Oscillator Circuit Evaluation Method (2)

Steps for evaluating oscillator circuits (oscillation allowance and drive level)

Preface

In general, a crystal unit needs to be matched with an oscillator circuit in order to obtain a stable oscillation. A poor match between crystal unit and oscillator circuit can produce a number of problems, including, insufficient device frequency stability, devices stop oscillating, and oscillation instability. When using a crystal unit in combination with a microcontroller, you have to evaluate the oscillator circuit. In order to check the match between the crystal unit and the oscillator circuit, you must, at least, evaluate (1) oscillation frequency (frequency matching), (2) oscillation allowance (negative resistance), and (3) drive level.
The previous Technical Notes explained frequency matching. These Technical Notes describe the evaluation methods for oscillation allowance (negative resistance) and drive level.

1. Oscillation allowance (negative resistance) evaluations

One process used as a means to easily evaluate the negative resistance characteristics and oscillation allowance of an oscillator circuits is the method of adding a resistor to the hot terminal of the crystal unit and observing whether it can oscillate (examining the negative resistance R_N). The oscillator circuit capacity can be examined by changing the value of the added resistance (size of loss).
The circuit diagram for measuring the negative resistance is shown in Fig. 1. The absolute value of the negative resistance is the value determined by summing up the added resistance r and the equivalent resistance (R_e) when the crystal unit is under load. Formula (1)

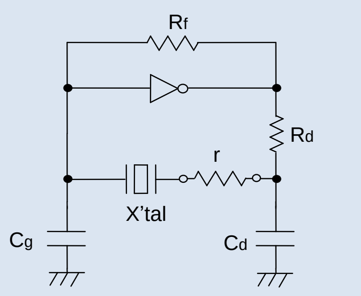

Fig.1 Check of Negative resistance

$$|-R_N| = Connect\_r + R_e \quad \ldots \quad \text{Formula(1)}$$

Hence, the equivalent resistance (R_e) when the crystal unit is under load is determined by Formula (2) shown below.
R_1 is the motional resistance of a crystal unit without load capacitance.

$$R_e = R_1 \times \left[1 + \frac{C_0}{C_L}\right]^2 \quad \ldots \quad \text{Formula(2)}$$

When R_e is calculated using the crystal unit constants introduced in the previous Technical Notes *Oscillator Circuit Evaluation Method (1)* (R_1 = 33.7 Ω, C_0 = 1.11 pF, C_L = 7.8 pF), and Formula (2) shown above, the result is 44 Ω.
R_1 at this time is the actual measurement value for the crystal unit, not a standard value. Caution must be exercised because R_e will increase to 74 Ω due to the load capacitance if R_1 reaches 57 Ω as the standard maximum value.

Fig. 2 shows an example of adding a resistor for measurement of negative resistance

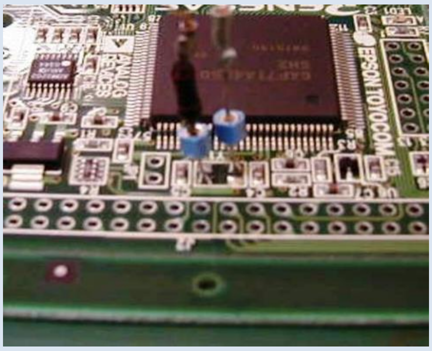

Table 1 Example of oscillation allowance (R_N/R_e) calculation based on negative resistance R_N

Connect the resistance (Ω)	Negative resistance (Calculated value) (Ω)	Oscillation allowance	Confirmation of oscillation using an oscilloscope
500	545	7	OK
1000	1045	14	OK
1600	1645	22	OK
2000	2045	-	No oscillation

Fig. 2: A resistor is added to measure negative resistance

For the states shown in Fig. 2, confirm the waveform using an oscilloscope. Search for the point at which oscillations cease, by gradually changing the added resistance r from a small to larger value. When doing so, disregard the drop in the oscillation output and the changes in the oscillation frequency that result from adding a resistor, and judge only whether an oscillation occurs.

After negative resistance R_N has been determined, calculate the oscillation allowance (R_N/ R_e) (Table 1 above).

Care is required for this step because of problems that occur when the oscillation allowance is small, including unstable oscillation, oscillation failure, and delayed oscillation start up time, which result from variation of the circuit characteristics.

In general, it will be enough if the oscillation allowance is at least five times greater [i.e., the oscillator circuit possesses the capacity (a degree of amplification) to sufficiently excite the crystal unit]. If the oscillation allowance is less than five times, maintaining an oscillation allowance of at least five times, by changing the circuit constants of the oscillator circuit, increasing the negative resistance R_N or reducing the motional resistance R_e of the crystal unit, is recommended.

When the oscillator circuit's circuit constants for trimmer capacitors (C_g and C_d) and limiting resistors (R_d) are reduced, negative resistance increases and the oscillation allowance becomes larger. However, the changes in the circuit constants will also result in changes in the oscillator circuit's load capacitance as well as the oscillation frequency. When you wish to reduce the motional resistance R_1 of the crystal unit, you must contact the crystal manufacturer.

2. Drive level evaluations

The drive level indicates the power consumption when the crystal unit is oscillating. Note that the drive level should normally be maintained within the crystal unit specifications, a level of 100 µW or less is generally recommended. However, each crystal manufacturer's specification will differ slightly.

A high drive level will result in such problems such as oscillation frequency fluctuations, degraded stabilities, varying equivalent circuit parameters, and frequency distortions. In the worst case, irregular oscillations might occur repeatedly and cause circuit damage. The drive level (P) is determined by Formula (3) below.

$$P = I^2 \times R_e \quad \dots \quad \text{Formula(3)}$$

Where I is the current flowing to the crystal unit, and R_e is the equivalent resistance when the crystal unit is under load. If the drive level is higher than the standard, the oscillator circuit constants must be adjusted and the current flowing to the crystal unit is reduced. The drive level can be constrained by making C_g or C_d smaller, but this will also change the load capacitance of the oscillator circuit. Note that, while the easiest method is to increase R_d, this will increase the loss, and negative resistance, as a result becomes smaller.

Drive level is not a value that can be measured directly.
The means of measuring drive level is described below.
Apply a current probe to the terminal of a crystal unit to be evaluated and place the crystal unit in the designated position on a printed circuit board.
After confirming the oscillations using an oscilloscope, measure the Vpp based on the waveform.

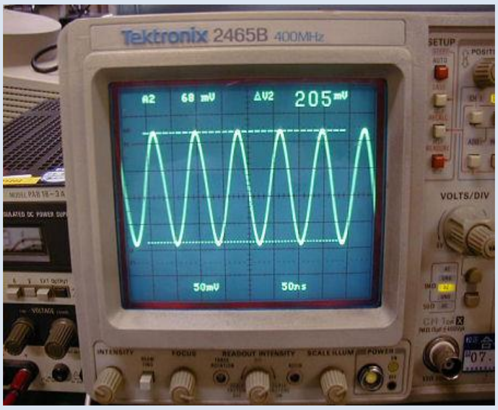

Fig. 3: Drive level measurement

For example, if Vpp = 0.205 V based on the oscilloscope waveform, a measurement probe setting of 1 mA / div, probe impedance of 50 Ω, an oscilloscope measurement range of 50 mV / div, and an equivalent resistance R_e of 45 Ω for when crystal unit is under load,

$$\text{Vpp} / 50\ [\text{mV} / \text{div}] = 205/50 = 4.1\ \text{div}$$

$$4.1 / (2\sqrt{2}) = 1.45\ \text{div}$$

Because 50 [mV / div] / 50 Ω = 1 mA / div, the current I flowing through the crystal unit is 1.45 div × 1m A / div = 1.45 mA.

Using Formula (3) from the previous page, the drive level P can be calculated as 1.45 × 1.45 × 45 = 95 µW.

3. Conclusion

To produce the optimal oscillator circuits, three aspects must be optimized: (1) frequency matching, (2) oscillation allowance (negative resistance), and (3) drive level.
It is ideal if the optimal circuit constants can be established for each item, but this does not hold true in all cases. The steps to take in such cases are summarized below.

Table 2 Evaluation results and measures of frequency matching, negative resistance, and drive level

Frequency matching	Negative resistance	Drive level	**Measures**
OK	OK	OK	**A**
OK	OK	NG	**B**
OK	NG	OK	**C**
NG	OK	OK	**D**
NG	NG	NG	**E**
OK	NG	NG	**F**
NG	OK	NG	**G**
NG	NG	OK	**H**

A: Circuit constants at the time of evaluation have no problems.

B: Crystal unit specifications for the drive level need to be revised. Verify if the drive level obtained from the evaluation may not cause any problems to the crystal oscillator.

C: Crystal unit specifications for negative resistance need to be revised. Study the possibility of changing the motional resistance standard value R_1 for the crystal unit to make the oscillation allowance at least five times.

D: For frequency matching, study the possibility of adjusting the predefined standard load capacitance so that it matches the load capacitance of the actual PCB, on which a crystal unit is mounted.

E: Need to measure by combining "B+C+D."
F: Need to measure by combining "B+C".
G: Need to measure by combining "B+D".
H: Need to measure by combining "C+D".

We hope the information provided in these Technical Notes serve as a useful reference when you design a highly reliable oscillator circuits.