*==========Free_Running_Serial_CRYSTAL_OSC==========

How well does Spice simulate a free running oscillator?
Being able to use the output waveform data to see time delays
can come in handy.

```
*=========CRYSTAL_SubCircuit==========================================
.SUBCKT   XCRYST VA     VB
 RS       VA     VCS    340
 CS       VCS    VLS    7f
 LS       VLS    VB     3.5
 CP       VA     VB     .03pf
.ENDS     XCRYST
*
*                     VCS  VLS/¯\/¯\/¯\
*   ___               ___              ___
*  |VA |__/\  /\  /\__||____| () () |___|VB |
*  |___|   \/  \/                      |___|
*           RS         CS     LS         _|_
*                                        ///
*          |____||____________________|
*                CP
*                                 CS LS = 29.97meg @ 885Gohms
*
*                      ___
*                     |   |
*            ___      |   |      ___
*           |VA |_____|   |_____|VB |
*           |___|     |___|     |___|
*
*
* Freq                Mode  L1     C1       R1    C0      Q
* 1 MHz               fund  3.5H   0.007pf  340   3pf     64679
==========================================================================
```

One can make a sub-circuit using typical crystal models.
In this case a 1MegHz crystal is being used to run
in the series mode.

```
*=========CRYSTAL_Oscillator==========================================
*
*    ^  VCC                    _________
*   /_\                       |         |
*   _|_  D1                   |   |\    |
*    ^          R1            |___| \/\_|__|VREF|
*   /_\   1Meg                     |/\/   |____|
*    |__/\  /\  /\__                |/
*       \/  \/      |              XINV4
*                   |   C1
*    |\             |     |\
*    |_____| \/\____|__||__| \/\__
*    |     |/\/          |/\/    |
*    |     |/            |/      |
*          XINV1         XINV2   |
*                                |
*    ___  |___|                  |
*   |VA |__|   |__|OUT|__________|
*   |___|  |___|  |___|
*    _|_          XCRY1
*    ^
*   /_\  D2
*    |
*   ///
*
==========================================================================
```

In this mode, the Crystal is operating more like a short circuit.
The phase across the crystal is expected to be zero.

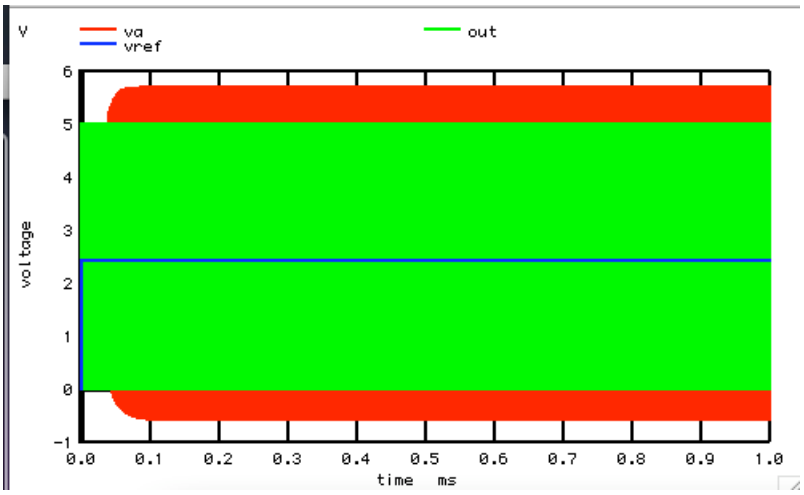
```
*=========Run_transient===========================================
*.OPTIONS GMIN=1e-18    METHOD=trap   ABSTOL=1e-18  TEMP=27 srcsteps = 1  gminsteps = 1
VCC       VCC     0       DC      5
XCRY1     VA      OUT     XCRYST
XINV      VA      VC      VCC     INV_R
XINV2     VD      OUT     VCC     INV_R
XINV4     VREF    VREF    VCC     INV_R
R1        VA      VC      1meg
C1        VC      VD      .1u     IC=0
D1        VA      VCC     DD
D2        0       VA      DD
*TRAN     TSTEP   TSTOP   TSTART TMAX   ?UIC?
.tran     10n     600u  0     10n    UIC

.control
run
set       pensize = 2
plot      va    out  vref
```

```
plot      out   va   vref
plot      out   vc   va  vref xlimit 590u 600u
print     mean(vref)
```

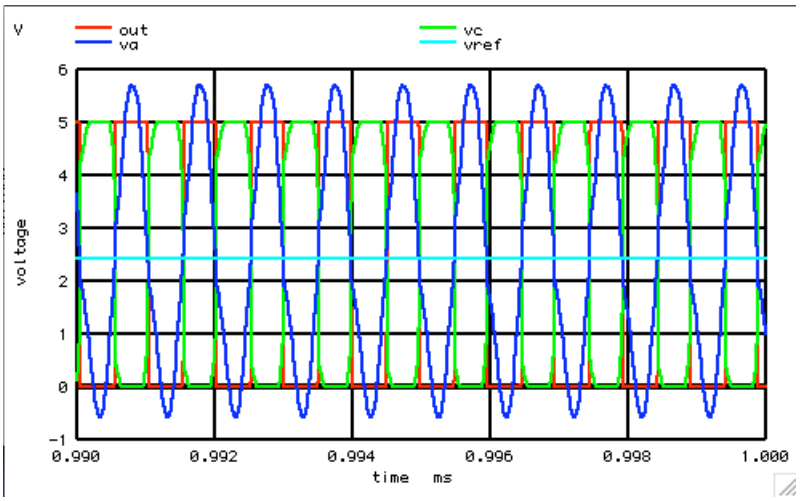
==========

There is always a question of how long does it take to reach steady state.



==========

One needs to look at the last few cycles over a smaller time to see some detail.



==========

Some of the nonlinearities are visible. Notice that some clamp diodes have been added to simulate ESD diodes.

```
*
*    ^  VCC                    _________
*   /_\                       |         |
*   _|_  D1                   |    |\    |
*    ^          R1            |___|  \/\_|__|VREF|
*   /_\   1Meg                    |  /\/    |____|
*    |__/\  /\  /\__             |/
*    |    \/  \/    |              XINV4
*    |              |   C1
*    |     |\    VC |        |\
*    |_____| \/\____|__||__| \/\__
*    |     | /\/         ||   | /\/   |
*    |     |/            VD |/        |
*    |       XINV1          XINV2     |
*    |       ___                      |
*   _|_    ||   ||                   |
*  |VA |__||   ||__|OUT|_____________|
*  |___|   ||   ||  |___|
*   _|_    ||___||
```

```
*    ^          XCRY1
*   /_\  D2
*    |
*   ///
*
```

==========

But how well can the timing be trusted? One needs a mathematical way to process the output data. In this example the last 50 transitions will be looked at.

```
*=========Process_Output_Arrays========
let       Numb_Pt= length(out)
compose   time_tp start = 0 stop = 49 step =1
compose   dt_tp   start = 0 stop = 49 step =1
*=========Look_at_Last_50_edges========
let       i = Numb_Pt-2
let       n = 0
while     (n < 50)
if        ( out[i]-2.5 >= 0 & out[i-1] -2.5 <= 0)
let       tp = time[i]
let       time_tp[n]=tp
* echo    $&n   $&tp
let       n=n+1
endif
let i=i-1
endwhile
```

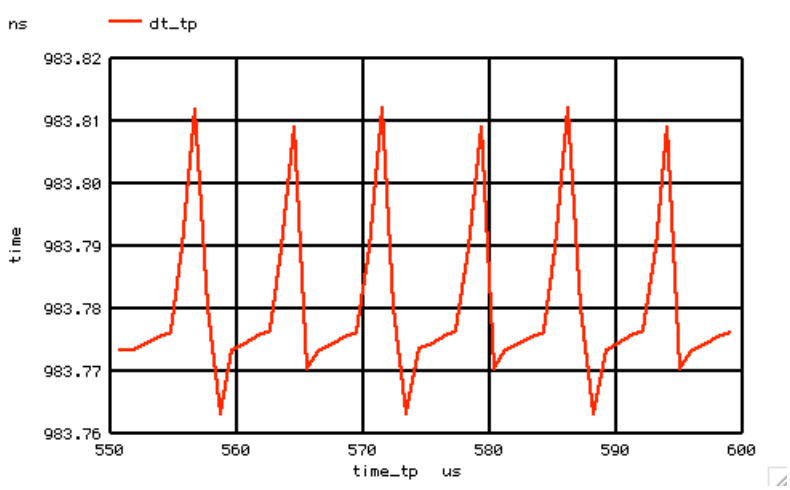
==========

The oscillator's period can be found by subtracting the edge time points

```
*=========Find_and_Plot_periods========
let       i = 0
repeat    49
let       dt_tp[i] = -time_tp[i+1]+time_tp[i]
let       i=i+1
endrepeat
let       dt_tp[49] =dt_tp[48]
plot      dt_tp vs time_tp
```

==========

And plotting the time periods versus time can show all the simulation errors.




```
*=========Print_Frequency========
print     mean(1/dt_tp)
.endc
```

==========

The mean can be taken and the output frequency can be printed out.

```
Circuit:          OneMeg_FreeRun_Serial_Crystal
mean(vref) =      2.42844e+00
mean(1/dt_tp) =   1.01649e+06
```

==========

This value should come close to what an AC analysis will predict for the sub-circuit below.

```
*=========CRYSTAL_SubCircuit==========================================
.SUBCKT    XCRYST VA     VB
 RS        VA     VCS    340
 CS        VCS    VLS    7f
 LS        VLS    VB     3.5
 CP        VA     VB     .03pf
.ENDS      XCRYST
*
*                        VCS  VLS/¯\/¯\/¯\
*    |VA|__/\   /\   /\__||____| () () |___|VB|
*    |__|  \/   \/      ||                |__|
*           RS          CS     LS            |
*                                            ///
*           |____||____________________|
*                CP
*                                   CS LS = 29.97meg @ 885Gohms
*
*                          ___
*                         |   |
*              |VA|__|   |   |  |__|VB|
*              |__|      |___|
*
* Freq                    Mode  L1     C1       R1    C0      Q
* 1 MHz                   fund  3.5H   0.007pf  340   3pf     64679
=======================================================================

============Full_Netlist_For_Copy_Paste=========================
OneMeg_FreeRun_Serial_Crystal
*
*     ^  VCC                          _________
*    /_\                             |         |
*    _|_  D1                         |   |\    |
*     ^          R1                  |___| \/\_|__|VREF|
*    /_\   1Meg                      |   | /\/
*     |__/\   /\   /\__              |   /
*        \/   \/      |                XINV4
*                     |   C1
*                     |\          |\
*     |_____|\/\_____|__||__|\/\__
*     |     /\/     |     |  /\/   |
*     |    /        |     |/       |
*     |     XINV1                  XINV2
*     |     ___     |
*    _|_   |   |    |
*   |VA|__|   |  |__|OUT|__________|
*   |__|    |___|
*    _|_
*     ^          XCRY1
*    /_\  D2
*    _|_
*    ///
*
* .OPTIONS  GMIN=1e-18    METHOD=trap   ABSTOL=1e-18  TEMP=27 srcsteps = 1  gminsteps = 1
VCC        VCC    0      DC      5
XCRY1      VA     OUT    XCRYST
XINV       VA     VC     VCC     INV_R
XINV2      VD     OUT    VCC     INV_R
XINV4      VREF   VREF   VCC     INV_R
R1         VA     VC     1meg
C1         VC     VD     .1u    IC=0
D1         VA     VCC    DD
D2         0      VA     DD

*TRAN      TSTEP  TSTOP  TSTART TMAX   ?UIC?
.tran      10n    600u  0     10n    UIC

.control
run
set        pensize = 2
plot       va    out  vref
plot       out   va   vref
plot       out   vc   va  vref xlimit 590u 600u
print      mean(vref)

*=========Process_Output_Arrays========
let        Numb_Pt= length(out)
compose    time_tp start = 0 stop = 49 step =1
compose    dt_tp   start = 0 stop = 49 step =1

*=========Look_at_Last_50_edges========

let        i = Numb_Pt-2
let        n = 0
```

```
while     (n < 50)
if        ( out[i]-2.5 >= 0 & out[i-1] -2.5 <= 0)
let       tp = time[i]
let       time_tp[n]=tp
* echo    $&n   $&tp
let       n=n+1
endif
let i=i-1
endwhile

*=========Find_and_Plot_periods========
let       i = 0
repeat    49
let       dt_tp[i] = -time_tp[i+1]+time_tp[i]
let       i=i+1
endrepeat
let       dt_tp[49] =dt_tp[48]
plot      dt_tp vs time_tp

*=========Print_Frequency========
print     mean(1/dt_tp)
.endc

.model    DD            D(IS=3.15e-18 RS=100 CJO=10f )

*=========CRYSTAL_SubCircuit=============================================
.SUBCKT   XCRYST VA     VB
 RS       VA     VCS    340
 CS       VCS    VLS    7f
 LS       VLS    VB     3.5
 CP       VA     VB     .03pf
.ENDS     XCRYST
*
*                    VCS  VLS/¯\/¯\/¯\
*   |VA |__/\  /\  /\__||____| () () |___|VB |
*   |___|  \/  \/      ||                |___|
*          RS          CS     LS          |
*                                          ///
*          |____||_____________________|
*                CP
*                                  CS LS = 29.97meg @ 885Gohms
*
*                  |||
*             |VA |__|||__|VB |
*             |___|  |||  |___|
*
* Freq                Mode  L1     C1       R1    C0      Q
* 1 MHz               fund  3.5H   0.007pf  340   3pf     64679
*
*=========Real_Inverter=========================
.SUBCKT   INV_R  IN    OUT    VCC
 MN1      OUT    IN    0      0      NMOSC   W=30u     L=1u
 MP1      OUT    IN    VCC    VCC    PMOSC   W=90u     L=1u
 C1       OUT    0     1p
.ENDS     INV_R
*
*              ^
*  INV_R      /_\ VCC
*              |
*            <-
*          ||___   480ps at 6 stages
*
*       __||_ MP1
*  |VIN|__|     |___
*  |___|     |__|VOUT
*            _|  |___|
*       __||
*          ||___ MN1
*          ||->
*            |
*            ///
*
*==================CMOS_Models=========================
.model            NMOSC              NMOS(
+ Level=  8       Tnom=27.0
*------------------Process-----------------------------------------------
+ tox=160e-10     xj=0.25e-06        nch=0.5e+17
*------------------V_threshold-------------------------------------------
+ vth0=0.72       nlx=0.12e-06
*------------------Bulk--------------------------------------------------
+ k1=1.04         k2=-1.209E-01
+ cdsc=-2.4E-4    cdscd=-1.506E-04   cdscb=-2.219E-04
*------------------mobility----------------------------------------------
```

```
+ u0=678            ua=8.964e-10
+ ub=1.472e-18      uc=-4.441E-17       vsat=86000
*-------------------Subthresshold----------------------------------------
+ nfactor=1.8
+ cit=-5.0E-04      voff=-7.862E-02
+ eta0=4.441e-16    etab=-2.E-01        dsub=0.7
*-------------------Hot electrons----------------------------------------
* alpha0=1.61e-05   beta0=36.68
*-------------------VAF--------------------------------------------------
+ lint=.12e-06      pclm=.19            pscbe1=3.79e+08   pscbe2=9.4e-05
+ delta=0.01655     pvag=0.4484
*-------------------Bulk_diode-------------------------------------------
+ js=5.858e-08
*-------------------Resistance-------------------------------------------
+ rsh=70            rdsw=375
+ wr=0.7586         prwb=0              prwg=-4.441E-17
*-------------------Capacitance------------------------------------------
+ cj=0.0002424      cjsw=2.73e-10       mj=0.3551           mjsw=0.3873
+ cgso=9e-13        cgdo=9e-13          cgbo=7e-10
+ pb=0.5614         pbsw=0.8            xpart=0
+ dlc=5e-08         dwc=1.5e-07
*-------------------BulkChargeEffect-------------------------------------
* a0=0.7            a1=0                 a2=1                 ags=0.05583
* b0=6.305e-08      b1=6.579e-08         keta=-1.531E-02
*-------------------ShortChannel-----------------------------------------
+ dvt0=2.2          dvt1=0.53           dvt2=-1.521E-01      drout=0.76
+ pdiblcb=.4        pdiblc1=0.00886     pdiblc2=0.00029
*-------------------NarrowChannel----------------------------------------
+ w0=2.6e-04        wint=0.16e-06
+ ww=-9.525E-14     wwn=1.0
+ dvt0w=0           dvt1w=5.3e6         dvt2w=-1.E-01
+ k3=2.53           k3b=-5              dwg=0                dwb=0
*-------------------Noise------------------------------------------------
* af=1              kf=1e-28            ef=0.95
*-------------------Temperature------------------------------------------
* pvsat=0           ute=-1.258E+00      kt1=-3.85E-01
* kt1l=0            kt2=-3.098E-02      ua1=5.705e-09
* ub1=-1.147E-17    uc1=-1.302E-01      at=20380
* prt=-3.287E+02    lk1=0               lk2=0
* lvsat=0           la0=0               lags=0              lute=0
+ luc=0                                                                )

.model              PMOSC               PMOS(
+ Level=  8         Tnom=27.0
*-------------------Process----------------------------------------------
+ tox=1.725e-08     xj=2e-07            nch=1e+17
*-------------------V_threshold------------------------------------------
+ vth0=-0.90        nlx=1.84e-08
*-------------------Bulk-------------------------------------------------
+ k1=0.3969         k2=0.03536
*-------------------mobility---------------------------------------------
+ u0=268            ua=4.124e-09
* ub=-3.8E-19       uc=-1.512E-02       vsat=140000
*-------------------Subthresshold----------------------------------------
+ nfactor=.5016
* cit=0.0001        voff=-0.08           nfactor=1.0016   vth0=-0.94
* eta0=0.038        etab=-1.057E-02      dsub=0.3501
*-------------------Hot electrons----------------------------------------
+ alpha0=2.5e-08      beta0=28.92
*-------------------VAF--------------------------------------------------
+ lint=.1e-06       pclm=3.2             pscbe1=5e+08       pscbe2=1e-05
* delta=0.009       pvag=4
*-------------------Bulk_diode-------------------------------------------
+ js=3.95e-08
*-------------------Resistance-------------------------------------------
+ rsh=135           rdsw=2500
* prwg=-7.2E-02     prwb=0.06           wr=0.8625
*-------------------Capacitance------------------------------------------
+ cj=0.0002424      cjsw=2.73e-10       mj=0.3551           mjsw=0.3873
+ cgso=9e-13        cgdo=9e-13          cgbo=7e-10
* cdsc=-2.4E-4      cdscd=-1.506E-01    cdscb=-2.219E-04
* pb=0.85           pbsw=0.88           xpart=0
* dlc=5e-08         dwc=1.5e-07
*-------------------BulkChargeEffect-------------------------------------
* a0=1              a1=0                a2=2                 ags=0.268
* b0=5e-07          b1=1e-07            keta=-1.0E-02
*-------------------ShortChannel-----------------------------------------
* dvt0=2.9          dvt1=0.2            dvt2=-1.521E-01      drout=0.175
* pdiblcb=0         pdiblc1-            pdiblc2=0.001
*-------------------NarrowChannel----------------------------------------
+ w0=2.6e-04        wint=0.16e-06
+ ww=-3.1E-19       wwn=1.9
* dvt0w=0.68        dvt1w=5.3e6         dvt2w=0.051
* k3=56             k3b=-3              dwg=0                dwb=1e-08
```

```
*------------------Noise-----------------------------------------------
+ af=0.8           kf=1.50e-30        ef=0.95
*------------------Temperature-----------------------------------------
* ldelta=0.02282   lpdiblc1=0.01877   ute=-1.500E+00
* cgsl=1.5e-10     cgdl=1.5e-10       ckappa=0.2463      cf=0
* kt1=-4.684E-01   kt1l=-2.0E-08      kt2=-2.818E-02
* ua1=-2.E-10      ub1=-4.5E-18       uc1=-2.000E-02
+ at=-1.5E+05      prt=1400                                          )

.end
```

4.11.10_4.54PM

dsauersanjose@aol.com
Don Sauer
http://www.idea2ic.com/