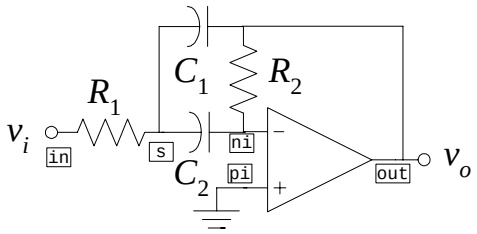
Parameter Extraction using a Multiple-Feedback 2nd Order Band-Pass Filter

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% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
% Dr. José Ernesto Rayas-Sanchez                              February 27, 2004
% Department of Electronics, Systems and Informatics                    ITESO
% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
% Parameter Extraction using a Multiple-Feedback 2nd Order Band-Pass Filter


% Target Response (Voltage gain at 51 frequency points, from 5KHz to 25 KHz)
Rt = [1.4997235e+001  1.6540436e+001  1.8180759e+001  1.9933591e+001  2.1817072e+001
2.3852793e+001  2.6066714e+001  2.8490387e+001  3.1162601e+001  3.4131636e+001  3.7458417e+001
4.1220990e+001  4.5521042e+001  5.0493625e+001  5.6322082e+001  6.3261731e+001  7.1678887e+001
8.2118172e+001  9.5424974e+001  1.1298337e+002  1.3721699e+002  1.7275469e+002  2.2949997e+002
3.3183865e+002  5.4311573e+002  7.9993004e+002  5.5096753e+002  3.4674092e+002  2.4694616e+002
1.9128505e+002  1.5630701e+002  1.3241012e+002  1.1508165e+002  1.0194960e+002  9.1655582e+001
8.3368113e+001  7.6550679e+001  7.0841976e+001  6.5989964e+001  6.1813550e+001  5.8179311e+001
5.4986796e+001  5.2158948e+001  4.9635674e+001  4.7369422e+001  4.5322076e+001  4.3462724e+001
4.1766034e+001  4.0211050e+001  3.8780282e+001  3.7459024e+001];

% Starting Point
R1 = 265.2582; % Resistor (ohms).
R2 = 424.41; % Resistor (Kohms).
C = 1;   % Capacitor (nF).
Xo = [R1 R2 C];

IF = 5e3;  % Initial frequency (Hz).
FF = 25e3; % Final frequency (Hz).
FP = length(Rt);
ft = 1e-3*linspace(IF,FF,FP); % Vector of frequency points (KHz).

% RESULTS BEFORE PARAMETER EXTRACTION
% Calculate Circuit Response
FP = 200;
[psi,R] = MFBP2_SPICE(Xo,FP,IF,FF);
f = psi*1e-3; % Frequency (KHz).
Av = R{1};
% Plot Circuit and Target Responses
SetUpWindow('PE_MFBP2-1')
NicePlot(ft,Rt,'.','frequency (KHz)','Voltage Gain')
NicePlot(f,Av,'-','frequency (KHz)','Voltage Gain')
Title('Before Parameter Extraction');
pause

% PARAMETER EXTRACTION
options = optimset('MaxFunEvals',10000,'MaxIter',10000,'TolX',0.001);
[x,FunVal,EF,output]=fminsearch('OF_PE_MFBP2',Xo,options)
R1_opt = x(1)
R2_opt = x(2)
C1_opt = x(3)
C2_opt = x(3)

% RESULTS AFTER PARAMETER EXTRACTION
% Calculate Circuit Response
FP = 200;
[psi,R] = MFBP2_SPICE(x,FP,IF,FF);
f = psi*1e-3; % Frequency (KHz).
Av = R{1};
```

```
% Plot Circuit and Target Responses
SetUpWindow('PE_MFBP2-2')
NicePlot(ft,Rt,'.','frequency (KHz)','Voltage Gain')
NicePlot(f,Av,'-','frequency (KHz)','Voltage Gain')
Title('After Parameter Extraction');
```

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% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
% Dr. José Ernesto Rayas-Sanchez                          February 27, 2004
% Department of Electronics, Systems and Informatics                 ITESO
% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
%           Objective Function for Parameter Extraction using
%              Multiple-Feedback 2nd Order Band-Pass Filter

function u = OF_PE_MFBP2(x)

% Target Response (Voltage gain at 51 frequency points, from 5KHz to 25 KHz)
Rt = [1.4997235e+001  1.6540436e+001  1.8180759e+001  1.9933591e+001  2.1817072e+001
2.3852793e+001  2.6066714e+001  2.8490387e+001  3.1162601e+001  3.4131636e+001  3.7458417e+001
4.1220990e+001  4.5521042e+001  5.0493625e+001  5.6322082e+001  6.3261731e+001  7.1678887e+001
8.2118172e+001  9.5424974e+001  1.1298337e+002  1.3721699e+002  1.7275469e+002  2.2949997e+002
3.3183865e+002  5.4311573e+002  7.9993004e+002  5.5096753e+002  3.4674092e+002  2.4694616e+002
1.9128505e+002  1.5630701e+002  1.3241012e+002  1.1508165e+002  1.0194960e+002  9.1655582e+001
8.3368113e+001  7.6550679e+001  7.0841976e+001  6.5989964e+001  6.1813550e+001  5.8179311e+001
5.4986796e+001  5.2158948e+001  4.9635674e+001  4.7369422e+001  4.5322076e+001  4.3462724e+001
4.1766034e+001  4.0211050e+001  3.8780282e+001  3.7459024e+001];

% Calculate Filter Response and Error Vector
IF = 5e3;  % Initial frequency (Hz).
FF = 25e3; % Final frequency (Hz).
FP = length(Rt);
[psi,R] = MFBP2_SPICE(x,FP,IF,FF);
f = psi*1e-3; % Frequency (KHz).
Av = R{1};
e = Av - Rt';

% Calculate norm of the error vector
u = norm(e,2)
% u = norm(e,2)^2
% u = norm(e,inf)
```
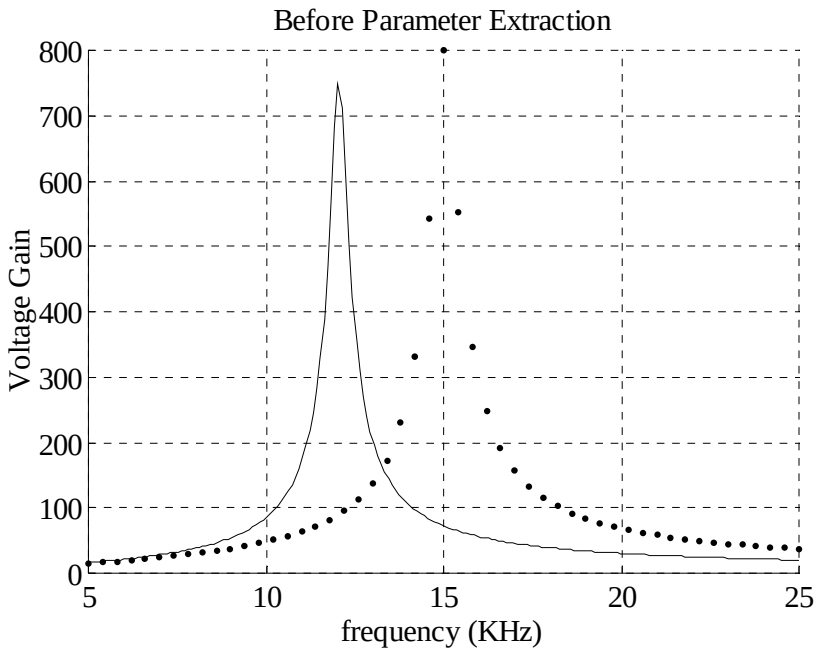

```
% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
% Dr. José Ernesto Rayas-Sanchez                            07-Jul-2003
% Department of Electronics, Systems and Informatics                 ITESO
% ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
%                        Driving MFBP2 from Matlab
%
% This function drives the WinSpice file MFBP2_m.cir from
% Matlab, and returns the simulation results in vectors psi and R.
%
% Usage: [psi,R] = MFBP2_SPICE(x,FP,IF,FF)
%         psi: vector containing the independent variable values
%         R: cell array containing the circuit response values
%         x: vector of selected parameterized elements
%         x = [R1 R2 C], with C=C1=C2
%         FP: Number of frequency points per frequency sweep
%         IF: Initial frequency (Hz)
%         FF: Final frequency (Hz)

function [psi,R] = MFBP2_SPICE(x,FP,IF,FF)

x(2) = x(2)*1e3;
x(3) = x(3)*1e-9;
```

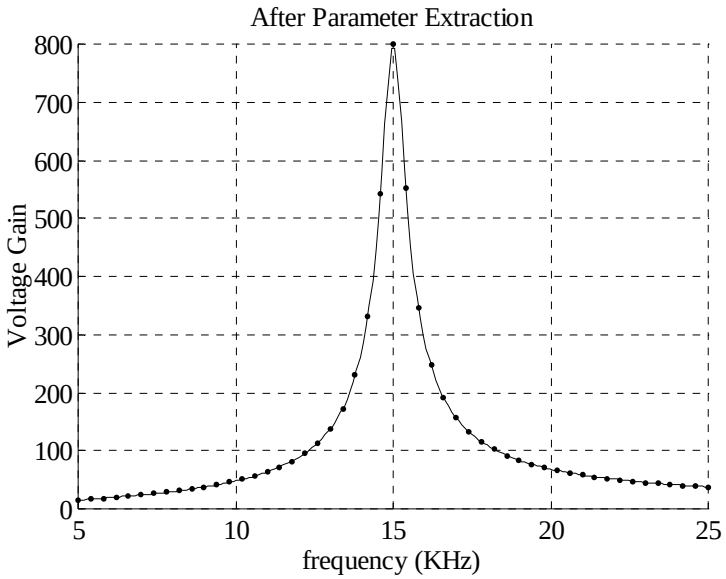
```
ss{1} = 'Multiple-Feedback 2nd Order Band-Pass Filter';
ss{2} = '* -------------------------------------------------';
ss{3} = '* Dr. J.E. Rayas-Sánchez                        ITESO';
ss{4} = '*                                      July 7, 2003';
ss{5} = '* -------------------------------------------------';
ss{6} = '*    Multiple-Feedback 2nd Order Band-Pass Filter';
ss{7} = 'Vcc  vp   0    DC 12';
ss{8} = 'Vee  vn   0    DC -12';
ss{9} = 'Vi   in   0    DC 0 AC 1';
ss{10} = ['R1 in s ' mat2str(x(1))];
ss{11} = ['R2 out ni ' mat2str(x(2))];
ss{12} = ['C1 s out ' mat2str(x(3))];
ss{13} = ['C2 s ni ' mat2str(x(3))];
ss{14} = 'XOA1  0 ni vp vn out uA741';
ss{15} = '.control';
ss{16} = ['AC LIN ' mat2str(FP) ' ' mat2str(IF) ' ' mat2str(FF)];
ss{17} = 'Av = vm(out)/vm(in)';
ss{18} = 'write MFBP2_out1.csv Av';
ss{19} = 'quit';
ss{20} = '.endc';
ss{21} = '* Texas Instruments';
ss{22} = '* CREATED USING PARTS RELEASE 4.01 ON 07/05/89 AT 09:09';
ss{23} = '* (REV N/A)      SUPPLY VOLTAGE: +/-15V';
ss{24} = '* CONNECTIONS:   NON-INVERTING INPUT';
ss{25} = '*                | INVERTING INPUT';
ss{26} = '*                | | POSITIVE POWER SUPPLY';
ss{27} = '*                | | | NEGATIVE POWER SUPPLY';
ss{28} = '*                | | | | OUTPUT';
ss{29} = '*                | | | | |';
ss{30} = '.SUBCKT UA741    1 2 3 4 5';
ss{31} = '*';
ss{32} = 'C1   11 12 4.664E-12';
ss{33} = 'C2    6  7 20.00E-12';
ss{34} = 'DC    5 53 DX';
ss{35} = 'DE   54  5 DX';
ss{36} = 'DLP  90 91 DX';
ss{37} = 'DLN  92 90 DX';
ss{38} = 'DP    4  3 DX';
ss{39} = 'EGND 99  0 POLY(2) (3,0) (4,0) 0 .5 .5';
ss{40} = 'FB    7 99 POLY(5) VB VC VE VLP VLN 0 10.61E6 -10E6';
ss{41} = '+            10E6 10E6 -10E6';
ss{42} = 'GA 6  0 11 12 137.7E-6';
ss{43} = 'GCM 0  6 10 99 2.574E-9';
ss{44} = 'IEE  10  4 DC 10.16E-6';
ss{45} = 'HLIM 90  0 VLIM 1K';
ss{46} = 'Q1   11  2 13 QX';
ss{47} = 'Q2   12  1 14 QX';
ss{48} = 'R2    6  9 100.0E3';
ss{49} = 'RC1   3 11 7.957E3';
ss{50} = 'RC2   3 12 7.957E3';
ss{51} = 'RE1  13 10 2.740E3';
ss{52} = 'RE2  14 10 2.740E3';
ss{53} = 'REE  10 99 19.69E6';
ss{54} = 'RO1   8  5 150';
ss{55} = 'RO2   7 99 150';
ss{56} = 'RP    3  4 18.11E3';
ss{57} = 'VB    9  0 DC 0';
ss{58} = 'VC 3 53 DC 2.600';
ss{59} = 'VE   54  4 DC 2.600';
ss{60} = 'VLIM  7  8 DC 0';
ss{61} = 'VLP  91  0 DC 25';
ss{62} = 'VLN   0 92 DC 25';
ss{63} = '.MODEL DX D(IS=800.0E-18)';
ss{64} = '.MODEL QX NPN(IS=800.0E-18 BF=62.50)';
ss{65} = '.ENDS';
ss{66} = '.end';

% Saving WinSpice Circuit File in Matlab Working Directory
ckt_file = str2mat(ss);
[rows,columns]=size(ckt_file);
fp = fopen('MFBP2_m.cir','w+');
```

```
for i = 1:rows
   for j = 1:columns
      fprintf(fp, '%s', ckt_file(i,j) );
   end
   fprintf(fp,'%s\n','');
end
fclose(fp);

% Run WinSpice
% (wspice3.exe must be located in the Matlab working directory)
! wspice3 MFBP2_m.cir

% Read WinSpice Output File
% It is assumed that just one kind of analysis is
% realized (DC sweep, FREQ sweep or TRAN)
[psi,R{1}] = GetSpiceOutput('MFBP2_out1.csv');

% Erase Previous CSV Data Files
delete MFBP2_out1.csv;
```



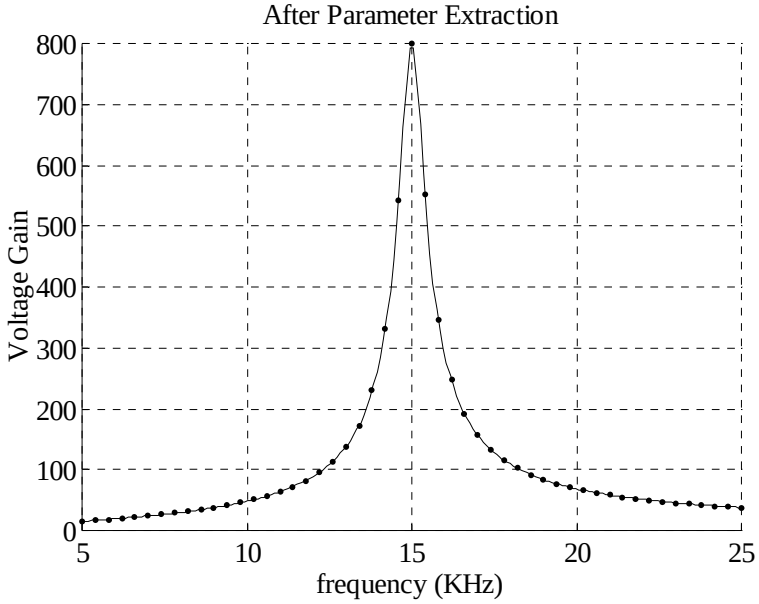
Using norm(e,2):

```
Optimization terminated successfully:
 the current x satisfies the termination criteria using OPTIONS.TolX of 1.000000e-003
 and F(X) satisfies the convergence criteria using OPTIONS.TolFun of 1.000000e-004
x =  1.0e+003 *    0.5193    1.8434    0.0002
FunVal =    0.0084
EF =     1
output =
    iterations: 449
     funcCount: 793
     algorithm: 'Nelder-Mead simplex direct search'
R1_opt =  519.3294
R2_opt =  1.8434e+003
C1_opt =    0.2302
C2_opt =    0.2302
```



Using norm(e,2)^2:

```
Optimization terminated successfully:
 the current x satisfies the termination criteria using OPTIONS.TolX of 1.000000e-003
 and F(X) satisfies the convergence criteria using OPTIONS.TolFun of 1.000000e-004
x =  1.0e+003 *    0.5193    1.8434    0.0002
FunVal =  7.0856e-005
EF =     1
output =
    iterations: 449
     funcCount: 793
     algorithm: 'Nelder-Mead simplex direct search'
R1_opt =  519.3294
R2_opt =  1.8434e+003
C1_opt =    0.2302
C2_opt =    0.2302
```



Using norm(e,inf):

```
Optimization terminated successfully:
 the current x satisfies the termination criteria using OPTIONS.TolX of 1.000000e-003
 and F(X) satisfies the convergence criteria using OPTIONS.TolFun of 1.000000e-004
x =  286.0501  462.2543    0.7025
FunVal =  100.4694
EF =     1
output =
    iterations: 72
     funcCount: 143
     algorithm: 'Nelder-Mead simplex direct search'
R1_opt =  286.0501
R2_opt =  462.2543
C1_opt =    0.7025
C2_opt =    0.7025
```