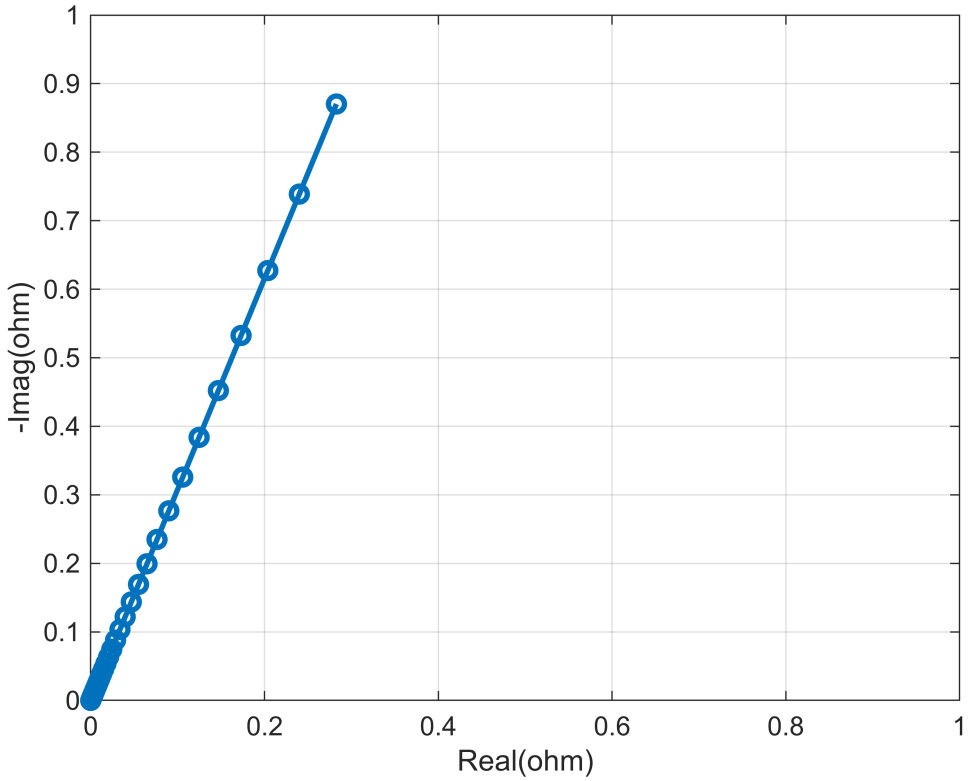
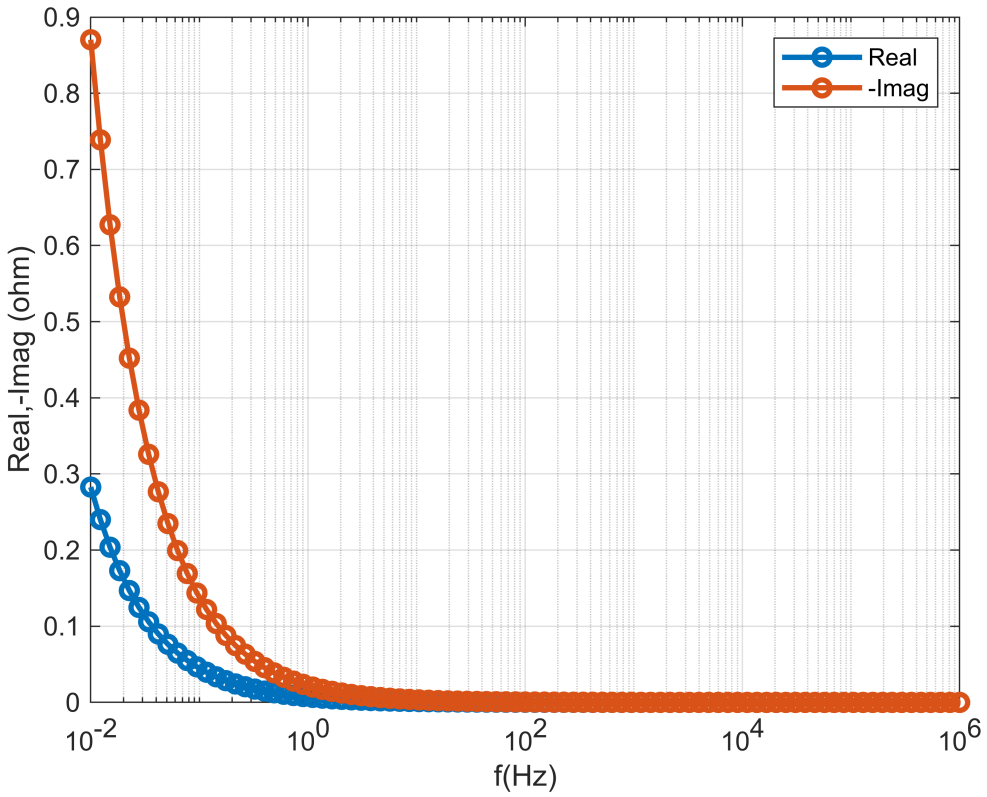
# 基本元器件

### 1.常相角原件 Q

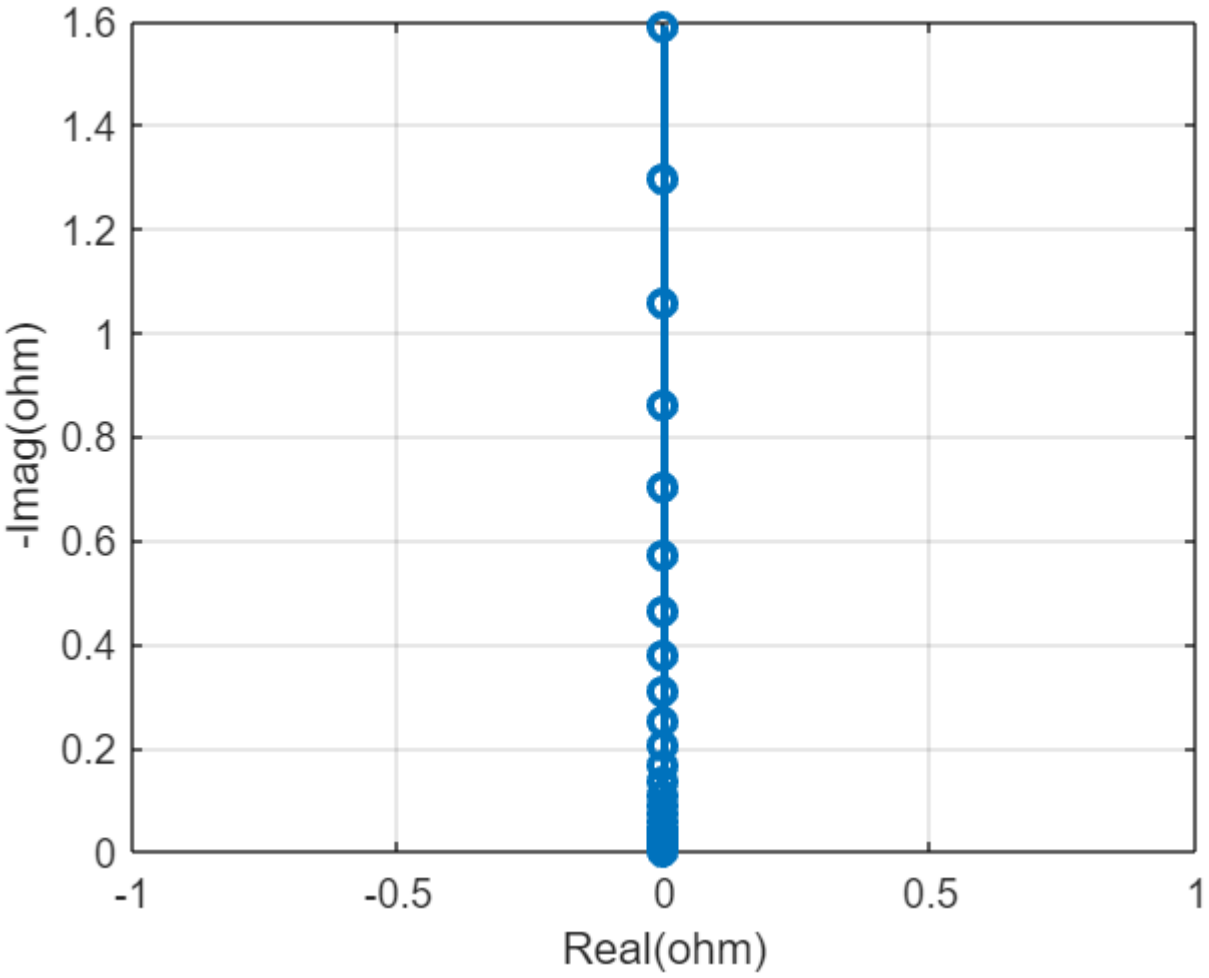
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_Q_example=Q(2*pi*f,"n",0.8,"Q",10);
plot_EIS(w,Z_Q_example,"Nyquist",'on',"Bode",'on',"xlim_switch",'on')
```





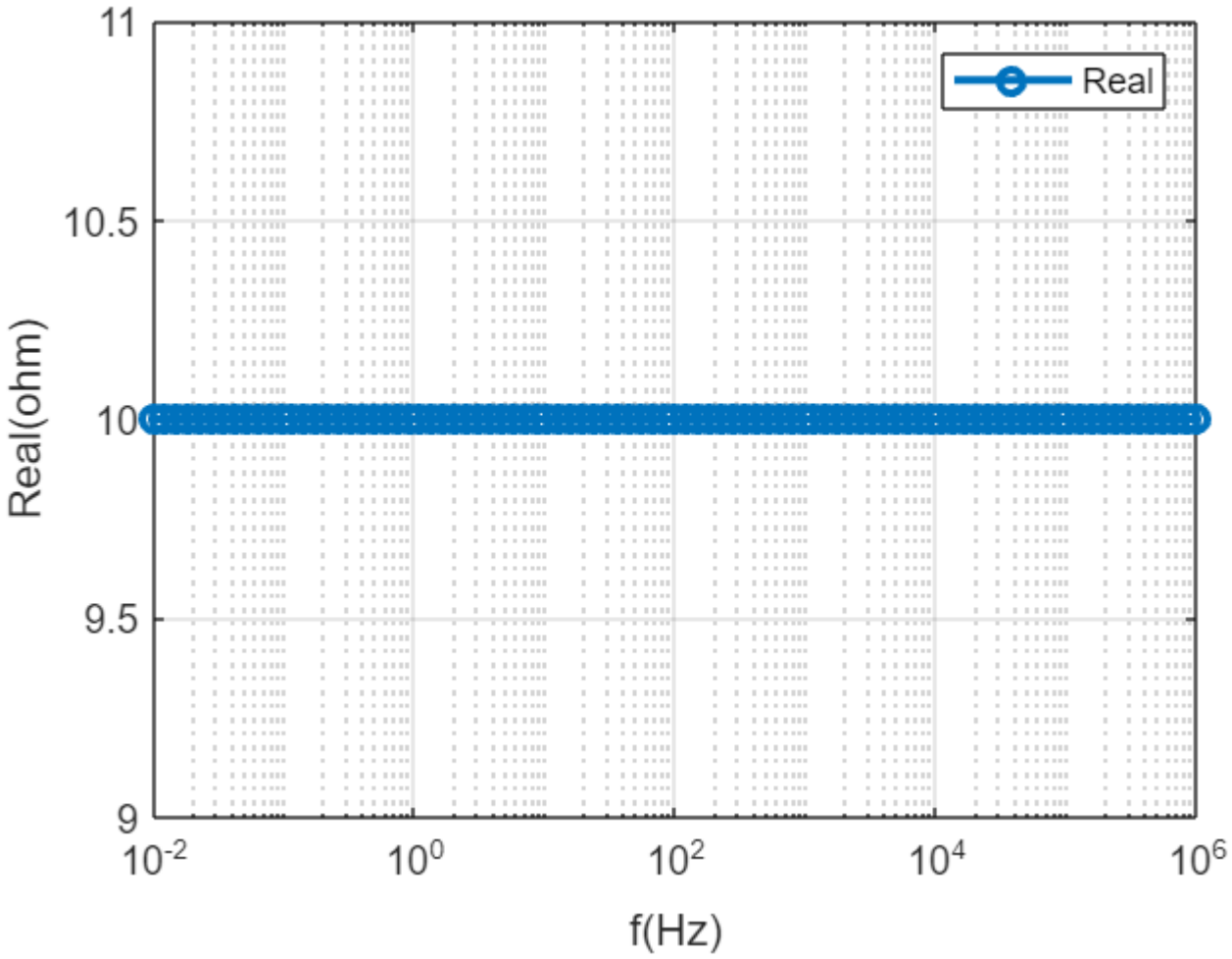

**2.理想电容 C**

```
f=logspace(-2,6,91);
w=2*pi*f;
Z_C_example=C(w,"C",10);
plot_EIS(w,Z_C_example)
```



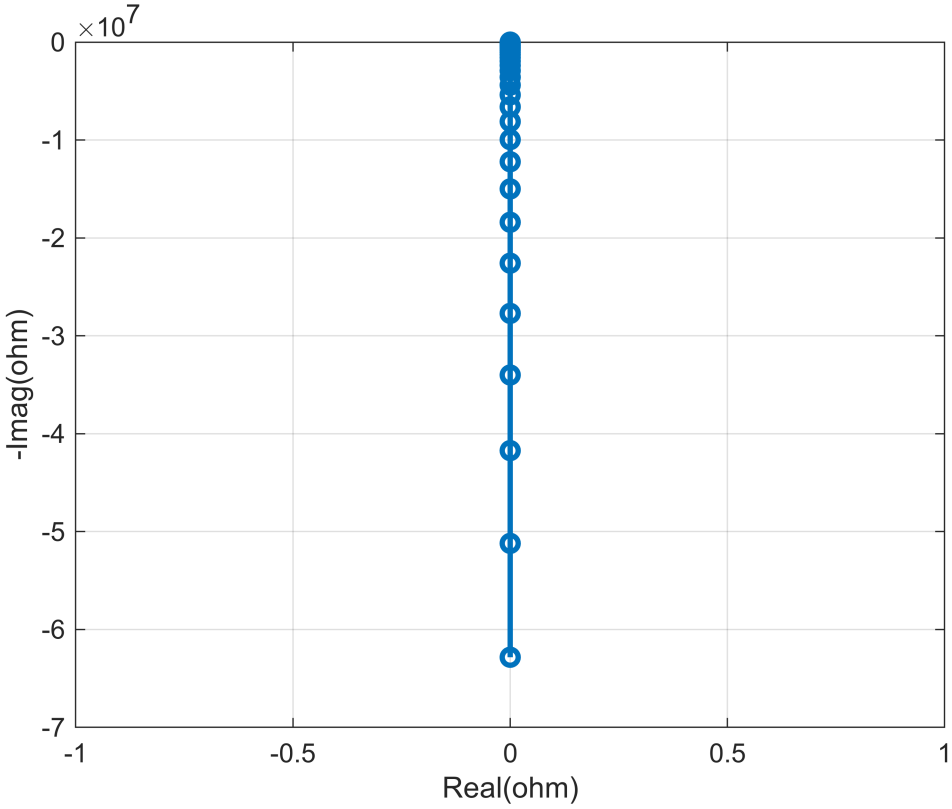

**3.纯电阻 R**

```
f=logspace(-2,6,91);
w=2*pi*f;
Z_R_example=R(w,"R",10);
plot_EIS(w,Z_R_example,"Nyquist","off","Bode","real")
```



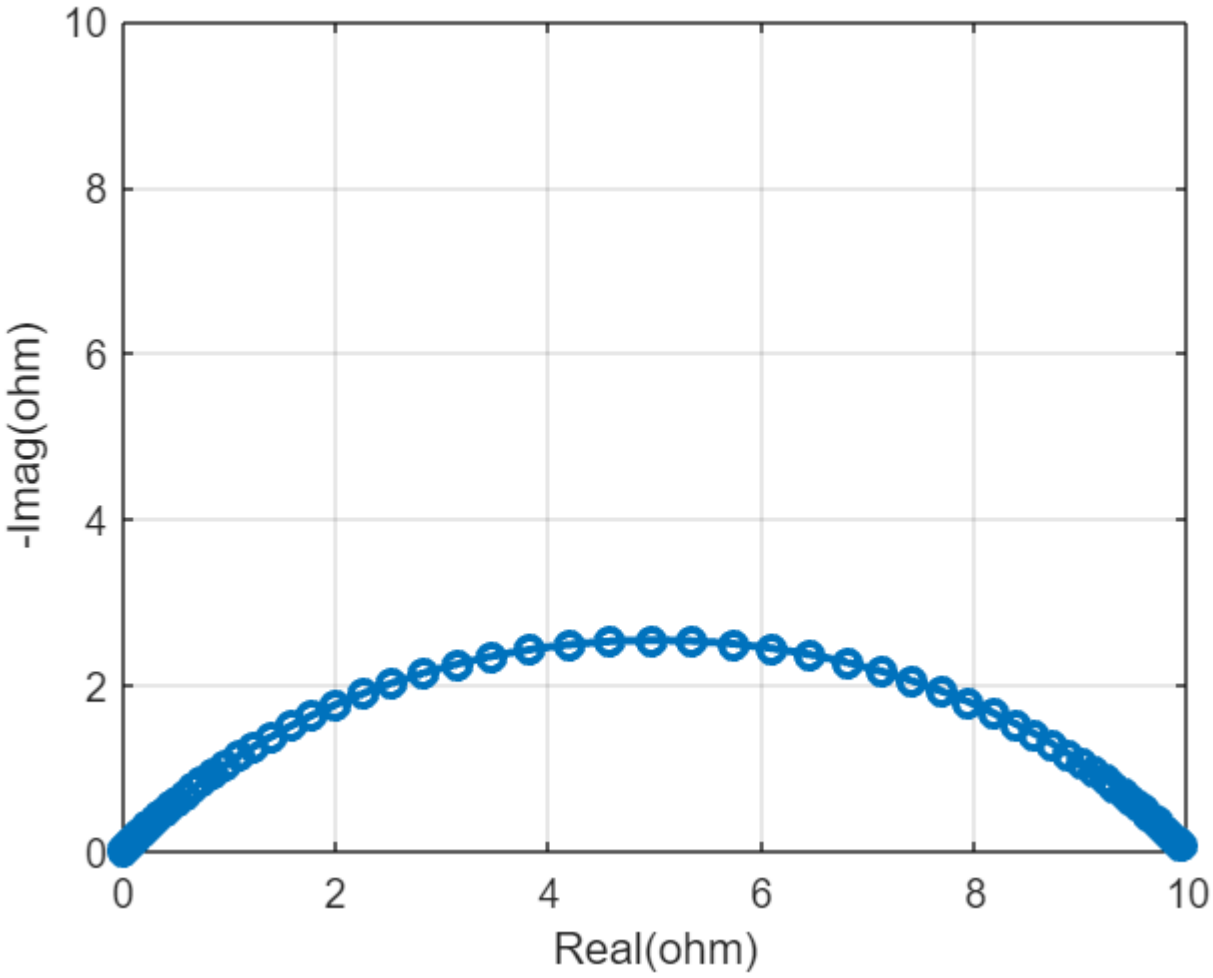

**4.纯电感 L**

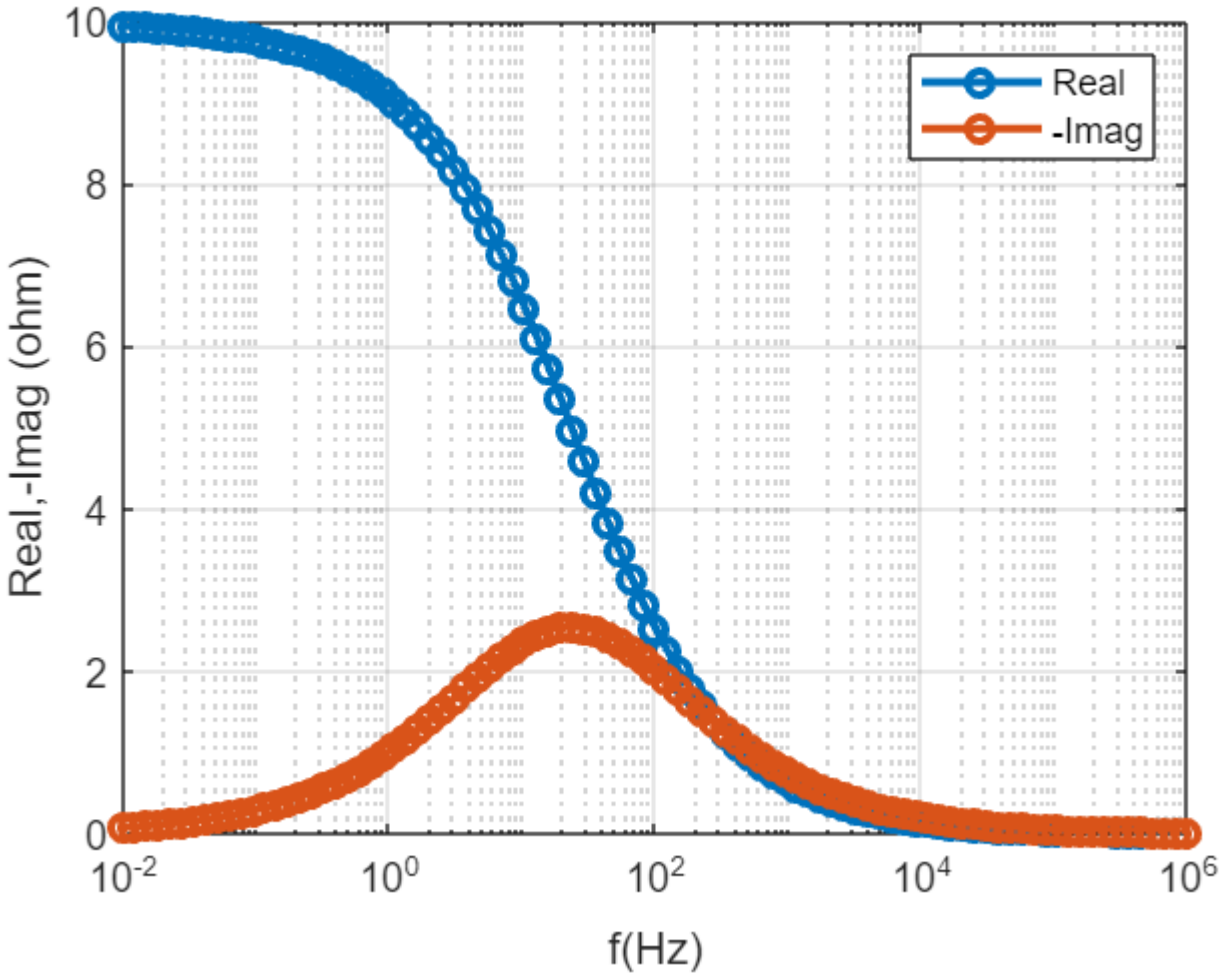
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_L_example=L(w,"L",10);
plot_EIS(w,Z_L_example,"Nyquist","on")
```




**5.RQ 环路**

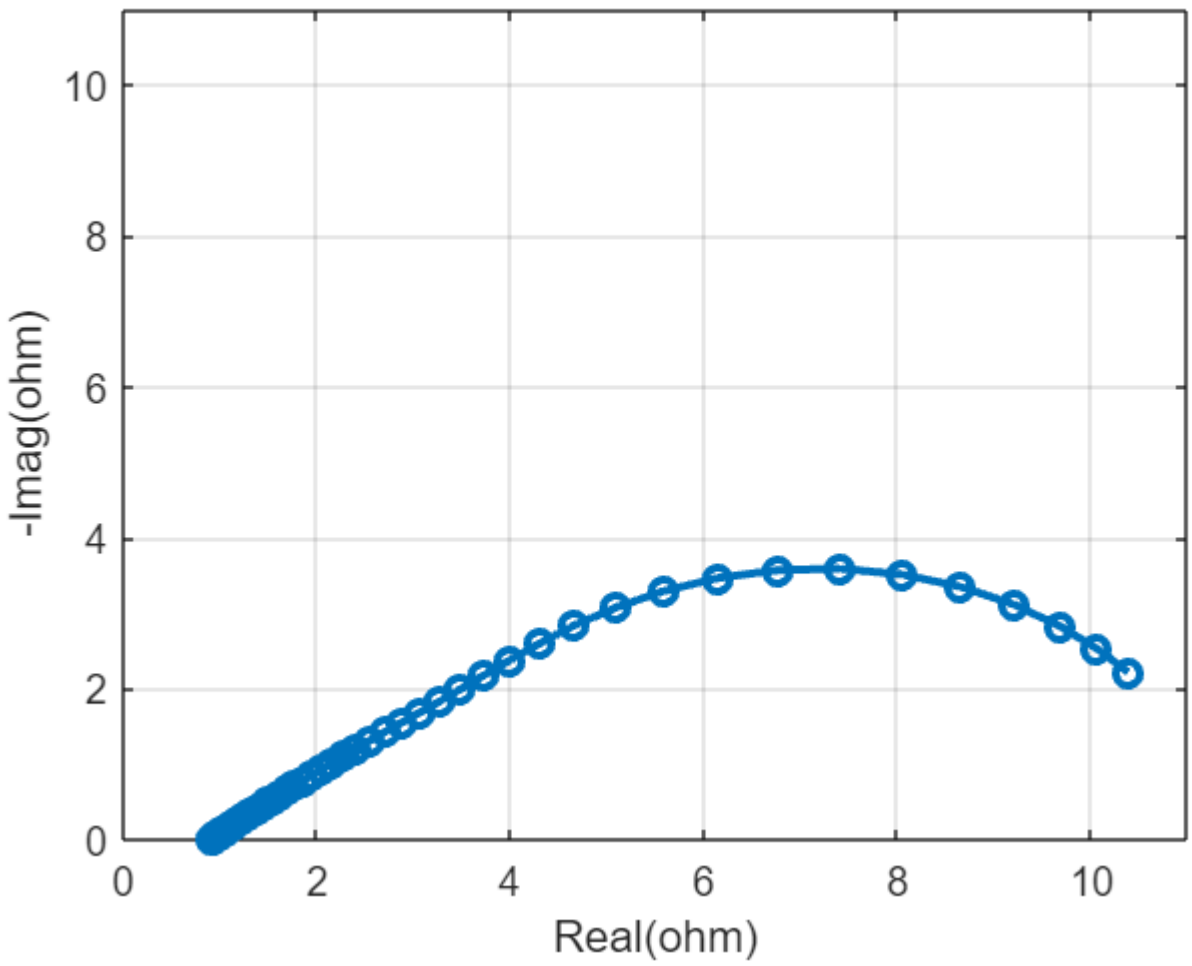
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_RQ_example=RQ(2*pi*f,'R', 10, 'Q', 5e-3,'n',0.6);
plot_EIS(w,Z_RQ_example,"Nyquist","on","Bode","on","xlim_switch",'on')
```

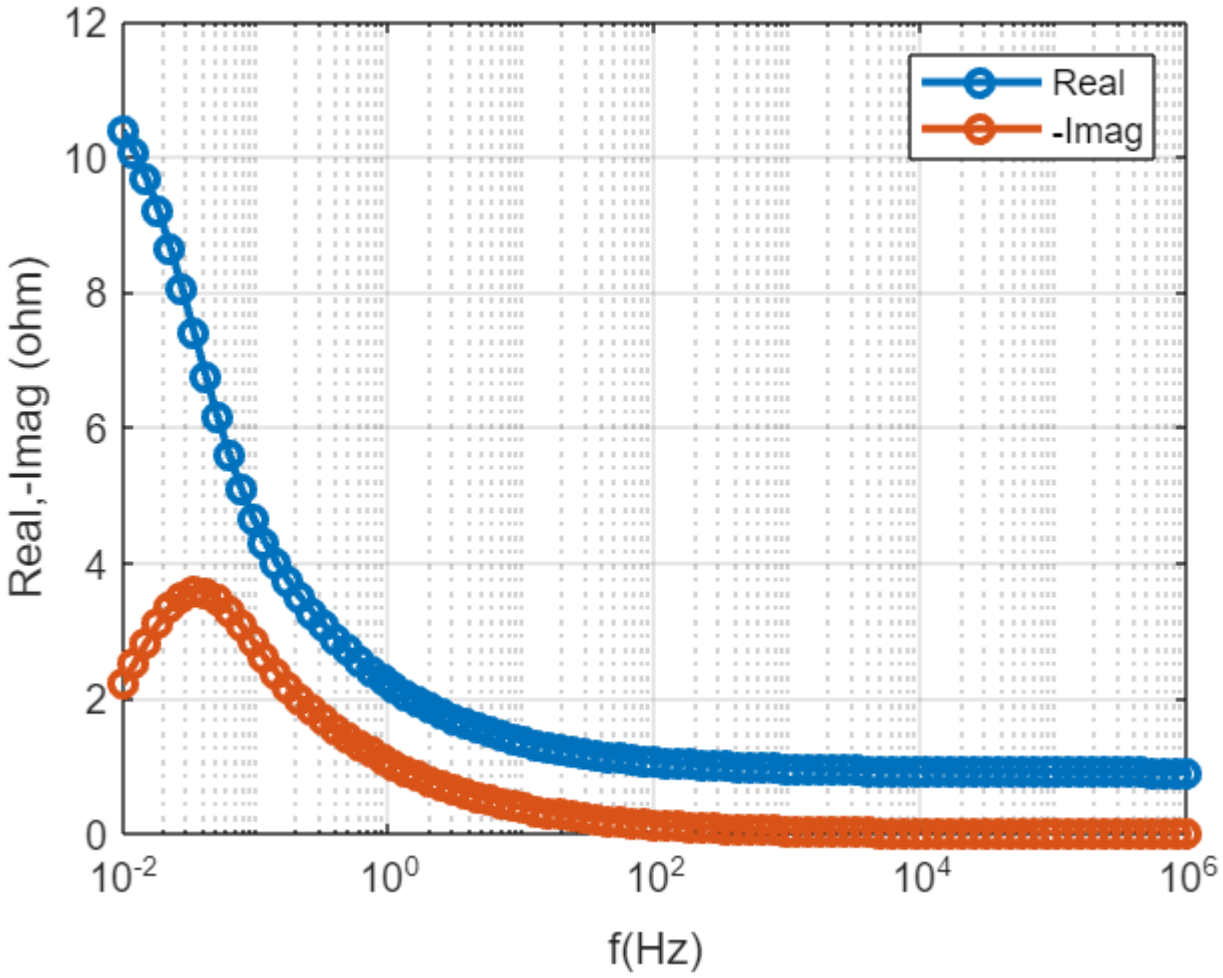

10
8
6
4
2
0
-Imag(ohm)
0
2
4
6
8
10
Real(ohm)




**6.**传输线**模型 TLM(含 Rct)**

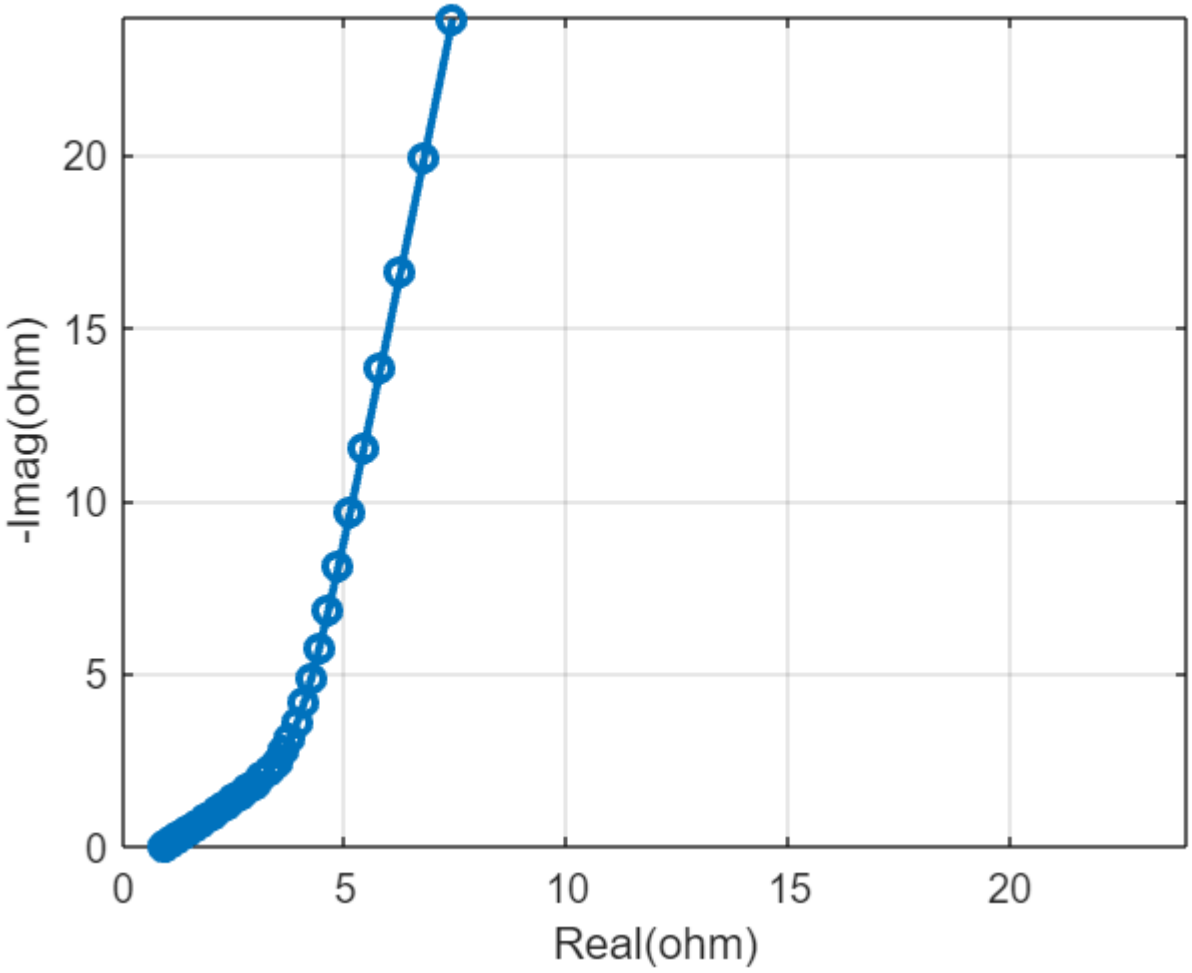
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_interface=@(w,Rct,Qct,n_ct) RQ(w,"R",Rct,"Q",Qct,"n",n_ct);%界面阻抗表达式，采用 RQ 回路表示法拉
Z_tlm=@(w,L,Re,Ri,Rct,Qct,n_ct) TLM(w,"L",L,"Re",Re,"Ri",Ri,"Zt",Z_interface(w,Rct,Qct,n_ct));
Z_tlm_example=Z_tlm(w,0.1,10,100,0.8,5,0.9);
plot_EIS(w,Z_tlm_example,"Bode","on","xlim_switch",'on')
```

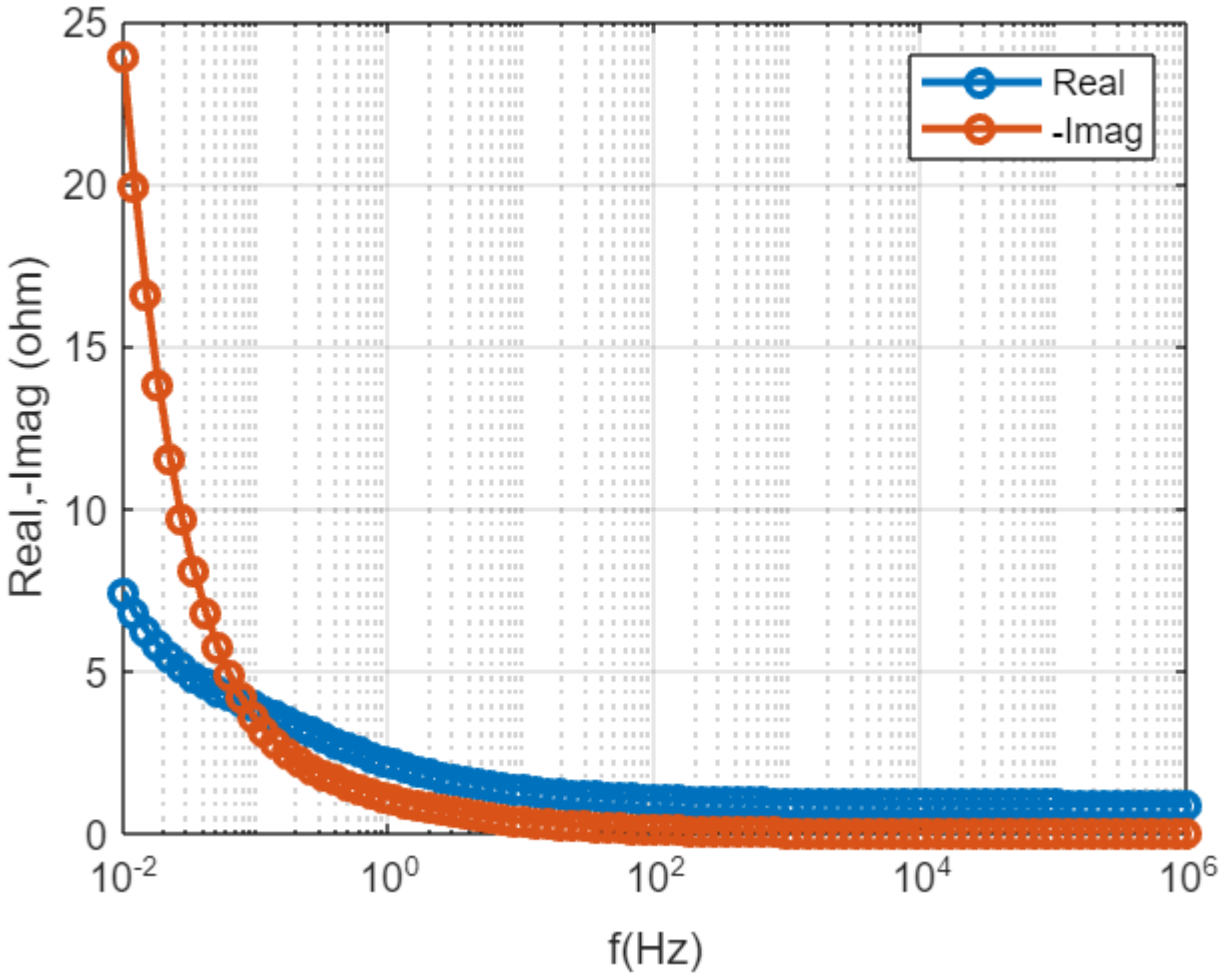

10
8
6
4
2
0
-Imag(ohm)
0
2
4
6
8
10
Real(ohm)




**7.**传输线**模型 TLM(不含 Rct)**

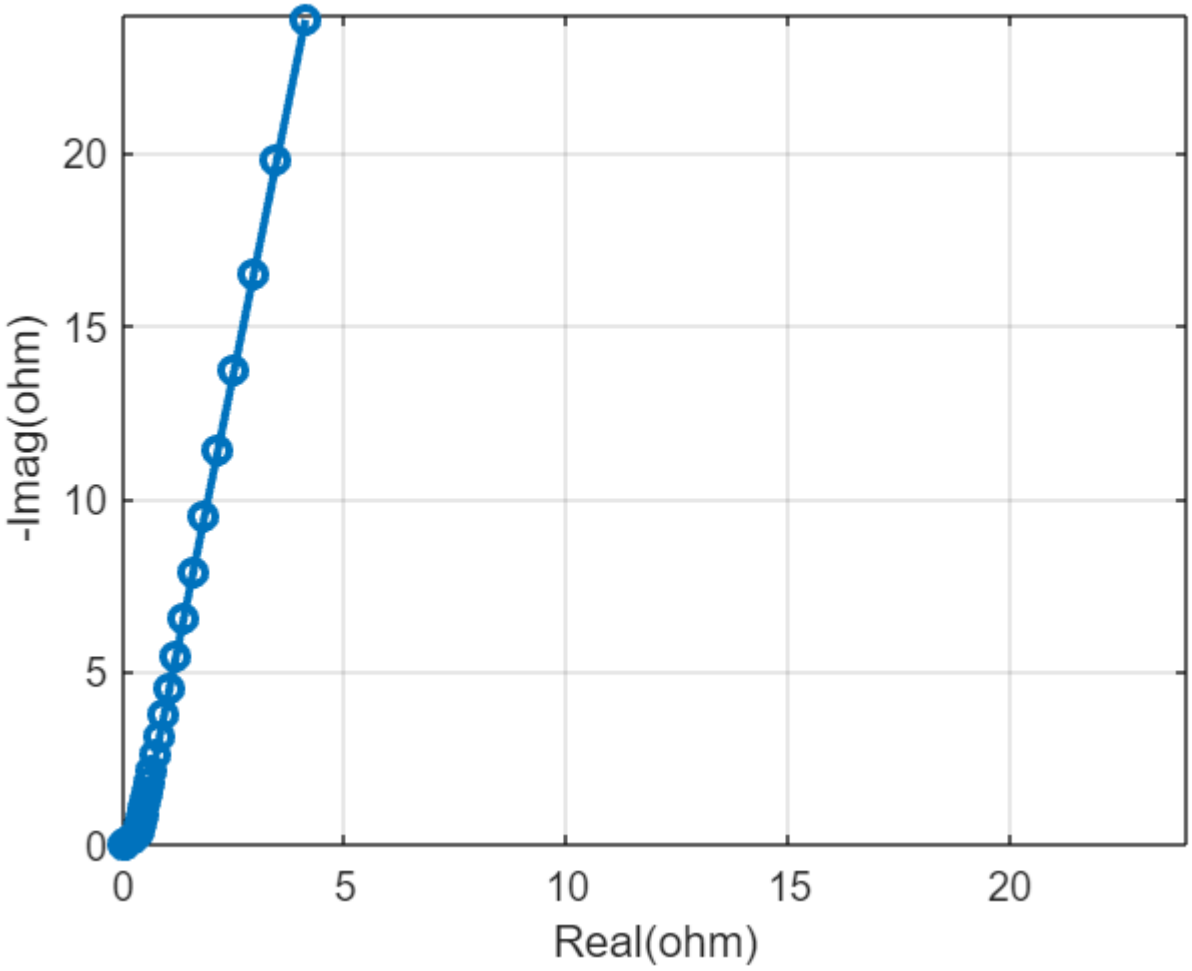
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_interface2=@(w,Q_interf,n_interf) Q(w,"Q",Q_interf,"n",n_interf);%界面阻抗表达式，采用 Q 回路表示
Z_tlm=@(w,L,Re,Ri,Q_interf,n_interf) TLM(w,"L",L,"Re",Re,"Ri",Ri,"Zt",Z_interface2(w,Q_interf,n
Z_tlm_example=Z_tlm(w,0.1,10,100,5,0.9);
plot_EIS(w,Z_tlm_example,"Bode","on","xlim_switch",'on')
```

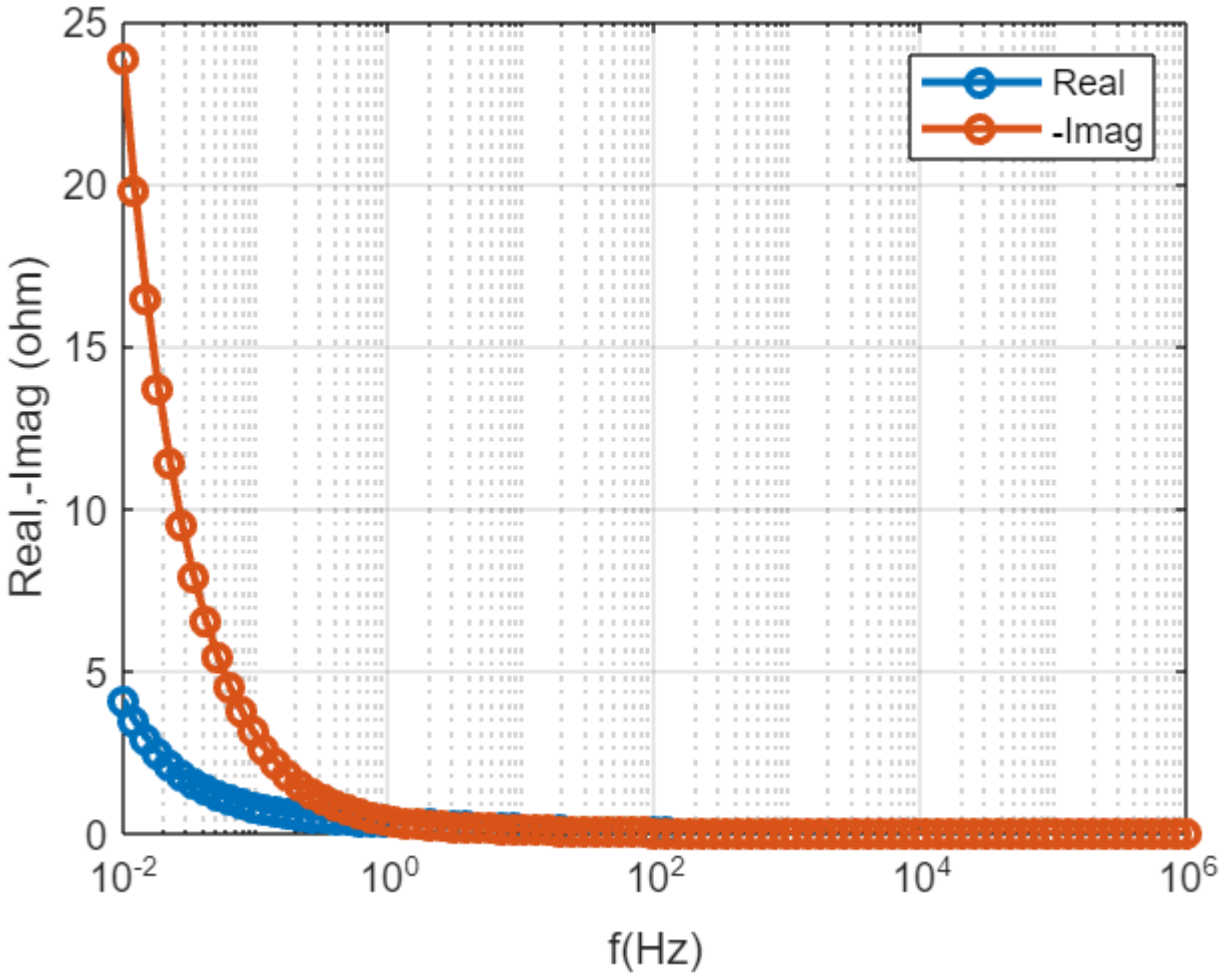

-Imag(ohm)
Real(ohm)
0
5
10
15
20
0
5
10
15
20




**8.简化传输线模型 TLMs(忽略电子电阻，不含 Rct)**

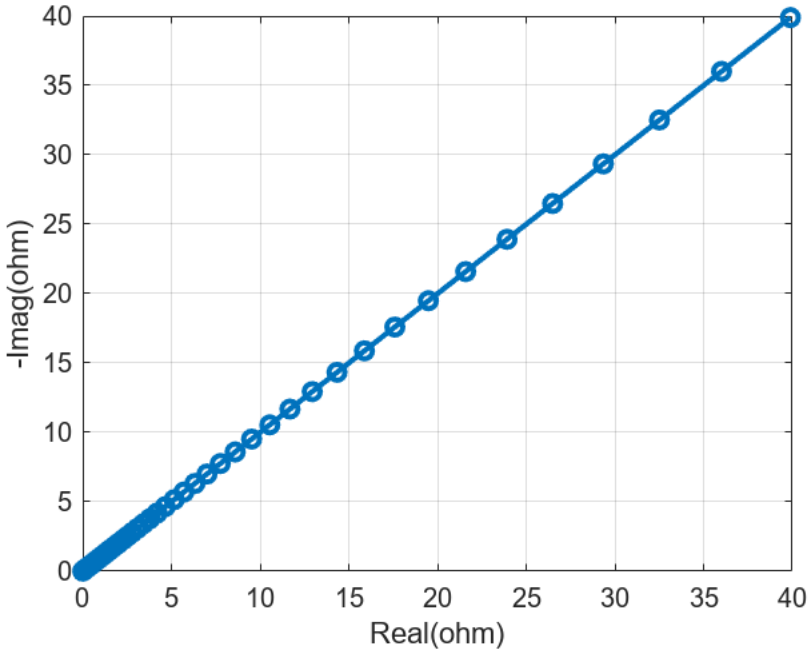
```
f=logspace(-2,6,91);
w=2*pi*f;
Z_interface2=@(w,Q_interf,n_interf) Q(w,"Q",Q_interf,"n",n_interf);%界面阻抗表达式，采用 Q 回路表示
Z_tlm2=@(w,L,Ri,Q_interf,n_interf) TLM(w,"L",L,"Ri",Ri,"Zt",Z_interface2(w,Q_interf,n_interf));
Z_tlm2_example=Z_tlm2(w,0.1,10,5,0.9);
plot_EIS(w,Z_tlm2_example,"Bode","on","xlim_switch",'on')
```

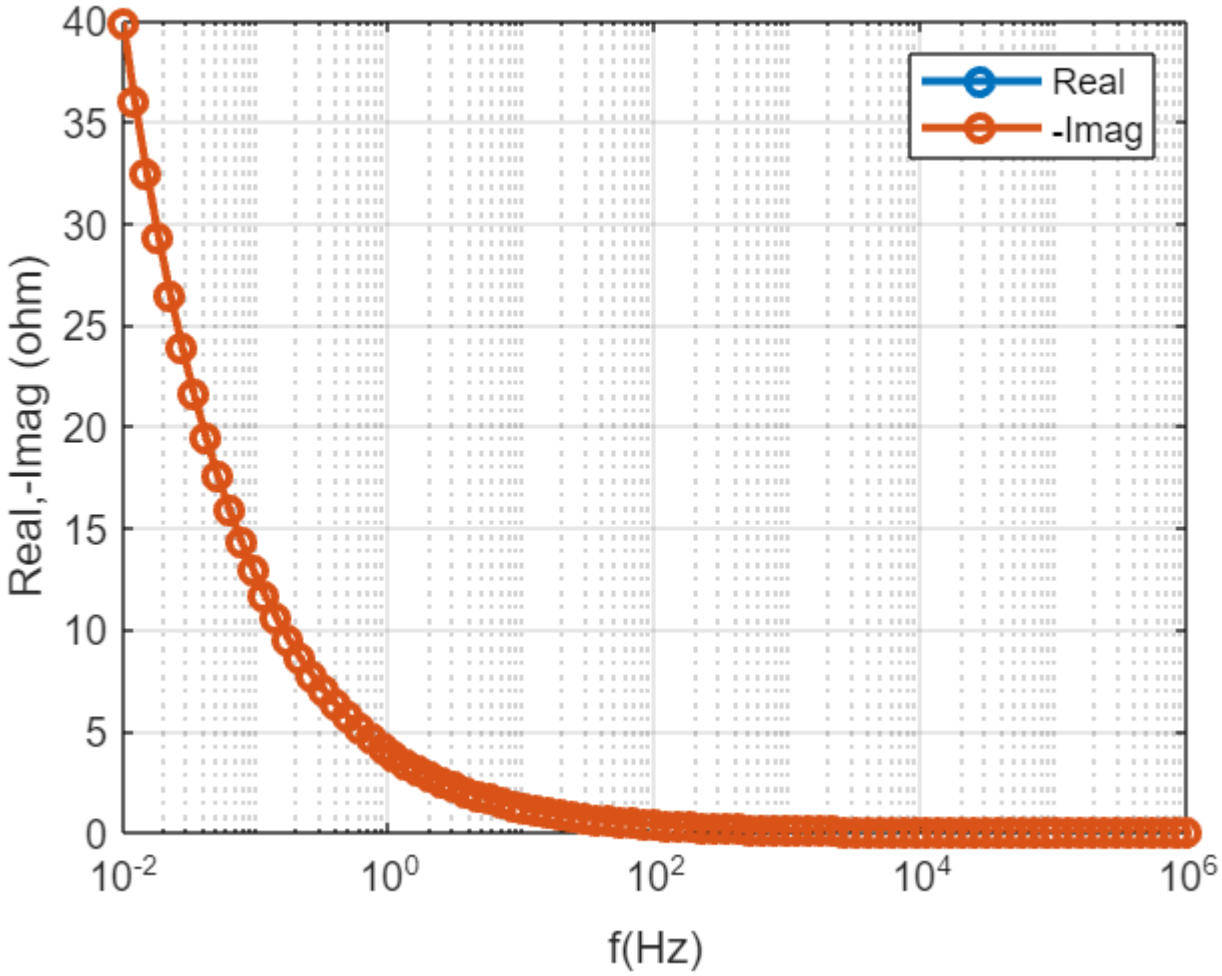

-Imag(ohm)
Real(ohm)
0
5
10
15
20
0
5
10
15
20




**9.半无限扩散阻抗 Zw**

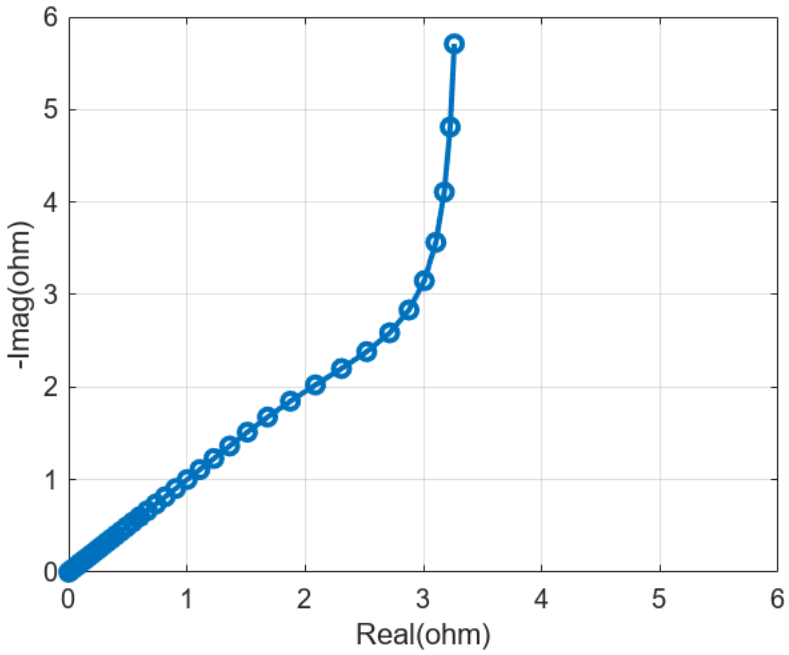
```
f=logspace(-2,6,91);
w=2*pi*f;
Zw_example=Zw(w,"sigma",10);
plot_EIS(w,Zw_example,"Bode","on")
```

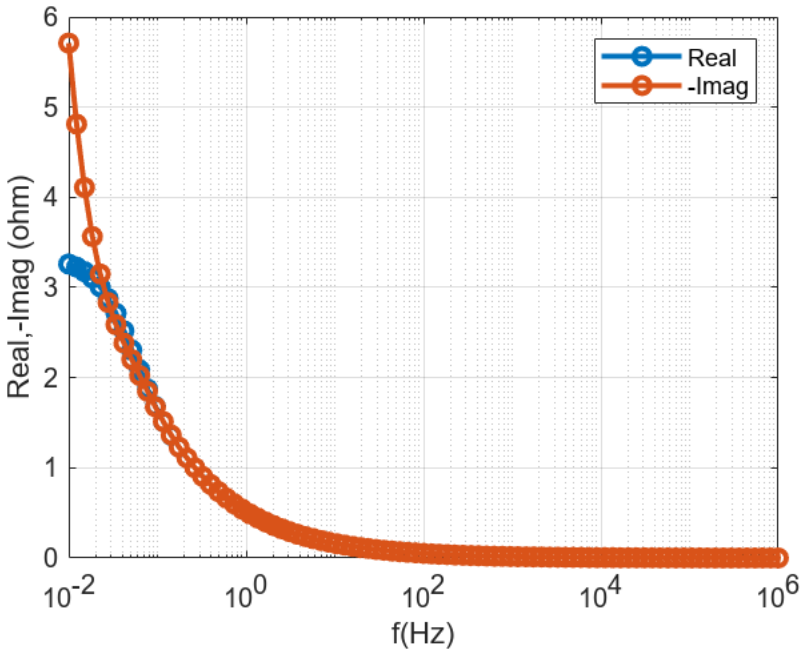



**10.有限空间扩散阻抗 ZT**

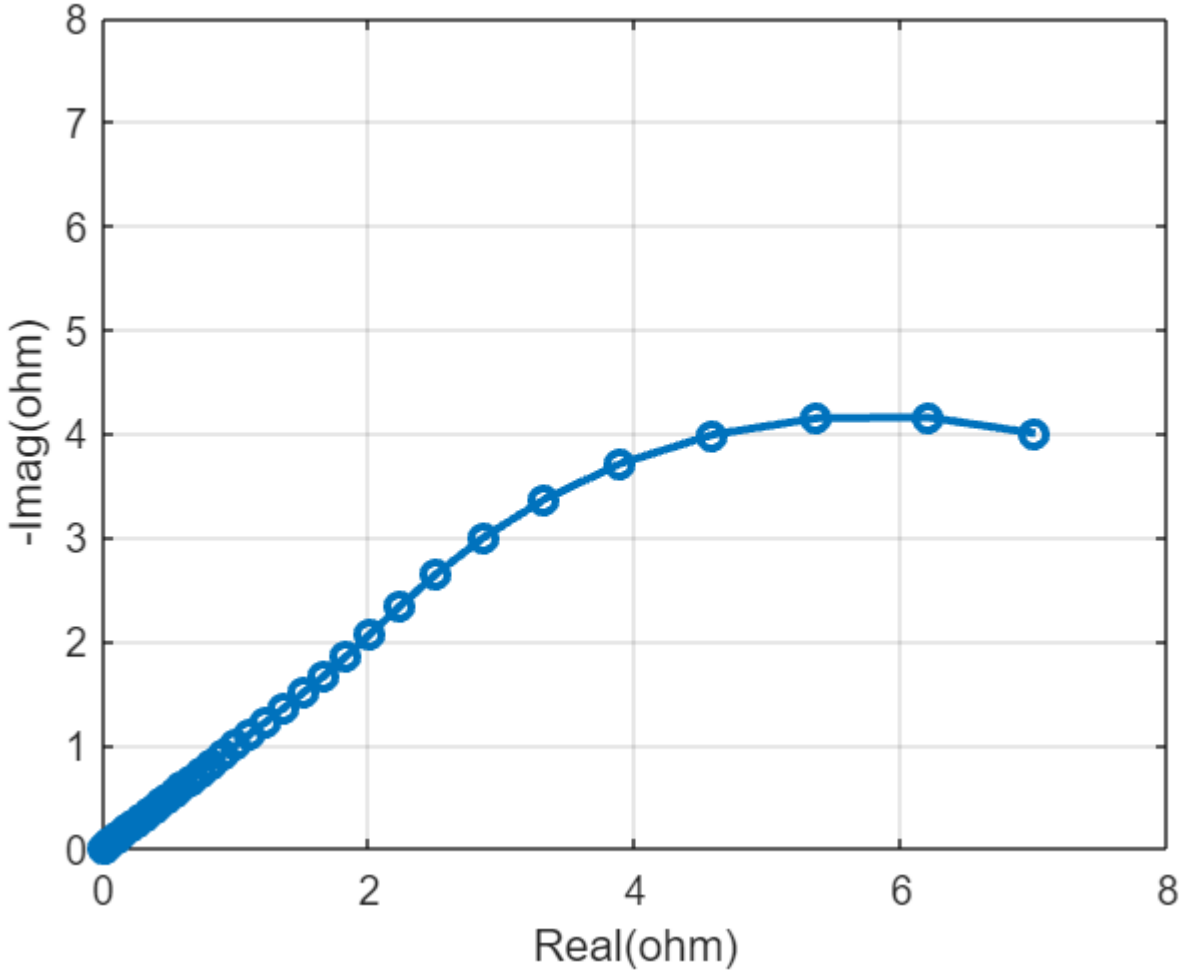
```
f=logspace(-2,6,91);
w=2*pi*f;
ZT_example=ZT(w,"Rw",10,"tau",30,"n_w",0.5);
plot_EIS(w,ZT_example,"Bode","on","xlim_switch",'on')
```

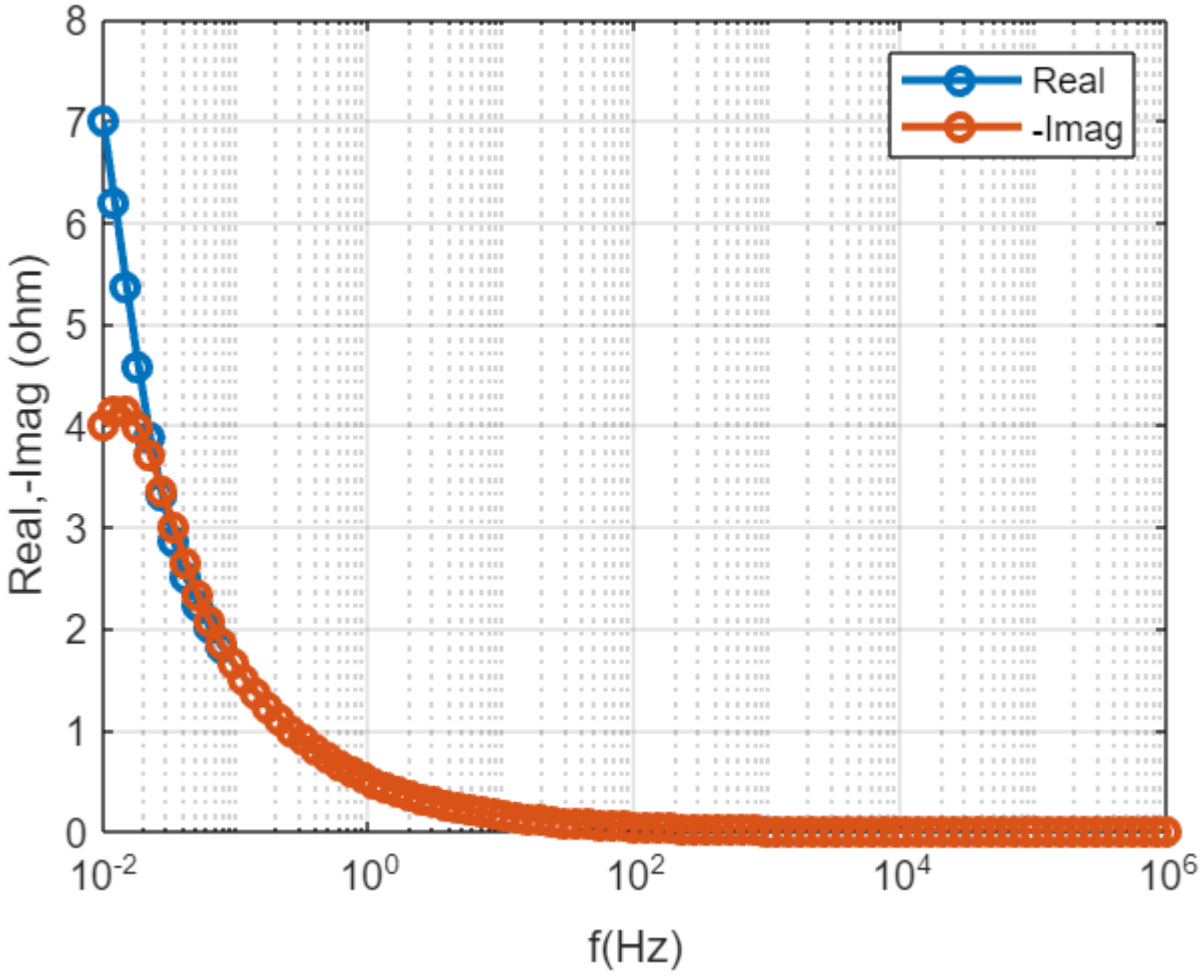



**11.有限长度扩散阻抗**

```
f=logspace(-2,6,91);
w=2*pi*f;
Zo_example=Zo(w,"Rw",10,"tau",30,"n_w",0.5);
plot_EIS(w,Zo_example,"Bode","on","xlim_switch",'on')
```

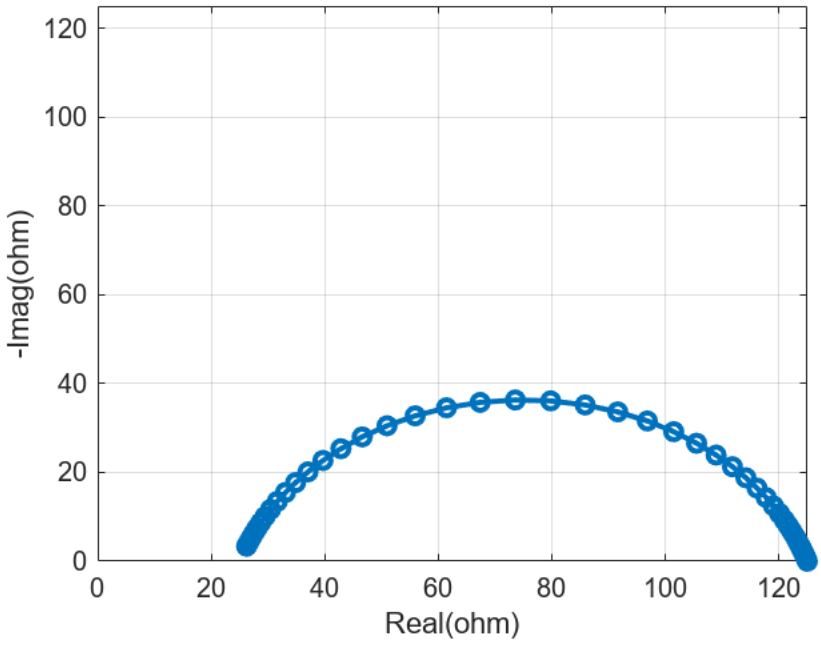

-Imag(ohm)
Real(ohm)
0
1
2
3
4
5
6
7
8
0
2
4
6
8

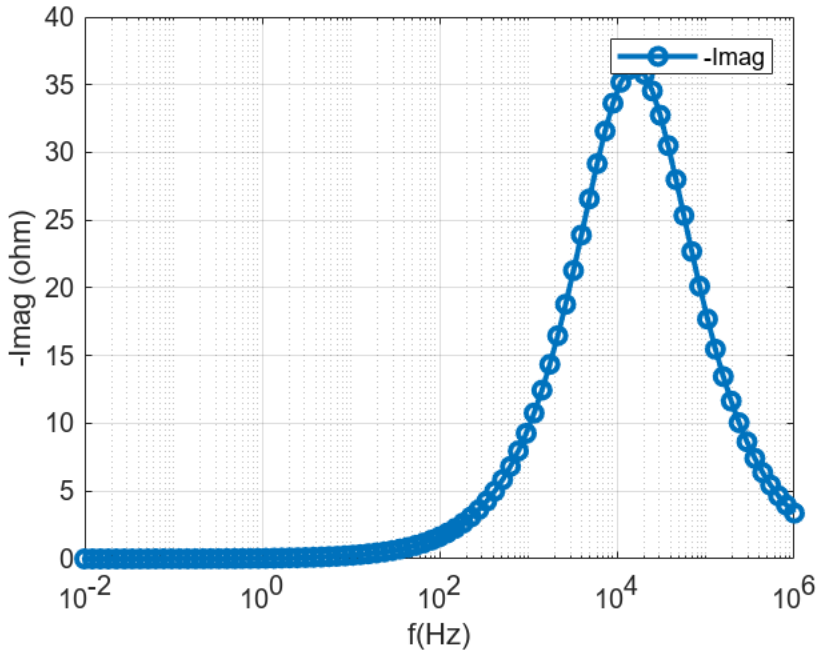



## 使用函数句柄组成复杂电路

### 1.Rs-RQ(Randles)

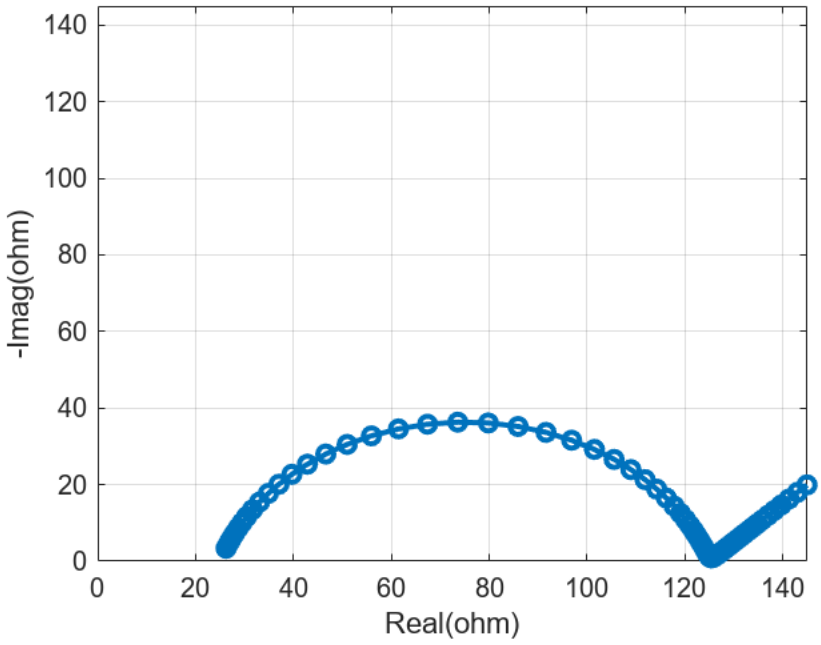
```
f=logspace(-2,6,91);
w=2*pi*f;
Z1=@(w,R0) R(w,'R',R0);
Z_RQ=@(w,R1,Q1,n) RQ(w,'R', R1, 'Q', Q1,'n',n);
Z_Randles=@(w,R0,R1,Q1,n) Z1(w,R0)+Z_RQ(w,R1,Q1,n);
Z_Randles_example=Z_Randles(w,25,100,10^-6,0.8);
plot_EIS(w,Z_Randles_example,"Bode","imag","xlim_switch",'on')
```



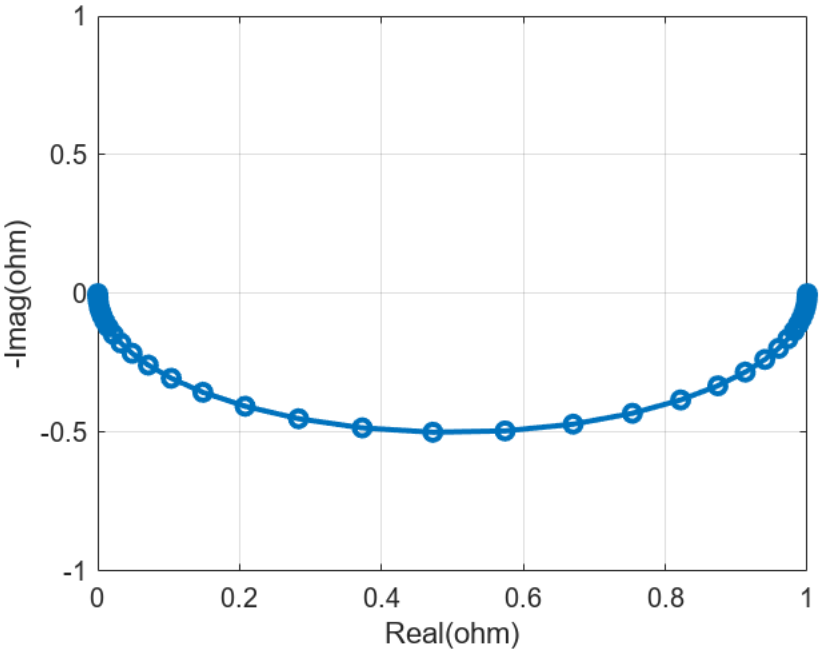

**2.Rs-RQ-Zw**

```
f=logspace(-2,6,91);
w=2*pi*f;
Z1=@(w,R0) R(w,'R',R0);
Z_RQ=@(w,R1,Q1,n) RQ(w,'R', R1, 'Q', Q1,'n',n);
Z_W=@(w,sigma) Zw(w,"sigma",sigma);
Z_Randles=@(w,R0,R1,Q1,n,sigma) Z1(w,R0)+Z_RQ(w,R1,Q1,n)+Z_W(w,sigma);%各部分串联，使用加和
Z_Randles_example2=Z_Randles(w,25,100,10^-6,0.8,5);
plot_EIS(w,Z_Randles_example2,"xlim_switch",'on')
```




### 3. RL

```
f=logspace(-2,6,91);
w=2*pi*f;
Z_R=@(w,R0) R(w,'R',R0);
Z_L=@(w,L1) L(w,"L",L1);
Z_RL=@(w,R0,L1) 1./(1./Z_R(w,R0)+1./Z_L(w,L1));%并联，使用导纳加和
plot_EIS(w,Z_RL(w,1,1e-3),"xlim_switch",'on')
```

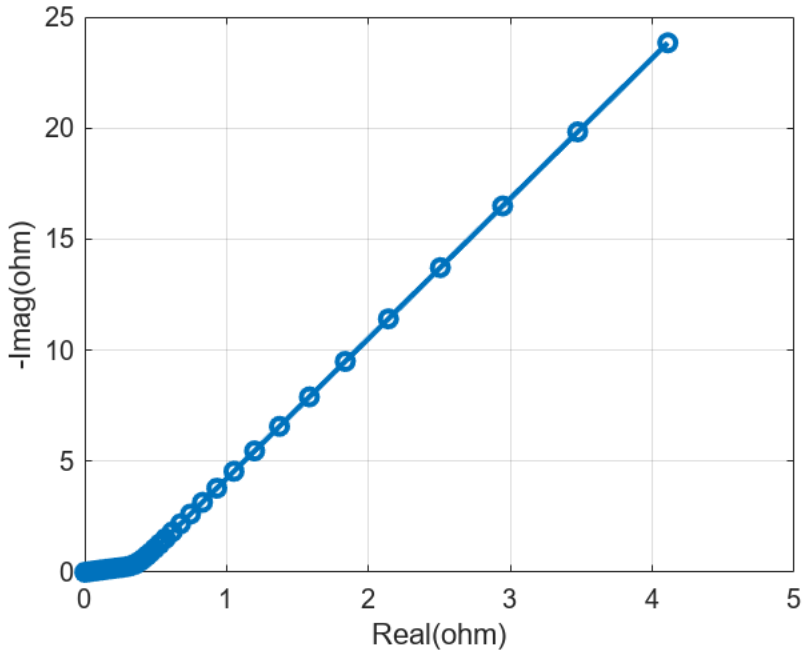


# 电路参数拟合

**案例 1:-TLMs-**

**step1:使用函数句柄定义电路，以 TLMs 为例**

```
f=logspace(-2,6,91);
w=2*pi*f;

Z_interface=@(w,Q_interf,n_interf) Q(w,"Q",Q_interf,"n",n_interf);%界面阻抗表达式，采用 Q 回路表示
Z_tlms=@(w,L,Ri,Q_interf,n_interf) TLM(w,"L",L,"Ri",Ri,"Zt",Z_interface(w,Q_interf,n_interf));
%定义待拟合电路，待拟合参数向量化
sim_circuit=@(param)Z_tlms(w,param(1),param(2),param(3),param(4));

%准备实验数据
Z_tlms_example=Z_tlms(w,0.1,10,5,0.9);
plot_EIS(w,Z_tlms_example,"Bode","off")
```




**step2:使用 fit_EIS 进行拟合**

```
help fit_EIS
```

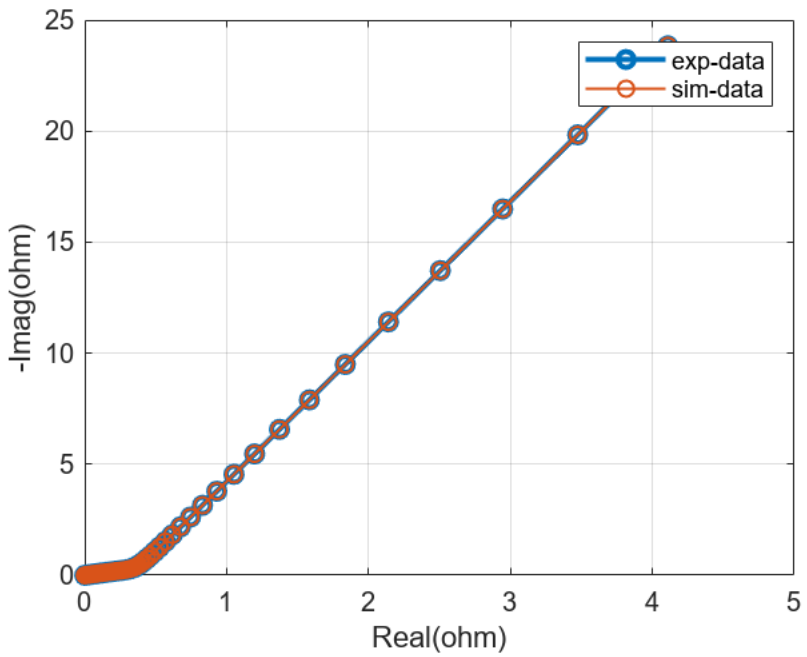
```
Return the circuit paramter value and erros
Inputs
---------------
 w:= Angular frequency [1/s]
 exp_data:a complex matrix size:(1*length(w))
 sim_circuit:object circuit function handle
 param_0: the inital of circuit parameter,size:(1:N)
 options:is a structure with fields:
 method:slover method,the default is 'fminunc';Include:'lsqnonlin','fminunc','fmincon','pso'
 ub:the upper of circuit paramter, size:(1:N)
```

```
lb:the lower of circuit paramter, size:(1:N)
error_type:The type of error function to calculate,the default is 'Chi-2';Include:'Chi-2','RMSE'
```

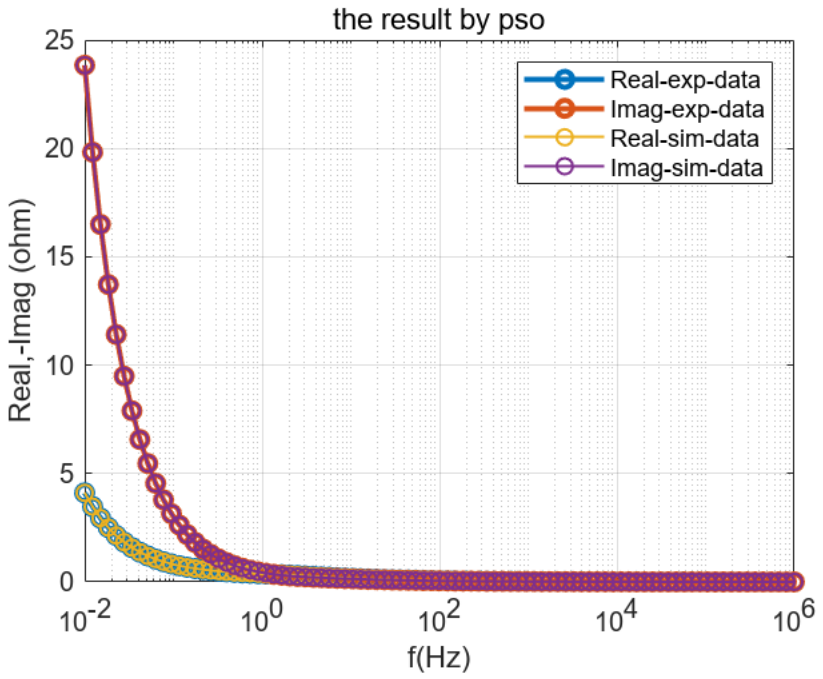
```
%设置待辨识参数上下界
param_0=[0.1,5,2,0.75];
lb=0.1*param_0;lb(end)=0.5;lb(1)=0.99*param_0(1);
ub=10*param_0;ub(end)=1;ub(1)=1.01*param_0(1);

%pso 求解,需提供上下界
[x,fav]=fit_EIS(w,Z_tlms_example,sim_circuit,[],'method','pso','lb',lb,'ub',ub)
```

```
Optimization ended: relative change in the objective value
over the last OPTIONS.MaxStallIterations iterations is less than OPTIONS.FunctionTolerance.
x = 1×4
    0.1000   10.0017    5.0008    0.9000
fav = 3.4623e-13
```

```
%绘制结果
% plot_EIS(w,sim_circuit(x))
% hold on
% plot(real(Z_tlms_example),-imag(Z_tlms_example),'-o','DisplayName','exp'),legend({'sim','exp
plot_fit_result(w,Z_tlms_example,sim_circuit,x,"Nyquist",'on','Bode','on')
```



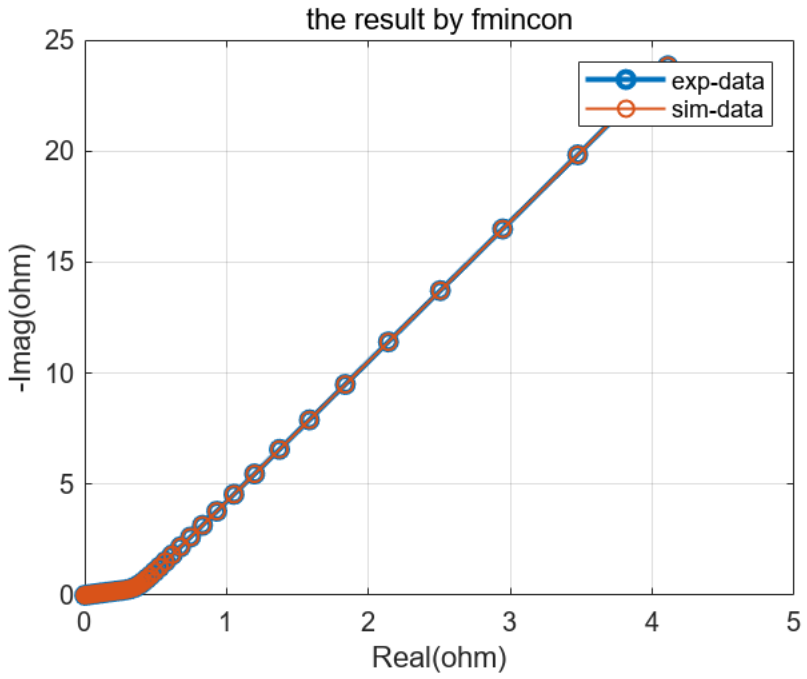

```
title('the result by pso')
```




```
%'fmincon'求解,需要提供猜测初始值与上下界
[x,fav]=fit_EIS(w,Z_tlms_example,sim_circuit,param_0,'method','fmincon','lb',lb,'ub',ub)
```

```
Local minimum possible. Constraints satisfied.

fmincon stopped because the size of the current step is less than
the value of the step size tolerance and constraints are
satisfied to within the value of the constraint tolerance.

<stopping criteria details>
x = 1×4
    0.1000   10.0008    5.0004    0.9000
fav = 1.8166e-13
```

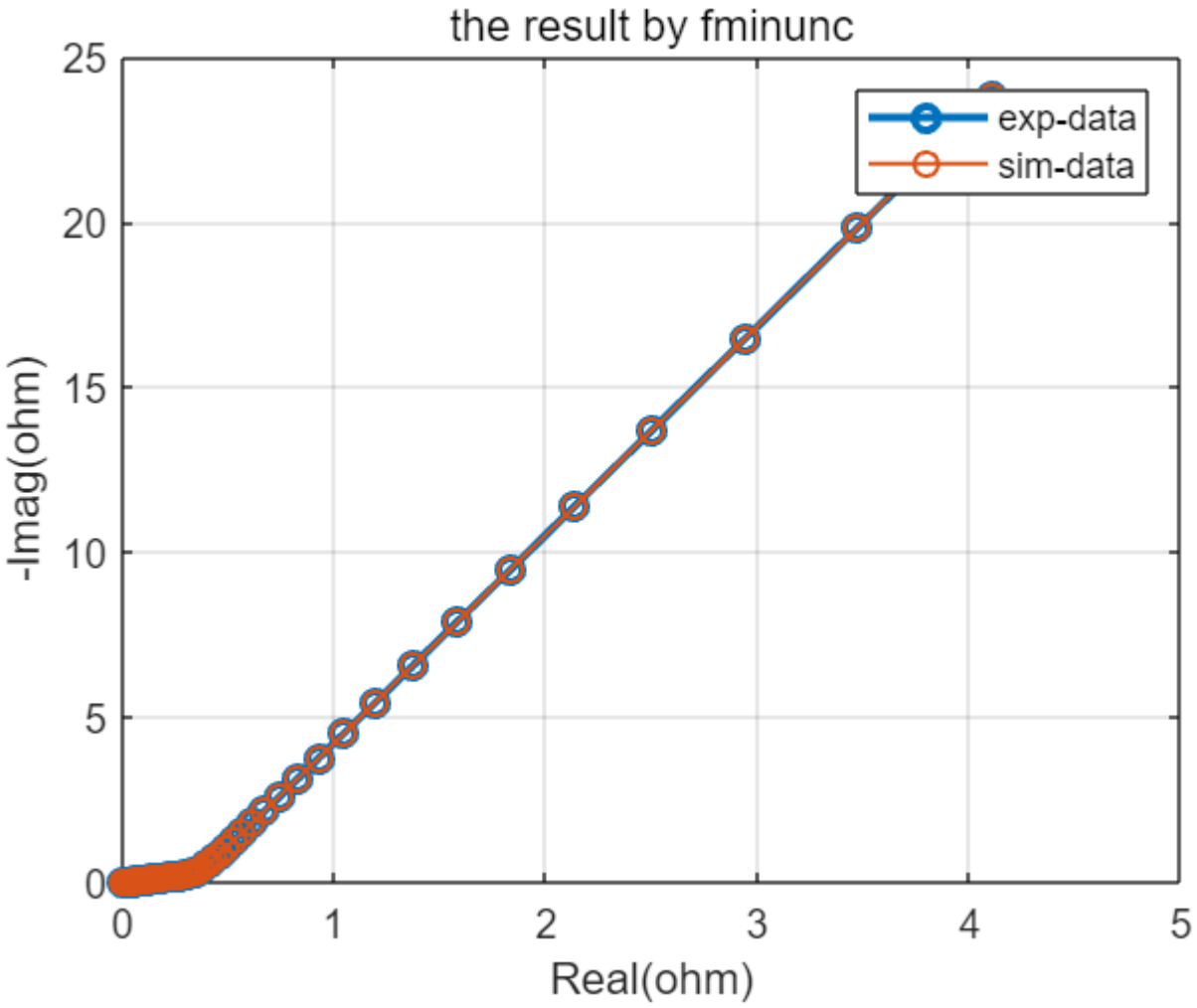
```
%绘制结果
plot_fit_result(w,Z_tlms_example,sim_circuit,x)
title('the result by fmincon')
```




```
%'fminucn'求解,需要提供猜测初始值
[x,fav]=fit_EIS(w,Z_tlms_example,sim_circuit,param_0,'method','fminunc')
```

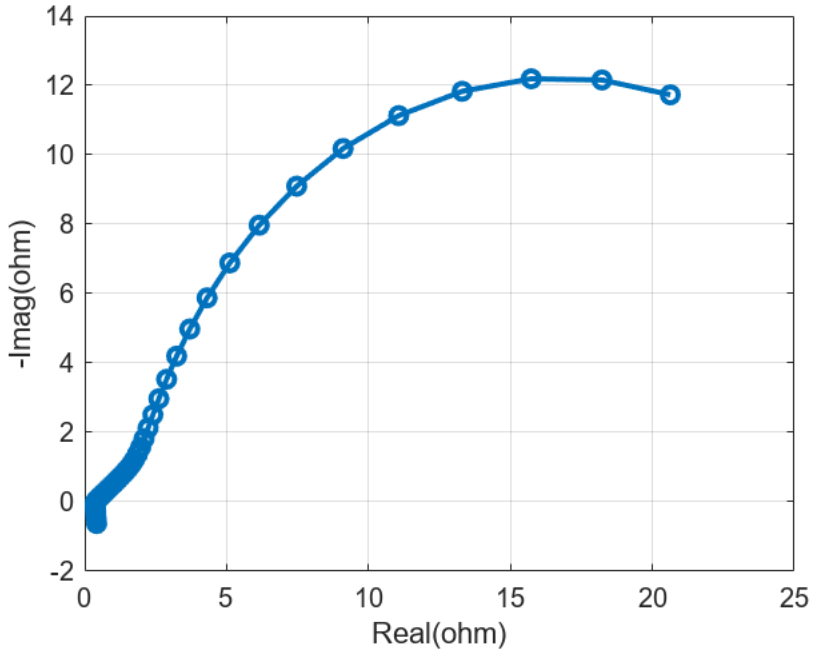
```
Local minimum found.

Optimization completed because the size of the gradient is less than
the value of the optimality tolerance.

<stopping criteria details>
x = 1×4
    0.2072    4.8259    2.4130    0.9000
fav = 9.8210e-10
```

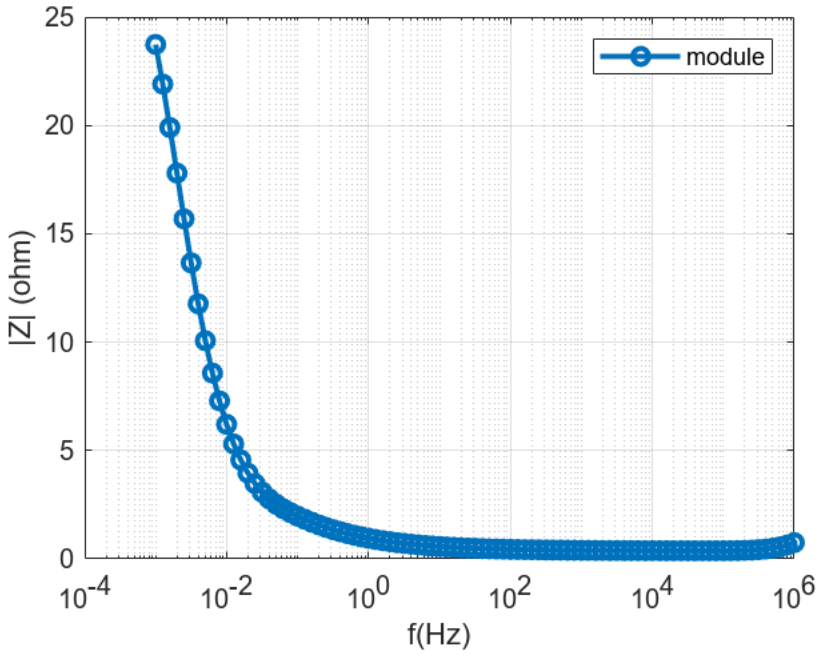
```
%绘制结果
plot_fit_result(w,Z_tlms_example,sim_circuit,x)
title('the result by fminunc')
```




**案例 2:-L-TLM-**

```
% 定义拟合电路
f=logspace(-3,6,91);
w=2*pi*f;
Z_L=@(w,L1) L(w,"L",L1);
Z_R=@(w,R1) R(w,"R",R1);
Z_interface=@(w,R_ct,Q_interf,n_interf) RQ(w,"R",R_ct,"Q",Q_interf,"n",n_interf);
Z_total=@(w,L1,R1,delta,Ri,Re,R_ct,Q_interf,n_interf) 1./(1./Z_L(w,L1)+1./Z_R(w,R1))...
    +TLM(w,"L",delta,"Ri",Ri,"Re",Re,"Zt",Z_interface(w,R_ct,Q_interf,n_interf));
sim_circuit=@(param) Z_total(w,param(1),param(2),param(3),param(4),param(5),param(6),param(7),p

%准备实验数据
Z_tlm_example=Z_total(w,1e-7,8,0.1,50,4,3,20,0.87);
plot_EIS(w,Z_tlm_example,"Bode","module")
```



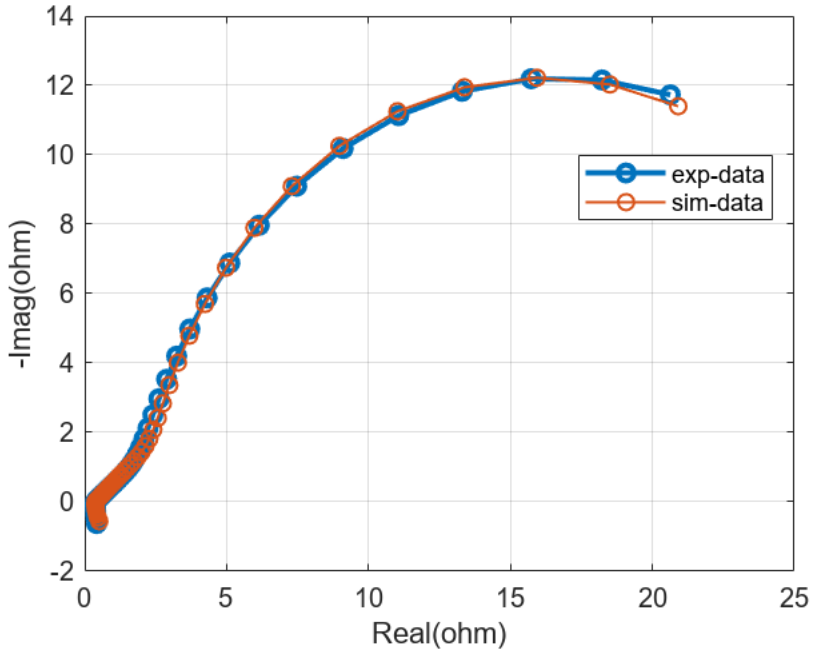

```
%猜测初始值，设置上下界
param_0=[0.6/(2*pi*10^6),0.5,0.1,60,0.6,5*0.1,1/(2*pi*0.01*5),0.75]
```

```
param_0 = 1×8
    0.0000    0.5000    0.1000   60.0000    0.6000    0.5000    3.1831    0.7500
```

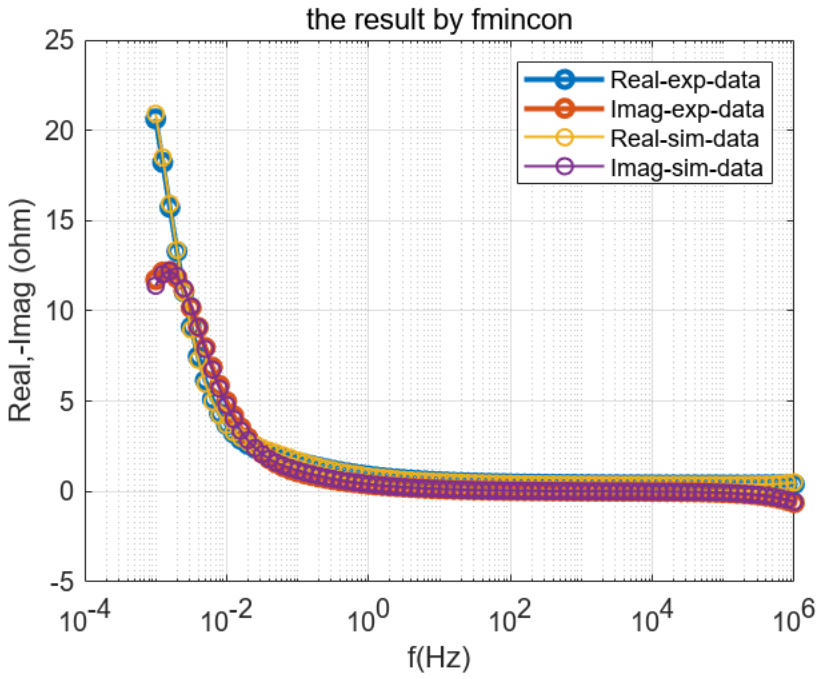
```
lb=0.01*param_0;
ub=100*param_0;
lb(3)=0.99*param_0(3);ub(3)=1.01*param_0(3);
lb(end)=0.5;ub(end)=1;
[x,fav]=fit_EIS(w,Z_tlm_example,sim_circuit,param_0,'method','fmincon','lb',lb,'ub',ub)
```

```
Local minimum found that satisfies the constraints.

Optimization completed because the objective function is non-decreasing in
feasible directions, to within the value of the optimality tolerance,
and constraints are satisfied to within the value of the constraint tolerance.

<stopping criteria details>
x = 1×8
    0.0000    2.3440    0.0999   64.4441    3.9394    2.7875   24.8421    0.9148
fav = 0.2015
```

```
%绘制拟合结果
plot_fit_result(w,Z_tlm_example,sim_circuit,x,"Nyquist",'on','Bode','on')
```

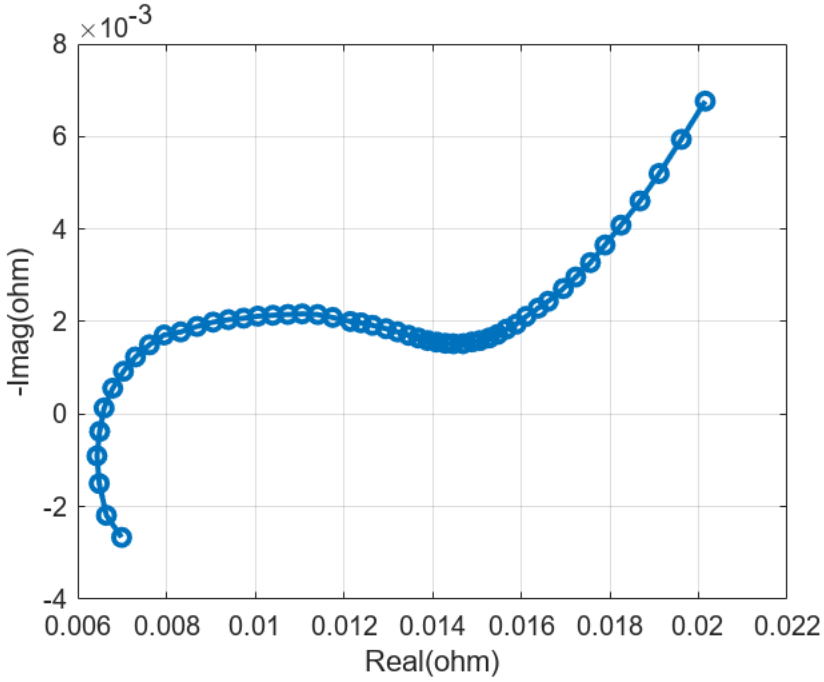


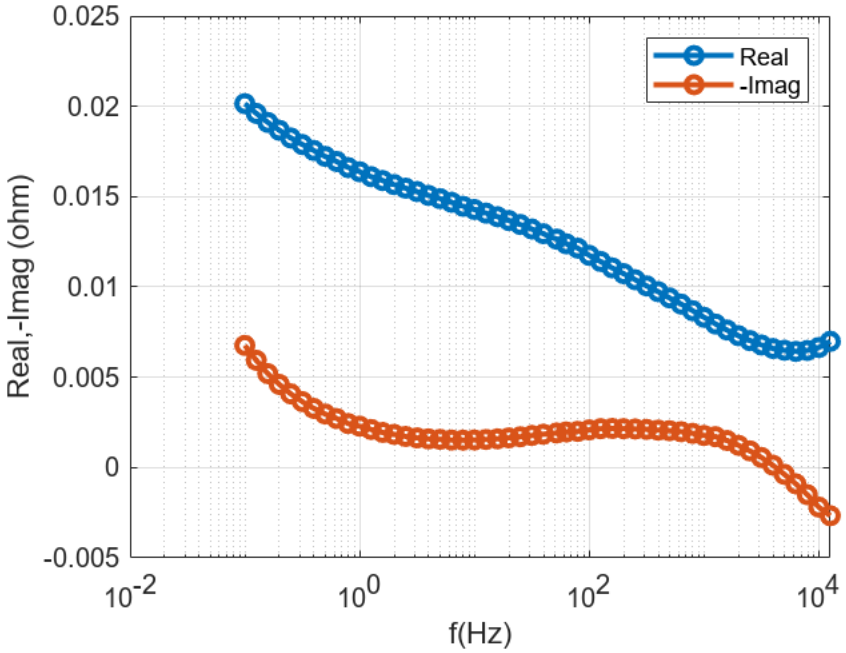

```
title('the result by fmincon')
```




**案例 3：-LRs-RQ-Wo-**

```
%导入实验数据并绘 Nyquist & Bode 图
raw_exp=readmatrix("EIS_data.xlsx");
star_index=10;
f=raw_exp(star_index:end,1);
w=2*pi*f;
exp_data=raw_exp(star_index:end,2)'+1j*(raw_exp(star_index:end,3)');
plot_EIS(w,exp_data,"Bode",'on')
```

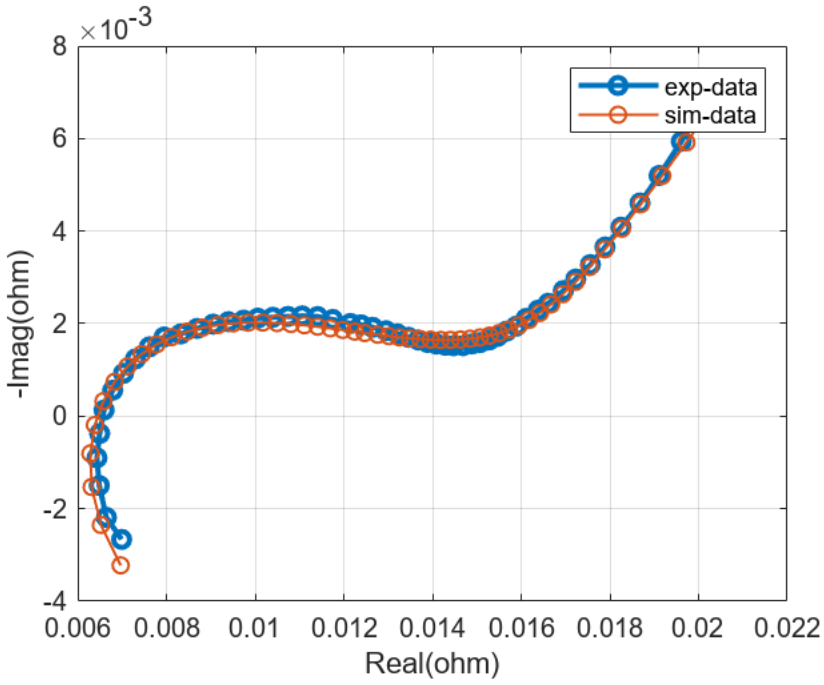


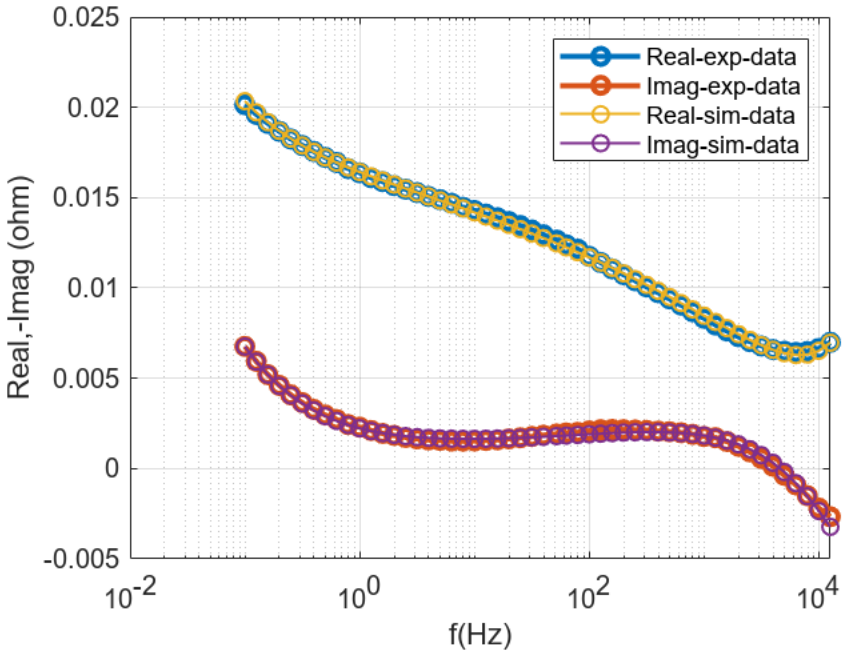



```
%使用函数句柄定义拟合电路
Z_R=@(w,R0) R(w,'R',R0);
Z_L=@(w,L1) L(w,"L",L1);
Z_RQ=@(w,R1,fs,n) RQ(w,'R', R1, 'fs', fs,'n',n);
Z_T=@(w,Rw,tau_w,n_w) ZT(w,"Rw",Rw,"tau",tau_w,"n_w",n_w);
Z_Randles=@(w,R0,L1,R1,fs,n,Rw,tau_w,n_w) 1./(1./Z_L(w,L1)+1./Z_R(w,R1))+Z_RQ(w,R1,fs,n)+Z_T(w,
sim_circuit=@(param) Z_Randles(w,param(1),param(2),param(3),param(4),param(5),param(6),param(7)

%设置待拟合参数的上下界
param_0=[6e-5,0.0026/(2*pi*12590),0.008,300,0.8,0.005,100,0.8];
lb=0.01*param_0;
ub=10*param_0;
lb(4)=100;ub(4)=2000;
lb(5)=0.1;ub(5)=1;
lb(end)=0.1;ub(end)=0.5;

%求解与绘制结果
[x,fav]=fit_EIS(w,exp_data,sim_circuit,param_0,'method','pso','lb',lb,'ub',ub)
```

```
Optimization ended: number of iterations exceeded OPTIONS.MaxIterations.
x = 1×8
10^3 ×
    0.0000    0.0000    0.0000    1.9987    0.0004    0.0000    0.0012    0.0003
fav = 1.5769e-04
```

```
plot_fit_result(w,exp_data,sim_circuit,x,"xlim_switch",'off','Bode','on')
```


×10^-3
8
6
4
2
0
-2
-4
-Imag(ohm)
0.006
0.008
0.01
0.012
0.014
0.016
0.018
0.02
0.022
Real(ohm)
exp-data
sim-data


0.025
0.02
0.015
0.01
0.005
0
-0.005
Real,-Imag (ohm)
10^-2
10^0
10^2
10^4
f(Hz)
Real-exp-data
Imag-exp-data
Real-sim-data
Imag-sim-data