AN1558/D

Characterization of Retrigger Time in the HC4538A Dual Precision Monostable Multivibrator

ON Semiconductor
Formerly a Division of Motorola
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APPLICATION NOTE

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Introduction

The MC74HC4538A is a monostable multivibrator commonly used as a one–shot, or in applications that require a pulse width of reliable dimensions. The pulse width and the minimum retrigger time are usually well behaved over the suggested pulse–width range of 1µs to 1 second. However, some customers have found that in using shorter than recommended pulse widths the retrigger time did not behave as it had at longer pulse widths. ON Semiconductor has done an overall characterization of the minimum retrigger time in an investigation of this phenomenon.

The retrigger time is applicable when the device is triggered a second time within the period of the output pulse. When this happens, the output pulse remains high for a period of $\tau + T_{rr}$. The earliest the part can be retriggered, or the minimum retrigger time, is the focus of this characterization. A trigger pulse on A or B inputs before this minimum retrigger time would be ignored.

Analysis and Data

When used in the retriggerable mode (Figure 1), the MC74HC4538A uses an external R_X & C_X to regulate the output pulse width, and the minimum retrigger time (T_{rr}). The minimum retrigger time depends on:

1) Time to discharge R_XC_X from V_{CC} to (V_{ref} lower=1/3 V_{CC}) $T_{discharge}$. This discharge occurs quickly because external resistance, R_X, does not have any effect on the R_C time constant. The resistance in the discharge path, as seen in Figure 2, is the on–resistance of M3, and the interconnect resistance. The interconnection resistance is dependent on the polysilicon sheet resistance, the metal sheet resistance, and the contact resistance. The interconnection resistance is heavily process dependent, but fortunately it is small overall and doesn't vary significantly from lot to lot.
The discharge time can be computed from:

$$T_{discharge} = \left(Ln\frac{3}{2}\right) \cdot R_i \cdot C_X$$

(Equation 1)

Typically the value of R_i would be near 300Ω.

2) Loop delay (T_{delay} = constant) ranges from 20–60ns, and is strongly correlated to V_{CC}. This is the time for the signal coming from the lower reference circuit to reset the flip–flop, and turn off M3. The amount of the undershoot voltage is a function of the loop delay, and for small values of capacitance the undershoot voltage is well below the lower reference voltage.

3) The time to charge R_XC_X from the undershoot voltage back to the lower reference voltage (V_{ref} lower). This time is given by the R_XC_X transient equation:

$$T_{charge} = R_X \cdot C_X \cdot Ln\left(1 + \frac{3 \cdot V_{undershoot}}{2 \cdot V_{CC}}\right)$$

(Equation 2)

where $V_{undershoot}$ = (V_{ref} lower) – Gnd. Hence the retrigger time is given by:

$$T_{rr} = T_{discharge} + T_{delay} + T_{charge}$$

(Equation 3)

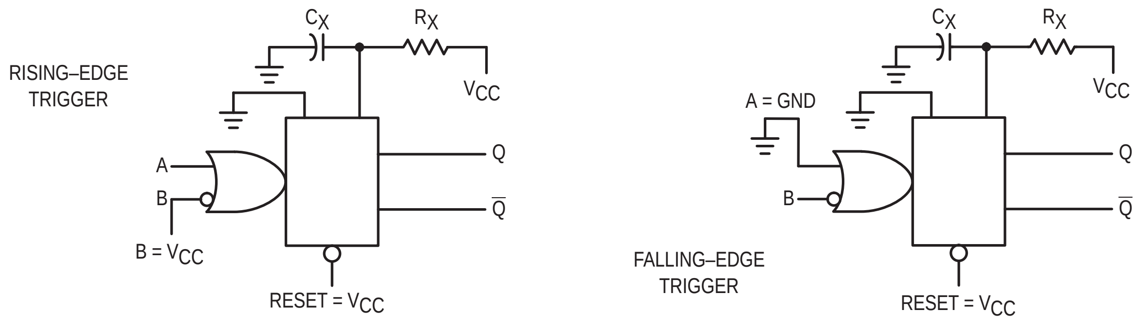

Figure 1. Retriggerable Monostable Circuitry

LOGIC DETAIL
(1/2 THE DEVICE)

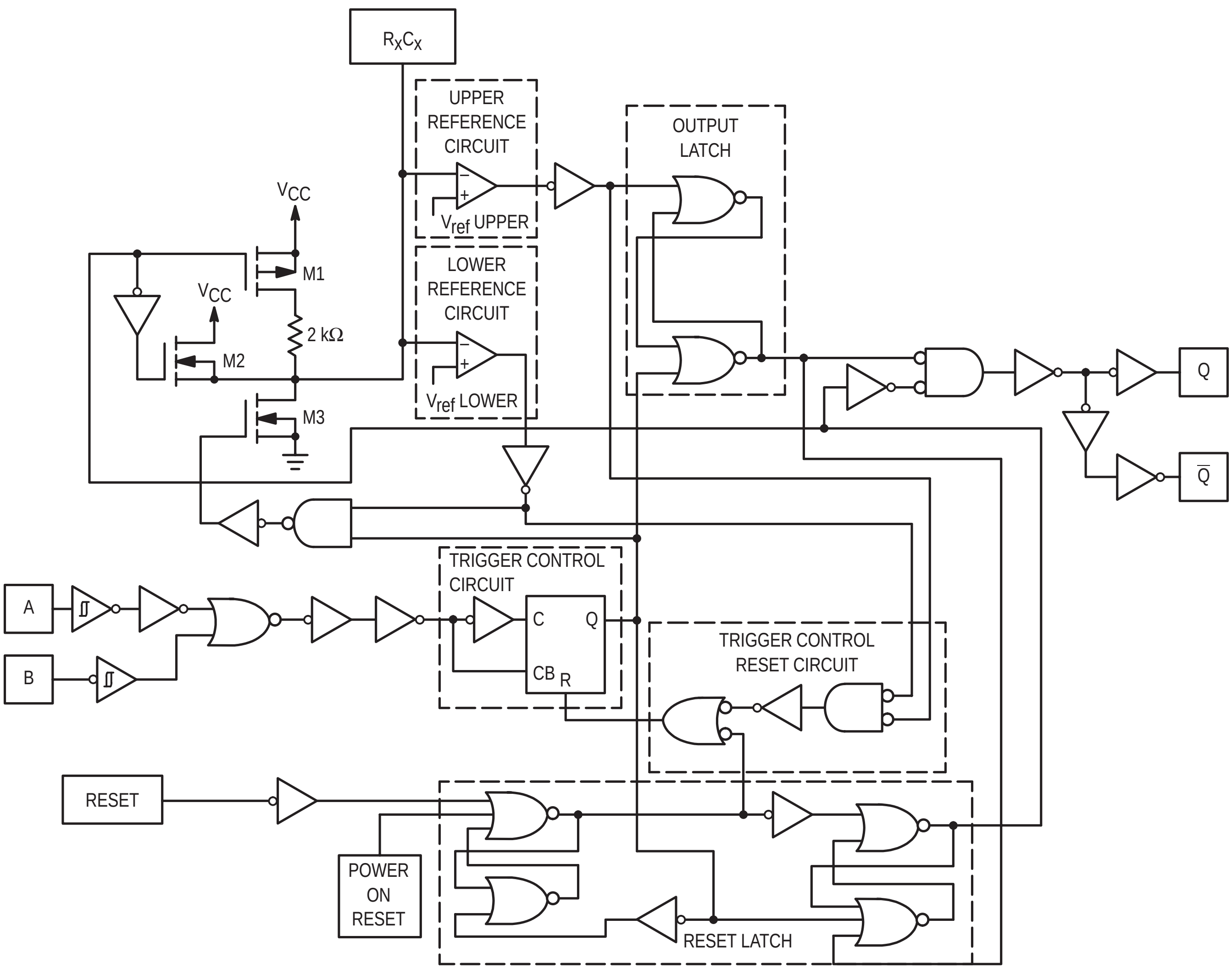

Figure 2. MC74HC4538A Logic Circuit Detail

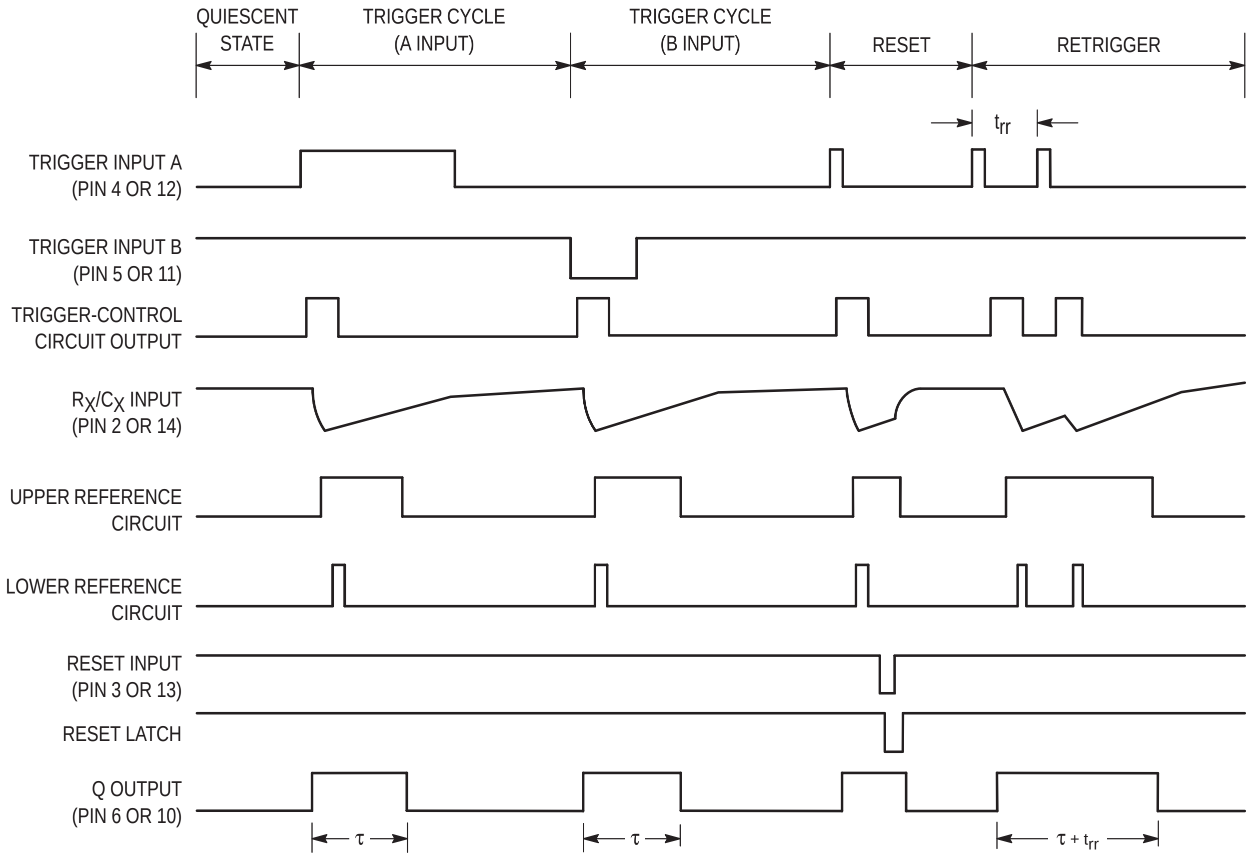

Figure 3. Timing Diagram

Design and Applications

The output pulse width of the HC4538A is determined by the external timing components, R_X and C_X, and can be represented linearly as shown in Figure 10.

The array in Table 1 was generated to make a concise study of the behavior for the retrigger time for short pulse widths. A sample of 10 pieces from each of 7 non–consecutive wafer lots were tested at each condition.

The retrigger time for external capacitance that ranges from 3000pF < C_X < 4.7μF, Region 3 on the graphs, can be computed by making use of the following linear equation (Equation 4).

Table 1. Test Matrix

C_X/R_X	10pF	100pF	220pF	1000pF
2KΩ	4.5V	4.5V	4.5V	4.5V
10KΩ	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V
100KΩ	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V
1MΩ	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V	3.0V 4.5V

$$T_{rr} = 10^{z},$$

$$\text{where } z = \Big[-1062.41 - (0.1236764 \cdot V_{CC}) + (1.13509292 \cdot (\text{Log } C_X)^3) - (2.875 \times 10^{-17} \cdot R_X^3) + (3.5256 \times 10^{-16} \cdot (\text{Log } C_X)^2 \cdot R_X) + (5.9621 \times 10^{-12} \cdot (\text{Log } C_X) \cdot R_X^2) + (4.03306325 \cdot (\text{Log } C_X)^2) + (7.9452 \times 10^{-11} \cdot R_X^2) + (5.1513 \times 10^{-5} \cdot (\text{Log } C_X) \cdot R_X) + (0.02312176 \cdot \text{Log } R_X) + (1.8339 \times 10^{-4} \cdot R_X) - (171.91718 \cdot \text{Log } C_X) + (4.64784302 \times 10^{8} \cdot C_X) \Big]$$

Equation 4. Retrigger Time for 4.7μF > C_X > 3000pF

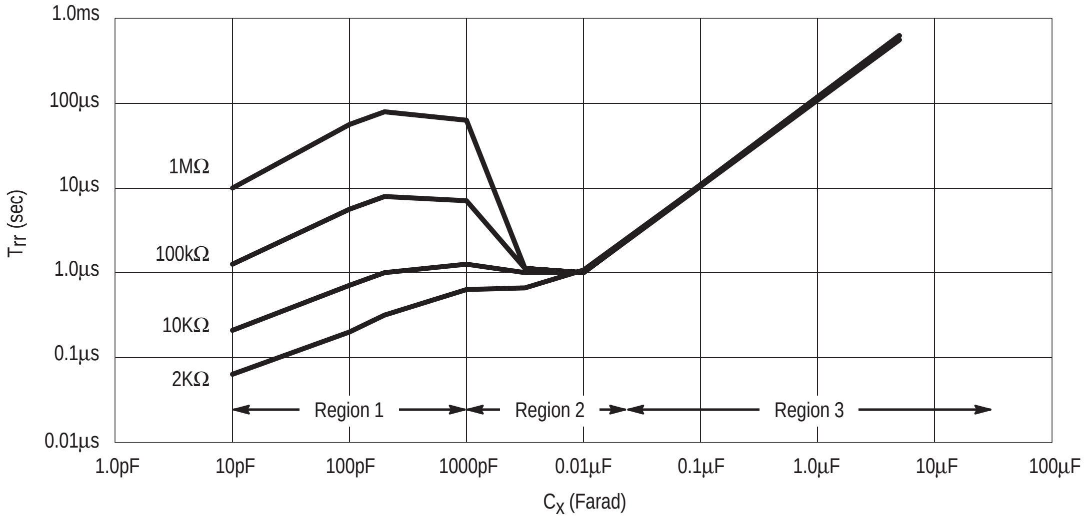

Figure 4. Retrigger Time versus Timing Capacitance at V_{CC} = 4.5V

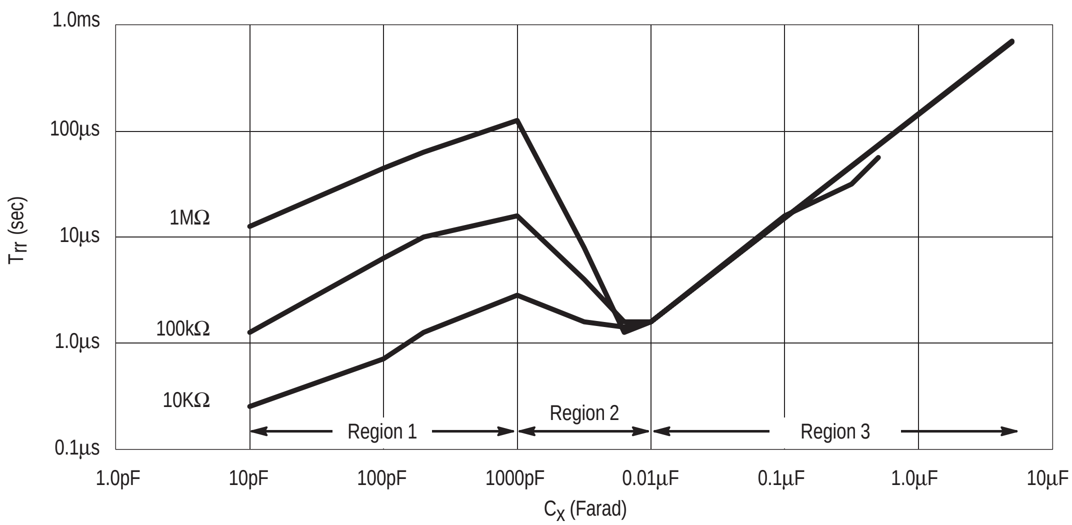

Figure 5. Retrigger Time versus Timing Capacitance at V_{CC} = 3.0V

For values of 1000pF < C_X < 3000pF, the non–linear portion of the curves are converging. In this region, Region 2, the equation was represented by too few measurements to generate a reasonably accurate equation. Therefore, the equation in Region 2 will remain underived. A value may be approximated from the graphs in Figure 4 and Figure 5.

It was determined from experiment and statistical analysis of the data that the retrigger time for small values of external capacitance within the range of 10pF < C_X < 1000pF, Region 1, can be characterized with the following linear equation (Equation 5).

$T_{rr} = 10^{z}$,

$$\text{where } z = \Big[-315.29624 - (0.082881 \cdot V_{CC}) - (0.3146338 \cdot (\text{Log } C_X)^3) + 4.3277 \times 10^{-16} \cdot R_X^3) - (3.984 \times 10^{-7} \cdot (\text{Log } C_X)^2 \cdot R_X) + (3.0657 \times 10^{-12} \cdot (\text{Log } C_X) \cdot R_X^2) - (9.467093 \cdot (\text{Log } C_X)^2) - (4.575 \times 10^{-10} \cdot R_X^2) - (1.124 \times 10^{-5} \cdot (\text{Log } C_X) \cdot R_X) - (94.092747 \cdot \text{Log } C_X) + (1.36599588 \times 10^{8} \cdot C_X) - (1.423 \times 10^{-5} \cdot R_X) \Big]$$

Equation 5. Retrigger Time for $10pF < C_X < 1000pF$

Here, the same components of:

$$T_{rr} = T_{discharge} + T_{delay} + T_{charge}$$

(Equation 3)

are still represented, but have become combined by the linear regression. The constant and V_{CC} dependent term still derive from the loop delay, and serve to shift the components along the vertical axis. The major difference between this and the larger values of C_X is twofold.

First, over all of Region 3 the undershoot is effectively 0 volts. This results in T_{charge} not contributing to T_{rr} and the predictable minimum T_{rr} occurring in Region 2.

Second, as we progress to smaller values of capacitance in Region 1, C_X is too small to support V_{ref}lower as the charge is drained through M3. This is why the resistance of R_X now plays a role in T_{rr}. This condition creates the undershoot of V_{ref}lower and the time of T_{charge} is then controlled by the current through R_X. This is also why as the value of C_X increases for the same resistance, T_{rr} increases as it takes longer to charge the larger capacitor. For values of $R_X > 10k\Omega$, this increasing undershoot of V_{ref}lower and the resultant increase in T_{charge} negates any improvement in T_{rr}.

At small values of C_X, the circuit capacitance will also come into play. The size of the undershoot of V_{ref}lower can vary as a function of normal process variance. This will also introduce an uncertainty into T_{rr} for these smaller values. The curves and regression equations here were derived statistically and only represent the mean of the variance in 7 non–consecutive production lots.

This difference in the non–zero value of T_{charge} in Region 1 can also be seen in Figure 6 and Figure 7 as the slope of T_{rr} becomes zero as the undershoot becomes zero.

Also, note that in Figure 8 through Figure 11, this effect has no influence on the Output Pulse Width as the Pulse Width is controlled by $R_X C_X$ and V_{ref}upper.

$\tau = 10^{z}$,

$$\text{where } z = \Big[-1.0059363 - (7.6336 \times 10^{-3} \cdot V_{CC}) + (0.87653815 \cdot \text{Log } R_X) + (0.8635535 \cdot \text{Log } C_X) - (9.3203 \times 10^{-3} \cdot \text{Log } R_X \cdot \text{Log } C_X) \Big]$$

Equation 6. Pulse Width

Equation 6 is a linear regression equation for calculating the pulse width and is also made from the data means. From the logarithmic plots in Figure 8 through Figure 11, it can be seen that there is no cubic dependency similar to T_{rr}, even at the small values of capacitance. The pulse width is completely controlled by the relationship between $R_X C_X$ and V_{ref}upper. This predictability of the pulse width has tempted some customers into trying to use the part for very short pulse widths. Unfortunately it has also resulted in inconsistent performance for T_{rr}.

Summary

While smaller pulse widths and T_{rr} values can be achieved, selection of the external components must take into account the introduction of undershoot of V_{ref}lower. Also, as we have stated above, as the value of C_X decreases in the non–linear region, the total capacitance becomes more dependent upon internal circuit capacitance. Since the internal circuit capacitance is process dependent, it can vary from lot to lot, and from manufacturing site to manufacturing site. It is for this reason that the device is not recommended to be used in this range, as doing so would potentially result in inconsistent performance over large production runs. The curves represented in this applications note were made using linear regression on a number of lots widely separated in time, but all from the same manufacturing site. As a result, the curves can only be regarded as statistical means, and may not represent the performance of any particular device the customer may encounter.

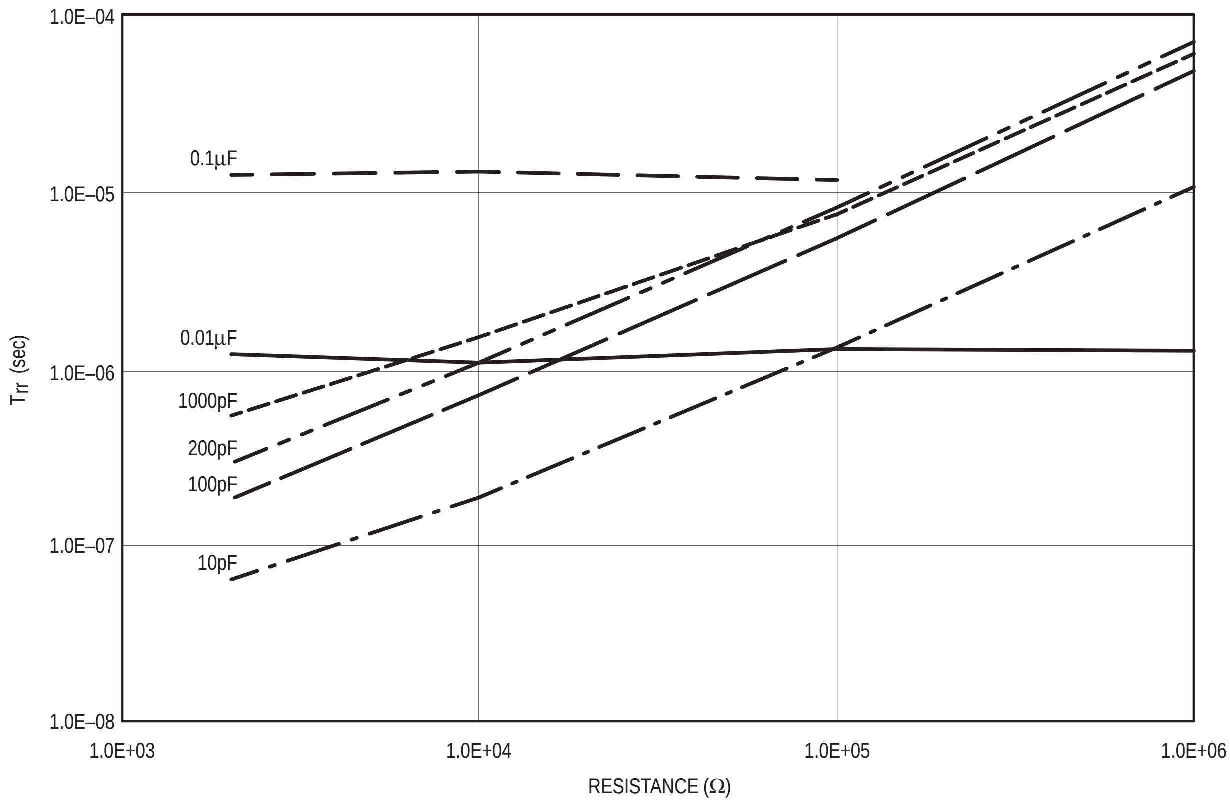

Figure 6. Retrigger Time vs Resistance at V_{CC} = 4.5V

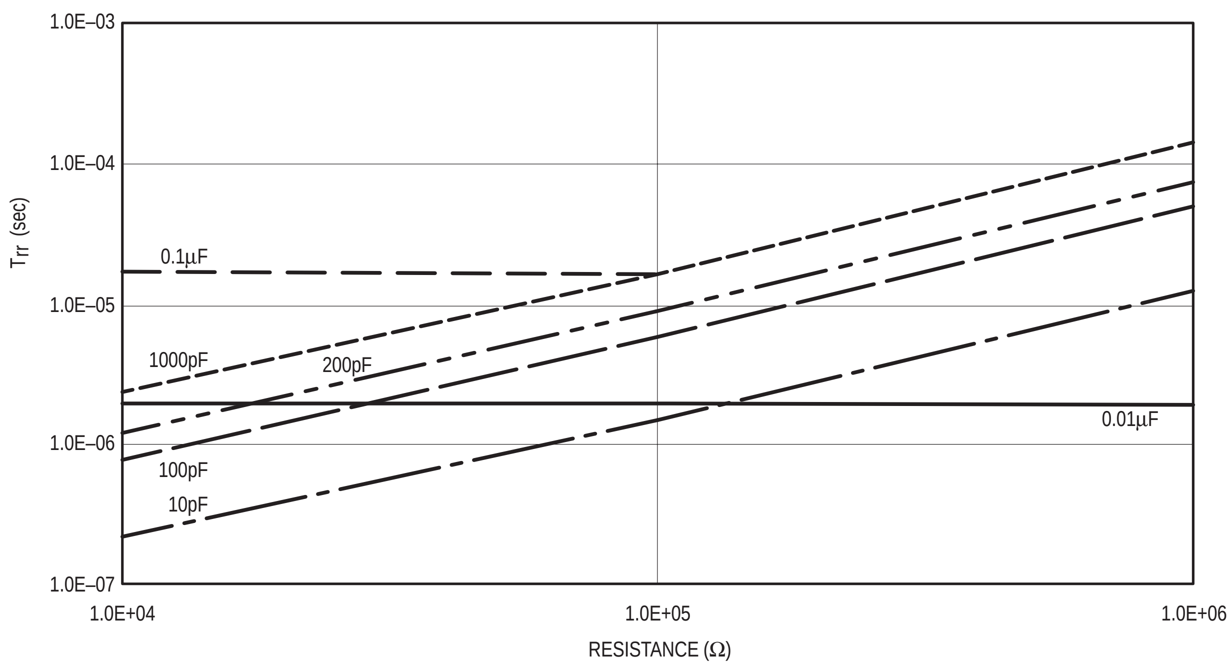

Figure 7. Retrigger Time vs Resistance at V_{CC} = 3.0V

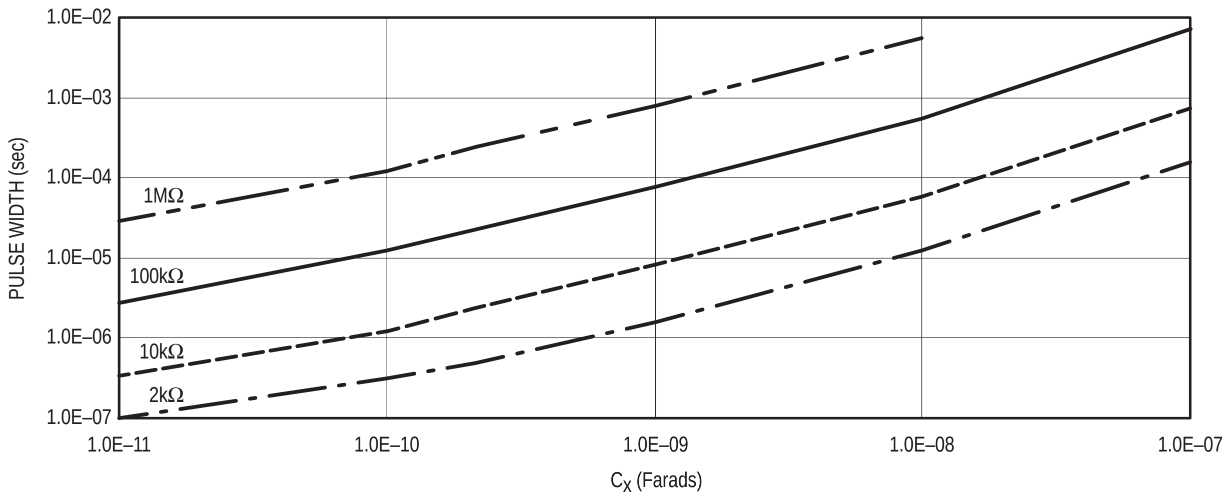

Figure 8. Pulse Width vs Timing Capacitance at V_{CC} = 4.5V

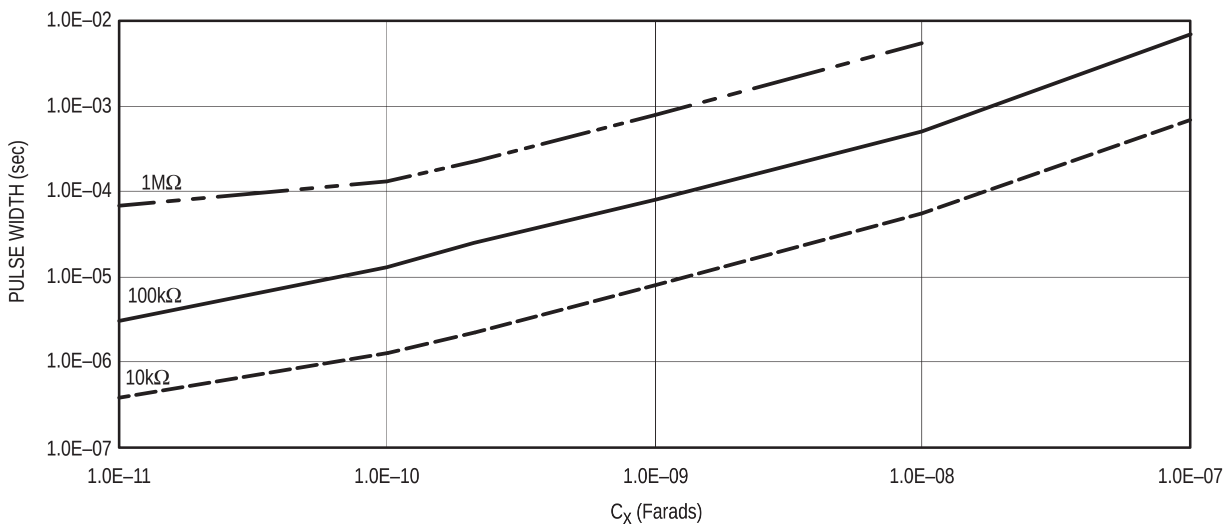

Figure 9. Pulse Width vs Timing Capacitance at V_{CC} = 3.0V

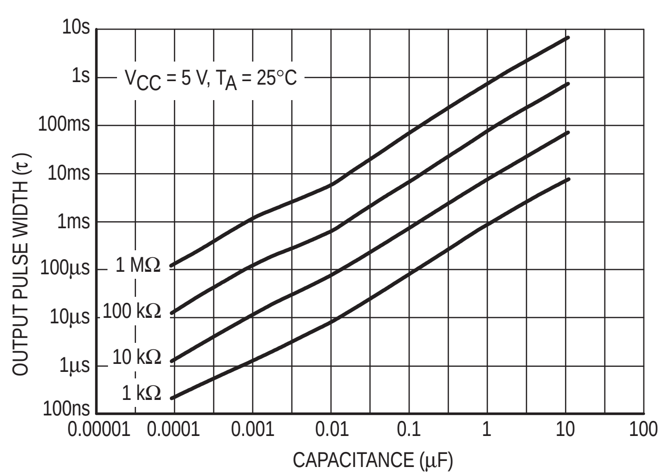

Figure 10. Output Pulse Width vs Timing Capacitance

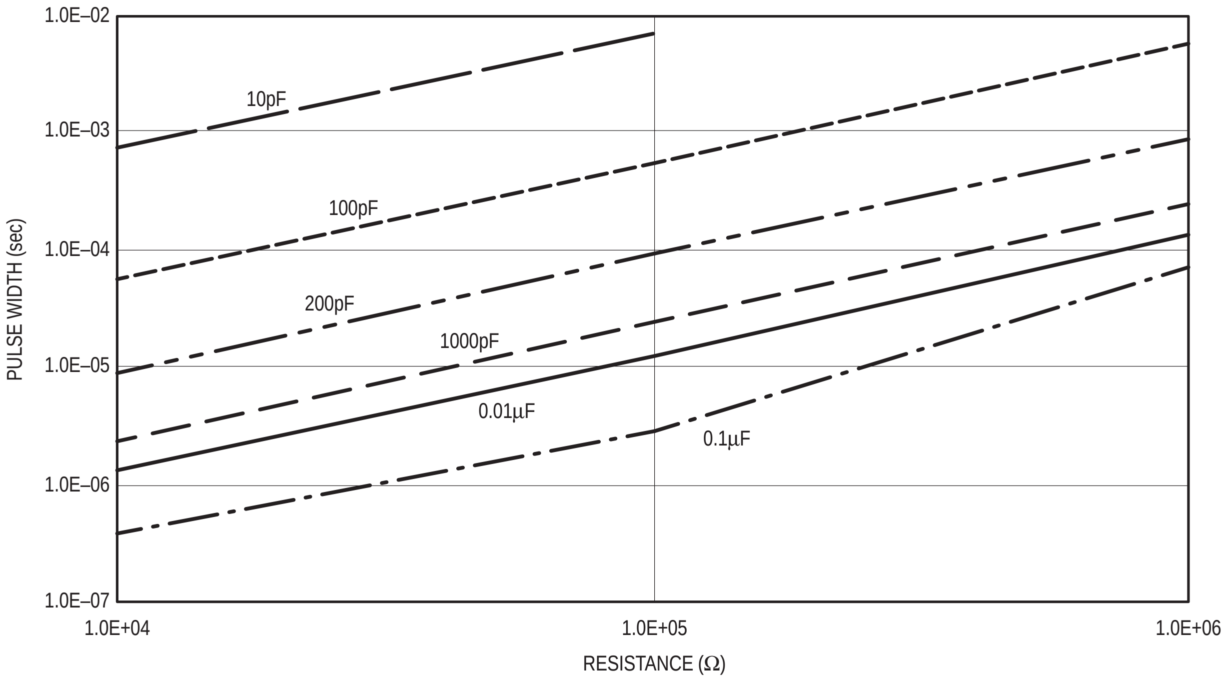

Figure 11. Pulse Width versus Resistance at V_{CC} = 3.0V

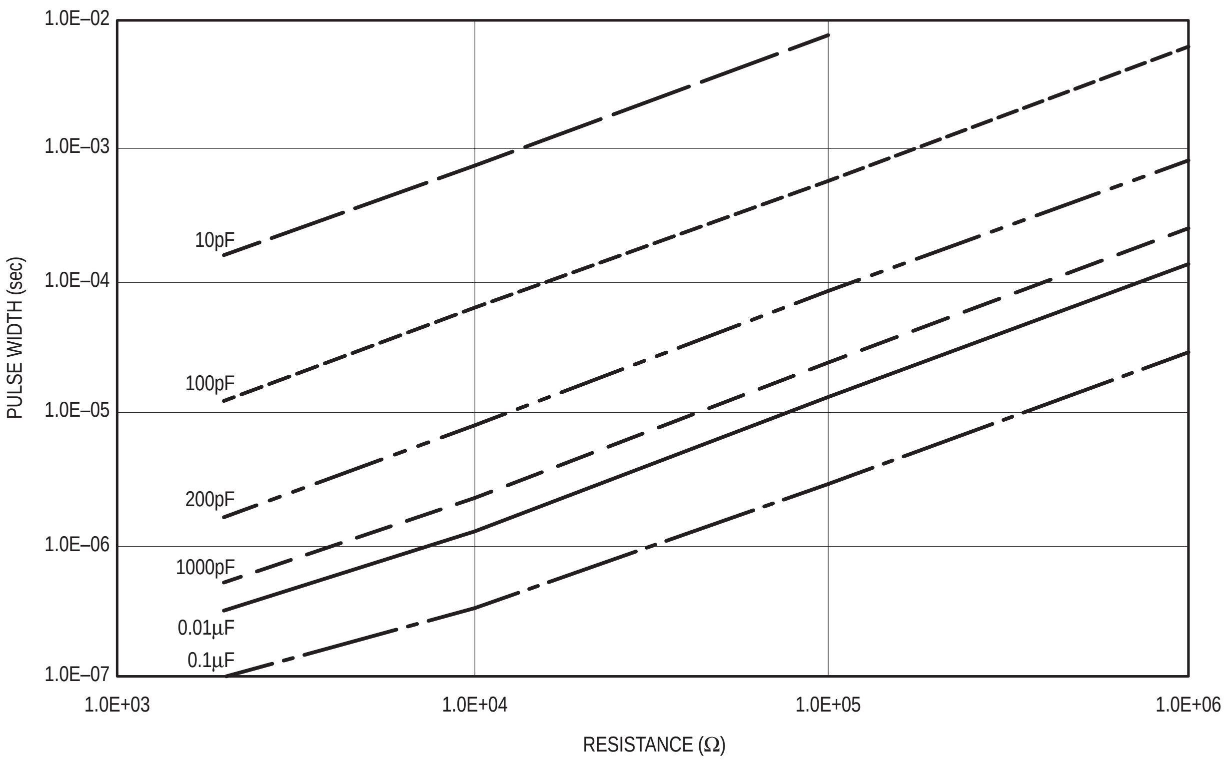

Figure 12. Pulse Width versus Resistance at V_{CC} = 4.5V

Notes

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