V once it starts from a minimum of 2.5V dc, allowing the switcher to fully discharge a pair of alkaline cell batteries nearing end of life. The power supply can also run efficiently off higher input voltages, such as 12V automotive power. The heart of the circuit is a SEPIC (single-ended-primary-inductance-converter)-based switching power supply, which provides an output voltage greater than or less than the input voltage (Reference 1).

This power supply includes bootstrap circuitry comprising IC1, an LT3008

![Figure 1](image)

NOTES: INDUCTOR MODEL IS BASED ON 4.7-µH WÜRTH 744878004 DUAL INDUCTOR FOR 600 kHz. L1 AND L2 ARE WOUND ON A COMMON CORE.

Figure 1 The power supply can provide a 3.3V output from 2.5 to 20V input voltages. It needs 2.5V to start.
voltage regulator; Schottky diode $D_1$; and capacitor $C_2$. It needs a minimum of 2.5V to start. Voltage regulator IC$_1$ provides 2.5V to start SEPIC controller IC$_2$. Once the output voltage of the SEPIC power supply reaches its normal output voltage of 3.3V, $D_1$ lets the output power of the switcher flow back to power IC$_2$. Once this action occurs, IC$_1$ drops out of the circuit because the voltage at its output is above its setpoint voltage. The converter’s own output now powers IC$_2$, and the regulator’s internal circuitry prevents backflow of power through IC$_1$. MOSFET Q$_1$ has low threshold voltage, appropriate on-resistance to provide current feedback to IC$_2$, and a maximum drain-to-source voltage of 30V to allow for operation up to a 20V input.

The bootstrap circuit allows the converter to run from very low input voltages by maintaining the input voltage to IC$_2$, and it increases efficiency at high input voltages by eliminating the use of IC$_2$’s internal linear voltage regulator. Figure 2 shows the efficiency of the prototype power supply at both 50- and 500-mA loads. The power supply’s efficiency is consistent over a range of operating voltages because of the bootstrap-pumping circuit.

Because the circuit uses a low-threshold-voltage MOSFET, the switch, keeping the gate drive voltage low, reduces the total charge that must go into and out of the MOSFET gate, further improving efficiency. SEPIC controller IC$_2$ normally uses its internal low-dropout capability to generate an operating voltage of 5V from the input. Running IC$_2$ from the bootstrapped output reduces IC$_2$’s operating voltage to approximately 3V, which also limits the drive voltage to Q$_1$’s gate.

Table 1 lists the key components for the power supply, including an appropriate commercially available coupled inductor. The PCB (printed-circuit-board) design and the choice of coupled inductors for this power supply are critical for good performance. For the power supply to achieve high efficiency at low input voltages and high output current, the coupled inductor must have low-resistance windings, and the high current tracks should use wide copper pours to minimize resistance.

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**Figure 2** The power supply’s efficiency is consistent over 50- and 500-mA loads.

**Figure 3** The complete power supply fits onto a 23×15×3.5-mm PCB.

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**Table 1: Key Parts for Power Supply**

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input capacitor</td>
<td>22-μF, 25V, 10%-tolerance, 1210-size X5R ceramic capacitor</td>
<td>AVX</td>
<td>12063D106KAT2A</td>
</tr>
<tr>
<td>Output capacitor</td>
<td>100-μF, 6.3V, 1206-size X5R ceramic capacitor</td>
<td>Kemet</td>
<td>C1206C107M9PACTU</td>
</tr>
<tr>
<td>Coupled inductor</td>
<td>4.7-μH coupled-inductor Cuk SEPIC</td>
<td>Würth</td>
<td>744878004</td>
</tr>
<tr>
<td>Bootstrap low-dropout regulator</td>
<td>Regulated-low-dropout-adjustment, 20-mA, 6-DFN-packaged IC</td>
<td>Linear Technology</td>
<td>LT3008EDC#TRMPBF</td>
</tr>
<tr>
<td>SEPIC controller</td>
<td>10-MSOP-packaged current-mode-IC controller</td>
<td>Linear Technology</td>
<td>LTC1871EMS#PBF</td>
</tr>
<tr>
<td>MOSFET</td>
<td>30V, 5A, N-channel microMOSFET</td>
<td>Fairchild Semiconductor</td>
<td>FDMA430NZ</td>
</tr>
<tr>
<td>Bootstrap diode</td>
<td>SOD-523-packaged, 40V Schottky diode</td>
<td>Diodes Inc</td>
<td>ZLLS350TA</td>
</tr>
<tr>
<td>SEPIC diode</td>
<td>2A, 30V Schottky power diode</td>
<td>Diodes Inc</td>
<td>DFLS230L-7</td>
</tr>
</tbody>
</table>
losses and unwanted inductance. A prototype of the power supply measures 23×15×3.5 mm (Figure 3). It uses a custom coupled inductor, but you can choose from many off-the-shelf coupled inductors available from BH Electronics (www.bhelectronics.com), Coilcraft (www.coilcraft.com), and Würth Elektronik (www.we-online.com). You can download the Linear Technology LTSpice code for this circuit from the online version of this Design Idea at www.edn.com/110217dia.

**REFERENCE**


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**Circuit lets you test capacitors**

Raju R Baddi, Tata Institute of Fundamental Research, Maharashtra, India

Electrolytic capacitors tend to leak with time. The circuit in Figure 1 lets you test capacitors and decide whether they’re worth using. You can set the constraint on the leakiness through the values of $C_{REF}/R_{REF}$. The values in the figure are typical for general testing of all capacitors, from 1-nF ceramic versions to 1000-μF electrolytic types. The value of $C_{REF}$ in the circuit is near the value of the test capacitor, $C_X$. You can also choose $R_{REF}$ by a rotary-switching arrangement, to be greater than or less than 22 MΩ.

When the pushbutton switch closes, capacitors $C_{REF}$ and $C_X$ charge through their respective PNP transistors. When the switch opens, the capacitors begin to discharge. $C_{REF}$, assuming that it is in good condition, has an additional discharge external resistance, $R_{REF}$. The capacitor under test, $C_X$, discharges through its internal resistance. If the leakage in $C_X$ is greater than that of $C_{REF}$ through $R_{REF}$, then its voltage will fall faster. Thus, the voltage at the op amp’s noninverting input will be lower than at its inverting input, forcing the op amp’s output low and lighting the red LED. This LED indicates that the test capacitor leaks. Testing of the circuit reveals that even a 1-nF ceramic capacitor holds against the reference. Check the voltage rating on the test capacitor to make sure that it is higher than the voltage to which it will be charged—in this case, $V_{SUPPLY}$ is −1.8V.

The LF357 has a minimum supply voltage of 10V, but the testing took place at only 6V to allow a low upper-limit voltage for the test capacitor. Make sure the capacitor has a FET or a MOS-FET input stage.

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Figure 1 Electrolytic capacitors tend to leak over time, but this circuit lets you test them and decide whether they’re worth using.