Benefits of Automatic Level Control (ALC)

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Variations in the process, voltage, temperature, etc. influence the operation of a crystal oscillator circuit. There could be start up problems, signal clipping, frequency drift and crystal mode coupling issues. Current oscillator designs employ various techniques to overcome the above problems, but PhaseLink solves the related, mentioned above, in a unique circuitry design called Automatic Level Control (ALC).

Basically, an oscillator circuit consists of an amplifier and a feedback network that creates a path from the amplifier output, back to the amplifier input. To stabilize the feedback path, a quartz crystal is used to limit the 'instability' and force it to occur at the crystal's frequency. This produces a signal with a very accurate frequency. This is why crystal oscillators are so popular. However, there are side effects that have a significant influence on the frequency accuracy and the ALC circuit is helping to prevent these side effects for the best possible frequency accuracy and stability.

ALC Maintains the Drive Level Steady

The problem with most crystal oscillators is that the frequency may be very well controlled but the oscillation signal level is not. Usually, after 'power on', the oscillation signal level will start increasing until the amplifier starts 'clipping'. Oscillator circuits are often designed with very large gain margins to assure oscillation even with the worst of crystals. The result is that with most 'good' crystals the oscillation signal level increases to high levels and clipping is rather violent. Ten years ago, this was not really a problem since the crystals then used sizable pieces of quartz that were able to deal with the power levels. A common specification, in those days, was 500µW or 1mW maximum power or "drive level". These days, however, we're faced with dealing with tiny quartz crystals, in ceramic substrates, that are as small as $2.5\times2.0mm^2$ and $2.0x1.6mm^2$. Power handling of these small crystals is more like 50µW maximum.

ALC Limits Drive Power

PhaseLink's PLL600, PL610, PL611s, PL671 and PL613 family of clock IC's are designed with the ALC feature in the crystal oscillator circuit. The ALC circuitry can constantly maintain the oscillation signal to a defined level. With ALC, the drive level is typically between 10µW and 40µW, making the clock ICs with ALC feature an ideal clock for use with small crystals, in small ceramic substrates. Overdriving quartz crystals leads to aggravating effects like mode coupling and it might also speed up aging.
See Figure 1 in "Measurements" below for a Drive Power example.

ALC Improves Crystal Oscillator Startup

The oscillator gain or "negative resistance" of a crystal oscillator is often designed as a compromise between having enough gain to start up and not have so much gain that signal clipping or drive power, once started up, becomes a problem. The ALC allows us to not worry about having too much gain so we have designed our crystal oscillator with ALC with a lot more gain margin than what is usually implemented. The bigger oscillator gain improves startup reliability with crystals that have a relatively high ESR value. As a bonus the startup time is also reduced significantly versus conventional crystal oscillator designs.

ALC Improves Phase Noise

Limiting the power or the drive level are not the only contributions of the ALC circuitry to the clock IC design. The violent clipping of the amplifier in an uncontrolled oscillator causes additional phase noise. The ALC circuit now limits the oscillation signal level and there is no more violent clipping of the amplifier. As a result, the phase noise properties of PLL600, PL610, PL611s, PL663 IC families are excellent.
See Figure 3 in “Measurements” below for an example phase noise plot.

ALC Improves Power Supply Immunity

The signal level that an amplifier can sustain depends greatly upon the power supply voltage. As a result, the drive level varies a lot with the power supply voltage. More importantly, circuit properties that influence frequency also vary a lot with the power supply voltage! Frequency variations of ±5ppm with ±10% power supply variation are common. The ALC, on the other hand, keeps the oscillation level constant so there are no large drive level fluctuations or frequency variations. For example, the frequency variation of PhaseLink’s PL610 with a typical fundamental crystal and 10% power supply is typically ±0.2ppm. Changing the power supply from 1.6V to 3.6V (operating power supply range for PL610) does not result in more than 1ppm frequency change. Without ALC, power supply voltage regulators (LDO’s) may be required, if good power supply immunity is needed. The ALC regulates the oscillation signal level very well, so additional regulation of the power supply is not required.
See Figure 2 in “Measurements” below for an example VDD immunity graph.

ALC Improves Temperature Stability

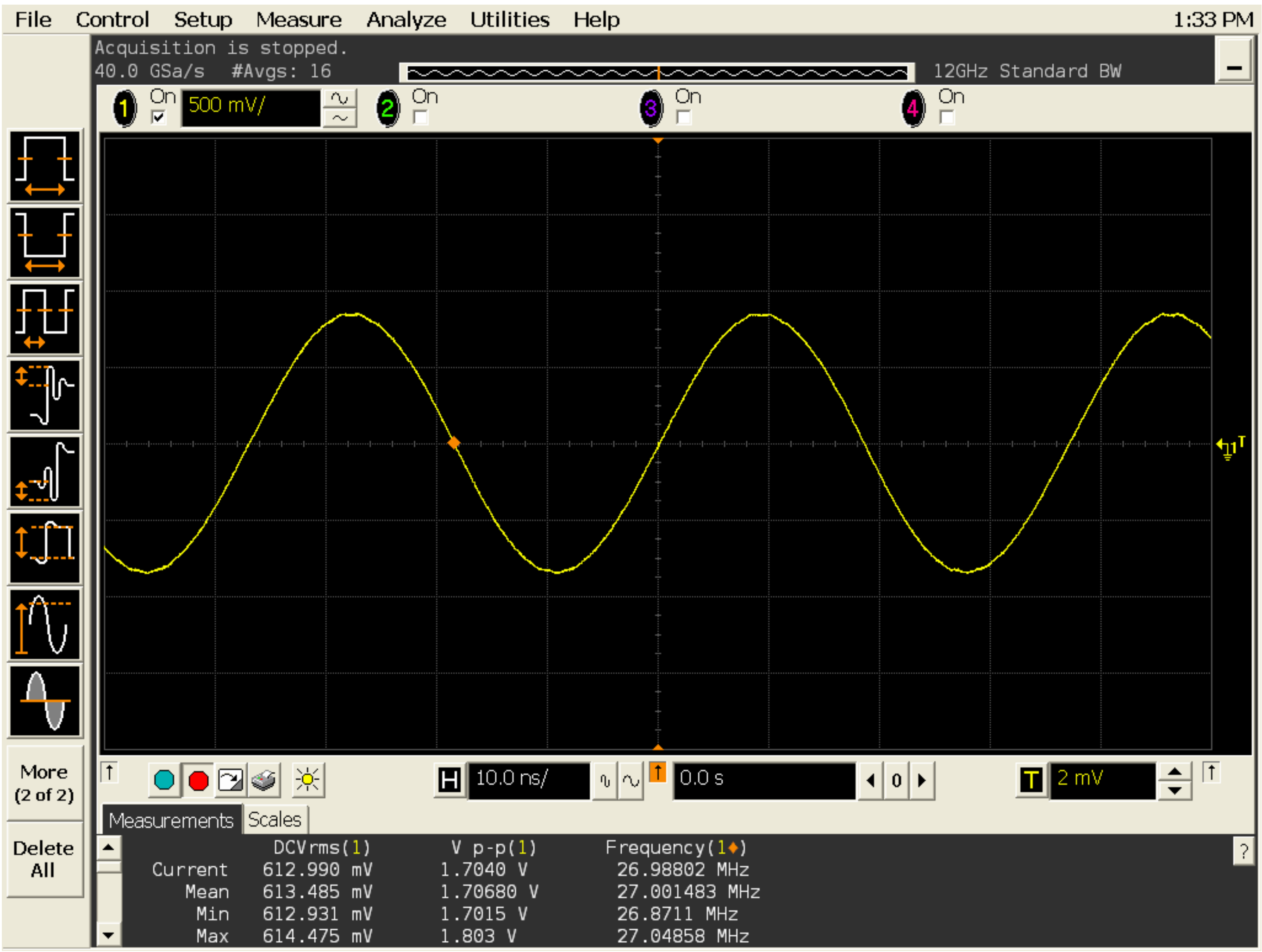
Clipping the oscillation signal in the power supply rails or pushing amplifier transistors deep into saturation will have temperature dependent side effects. Often one needs to correct the crystal angle to end up with an overall acceptable temperature curve. But then, variation in the crystal resistance occurs that results in changing the temperature coefficient again. The end result is much more variation in the overall temperature curves than the contribution of the crystal alone.
With ALC, the variation in the temperature coefficient, from the oscillator circuit, is minimal. Variation in crystal resistance has minimal influence on the overall temperature curve and you end up with less variation in temperature curves. The result is simply a more accurate output frequency.
See Figure 4 in “Measurements” below for example temperature curves.

Conclusion

PhaseLink’s ALC is the result of many years of experience and trials. It was first introduced in 2003 in the PLL600 series of clock oscillator IC’s and the success of the ALC in these IC’s made us use it in many more crystal oscillator designs after 2003. Our ALC technology is very mature and fully stable, and is designed in our PL611s (PicoPLL™) and PL610 (PicoXO™), the world’s smallest programmable clock products.
The presence of ALC makes is a very sweet little oscillator circuit, running a very low noise and stable oscillation, while providing plenty ‘gain margin’ at startup.

Measurements

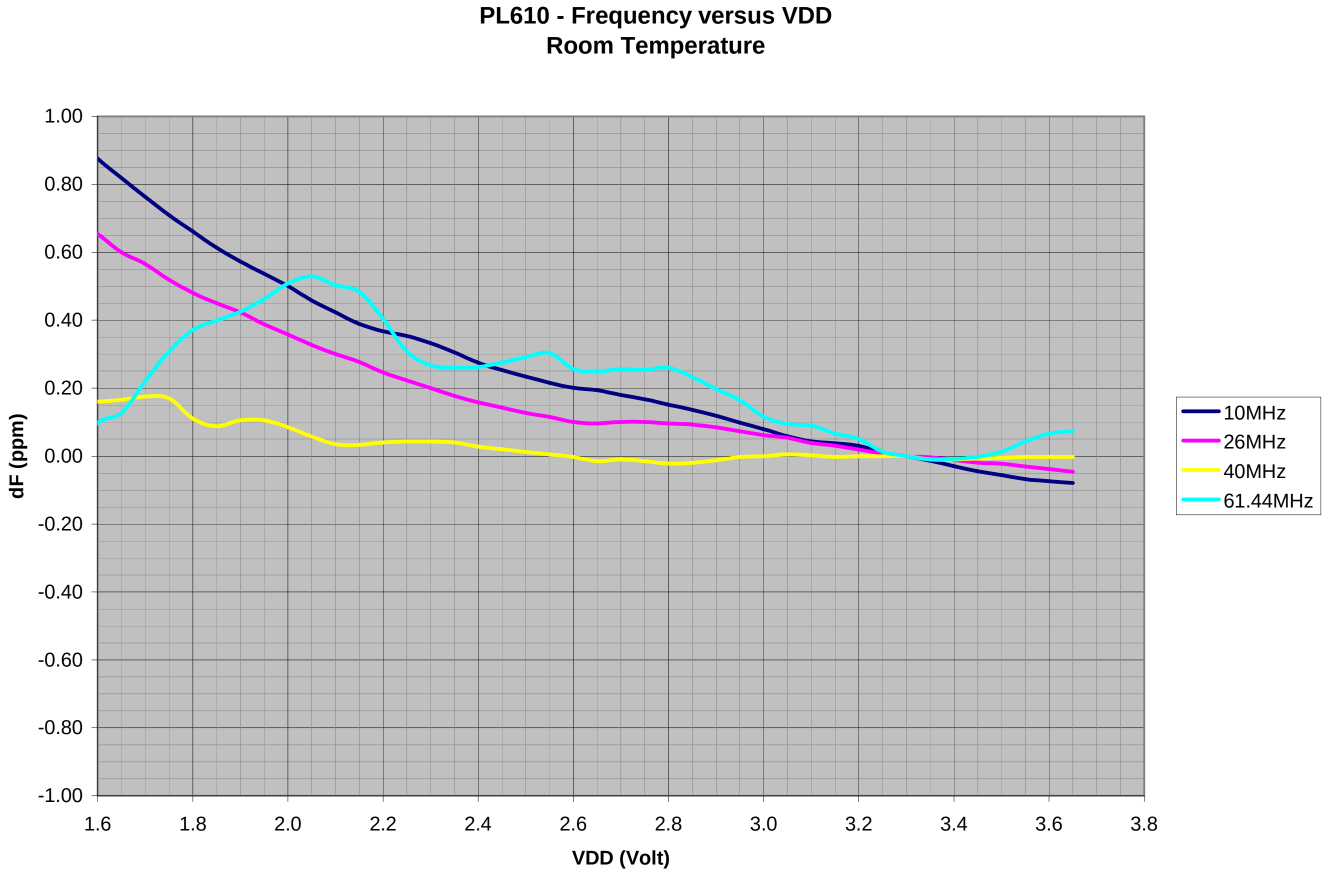
Figure 1: Voltage across the crystal with PL610 and 27MHz crystal



In this case the CL value of the PL610 is 12pF so the current through the crystal is about 1.25mArms. With a typical crystal ESR of 20 ohms this would be about 30uW of power drive.

This waveform was measured with a differential probe across the crystal.

Figure 2: Power Supply Variation Immunity



This graph shows how with the PL610 the total frequency variation from VDD=1.6V to VDD=3.6V stays within +/-1ppm for frequencies between 10MHz and 60MHz.

Figure 3: Phase Noise

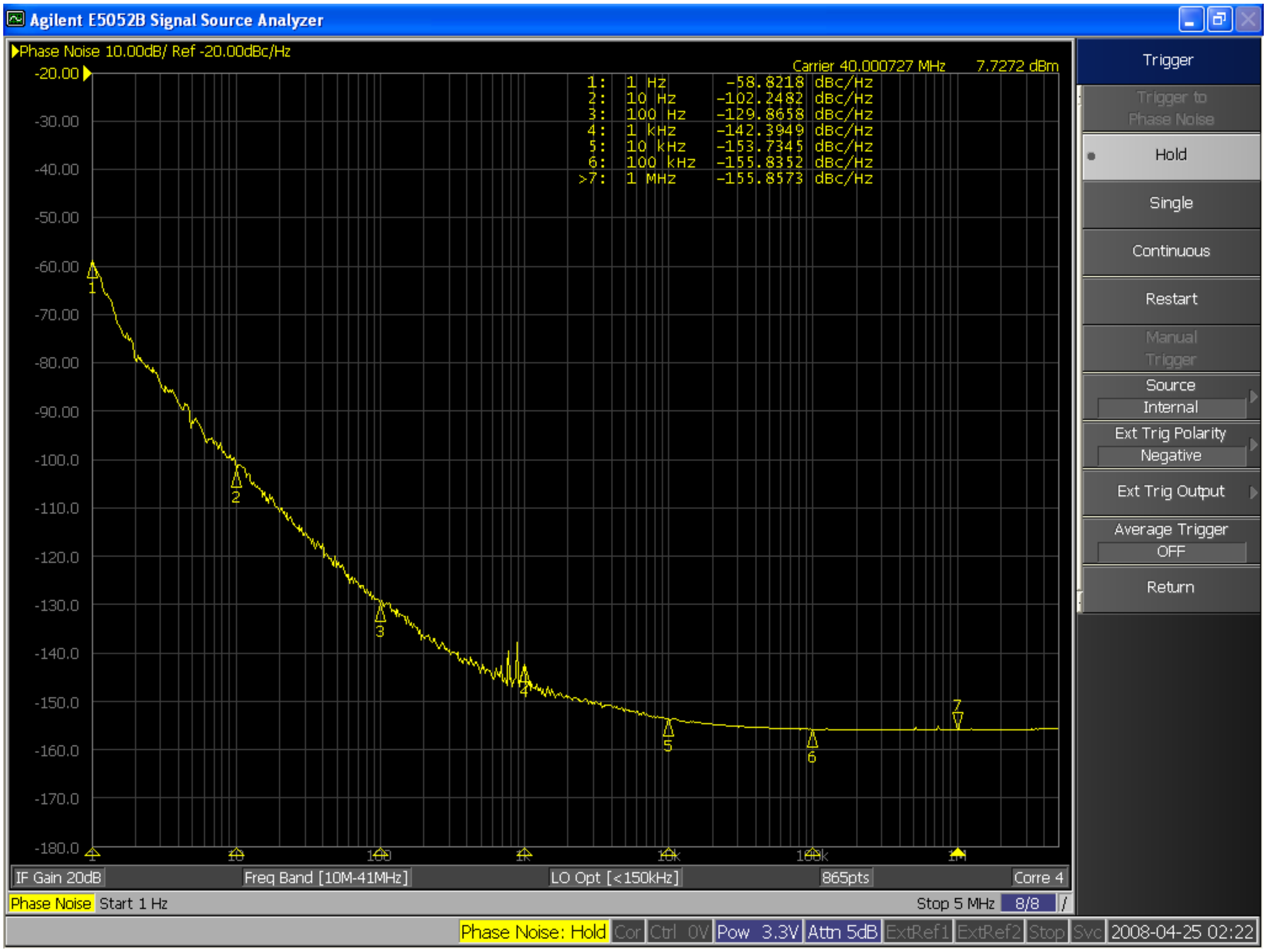


Figure 4: Temperature Curves