

## Design of Voltage Controlled Oscillators with MMICAD

This application note explains the usage of MMICAD for the design of voltage controlled oscillators. The design approach is based on the method explained in reference 1.

### I. Varactor Diode Model

A varactor diode is a variable-reactance element. The variable reactance is provided by the junction capacitance which varies as a function of the applied voltage. A simplified equivalent circuit for a varactor diode under reverse bias conditions consists of a variable capacitor and a fixed series resistor. A series and a parallel capacitor may be included to take the package reactance into account.

The variable capacitance is given by

$$C(V) = C_0 / (1 + V/\phi)^\gamma$$

where  $C_0$  is the zero-bias junction capacitance  
 $\phi$  is the built-in voltage  
 $\gamma$  is the ideality factor.

The definition of a bias dependent varactor model in MMICAD is shown in the following table:

```
! VARACTOR DIODE MODEL
! MODEL PARAMETERS:      V=control voltage (reverse)
!                          C0=zero bias capacitance
!
CKT
MODVAR V=0 C0=2.5
SRLC 1 2 R=3 L=.05 C={ C0/(1+V/.7)^.6 }
CAP 1 2 C=.01
DEF2P 1 2 VARAC ( V C0 )
```

An ideality factor of 0.6 and a build-in voltage of 0.7V have been used in the above model.

Assuming a zero-bias capacitance of 2.5pF and a control voltage range of 0 to 30 volts, the junction capacitance may be varied from 2.5pF to 0.f, as shown in Figure 1:

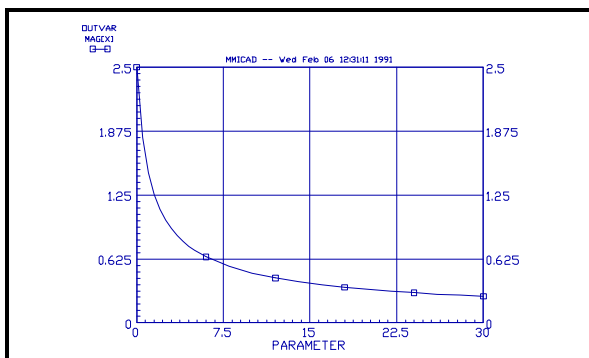


Figure 1

### II. Oscillator Design - Initial Optimization

For a given minimum varactor capacitance and a maximum oscillation frequency, we may now calculate the reactance required at the input of the 'active' circuit to fulfil the oscillation condition. Assuming  $f_{max}=12\text{GHz}$  and  $C_{min}=0.25\text{pF}$ , we find

$$\text{Im}\{ Z_{in} \} = 1 / 2 * \pi * f_{max} * C_{min} = 53 \text{ Ohm.}$$

The minimum oscillation frequency is mainly determined by the 'active' circuit itself, since the reactance seen at the input becomes negative (capacitive) for lower frequency values. Since the capacitor used as tuning element always presents a negative reactance, we require a positive input reactance of the 'active' circuit to fulfil the oscillation conditions.

After selecting an appropriate transistor we may now start to perform the initial oscillator design. We must design a circuit which, with its load connected at the output, presents at the input:

- (1) a negative resistance ( $Z_{in} < 0$ ) and
- (2) a positive reactance ranging from 0 at  $f_{min}$  up to 53 Ohm at  $f_{max}$ .

These two criteria may now be used to initially construct the oscillator circuit, consisting of the input, source feedback and output circuitry.

The error function definitions used in the MMICAD circuit file are shown in the next table:

```
! OPTIMIZATION GOAL DEFINITIONS
OPT
OCIR re[z11] in -7.5 2.5
OCIR im[z11] in 50 50
```

This error function becomes zero, when the real part of the input impedance over the specified frequency range shows values in the range from -10 to -5 Ohms, and the imaginary part varies between 0 and 100 Ohms.

```

!FILE NAME: VCO1.CKT
!NOTES: VCO DESIGN USING MMICAD
!Usage: Conduct a variational analysis, display the real and imaginary
impedances, followed by the frequency and frequency sensitivity plots.

! notes: * THE OSCILLATION FREQUENCY LIST MAY BE MERGED
INTO THE EDITOR BY TYPING ALT-O AFTER VARIATIONAL
ANALYSIS.
! * IF THE OSC FRAME IS NOT DEFINED IT IS NOT DISPLAYED

! * IF THE OSCS FRAME IS NOT DEFINED IT IS NOT DISPLAYED
!set the oscillation mode:

mode osc

var
CVAR=2.5
LIN1=? 450 980 2000 ?
LIN2=? 1500 2000 3000 ?

ckt
!define a user defined model for a varactor diode:
MODVAR V=0 C0=2.5
SRLC 1 2 r=3 l=.1 C={ C0/(1+V/.7)^.6 }
DEF2P 1 2 VARAC ( V C0 )

ckt
MSUB ER=9.4 H=250 T=0.1 RHO=1 TAND=0 @SUB0
MTRLND 10 1 W=70 L=LIN1 @SUB0
MTRLND 1 0 W=80 L=? 2475 ? @SUB0
MTRLND 1 2 W=400 L=LIN2 @SUB0
FET 2 3 4 GM=35 CGS=0.23 RDS=400 CGD=0.017 CDS=0.1&
RGS=4.6 TAU=3 RG=2 &
RS=0.6 RD=1 LG=0.001 LS=0.001 LD=0.001
MTRLND 3 5 W=? 95 ? L=? 340 ? @SUB0
MTRLND 5 0 W=? 185 ? L=? 1700 ? @SUB0
MTRLND 5 6 W=? 250 ? L=? 1600 ? @SUB0
CAP 4 0 C=0.47
MTRLND 4 0 W=? 95 ? L=? 2485 ? @SUB0
RES 6 0 R=50
DEFIP 10 ACT

! define the oscillator
ACT 10 0 M=1
VARAC 20 10 0 V=PARAM C0=CVAR
DEFIP 20 OCIR

freq
sweep 6 12 .25

param
fixed 0
sweep 0 30 2

out
ocir im[z11] zp r
ocir s11 sc
ocir re[z11] zp

opt
ocir re[z11] in -7.5 2.5
ocir im[z11] in 50 50

grid
zp 6 12 -20 20 r -200 200
sc 2
!the following grid defines the oscillation frequency vs voltage frame:
osc
0 30 6 12
!the following grid defines the phase sensitivity frame:
osc_s 0 30 0 .4

label
Oscillator Design

```

Table 1

The MMICAD circuit file of the oscillator circuit is shown in Table 1. The NETLIST contains a user-defined model of the bias-dependent varactor model. The active circuit **ACT** is defined as a one port with a 50 Ohm load connected at the output. The complete oscillator circuit **OSC** consists of the varactor diode and the active circuit, therefore allowing verification of the oscillation condition with respect to a perfect short (as explained in Ref. 1).

The **PARAM** keyword is used to define the control voltage settings. Using the Variational Analysis feature of MMICAD, we are able to automatically display the oscillator performance for all defined control voltages.

Also note the special keyword **OSC** in the **MODE** line and the grid definitions where the frame called **OSC** has been defined.

These definitions, used in combination with the Variational Analysis feature of MMICAD, allow the user to determine the oscillation frequency as a function of the control voltage. MMICAD first sweeps the networks for each voltage point over the given frequency range and displays the input impedance.

We observe a change in the imaginary part of the input impedance because of the increasing control voltage. The control voltage has been swept from 0 to 30 volts in 5 volt steps in the above example.

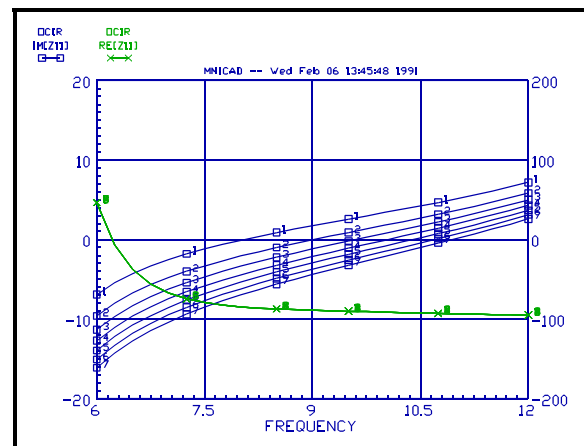


Figure 2

MMICAD was used to perform optimization of the oscillator circuit shown in Figure 2.

Figure 3 shows the real and imaginary part of the impedance seen at the input of the oscillator with a 50 Ohm load connected at the output.

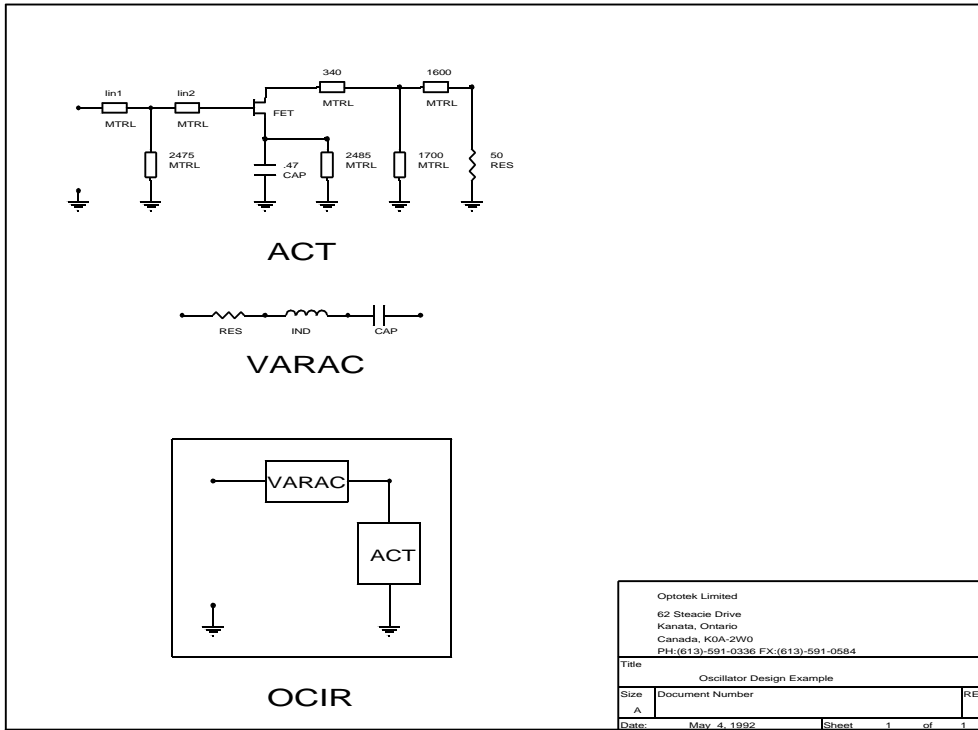


Figure 3

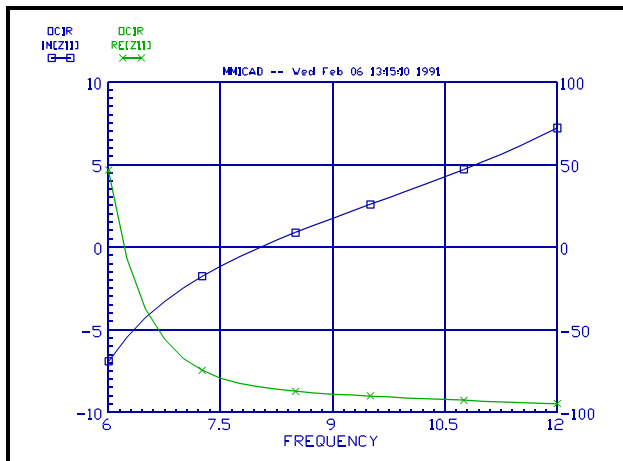


Figure 4

This example also demonstrates the 'SMART RE-ANALYSIS' feature of MMICAD. The **ACT** network does not depend on the control voltage (**PARAM**), but only the varactor in the **OSC** network changes during the Variational Analysis run. Only networks where an element value has been modified since the last analysis have to be re-analyzed, hence execution speed may be increased substantially during tune, variational analysis and optimization by splitting the total network into several sub-networks.

Having the **OSC** keyword included in the **MODE** line and also a frame **OSC** defined in the grid block will cause MMICAD to calculate and display the frequency of oscillation of the network. This is done by seeking the root of the first trace of the frame displayed during variational analysis.

Having defined the imaginary part of the **OSC** network as the first member of the frame **ZP**, MMICAD will find the frequency where the oscillation condition  $IM\{ Z_{11} \} = 0$  is valid. A different frequency point will be found for each control voltage setting. Please note that MMICAD does not verify any other conditions. The user should always ensure that the real part of the **OSC** network is negative.

The **OSC** frame definitions are now used to display the oscillation frequency as a function of the control voltage, as shown in Figure 5.

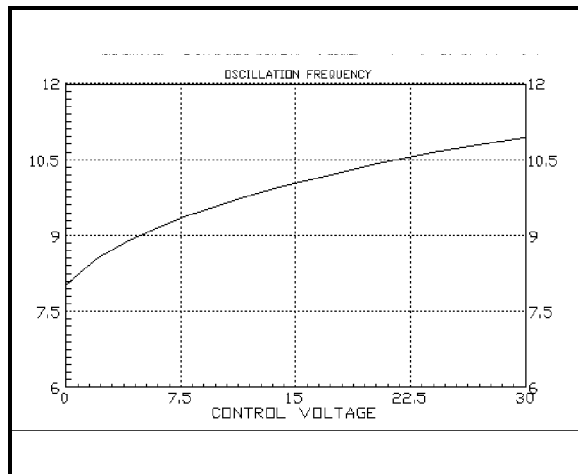


Figure 5

If the user defines an **OSC-S** frame in the **GRID** block, the tuning sensitivity will be displayed next, as in Figure 6.

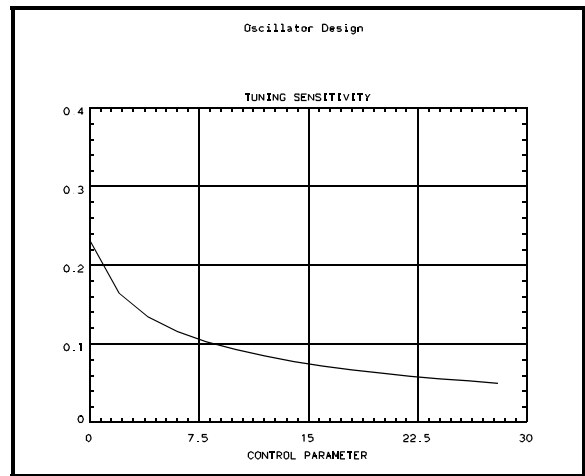


Figure 6

### III. Conclusion

This application note demonstrates several special features included in MMICAD which are used to facilitate the design of voltage controlled oscillators.

<sup>1</sup>W. El-Kamali, J.P. Grimm, R. Meierer and C. Tsironis, "New Design Approach for Wide-Band FET Voltage-Controlled Oscillators", IEEE MTT, Vol. 34 No.10, Oct. 1986, pp.1059-1063.