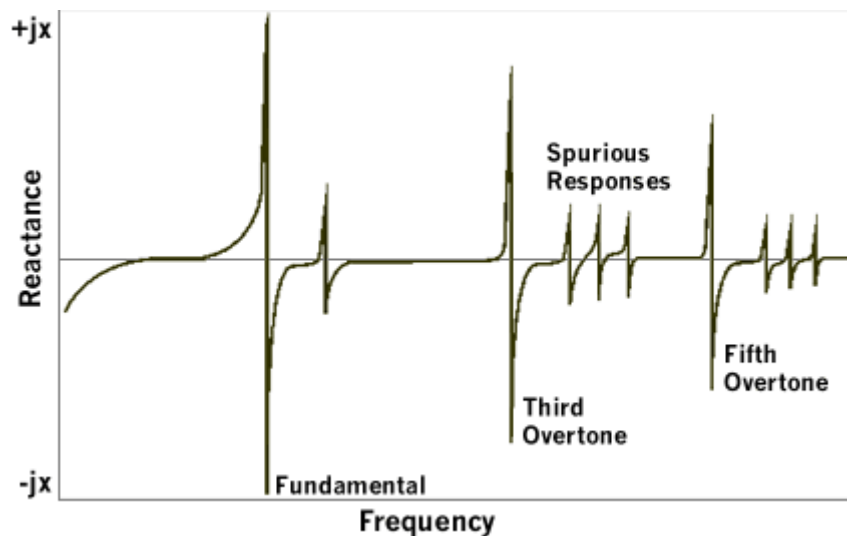




SPURIOUS MODES

Introduction

Often called an "unwanted response", spurious modes are an unwanted mode of operation in AT cut crystal resonators. These unwanted modes are caused by inharmonic modes of oscillation at frequencies located just above (typically 1000ppm to 2000ppm above), the desired, or 'wanted' operational frequency. A pictorial example of one spurious mode is shown in Figure 1 below. Note that a crystal can often exhibit one or more spurious modes. Spurious modes are responses unrelated to the fundamental and overtone responses and are unique for each crystal.



In a quartz crystal resonator, the resistance of a spurious mode can be near that of 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 some measurable control over the quantity of spurs, the location of the spur, and the resistance value of the spurious modes through resonator design and processing. For fundamental mode crystals, this is easily achieved through energy trapping and other design techniques. However, for overtone mode crystals, the elimination of spurious responses is more difficult to achieve. For the crystal designer, there is often a design trade-off between crystal resistance or motional capacitance and spurious resistance. The suppression or the elimination of spurious modes becomes more difficult as the overtone mode increases (i.e. third or fifth overtone mode...) or as the 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 conditions (i.e. phase and gain...) for oscillation at the spurious frequency. Typically, the oscillator design can not be constructed (i.e. limiting pass band) in such a way as to limit 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

Caliber utilizes the Saunders and Associates, Inc S&A250A and S&A350A/B Transmission Test Systems for measurement of spurious modes (See: <http://www.saunders-assoc.com>). This transmission system is defined by the guidelines set in IEC-444. This method measures the crystal series resonant frequency and motional parameters of the crystal using a frequency synthesizer and vector voltmeter, or similar. These test systems can 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 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. This is specified as a maximum value due to high RR values in oscillators circuits causing a no start-up or intermittent start-up condition. For the specification of spurious modes, the designer has several choices. Firstly, if the location of the spur is important, then a minimum or maximum SPFR value should be specified. However, due to the close proximity of spurs to each other and to the main mode, the specification of this parameter is often not applicable. Secondly, the magnitude of the spurious resistance or the ratio of the spurious resistance to the main mode resistance should be specified. There are two options in specifying spurious resistance: SPUR or SPRR. Typically, SPUR is specified as a minimum resistance, measured in ohms. Note that this specification is listed as a minimum specification due to ones desire to have the ohmic value of the spur be as large as possible, thus preventing oscillation on the



spurious frequency. An alternate specification for SPUR, is to specify this parameter in decibels 'down'. This is a term used to define the dB relationship between the main mode resistance and the spurious mode resistance. For the S&A Transmission Test Systems, SPUR (dB) is defined in Equation 1 below.

$$\text{SPUR (db)} = 20 \log (R_x + R_{\text{SPUR}}) / (R_x + R_{\text{MAIN}})$$

where: R_x = Test fixture pi head resistance (Typically 25 ohms)
 R_{SPUR} = Spurious mode resistance in ohms
 R_{MAIN} = Main mode resistance in ohms

EQUATION 1

The second and less common method of specifying spurious modes 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 due to ones desire to have the ohmic value of the spur be as large as possible, thus preventing oscillation on the spurious frequency.

Oscillator Design Considerations

For crystals that exhibit spurious modes near the desired response, specifying the minimum SPUR (in ohm) resistance can prevent oscillation on a spurious mode. Oscillation margin can be checked by testing the circuit design with a 'known' crystal (i.e. known RR, spurious resistance and spurious frequency...) and by inserting additional series resistance (R') in series with the crystal until the circuit does not oscillate. The 'no oscillation' resistance value R_t ($R_t = RR + R'$) can be calculated. As a guideline, the minimum value of the spurious resistance, SPUR (ohms), should be specified to a value equal to or greater than this R_t value. Thus, setting a minimum spurious resistance for the crystal will prohibit oscillation on the crystal spurious frequency.

It should be noted that specifying a minimum SPRR or a minimum SPUR (in dB) might not always be adequate for the elimination of spurious oscillations. For example, the RR value of a particular device within the lot may be low (well below its maximum specification) and the SPUR and SPRR values may also meet the designer's specification requirement and yet still violate the minimum R_t value. Thus for critical applications, a minimum RR value should also be specified, when practical. For higher third and fifth overtone crystals, a minimum SPUR (in ohms) value significantly larger than the value of RR is often difficult to obtain due to low process yields. Thus, specifying a minimum RR value for these applications may not be practical.