



WHITE PAPER:

ANALOG FREQUENCY MULTIPLIER

Enabling Low Cost Frequency Source While Preserving
Phase Noise and Jitter in High Frequency Applications

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OVERVIEW

With faster data transmission rates and the growth of RF applications demanding stable frequency sources (such as SONET/SDH, Fiber Channel, 10Gbit Ethernet, etc.), engineers are often struggling to find low jitter, low phase noise and low cost solutions for frequencies between 50MHz and 1GHz. Several elements contribute to the difficulty of meeting apparently contradicting, if not technically impossible, objectives.

In this White Paper, we will explore these existing limitations in order to better understand the solutions that are offered to engineers. This will thus help us confront the drawbacks of solutions that are now offered and highlight the reasons why Analog Frequency Multiplication is a highly attractive solution from technical as well as economical aspects.

PhaseLink's Analog Frequency Multiplication is an integrated design approach that reaches high frequency with the best possible jitter and phase noise performance, with only a limited cost impact. The advantages of Analog Frequency Multiplication are presented in more details later in this White Paper.

1. TECHNICAL LIMITATIONS TO COMMON CLOCK REFERENCE SOLUTIONS

With regard to clock references, it is well known that cost is in direct relationship with the desired clock frequency and its target accuracy (jitter and phase noise). Unfortunately, this relationship can impact the price of a clock solution by one or more orders of magnitude as both frequency and accuracy specifications are tightened. Most common technologies use Bulk Acoustic Wave (BAW) crystals and Surface Acoustic Wave (SAW) crystals as a reference clock when accuracy is most critical, and/or implement Phase Locked Loop designs around ring oscillators or LC-VCOs to reach higher frequencies, often starting from a reference signal itself generated by a crystal.

In the paragraphs below, we rapidly present the main limitations that PhaseLink's Integrated *Analog Frequency Multiplier* (AFM™) can overcome.

1.1. BULK ACOUSTIC WAVE (BAW) CRYSTALS: TOO EXPENSIVE AT HIGH FREQUENCY

It is widely accepted that of all forms of commercially available oscillators, piezo-electric crystals provide the only acceptable performance for high-end applications that require low phase noise and low jitter, using the high quality (Q) factor of such oscillators. However, these solutions have frequency and affordability limitations.

The most common crystals found commercially are BAW crystals. They vary in terms of their oscillation modes (overtone or fundamental) and their fabrication (flat or mesa blanks); these two elements are directly related to the complexity of their manufacturing and thus their cost. The general rule is that the higher the frequency, the more difficult to manufacture, the lower the yield and the higher the cost. As a consequence, BAW crystals present two main limitations: affordability and available frequency.

Two important differences between fundamental and overtone crystals explain their differences in cost and target applications: 1) for a given oscillation frequency, overtone crystals will be cheaper to manufacture than fundamental crystals, 2) fundamental crystals have higher pull sensitivities than overtone crystals.

From a user perspective, the pull sensitivity translates in the possibility to tune the oscillation frequency of a fundamental crystal by up to 200 ppm around the nominal frequency by altering the capacitive load presented to the crystal. This property has been widely exploited in Voltage Controlled Crystal Oscillators (VCXO), which use an input voltage to control a variable capacitor. Unlike fundamental crystals, the pull sensitivity of overtone crystals only permits frequency excursions of up to 50 ppm, making them unusable for VCXO.

For fixed frequency oscillators (generally called crystal oscillators - XO), both overtone and fundamental crystals are used, with manufacturing cost as the main determinant for selection. In general, an XO will cost much less than a VCXO.

Table 1 summarizes the manufacturing limits of BAW crystals, and their impact on prices (typical price ranges, actual prices depend on volume, suppliers and other crystal specificities, and continuous technology improvements from crystal manufacturers. Prices

only reflect the price of the crystal, and do not include additional costs for an oscillator circuit used in manufacturing an XO or a VCXO).

Crystal Types	Flat Blanks		Mesa Blanks	
Crystal Cost	< \$0.25	< \$1.00	< \$6.00	< \$15.00
Fundamental	< 35MHZ	< 60MHZ	< 160MHZ	< 250MHZ
3 rd Overtone	< 100MHZ	< 150MHZ	< 400MHZ	< 400MHZ

Table 1. Price impact of BAW manufacturing limits

Typical price ranges, actual prices depend on volume, suppliers and other crystal specificities, and continuous technology improvements from crystal manufacturers. Prices for crystal only, excluding additional costs for manufacturing XOs or VCXOs. See Table 2 for typical pricing table using Analog Frequency Multiplication.

As shown on Table 1, fundamental crystals stop being available as of frequencies above 250 MHz, and third overtone crystals stop being available as of above 400MHz.

1.2. SURFACE ACOUSTIC WAVE (SAW) CRYSTALS: INADEQUATE TEMPERATURE TOLERANCE

SAW crystals tend to be less common in frequency reference applications given their wider temperature tolerance (> 200ppm from -40°C to +85°C), and higher tooling costs for a given frequency make SAW based clock reference solutions inadequate for most high accuracy applications. However, SAW based technologies are most suitable to reach higher frequency ranges, from 200MHz to 800MHz. As a result SAW based products are most typically used as high frequency VCOs in PLL designs (or as filters, which are beyond the scope of this White Paper).

In addition to the poor temperature tolerance of SAW devices, the limited number of SAW crystal producers for reference clock applications further contributes to the dominance of BAW crystals in this field. PhaseLink’s *Analog Frequency Multiplier* clearly offers a high end alternative to high frequency applications requiring low phase noise and jitter.

1.3. PHASE LOCKED LOOPS: POORER JITTER AND PHASE NOISE FROM VCO

By slaving a high frequency VCO (ring oscillator, LC-VCO, etc.) to a reference signal as done in a Phase Locked Loop (PLL), a high frequency output can be reached starting from a relatively low cost crystal reference. Phase noise and jitter characteristics of the resulting signal are however essentially determined by the quality of the VCO used in the PLL. While PLL solutions have been broadly adopted for applications that do not require high accuracy clock references, Phase Locked Loops often do not meet the tight phase noise and jitter requirements of many high-speed data communication and telecommunication systems.

These tight clock accuracy requirements have long forced the higher end applications to fall back on expensive crystal based reference clock solutions, or to compromise with non ideal jitter and phase noise performance of PLL' s. The objectives of Analog Frequency Multiplication are precisely to alleviate this need to compromise.

2. ANALOG FREQUENCY MULTIPLICATION: THE BENEFITS WITHOUT THE COST

Starting from a crystal reference, PhaseLink' s Analog Frequency Multiplication solutions provide an output at double or quadruple frequency with practically no jitter and phase noise deterioration. They implement an analog amplification of the higher frequency harmonics (at double or quadruple frequency) combined with an attenuation of the fundamental of the reference crystal.

2.1. PERFORMANCE EQUIVALENT TO A CRYSTAL' S, BUT AT HIGHER FREQUENCY

The performance of Analog Frequency Multiplication can be demonstrated by measuring the resulting phase noise, jitter histogram and subharmonic levels. Figure 1 shows the jitter histogram of the *2x Analog Frequency Multiplier* at 156MHz. Likewise, Figure 2 shows how the output phase noise of a *2x Analog Frequency Multiplier* from PhaseLink and the phase noise of a fundamental crystal are virtually undistinguishable (measurements made at 156MHz), while figure 3 shows the very low rejection levels of subharmonics that correspond to the exceptionally low jitter performance.

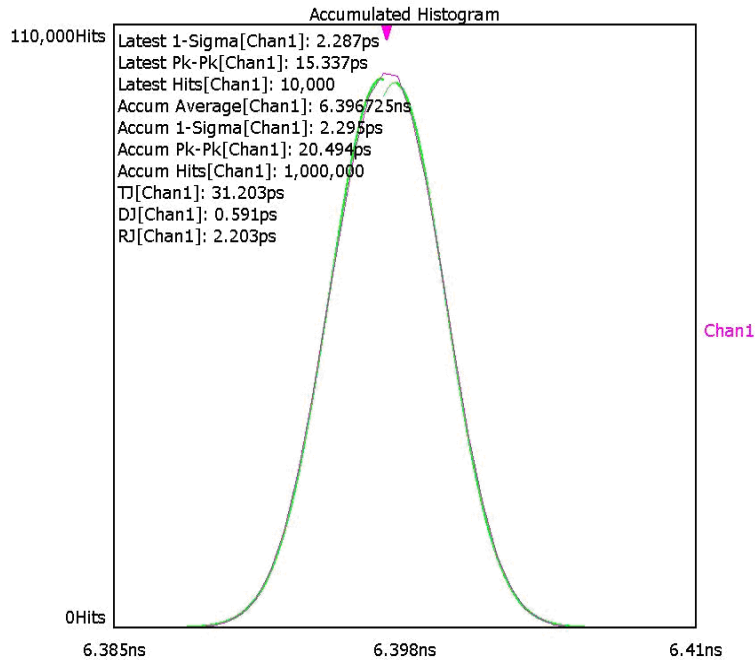


Figure 1. Jitter Histogram at 156.25MHZ

2x Analog Frequency Multiplier with 78.125MHz crystal

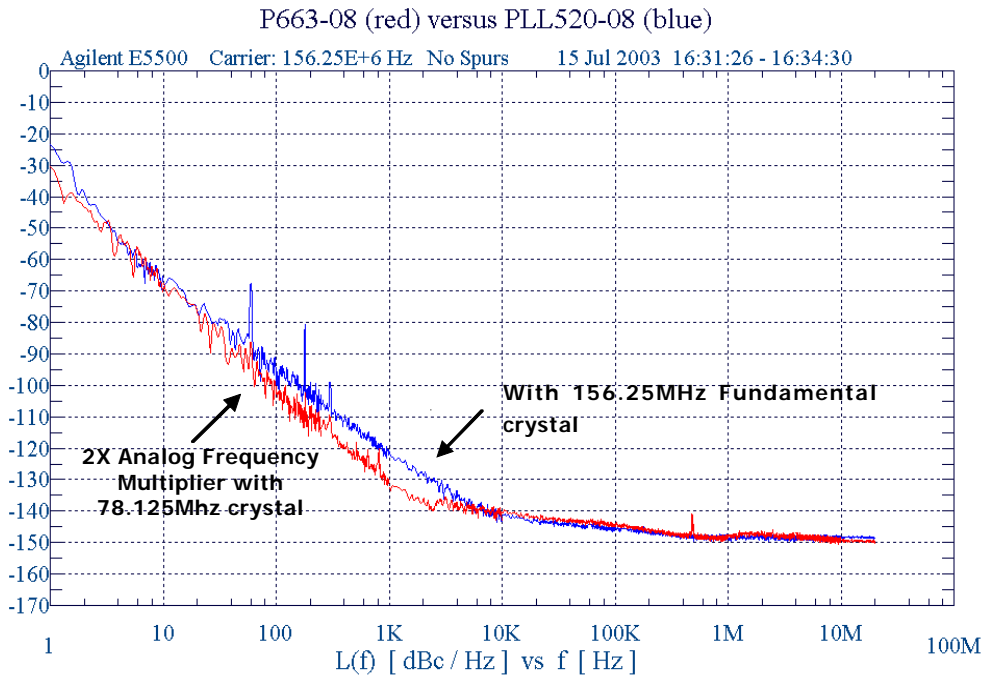


Figure 2. Phase Noise at 156.25MHZ

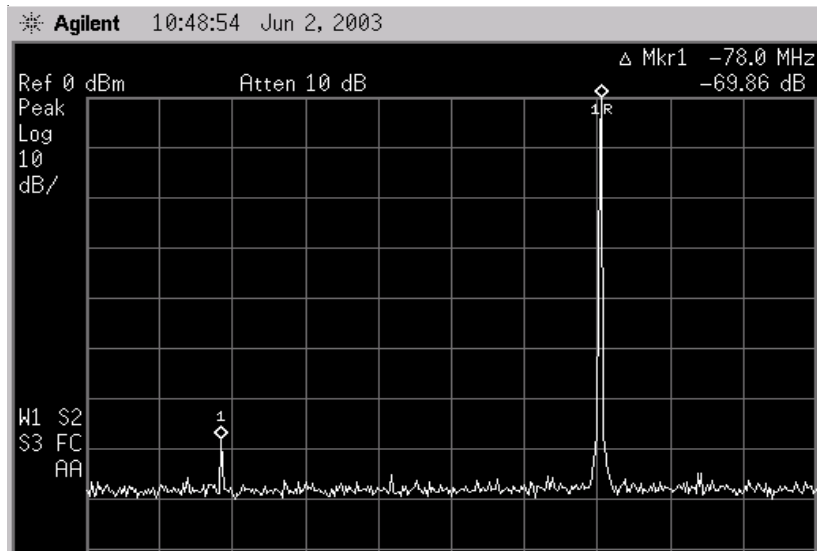


Figure 3. Spectrum Analysis at 156.25MHZ
2x Analog Frequency Multiplier with subharmonic below -69 dBc

Figures 1 to 3 clearly show how Analog Frequency Multiplication is achieved without altering Phase Noise, jitter (peak-to-peak period jitter without filtering still below 17ps, equivalent to a 12kHz to 20MHz bandwidth integrated jitter below 0.3ps), and subharmonic rejection levels below -69dBc (for 2x Analog Frequency Multiplication, 4x Analog Frequency Multiplication achieves subharmonic rejection levels of -45dBc).

2.2. SIGNIFICANTLY LOWER COSTS: UP TO 95% COST SAVING ON CRYSTALS

The major benefit from Analog Frequency Multiplication is therefore its capability to take advantage of lower cost crystals while still reaching higher frequencies (double or quadruple) without compromising on performances.

The direct cost impact has been summarized on Table 2. Prices shown are only indicative and vary from supplier to supplier, volume and exact specifications. For clarity and comparative purposes, Table 1 has been reproduced below Table 2.

Crystal Types	Flat Blanks				Mesa Blanks			
Crystal Cost	< \$0.25		< \$1.00		< \$6.00		< \$15.00	
Analog Frequency Multiplication	2 x	4 x	2 x	4 x	2 x	4 x	2 x	4 x
Fundamental	< 70MHZ	< 140MHZ	< 120MHZ	< 240MHZ	< 320MHZ	< 640MHZ	< 500MHZ	< 1GHZ
3 rd Overtone	< 200MHZ	< 400MHZ	< 300MHZ	< 600MHZ	< 640MHZ	< 1GHZ	< 800MHZ	

Table 2. Maximum Frequency Range given Crystal Type and Cost (using Analog Frequency Multiplication)

Crystal Types	Flat Blanks		Mesa Blanks	
Crystal Cost	< \$0.25	< \$1.00	< \$6.00	< \$15.00
Fundamental	< 35MHZ	< 60MHZ	< 160MHZ	< 250MHZ
3 rd Overtone	< 100MHZ	< 150MHZ	< 400MHZ	< 400MHZ

Table 1. Price impact of BAW manufacturing limits

Typical price ranges, actual prices depend on volume, suppliers and other crystal specificities, and continuous technology improvements from crystal manufacturers. Prices for crystal only, excluding additional costs for manufacturing XOs or VCXOs.

As seen on the above tables, Analog Frequency Multiplication allows users to reach frequencies of 200MHz (using a 2x *Analog Frequency Multiplier*) or even 400MHz (using a 4x *Analog Frequency Multiplier*) starting from a low cost 3rd overtone crystal, bringing a crystal cost saving between 75% and 95%!

3. CONCLUSIONS

PhaseLink's *Analog Frequency Multiplier (AFM™)* is the industry's first 'balanced Oscillator' in CMOS technology, which combined with low frequency crystals, doubles or quadruples the output oscillation frequency without noticeable jitter or phase noise deterioration. This not only permits to reduce crystal costs by up to 95%, but also reaches higher frequencies so far unattainable with similar high performance.

Analog Frequency Multiplication solutions are available in die or IC, as well as PhaseLink's 5.5x7 Integrated Clock Module (ICM) packaging (available for VCXO and XO). Output types include CMOS, LVDS and LV-PECL.

Consult PhaseLink Corporation or visit www.phaselink.com for detail product selector guide.

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