APPLICATION NOTE

APN1004: Varactor SPICE Models for RF VCO Applications

Varactor Equivalent Circuit Model Definitions

A simplified equivalent circuit of varactor is shown in Figure 1.

This varactor model is useful for RF VCO applications although it neglects some parasitic components often needed for higher frequency microwave applications, such as the distributed line package model and some capacitance due to ground proximity. For most RF VCO applications, to about 2.5 GHz, these parasitic components would not be important unless higher harmonics generated by the varactor 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, defined for the Libra IV environment, is shown in Figure 2, with the description of the parameters employed. It neglects the package capacitance, C_P, its typical 0.10 pF value is absorbed within the junction capacitance C_V.

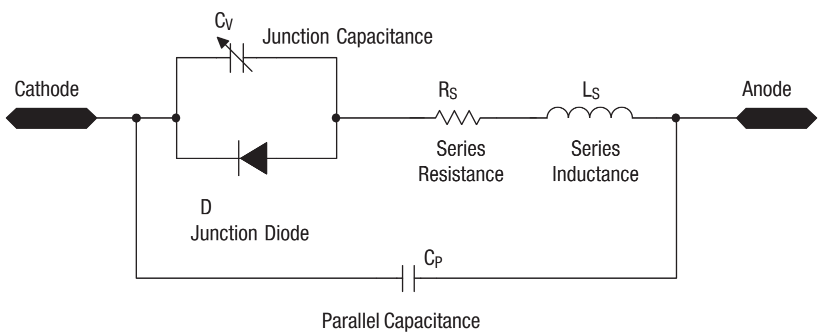

Figure 1. Simplified Equivalent Circuit of Varactor

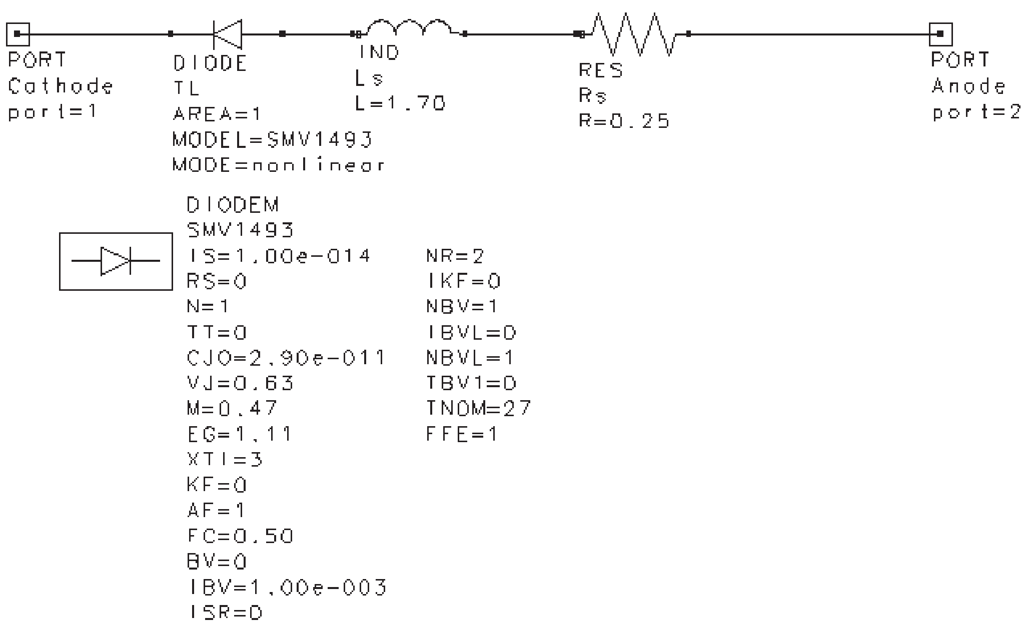

Figure 2. Libra IV SPICE Model

Parameter	Description	Unit	Default
IS	Saturation current (with N, determine the DC characteristics of the diode)	A	1e-14
R_S	Series resistance	Ω	0
N	Emission coefficient (with IS, determines the DC characteristics of the diode)	-	1
TT	Transit time	s	0
C_{J0}	Zero-bias junction capacitance (with V_J and M define nonlinear junction capacitance of the diode)	F	0
V_J	Junction potential (with V_J and M define nonlinear junction capacitance of the diode)	V	1
M	Grading coefficient (with V_J and M define nonlinear junction capacitance of the diode)	-	0.5
EG	Energy gap (with XTI, helps define the dependence of IS on temperature)	EV	1.11
XTI	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
B_V	Reverse breakdown voltage	V	Infinity
I_{BV}	Current at reverse breakdown voltage	A	1e-3
ISR	Recombination current parameter	A	0
NR	Emission coefficient for ISR	-	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
T_{NOM}	Nominal ambient temperature at which these model parameters were derived	°C	27
FFE	Flicker noise frequency exponent	-	1

Table 1. SPICE Model Parameters

Table 1 describes the model parameters. It shows default values 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 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 0.2 V peak. Therefore, the varactor is maintained in its reverse bias state. However, in a large signal application where it is necessary to consider the diode's rectifying properties, it may be done by entering the additional diode parameters in the SPICE model defined for the LIBRA IV environment.

According to the SPICE model in Table 1, the varactor capacitance, C_V, is a function of the applied reverse DC voltage, V_R, and may be expressed as follows:

$$C_V = \frac{C_{J0}}{\left(1 + \frac{V_R}{V_J}\right)^M} + C_P$$

This equation is a mathematical simulation of the capacitance characteristic. The model is accurate for abrupt junction varactors (SMV1400 Series); for hyperabrupt junction varactors the model is less accurate but very reliable. 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 $C_V(V_R)$ data for each varactor part number.

Series resistance, R_S, is a function of 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 constant at a value of 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 gives values for the plastic packaged varactors that may be used for SPICE model simulation equation. It may be employed for each varactor junction in the SOD-323 and SOT-23 package. It also gives calculated values for the capacitance ratio between 0.5–2.5 V for each diode that is a typical voltage range for battery operated wireless VCO circuits.

Note: The values listed for V_J, M and C_P in the table were empirically determined and do not represent the precise physical or electronic properties of the semiconductor or the package.

Part Number	C_{J0} (pF)	V_J (V)	M	C_P (pF)	R_S (Ω)	L_S (nH)	C0.5/C2.5
SMV1127	23.9	2.2	1	0	0.5	1.7	1.68
SMV1129	27.5	2.8	1.1	0	0.4	1.7	1.73
SMV1139	8	1.2	0.65	0	0.6	1.7	1.68
SMV1140	70.44	3.5	1.4	0	0.3	1.7	1.68
SMV1141	7.32	2.2	1	0	0.7	1.7	1.66
SMV1142	13.38	2.2	1	0	0.7	1.7	1.67
SMV1143	18.99	2.2	1	0	0.65	1.7	1.67
SMV1144	24.01	2.2	1	0	0.65	1.7	1.67
SMV1145	41.8	2.5	1.1	0	0.6	1.7	1.68
SMV1146	61.13	2.5	1.1	0	0.6	1.7	1.68
SMV1147	89.52	2.5	1.1	0	0.55	1.7	1.68
SMV1148	104.7	2.25	1.1	0	0.5	1.7	1.7
SMV1175	13.43	3	1.15	0	1	1.7	1.68
SMV1206	26.11	4	1.45	0.3	0.7	1.7	1.69
SMV1207	59.4	6.5	2.3	2	0.4	1.7	1.73
SMV1212	72.47	110	67	4.5	0.45	1.7	2.82
SMV1213	28.9	190	105	2.2	0.8	1.7	2.53
SMV1214	22.74	190	106	1.5	0.7	1.7	2.6
SMV1215	14.36	190	115	1.1	1	1.7	2.73
SMV1223	25.19	100	45	2.5	1.5	1.7	2.1
SMV1224	25.19	100	45	2.5	1.5	1.7	2.1
SMV1225	17.46	110	47	1.6	1.8	1.7	2.05
SMV1227	52.46	5	1.8	0	0.55	1.7	1.75
SMV1228	130.1	5	1.8	0	0.32	1.7	1.75
SMV1229	271.72	5	1.8	0	0.25	1.7	1.75
SMV1232	4.2	1.7	0.9	0	1.5	1.7	1.87
SMV1233	4.12	1.7	0.9	0.7	1.2	1.7	1.71
SMV1234	8.75	2.3	1.1	1.2	0.8	1.7	1.82
SMV1235	16.13	8	4	2	0.6	1.7	1.84
SMV1236	21.63	8	4.2	3.2	0.5	1.7	1.86
SMV1237	66.16	10	5.3	9	0.13	1.7	2.05
SMV1245	6.9	3.5	1.7	0.47	2	1.7	1.82
SMV1247	9.22	100	100	0.55	2	1.7	2.15
SMV1248	21.54	13	10.5	0	1.8	1.7	6.2
SMV1249	39	17	14	0	1.5	1.7	6.75
SMV1250	47	17	14	0	1.5	1.7	5.41
SMV1251	60	17	14	0	1.3	1.7	5.86

Table 2. Plastic Packaged Varactor Values for SPICE Model Simulation Equation

Part Number	C_{JO} (pF)	V_J (V)	M	C_P (pF)	R_S (Ω)	L_S (nH)	C0.5/C2.5
SMV1253	70	17	14	0	1.2	1.7	5.88
SMV1255	82	17	14	0	1	1.7	4.42
SMV1299	13.73	190	110	1.1	2.5	1.7	2.61
SMV1405	2.92	0.68	0.41	0.05	0.8	1.7	1.41
SMV1408	3.7	0.8	0.43	0.13	0.6	1.7	1.5
SMV1409	5.2	0.8	0.45	0.13	0.5	1.7	1.51
SMV1410	5.54	0.8	0.45	0.13	0.45	1.7	1.52
SMV1411	7.575	0.8	0.45	0.13	0.4	1.7	1.52
SMV1413	9.2	0.79	0.45	0.13	0.35	1.7	1.52
SMV1414	11.2	0.78	0.46	0.13	0.3	1.7	1.54
SMV1415	12.8	0.78	0.46	0.13	0.27	1.7	1.55
SMV1416	16.04	0.84	0.48	0.13	0.24	1.7	1.54
SMV1417	19.2	0.84	0.48	0.13	0.22	1.7	1.54
SMV1419	21.4	0.87	0.54	0.13	0.2	1.7	1.61
SMV1420	30.2	0.8	0.47	0.13	0.19	1.7	1.59
SMV1421	36.1	0.8	0.47	0.13	0.18	1.7	1.57
SMV1493	29	0.63	0.47	0	0.25	1.7	1.63
SMV2022	7.08	7	2.3	0.4	2.1	1.7	1.65
SMV2023	25.79	250	110	2.4	1.3	1.7	2.09

Table 2. Plastic Packaged Varactor Values for SPICE Model Simulation Equation (Continued)

Examples

Figure 3 shows the SPICE model calculated capacitance of the abrupt junction varactor SMV1493-011 with measured capacitance values.

Figure 4 shows the SPICE model calculated capacitance for the hyperabrupt junction varactor SMV1235-011 with measured capacitance values.

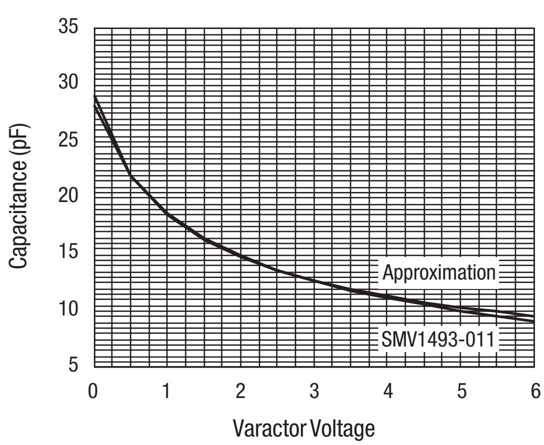

Figure 3. SMV1493-011 C_V = 29/(1-V_{VAR}/0.63)^0.47

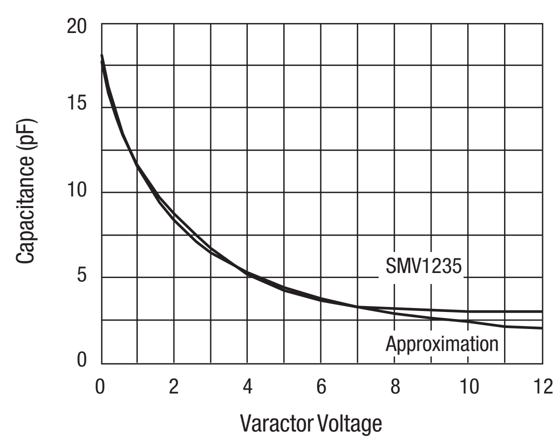

Figure 4. SMV1235 7.575/(1-V_V/0.8)^0.45