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Analog - Resonant Bridge Oscillators for Piezoelectric Buzzers

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Associated Project: Yes

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Software Version: PSoC® Designer™ 5.4

Related Application Notes: AN2041

To get the latest version of this application note, or the associated project file, please visit http://www.cypress.com/go/AN2282.

This Application Note shows an example of a piezoelectric resonator with an excitation throughout its frequency range using the PSoC® 1 device. This technique allows the user to obtain the maximum output power for a given supply voltage. The oscillators have no CPU overhead during operation.

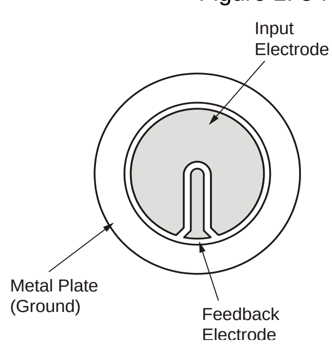
Contents

Introduction

Piezoelectric buzzers are widely used in various embedded systems including alarm systems, vending machines, kiosks, access control devices, entertainment systems, home appliances, and medical equipment. In most cases, only a 3.0- to 5.0-volt supply is available, which makes it more difficult to obtain a loud audio signal because piezoelectric materials usually require higher operating voltages. Combining a bridge buzzer together with resonant frequency excitation renders higher power supply voltage usage and increases the generated sound pressure level.

Let us consider some characteristics of a piezoelectric resonator (buzzer) and its excitation modes. Piezoelectric resonators are produced with either 2 pins or 3 pins (with an additional feedback pin).

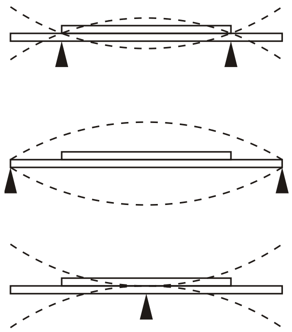
Figure 1. 3-Pin Buzzer



Buzzers with 3 pins (see Figure 1) are manufactured for resonance oscillators specifically; the feedback signal can be used for switching excitation voltage. There are resonators without the separate feedback electrode; they are called 2-pin resonators.

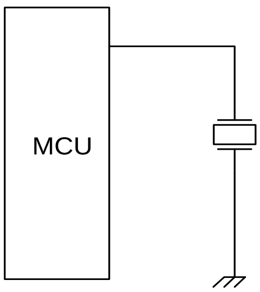
Applying external voltage causes distortion of the piezoelectric material. The resonant frequency depends on the plane support placement. Figure 2 illustrates several possible support placements and plane distortions.

Figure 2. Plane Oscillations for Different Support Placements (Marked as Vertical Arrows)



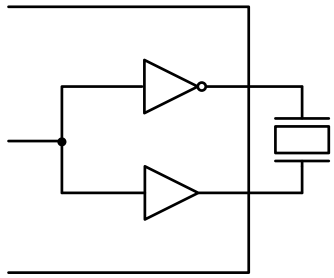
There are several piezoelectric buzzer excitation modes applicable to microcontrollers (see Figure 3). The simplest mode is direct connection of the buzzer to the PSoC device's output port pin and ground. In this mode, the excitation signal changes between zero and the power supply level, and plane distortions are one-sided.

Figure 3. Simplest Resonator Connection



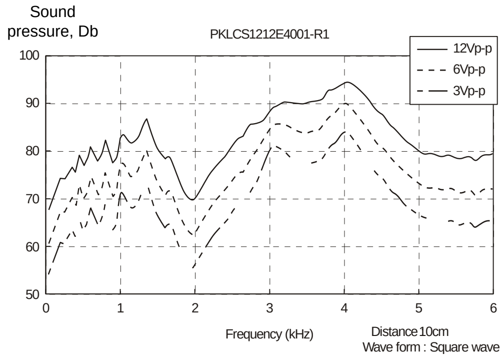
A bridge resonator can be used to increase the output power. The piezoelectric buzzer is connected in the bridge diagonal. To implement the PSoC device, the two output drivers should be in strong mode sourced by paraphase signals, which can be formed from one source with the use of a follower and an inverter. Figure 4 illustrates the simplified schematic of this connection. The PSoC device's row lookup tables (LUTs) are ideal for forming these signals.

Figure 4. Bridge Resonator Excitation



The piezoelectric buzzers have clearly identified resonant properties. Figure 5 illustrates the dependence of sound pressure versus excitation frequency for the PKLCS1212E4001-R1 buzzer from Murata.

Figure 5. Sound Pressure versus Excitation Frequency Sample



As seen from Figure 5, to achieve the maximum sound pressure level, the excitation frequency should equal the resonant frequency. This frequency depends on:

- Resonator plane support placements
- Piezoelectric material thickness
- Plane geometry characteristics
- Resonator chamber parameters
- Ambient temperature
- Driving waveform type

Taking into account all of these factors complicates the resonant frequency calculation because some of the parameters are not well defined. Therefore, the best method to obtain the frequency is by providing a driver circuit that automatically oscillates at the buzzer's local resonant frequency. This Application Note demonstrates possible solutions on how to do this.

The simplest and most convenient setup is to use a 3-pin resonator (or a 2-pin resonator with a separate feedback electrode). Both resonators send a feedback signal to the main electrodes, which drive the voltage control. The oscillator for the 2-pin resonator can be created by use of the resonator's current sensor to separate the feedback signal. For stability, the following conditions should be met in any oscillator:

- For the phase balance condition, the loop phase shift at oscillation frequency should be equal to 360 degrees.
- The open-loop gain on the oscillation frequency should be more than 0 -dB.

The feedback resonator output couples capacitively to the plane. Therefore, the voltage signal on the feedback pin is phase-delayed at 90 degrees, relative to the main pins at the resonant frequency.

In other words, the oscillator plates reach the self-maximum deviation in time equal to 1/4 of the oscillator's resonant frequency period. The moment the maximum voltage is attained on the feedback, the electrode is optimal for reversing the voltage sign on the main resonator's electrodes. The best method to form the driving signal is zero-crossing analysis of the 90 degree shifted feedback electrode signal. There are suitable alternative solutions for the PSoC device to implement the phase shifter:

- Use a second order low-pass filter (LPF), where the roll-off frequency is approximately equal to the resonator resonant frequency.
- Use the switched capacitor integrator.

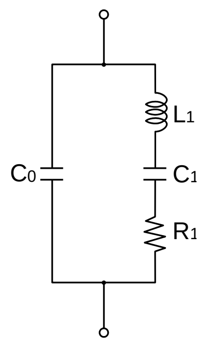
There are additional high-frequency resonances for the piezoelectric buzzer. To prevent oscillations at these higher frequencies, the open-loop gain for these frequencies should be less than 0 dB.

The piezoelectric resonator system can be modeled as a serial resonance circuit with parallel capacitance in the resonant frequency domain (see Figure 6). A real resonator has several resonances; a more accurate model can include several resonant circuits to simulate each resonance. The circuit shown in Figure 6 has two resonance frequencies:

- Series, when the resonator's current is in phase with the applied voltage.
- Parallel, when the current is shifted 90 degrees for the relative applied voltage.

The resonant oscillator can use either series or parallel resonance frequencies.

Figure 6. Simple Resonator-Equivalent Circuit

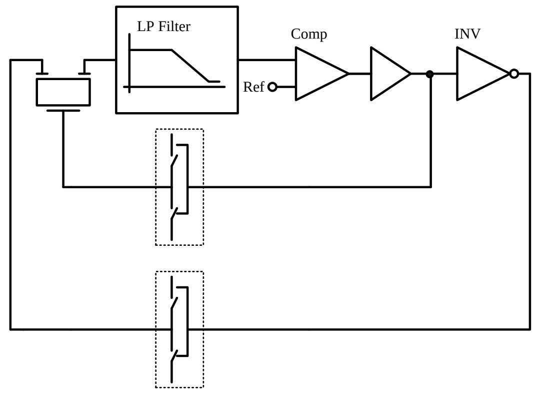


The following sections describe several practical resonator oscillator circuits for 3-pin and 2-pin (without separate feedback pin) buzzers using the series or parallel resonances.

3-Pin Oscillator

The oscillator's functional diagram is represented in Figure 7. The oscillator consists of the buzzer, a LPF, a threshold comparator, and an output buffer to drive the resonator.

Figure 7. 3-Pin Oscillator

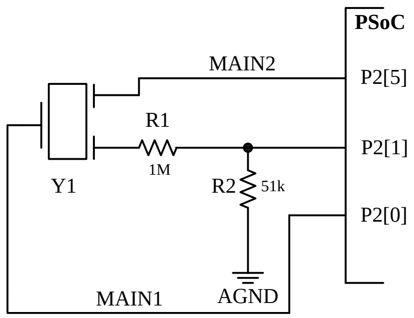


The buzzer's feedback output electrode signal through a matching circuit is passed to the second order LPF; and the amplified and phase-delayed signals are passed to the comparator. The digital comparator signal is routed via inverting/non-inverting buffers to the buzzer, closing the feedback loop. The oscillator operates at series resonance.

As an alternative solution, the integrator can be used as a phase shifter instead of a LPF. The integrator meets the 90-degree phase-delay and gain reduction at high-frequencies. This solution requires slightly less hardware resources.

Regardless of implementation details, the external-component schematic is the same for the filter-based or integrator-based 3-pin resonant oscillator and is represented in Figure 8.

Figure 8. 3-Pin Resonant Oscillator Schematic



The feedback electrode output voltage is greater than the typical power supply level. The resistors R_1 and R_2 combined with the switched capacitor block input stage impedance form the voltage divider and limit the PSoC device's input pin current. Note that the resistor R_2 does not have to be used because the switched capacitor block input acts as a resistor connected to the PSoC device's AGND. The rest of the oscillator circuit is implemented inside the PSoC device.

The PSoC device's internal user module placement for integrator- or filter-based implementation is shown in Figure 9 and Figure 10, accordingly.

The LPF's roll-off frequency must be set close to the nominal oscillation frequency. Another method to obtain this frequency is to experiment with changing the column clock divider and obtaining the maximum voltage level on the resonator feedback electrode. The filter's gain must be selected empirically to provide reliable generation at all power supply levels, because buzzer manufacturers do not specify the feedback electrode gain factor.

When the integrator is used as a phase shifter, the integrator's gain is calculated from the following equation:

$$Gain = \frac{1}{s} \cdot f_s \cdot \frac{C_a}{C_f} \qquad \text{Equation 1}$$

C_a and C_f are the values of the switched capacitor blocks, and f_s is the column's internal sample frequency.

The main concepts of the SCBlock User Module integrator are described in Application Note *AN2041 – Understanding PSoC® 1 Switched Capacitor Analog Blocks*. f_s and $\frac{C_a}{C_f}$ should be selected to satisfy the amplitude balance condition at a frequency that is very close to the piezoelectric resonator's resonance frequency. The integrator provides a 90-degree phase-delay for all of the frequencies except when it enters saturation. Both the LPF and the integrator provide gain deterioration as the frequency increases, thus preventing parasitic oscillations at high frequencies.

The DigBuf User Module is used to connect the analog comparator bus to the global output bus. This bus is routed to external pins via the row LUTs with the follower and inverter functions.

Figure 9. 3-Pin Oscillator with Internal LPF

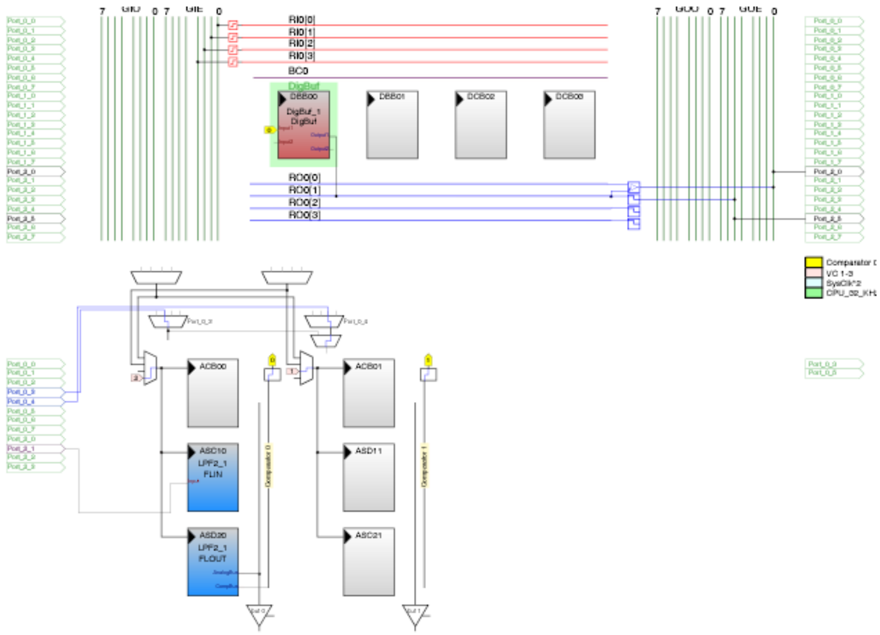
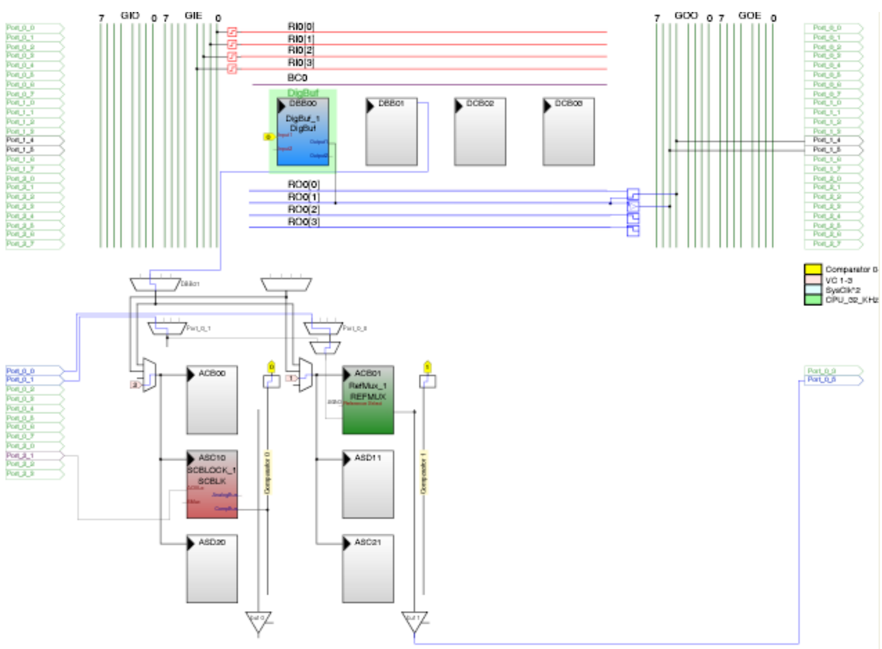


Figure 10. 3-Pin Oscillator with Internal Integrator



The oscillator was built and tested and the waveforms recorded. The scope images are shown in figures 14 through 17 of Appendix A. Scope Images. These figures show filter settings when the roll-off frequency is equal to, much below, and higher than optimal. The feedback electrode signal amplitude is reduced in the last two setups, reflecting the reduced sound pressure. Note that the feedback electrode signal swing is proportional to the amplitude of resonator plane oscillation.

The main resonant frequency for the specified oscillator is equal to 3.45 kHz. It is important that the frequency of the designed generator is very close to the resonant frequency but not exactly equal to it because the real phase-delay in filter-based or integrator-based implementation is not always precisely equal to 90 degrees for the preset filter clock value.

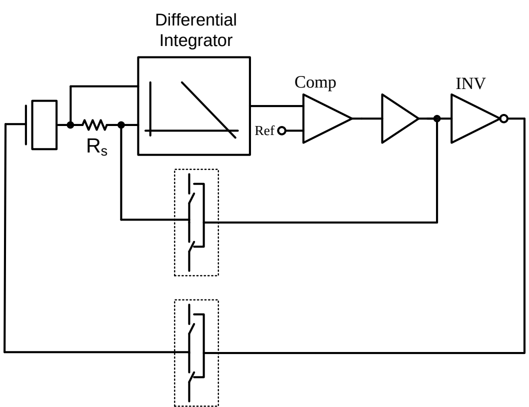
2-Pin Oscillator Excitation Modes

The examples below describe how to build the oscillator for series or parallel resonance frequencies. Only one external resistor is required for the resonator's current sense purposes; all of the other processes are implemented inside the PSoC device. The resistor is connected in series to the resonator and the current signal is separated with the use of an instrumentation amplifier, which is configured on the switched capacitor block.

Parallel Resonance Oscillator

The generator's functional diagram is represented in Figure 11.

Figure 11. 2-Pin Oscillator Excitation Mode Functional Diagram



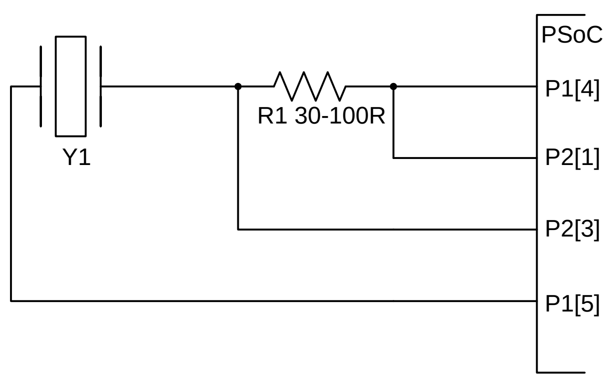
A 2-pin oscillator differs from a 3-pin oscillator because the feedback signal is obtained from the current sense resistor instead of a separate electrode, and the integrator is used as a phase shifter. The PSoC device's differential integrator on the SCBlock User Module is ideal for this purpose. The buzzer's driver should be switched when the current through the piezoelectric resonator reaches its maximum value. The integrator performs the phase shift. The output comparator detects when the current reaches its maximum value and switches the driving electrodes' polarity, causing the current to decrease. When the current through the resonator reaches its own minimum value, the resonator's voltage is reversed again.

The integrator's time constant should be set in such a way that it prevents saturation at the expected operating frequency and the current sense resistor signal value. This is achieved by changing the column clock value, and the relation between the input capacitors (C_a and C_b) and the feedback capacitor (C_f).

Note: Switching the buzzer's electrodes may create a short current ripple via the sense resistor due to the recharging of the piezoelectric buzzer's plane capacitance. Integrating this ripple shifts the integrator phase-delay from the expected 90 degrees. Therefore, the buzzer's integration time constant should be refined by testing for stable oscillation and verifying the output waveform with a scope.

Figure 12 illustrates the schematic of this implementation. The current sensor resistor value is determined by the piezoelectric buzzer's plane capacitance and should be within the range of 30- to 100-Ω.

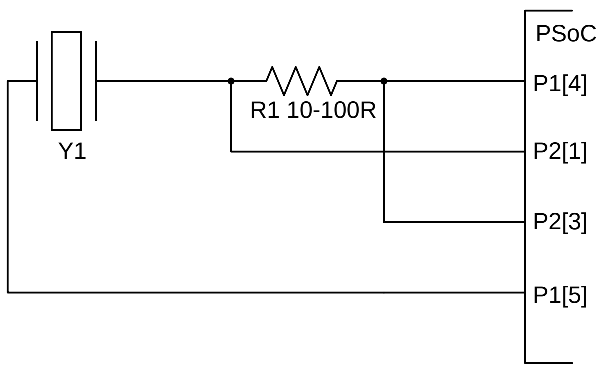
Figure 12. 2-Pin Oscillator Schematic - Parallel Resonance



Series Resonance Oscillator

The resonator's current is in-phase with the applied voltage in series resonance. The current's zero crossing should be used to reverse the piezoelectric resonator's voltage. There are several ways to build this type of an oscillator with the PSoC device. The simplest and optimal way uses the same hardware resources used in the parallel resonance oscillator shown in Figure 11. The difference between the parallel resonance oscillator and the series resonance oscillator is that the integrator's time constant is set much lower than the expected resonance period. This setup converts the differential integrator into the saturated instrumentation amplifier with a high differential gain. The schematic of the series resonance oscillator, shown in Figure 13, uses a slightly different pin layout (to achieve better signal stability) and different current sense resistor values.

Figure 13. 2-Pin Oscillator Schematic - Series Resonance



When the resonator's current reaches zero and the voltage polarity reverses, the instrumentation amplifier changes the output signal sign, which is detected by switching the switched capacitor block's zero-crossing comparator. The comparator changes the voltage polarity at the piezoelectric plane electrodes, which causes the current to increase through the resonator, thus matching the phase balance rule.

The scope images for parallel and series resonance are shown in Figure 18 and Figure 19 of Appendix A. Scope Images. A table listing all the associated projects and their description is in Appendix B. Projects.

Summary

Resonant bridge oscillators for piezoelectric buzzers were considered for 2-pin and 3-pin piezoelectric resonators in series and parallel resonance modes. Note that only 2-pin piezoelectric resonators operate at a precise resonant frequency, so there is no 90-degree phase shift, which varies with changes in frequency. The operational frequency for the other oscillators is very close to the resonant frequency and the reduction of the generated power pressure is insignificant.

The price of a 2-pin buzzer is essentially less than a 3-pin buzzer (we noticed the differences in several different distributors' catalogs). Therefore, a 2-pin buzzer in series resonance mode is the preferable, cost-friendly solution for most applications.

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Appendix A. Scope Images

Figure 14. 3-Pin Oscillator Waveforms
Filter Roll-Off Frequency is Optimal

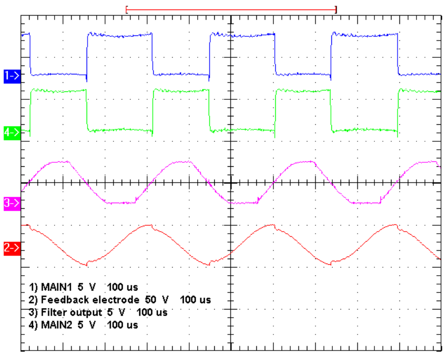


Figure 15. 3-Pin Oscillator Waveforms
Filter Roll-Off Frequency is less than Optimal

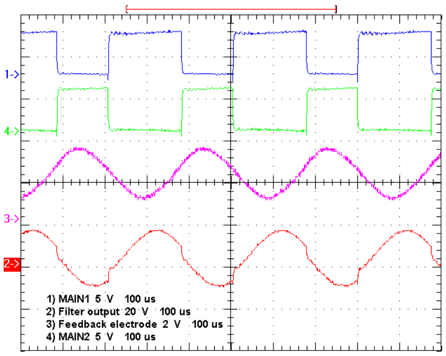


Figure 16. 3-Pin Oscillator Waveforms
Filter Roll-Off Frequency is greater than Optimal

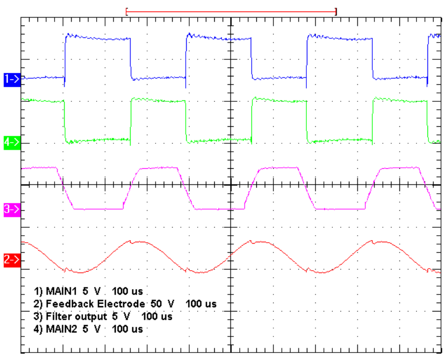


Figure 17. 3-Pin Oscillator Waveforms
Integrator Used as a Phase Shifter

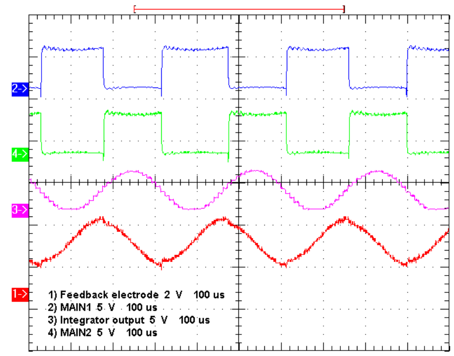


Figure 18. 2-Pin Oscillator Parallel Resonance Mode

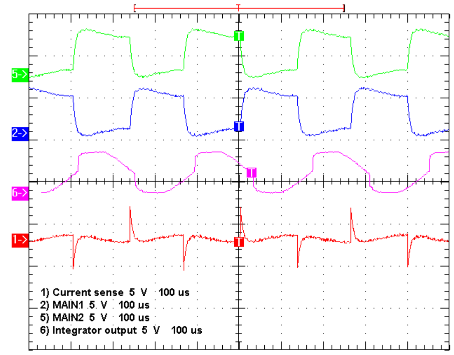
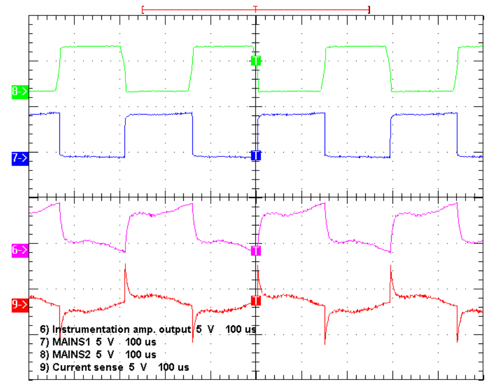


Figure 19. 2-Pin Oscillator Series Resonance Mode



Note MAIN1 and MAIN2 – main buzzer electrodes

Appendix B. Projects

Table 1. PSoC Projects

Project Name	Description
AN2282_3P_AGND	3-pin generator with AGND out to external port
AN2282_3P_FLT	3-pin generator with LPF
AN2282_3P_INT	3-pin generator with integrator
AN2282_2P_SER	2-pin generator with serial resonance
AN2282_2P_PAR	2-pin generator with parallel resonance

Document History

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**	1486965	MAPS_UKR	09/19/2007	New application note
*A	3352378	ANBI_UKR	08/23/2011	Modified title. Updated attached project to support the latest version of PSoC designer.
*B	4511164	DCHE	10/06/2014	Updated Software Version as “PSoC® Designer™ 5.4” in page 1. Updated example projects to PSoC Designer 5.4. Updated in new template. Completing Sunset Review.

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