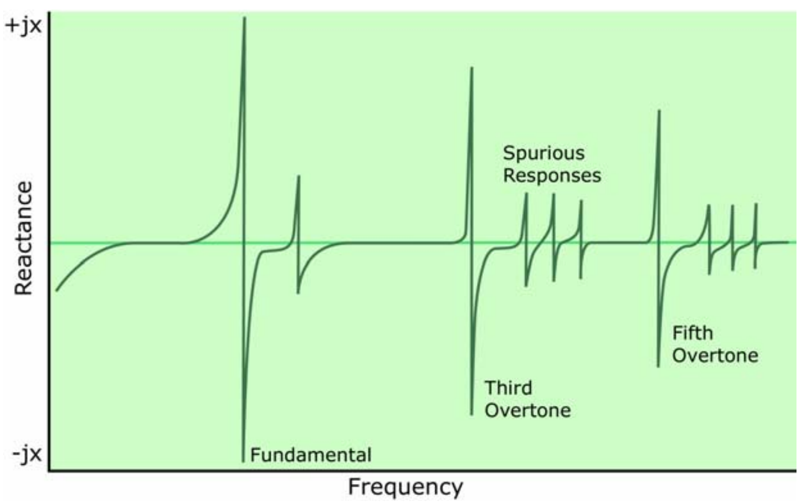
# Application Note: Spurious Modes of AT Cut Quartz Crystals

## Introduction

Often called an "unwanted response", spurious modes are an unwanted mode of operation in bulk acoustic wave (BAW) AT cut quartz crystal resonators. These unwanted modes are caused by inharmonic modes of oscillation at frequencies located typically 500ppm to 3000ppm above the desired or “wanted” operational frequency.

A pictorial example of spurious modes is shown in Figure 1 below. Note that a crystal can exhibit one or more spurious modes and that these spurious modes are located near the odd harmonics of the main modes. Spurious modes are unique to each quartz crystal design.

***Figure 1: Spurious Modes***




In a quartz crystal resonator, the resistance of a spurious mode can be greater than the main mode resistance or it can be equal to or less than the main mode resistance, depending upon crystal resonator design and processing. A crystal designer has measurable control over the quantity of spurs, the location of the spurs, and the resistance value of the spurious modes.

For fundamental mode crystals, the reduction of spurious modes is easily achieved through energy trapping and other design techniques. However, for overtone mode crystals, the elimination or reduction of spurious responses is more challenging. For the crystal designer, there is often a design trade-off between crystal resistance, motional capacitance, and spurious resistance. The suppression or the elimination of spurious modes becomes more complex as the mode increases or as the resonant frequency increases.

In a quartz crystal oscillator that utilizes crystals with spurious modes, oscillation can occur at the spurious frequency. The frequency of operation is dependent upon the oscillator circuit design and the quartz crystal design. For example, oscillation can occur on a spurious mode if the oscillator circuit meets the phase and gain conditions for oscillation at the spurious frequency. Typically, the limited pass band of the oscillator circuitry can not be designed in such a way as to isolate oscillation only to the main mode of operation. Thus, the burden of spurious mode oscillations is often on the crystal designer to minimize crystal spurious responses.

### Measuring Crystal Resistance and Spurious Modes

Ecliptek utilizes crystal transmission test systems defined by the guidelines set forth in IEC-444. These systems measure the crystal resonant frequency and motional parameters of the device using a frequency synthesizer and vector voltmeter. They measure the key resistance and spurious mode parameters such as RR, SPUR, SPRR, and SPFR. These are defined as follows:

- **RR:** Locates the series resonant frequency of the main mode and measures the series resonant resistance (ESR) in ohms at a specified drive level.
- **SPUR:** Locates the largest spurious resonant frequency and measures the resistance of the spur (over specified frequency range). Measurement can be output in ohms or in dB (with respect to the main mode).
- **SPRR:** Ratio of the minimum resistance spurious mode to the resistance of the main mode (over specified frequency range). Measurement output is ratio (no units)
- **SPFR:** The frequency of the minimum resistance spur. Measurement output is specified in hertz or ppm (relative to main mode).

### Specifying Crystal Resistance and Spurious Modes

Main mode crystal resistance (RR) or ESR is typically specified as a maximum value, in ohms. A high RR value is one of the primary causes of a no start-up or intermittent start-up condition in oscillator circuits. For the specification of spurious modes, the designer has several choices.

Firstly, specify the magnitude of the spurious resistance. The SPUR term is specified as a minimum resistance, measured in ohms. Note that this specification is listed as a minimum specification. The goal is to have the ohmic value of the spur be as large as possible, thus preventing oscillation on the spurious frequency.

Secondly, specify the ratio of the spurious resistance to the main mode resistance. The SPUR term is used to define the dB relationship between the main mode resistance and the spurious mode resistance. SPUR (dB) is defined in Equation 1 below.

$$\text{SPUR (db)} = 20 \log (R_X + R_{SPUR}) / (R_X + RR)$$

**EQUATION 1**

where: SPUR = Spurious ratio in decibels

$R_X$ = Test fixture pi head resistance (Typically 25 ohms)

$R_{SPUR}$ = Spurious mode resistance in ohms

RR = Main mode resistance in ohms

The alternate and less common method of specifying spurious modes with respect to the main mode is the use of the SPRR parameter. Typically, the SPRR ratio is specified as a minimum value. Again, note that this specification is listed as a minimum specification. The goal is to have the ohmic value of the spur be as large as possible, thus preventing oscillation on the spurious frequency. SPRR (dB) is defined in Equation 2 below.

$$\text{SPRR (no units)} = R_{SPUR} / RR$$

**EQUATION 2**

where: SPRR = Spur ratio (no units)

$R_{SPUR}$ = Minimum spurious mode resistance in ohms

RR = Main mode resistance in ohms