

APPLICATION NOTE

Varactor SPICE Models for RF VCO Applications

The varactor SPICE model described in this Application Note is useful for RF Voltage Controlled Oscillator (VCO) applications. However, the model neglects some parasitic components often needed for high frequency microwave applications, such as the distributed line package model and some capacitance due to ground proximity. A simplified equivalent circuit diagram for a varactor is shown in Figure 1.

For most RF VCO applications to about 2.5 GHz, parasitic components would not be important unless the varactor

generates higher harmonics that affect performance of the VCO. In this case, a more detailed equivalent circuit model is needed. The technique used should be based on the varactor model extraction procedure from S-parameter data.

A SPICE model and S-parameters, defined for the Libra IV environment, are shown in Figure 2. This model neglects the package capacitance, C_P . The typical package capacitance value of 0.10 pF is absorbed within the junction capacitance, C_J .

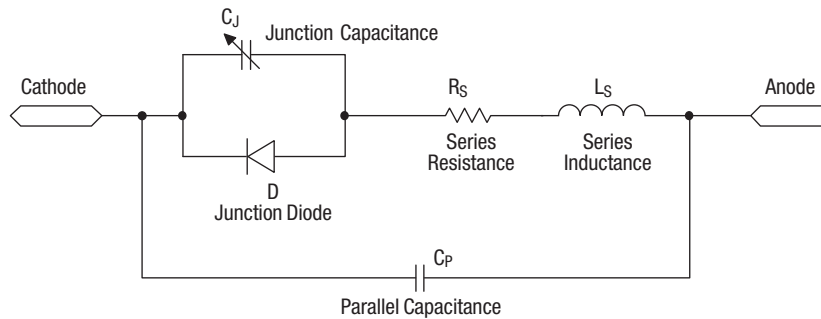


Figure 1. Simplified Equivalent Varactor Circuit

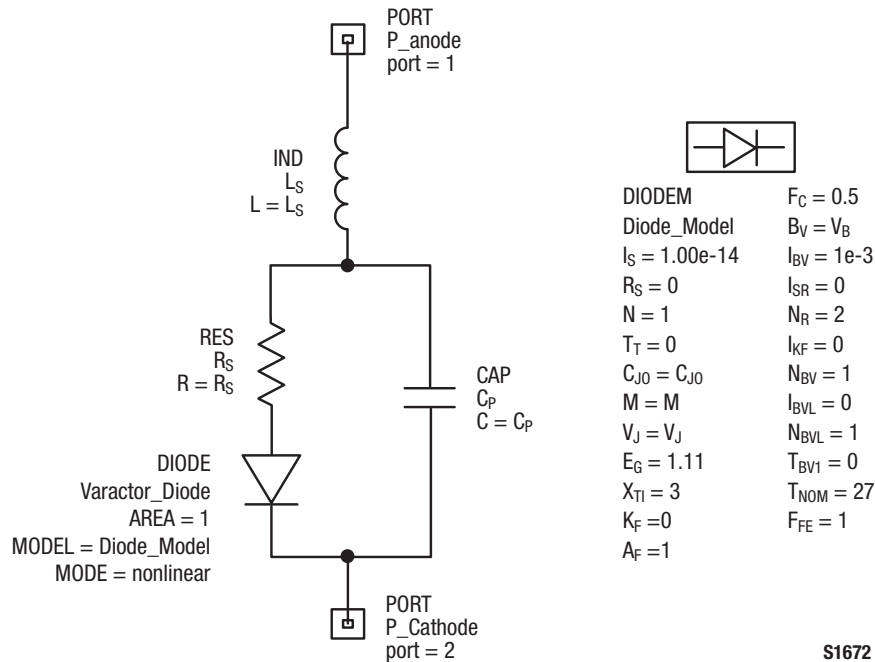


Figure 2. Libra IV SPICE Model

Table 1. SPICE Model Parameters

Parameter	Description	Unit	Default Value
IS	Saturation current. With N, determines the DC characteristics of the diode.	A	1e-14
RS	Series resistance.	Ω	0
N	Emission coefficient. With IS, determines the DC characteristics of the diode.	–	1
TT	Transit time.	sec	0
CJO	Zero-bias junction capacitance. With VJ and M, defines nonlinear junction capacitance of the diode.	F	0
VJ	Junction potential. With CJO and M, defines nonlinear junction capacitance of the diode.	V	1
M	Grading coefficient. With CJO and VJ, defines nonlinear junction capacitance of the diode.	–	0.5
EG	Energy gap. With XT1, helps define the dependence of IS on temperature.	EV	1.11
XT1	Saturation current temperature exponent. With EG, helps define the dependence of IS on temperature.	–	3
KF	Flicker noise coefficient.	–	0
AF	Flicker noise exponent.	–	1
FC	Forward-bias depletion capacitance coefficient.	–	0.5
BV/VB	Reverse breakdown voltage.	V	Infinity
IBV	Current at reverse breakdown voltage.	A	1e-3
ISR	Recombination current parameter.	A	0
NR	Emission coefficient for ISR parameter.	–	2
IKF	High injection knee current.	A	Infinity
NBV	Reverse breakdown ideality factor.	–	1
IBVL	Low-level reverse breakdown knee current.	A	0
NBVL	Low-level reverse breakdown ideality factor.	–	1
TNOM	Nominal ambient temperature at which these model parameters were derived.	°C	27
FFE	Flicker noise frequency exponent.	–	1

SPICE model parameters are defined in Table 1. Default values are noted that are appropriate for silicon varactor diodes, which may be used by the Libra IV simulator unless others are specifically defined.

The effect of the diode junction is ignored in this model. This simplification ignores the rectifying effect of a diode during a positive voltage swing. However, for most RF VCO applications, the lowest practical DC control voltage value is 0.5 V and the magnitude of RF voltage rarely exceeds a peak of 0.2 V. Therefore, the varactor is maintained in its reverse bias state.

However, with a large signal application where it is necessary to consider the rectifying properties of a diode, the effect of the diode can be considered by entering additional diode parameters into the SPICE model defined for the Libra IV environment.

The varactor junction capacitance, C_J , is a function of the applied reverse DC voltage, V_R , as well as the parameters C_{JO} , M , and V_J that are shown in Table 1. The SPICE model defines junction capacitance as a function of reverse voltage, V_R , as follows:

$$C_J(V_R) = \frac{C_{JO}}{\left(1 + \frac{V_R}{V_J}\right)^M} \tag{1}$$

The total capacitance, C_T , is the parallel combination of the junction capacitance and the package capacitance, C_P .

$$C_T(V_R) = \frac{C_{JO}}{\left(1 + \frac{V_R}{V_J}\right)^M} + C_P \tag{2}$$

The model is accurate for abrupt junction varactors (e.g., Skyworks SMV1400 Series). The model is less accurate for hyperabrupt junction varactors, but can be adapted to produce reasonably accurate simulation results. The form is similar to the traditional varactor equation but uses values for V_J , M , and C_P that were extracted individually from measured $C_T(V_R)$ data for each varactor part number.

The series resistance, R_S , is a function of the applied voltage and operating frequency, and may be considered constant. The value

used should be taken from the specified maximum value or derived from its Q specification.

Series inductance, L_S , is also considered a constant value at 1.7 nH. This incorporates the 1.5 nH package inductance with some insertion inductance typical for PC boards in RF wireless applications.

Table 2 provides values for the plastic packaged varactors that may be used with Equations 1 and 2.

Table 2. SPICE Model Parameters for Skyworks Plastic Packaged Varactor Diodes (1 of 2)

Part Number	C_{JO} (pF)	V_J (V)	M	C_P (pF)	R_S (Ω)
SMV1127	23.90	2.20	1.00	0	0.50
SMV1129	27.50	2.80	1.10	0	0.40
SMV1139	8.00	1.20	0.65	0	0.60
SMV1140	70.44	3.50	1.40	0	0.30
SMV1141	7.32	2.20	1.00	0	0.70
SMV1142	13.38	2.20	1.00	0	0.70
SMV1143	18.99	2.20	1.00	0	0.65
SMV1144	24.01	2.20	1.00	0	0.65
SMV1145	41.80	2.50	2.20	0	0.60
SMV1146	61.13	2.50	1.10	0	0.60
SMV1147	89.52	2.50	1.10	0	0.55
SMV1148	104.70	2.25	1.10	0	0.50
SMV1175	13.43	3.00	1.15	0	1.00
SMV1206	26.11	4.00	1.45	0.30	0.70
SMV1207	59.40	6.50	2.30	2.00	0.40
SMV1212	72.47	110.00	67.00	4.50	0.45
SMV1213	28.90	190.00	105.00	2.20	0.80
SMV1214	22.74	190.00	106.00	1.50	0.70
SMV1215	14.36	190.00	115.00	1.10	1.00
SMV1223	25.19	100.00	45.00	2.50	1.50
SMV1224	25.19	100.00	45.00	2.50	1.50
SMV1225	17.46	110.00	47.00	1.60	1.80
SMV1227	52.46	5.00	1.80	0	0.55
SMV1228	130.10	5.00	1.80	0	0.32
SMV1229	271.72	5.00	1.80	0	0.25
SMV1232	4.20	1.70	0.90	0	1.50
SMV1233	4.12	1.70	0.90	0.70	1.20
SMV1234	8.75	2.30	1.10	1.20	0.80
SMV1235	16.13	8.00	4.00	2.00	0.60
SMV1236	21.63	8.00	4.20	3.20	0.50

Table 2. SPICE Model Parameters for Skyworks Plastic Packaged Varactor Diodes (2 of 2)

Part Number	C _{J0} (pF)	V _J (V)	M	C _P (pF)	R _S (Ω)
SMV1237	66.16	10.00	5.30	9.00	0.13
SMV1245	6.90	3.50	1.70	0.47	2.00
SMV1247	9.22	100.00	100.00	0.55	2.00
SMV1248	21.54	13.00	10.50	0	1.80
SMV1249	39.00	17.00	14.00	0	1.50
SMV1250	47.00	17.00	14.00	0	1.50
SMV1251	60.00	17.00	14.00	0	1.30
SMV1253	70.00	17.00	14.00	0	1.20
SMV1255	82.00	17.00	14.00	0	1.00
SMV1299	13.73	190.00	110.00	1.10	2.50
SMV1405	2.92	0.68	0.41	0.05	0.80
SMV1408	3.70	0.80	0.43	0.13	0.60
SMV1409	5.20	0.80	0.45	0.13	0.50
SMV1410	5.54	0.80	0.45	0.13	0.45
SMV1411	7.58	0.80	0.45	0.13	0.40
SMV1413	9.20	0.79	0.45	0.13	0.35
SMV1414	11.20	0.78	0.46	0.13	0.30
SMV1415	12.80	0.78	0.46	0.13	0.27
SMV1416	16.04	0.84	0.48	0.13	0.24
SMV1417	19.20	0.84	0.48	0.13	0.22
SMV1419	21.40	0.87	0.54	0.13	0.20
SMV1420	30.20	0.80	0.47	0.13	0.19
SMV1421	36.10	0.80	0.47	0.13	0.18
SMV1493	29.00	0.63	0.47	0	0.25
SMV2022	7.08	7.00	2.30	0.40	2.10
SMV2023	25.79	250.00	110.00	2.40	1.30

The values shown in Table 2 can be used for each varactor junction in the SOD-323 and SOT-23 package types for these varactors. The Table also provides calculated values for the capacitance ratio between 0.5 and 2.5 V for each varactor. This is a typical voltage range for battery operated wireless VCO circuits.

Note that the values listed in Table 2 for V_J, M, and C_P were empirically determined and do not represent the precise physical or electronic properties of the semiconductor or the package type.

Examples

Figure 3 plots the calculated and measured SPICE model capacitance of the abrupt junction varactor SMV1493-011 against voltage. Figure 4 plots the calculated and measured SPICE model capacitance for the hyperabrupt junction varactor SMV1235-011 against voltage.

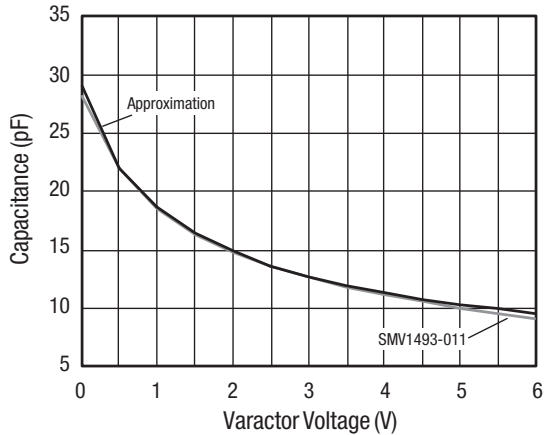


Figure 3. SMV1493-011 Capacitance vs Voltage
 $(C_v = 29[1 - V_{VAR}/0.63]^{0.47})$

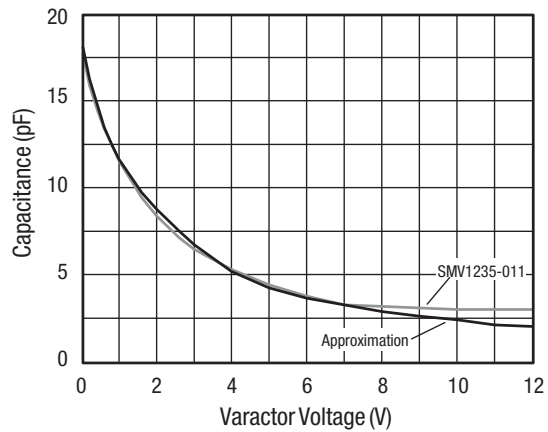


Figure 4. SMV1235-011 Capacitance vs Voltage
 $(7.575/[1 - V_V/0.8]^{0.45})$

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