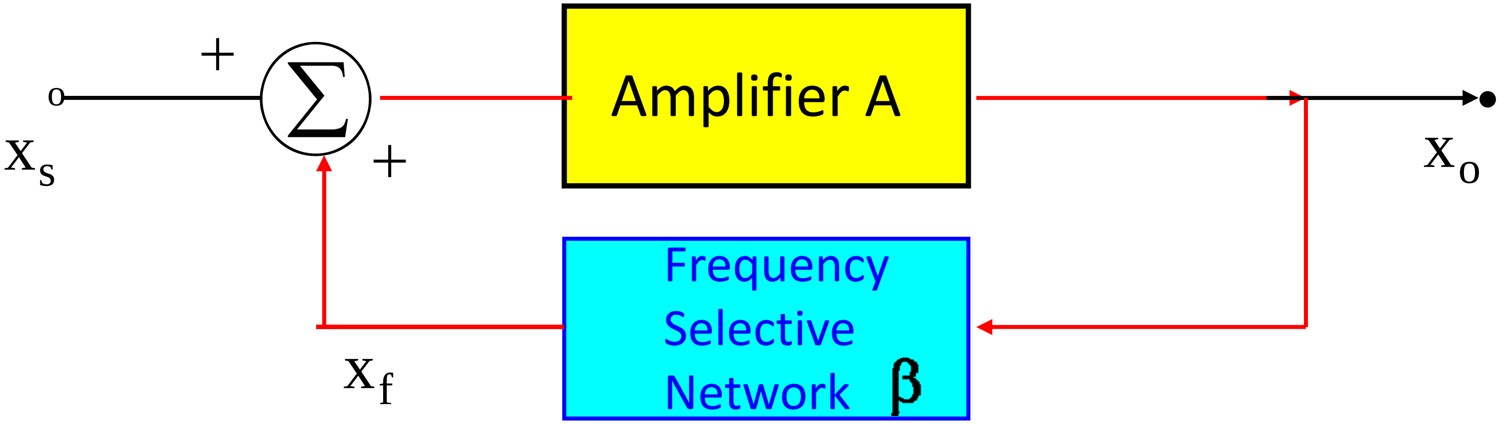
ECE 457 (ESS)
TAMU-AMSC

OSCILLATORS

Fundamentals. Linear Aspects: Oscillation conditions.



$$A_f = \frac{x_o}{x_s} = \frac{A}{1-\beta A} = \frac{A(s)}{1-\beta(s)\,A(s)}$$

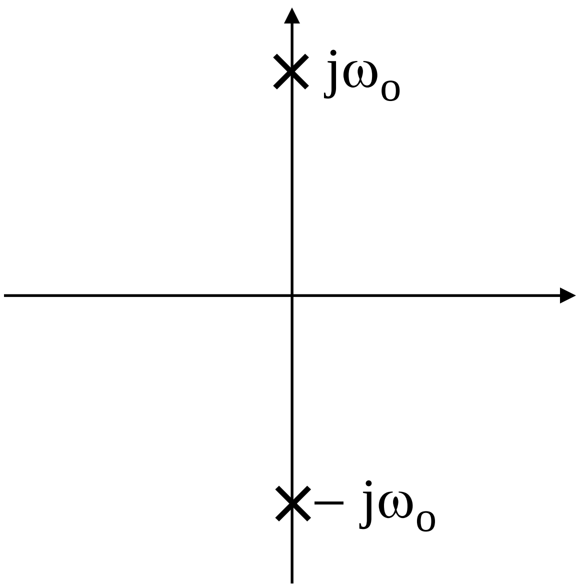
$$D(s) = 1-\beta(s)\,A(s) = 1 - L(s)$$

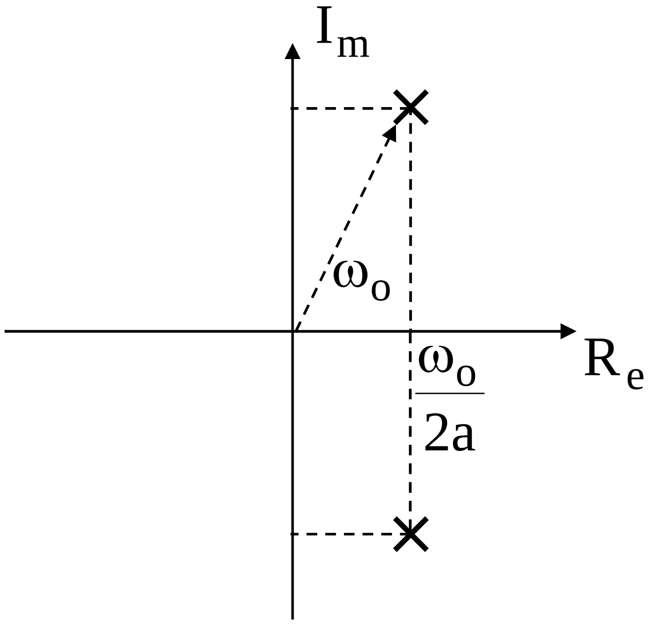
$$L(j\omega_o) \triangleq A(j\omega_o)\,\beta(j\omega_o) = 1$$ **Barkhausen Criteria**

Note that for the circuit to oscillate at one frequency the oscillation criterion should be satisfied at one frequency only; otherwise the resulting waveform will not be a simple sinusoid.

Need of Nonlinear Amplitude Control

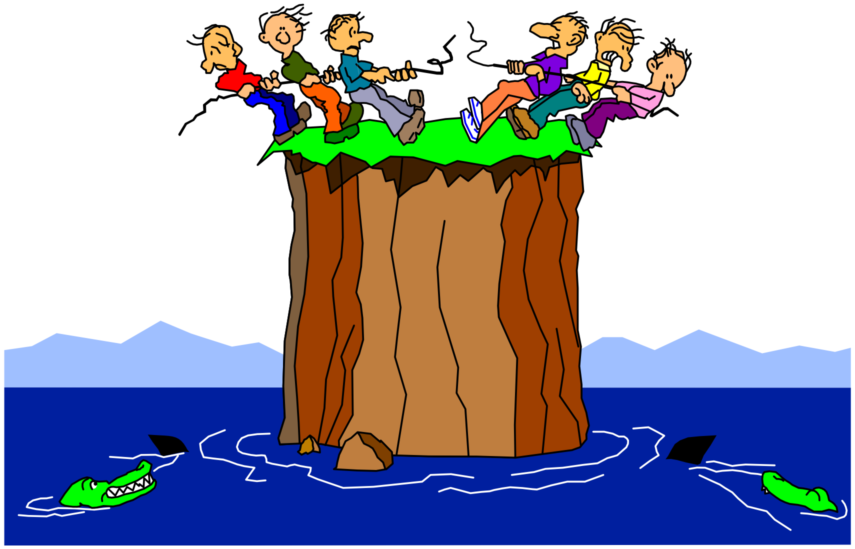
Location of poles





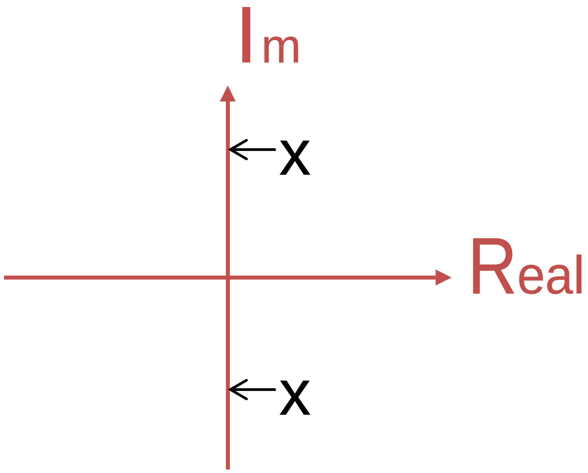
Not practical
why?

Practical.
How do you push
the poles into the
$j\omega$ axis?

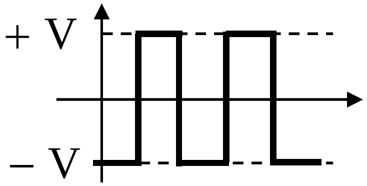


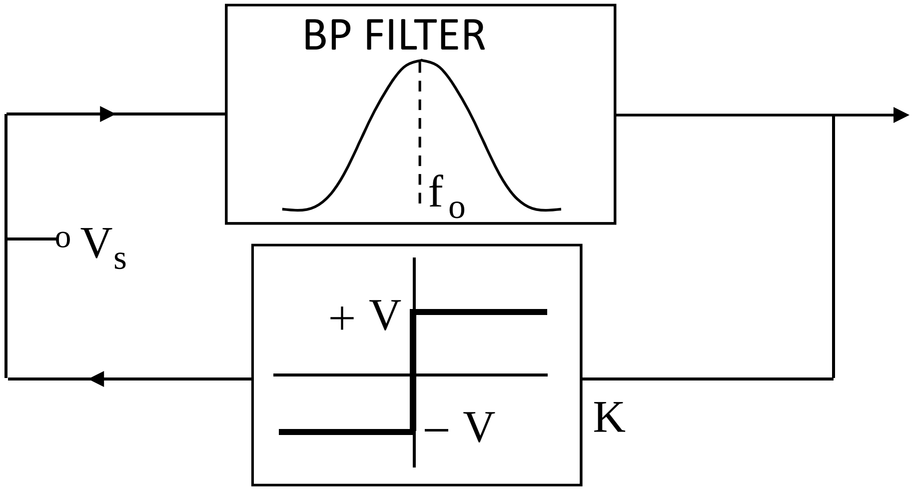
In the ideal case this is easy to design, but in the real case there a lot of system parameters that can change the poles due to their physical characteristics.

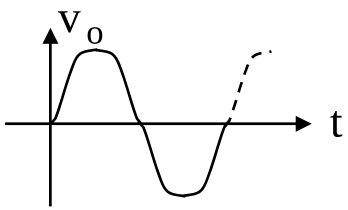
Therefore, the poles should not lie on the imaginary axis. One should design the poles so that they lie in the right half of the s-plane. This creates positive feedback and guarantees that the circuit will oscillate. How far should we place the poles ?



BP Based Oscillator







Let

$$H_{BP}(s) = \frac{K_1 s}{s^2 + \frac{\omega_o}{Q}s + \omega_o^2}$$

$$D(s) = 1 - KH_{BP}(s)$$

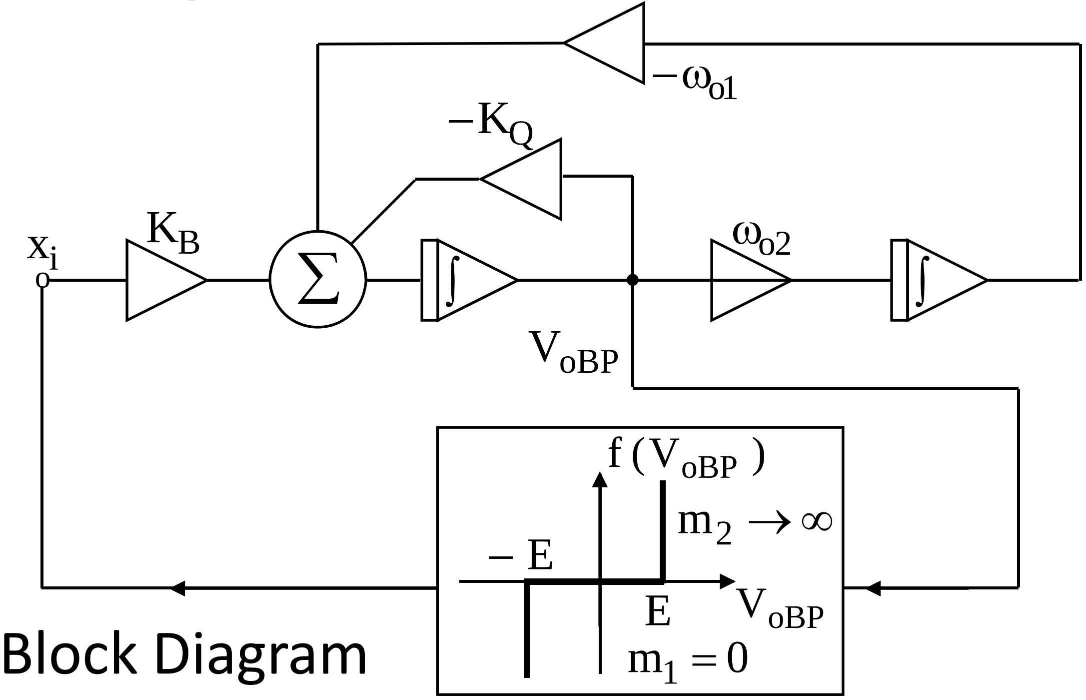
$$\left(s^2 + \frac{\omega_o}{Q}s + \omega_o^2\right)D(s) = s^2 + \frac{\omega_o}{Q}s + \omega_o^2 - KK_1S$$

Characteristic Equation

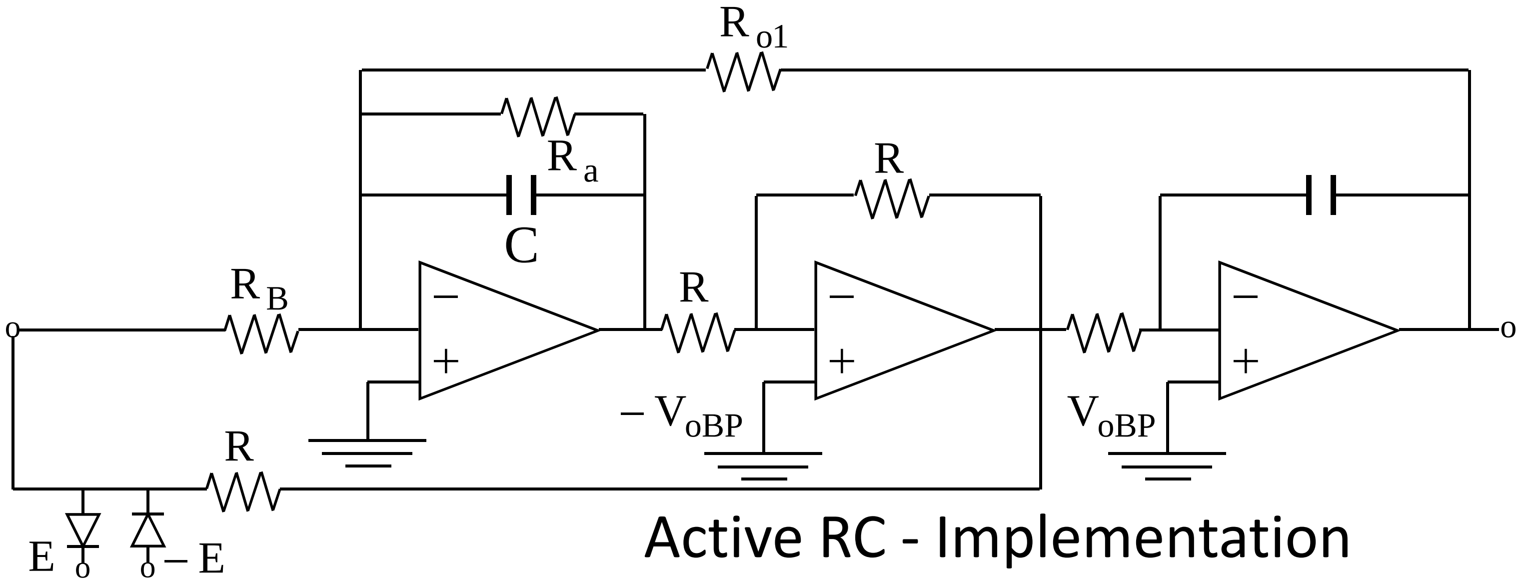
$$s^2 - s\left(KK_1 - \frac{\omega_o}{Q}\right) + \omega_o^2$$

$$KK_1 > \frac{\omega_o}{Q}$$ i.e. positive feedback

A bandpass based Sinusoidal Oscillator

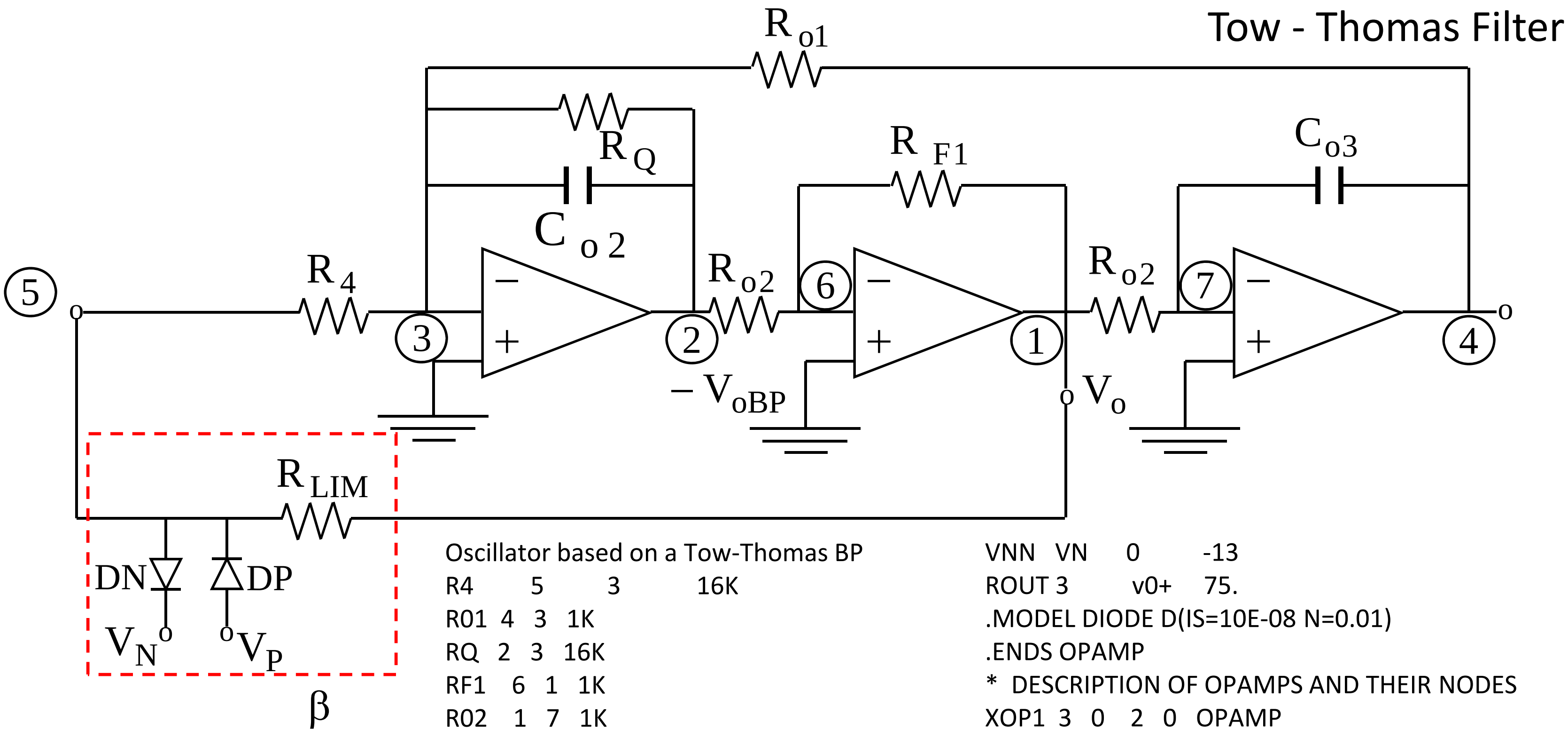


Block Diagram

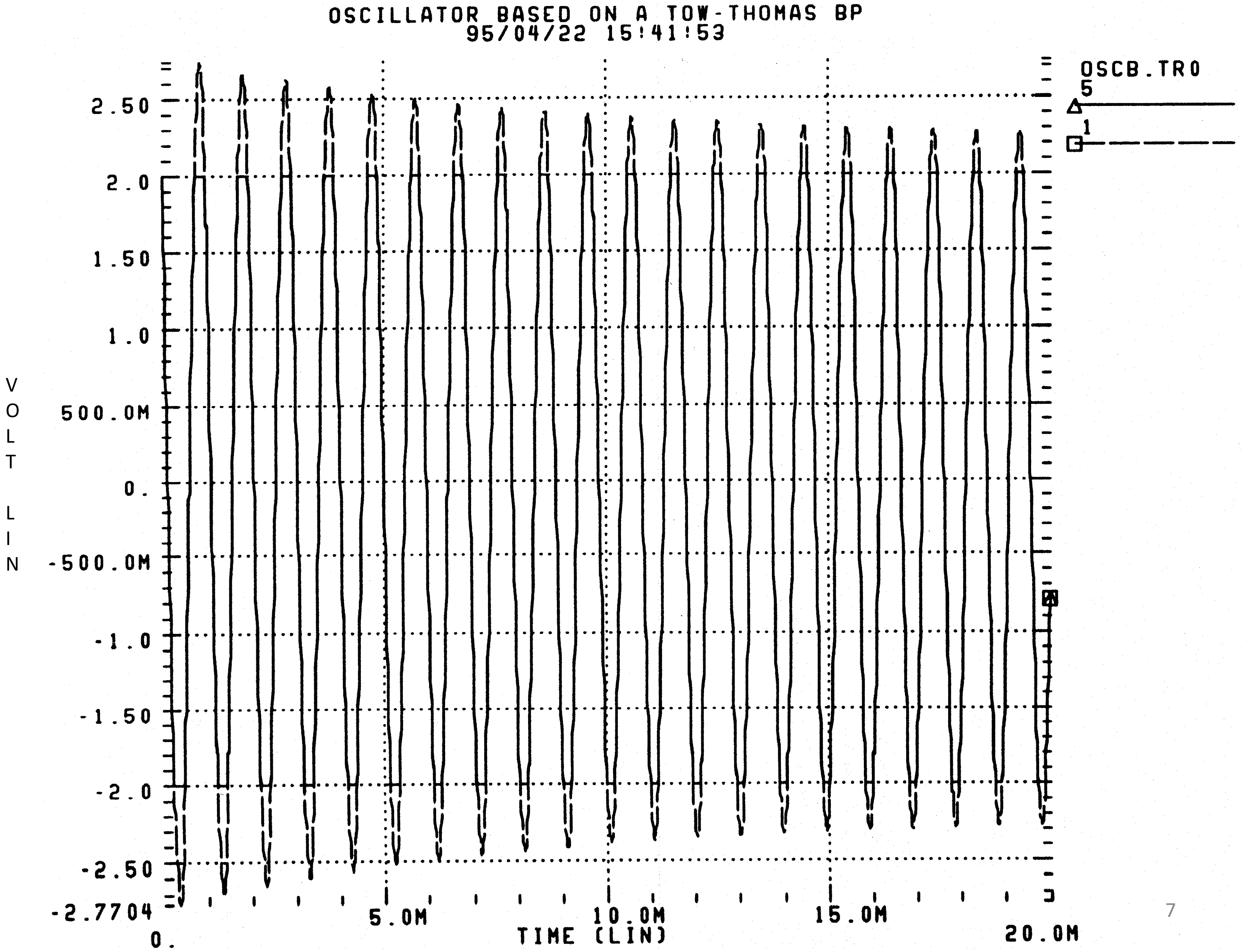


Active RC - Implementation

BP Oscillator

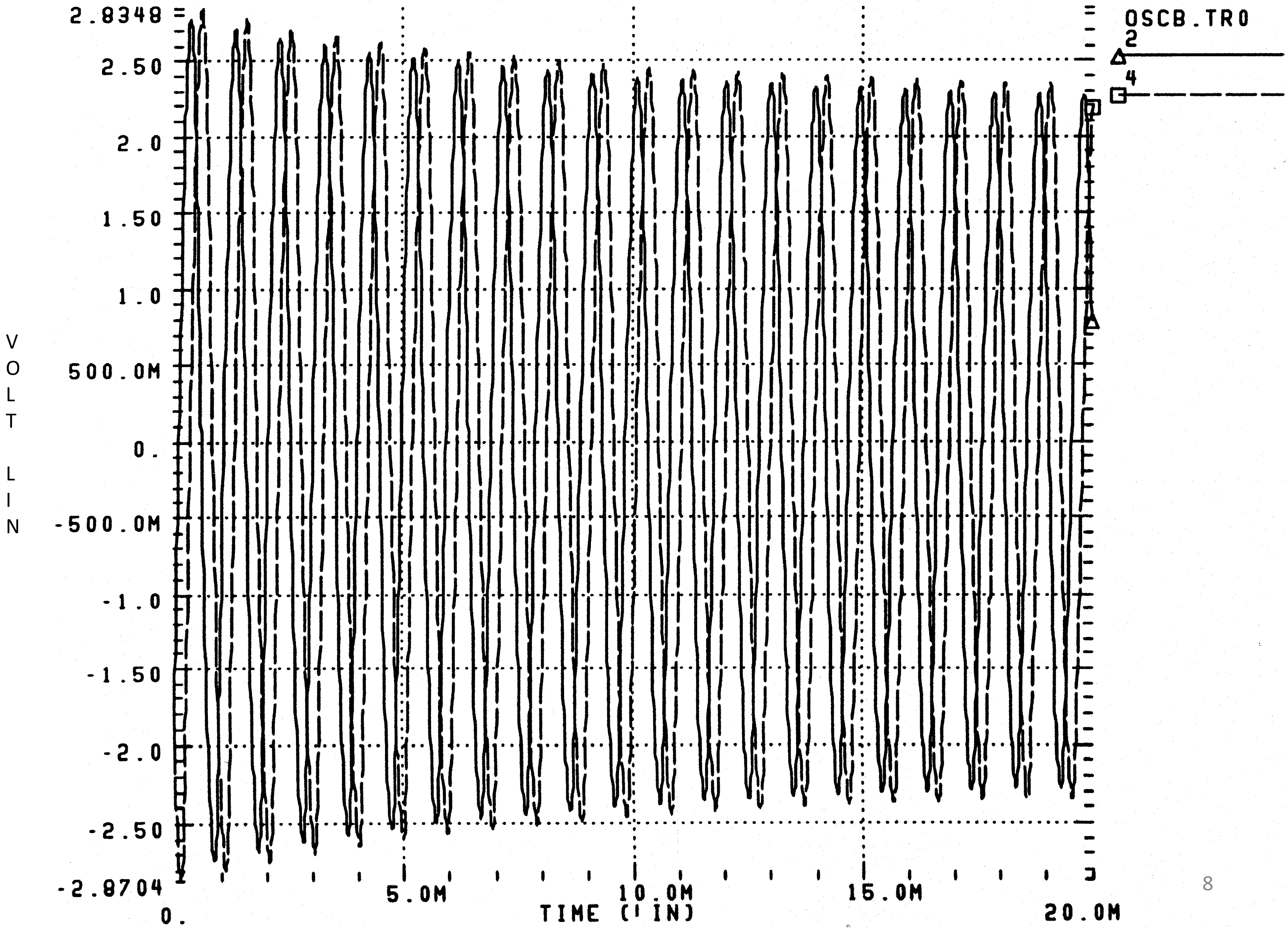


```
Oscillator based on a Tow-Thomas BP
R4       5       3        16K
R01  4   3   1K
RQ   2   3   16K
RF1    6   1   1K
R02    1   7   1K
C02    3   2          0.1591549U
R03        2      6          1K
C03    7   4   0.1501549U
.SUBCKT OPAMP vi-   vi+   v0+   v0-
*
*
RIN      vi-     vi+     10E6
EIN      1       0       vi+      vi-      2E05
R3DB  1       2       1K
C3DB  2       0       0.159E-04
EOUT  3       VO-     2        0        1
DP       2       VP      DIODE
DN       VN      2       DIODE
VPP     VP      0       13
VNN   VN     0       -13
ROUT 3        v0+    75.
.MODEL DIODE D(IS=10E-08 N=0.01)
.ENDS OPAMP
*  DESCRIPTION OF OPAMPS AND THEIR NODES
XOP1  3   0   2   0   OPAMP
XOP2    6    0    1    0     OPAMP
XOP3    7    0    4    0     OPAMP
*LIMITER CIRCUIT DESCRIPTION
RLIM       1          5           200
DP         5          VP          DL
DN         VN         5           DL
.MODEL   DL         D (IS=10E-09 N=0.0001)
VNL        VN         0           -2
VPL        VP         0           2
.TRAN      5U         20m         UIC
.FOURIER              57          V(1)       V(2)       V(4)
.IC  V(1)=2  V(2)=-2  V(4)=-2  V(5)=2
.OPTIONS POST
.END
```



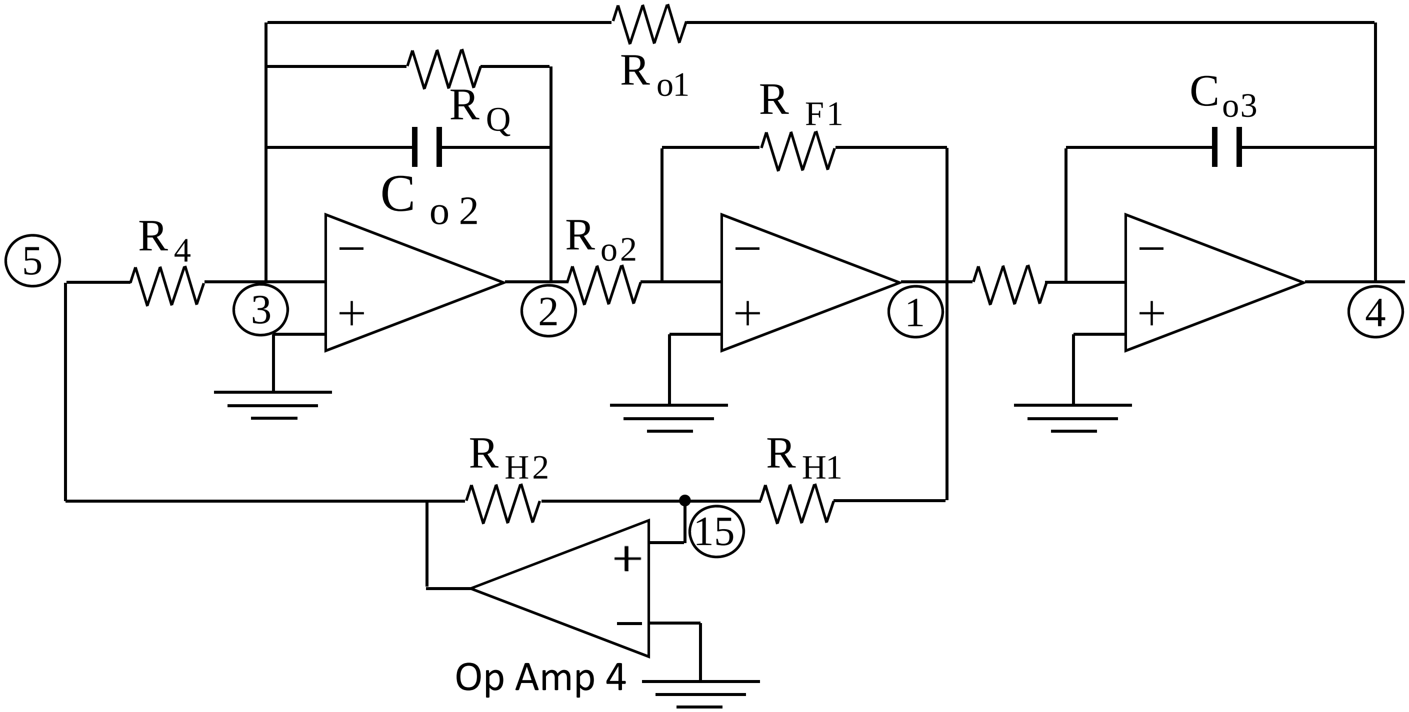
OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53

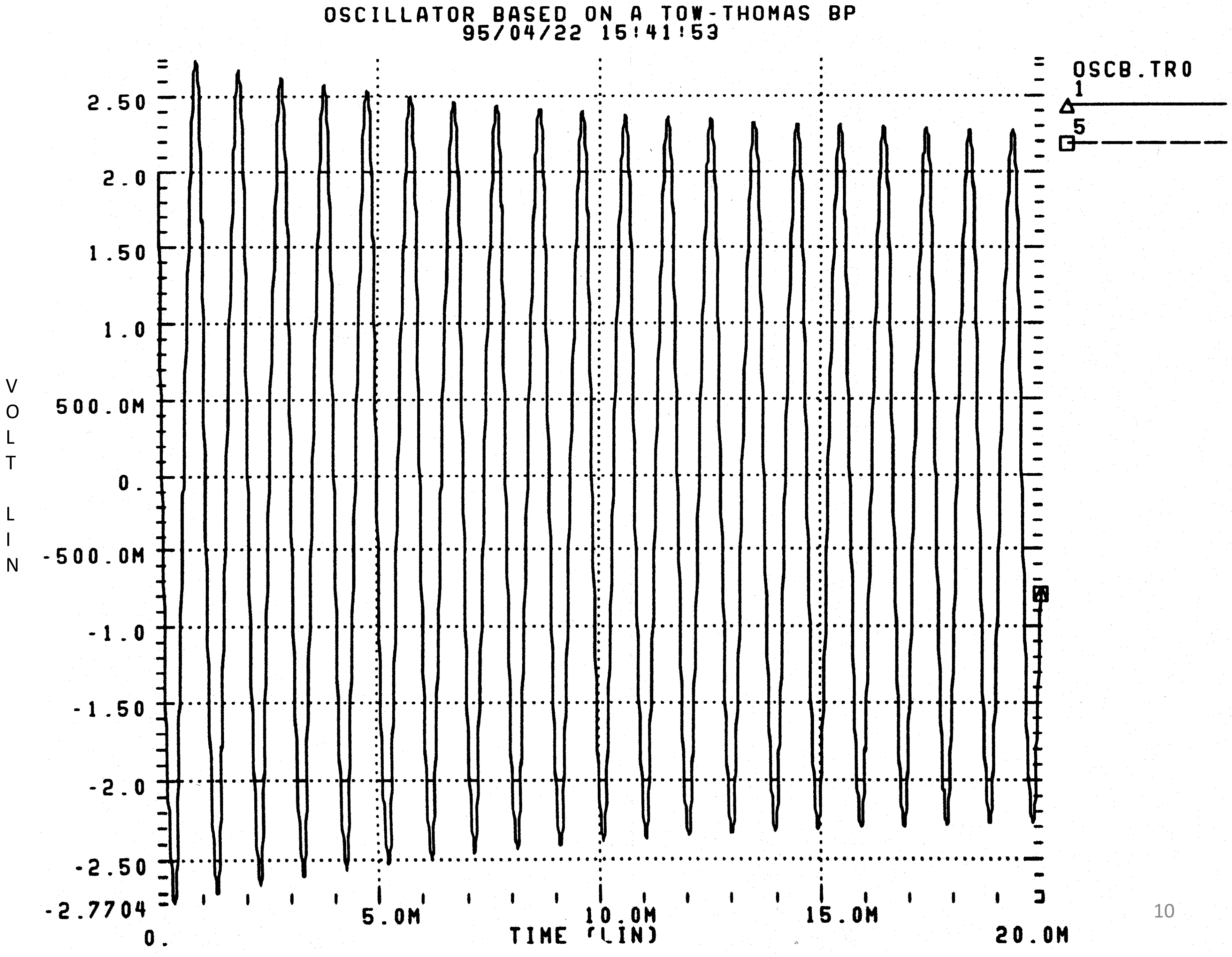
OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53

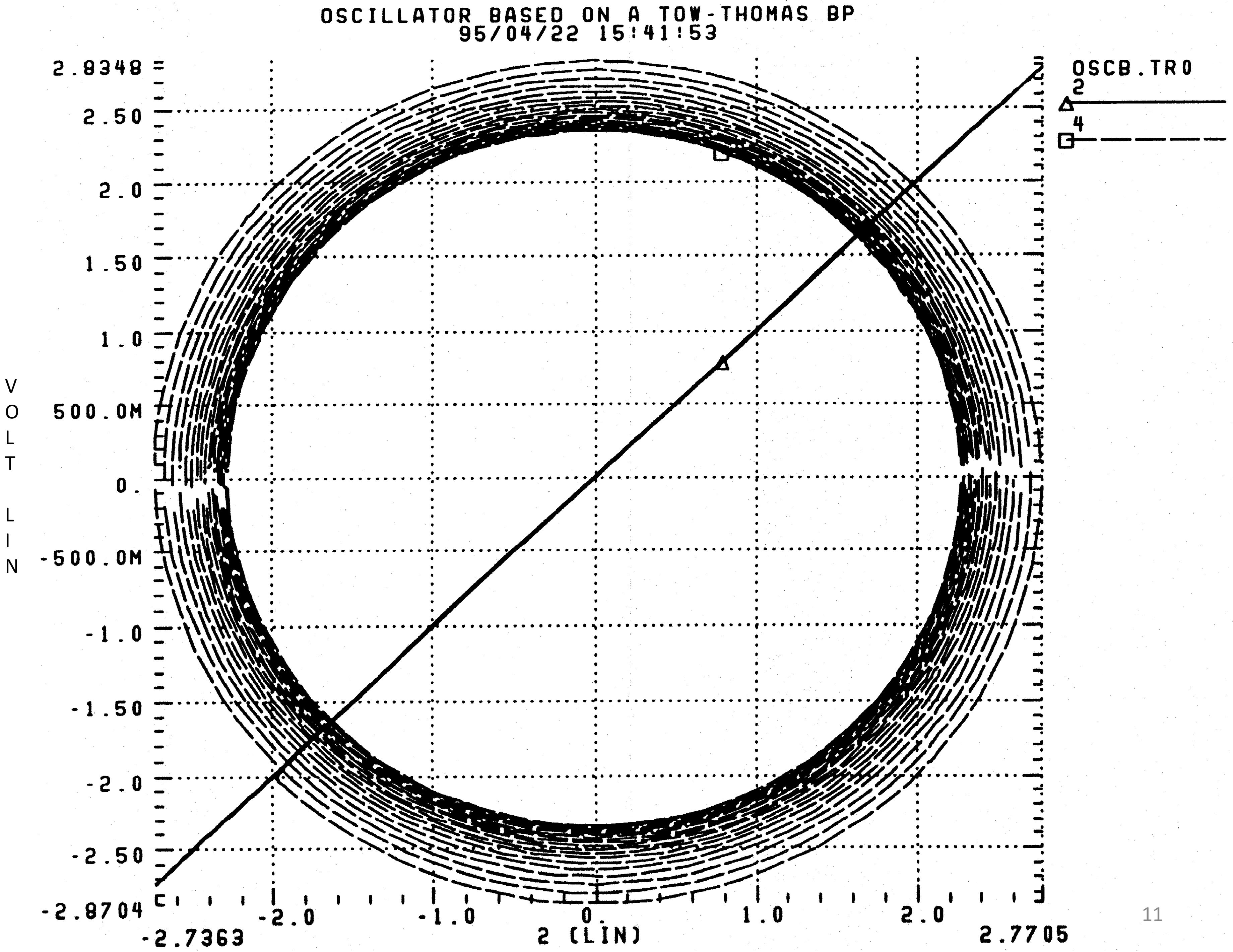


```
Oscillator based on a Tow-Thomas BP
R4      5        3         16K
R01  4   3   1K
RQ   2   3   16K
R       6   1   1K
R       1   7   1K
C02   3   2      0.1591549U
R03      2      6           1K
C03   7   4   0.1501549U
.SUBCKT OPAMP  vi-    vi+    v0+    v0-
*
*
RIN       vi-     vi+     10E6
EIN       1       0       vi+      vi-      2E05
R3DB    1       2       1K
C3DB    2       0       0.159E-04
EOUT   3       V0-     2        0       1
DP       2       VP     DIODE
DN      VN      2       DIODE
```

```
VPP     VP     0      13
VNN     VN     0      -13
ROUT   3       v0+    75.
.MODEL DIODE D(IS=10E-08 N=0.01)
.ENDS OPAMP
*  DESCRIPTION OF OPAMPS AND THEIR NODES
XOP1   3   0    2   0   OPAMP
XOP2     6     0    1    0       OPAMP
XOP3     7     0    4    0       OPAMP
*LIMITER Hysteresis CIRCUIT DESCRIPTION
RH1         1          15          2K
RH2         15         5           13K
XOP4      0          15          5          0          OPAMP
*  DESIRED ANALYSIS RESPONSE
.TRAN      5U          20m          UIC
.FOURIER              57              V(1)    V(2)    V(4)
.IC  V(1)=2  V(2)=-2  V(4)=-2  V(5)=2
.OPTIONS POST
.END
```



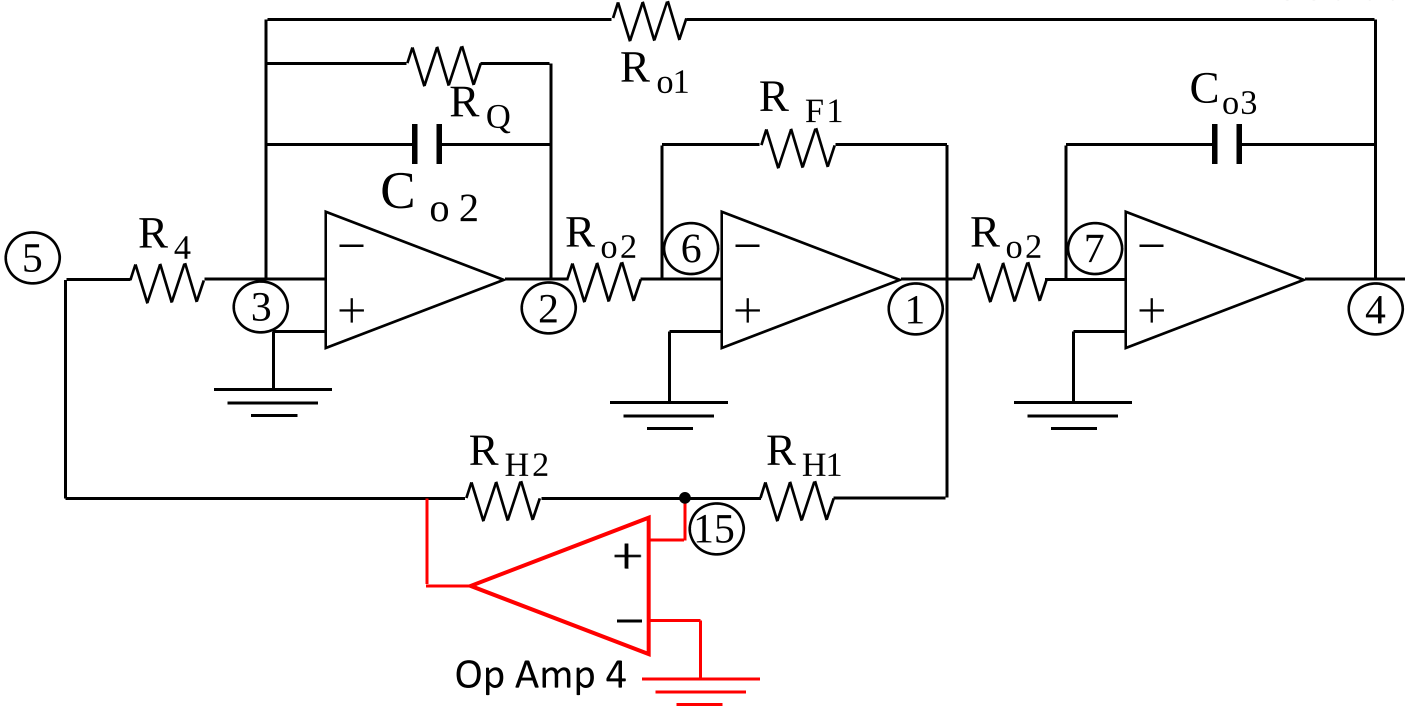

OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53
OSCB.TR0
1
5
2.50
2.0
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
-2.0
-2.50
-2.7704
VOLT LIN
0.
5.0M
10.0M
15.0M
20.0M
TIME (LIN)

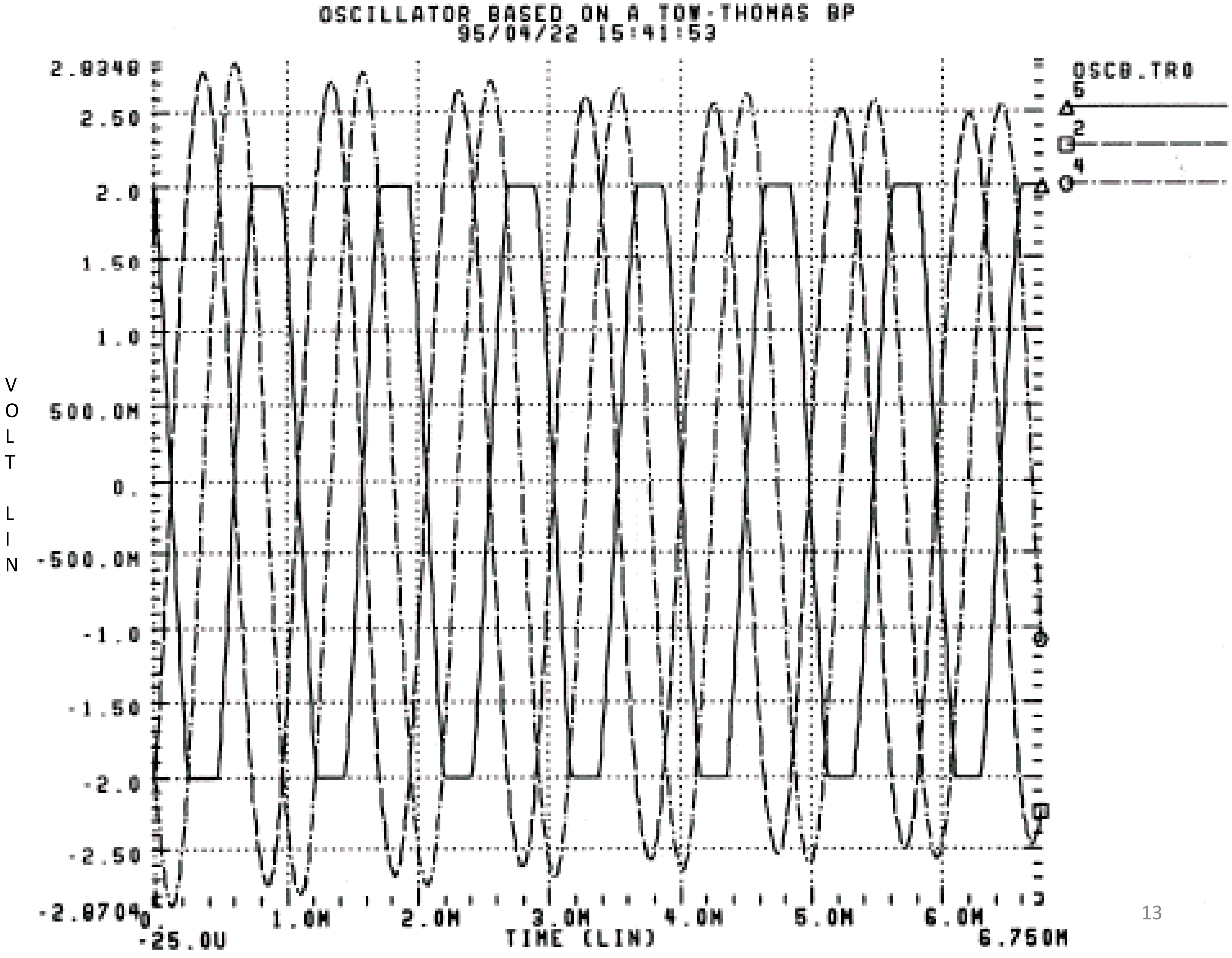

OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53
OSCB.TR0
2
4
2.8348
2.50
2.0
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
-2.0
-2.50
-2.8704
VOLT LIN
-2.7363
-2.0
-1.0
0.
1.0
2.0
2.7705
2 (LIN)

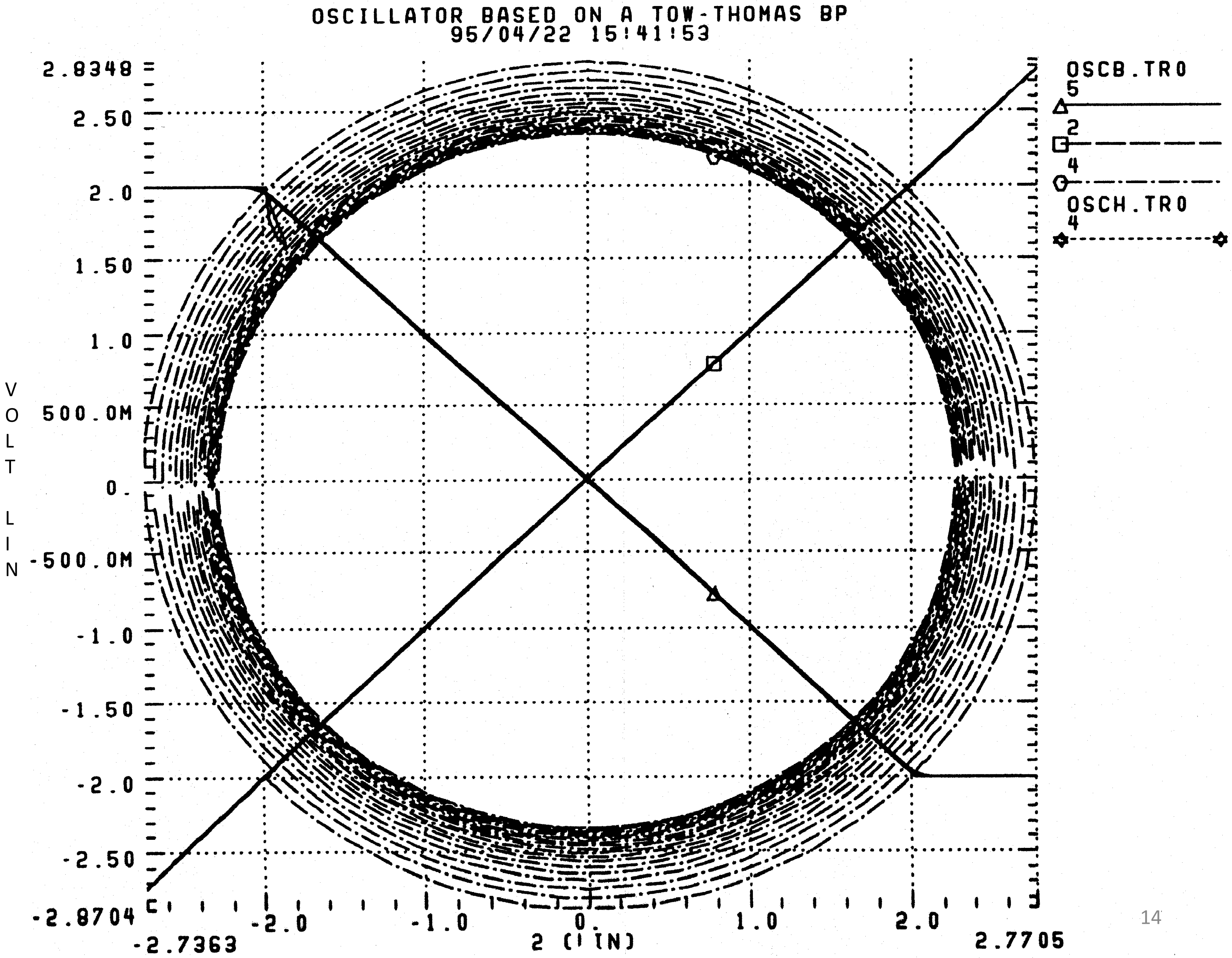
Double Positive Feedback

```
Oscillator based on a Tow-Thomas BP
R4       5         3          35K
R01  4   3   1.4K
RQ   1   3   9.6K
R       6   1   1K
R       1   7   1K
C02    3   2       0.1591549U
R03        2       6              1K
C03    7   4   0.1501549U
.SUBCKT OPAMP  vi-    vi+    v0+    v0-
*
*
RIN       vi-     vi+     10E6
EIN       1       0       vi+     vi-     2E05
R3DB    1       2       1K
C3DB    2       0       0.159E-04
EOUT   3       V0-     2         0       1
DP       2       VP     DIODE
DN      VN      2       DIODE
```

```
VPP     VP     0       13
VNN     VN     0       -13
ROUT   3       v0+    75.
.MODEL DIODE D(IS=10E-08 N=0.01)
.ENDS OPAMP
*  DESCRIPTION OF OPAMPS AND THEIR NODES
XOP1   3   0    2   0   OPAMP
XOP2     6    0    1    0       OPAMP
XOP3     7    0    4    0       OPAMP
*LIMITER Hysteresis CIRCUIT DESCRIPTION
RH1         1           15          2K
RH2         15          5           13K
XOP4      0           15           5           0          OPAMP
*  DESIRED ANALYSIS RESPONSE
.TRAN      5U           20m          UIC
.FOURIER               57               V(1)    V(2)    V(4)
.IC  V(1)=2  V(2)=-2  V(4)=-2  V(5)=2
.OPTIONS POST
.END
```




OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53
OSCB.TR0
5
2
4
2.8348
2.50
2.0
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
-2.0
-2.50
-2.8704
VOLT LIN
0
-25.0U
1.0M
2.0M
3.0M
4.0M
5.0M
6.0M
6.750M
TIME (LIN)

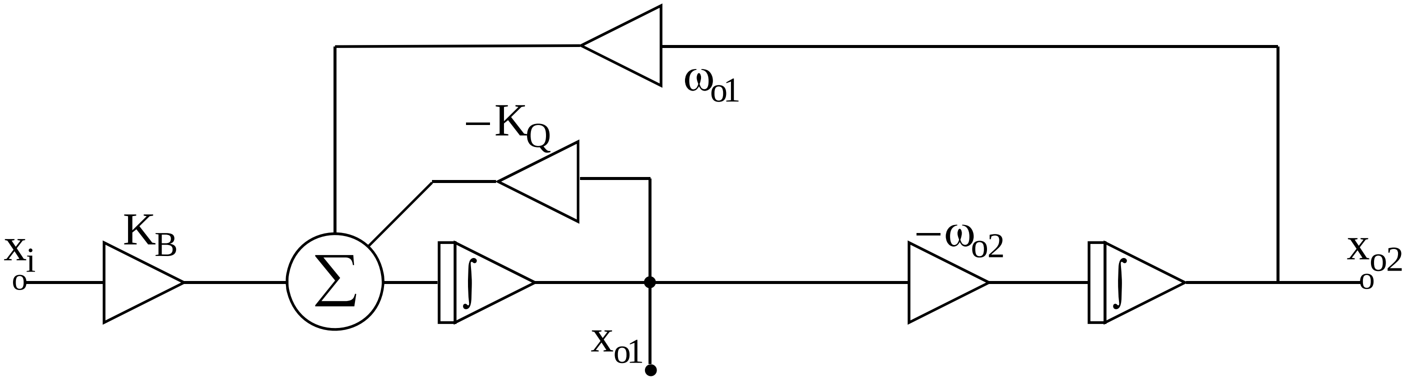

OSCILLATOR BASED ON A TOW-THOMAS BP
95/04/22 15:41:53
2.8348
2.50
2.0
1.50
1.0
500.0M
0.
-500.0M
-1.0
-1.50
-2.0
-2.50
-2.8704
V O L T   L I N
-2.7363
-2.0
-1.0
0.
1.0
2.0
2.7705
2 (I IN)
OSCB.TR0
5
2
4
OSCH.TR0
4

Simulations
Active-Filter Tuned Oscillator

Hints

- First design a band pass filter
  - High Q
  - Gain
- Next decide on type of limiter
- Finally be sure the path from the band pass output through the limiter to the input is positive feedback.

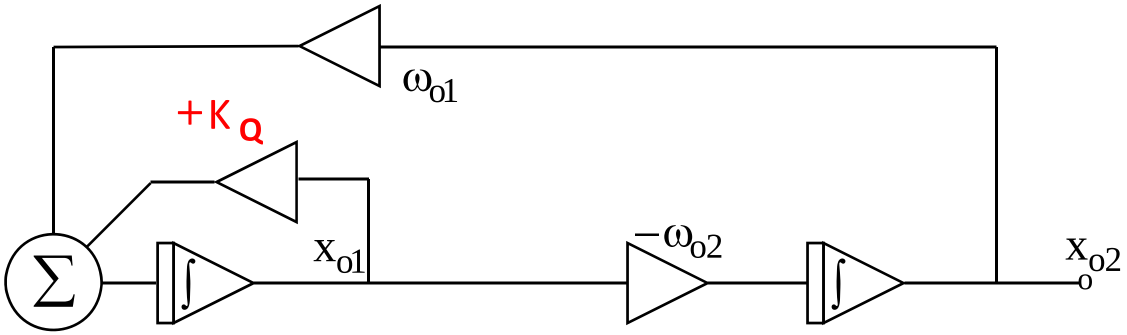
Quadrature Oscillator



Two Integrator Loop Filter

$$H_1(s) = \frac{x_{o1}(s)}{x_i(s)} = \frac{\dfrac{K_B}{s}}{1+\dfrac{K_Q}{s}+\dfrac{\omega_{o1}\cdot\omega_{o2}}{s^2}} = \frac{K_B s}{s^2+K_Q s+\omega_{o1}\omega_{o2}}$$

$H_1(s)$ is a second-order bandpass. The topology of this integrator loop can be modified to yield a *quadrature oscillator*.



Quadrature Oscillator Architecture

Observe that the characteristic equation yields:

$$1 - \frac{K_Q}{s} + \frac{\omega_{o1}\omega_{o2}}{s^2} = 0$$

or

$$s^2 - K_Q s + \omega_{o1}\omega_{o2} = 0$$

The roots are placed at

$$s_{1,2} = \frac{K_Q \pm \sqrt{K_Q^2 - 4\omega_{o1}\omega_{o2}}}{2}$$

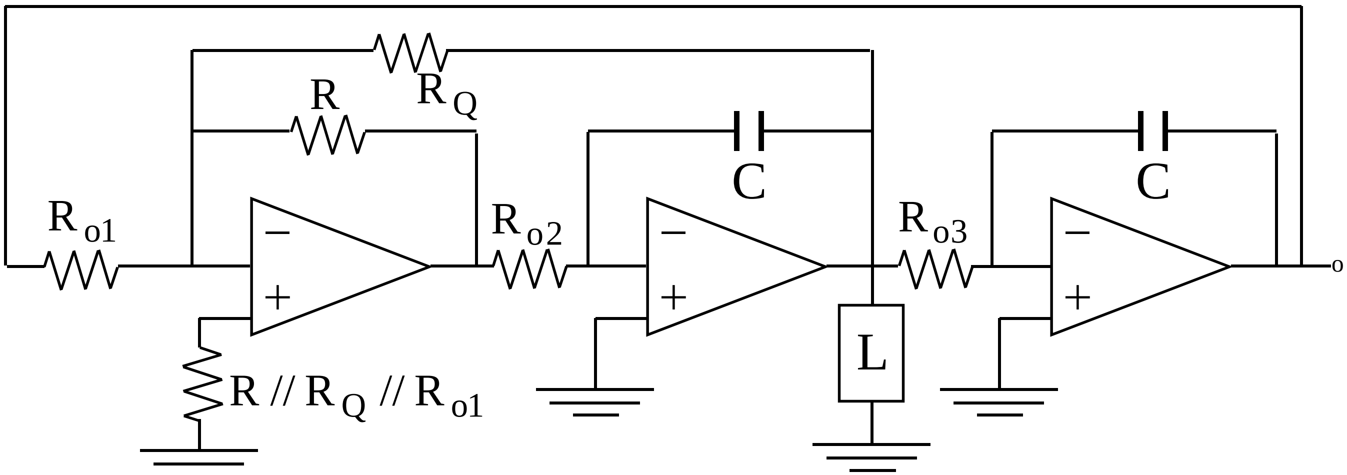
$$= \frac{K_Q}{2} \pm \frac{j}{2}\sqrt{4\omega_{o1}\omega_{o2} - K_Q^2}$$

$$K_Q^2 < 4\omega_{o1}\omega_{o2}$$

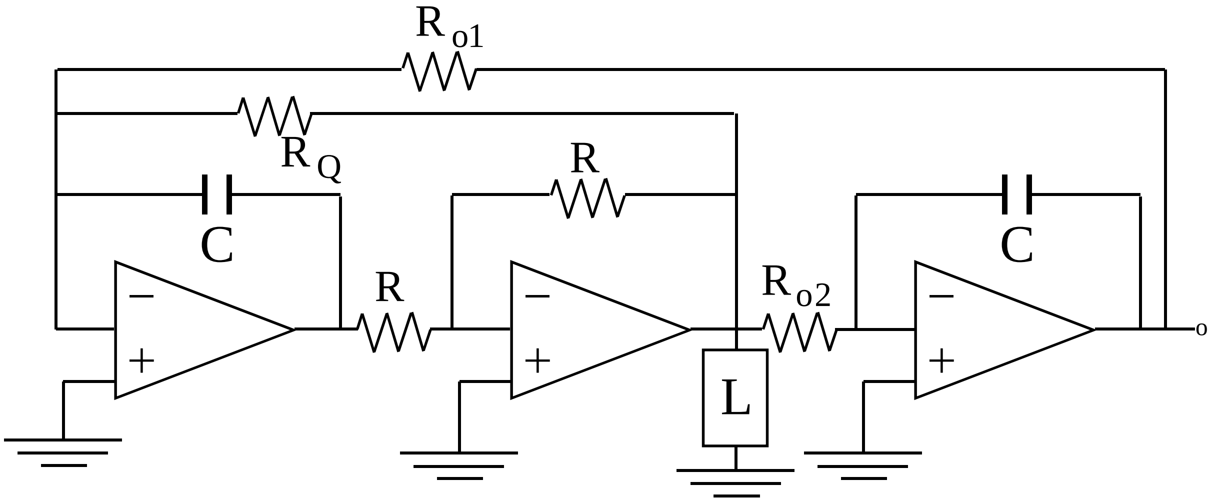
To provide sustained oscillations we need to locate the poles on the $j\omega$ axis, this requires:

i) $K_Q = E$ small positive value

ii) To limit the output by means of a nonlinear gain control.

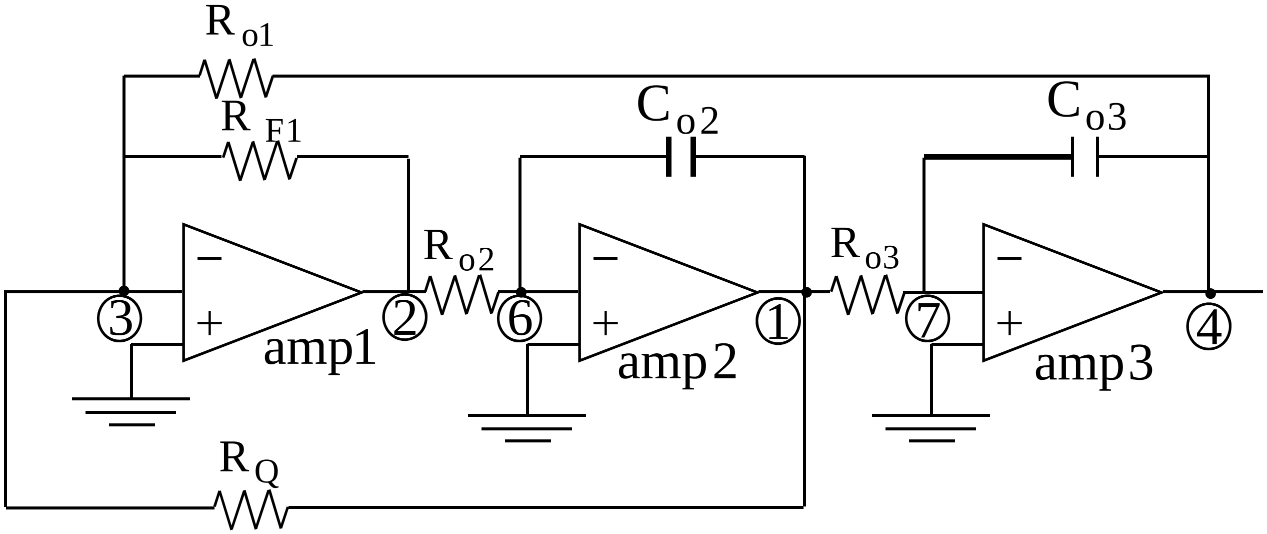


One possible Quadrature Oscillator Structure

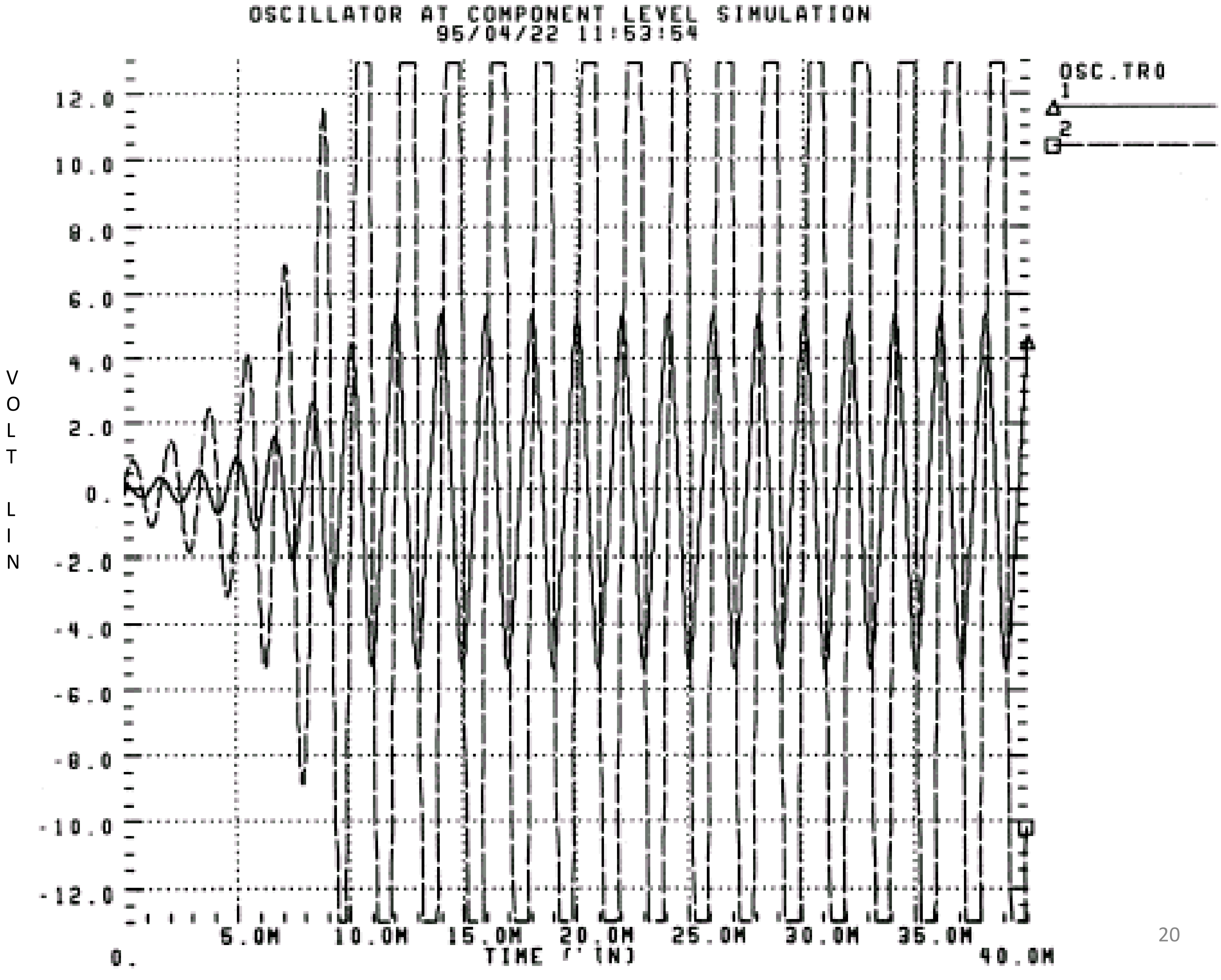


```
Oscillator at component level simulation
RO1    4    3    220K
RQ       1    3    510K
RF1     3    2    310K
RO2    2    6    100K
CO2    6    1    0.01U
RO3    1    7    100K
CO3    7    4    0.001U
.SUBCKT OPAMP    vi-     vi+     v0+     v0-
*
*
RIN      vi-    vi+    10E6
BIN      1       0       vi+       vi-       2E05
R3DB   1       2        1K
C3DB   2       0        0.159E-04
BOUT  3     V0-     2        0       1
DP        2     VP      DIODE
```

```
DN       VN      2      DIODE
VPP      VP      0      13
VNN    VN      0      -13
ROOT    3       v0+   75.
.MODEL DIODE D (IS=10E-0S N=0.001)
.ENDS OPAMP
*    DESCRIPTION OF OPAMPS AND THEIR NOOES
XOP1         3       0       2       0       OPAMP
XOP2               6       0       1       0       OPAMP
XOP3               7       0       4       0       OPAMP
.TRAN              10U   40m   UIC
.FOURIER         57    V(1)    V(2)     V(4)
.IC                   V(1)=.2     V(2)=-.2    V(4)=-.2
.OPTIONS POST
.OP .08
.END
```



QUADRATURE OSCILLATOR
(NO EXTERNAL LIMITER)


OSCILLATOR AT COMPONENT LEVEL SIMULATION
95/04/22 11:53:54
OSC.TR0
1
2
12.0
10.0
8.0
6.0
4.0
2.0
0.
-2.0
-4.0
-6.0
-8.0
-10.0
-12.0
VOLT LIN
0.
5.0M
10.0M
15.0M
20.0M
25.0M
30.0M
35.0M
40.0M
TIME (LIN)