Keywords: FAQ, TDC, ultrasonic, metering

MAX35101, MAX35102, MAX35103 FREQUENTLY ASKED QUESTIONS

Abstract: A frequently asked questions (FAQ) for the MAX35101, MAX35102, MAX35103, MAX35101 EV Kit, and MAX35103 EV kit devices. It includes answers for suitable application questions, EV kit setup and debugging questions, device operation questions, external and application component questions.

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Suitable Application Questions

Can the MAX35101, MAX35102, and MAX35103 be used as a generic time-to-digital converter (TDC) for a broad range of applications?
No, the MAX35101, MAX35102, and MAX35103 cannot be used as a generic time-to-digital converter for applications that require externally generated start and stop signals. They cannot be used to measure the duration of asynchronous independent events. There is no way to use an external signal to start the time-to-digital converter. These devices provide only timing results from the internally generated start pulse to a string of zero-crossing stop pulses.

Can the MAX35101, MAX35102, and MAX35103 be used for clamp-on water meter applications?
Yes, the devices are suitable for use in clamp-on water meter applications. There are currently no application notes, reference designs, or recommended schematics.

Note that additional circuitry and components are required. In a clamp-on meter, the launch and return signal has to propagate through the pipe walls into the channel and out of the pipe walls. This additional signal path causes significant signal attenuation versus a series water meter, where the transducers are directly interfacing with the water. The two options available to normalize signal amplitudes back to suitable device levels are to increase the launch signal power by increasing launch voltage and/or to increase receive signal sensitivity by adding an amplifier circuit. Analog switches are also required with time domain multiplexing to connect the appropriate signals to their correct signal chains at the appropriate times.

The devices have a very sensitive front-end, specified with a typical min value of 10mV. However, the best operating amplitude for the return signal is 350mV. Amplifying the launch/receive signal to achieve this signal amplitude at the devices' stop pins is ideal.

Can the MAX35101, MAX35102, and MAX35103 be used for gas meter applications?
Yes, the devices are suitable for use in gas meter applications. There are currently no application notes, reference designs, or recommended schematics. The devices have a 200kHz and 500kHz pulse launch frequencies which are most common amongst gas medium applications.

Note additional circuitry and components are required. In a gas meter, the attenuation of acoustic waves is much larger through the medium than in a water meter. The two options available to normalize signal amplitudes back to suitable device levels are to increase the launch signal power by increasing launch voltage and/or increasing receive signal sensitivity by adding an amplifier circuit. Analogue switches will also be required with time domain multiplexing to connect the appropriate signals to their correct signal chains at the appropriate times.

The devices have a very sensitive front-end, specified with a typical minimum value of 10mV. However, the best operating amplitude for the return signal is 350mV. Amplifying the launch/receive signal to achieve this signal amplitude at the devices' stop pins is ideal.

Can the MAX35101, MAX35102, and MAX35103 be used for pulse echo applications?
Yes, the devices are usable for pulse echo applications. There are currently no application notes, reference designs, or recommended schematics. The devices have a 200kHz and 125kHz pulse launch frequencies that are usable for air pulse echo distance measurement applications.

Pulse echo applications use single-ended, single-transducer, time-of-flight measurements that rely on accurate absolute time-of-flight measurements. These devices are not designed for accurate absolute time-of-flight results so significant characterization and calibration is required.

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What materials can the MAX35101, MAX35102, and MAX35103 measure (liquids, gasses, slurries)?
The devices are targeted for the industrial to residential water, heat, and gas meter markets. However, the devices can measure any substance that allows for the ultrasonic time-of-flight difference measurement methodology to be implemented. This means the substance being measured must also be the medium in which the ultrasonic signals propagate, and therefore, the mediums must allow reliable ultrasonic signal propagation across the pipe in a repeatable and relatively efficient manner.

Most gasses (helium, nitrogen, natural gas) and true liquids (water, milk, apple juice, oil) are suitable candidates. Liquids with entrained gasses are difficult to measure reliably. Mediums that are homogenous are preferred. Different calculations techniques and equations for volume and flow rates are required for different measurement materials. The flow profiles and movement dynamics of various materials through the pipe also must be accounted for and drastically vary.

The ultrasonic time-of-flight measurement method cannot measure liquids or semiliquids with large amounts of nonwater soluble materials such as slurries and sludges (example.g., concrete).

EV Kit Setup and Debugging Questions

How does the user debug an EV kit setup after connecting piezoelectric transducers when the timing results are not as expected or nonexistent?
The time-of-flight result of 16,383,99... indicates a timeout has occurred. A timeout can occur due to an incomplete signal path typically arising from incomplete connection between the EV kit hardware and the piezoelectric transducers, or the acoustic path between the piezoelectric transducers themselves. Upon attaching piezoelectric transducers to the EV kit, verify the transducers and their associated acoustic paths are fully submerged in water. If using loose transducers not mounted in a spool body, then make sure they are pointing at each other and are an appropriate acoustic path distance apart. Start with 70mm.

Once set up, modify a few EV kit software parameters to check for a complete signal path. First, the TOF measurement delay window can be adjusted to the minimum value of 10µs to ensure the analog front-end (AFE) is active for all acoustic wavelengths.

The STOP_UP and STOP_DN comparators are programmable through the EV kit software in the Timeof-flight tab on the right side in the group box named Comparator Offsets. Adjust these slider bars and see if the comparator triggers and provides a resulting time-of-flight measurement. Refer to **Figure 5** of the MAX35101 data sheet for further explanation.

Second, verify electrical signals using an oscilloscope. The CMP_OUT/UP_DN pin of the MAX35101 can be used for debugging purposes such as this one. Use the EV kit software to enable the comparator functionality of this pin by selecting it in the tool strip menu bar under Device Pins. Now probing the CMPOUT test point shows the output of the comparator for the STOP pins. This needs to be transitioning during the act of receiving the stop signals before the device generates any timing data. Probe the STOP_DN, LAUNCH_DN, and CMPOUT test points and perform a TOF_DOWN command. A complete signal path results in signals similar to the image **Figure 1**.
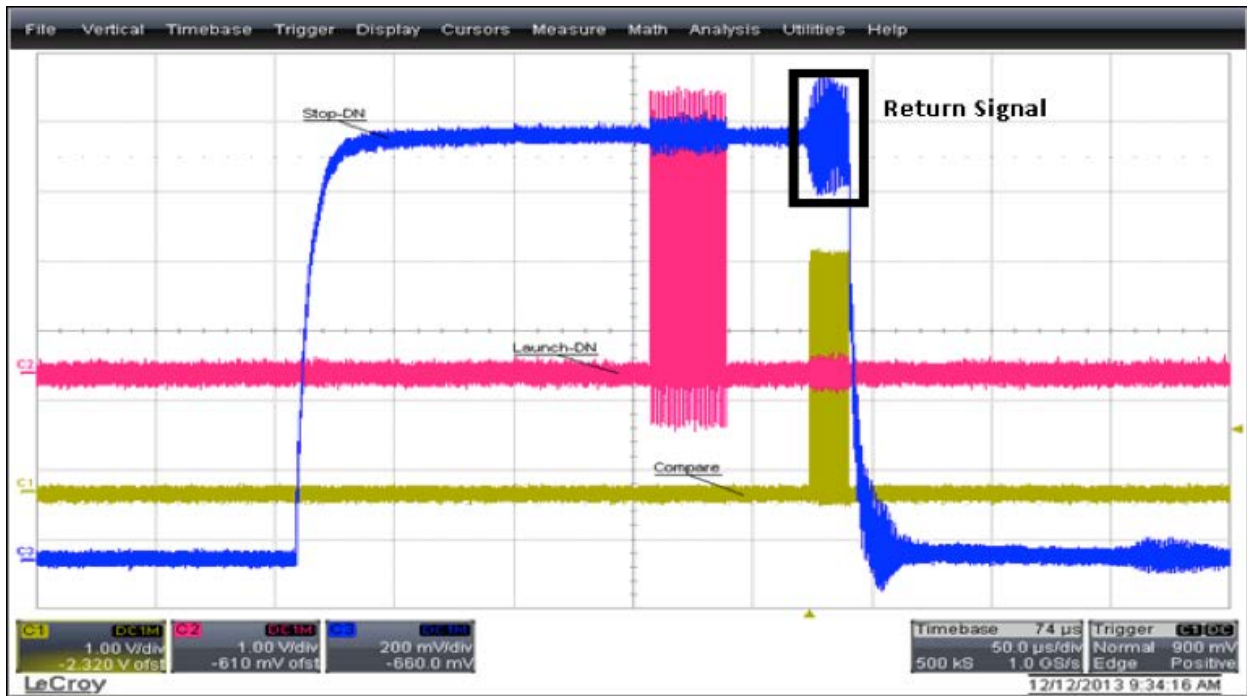
Figure 1. Complete signal path signals.

An incomplete signal path shows the STOP_DN pin being charged to the $3/8V_{CC}$ common mode and held with no return signal. Without a return signal the CMPOUT (compare signal) never goes active.

Figure 2 shows an expected return signal and its associated CMPOUT (compare signal) output.
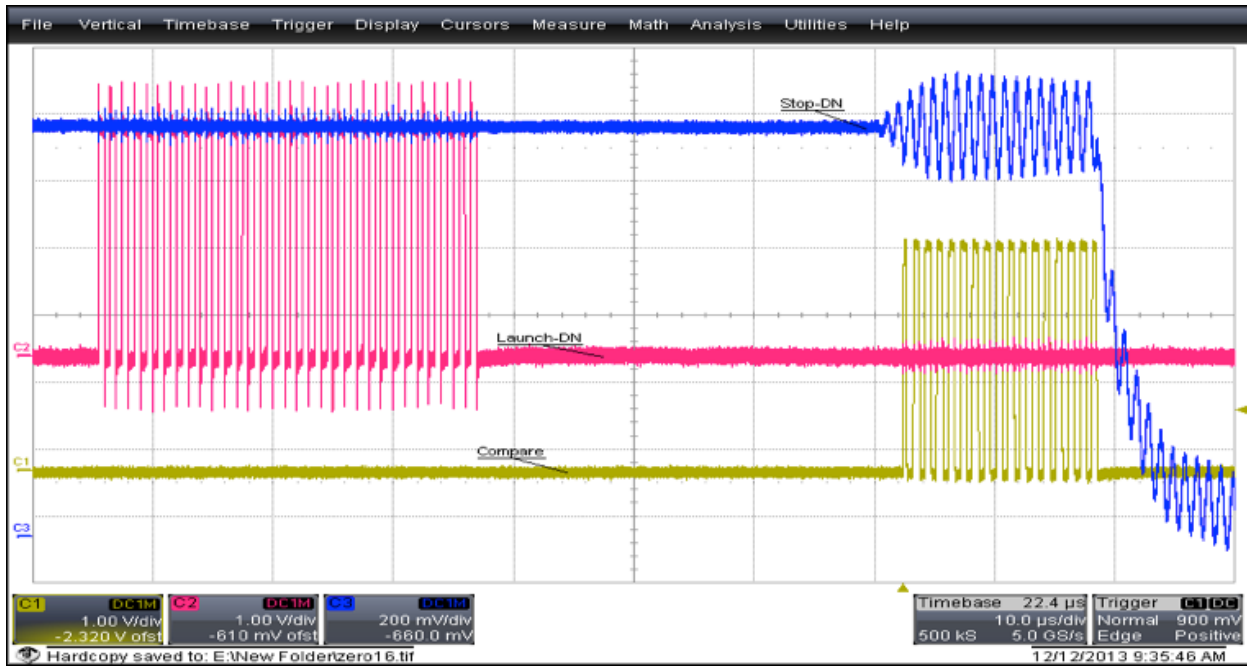

Figure 2. Expected return signal and its associated CMPOUT output.

Look at the STOP_UP pin signal and notice the common mode applied to the pin prior to Launch_Down pulse train being sent (refer to **Figure 3** of the MAX35101 data sheet). Make sure the common mode is solid $3/8V_{CC}$ throughout the entire measurement, loading and leakage causes common-mode shifts. The comparator trigger value for stopping the measurement is $3/8V_{CC}$ ± any programmed offsets.

Where are the default configurations originally stored in the EV kit?
How to restore the device to the initial default state..
To download the most recent EV kit software from www.maximintegrated.com, search for MAX35101 EV Kit. The .ZIP contains the .XML file of the initially stored configuration values of the device. Selecting File >> Load Config writes these configurations to the device's SRAM. The settings can then be transferred to flash memory using the Store Config to FLASH command.

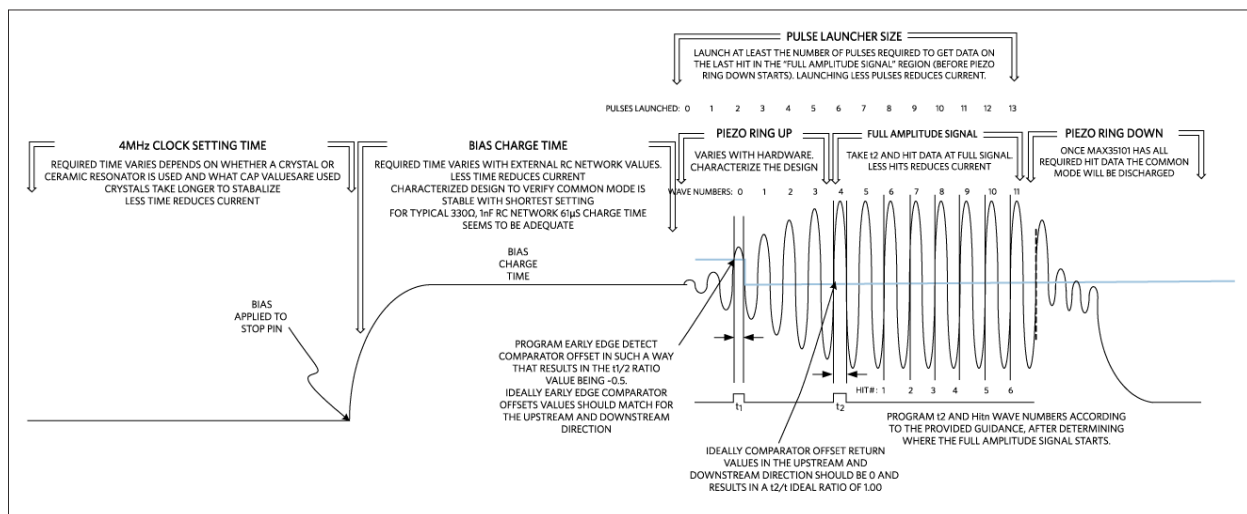**How should the comparator offsets be configured?**

Figure 3. Comparator Offset Configuration

What causes the unstable time-of-flight results if the return signals vary in amplitude?
If there is air in the pipe the result times out. However, when there are air bubbles in the pipe, it can be assumed that this air passes through the acoustic path of the given spool body. When the acoustic wave (launched from the transducers) meets these air bubbles, the signal attenuates more than usual (since attenuation of a sound wave is greater in air than in water). This attenuation is unpredictable and is dependent on the size, position, and number of the air bubbles in the pipe. This causes the return signal to be unstable and unpredictable.

Analysis the t1/t2 and t2/tideal ratios can provide insight into this behavior and be used to detect its occurrence. This is a feature of ultrasonic flow measurement technology, not a disadvantage. The system can detect air bubbles in water pipes and react accordingly.

What causes a fairly large offset in the zero-flow readings that is not constant over time and environmental factors?
Verify proper post-assembly board cleaning procedure. Refer to the solder type's cleaning specification procedure and thoroughly clean all boards in the proper manner. Some methods are alcohol scrub, deionized water scrub, ultrasonic cleaning, soap scrub, etc.(solder dependent). Then thoroughly dry the boards and do a post-clean bake of the boards, preferably at +75°C for a few hours or overnight.

Can data from the EV kit be saved and exported for further analysis?
Yes, To export the data from the Time-of-flight' tab after running repetitious TOF commands, use the 'Save to .tsv' button found on the 'Data Log Graph' tab.

Version 2.5 of the EV kit software does not support exporting data from the 'Temperature' tab. To export data from the 'Event Timing Modes' tab, simply highlight, copy, and paste the information into a spreadsheet.

MAX35101, MAX35102, MAX35103 Device Operation Questions

Why is the device consuming more current than what is specified in the data sheet?
The current consumption of these devices is very dynamic. In the data sheet, the current is specified for various functional blocks within the IC. These blocks are turned on when they are needed for a measurement and then turned off when they are not required. The figures of merit current specified in these data sheets as device current drain are typical numbers that are achievable through power consumption conscious configuration settings and with the device running at VCC = 3.0V. The configurations in which these Device Current Drain numbers apply are shown in Table 1.

There are also additional currents not included in the device current drain specification. One additional current is the LDO power on current. This is omitted because it depends significantly on the residual charge remaining on the LDO's bypass capacitor. Another additional current is the current required to charge the capacitors that provide the common-mode bias on the STOP pins. The device current drain does not include the TOF launch currents required to stimulate the transducers. This is omitted because the piezo stimulation current depends upon the load connected to the launch pins. The launch pins are specified as 50mA drivers that drive the RC network of external components and the piezoelectric transducers themselves.

Table 1. TOF Rate Configuration Settings for Average ICC Values

Control Bit(s)	6 Hit Settings		3 Hit Settings	
	Value	Bit Settings	Value	Bit Settings
Calibration Usage	Disabled	CAL_USE=0	Disabled	CAL_USE=0
Clock Settling Time	488µs	CLK_S[2:0]=000	488µs	CLK_S[2:0]=000
Bias Charge Time	61µs	CT[1:0]=00	61µs	CT[1:0]=00
Pulse Launch Frequency	1MHz	DPL[3:0]=0001	1MHz	DPL[3:0]=0001
Pulse Launcher Size	15	PL[7:0]=00001111	15	PL[7:0]=00001111
TOF Duty Cycle	19.97ms	TOF_CYC[2:0]=111	19.97ms	TOF_CYC[2:0]=111
Stop Hits	6	STOP[2:0]=101	3	STOP[2:0]=010
T2 Wave Selector	Wave 2	T2WV[5:0]=000110	Wave 2	T2WV[5:0]=000110
Hit 1 Wave Select	7	HIT1WV[5:0]=000111	7	HIT1WV[5:0]=000111
Hit 2 Wave Select	8	HIT2WV[5:0]=001000	8	HIT2WV[5:0]=001000
Hit 3 Wave Select	9	HIT3WV[5:0]=001001	9	HIT3WV[5:0]=001001
Hit 4 Wave Select	10	HIT4WV[5:0]=001010	n/a	n/a
Hit 5 Wave Select	11	HIT5WV[5:0]=001011	n/a	n/a
Hit 6 Wave Select	12	HIT6WV[5:0]=001100	n/a	n/a
Temperature Port Number	4	TP[1:0]=11	4	TP[1:0]=11
Preamble Temperature Cycle Number	1	PRECYC[2:0]=001	1	PRECYC[2:0]=001
Port Cycle Time	256µs	PRECYC[1:0]=01	256µs	PRECYC[1:0]=01

Average ICC vs. TOF Test Configuration Notes

1. This data is valid for the ceramic resonator
2. Crystal oscillator starup adds   0.5uA per TOFDiff
3. Since the TOF cycle time is long the 4 Mhz Oscillator powers up twice

How accurate is the device?
What does the typical 20ps time measurement accuracy specification mean?

20ps accuracy is the specification of the time-to-digital converter. This specification assumes ideal 32kHz and 4MHz signals.

The accuracy of an actual measurement is directly related to the accuracy of the crystal. This will always be the case because the crystal oscillator frequency is the reference for the measurement. The accuracy of a TOF_DIFF measurement, assuming ideal external components, can be thought of as = 20ps + (DeltaTOF: Result) × (PPM error of reference of choice.)

A typical sample set of data taken under no flow conditions with an EV kit connected to a spool body is shown in **Figure 4**.
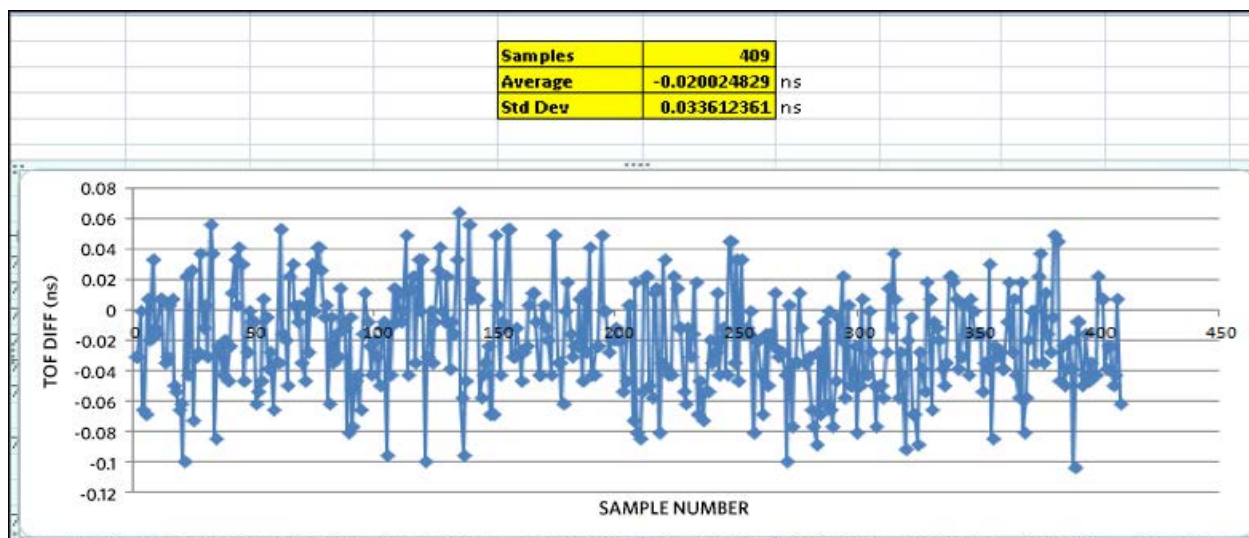

Figure 4. Sample set of data under no flow conditions with EV kit connected to a spool body.

Why do the SRAM configuration register values reset after an initialization command is sent?
Can you provide clarification of the initialization command?
The initialization command recalls all the stored devices configurations from flash during its initialization routine. Before using the initialization command, it is best to write to the configuration registers, and then

perform a transfer configuration to flash command (Opcode 06h). This writes all the desired configurations into flash. Now, during execution of the initialization command, the desired configuration values are recalled from flash and programmed in SRAM.

What launch frequencies does the device support?
Can I use a different frequency value for the 4MHz crystal?
The device was designed for a 4MHz resonator. No other frequency of resonator is supported.

The maximum piezoelectric transducer drive frequency is 1MHz and the minimum is 125kHz. The drive frequency is adjusted with the Pulse Launch Divider (DPL[3:0]) bits in the TOF1 register.

Full List of Supported Pulse Launch Frequencies
1.00MHz
666.67kHz
500.00kHz
400.00kHz
333.33kHz
285.71kHz
250.00kHz
222.22kHz
200.00kHz
181.82kHz
166.67kHz
153.85kHz
142.86kHz
133.33kHz
125.00kHz

Drive frequencies not on this list are not supported.

Can an external 4MHz signal be used to drive the MAX35101, MAX35102, and MAX35103?
No, do not use an external 4MHz signal to drive the devices. The circuit wasn't designed to allow over clocking. If a CMOS signal is used to drive X2, the device could consume a huge amount of current. Since the metallization isn't designed to handle high current it could damage the device.

Can the pulse launcher phase, polarity, or post launch logic be adjusted?
After the launch sequence is complete the launch signals stay high until the completion of the measurement. Refer to Figure 3 of the MAX35101 data sheet to see the actual device operation.
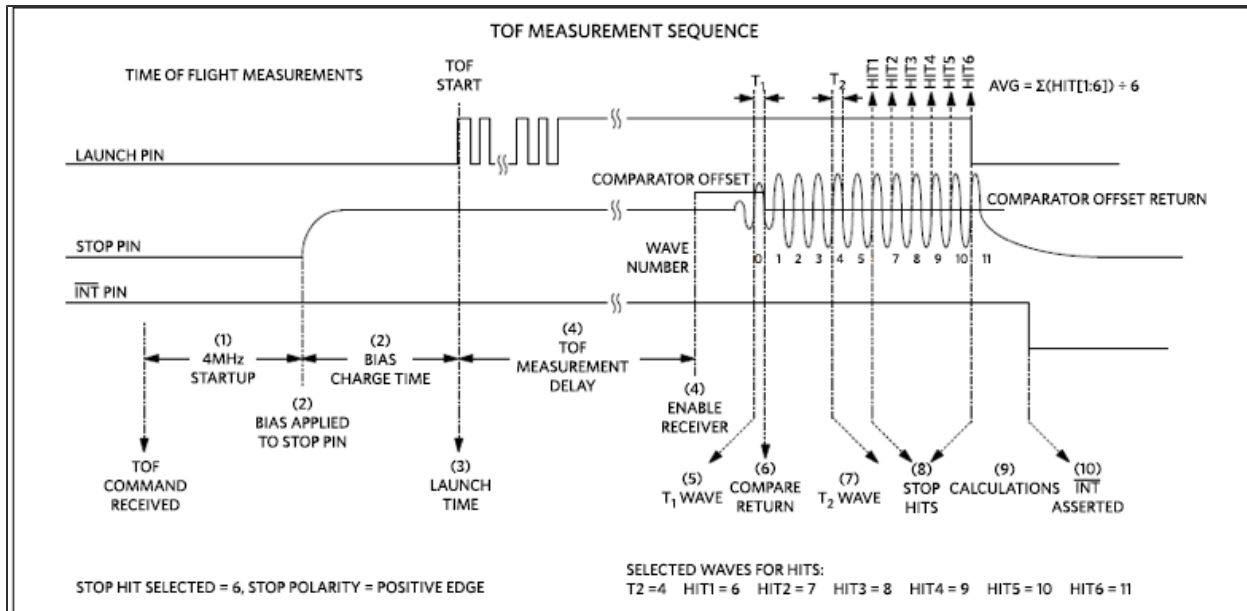

Figure 5. Time-of-flight measurement sequence.

The state of the inactive launch pin is not programmable. The phase and polarity of the launch sequence are not programmable.

Is the gain adjustable for the MAX35101/2/3 receiver front-end?
The devices analog front-end is not gain adjustable. The front-end amplifier does not need to be adjustable for heat and water meter applications. It is an integrated amplifier/comparator design that is precisely configured to provide 10mV $_{P-P}$ sensitivity.

External and Application Component Questions

What piezoelectric transducers are recommended and where can they be acquired?
What transducers are supported by the device?
Audiowell ultrasonic transducers are recommended. The company is based in Guangzhou, China. Visit www.audiowell.com for more information.

Another recommended company is Morgan Technical Ceramics:
www.morgantechnicalceramics.com/products/product-groups

For off the shelf, orderable transducers, Maxim recommend Steiner & Martins, Inc.: www.steminc.com/PZT

The MAX35101, MAX35102, and MAX35103 are compatible with a wide variety of transducers. The devices include 50mA CMOS output drivers with adjustable launch frequencies.

How to choose the RC component values that connect the device to the transducers?

For that RC network, we recommend 330 resistors and 1nF capacitors for the majority of transducers and spool bodies. These values can be tweaked if so desired depending on the electrical properties and sensitivities of the transducers and the construction of the spool body.

The analog input voltage range on STOP_UP and STOP_DOWN is (3/4 × VCC) mV_{P-P} (max), and 10 mV_{P-P} (min) dictated by the device's receiver sensitivity. The signal amplitude launched and received from the transducers depends upon the RC network's selected values.

The RC values can be tuned, start by adjusting the values of the series resistor, such that the receive signal amplitude is typically around the ideal range of 350mV $_{P-P}$

What is the maximum pipe diameter that can be used with the MAX35101, MAX35102, and MAX35103?

What are the limiting factors for pipe diameters?

Pipe diameter is important is because some paths are diagonal, V-shaped, or U-shaped. The acoustic path traverses the medium either oblique to the flow, or first perpendicular to the flow before being reflected to travel parallel to the flow. If the system is using the recommended application circuit provided in the MAX35101 data sheet, the pipe diameter is limited by the attenuation of the launch signal through the medium. The amplitude of the return signal varies with the medium, acoustic path, path length, selected transducers, and drive voltage.

Extra gain circuits for the launch and or receive signals may be required depending upon the acoustic path length and the signal attenuation. The devices have a very sensitive front-end, specified with a typical minimum value of 10mV. However, the best operating amplitude for the return signal is 350mV, so amplifying the launch/receive signal to achieve this signal amplitude at the devices Stop Pins would be ideal.

If the return signals are large enough or amplified enough to be usable by the device, then the pipe diameter is limited by the 8ms (max) time of flight value. The speed of sound in water is ~1497m/s. Assuming a straight across the pipe acoustic path with an 8ms (max) time of flight allows the pipe diameter to be ~12 meters.

Can a thermistor be used for temperature measurement instead of a PT1K or PT500 RTD?

Yes. Using a thermistor is an option. The RC time constant shown in the system diagram in the MAX35101 data sheet must be preserved for both the temperature measurement port used AND the reference temperature measurement port. So, for an NTC with R25 = 10k , the reference resistor must also be changed to 10k . The 100nF NPO capacitor in the temperature measurement circuit in same system diagram would then be changed to a 10nF NPO capacitor.

A lookup table in the microcontroller firmware is still required that represents calculated values of resistance from the Steinhart-Hart equation:

$$T \ (°C) = [1/\{A + B(LnR) + C(LnR)^3\}] - (273.15)$$

Related Parts		
MAX35101	Time-to-Digital Converter with Analog Front-End	Free Samples
MAX35101EVKIT	Evaluation Kit for the MAX35101	
MAX35102	Time-to-Digital Converter Without RTC	Free Samples
MAX35103	Reduced Power Time-to-Digital Converter with AFE, RTC, and Flash	Free Samples
MAX35103EVKIT	Evaluation Kit for the MAX35103	

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