Precautions for using Radio-frequency semiconductor devices

Description

This document outlines the maximum ratings and electrical characteristics of radio-frequency semiconductor devices, including an overview and operating principles.

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This is a reference material. Do not design the final equipment in this document.

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Maximum Ratings and Electrical Characteristics

1.Definition of Maximum Ratings

For semiconductor devices, applied voltage, current, temperature, and power loss are major factors that limit operational functionality.

Maximum ratings are the maximum allowable values that must not be exceeded to ensure effective operation and sufficient reliability of semiconductor devices, defined as absolute maximum ratings.

Absolute maximum ratings (hereafter referred to as maximum ratings) are defined as "limit values that must not be exceeded even momentarily, and no two items should reach these limit values simultaneously." Exceeding the maximum ratings may cause destruction, damage, and degradation, leading to failures due to rupture or combustion.

1.1.1. Maximum Ratings (Switching Diodes and Schottky Barrier Diodes)

(1) Reverse Voltage (V_R)
The maximum allowable value of reverse voltage that can be applied at the specified ambient temperature.

(2) Peak Reverse Voltage (V_{RM})
The maximum allowable instantaneous value of reverse voltage (DC + AC signal) that can be applied at the specified ambient temperature.

(3) Forward Current (I_F)
This is the maximum allowable forward current at the specified ambient temperature.
It usually decreases with the rise in ambient temperature.

(4) Junction Temperature (T_j)
It is the maximum allowable temperature of the junction during operation. The forward current value and operating temperature range of the device must be set within this value.

(5) Storage Temperature (T_{stg})
This is the allowable range of ambient temperature that can be stored when not in operation. This range ensures that the device characteristics do not degrade during storage.

1.1.2. Maximum Ratings (Variable Capacitance Diode)

(1) Reverse Voltage (V_R)
This is the maximum allowable reverse voltage that can be applied at the specified ambient temperature.

(2) Peak Reverse Voltage (V_{RM})
This is the maximum allowable instantaneous value of reverse voltage (DC + AC signal) that can be applied at the specified ambient temperature.

(3) Junction Temperature (T_j)
This is the maximum allowable temperature of the junction during operation. The forward current value and operating temperature range of the device must be set within this range.

(4) Storage Temperature (T_{stg})
This is the allowable range of ambient temperature that can be maintained when not in operation. This range ensures that the device characteristics do not degrade during storage.

2. Electrical Characteristics

2.1. Electrical Characteristics (Variable Capacitance Diode)

Item	Symbol	Function Description
Reverse Voltage	V_R	Reverse voltage generated when specified reverse current flows
Reverse Current	I_R	Leakage current flowing when specified reverse voltage is applied
Capacitance	C_{*V}	Equivalent capacitance between terminals when applying the specified reverse bias voltage (*V) at the specified frequency
Capacitance ratio	C_{*^1V}/C_{*^2V}	Ratio of capacitance at reverse bias voltage ($*^1V$) to capacitance at $*^2V$
Series resistance	r_S	Series equivalent resistance when applying the specified reverse bias voltage at the specified frequency
Performance index	Q	Performance index when applying the specified reverse bias voltage at the specified frequency

2.2. Electrical Characteristics (Switching Diode)

Item	Symbol	Function Description
Reverse Voltage	V_R	Voltage generated when the specified reverse current flows
Reverse Current	I_R	Leakage current flowing when the specified reverse voltage is applied
Forward voltage	V_F	Terminal voltage generated when the specified forward current is applied
Capacitance	C_T	Equivalent capacitance between terminals when the specified reverse bias voltage is applied at the specified frequency
Series resistance	r_S	Series equivalent resistance when the specified forward current is applied at the specified frequency
Minority carrier lifetime	τ	Minority carrier lifetime when the specified forward current is applied and then the specified reverse current is immediately applied

2.3. Electrical Characteristics (Schottky Barrier Diode)

Item	Symbol	Function description
Reverse voltage	V_R	Voltage generated when the specified reverse current is applied
Reverse current	I_R	Leakage current that flows when the specified reverse voltage is applied
Forward voltage	V_F	Terminal voltage generated when the specified forward current is applied
Forward current	I_F	Forward current that flows when the specified reverse voltage is applied
Capacitance	C_T	Equivalent capacitance between terminals when applying the specified reverse bias voltage at the specified frequency

Explanation

3. Radio-Frequency Diode

3.1.1. Variable Capacitance Diode

A variable capacitance diode is commonly called a varicap diode, and unlike rectifying diodes and switching diodes that utilize the rectifying action of a PN junction, or constant voltage diodes that utilize Zener breakdown and avalanche breakdown, it utilizes the change in the PN junction capacitance of the diode with reverse bias voltage.

TV tuners and FM/AM tuners using this variable capacitance diode can be made smaller, thinner, and lighter.

3.1.2. Basic operating principle of variable capacitance diode

When a PN junction diode is reverse-biased, the depletion layer changes due to this reverse bias voltage VR. The PN junction capacitance varies depending on the depletion layer region.

When the depletion layer region is wide, the capacitance is small, and conversely, when the depletion layer region is narrow, the capacitance is large.

In other words, a variable capacitance diode changes the depletion layer with the reverse bias voltage VR, and this change in the depletion layer alters the junction capacitance.

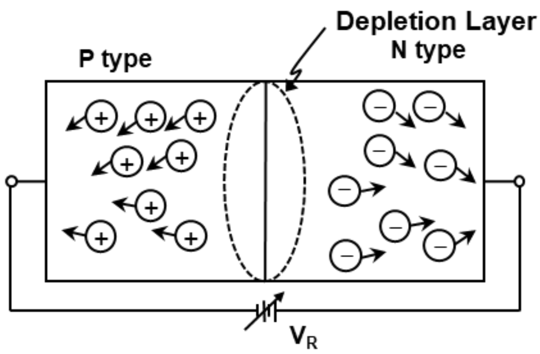
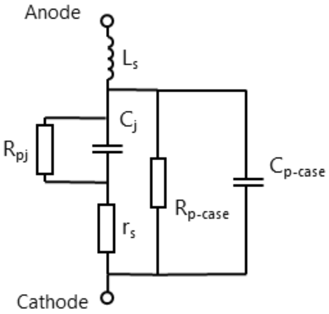


Figure 3.1 Operation Description Diagram

3.1.3. Equivalent Circuit of Variable Capacitance Diode

When representing a variable capacitance diode with an equivalent circuit, it appears as shown in Figure 3.2.



C_j : Junction Capacitance
r_s : Series Resistance
R_{pj} : Junction Loss Resistance
$R_{p\text{-case}}$: Case Loss Resistance
(Depends on the tanδ of the resin used in the case.)
$C_{p\text{-case}}$: Case Capacitance
L_S : Lead Inductance

Figure 3.2 Equivalent circuit of Variable Capacitance Diode

When the operating frequency is low, the lead inductance L_S can be ignored, and when the junction capacitance C_j is large, the case capacitance $C_{p\text{-case}}$ can be ignored.

3.1.4. Types and characteristics of variable capacitance diodes

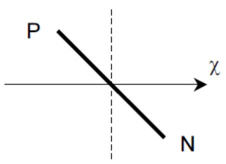
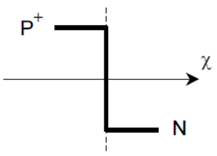
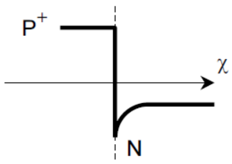
Variable capacitance diodes can be broadly classified into three types based on impurity concentration distribution: abrupt junction type, step junction type, and super step junction type. This is shown in Table 3.1.

Here, n is the coefficient that determines the slope of the capacitance (C)–reverse voltage (V_R) characteristic.

$C = K (V_R + \varphi)$-n ………………………………………………… (1)
K: A constant determined by impurity concentration, dielectric constant, and junction area
φ: Diffusion potential

There is a relationship.

Table 3.1 Types and characteristics of variable capacitance diodes

Classification	Impurity concentration distribution	$\frac{1}{n}$	Main use	Features
Graded junction type		$\frac{1}{3}$	General purpose For switching	The variable range of capacitance is narrow, and it is rarely used as a variable capacitance diode.
Step junction type		$\frac{1}{2}$	For AFC For tuning For modulation	Good stability of C–V curve, no pairing required even when used for tuning. However, the capacitance change ratio is small, and a high control voltage is required.
Super step junction type		$\frac{1}{2}$Above	For tuning	The capacitance change ratio can be increased even if the operating voltage range is narrow, but on the other hand, many diffusion processes are required, and the stability of the C-V curve is poor.

3.1.5. Basic parameters of variable capacitance diodes

V_R: Reverse Voltage
Applied permissible voltage in the reverse bias state of a variable capacitance diode

C_T: Capacitance between terminals
Total capacitance between anode and cathode shown in the equivalent circuit of Figure 3.2

C_{3V}: Capacitance between terminals at V_R=3 V (similarly for C_{9V}, C_{25V}, etc.)
C_{3V}/C_{9V}: Capacitance ratio between terminals at V_R=3 V, 9 V (used for tuning variable capacitance diodes)

K: Capacitance ratio

$$K = \frac{(\text{Terminal capacitance at each voltage})-(\text{Terminal capacitance at reference voltage})}{\text{Terminal capacitance at reference voltage}}$$

Q: Performance index

The ratio of energy stored to energy consumed by the resistive component in a circuit or material. Ignoring lead inductance L_S and case capacitance $C_{p\text{-}case}$ in the equivalent circuit of Figure 3.2

$$K = \frac{1}{\omega C_j r_S + \left(\frac{1}{R_{Pj}}+\frac{1}{R_{P-case}}\right)/\omega C_j} \quad \text{.......... (2)}$$

Can be expressed.
Generally,

$$Q = \frac{1}{\omega C_j r_S} \quad \text{.......... (3)}$$

Represented by.
r_S: Series resistance

It can be expressed by a single parameter representing the performance index Q, which can be expressed by the following equation.

$$r_S = \frac{1}{S_j}\int \frac{dx}{q\mu_n N(x)} + \frac{1}{S_j}\int \frac{dx}{q\mu_p P(x)} + R_C \quad \text{.......... (4)}$$

S_j: Junction area, μn: Electron mobility, μp: Hole mobility,
N (x): Impurity concentration distribution on the N side, P (x): Impurity concentration distribution on the P side,
R_C: Contact resistance

Matching:
In the case of a tuning variable capacitance diode, the variable capacitance diode used in the same tuner must have matched characteristics.
This is necessary to ensure the tracking of the tuner, and the pair deviation of the terminal capacitance at each reverse voltage V_R is generally less than 3%.

3.1.6. Voltage dependence of capacitance

Depending on the impurity concentration distribution, variable capacitance diodes can be broadly classified into graded junction type, step junction type, and super step junction type.

When given by a function with N-type impurity distribution,

$$E = \int \frac{qN(x)}{\varepsilon r \varepsilon 0} dx \quad \cdots\cdots (5)$$

$$V = -\int E(x)\, dx \quad \cdots\cdots (6)$$

$$C_j = \frac{\varepsilon r \varepsilon 0 S_j}{x} \quad \cdots\cdots (7)$$

ε0 : Permittivity of vacuum

εr : Relative permittivity can be expressed.

Also, the capacitance-reverse voltage relationship can be expressed as C = K (V_R + φ)-n as mentioned above, and in the case of a graded junction type

n=1/3, in the case of a step junction type n=1/2, and in the case of a super step junction type n=1/2 or more.

3.1.7. Temperature and pressure dependence of capacitance

The capacitance temperature change of a variable capacitance diode is due to ① the temperature change of the diffusion potential, ② the temperature change of the permittivity. This can be expressed by the following equation.

$$\frac{1}{C_j} \cdot \frac{\partial C_j}{\partial T} = \frac{1}{K} \cdot \frac{dK}{dT} - \frac{n}{V_R + \varphi} \cdot \frac{d\varphi}{dT} \quad \cdots\cdots (8)$$

Here, the temperature change of the dielectric constant in the first term is about 35ppm/°C for silicon. Also, the temperature change of the diffusion potential in the second term is about −2 mV/°C.

In a variable capacitance diode, as long as there is voltage dependence of capacitance, it is impossible to completely eliminate the temperature dependence of capacitance. However, when obtaining the same capacitance ratio, the temperature dependence of capacitance can be somewhat reduced by choosing n at a certain reverse voltage V_R.

3.1.8. Variation of average capacitance due to AC signal voltage

A variable capacitance diode utilizes the change in the depletion layer by changing the reverse bias voltage of the PN junction, and this change in the depletion layer results in a change in junction capacitance. Therefore, as shown in Figure 3.3, when an AC signal is superimposed on a certain DC bias voltage, the depletion layer changes due to the influence of this AC signal.

For this reason, the average value of the capacitance differs when this AC signal is applied and when it is not.

This is because the relationship between the capacitance shown in equation (1) and the reverse voltage is generally not a linear function.

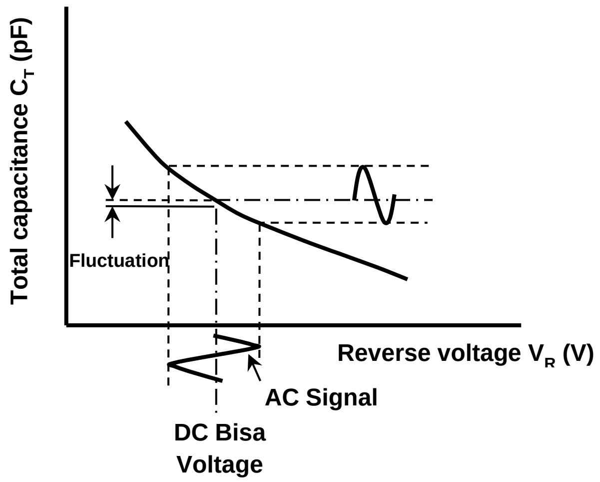


Figure 3.3 Capacitance Fluctuation as a Function of Reverse Voltage

The variation of average capacitance can be expressed by the following equation.

$$\frac{C_{jac}}{C_{j}DC} = \frac{1}{2\pi}\int_0^{2\pi}\left(1+\frac{v\sin\omega t}{V_R+\varphi}\right)^{-n}d(\omega t) \quad \text{.................................... (9)}$$

C_{jac} : Capacitance when an AC signal is applied
C_{jDC} : Capacitance when a DC bias is applied
usinωt : AC signal level

The rate of capacitance variation ΔC is given by the equation below.

$$\Delta C = \frac{C_{jac}-C_{jDC}}{C_{jDC}}\times 100(\%) \quad \text{.. (10)}$$

$$C_{jac} = \frac{1}{2\pi}\int_0^{2\pi} K(V_R+\varphi+v\sin\omega t)^{-n}d(\omega t) \quad \text{.......................... (11)}$$

Note that equations (9) to (11) are valid only in intervals where n can be approximated as constant, and caution is needed in cases where n changes due to reverse voltage, such as in super staircase junctions.
In variable capacitance diodes, it is impossible to completely eliminate the fluctuation of average capacitance due to AC signal voltage, just like the temperature dependence of capacitance.
However, even if the same capacitance change ratio is taken, it can be somewhat reduced by selecting n at a certain reverse voltage V_R.

3.1.9. Voltage and frequency dependence of Q

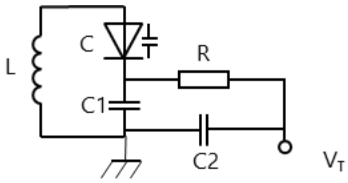
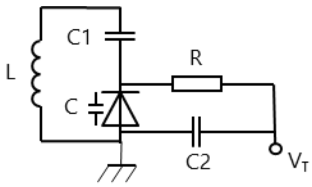
The performance index Q changes with reverse voltage because the junction capacitance C_j and series resistance r_s change. However, since the change in junction capacitance C_j is much larger than the change in series resistance r_s, the voltage dependence of Q is dominated by the voltage dependence of the junction capacitance C_j.
According to equation (3), the frequency dependence example of Q is inversely proportional to the frequency when the series resistance r_s is constant.
As the frequency increases, Q may decrease due to the influence of lead inductance L_S and the case loss resistance $R_{p\text{-}case}$.

3.1.10. Application of variable capacitance diode to tuning circuits

Bias method of variable capacitance diode

In electronic tuners, it is necessary to apply a DC voltage to the variable capacitance diode. The bias method is shown below.

Table 3.2 Bias method of variable capacitance diode

	Bias Circuit Example (1)	**Bias Circuit Example (2)**
Circuit	 C1, C2 » C	 C1, C2 » C
Q	C1 = C2 = 0.1μF , R = 100 kΩ $\omega = 1/\sqrt{LC}$ Let the Q of L be QL and the Q of varicap C be QC, then the circuit Q is given by the following equation. $Q = \frac{Q_C Q_L}{Q_C + Q_L}$.............. (2-1) C1 is much larger compared to C. Since R is not added in parallel to C and L, the circuit Q is not affected by R. Therefore, R does not necessarily need to be large.	C1 = C2 = 0.1μF , R = 100 kΩ $\omega = 1/\sqrt{LC}$ Let the Q of L be QL and the Q of varicap C be QC, then the circuit Q is given by the following equation. $Q = \frac{1}{\frac{1}{Q_C} + \frac{1}{Q_L} + \frac{1}{R}\sqrt{\frac{1}{C}}}$.............. (2-2) Since R is added in parallel to C and L, the circuit Q is affected by R and decreases as shown in equation (2-2). Especially when C is small, it is affected by R.
Recommended circuit stage	Suitable for stages requiring high Q of the circuit. (Example) AM tuner/antenna circuit, RF FM tuner/antenna circuit, RF, OSC	Suitable for stages that do not require high Q circuits or stages where Q is intentionally reduced. (Example) AM tuner/OSC

Two examples of the bias method of the variable capacitance diode are shown in Table 3.2, and selecting according to the usage stage is very effective. Additionally, as a precaution, it is considered appropriate for the bias resistor R to be 200 kΩ or less, considering the leakage current

Determination of constants for tracking circuits

The superheterodyne tuner creates an intermediate frequency f_{IF} from the received frequency fs and the local oscillation frequency f_0. The relationship between fs, f_0, and f_{IF} is as follows.

$f_{IF} = \left| f_0 - f_s \right|$ .... (2-3)

AM: f_{IF} = 450 kHz (considering coupling with PLL IC)
FM: f_{IF} = 10.7 MHz

Regarding the FM tuner, in the conventional circuit using a Variable capacitor, it is only necessary to replace the Variable capacitor with a variable capacitance diode, so the tracking circuit and determination of circuit constants can be done as before.

Regarding the AM tuner, compared to the conventional tracking-less Variable capacitor circuit, the antenna tuning circuit and RF tuning circuit are the same, but the local oscillation circuit is different. In the case of a tracking-less Variable capacitor, to satisfy equation (2-3) for a certain L, the capacitance versus rotation angle characteristic for the local oscillation is changed based on the capacitance versus rotation angle characteristic for the antenna and RF tuning. Since the capacitance versus voltage characteristic of the variable capacitance diode is the same for each stage used, ingenuity is required in the local oscillation circuit to satisfy equation (2-3).

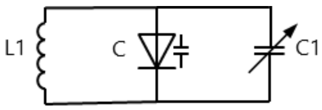
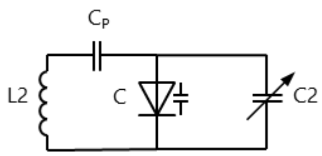
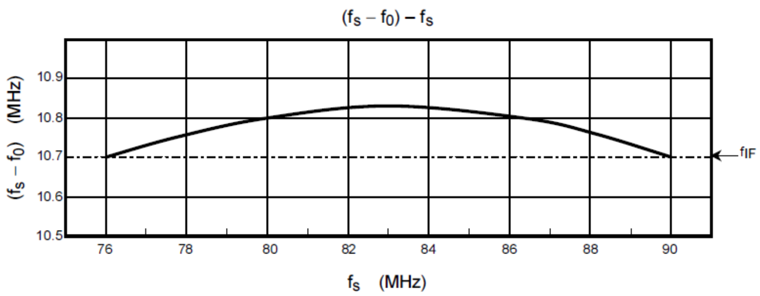
Below, using representative circuit examples, calculation formulas for determining constants are shown.

(1) Calculation of FM tracking circuit constants

Here, we replace the LC resonant circuit with an equivalent circuit and demonstrate the calculation of the two-point tracking circuit constants under the following conditions. Two-point tracking is adjusted so that the FIF becomes 10.7 MHz at only two points (generally the maximum and minimum frequencies) of the reception frequency.

(a) Operating voltage range of the variable capacitance diode: V_T = Vmin to Vmax
(b) Capacitance variation range of the variable capacitance diode: C = Cmax (at Vmin) to Cmin (at Vmax)
Note that the C-V_T characteristics of the variable capacitance diodes used in each stage are all the same.
(c) Reception frequency range: $f_s$min (at Cmax) to $f_s$max (at Cmin)
(d) Local oscillation frequency range: $f_0$min (at Cmax) to $f_0$max (at Cmin)
Note that f0min = $f_s$min ± 10.7 MHz, $f_0$max = $f_s$max = $f_0$max ± 10.7 MHz
(However, Japan is -, US/Europe is +)

Table 3.3 Calculation of two-point tracking circuit constants for the tuner

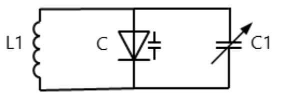
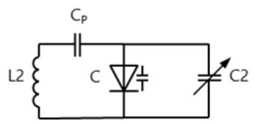
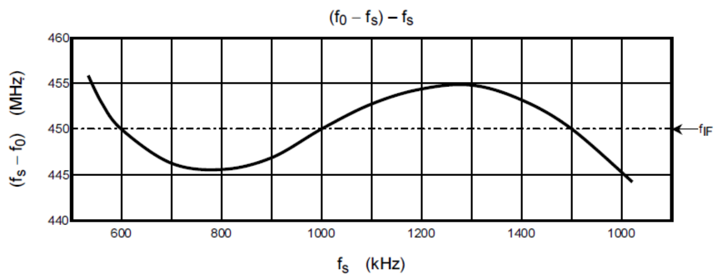
	Antenna RF circuit	Local oscillation circuit
Equivalent circuit		
Calculation formula for circuit constants	C1: Total capacitance including adjustment trimmer capacitance, circuit capacitance, and active element capacitance. $f_S = \frac{1}{2\pi\sqrt{L_1 (C+C_1)}}$ .... (2-4) Therefore $\left(\frac{f_S max}{f_S min}\right)^2 = \frac{Cmax+C_1}{Cmin+C_1}$ .... (2-5) Hence $C_1 = \frac{Cmax-\left(\frac{f_S max}{f_S min}\right)^2 Cmin}{\left(\frac{f_S max}{f_S min}\right)^2 -1}$ .... (2-6) Also $L_1 = \frac{1}{4\pi^2 f_S max^2 (Cmin+C_1)}$ .... (2-7)	C2: Total capacitance including trimming capacitance for adjustment, circuit capacitance, and active element capacitance. $f_0 = \frac{1}{2\pi\sqrt{L_2 (C+C_2)}}$ .... (2-8) Therefore $\left(\frac{f_0 max}{f_0 min}\right)^2 = \frac{Cmax+C_2}{Cmin+C_2}$ .... (2-9) However $\left[\begin{matrix} f_0 max = f_S max \pm f_{IF} \\ f_0 min = f_S min \pm f_{IF} \end{matrix}\right.$ Consequently $\therefore C_2 = \frac{Cmax-\left(\frac{f_0 max}{f_0 min}\right)^2 Cmin}{\left(\frac{f_0 max}{f_0 min}\right)^2 -1}$ ......(2-10) Also $\therefore L_2 = \frac{1}{4\pi^2 f_0 max^2 (Cmin+C_2)}$ ......(2-11)
Example of circuit constant calculation		

(2) Calculation of AM (medium wave) tracking circuit constants

AM medium wave has a larger change ratio in reception frequency compared to FM. Therefore, in two-point tracking, there is a part where f_{IF} deviates significantly from the 450 kHz wave. Hence, three-point tracking using the padding capacitor method is performed. In three-point tracking, f_{IF} matches 450 kHz at only three points—large, medium, and small—within the reception frequency, and slightly deviates at other frequencies. However, this is not a level that becomes a problem in implementation. Below, the calculation of tracking circuit constants is shown based on the following conditions.

(a) Usage voltage range of variable capacitance diode: V_T = Vmin to Vmax
(b) Capacitance change range of variable capacitance diode: C = Cmin (at Vmax) to Cmax (at Vmin)
Note that the C–V_T characteristics of the variable capacitance diodes used in each stage are all the same.
(c) Reception frequency range: $f_s = f_s$min to $f_s$max
(d) Local oscillation frequency range: f_0 = f0min to $f_0$max
(e) Three-point tracking points for received frequency: f_s1 (atC_{s1}), f_s2 (atC_{s2}), f_s3 (atC_{s3})
(f) Three-point tracking points for local oscillation frequency: f_01 (atC_{s1}), f_02 (atC_{s2}), f_03 (atC_{s3})
$f_01 = f_s1$ + 450 kHz
$f_02 = f_s2$ + 450 kHz
$f_03 = f_s3$ + 450 kHz

Table 3.4 Calculation of three-point tracking circuit constants for AM (medium wave) tuner

	Antenna･RF circuit	Local oscillation circuit
Equivalent circuit	 C1: Total capacitance including adjustment trimmer capacitance, circuit capacitance, and active element capacitance.	 CP: Padding capacitance C2: Total capacitance including adjustment trimmer capacitance, circuit capacitance, and active element capacitance.
Calculation formula for circuit constants	$f_S = \frac{1}{2\pi\sqrt{L_1(C+C_1)}}$ .... (2-12) Therefore $\left(\frac{f_S max}{f_S min}\right)^2 = \frac{Cmax+C_1}{Cmin+C_1}$ .... (2-13) Hence $C_1 = \frac{Cmax-\left(\frac{f_S max}{f_S min}\right)^2 Cmin}{\left(\frac{f_S max}{f_S min}\right)^2-1}$ .... (2-14) Also $L_1 = \frac{1}{4\pi^2 f_S max^2(Cmin+C_1)}$ .... (2-15)	$f_{0k} = \frac{1}{2\pi\sqrt{L_2\frac{C_P(C_{Sk}+C_2)}{C_{Sk}+C_2+C_P}}}$ .... (2-16) Also $C_{Sk} = \frac{1}{4\pi^2 f_{Sk}{}^2 L_1} - C_1$ .... (2-17) (However, k=1,2,3) Therefore $C_2 = \frac{(f_{01}{}^2-f_{02}{}^2)C_{S1}C_{S2}+(f_{02}{}^2-f_{03}{}^2)C_{S2}C_{S3}+(f_{03}{}^2-f_{01}{}^2)C_{S1}C_{S3}}{(f_{01}{}^2-f_{02}{}^2)C_{S3}+(f_{02}{}^2-f_{03}{}^2)C_{S3}+(f_{03}{}^2-f_{01}{}^2)C_{S2}}$ .... (2-18) $C_P = \frac{(f_{02}{}^2-f_{01}{}^2)(C_{S2}+C_{S1})(C_2+C_{S2})}{(f_{01}{}^2-f_{02}{}^2)C_2+f_{01}{}^2C_{S1}-f_{02}{}^2C_{S2}}$ ... (2-19) Also, $L_2 = \frac{C_{S1}+C_2+C_P}{4\pi^2 f_{01}{}^2 C_P(C_2+C_{S1})}$ .... (2-20)
Example of circuit constant calculation		

3.1.11. PIN diode

A PIN diode is a type of diode that has a PIN junction, which is formed by placing an intrinsic semiconductor layer (I layer) between a general PN junction diode. The PIN diode can change the high-frequency series resistance r_s by controlling the forward current of the PIN junction, and it is used for various applications such as microwave line switching, TV/radio band switching, and AGC.

3.1.12. Operating principle and structural diagram of the PIN diode

When a forward bias voltage like that in Figure 3.4 is applied to the PIN diode, electrons and holes are injected into the I layer. These injected electrons and holes either recombine to form a forward current or accumulate in the I layer. The accumulated electrons and holes in the I layer increase the conductivity of the I layer, reduce the series resistance r_s at high frequencies, and enable the operation as a high-frequency variable resistance element.
Figure 3.5 shows the structural diagram of the PIN diode.

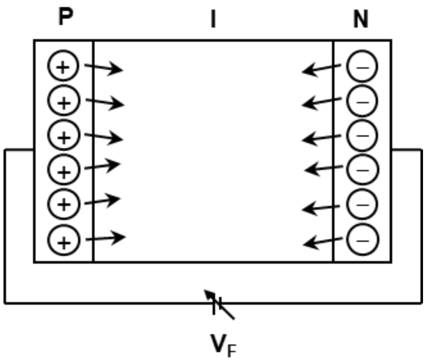


Fig. 3.4 Operating Diagram

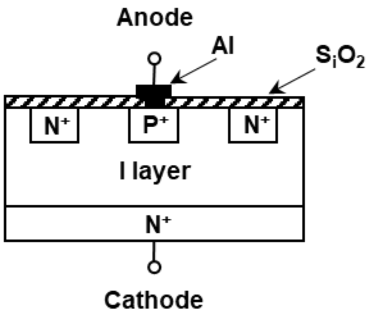


Fig. 3.5 Structural Diagram

Basic parameters of PIN diode

r_s: Series resistance
The series resistance r_s of the PIN diode in forward bias is,

$$r_s = r_i + r_c \quad \cdots\cdots (1)$$

r_i: Resistance of the I layer
r_c: Can be expressed as semiconductor contact resistance.

$$r_i = \frac{l^2}{I_F \tau (\mu_e + \mu_h)} \quad \cdots\cdots (2)$$

L : Thickness of the I layer
I_F : Direct current
μ_e : Electron drift mobility
μ_h : Hole drift mobility
τ : Carrier lifetime in the I layer

$$r_c = \frac{\rho_n{}^+ l_n{}^+ \; \rho P^+ l P^+}{A} + \frac{\rho_{cn}{}^+}{A} + \frac{\rho_c P^+}{A}$$
$$= \frac{\overline{\rho_c}}{A} \quad \cdots\cdots (3)$$

$\rho_n{}^+$, ρP^+	:	Specific n^+resistivity $P^+$of the layer
$l_n{}^+$, $l_P{}^+$	:	Specific n^+resistivity $P^+$of the layer
$\rho_{cn}{}^+$	:	Specific contact resistance between n^+metal and layer
$\rho_c P^+$	:	Specific contact resistance between P^+metal and layer
$\rho_c P^+$	:	Specific contact resistance between P^+metal and layer
$\overline{\rho_c}$	:	Total equivalent specific contact resistance
A	:	Diode area

Substituting equations (2) and (3) into equation (1), equation (4) is obtained.

$$r_s = \frac{l^2}{I_F \tau (\mu_e + \mu_h)} + \frac{\overline{\rho_c}}{A} \quad \cdots\cdots (4)$$

C_T: Capacitance between terminals
The total capacitance between the anode and cathode is dominated by junction capacitance and case capacitance.

3.1.13. Applied circuit example

Figure 3.6 is a π-type attenuator, Figure 3.7 is an example of a Radio-frequency switch circuit.

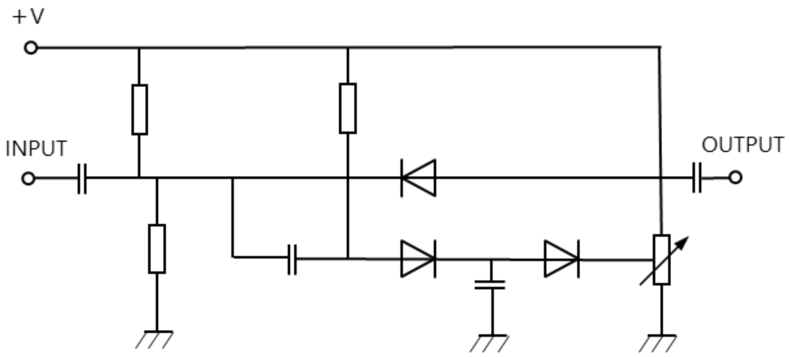


Figure 3.6 π-Type Attenuator

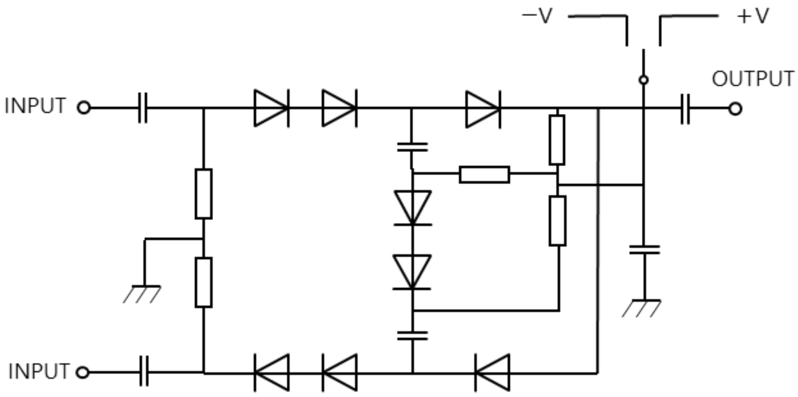


Figure 3.7 Radio-frequency Switch circuit

3.1.14. Schottky barrier diode

A diode that utilizes rectification due to the contact between metal and semiconductor, called a Schottky barrier diode because it was proposed by Schottky.

It is characterized by creating a Schottky barrier between the deposited metal and the N-type epitaxial layer. Typical metals that create a Schottky barrier include molybdenum (Mo) and titanium (Ti). The Schottky barrier diode has a forward voltage as low as a Ge diode and, unlike point-contact diodes, does not have complex factors like needle pressure, making it easier to handle in manufacturing.

This diode is primarily used in mixer and detector circuits above the UHF band, offering superior noise performance compared to point-contact types, and is mechanically and electrically strong, providing reliability benefits. Figure 3.8 shows the structure of a Schottky barrier diode.

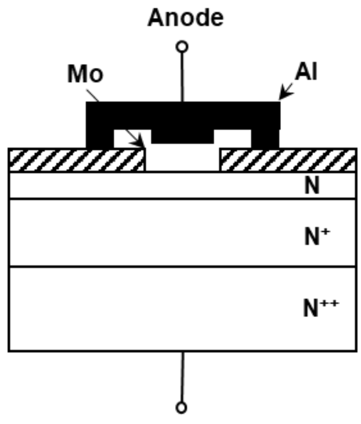


Figure 3.8 Schottky barrier diode structure diagram

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