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Crystal Detector Calibration Program and Procedure

by Neal Tesny

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14. ABSTRACT This report describes a computer program to automate the calibration of crystal detectors and outlines instructions in how to use it. The program is written in MATLAB. I also provide sample output and a program listing.					
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1. Introduction

Crystal (Xtal) detectors are semiconductor devices that are used extensively to rectify microwave signals so that their amplitudes and modulations can be monitored on oscilloscopes. Since they are nonlinear, they must be calibrated over many steps of power levels and over many frequencies. This is a time- and labor-consuming process.

To automate the calibration process of crystal detectors, I wrote a program in MATLAB that uses a programmable signal generator, power meter and sensor, and digital multimeter. The user can specify multiple frequencies or frequency ranges in the program for a calibration. The program also allows users to set the power level ranges.

2. Using the Program

2.1 General Description

The calibration process is a two-step process. In step 1, all of the power levels are measured and recorded. In step 2, all of the voltages of the Xtal are measured and recorded. These findings are used to calculate and display the calibration factor curve.

2.2 Running the Software

The user must enter the following three sets of variables into the program via the program editor:

1. Filename prefix: *filePrefix*. This variable should reflect the device being calibrated and the termination resistive load into which it is calibrated. Standard MATLAB format requires string variables be entered using single quotes. It is prudent to include an underscore, “_”, or other dividing character at the end since the program will append the frequency to the end of the filename. The following are examples showing the correct format:
 - `filePrefix = 'xtal 456_50ohms_';`
 - `filePrefix = 'xtal12345_620ohms_';`
 - `filePrefix = 'crystal_02482_50ohms_';`
2. Frequencies being calibrated: *frequencies*. This variable should be entered in standard MATLAB matrix format as per the following examples:
 - `frequencies=[2000,5000,8000];`
 - `frequencies=[4700];`

- `frequencies=1000:1000:10000;`
3. Power level ranges to use: *power_start*, *power_stop*, *power_step*. These three variables are defined as follows:
- *power_start*: the starting, or lowest, power level in dBm
 - *power_stop*: the ending, or highest, power level in dBm
 - *power_step*: the increment of power steps in dB

The following examples show the correct format:

- `power_start=-3; % dbm`
- `power_stop=20; % dbm`
- `power_step=1; % dB`

Warning: Most crystal detectors have a limit of 100 mW or +20 dBm input and will burn out if this power level is exceeded.

After entering in these variables and saving the program, the user can start the program by clicking the Run button in MATLAB or entering the program name in the MATLAB command window and pressing Enter. The program then directs the user to connect the power sensor up to the signal generator to measure its output. After this, the user is directed to connect the crystal detector input to the frequency synthesizer and the Xtal output to the digital multimeter. At this point, further measurements are made, and the calibration curve is plotted and saved on the laptop PC.

Note that when using a different power sensor, the “calibration curve” for it must be entered into the program. This is described in appendix A.

2.3 Equipment Setup

The equipment is set up as shown in figures 1 and 2 for steps 1 and 2, respectively.

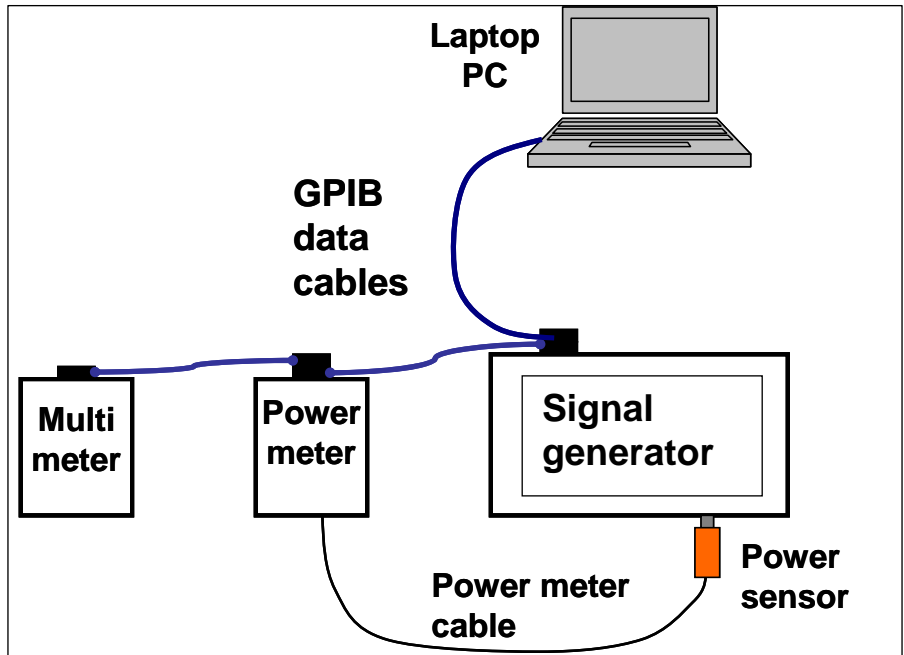


Figure 1. Equipment setup for step 1 of the calibration.

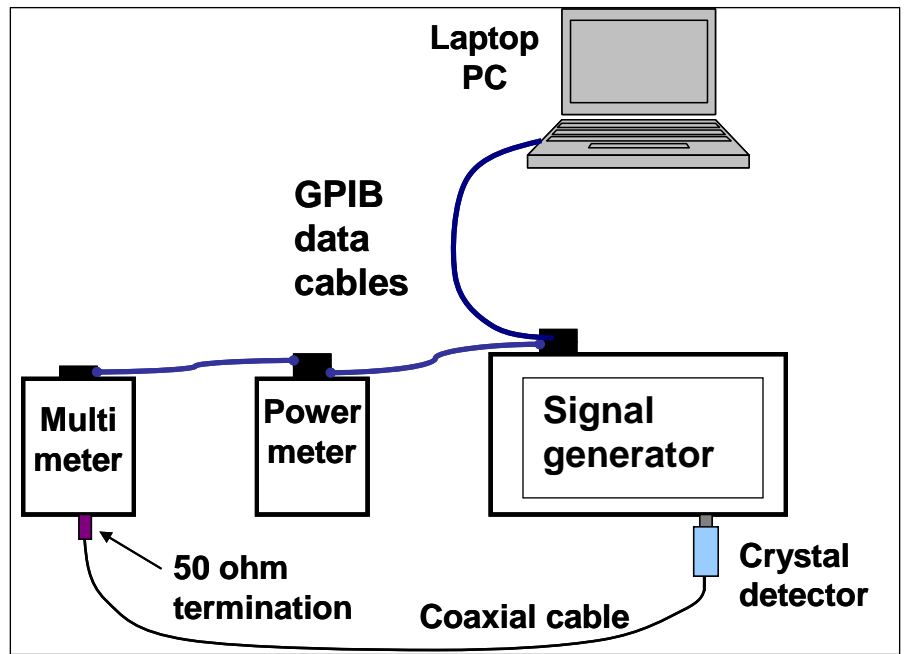


Figure 2. Equipment setup for step 2 of the calibration.

In step 1, the power sensor is connected directly to the signal generator. The instruments are connected to a laptop PC via a general purpose interface bus (GPIB). Before taking measurements, the user should calibrate the power meter in accordance with manufacturer specified procedures. The calibration of a HP 438A power meter is described in appendix A.

In step 2, the input of the crystal detector being calibrated is connected to the signal generator and its output is connected to the digital multimeter, which measures the output voltage of the crystal. Since the multimeter has a high-impedance input, a 50 Ω shunt termination must be placed on the multimeter's input. Termination values other than 50 Ω can be used. The pros and cons for different termination resistances are explained in appendix B.

The equipment currently used consists of the following:

- Dell Latitude D400 laptop PC
- Anritsu MG3692B signal generator
- Hewlett-Packard (HP) 438A power meter
- HP 8481H power sensor
- HP 3478A digital multimeter

One can use other equipment with the program, but to do so the program code would need to be modified in order to include the proper GPIB commands specific to each new instrument.

3. Program Output

3.1 Calibration Factor Curve

The program outputs a calibration curve that is a plot of input power in mW versus output voltage in mV. Sample output curves are shown in appendix C. These curves are used for future measurements, i.e., the user can find the voltage output from the crystal on the x -axis and determine the power level that was input to it from the y -axis of the curve.

3.2 Best-fit Trend Line

In addition, the program outputs the coefficients for a least squares best-fit curve, which can be used in a spreadsheet. These coefficients are output into a text file along with the x - y pairs of the measurements of voltage out versus power in, and used in the following manner.

Given the coefficients [c4, c3, c2, c1, c0], the input formula to a computer spreadsheet would be

$$P = c4*x^4 + c3*x^3 + c2*x^2 + c1*x + c0 ,$$

where P is the power detected by the crystal and x is the cell with the voltage out of the crystal.

I found that the most accurate best-fit, trend-line curve for crystal detectors was a third order curve with the intercept ($c0$) set to 0.

3.3 Saved Files

The measured data and best-fit curve coefficients are saved on the laptop PC as comma separated value (CSV) text files. A separate file is saved for each frequency measured. The filename of each file consists of the filename prefix with the frequency appended to it, e.g., “crystal_02483_50ohms_5000MHz.csv”. The program is currently set up to save the data in the C:\crystalCal\ directory.

In addition, all the recorded data are appended to the general file “crystalData.csv”, which holds a record of every calibration performed. This file is created as a backup in the event of accidental data file deletion.

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Appendix A. Power Meter Calibration

The user must calibrate the HP 438A power meter and sensor before use. The steps for performing this calibration are as follows:

1. Connect the sensor to the meter output.
2. Zero the sensor by pressing the “zero” button and allowing the meter to finish.
3. Press “CF” button and enter the calibration number printed on the sensor—for the 8481H power sensor, this number is 100. The meter then turns on the 1-mW calibration signal to calibrate the sensor. Allow the meter to finish this process.
4. Press “Cal Factor” to enter the frequency-dependent calibration factor printed on the sensor. For this program, enter “100” since this number is already entered into the program.

Sensor Calibration Curve

When using a different power sensor, the user must enter the calibration factors with their frequencies into the program in order to perform correct measurements. These values are printed on the power sensor itself and are entered into the two variables “calFactors” and “calFreqs” in the program in standard MATLAB array format. The order of the values must be arranged so that the frequencies match the corresponding calibration values.

The following example shows the correct format:

```
calFactors=[1 0.98 0.97 0.967 0.965 0.96 0.96 0.965 0.975 0.97 0.975];  
calFreqs=[50 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000];
```

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Appendix B. Using Different Resistance Loads for Crystal Detector Output

Crystal detectors are typically terminated into $50\ \Omega$; however, they can be terminated into larger resistances, such as $1\ \text{k}\Omega$. The advantage of doing this is that the user can obtain many decibels more sensitivity from the crystal, which is helpful when measuring small signals. The disadvantage of doing this is that more ripples will occur on the output trace when observed on an oscilloscope, particularly at lower frequencies (a few GHz or less). However, if a repetitive signal is present, then this problem can usually be remedied through signal averaging with the oscilloscope.

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Appendix C. Sample Output

Sample plots of the output are given in figures C-1 and C-2. The curves are a plot of power in versus voltage out. A trace is plotted for each frequency measured; the frequencies are listed in the plot's legend.

Note that the variation of Xtal 59's response over the frequency range is 48% in output power, which is 1.7 dB, and Xtal 02466 varies by 21%, which is 0.8 dB.

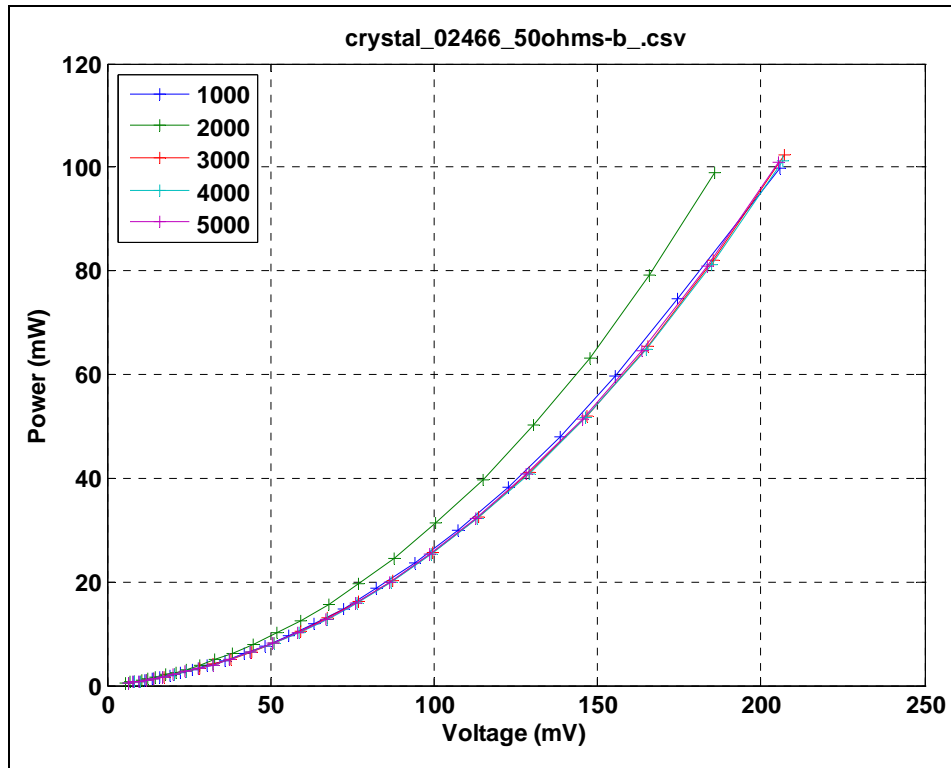


Figure C-1. Sample output for Xtal 02466.

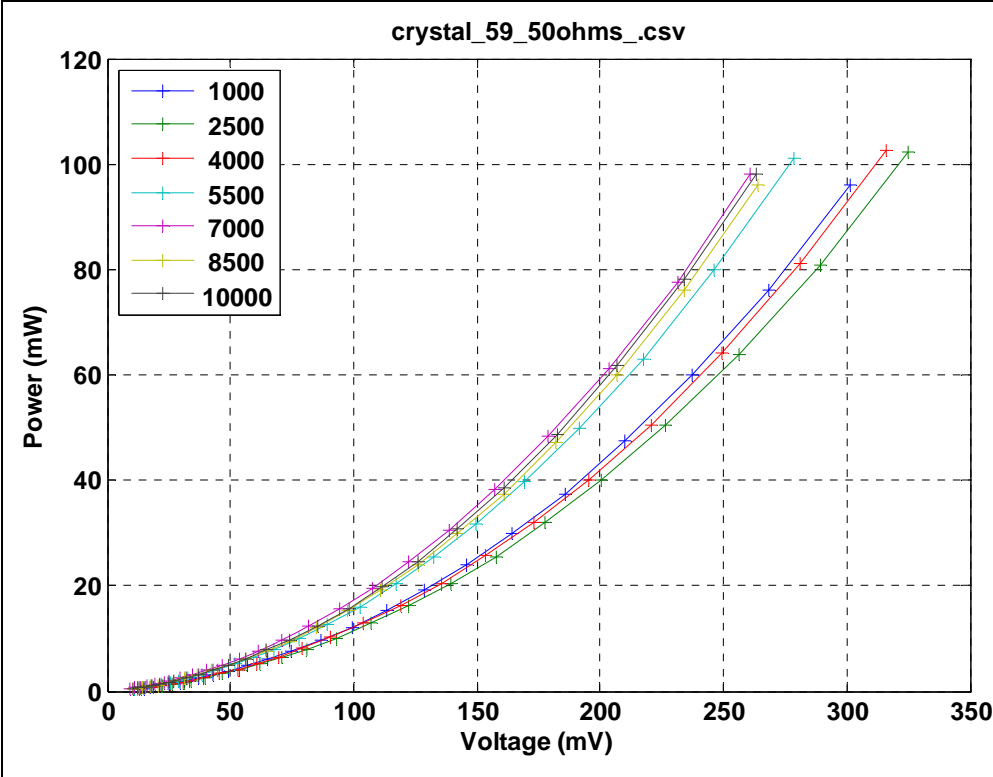


Figure C-2. Sample output for Xtal 59.

Appendix D. Program Listing

```
% crystal_cal4.m
% Apr 2005 N Tesny
% Automated calibration of crystal detectors
% controls 3 instruments: power meter, voltmeter, ANRITSU 3692B

filePrefix='crystal_02482_50ohms_';
% filePrefix='crystal_x2_50ohms_10dbPad_';

if true

    % variables:
    % frequencies=[400 500 600]; % MHz
%   frequencies=[2000 2500 3000 3500 4000]; % MHz
    % frequencies=[400 500 600 700 800 900 1000]; % MHz
%   frequencies=[1000 1200 1400 1600 1800 2000]; % MHz
%   frequencies=[2500 3500 4500 5500 6500 7500];
    frequencies=[2000,5000,8000];
%   filePrefix='xtal38_1kohm_';
%   filePrefix='xtal201AP_620ohm_lowPower_';

    power_start=-3; % dbm
    power_stop=21; % dbm
    power_step=1; % dB

    power_limit_absolute=200; % mW
    time_before_switch=0.25; % S
    time_after_switch=0.25; % S
    power_wait_time=0.9; % S
    tol_power=0.01; % dB
    system_gain=35; % dB
    pname='C:\crystalCal\';
    fileSuffix='MHz.csv';
    generalFile='C:\crystalCal\crystalData.csv';

    calFactors=[1 0.98 0.97 0.967 0.965 0.96 0.96 0.965 0.975 0.97 0.975];
    calFreqs=[50 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000]; %
frequency in MHZ

% GPIB addresses:
addressPowerMeter=13;
addressVom=23;
addressSwitch=28;
addressAnritsu=6;%need to change
% constants:
FALSE=0;TRUE=~FALSE;

% Initialization:
% Find power meter:
if ~exist('gPM'),
    gPM = gpib('ni',0,addressPowerMeter);
```

```

end
if strcmp(gPM.Status,'closed'),
    fopen(gPM)
end
set(gPM,'EOSMode','read&write')
set(gPM,'EOSCharCode','LF')

% Find voltmeter:
if ~exist('gVM'),
    gVM = gpib('ni',0,addressVom);
end
if strcmp(gVM.Status,'closed'),
    fopen(gVM)
end
set(gVM,'EOSMode','read&write')
set(gVM,'EOSCharCode','LF')

% Find anritsu:
if ~exist('gW'),
    gW = gpib('ni',0,addressAnritsu);
end
if strcmp(gW.Status,'closed'),
    fopen(gW)
end
set(gW,'EOSMode','read&write')
set(gW,'EOSCharCode','LF')
fprintf(gW,'DS1'); %tell it to turn off secure mode- display readings:

% Try to get 3 dBm onto crystal and power meter:
pStartDb=(power_start);
pStopDb=(power_stop);
p_mat=pStartDb:power_step:pStopDb;
if p_mat(length(p_mat))<pStopDb
    p_mat=[p_mat,pStopDb];
end
a=length(p_mat);
Vout=zeros(1,a);Pout=zeros(1,a);
nf=0;Pout_mat=[];Vout_mat=[];

h=msgbox('Connect Wiltron directly to Power Meter. SET TO DBM. Set Scale
Factor to 100% Then press Ok','Hello there');
uiwait(h);

for freq=frequencies
    nf=nf+1;
    cf = interp1(calFreqs,calFactors,freq);

    disp(' ');
    displayit('Putting in',num2str(freq),'MHz');
    fprintf(gW,'RF1'); %tell it to turn rf on:
    pause(0.1);
    a=['CF1 ',num2str(freq),' MH'];%-PUT IN freq in MHZ
    fprintf(gW,a); %tell it to change freq:
    pause(.1);

```

```

% Sweep thru powers:
k=0;
for p_in=p_mat,
    k=k+1;
    a=['L1 ',num2str(p_in),' dm'];%-PUT IN p_in dbm
    fprintf(gW,a); %tell it to change dbm:

    pwr=getPower(gPM,power_wait_time,tol_power);% get power
    %       v= getVoltage(gVM); % get voltage
    %       Vout(k)=v;
    pwr_mw = 10^( pwr/10);
    pwr_mw_adj = pwr_mw/cf;
    pwrdbAdj = 10*log10(pwr_mw_adj);
    Pout(k)=pwrdbAdj;
end
%     Pout2=10.^(Pout/10);
%     Vout2=-1000*Vout;
Pout_mat(:,nf)=Pout';
end

fprintf(gW,'RF0'); %tell it to turn rf off:

% Vout_mat(:,nf)=Vout2';
end

if 1
    h=msgbox('Connect crystal det on Wiltron, then into VOLTMETER. Then
press Ok','Hello again');
    uiwait(h);
    fprintf(gW,'RF1'); %tell it to turn rf on:
    pause(0.1);

    nf=0;
    for freq=frequencies
        nf=nf+1;
        disp(' ');
        displayit('Putting in',num2str(freq),'MHz');
        %     fprintf(gW,'RF0'); %tell it to turn rf off:
        %     pause(0.1);
        a=['CF1 ',num2str(freq),' MH'];%-PUT IN freq in MHZ
        fprintf(gW,a); %tell it to change freq:
        pause(.1);

        % Sweep thru powers:
        k=0;
        for p_in=p_mat,
            k=k+1;
            a=['LVL ',num2str(p_in),' dm'];%-PUT IN p_in dbm
            fprintf(gW,a); %tell it to change dbm:
            pause(0.9)
            % pwr=getPower(gPM,power_wait_time,tol_power);% get power
            v= getVoltage(gVM); % get voltage
            Vout(k)=v;
            % Pout(k)=pwr;
        end
        Vout_mat(:,nf)=Vout';
    end
end

```

```

end
fprintf(gW,'RF0'); %tell it to turn rf off:

if Vout_mat(1,1)<0,
    Vout_mat=-Vout_mat;
end
Vout_mat=1000*Vout_mat;

[a,b]=size(Pout_mat);
fid=fopen(generalFile,'a');
for fi=1:b
    c=[filePrefix,'frequency: ',num2str(frequencies(fi)),' MHz'];
    fprintf(fid,'%s\n',c);
    for i=1:a
        fprintf(fid,'%g,%g \n',Pout_mat(i,fi),Vout_mat(i,fi));
    end
end
fclose(fid);

Pout_mat_db=Pout_mat;
Pout_mat2 = 10.^(Pout_mat/10);
end
%a=[filename2,' ', num2str(freq),' MHz'];
a=0;
for freq=frequencies
    a=a+1;
    Pout2=Pout_mat2(:,a);
    Vout2=Vout_mat(:,a);
    p=polyfit(Vout2,Pout2,4);

pstr=[num2str(p(1),'%12.4E'),' ', num2str(p(2),'%12.4E'),' ', num2str(p(3),'%12.4E'),' ', num2str(p(4),'%12.4E'),' ', num2str(p(5),'%12.4E')];
    fname=[filePrefix,num2str(freq),fileSuffix];
    ascwrite(Vout2,Pout2,fname,'c4,c3,c2,c1,c0',pstr,'mV,mW',[pname,fname]);
    % [st]=ascwrite(x,Efield,'Electric Field','Electric Field',xlab,'V/m',[pathname2,'eField_',filename2]);
end
n=0;
for i=2:length(frequencies)
    n1=length(num2str(frequencies(i)));
    n=max(n,n1);
end

a=[num2str(frequencies(1))];
m=length(a);
for i=1:n-m
    a=[' ',a];
end
leg='';
leg=a;
for i=2:length(frequencies)
    a=[num2str(frequencies(i))];
    m=length(a);
    for i=1:n-m
        a=[' ',a];
    end
    leg=[leg;a];
end

```

```
end
figure;plot(Vout_mat,Pout_mat2,'-+');grid on
xlabel('Voltage (mV)');ylabel('Power (mW)');
title(fname,'Interpreter','none');
legend(leg,'location','NorthWest');
figure;loglog(Vout_mat,Pout_mat2,'-+');grid on
xlabel('Voltage (mV)');ylabel('Power (mW)');
title(fname,'Interpreter','none');
legend(leg,'location','SouthEast');
```

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