# AN10289

## LPC900 external crystal start-up

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**Application note**

Semiconductors

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# 1. Introduction

The LPC900 family high frequency crystal oscillator consists of an inverting linear transconductance amplifier that is capable of amplifying signals from 4 MHz to 12 MHz. Integral to the amplifier is a feedback resistor that is connected from the input to the output of the amplifier.

## 1.1 Scope

This document will describe how to bias the high frequency crystal oscillator of the LPC900 family by adding an external biasing resistor. Biasing the external crystal oscillator will result in a more robust start-up.

This document takes a close look at the characteristics of the LPC900 high frequency oscillator such as the DC characteristics of the LPC900 family's high frequency oscillator and the open circuit biasing point of the high frequency oscillator. Equations will be given to calculate the minimum $g_m$ required with a certain shunt capacitance.

# 2. LPC900 family high frequency oscillator characteristics

## 2.1 Oscillator feedback resistor

The typical value of the feedback resistor between the in and output of the inverter range from 1.3 M$\Omega$ to 1.5 M$\Omega$. The feedback resistor is shown in Figure 2.

## 2.2 DC transfer characteristics

The buffer's DC transfer characteristics were measured for a group of parts. Figure 1 shows typical DC transfer characteristics of the high frequency oscillator on the LPC900 family. The two horizontal lines on the graph indicate the output voltage range of the buffer in the open state. The graph indicates that the DC operating point is not in the centre of the linear region. In fact, it is near the bottom where the gain is slightly smaller.
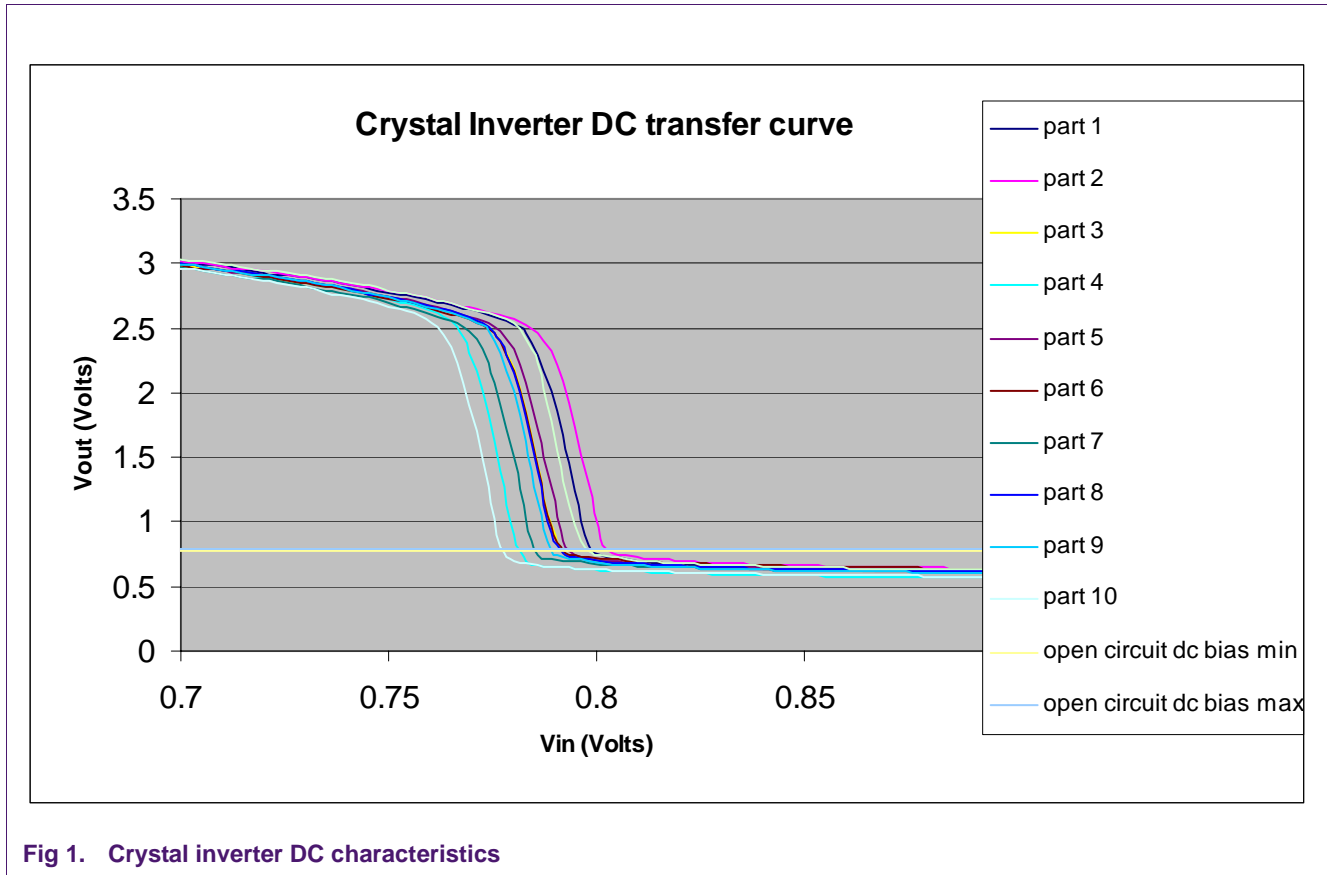
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**Crystal Inverter DC transfer curve**

Fig 1.   Crystal inverter DC characteristics
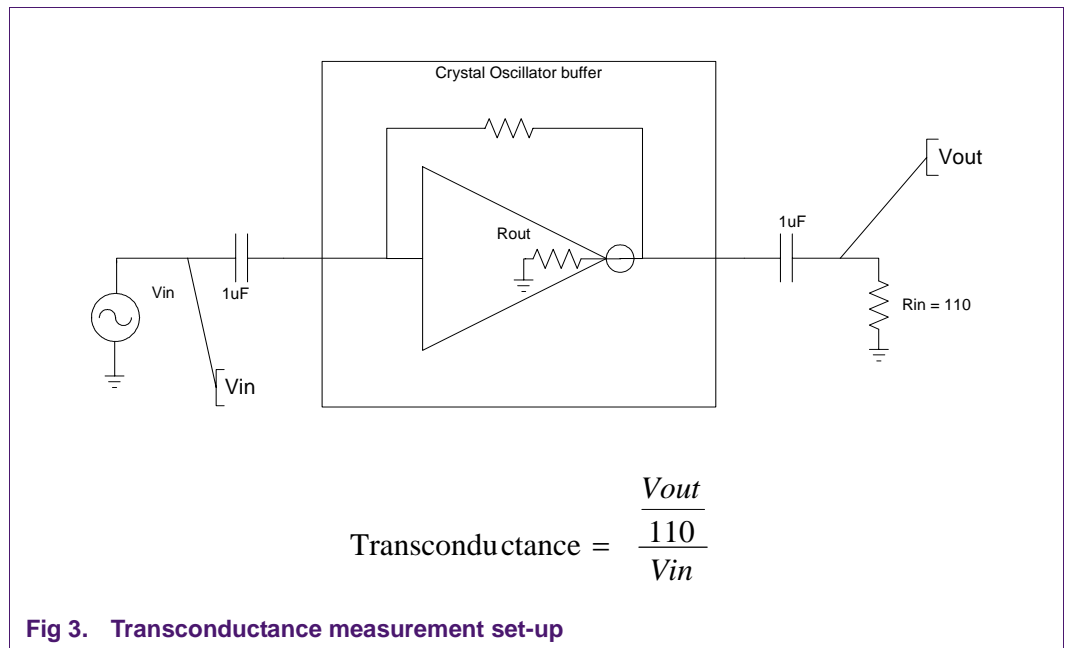
## 2.3   Small signal output impedance

Another measurement that was made on a group of parts was the small signal output impedance. This was done by AC coupling a signal into the output, and then measuring the ratio of the output voltage to the input voltage. Figure 2 shows the test circuit used to measure the output impedance and also the equation to calculate it based on the output to input voltage.

$$output\ impedance\ =\ \frac{Rin \cdot \dfrac{Vout}{Vin}}{1 - \dfrac{Vout}{Vin}}$$

**Fig 2.  Output impedance small signal test set up**
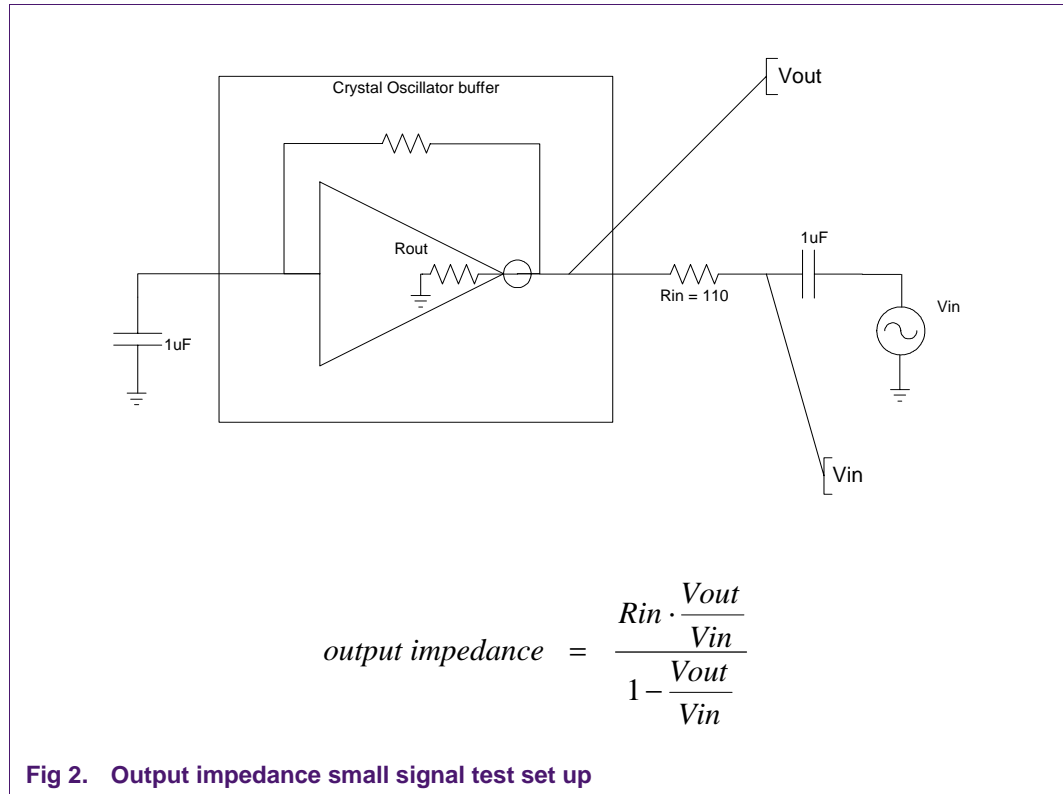
The data for this measurement ranged from 2 kΩ to 5 kΩ for the LPC900 family high frequency oscillator.

## 2.4  Small signal transconductance

The small signal transconductance was measured by AC coupling a fixed load to the output, then measuring the ratio of the output current to the input current. Figure 2 shows the test circuit used to measure the transconductance, and the equation to calculate it based on the output to input voltage. The measurements ranged from 0.0022 to 0.0029 when biased in the 'open' configuration; that is, it is not biased with external components.

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$$\text{Transconductance} = \frac{\dfrac{Vout}{110}}{Vin}$$

**Fig 3. Transconductance measurement set-up**

## 2.5 Bias point adjustment

When looking at the DC transfer curves the natural bias point of the high frequency oscillator did not provide the maximum gain for start up. The open circuit output voltage of the buffer ranged from 0.77 V to 0.79 V. This puts the small signal gain on the shallow part of the curve.

The DC operating point can be changed by putting a 1 MΩ resistor to ground on the input side of the oscillator buffer. This resistor is a external part and is labelled as Rbias in Figure 5.

By adding this resistor, the DC operating point of the buffer is centred in the middle of the linear region of the buffer, by biasing the crystal oscillator to the maximum gain region it will make start-up more robust.
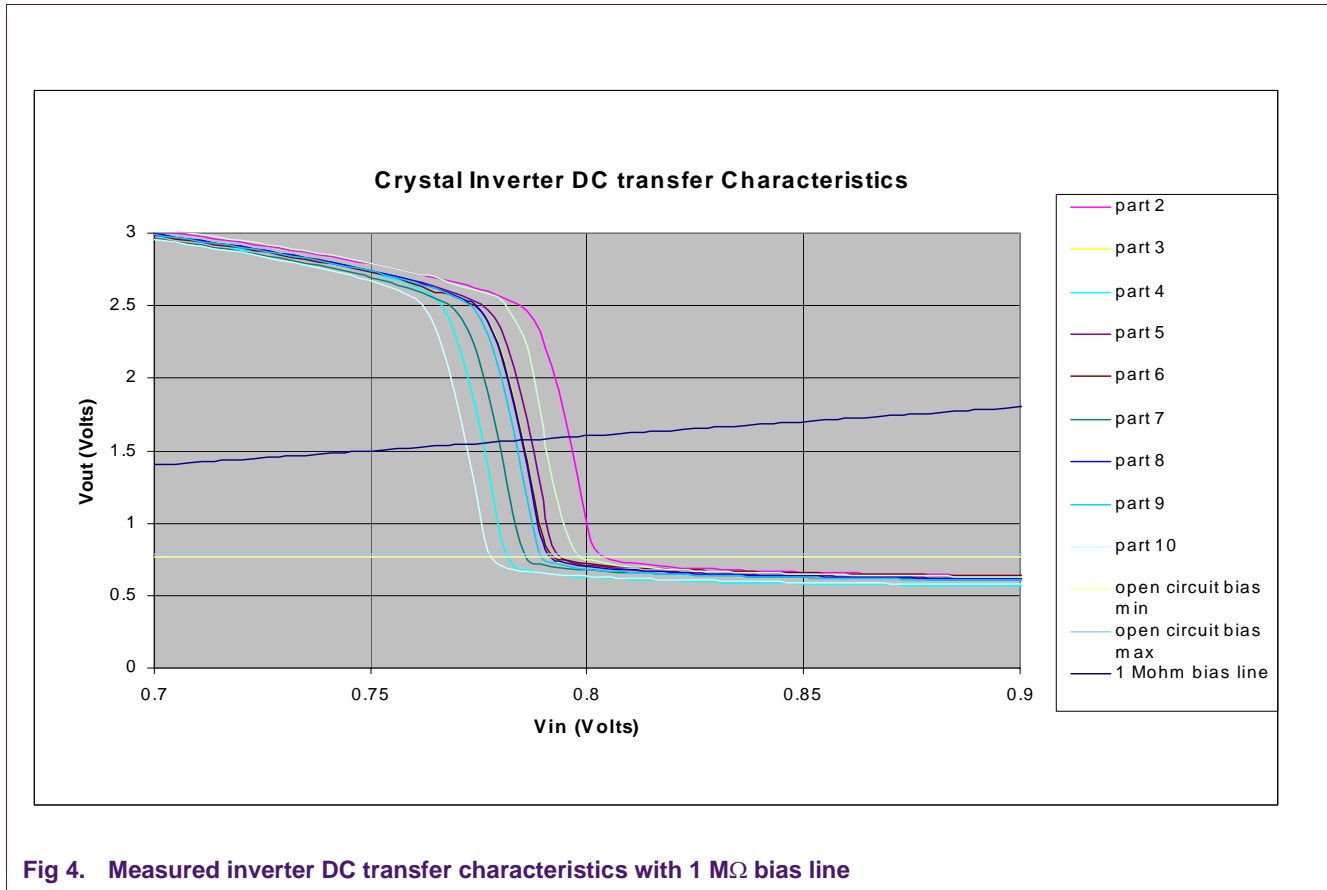
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**Fig 4. Measured inverter DC transfer characteristics with 1 MΩ bias line**

## 2.6 Minimum required transconductance

The minimum required transconductance for oscillation can be calculated from the formula shown in Equations (1) and (2). This equation is taken from [2], application note AN97090:

(1)

$$g_m \geq R_S \cdot \frac{\omega_o^2 C_O^2 (C_1 + C_2)^2}{C_1 C_2} + \frac{1}{R_P} \frac{(C_1 + C_2)^2}{C_1 C_2} + \frac{1}{R_O} \frac{C_1}{C_2}$$

If C1 = C2, this equation reduces to:

(2)

$$g_m \geq 4 \cdot R_S \cdot \omega_o^2 C_O^2 + \frac{4}{R_P} + \frac{1}{R_O}$$

**Equations (1) and (2) - Minimum requirements with no bias resistor.**

However, adding the bias resistor on the input side to ground increases the requirements. The equation for minimum requirements with the bias resistor is shown in Equations (3) and (4):

(3)

$$g_m \geq R_S \cdot \frac{\omega_o^2 C_O^2 (C_1 + C_2)^2}{C_1 C_2} + \frac{1}{R_P} \frac{(C_1 + C_2)^2}{C_1 C_2} + \frac{1}{R_O} \frac{C_1}{C_2} + \frac{1}{R_{Bias}} \frac{C_2}{C_1}$$

If C1 = C2, this equation reduces to:

(4)

$$g_m \geq 4 \cdot R_S \cdot \omega_o^2 C_O^2 + \frac{4}{R_P} + \frac{1}{R_O} + \frac{1}{R_{Bias}}$$

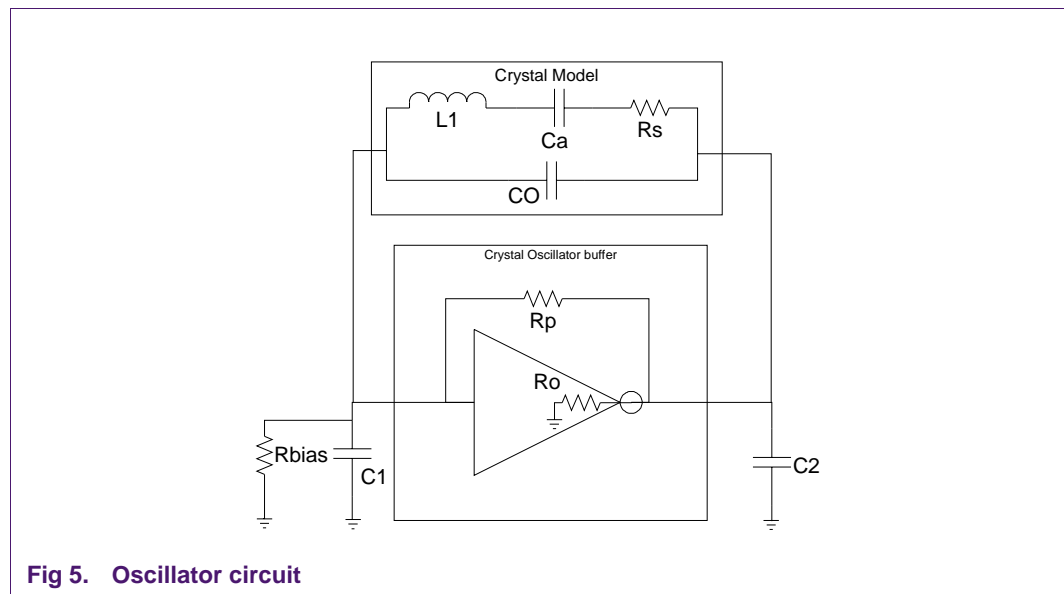**Equations (3) and (4) - Minimum requirements with bias resistor.**



**Fig 5.   Oscillator circuit**

## 2.7  Calculated $g_m$ requirements

Using the equations shown above, Table 1 shows the minimum $g_m$ required compared to what was measured.
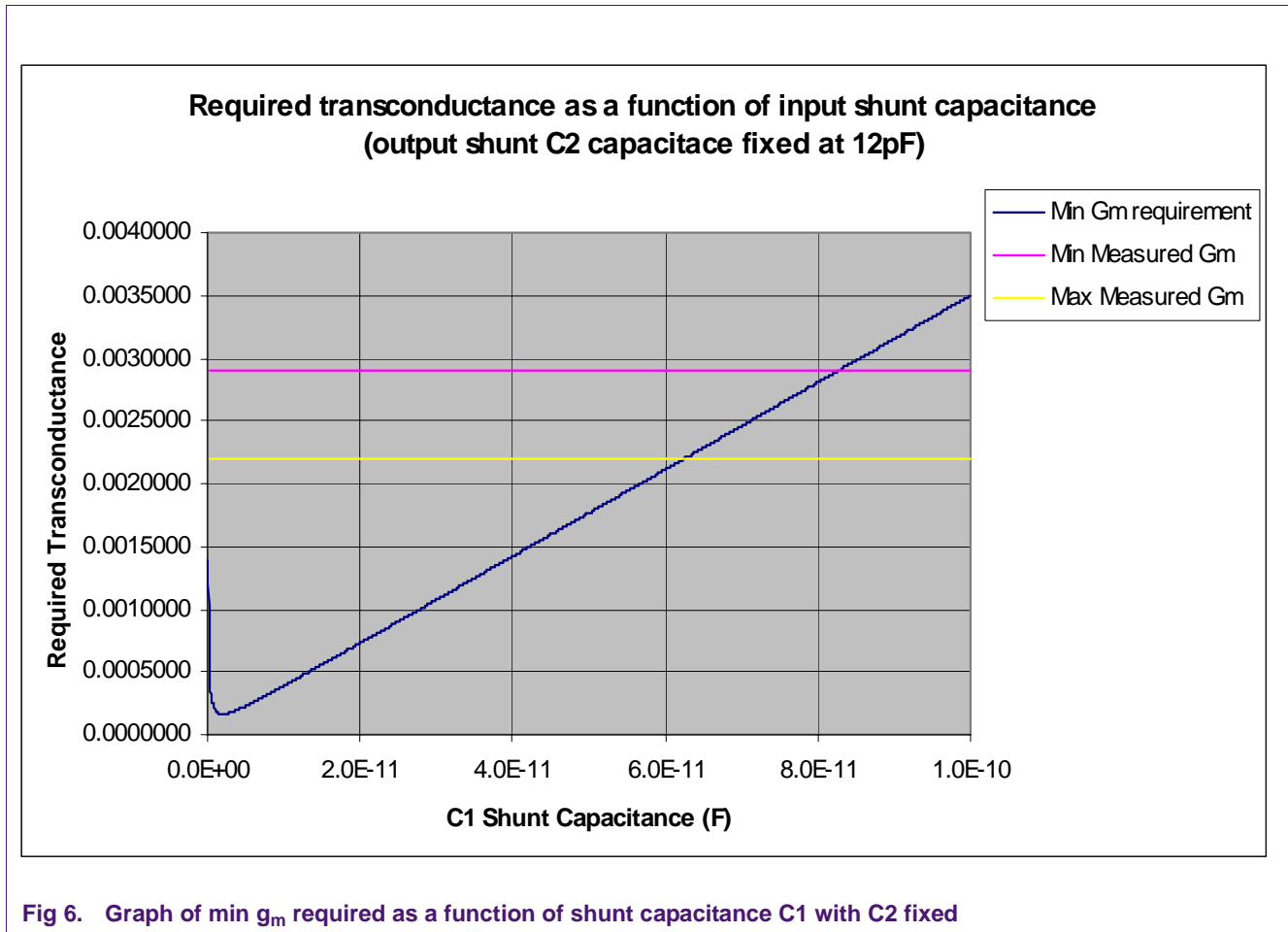
**Table 1:     $g_m$ calculations**

| F0 = 12 MHz | Rs = 3K | Rp = 1.3 M$\Omega$ | Co = 15 pF |
|---|---|---|---|
| Rbias = none | $g_m \geq 0.000387$ | $g_m$ measured min 0.0022 | |
| Rbias = 1M$\Omega$ | $g_m \geq 0.000388$ | $g_m$ measured min 0.0031 | |

The data in Table 1 shows that the part has significantly more gain than required with the 1 M$\Omega$ bias resistor. Rbias is the added external resistor to centre the oscillator buffer DC bias in the center of the linear region.

## 2.8  Additional $g_m$ verification test

Figure 6 shows a graph of the minimum $g_m$ required as a function of C1 with a fixed C2 shunt capacitance. Also plotted on this graph are the min and max measured $g_m$ from a sample of parts. It shows that the part should stop oscillating with a shunt capacitance

between 65 pF and 85 pF. A test circuit showed that oscillations stopped with approximately 80 pF for C1. This was another verification that the measured $g_m$ was within the correct range.

**Required transconductance as a function of input shunt capacitance
(output shunt C2 capacitace fixed at 12pF)**

Required Transconductance

- Min Gm requirement
- Min Measured Gm
- Max Measured Gm

C1 Shunt Capacitance (F)

**Fig 6.    Graph of min $g_m$ required as a function of shunt capacitance C1 with C2 fixed**

## 2.9  Bias resistor testing

Besides the calculations that were presented in this paper, the oscillator start up was also verified over temperature using the external bias 1 MΩ bias resistor. The temperature was adjusted from −55 °C to +125 °C and started over the full temperature range.

# 3.  Conclusions

The oscillator DC characteristics shows that the dc bias point was toward the bottom side of the transfer curve. This indicated that the start up gain of the oscillator could be slightly lower.Using an additional external resistor to raise the bias point to the centre of the inverter's linear region improves the start-up gain. This resistor increases the $g_m$ requirements slightly, but the part has adequate margin to overcome this increase.

## 3.1 Important note

Every crystal circuit will vary with the main variables being the selected crystal the shunt capacitors the microcontroller's oscillator characteristics and the PCB's board capacitance and noise immunity on the crystal pins.

All these variables will influence the crystal start-up of an application, care has to be taken to qualify the crystal start-up of each application.

# 4. References

**[1]** **X-tal oscillator on 8 bit microcontrollers AN96103 —** Audre Pauptit, Erik Norberg, Application note, 20 Sept 1996, Draft, Philips System laboratory group, Eindhoven the Netherlands, Telecom products group, Zuerich.

**[2]** **X-tal oscillators on 8 bit microcontrollers (2) AN97090 —** Audre Pauptit, Wim Rosink, , Application note, 11 Dec 1997, Draft, Philips System laboratory group, Eindhoven the Netherlands.

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