1. Shock & Drop • Vibration

Do not inflict excessive shock and mechanical vibration that exceeds the norm, such as hitting or mistakenly dropping, when transporting and mounting on a board. There are cases when pieces of crystal break, and pieces that are used become damaged, and become inoperable. When a shock or vibration that exceeds the norm has been inflicted, make sure to check the characteristics.

2. Cleaning

Since a crystal piece can be broken by resonance when a crystal device is cleaned by ultrasonic cleaning. Be careful when carrying out ultrasonic cleaning.

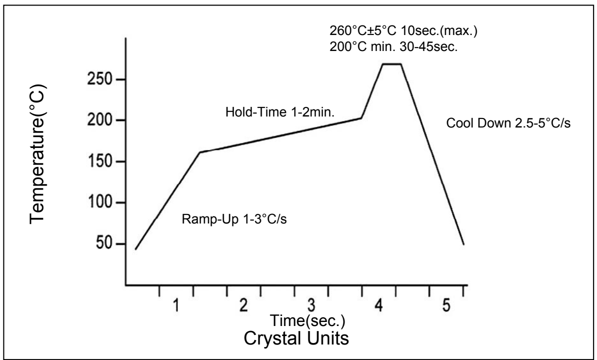
3. Soldering conditions

To maintain the product reliability, please follow recommended conditions.

Standard soldering iron conditions

	Crystal Units
Soldering iron	280°C to 340°C
Time	3+1/–0sec. max.

Reflow conditions (Example)



Recommended reflow Conditions vary depending upon products.
Please check with the respective specification for details.

4. Mounting Precautions

Leaded Devices

The special glass, located where the lead of the retainer base comes out, is aligned with the coefficient of thermal expansion of the lead, If the glass is damaged and cracks appear, there may be cases in which performance deteriorates and it fails to operate.
Consequently, when making the device adhere closely and applying solder, align the gap of the hole of the board with the gap of the lead and insert without excessive force.
When making the device adhere closely to a through hole board and applying solder, be careful that the solder does not get into the metal part of the retainer base and cause a short. Putting in an insulation spacer is one more method of preventing a short circuit.
When the lead is mounted floating, fix it as far as possible so that contact with other parts and the breakage due to the fatigue, and the mechanical resonance of the lead will not occur.
When the lead is bent and used, do not bend the lead directly from the base, separate it 0.5mm or more and then bend it. When bending, before attaching to the board, fix the place where the lead comes out in advance and attach it after bending so that a crack does not occur in the glass part.

Surface Mount Devices

The lead of the device and the pattern of the board is soldered on the surface. Since extreme deformation of the board tears off the pattern, tears off the lead metal, cracks the solder and damages the sealed part of the device and there are cases in which performance deteriorates and operation fails, use it within the stipulated bending conditions. Due to the small cracks in the board resulting from mounting, please pay sufficient attention when attaching a device at the position where the warping of the board is great.
When using an automatic loading machine, as far as possible, select a type that has a small impact and use it while confirming that there is no damage.
Surface mount devices are NOT flow soldering compatible.

5. Storage Condition

Since the long hour high temperature and low temperature storage, as well as the storage at high humidity are causes of deterioration in frequency accuracy and solderability.
Parts should be stored in temperature range of -5 to +40°C, humidity 40 to 60% RH, and avoid direct sunlight. Then use within 6 months.

For Proper Use of Crystal Units

1. Characteristics of crystal units

The thickness of crystal vibrator of the AT cut crystal unit as described in the previous page differs depending on the overtone mode.

(1) Relationship between thickness of crystal blank and oscillation frequency

Cut angle/mode overtone	Frequency range (MHz)	Formula of thickness of crystal blank
AT/Fundamental mode	3.5 to 33	1.67/f
AT/3’rd O. T	33 to 100	5.01/f
AT/5’th O. T	100 to 150	8.35/f
AT/7’th O. T	150 to 200	11.69/f

f : Series resonance frequency (MHz)

In case of calculating the thickness of AT-cut 16MHz
t=1.67/16=0.104(mm)

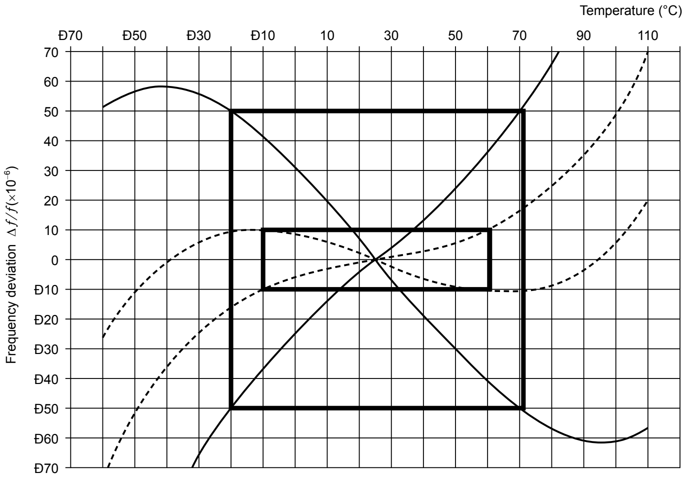
(2) Examples of specifications for frequency-temperature characteristics

The frequency-temperature characteristics of the AT cut crystal unit are tertiary curves.
The diagram below shows examples of the tertiary curves that pass temperature range and frequency deviation specifications.
The range enclosed by the smaller rectangular satisfies the following specification:

$\pm 10 \times 10^{-6}$ (-10 to 60: 25°C)

The range enclosed by the larger rectangular satisfies the following specification:

$\pm 50 \times 10^{-6}$ (-20 to 70: 25°C)



* These are examples. Required frequency-temperature specifications are determined through individual consultations.

(3) Equivalent electric circuit and equivalent constant of crystal unit

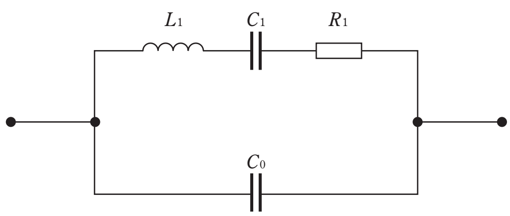
The following equivalent constants are used near the resonance frequency.

L_1 : Motional inductance in the equivalent electric circuit

C_1 : Motional capacitance in the equivalent electric circuit

R : Motional resistance in the equivalent electric circuit

C_0 : Parallel capacitance in the equivalent electric circuit



Equivalent electric circuit of a quarts crystal unit

(4) Items calculated by equivalent constants and load capacitance

f_s: Series resonance frequency $$f_s = \frac{1}{2\pi\sqrt{L1 \cdot C1}}$$

f_p: Parallel resonance frequency $$f_p = \frac{1}{2\pi\sqrt{L_1\frac{C_0 \cdot C_1}{C_0+C_1}}}$$

γ : Capacitance ratio $$\gamma = \frac{C_0}{C_1}$$

f_L : Load resonance frequency $$f_L = f_s\left(\frac{C_1}{2\cdot(C_0+C_L)}+1\right)$$

R_L : Load resistance $$R_L = R_1\left(1+\frac{C_0}{C_L}\right)^2$$

C_L : Load capacitance $$C_L = \frac{C_1}{2}\cdot\frac{1}{(f_L/f_s)-1} - C_0$$

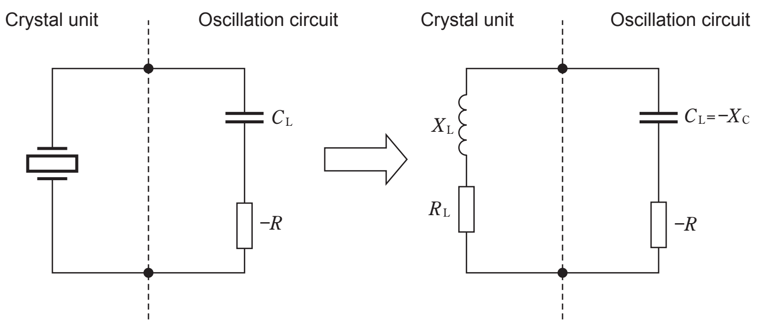
Q : Quality factor $$Q = \frac{2\pi \cdot f_s \cdot L_1}{R_1} = \frac{1}{2\pi \cdot f_s \cdot C_1 \cdot R_1}$$

The equation f_L shows that f_L varies as load capacitance C_L connected to the crystal unit changes and that f_L becomes larger as C_L becomes smaller.
The equation R_L shows the change in impedance with a load capacitance connected. The impedance of crystal unit becomes larger as C_L becomes smaller.

2. Oscillation circuit and crystal unit

(1) Equivalent circuit of oscillation circuit and oscillation conditions

A simplified equivalent circuit is shown below.



C_L : Load capacitance
$-R$: Negative resistance
X_L : Reactance of crystal unit
$-X_C$: Reactance of oscillation circuit
R_L : Load resonance resistance

The oscillation start-up conditions are described as

$$R_L \leq |-R|$$

and in order to oscillate the crystal unit accurately, it must be designed such that the negative resistance of the oscillation circuit becomes bigger comparing with the resonance resistance value at the time of loading. This ratio is called oscillation margin degree M_{OSC} and it is one of critical factors when designing the oscillation circuit and is described as below.
For oscillation circuit designing conditions, it is recommended that an oscillation circuit be designed using a negative resistance of a value five to ten times or more larger than RL calculated from the resonance resistance specification value.

$$M_{OSC} = |-R| / R_L \geq 5$$

In a steady oscillation state, the load resonance resistance is given as follows:

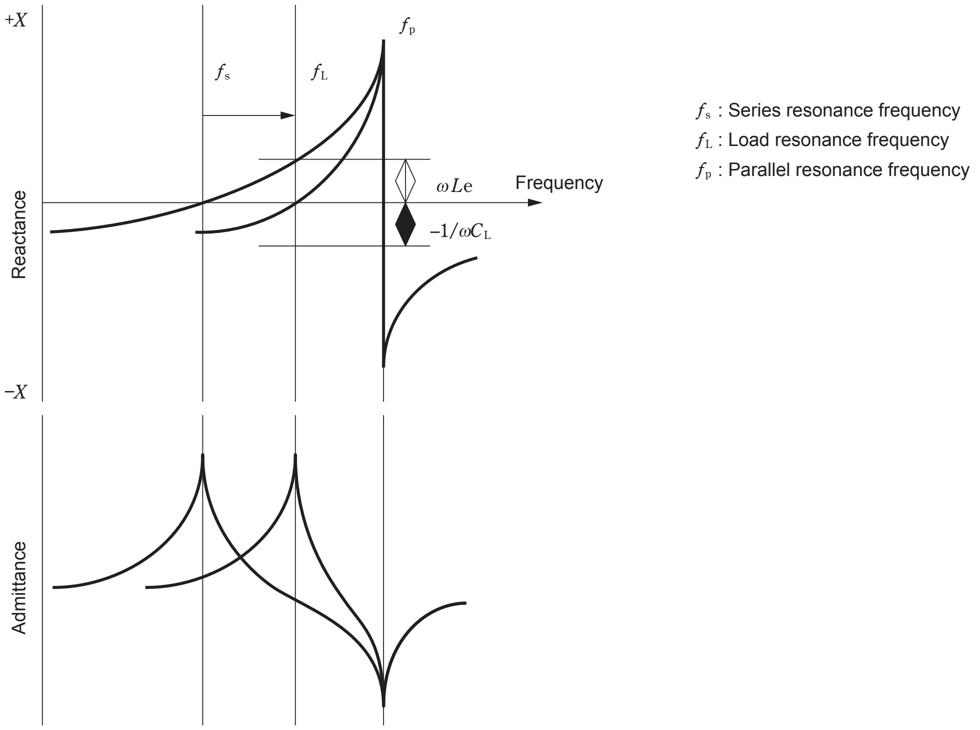
$$R_L = |-R|$$

The mutual conductance of the oscillation circuit decreases after the oscillation has started to continuously compensate for the power loss due to the load resonance resistance of the crystal unit, which continues oscillation.

The frequency condition is given as follows:

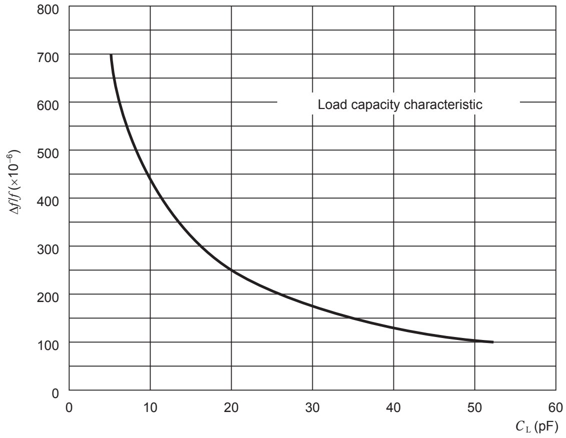
$$X_L = X_C,\ X_L - X_C = 0$$

As shown in the following figure, the reactance of the crystal unit varies to a value matching the load capacitance of the oscillation circuit $C_L = X_C$. Thus an oscillation frequency is determined.



(2) Changes of load capacitance and oscillation frequency

As shown above, the series resonance frequency of the crystal unit changes with load capacitance C_L of the oscillation circuit. In the actual oscillation circuit, however, fine adjustments of oscillation frequencies are carried out by varying C_L by the trimmer capacitor or the like. The following figure shows an example of load capacitance characteristics. The slope of the characteristics varies depending on the frequency, shape, the number of overtone mode, etc.



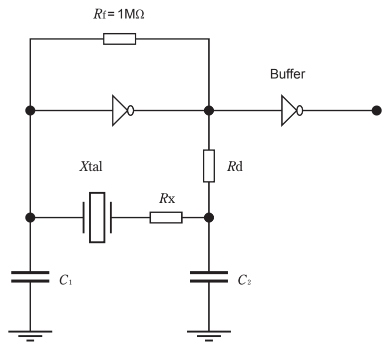
3. Crystal oscillation circuit

(1) CMOS fundamental crystal oscillation circuit

As shown above, the series resonance frequency of the crystal The figure on the right shows a standard CMOS inverter crystal oscillation circuit for oscillating crystal unit with fundamental mode.

* *Rx* is an element to reduce excitation current of the crystal unit preventing frequency fluctuation, but Rx is not used in some cases.

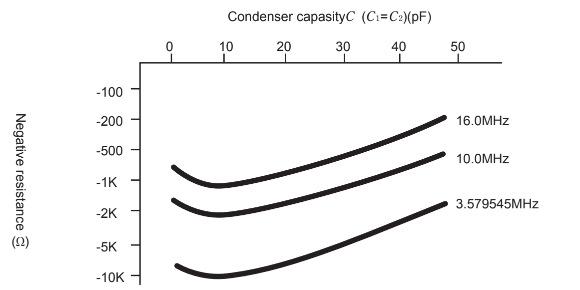
CMOS fundamental crystal oscillation circuit



Characteristics of the circuit when load capacitances C_1 and C_2 are changed under the condition of $C_1 = C_2$ are shown in the figure on the right.

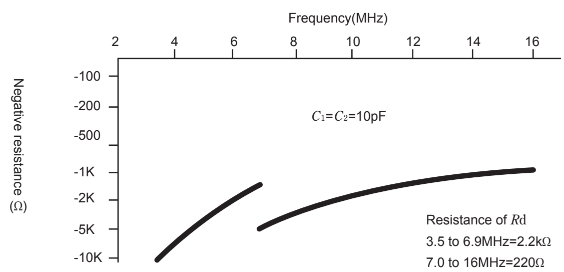
It is not desirable that the excessive increase of the value of condenser leads to a decrease of the negative resistance resulting in increasing the possibility of oscillation failure.

Variation of negative resistance with condenser capacity



*R*d mainly adjusts frequency characteristics of the negative resistance and is used to prevent oscillating by third Overtone mode. In case of a bigger circuit of the negative resistance, there is a case it is used to prevent the abnormal oscillation.

Frequency characteristics of negative resistance



Selection of ICs and circuit constants by frequency bands

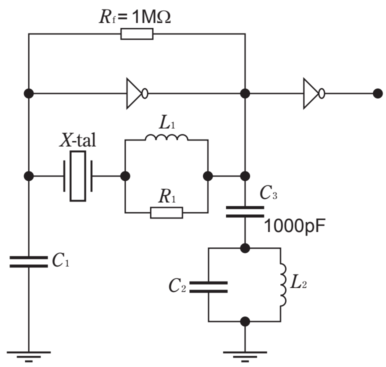
Frequency	3 to 4.9(MHz)	5 to 6.9(MHz)	7 to 9.9(MHz)	10 to 19.9(MHz)	20 to 30(MHz)
IC	TC4069UB TC4SU69F			TC74HCU04A TC7SU04F TC7WU04FU	TC74VHCU04 TC7SHU04F TC7WHU04FU
*R*f	1MΩ				
*R*d *1	1500(Ω)	470(Ω)	0(Ω)	0(Ω)	0(Ω)
*R*x *2	0 to 1500Ω				
C_1, C_2 *3	6 to 22(pF)			6 to 15(pF)	6 to 15(pF)

*1: Necessary for preventing overtone oscillation and must be changed depending on the frequency band or the C_1 and C_2 values.
*2: Used to reduce excitation current of the crystal unit. Necessary for stable operation of small-sized crystal units.
*3: The optimum value differs with the values of load capacitance and Rd.

(2) CMOS overtone crystal oscillation circuit

This figure shows a standard CMOS inverter crystal oscillation circuit to oscillate a crystal unit using the overtone mode.

CMOS overtone crystal oscillation circuit



There are same cases when L_1 and R_1 are matched to the value of load capacitance.

(3) Selection of ICs and circuit constants by frequency bands

Frequency range	20 to 60(MHz)
IC	TC74VHCU04 TC7SHU04F TC7WHU04FU
C_1	3 to 10pF
C_2	10 to 22pF

(4) Method of selecting circuit constants and functions of elements

C_1 : Forms load capacitance of the circuit together with C_2, L_1 and L_2. A value of approx. 5pF is used.

C_2 : Forms load capacitance of the circuit together with C_1, L_1 and L_2. Prevents fundamental wave oscillation. Shall be selected so that C_2 comes between the third overtone frequency at which resonance frequency with L_2 is to make oscillation and 1/3 of the third overtone frequency. A value of 10 to 22pF is used.

C_3 : A bypath capacitor

L_1 : A coil to adjust load capacitance of the oscillation circuit to a value near the series. A value of several μH is used.

L_2 : Forms load capacitance of the circuit together with C_1, C_2 and L1. Prevents fundamental wave oscillation. Shall be selected so that L2 comes between the third overtone frequency at which resonance frequency with C_2 is to make oscillation and 1/3 of the third overtone frequency. A value of 10 to 22pF is used.

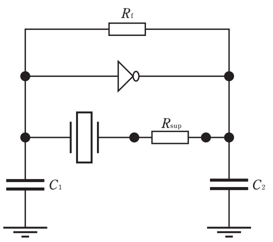
R_1 : A Q dump resistor for L_1 . As an element for preventing self-excited oscillation, A value of several kΩ to several tens of kΩ is used.

* L_1 and R_1 might not be used.

(5) Method of checking oscillation circuit

①Some ICs have a low upper-limit value of usable frequency, so refer to individual IC catalog to make sure that the IC can oscillate a crystal unit with an adequate negative resistance.

②The following figure shows an example of a CMOS oscillation circuit. Check resistance Rsup is connected in series with the crystal unit to check the negative resistance. Use 3 to 22pF for C_1 and C_2, and see the table below for values of check resistance.



Frequency range	Values of check resistance
3.5 to 4.5MHz	1.5kΩ
4.6 to 6.0MHz	1.0kΩ
6.1 to 10.0MHz	800Ω
10.1 to 14.0MHz	500Ω
14.1 to 20.0MHz	400Ω

③Using a spectrum analyzer or oscilloscope, check that every oscillation is normally activated while turning the power on and off several times. For oscillation circuits with no power regulator ICs, carefully check changes in the negative resistance against supply voltage and in frequencies.

④When oscillation is normal, remove the check resistance before using the crystal circuit.

⑤If oscillation is unstable or is not generated, gradually decrease the values of C_1 and C_2 until normal oscillation is obtained.

⑥If normal oscillation cannot be generated near 10MHz or near 20MHz, replace the IC with a new one suitable for higher frequencies.

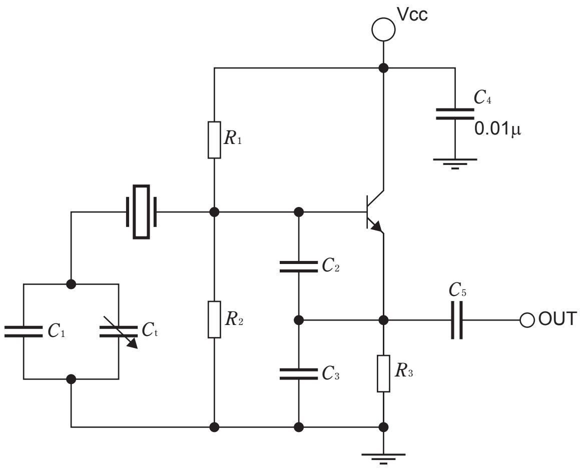
(6) Load capacitance and oscillation frequency of transistor/fundamental crystal oscillation circuit

Viewed from the connection terminals of a crystal unit, the load capacitance C_L of an oscillation circuit is generally comprised of C_1, C_t, C_2, and C_3 if stray capacitance of the circuit and the capacitance between base and emitter of the transistor are ignored. Since trimmer capacitor is adjusted to C_T = MIN. to MAX. for zero adjustment of the oscillation frequency, the value of C_L at this time can be obtained from the following equation.

$$C_L\text{MIN.} = \left(\frac{1}{C_1+C_T}+\frac{1}{C_2}+\frac{1}{C_3}\right)^{-1} \text{ to } C_L\text{MAX.} = \left(\frac{1}{C_1+C_T}+\frac{1}{C_2}+\frac{1}{C_3}\right)^{-1}$$

When these calculation results are substituted for the following equation for load resonance frequency, the oscillation frequency can be obtained.

$$f_L = f_s\left(\frac{C_1}{2\cdot(C_0+C_L)}+1\right)$$



Select each circuit constant so that the adjustment ranges of upper and lower frequencies of this circuit are even on the basis of the frequency of a single crystal unit measured using a specified load capacity, and that the margin of ±8 to 10 $\times 10^{-6}$ of the room temperature deviation of the crystal unit can be reserved.

To prevent the decrease in the negative resistance, always connect the crystal unit to the base of the transistor. For transistors used for oscillation circuits, hfe and fT are important.
To obtain the large negative resistance with small current consumption, select a transistor for high frequency amplification with hfe of over 250 and f_T of 1GHz or more.

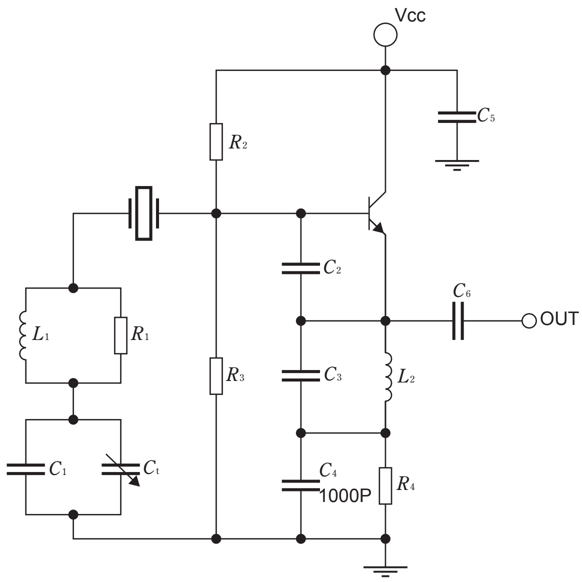
(7) Transistor third overtone oscillation circuit

①The resonance circuit comprised of L_2 and C_3 is required on the emitter side for preventing fundamental mode crystal oscillation. Set the resonance frequency to a value higher than the intermediate between fundamental wave frequency and third overtone frequency.

②Use L_1, referred to as an elongation coil, to connect the load capacitance of the oscillation circuit in series. R_1 prevents self-excited oscillation by L_1. Since it is difficult in general to design the oscillation circuit having adequate negative resistance in the overtone oscillation frequency band, there are no other effective means of obtaining adequate oscillation margin except for preventing the increase of load resonance resistance R_L of the crystal unit.

R_L in the equation of load resonance resistance can be made equal to R_S by connecting C_L in series, or making it infinite, which prevents increase in the load resonance resistance.

$$R_L = R_1\left(1+\frac{C_0}{C_L}\right)^2$$



To prevent decrease in the negative resistance, connect the crystal unit to the base of the transistor as in the fundamental mode crystal oscillation circuit. To use the crystal circuit for both oscillation and multiplication, connect a parallel resonance circuit having multiplication frequency as resonance frequency to the collector of the transistor.
When selecting circuit constants for zero adjustment range by trimmer capacitor, set the constants to values obtained by adding approx. ± 12 to 15×10^{-6} to the room temperature deviation of the crystal unit, centering the value obtained by measuring the crystal unit with load capacitances in series. (When the room temperature deviation specification of the crystal unit is $\pm 10\times10^{-6}$)

(8) Excitation power of oscillation circuit

Normal operation of crystal units is not assured when excitation power is raised. The allowable excitation power varies depending on the shape of the crystal unit or the stability of targeted frequency. When highly accurate oscillation is required, however, it is recommended to use an oscillation circuit with an excitation power of 5 to 50 μW or less. For other cases, refer to individual relevant crystal units on the pages of the catalog.

(9) Precautions for designing printed circuit board

Be sure to design printed circuit board patterns that connect a crystal unit with other oscillation elements so that the lengths of such patterns become shortest possible to prevent deterioration of characteristics due to stray capacitances and wiring inductance. For multi-layer circuit boards, it is important not to wire the ground and other signal patterns right beneath the oscillation circuit.