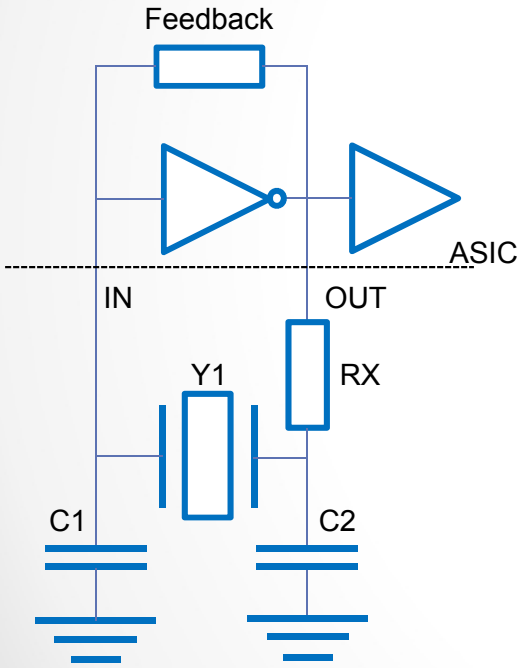
CRYSTAL DRIVE LEVEL AND SMALL PACKAGE SIZES

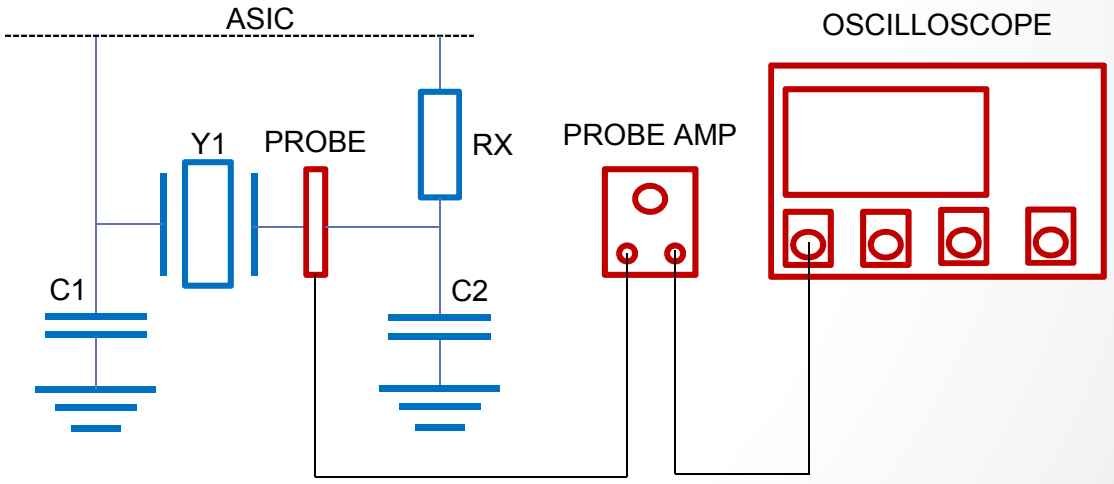
August 2013

Crystal Overdrive: Practical Example

Crystal Parameters: 26.000 MHz, C_L 20 pF, ±15 ppm calibration, ESR 40 Ω max., 10 µW typ., 0 ~ +85ºC



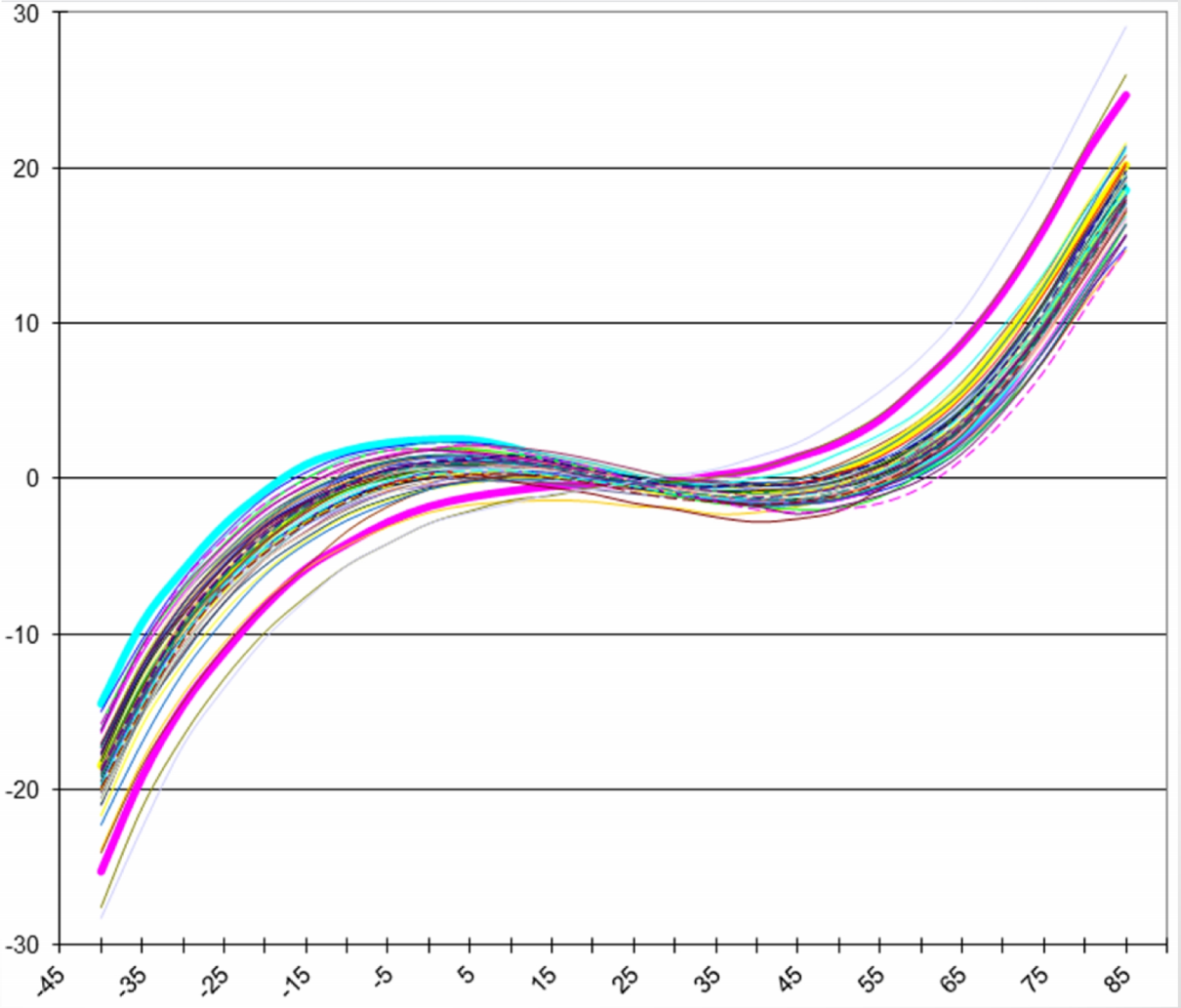
Oscillator Circuit



Drive Current Measurement

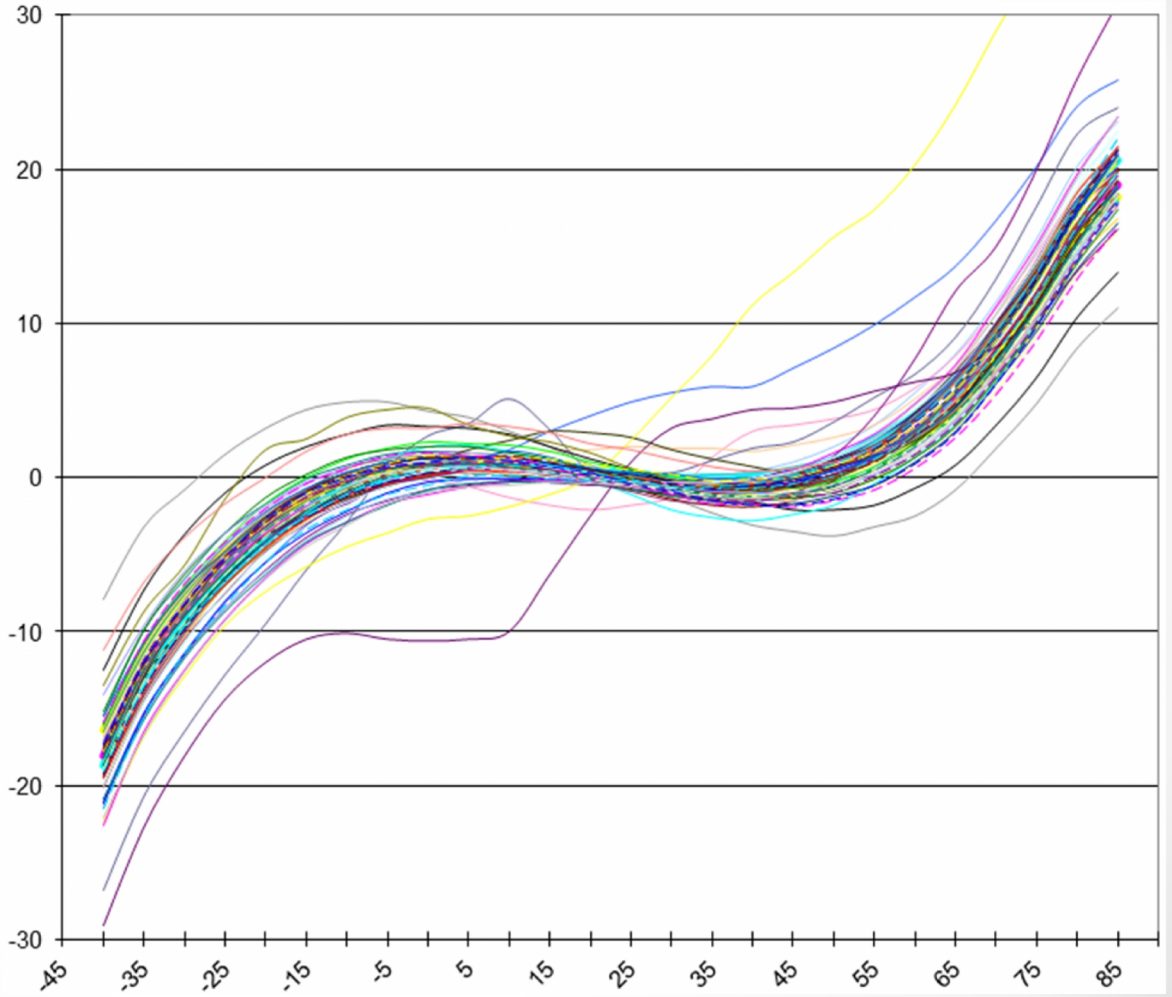
Crystal Overdrive: Practical Example

Note the smooth frequency curve over the operating temperature range of a properly configured crystal. In this example, the crystal is driven at 10 µW.



Crystal Overdrive: Practical Example

Note the “bumps” in the frequency curve over the operating temperature range of an improperly configured crystal. In this example, the crystal is over-driven at 500 µW.



Crystal Overdrive: Practical Example

This table shows the effect of adjusting the RX resistor in the crystal circuit. The RX resistor is used to help limit crystal drive current. As RX increases, negative resistance decreases.

Also, It is important to properly measure the oscillator negative resistance in the end application to ensure that correct circuit or design margins are used. Please see the application note on negative resistance for further information.

Note the following equations:

|-R| = R + Re where

-R = negative resistance of IC

Re = operating resistance of crystal = $R_{ESR}*(1+C_O/C_L)^2$

Effect of RX Adjustment

RX Ω	C1 pF	C2 pF	R Ω	Re Ω	-R Ω
0	33	27	225	10.5	236
100	33	27	200	10.5	211
200	33	27	174	10.5	185
301	33	27	163	10.5	174
453	33	27	140	10.5	151
500	33	27	120	10.5	131

Crystal Overdrive: Practical Example

This table shows the effect of adjusting C1 and C2 on negative resistance in the crystal circuit. These capacitors are used to adjust the phase of the oscillator circuit. As they are lowered in value, they provide more gain which results in higher negative resistance.

Effect of C1 and C2 Adjustment

RX Ω	C1 pF	C2 pF	R Ω	Re Ω	-R Ω
0	33	27	225	10.5	236
0	15	15	200	10.5	680
0	10	10	174	10.5	>1k
0	8.2	8.2	163	10.5	>1k

Crystal Overdrive: Practical Example

This table shows the effect on crystal drive of adjusting the RX resistor in the crystal circuit. As RX increases, drive decreases. This is the whole purpose for adding the RX resistor.

Note the following equation:

Drive Level = I^2 * Re where

I = crystal current (RMS)

Drive Level vs. RX Adjustment

RX Ω	C1 pF	C2 pF	I mA	Re Ω	DL µW
0	33	27	7.49	10.5	589
100	33	27	5.74	10.5	346
200	33	27	4.93	10.5	255
301	33	27	4.38	10.5	201
453	33	27	3.64	10.5	139
500	33	27	3.61	10.5	137

Crystal Overdrive: Practical Example

This table shows the effect of drive level after adjusting C1 and C2 in the crystal circuit. As C1 and C2 are lowered in value, the crystal drive level decreases and negative resistance also improves. These are desirable effects as well.

Drive Level vs. C1/C2 Adjustment

RX Ω	C1 pF	C2 pF	I mA	Re Ω	DL µW
0	33	27	7.49	10.5	589
0	15	15	5.06	10.5	269
0	10	10	3.62	10.5	138
0	8.2	8.2	3.38	10.5	120

Crystal Overdrive: Practical Example

This table shows the final results of the real customer circuit analysis and solution.

In this specific case, it was necessary to add an RX that was not previously being used to limit the crystal drive current. This has the adverse affect of reducing the oscillator negative resistance though. To offset that, the capacitors C1 and C2 must be lowered in value to increase the oscillator negative resistance. Ultimately, this lowers the crystal load capacitance as well. However, the end results are a circuit with lower crystal drive, clean frequency vs. temperature performance, potentially increased negative resistance, and better circuit margin.

Final Circuit Changes:

1.Insert RX value of 301 ohms

2.Revise C1 and C2 to 22 pF

3.Lower CL of crystal to 14 pF

Results:

1. Increased negative resistance
2. Decreased drive level.

DESIGN	CL pF	F ppm	RX Ω	C1 pF	C2 pF	F ppm	-R Ω	DL µW
Original	20	-4.6	0	33	27	-6.33	236	589
New	14	0.2	301	22	22	2.6	318	118

Crystal Overdrive: Design Flowchart

1. Characterize IC negative resistance vs. RX
2. Characterize IC negative resistance vs. C1/C2
3. Measure crystal current vs. RX
4. Calculate drive level vs. RX
5. Measure crystal current vs. C1/C2
6. Calculate drive level vs. C1/C2
7. Choose optimum RX and C1/C2 based on
   - Negative resistance
   - CL
   - Drive level

ALWAYS CONSULT YOUR CRYSTAL SUPPLIER

EARLY IN THE DESIGN CYCLE!