

# Application Note

## Turning Varactors



### Introduction

Tuning varactors are voltage variable capacitors designed to provide electronic tuning of oscillators and filters.

The two semiconductor materials used are silicon and gallium arsenide. Silicon typically offers lower manufacturing cost, while gallium arsenide diodes provide higher  $Q$  and may be used at higher microwave frequencies.

Within the general family of tuning varactors, there are several major categories, each designed for particular consideration of application and cost.

Circuit tuning requirements will define the appropriate device capacitance versus voltage curve and specific material doping gradients. Explanations of the various material gradients are as follows:

**Abrupt Junction:** As processing techniques improved and new ones developed, it became possible to obtain uniformly doped profiles, which resulted in inverse square root dependence. This type is called Abrupt Junction and is presently most commonly used.

**Hyperabrupt:** Many applications require a linear or nearly linear variation of frequency with applied control voltage. The inverse square root dependence of the Abrupt Junction design provides an inherent inverse fourth root frequency dependence, most decidedly non-linear. To provide linearity, it is necessary to add a linearizer or buffer logic stage to convert the applied control signal to a non-linear diode bias voltage, compensating for the C-V curve of the diode. This results in complexity, cost and inherently slower modulation capability. To remedy this problem, newer forms of C-V curves were developed. They were all called hyperabrupt diodes and were designed to produce a C-V variation that had, at least over a sometimes small portion of the curve, an inverse square law. This provides a narrow band linear frequency variation.

The first hyperabrupts made used ionimplantation to create the special nonuniform doping required. This technique results in excellent uniformity and reliability, and inherent low cost, together with large capacitance swings. Unfortunately, the laws of physics result in substantial reduction in  $Q$ , as compared to abrupt junction design, with the result being that hyperabrupt diodes can be used only at lower microwave frequencies, up to a few GHz at best.

**Linear Tuning:** Aeroflex / Metelics has developed a state of the art Tuning Varactor using new techniques for producing computer controlled variable epitaxial layer doping, (the epitaxial layer is the "active" part of a tuning varactor). This new diode has  $>$  square law C-V variation over its entire tuning range, providing direct linear tuning over more than one octave. In addition,  $Q$  is substantially higher than in ion implantation hyperabrupts..

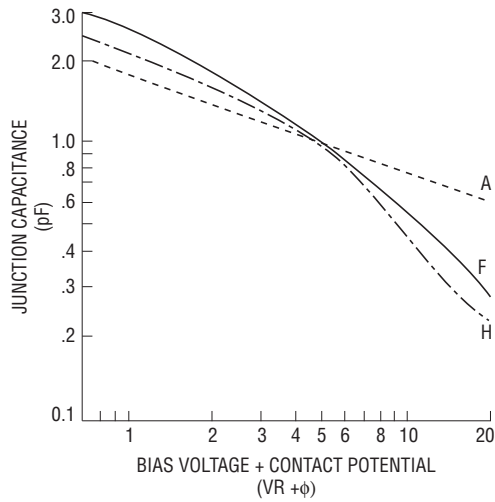
Figures 1, 2, and 3 (on the next page) show C-V curves,  $Q$  and frequencyvoltage curves for abrupt, implanted and linear diodes, in each case for a  $C_j = 1.0$  pF diode.

There are many design variations within each class, and the curves are indicative, rather than specific.



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Figure 1. Tuning Varactor C-V Curves



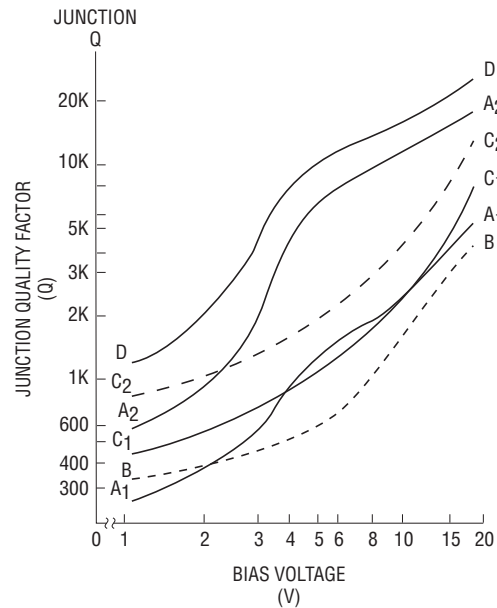
A = Abrupt Junction  $C_j(V_R) = \frac{C_{j0}}{\left(1 + \frac{V_R}{\phi}\right)^\gamma}$

F = Frequency Linear  $C_j(V_R) = \frac{C_{j0}}{(1 + V_R)^2}$

H = Hyperabrupt Junction  $C_j(V_R) = \frac{C_{j0}}{\left(1 + \frac{V_R}{\phi}\right)^\gamma}$

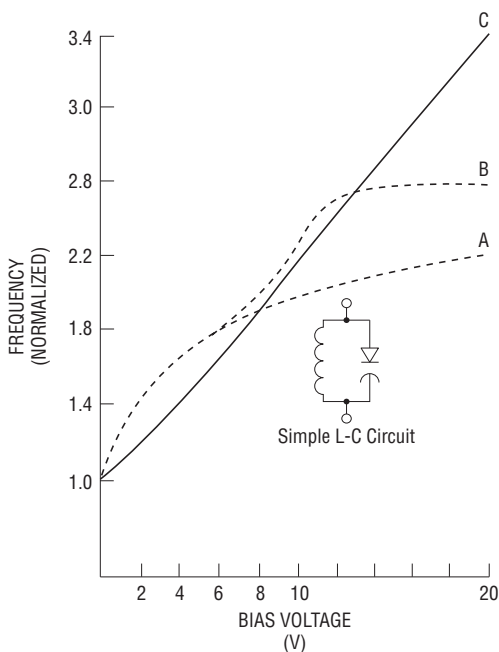
$\gamma = 0.5$  for Abrupt Junction,  $\gamma > 0.5$  for Hyperabrupt Junction  
 $\phi$  = Contact Potential ( $\phi = 0.7V$  for Si,  $\phi = 1.1 V$  for GsAs)

Figure 3. Tuning Varactor Frequency-Voltage Curves



A<sub>1</sub> = Abrupt Junction Ratio -10  
 A<sub>2</sub> = Abrupt Junction Ratio -5  
 B = Ion Implanted Hyperabrupt Ratio -5  
 C<sub>1</sub> = Controlled Epi Linear, Ratio -20  
 C<sub>2</sub> = Controlled Epi Linear, Ratio -8  
 D = GaAs Abrupt, Ratio -6  
 Ratio = C<sub>2</sub> MAX/C<sub>2</sub> MIN

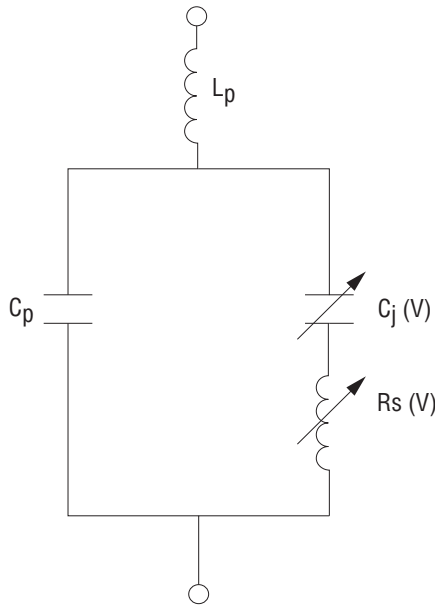
Figure 2. Tuning Varactor Q Variation



A = Abrupt Junction  
 B = Ion Implanted Hyperabrupt  
 C = Controlled Epi Linear

## Mathematical Model

A varactor diode is a P-N junction diode that changes its capacitance and the series resistance as the bias applied to the diode is varied. The property of capacitance change is utilized to achieve a change in the frequency and/or the phase of an electrical circuit. A simple mathematical model of a packaged varactor diode is shown below.



In the above figure,  $C_j (V)$  is the variable junction capacitance of the diode die and  $R_s (V)$  is the variable series resistance of the diode die.  $C_p$  is the fixed parasitic capacitance arising from the installation of the die in a package. Contributors to the parasitic capacitance are the package material, geometry and the bonding wires or ribbons. These factors also contribute to the parasitic inductance  $L_p$ . The contribution to the series resistance from the packaging is very small and may be ignored.

Variation of the junction capacitance and the junction series resistance as a function of applied reverse voltage is reported in the individual varactor data sheets of this catalog.

## Silicon Versus Gallium Arsenide

While it is true that gallium arsenide diodes typically have higher  $Q$  than silicon diodes, this doesn't necessarily result in better performance. It would be expected that substituting gallium arsenide tuning diodes for silicon ones in a VCO would result in better FM noise because of the higher  $Q$ . Instead, the FM noise usually gets worse due to up-conversion of surface noise. There is no known passivation for gallium arsenide which limits surface states and the associated "1/f" noise, like thermal does in the case of silicon.

For this reason, thermal oxide passivation silicon is a better choice for high power or wide band VCO's than gallium arsenide, if FM noise is a consideration.

Another reason for choosing silicon is the poor stability record of gallium arsenide diodes. Because of its higher thermal resistance, gallium arsenide does not settle as fast as silicon diodes in fast VCO's and the high surface state density in GaAs results in significant long-term drift compared to silicon.

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