In[1]:=
```
Clear["Global`*"];
```

L1 = comprimento do guia de onda injetor;
L2 = comprimento do guia de onda receptor;
ax =maior dimensão transversal do guia operando na banda-x;
a= maior dimensão transversal do guia injetor e receptor;
ϵa=permitividade analítica do material dentro do guia;
μa=permeabilidade analítica do material dentro do guia

In[2]:=
```
L1 = 5.05 × 10^-3 ; L2 = 0.0 × 10^-3; mi0 = 4 π 10^-7; aX = 22.85 10^-3;
d = 10.0 10^-3
```

Out[2]=
```
0.01
```

IMPORT DATA

In[3]:=
```
Sdata =
  Import[
   "C:\\Documents and
     Settings\\user\\Desktop\\PROGRAMA_BARROSO\Dados.txt",
   "Table"];
```

```
C : \ Documents and Settings \ user \ Desktop \ teste
```

In[4]:=
```
f[i_] := Sdata[[i]][[1]] / 10^9
```

In[5]:=
```
f[1]
```

Out[5]=
```
8.21575
```

In[6]:=
```
S11re[i_] := Sdata[[i]][[2]];
S11im[i_] := Sdata[[i]][[3]];
S21re[i_] := Sdata[[i]][[4]];
S21im[i_] := Sdata[[i]][[5]];
```

In[10]:=
```
S11im[20]
```

Out[10]=
```
0.221202
```

In[11]:=
```
S21im[20]
```

Out[11]=
```
-0.802345
```

In[12]:=
```
S11a[i_] := S11re[i] + i S11im[i]
S21a[i_] := S21re[i] + i S21im[i]
```

In[14]:=
```
S21a[75]
```

Out[14]=
```
-0.423151 - 0.785058 i
```

In[15]:=
```
λ0D[i_] := 2.998 × 10^8 / (f[i] * 10^9);
fc = 4.3 10^9;
fcX = 6.56 × 10^9;
λcD = 2.998 × 10^8 / fc;
λcDX = 2.998 × 10^8 / fcX;
λc = 2 aX;
```

In[21]:=
```
{λcDX, λc, λ0D[201]}
```

Out[21]=
```
{0.0457012, 0.0457, 0.0323557}
```

gama0 -> constante de propagação da onda TE10 no guia de onda injetor e receptor vazios;
gama0x -> constante de propagação da onda TE10 no guia de onda da banda x vazio

In[22]:=
```
gama0X[i_] := i 2 π √((1. / λ0D[i]^2 - 1 / λcDX^2));
```

In[23]:=
```
ϵa = 2.04 + i 0.0 ; μa = 1 + i 0.0;
```

In[24]:=
```
gamaX[i_] := i 2 π / λ0D[i] √(ϵa * μa - λ0D[i]^2 / λcDX^2)
```

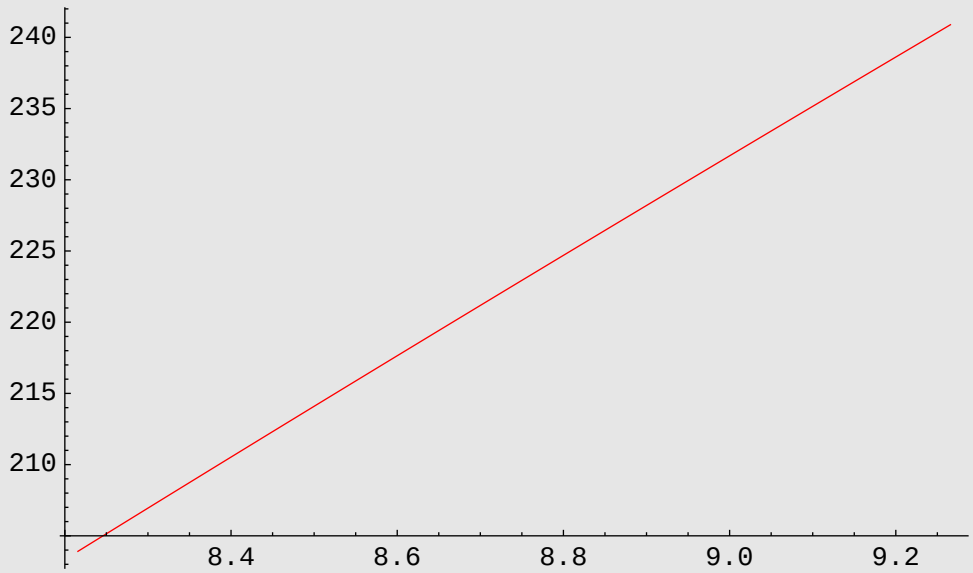
In[25]:=
$$\frac{i\,2\,\pi}{\lambda 0D[10]}\sqrt{\left(\epsilon a * \mu a - \frac{\lambda 0D[10]^2}{\lambda cDX^2}\right)}$$

Out[25]=
```
0. + 205.614 i
```

In[26]:=
```
grafgamaXi = Table[{f[i], Im[gamaX[i]] }, {i, 1, 201}];
```

In[27]:=
```
Plotgama0Xi = ListPlot[grafgamaXi,
  PlotStyle → {PointSize[0.01], RGBColor[1, 0, 0]}, Joined → True,
  PlotRange → All ]
```

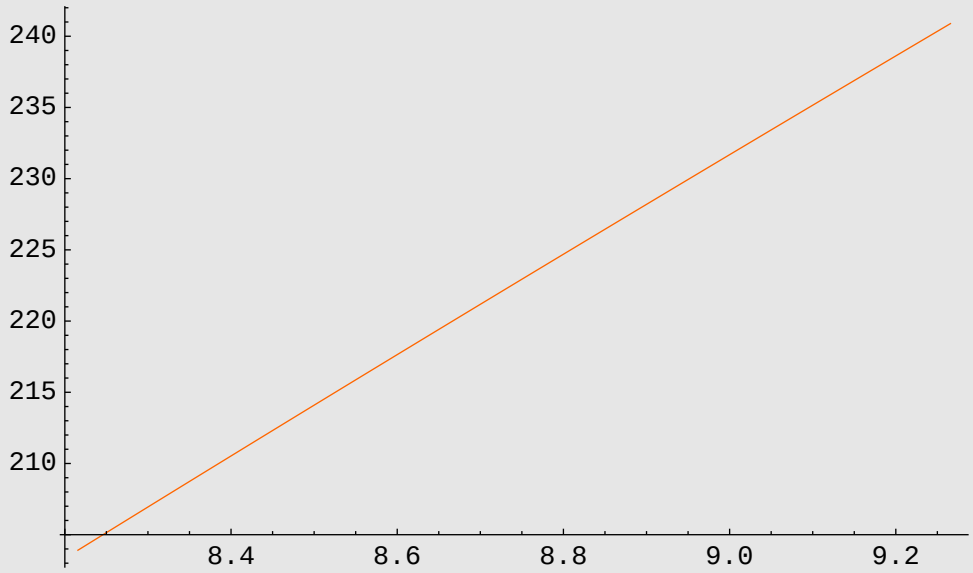
Out[27]=



In[28]:=
```
grafgamaXr = Table[{f[i], Im[gamaX[i]] }, {i, 1, 201}];
```

In[29]:=
```
PlotgamaXr = ListPlot[grafgamaXr,
  PlotStyle → {PointSize[0.01], RGBColor[1, 0.4, 0]}, Joined → True,
  PlotRange → All ]
```

Out[29]=



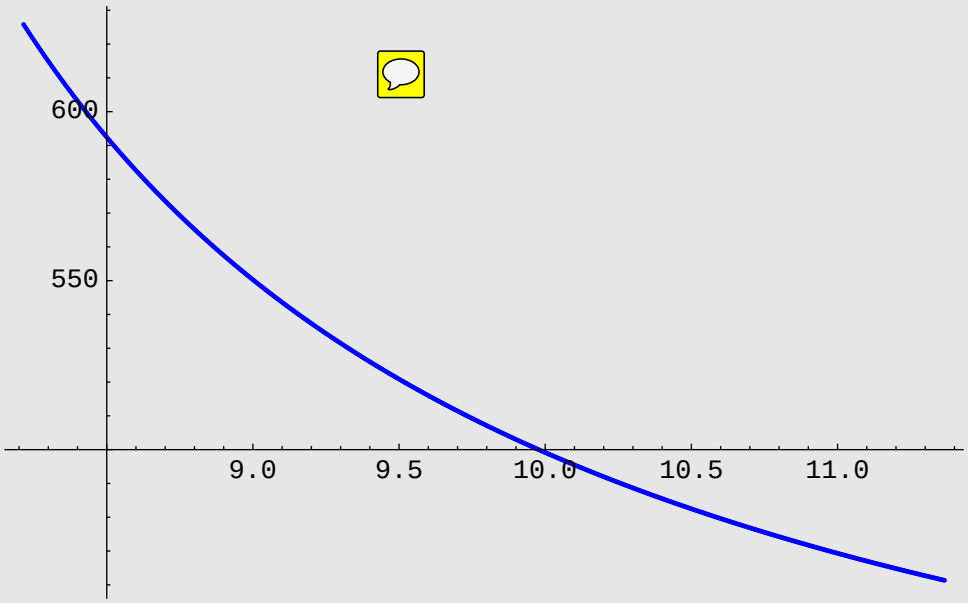
In[30]:=
```
Z0anlt[i_] := ⅈ * mi0 * 2 π f[i] * 10^9 / gama0X[i]
```

In[31]:=
```
Z0anlt[5]
```

Out[31]=
```
622.989
```

In[32]:=
```
Zanlt = ListPlot[Table[{f[i], Re[Z0anlt[i]]}, {i, 1, 601}],
  PlotRange → All,
  PlotStyle → {PointSize[0.005], RGBColor[0, 0, 1]}]
```

Out[32]=




```
S11M[i_] := S11mag[i] * Exp[2 * Re[gama0X[i]] * L1];
S21M[i_] := S21mag[i] * Exp[2 * Re[gama0X[i]] * L1];
```

```
phS11M[i_] := phs11[i] - 2 * Im[gama0X[i]] * L1
```

```
phS21M[i_] := phs21[i] - 2 * Im[gama0X[i]] * L1
```

```
S11C[i_] := S11M[i] Exp[i phS11M[i]]
S21C[i_] := S21M[i] Exp[i phS21M[i]]
```

In[33]:=
```
S11C[i_] := S11a[i] Exp[2 * gama0X[i] * L1]
S21C[i_] := S21a[i] Exp[1 * gama0X[i] * L2] Exp[1 * gama0X[i] * L1]
```

In[35]:=
```
{S11a[200], S11C[200]}
```

Out[35]=
```
{-0.249986 + 0.250238 i, -0.292395 - 0.19904 i}
```

In[36]:=
```
phS11C[i_] := 1/π ArcTan[Re[S11C[i]], Im[S11C[i]]] * 180
```

```
phS11x[i_] := 1/π ArcTan[Im[S11C[i]] / Re[S11C[i]]] * 180
```

In[37]:=
```
phS21C[i_] := 1/π ArcTan[Re[S21C[i]], Im[S21C[i]]] * 180
```

In[38]:=
```
phS11C[1]
```

Out[38]=
```
-143.495
```

In[39]:=
```
phS21C[1]
```

Out[39]=
```
-80.6833
```

In[40]:=
```
graf11m = Table[{f[i], Abs[S11C[i]] }, {i, 1, 745}];
```

In[41]:=
```
graf11ph = Table[{f[i], phS11C[i] }, {i, 1, 745}];
```

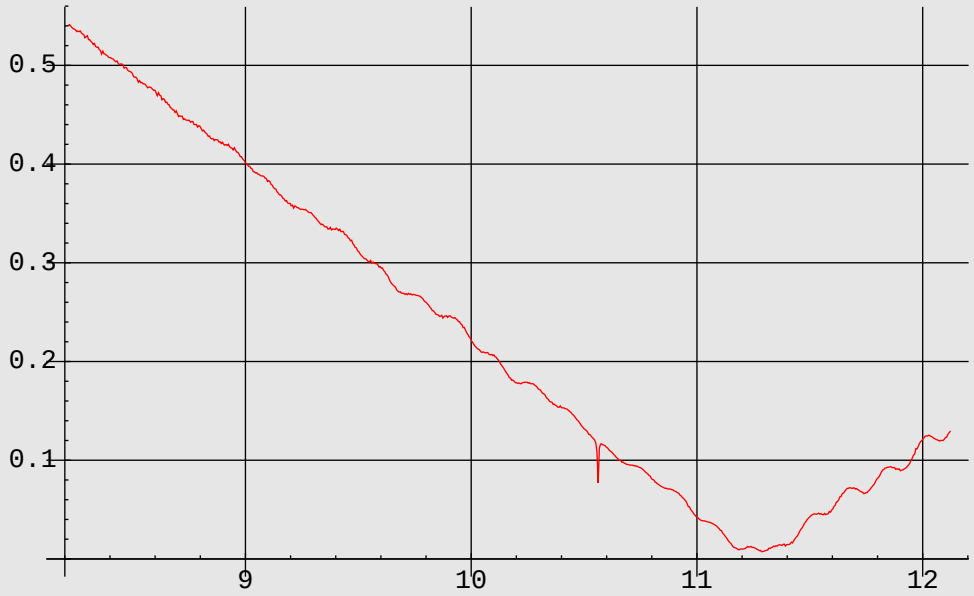
In[42]:=
```
graf21ph = Table[{f[i], phS21C[i]}, {i, 1, 745}];
```

In[43]:=
```
graf21m = Table[{f[i], Abs[S21C[i]] }, {i, 1, 745}];
```

```
Export[
  "C:\\Users\\Barroso\\Documents\\Miguel\\Results\\teflon\\3MagS11.
    dat", graf11m, "Table"];
```

In[44]:=
```
Mod11 = ListPlot[graf11m,
  PlotStyle → {PointSize[0.01], RGBColor[1, 0, 0]}, Joined → True,
  PlotRange → All , GridLines → Automatic,  AxesOrigin → {8.2, 0}]
```

Out[44]=

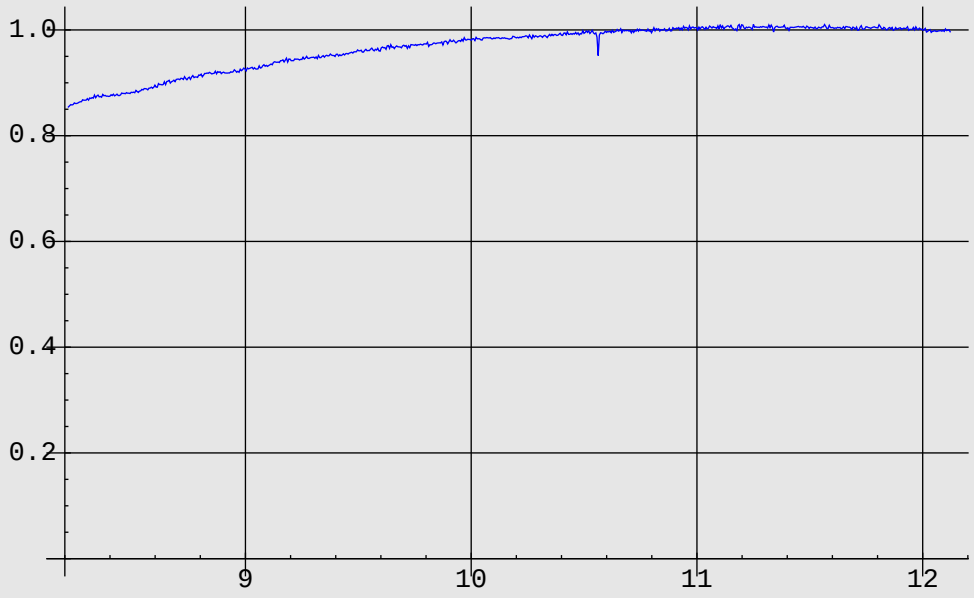


In[45]:=
```
{Abs[S11C[90]], Abs[S11a[90]]}
```

Out[45]=
```
{0.454858, 0.454858}
```

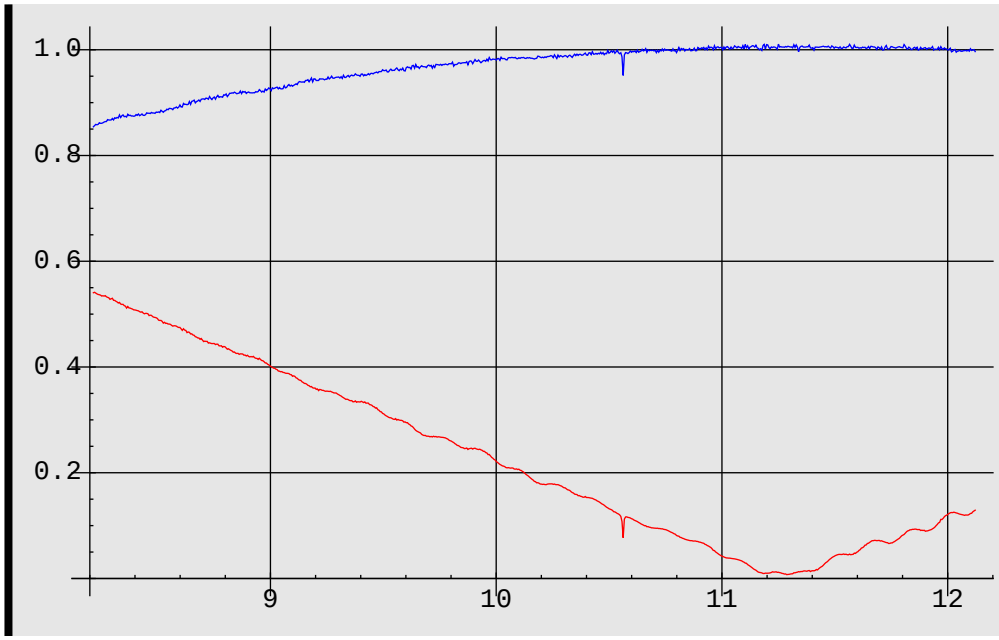
In[46]:=
```
Mod21 = ListPlot[graf21m,
  PlotStyle → {PointSize[0.01], RGBColor[0, 0, 1]}, Joined → True,
  PlotRange → All, GridLines → Automatic,  AxesOrigin → {8.2, 0}]
```

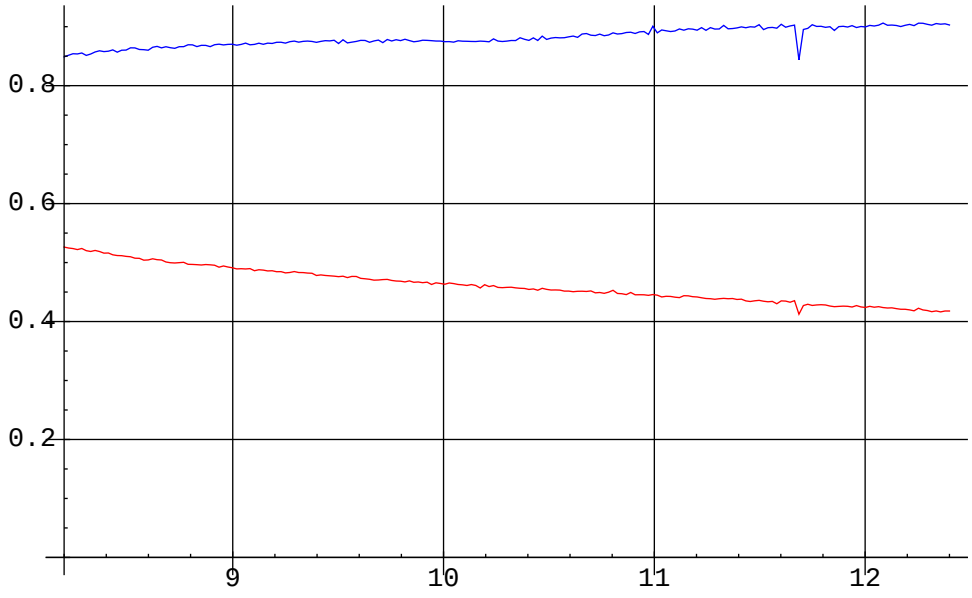
Out[46]=



In[47]:=
```
Show[{Mod11,Mod21}]
```

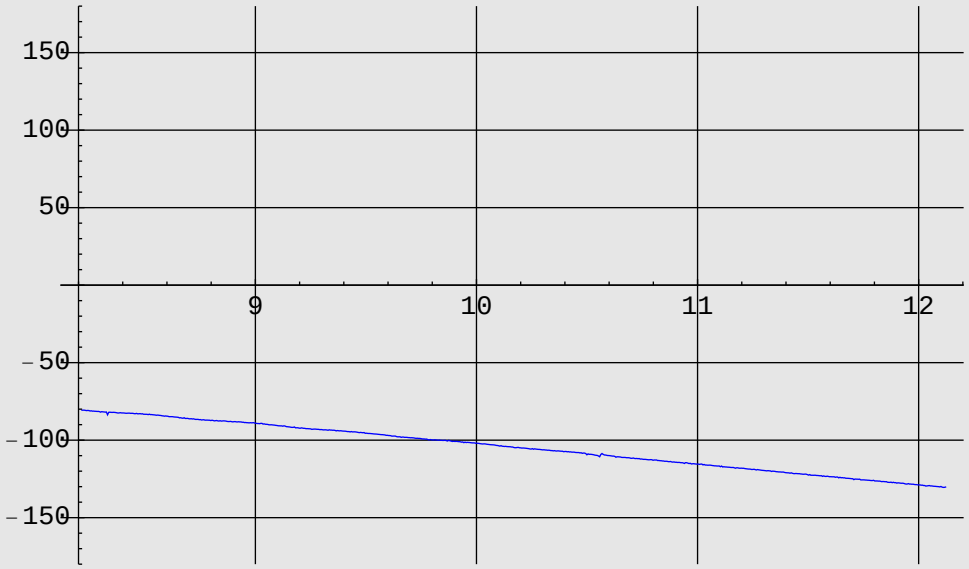
Out[47]=





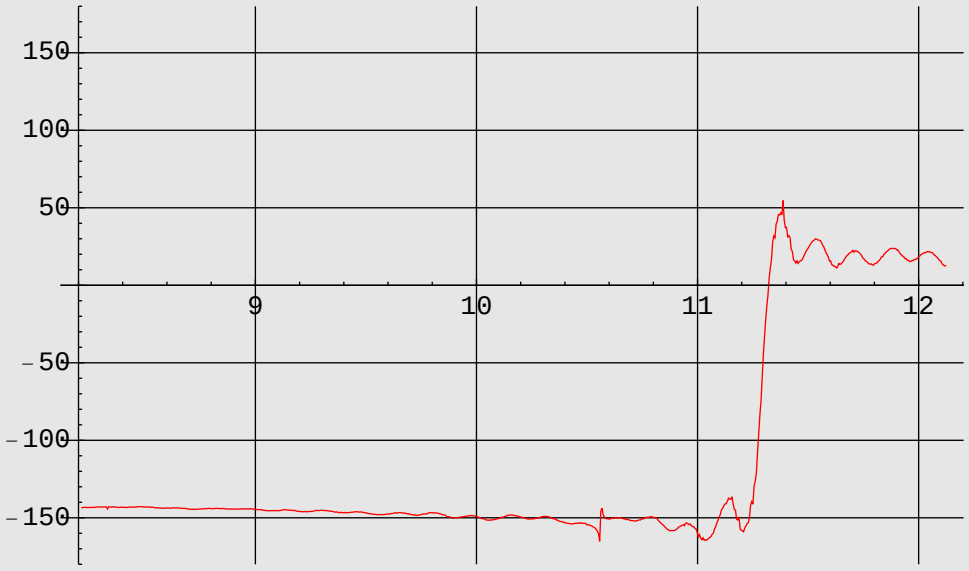
In[48]:=
```
Fase21 = ListPlot[graf21ph,
  PlotStyle → {PointSize[0.009], RGBColor[0, 0, 1]}, Joined → True,
  GridLines → Automatic,  AxesOrigin → {8.2, 0}, PlotRange → {-180, 180}]
```

Out[48]=



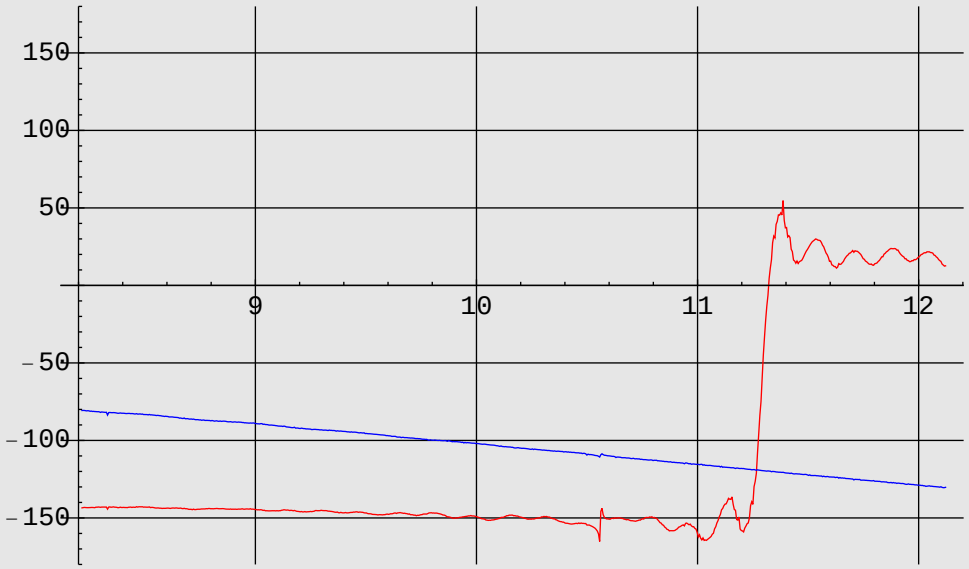
In[49]:=
```
Fase11 = ListPlot[graf11ph,
  PlotStyle → {PointSize[0.009], RGBColor[1, 0, 0]}, Joined → True,
  GridLines → Automatic,  AxesOrigin → {8.2, 0}, PlotRange → {-180, 180}]
```

Out[49]=



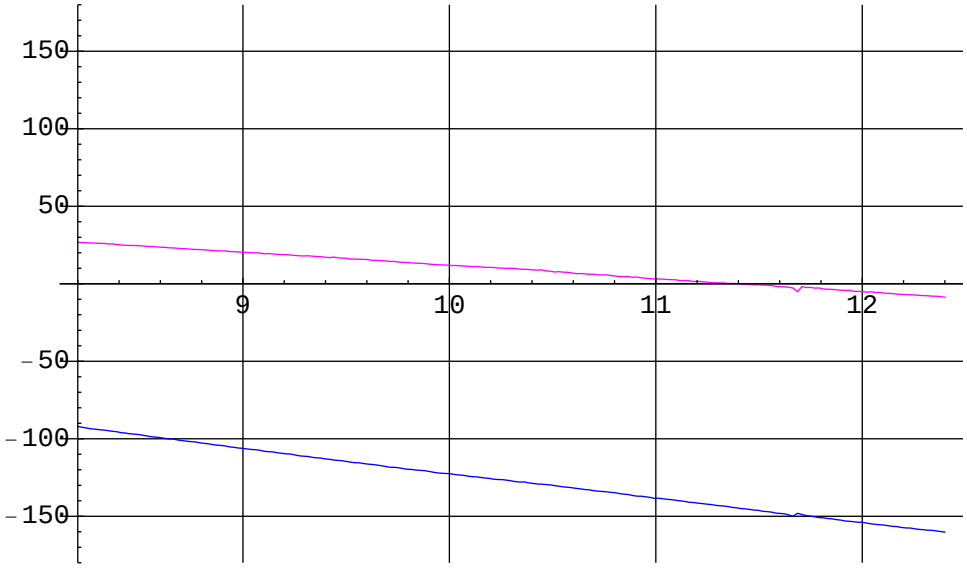
In[50]:=
```
Show[{Fase11, Fase21}]
```

Out[50]=



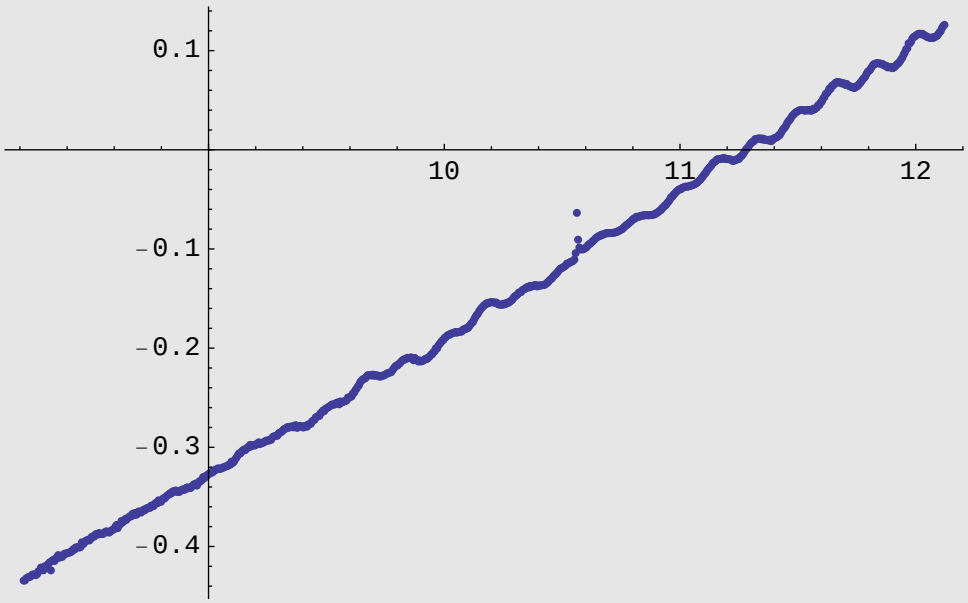
In[51]:=
```
{phS21C[1], phS11C[1]
}
```

Out[51]=
```
{−80.6833, −143.495}
```



In[52]:=
```
ListPlot[Table[{f[i], Re[S11C[i]]}, {i, 1, 745}]]
```

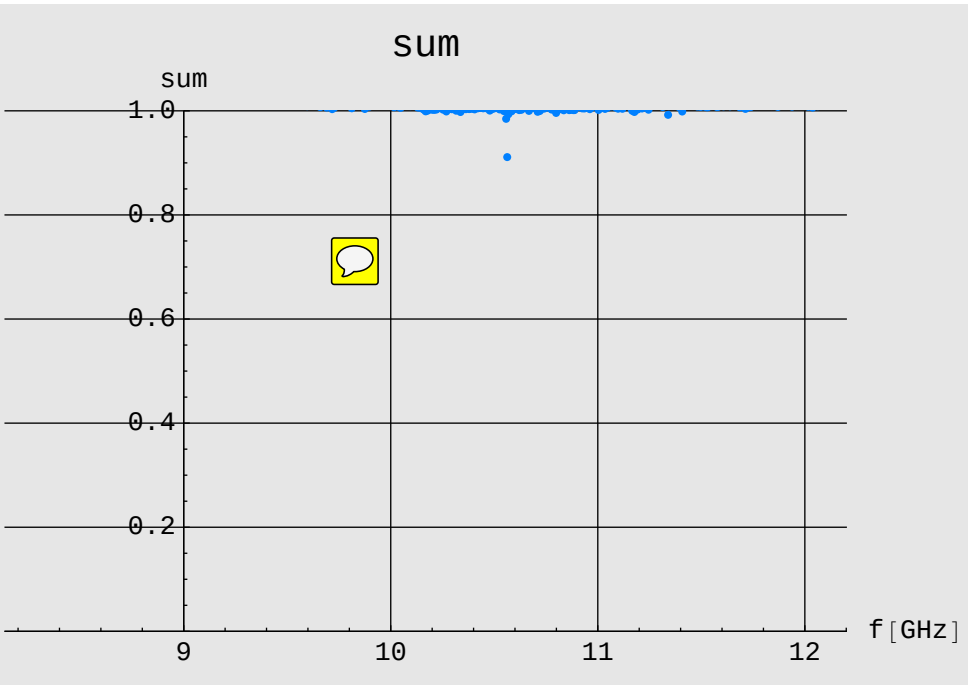
Out[52]=



In[53]:=
```
sum[i_] := Abs[S11C[i]]^2 + Abs[S21C[i]]^2
```

In[54]:=
```
soma = ListPlot[Table[{f[i], sum[i]}, {i, 1, 745}],
  PlotStyle → {AbsoluteThickness[1.5], RGBColor[0, 0.5, 1]},
  PlotLabel → "sum", AxesLabel → {"f[GHz]", "sum"},
  GridLines → Automatic, PlotRange → {0, 1}]
```

Out[54]=



IMPEDANCE

In[55]:=
$$Zb[i\_] := \sqrt{\frac{(1.0 + S11C[i])^2 - S21C[i]^2}{(1.0 - S11C[i])^2 - S21C[i]^2}}$$

In[56]:=
$$Zbanlt[i\_] := \frac{i * 2 * \pi * f[i] * 10^9 \, mi0 * \mu a}{gamaX[i]} \Big/ Z0anlt[i]$$

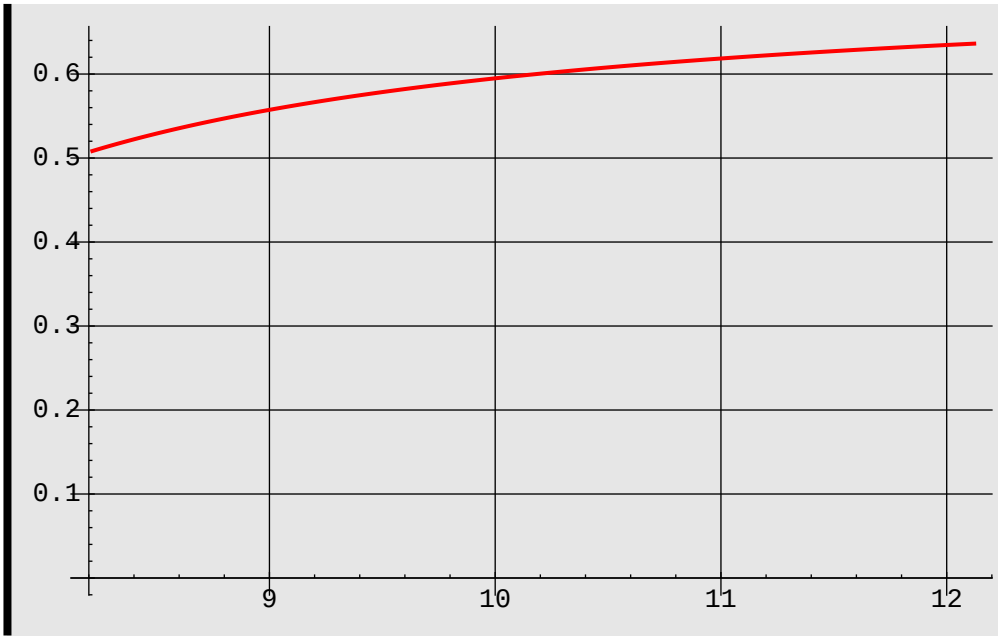
In[57]:=
```
Zanlt=Table[{f[i],Re[Zbanlt[i]]},{i,1,745}];
```

In[58]:=
```
Zbanlt[1]
```

Out[58]=
```
0.508371 + 0. i
```

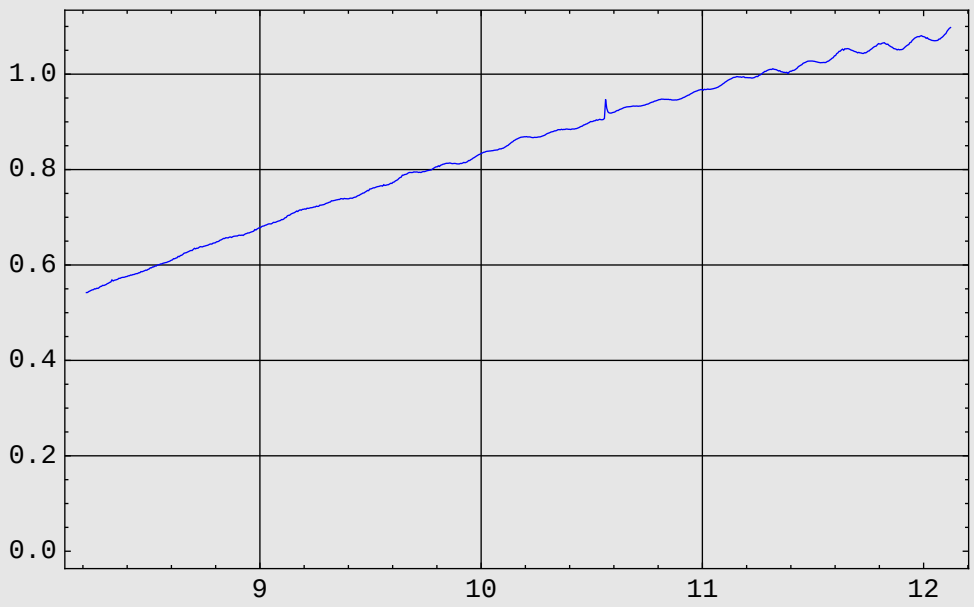
In[59]:=
```
ZbanltRe=ListPlot[Table[{f[i],Re[Zbanlt[i]]},{i,1,745}],
PlotStyle→{AbsoluteThickness[1.5],
    RGBColor[1,0,0]},Joined→True, PlotRange→All,
    GridLines → Automatic, AxesOrigin → {8.2, 0}]
```

Out[59]=



In[60]:=
```
ZbRe=ListPlot[Table[{f[i],Re[Zb[i]]},{i,1,745}],
PlotStyle→{PointSize[0.012],
    RGBColor[0,0,1]},Joined→True, PlotRange→All,
    GridLines → Automatic, AxesOrigin → {8.2, 0},Frame->True]
```

Out[60]=

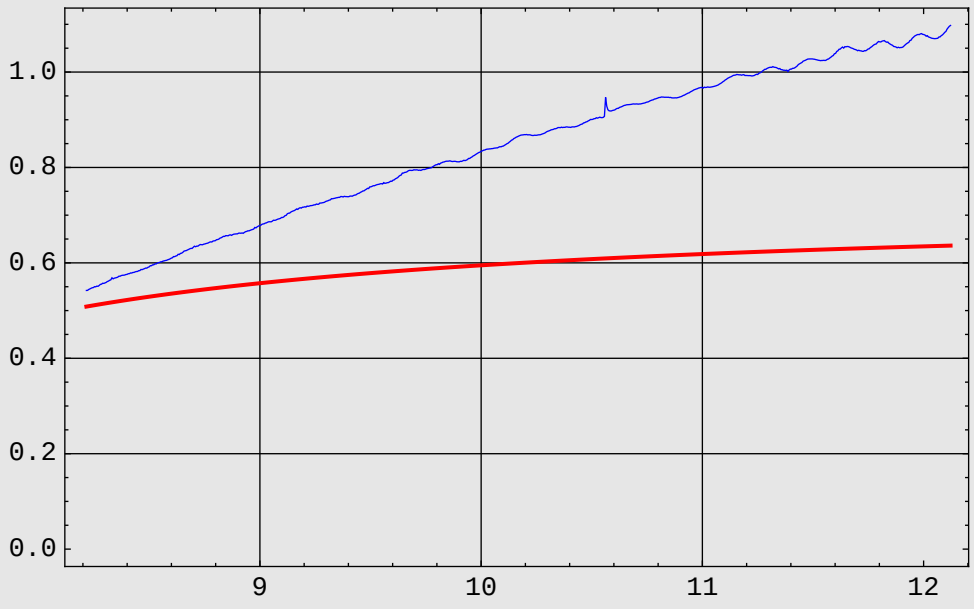


In[61]:=
```
Zbexp=Table[{f[i],Re[Zb[i]]},{i,1,745}];
```

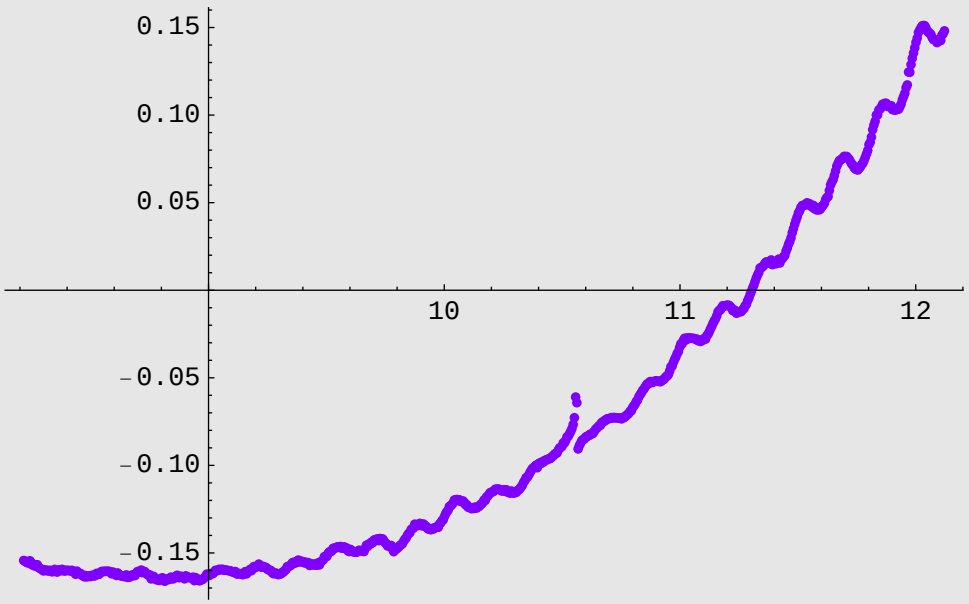
λG -> comprimento de onda guiado no guia de banda X

In[62]:=
```
Show[ZbRe, ZbanltRe]
```

Out[62]=



```
ZbIm=ListPlot[Table[{f[i],Im[Zb[i]]},{i,1,745}],
PlotStyle→{PointSize[0.01],
    RGBColor[0.5,0,1]},Joined→False, PlotRange→All]
```



S11 and 21 MAPPING

NRW Explicit Calculation

$$K[i\_] := \frac{S11C[i]^2 - S21C[i]^2 + 1.0}{2\,S11C[i]}$$

```
K[1]
```

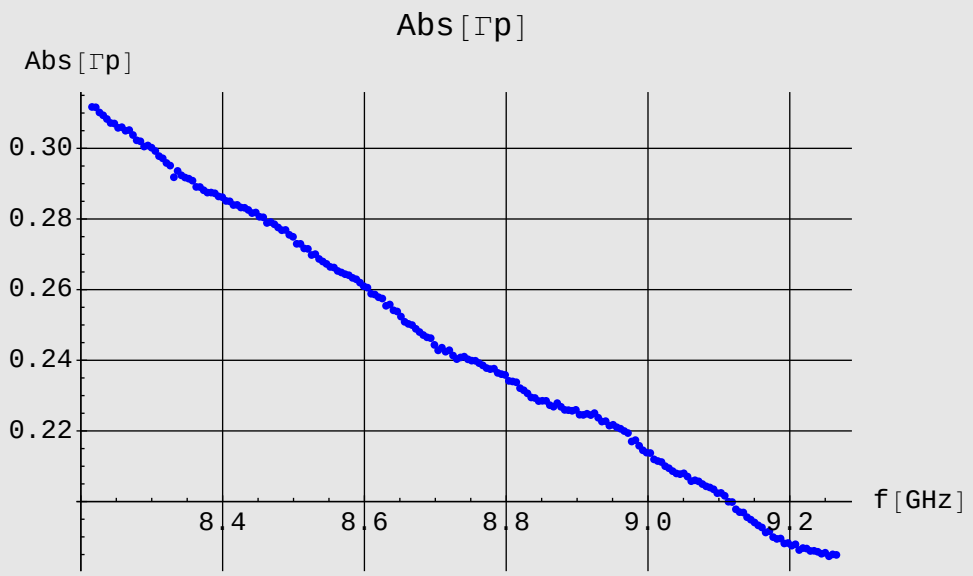
```
-1.60347 + 0.596837 i
```

-2.05976 + 0.0000108604 I

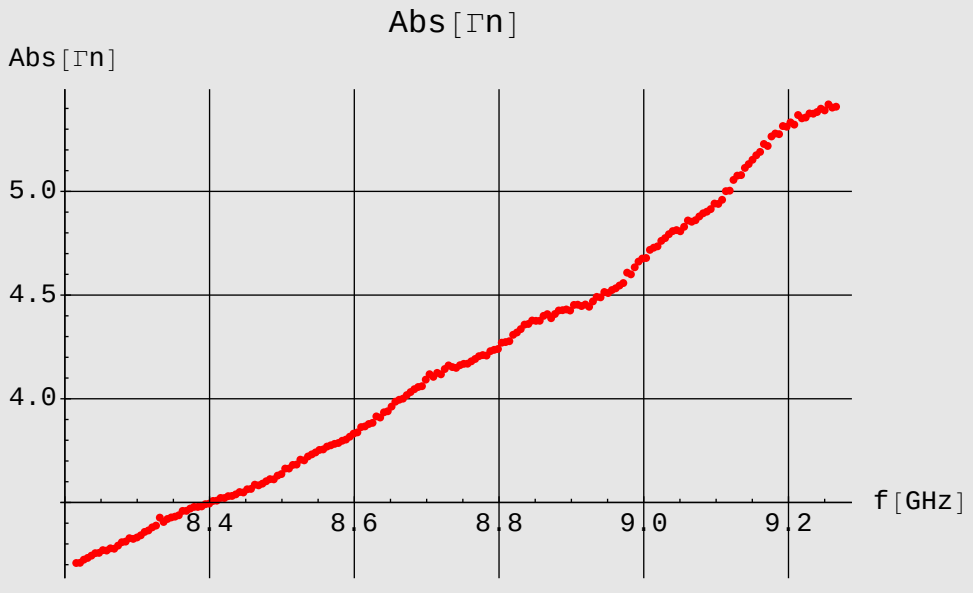
$$\Gamma p[i\_] := K[i] + \sqrt{K[i]^2 - 1}$$

$$\Gamma n[i\_] := K[i] - \sqrt{K[i]^2 - 1}$$

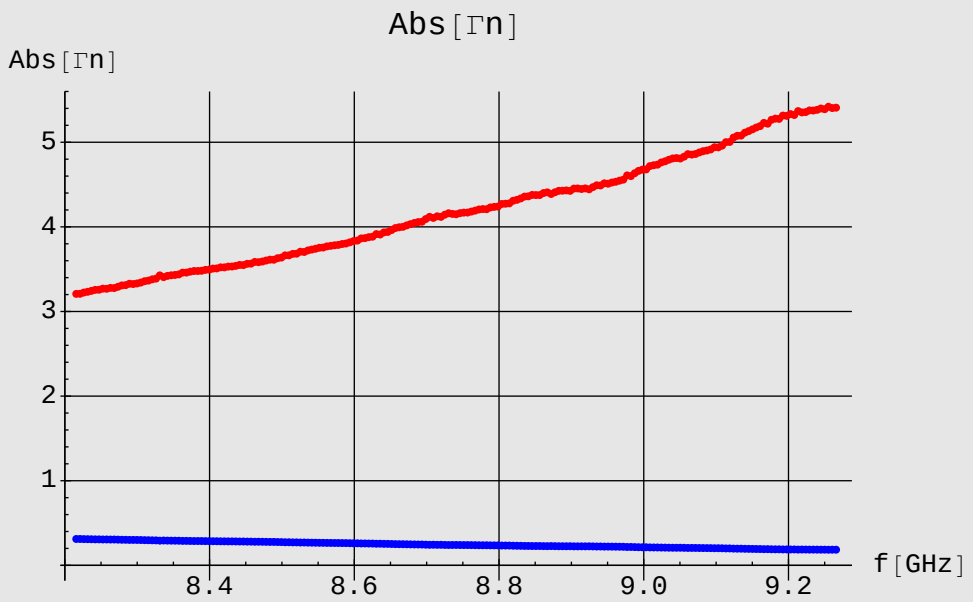
```
gamasP = ListPlot[ Table[{f[i], Abs[Γp[i]]}, {i, 1, 201}],
  PlotStyle → {PointSize[0.01], RGBColor[0, 0, 1]}, Joined → False,
  PlotLabel → StyleForm["Abs[Γp]", {"Helvetica", 12}],
  AxesLabel → {"f[GHz]", "Abs[Γp]"}, GridLines → Automatic]
```




```
gamasN = ListPlot[ Table[{f[i], Abs[Γn[i]]}, {i, 1, 201}],
  PlotStyle → {PointSize[0.01], RGBColor[1, 0, 0]}, Joined → False,
  PlotLabel → StyleForm["Abs[Γn]", {"Helvetica", 12}],
  AxesLabel → {"f[GHz]", "Abs[Γn]"}, GridLines → Automatic]
```



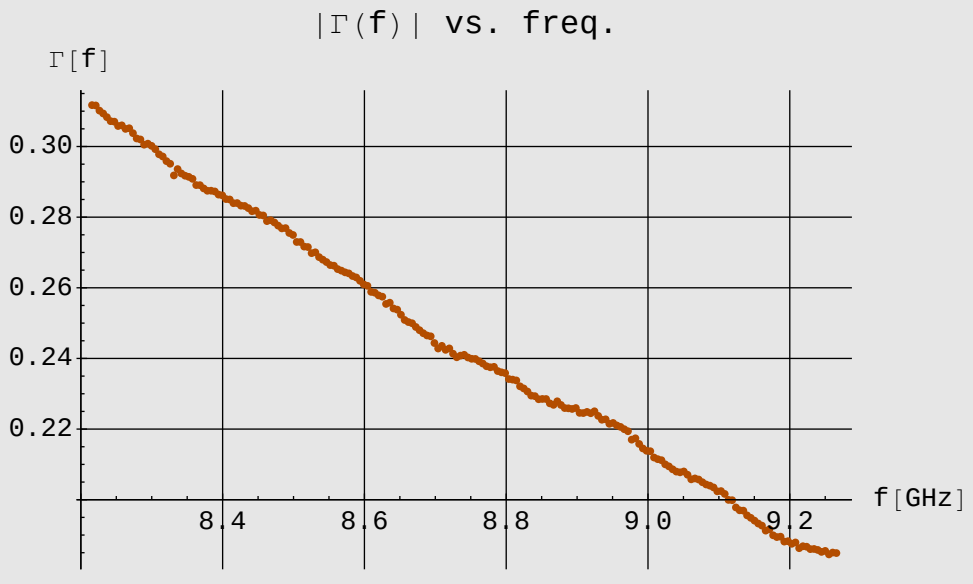
```
Show[{gamasN,gamasP}]
```




```
sinalΓ[i_] := Which [Abs[Γp[i]] < 1, 1, Abs[Γn[i]] ≤ 1, -1]
```

```
Γnrw[i_] := K[i] + sinalΓ[i] √(K[i]^2 - 1)
```

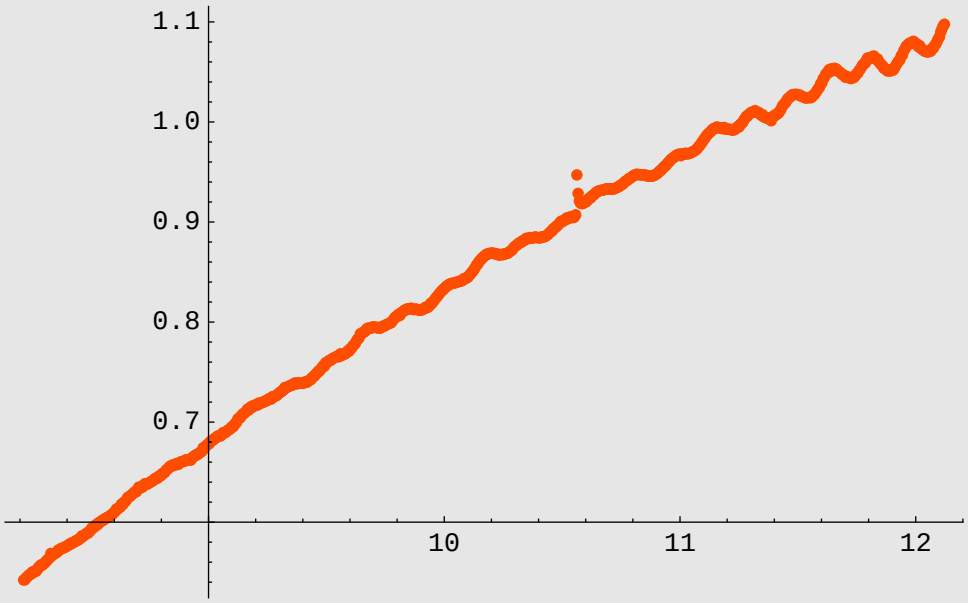
```
Gama = ListPlot[ Table[{f[i], Abs[Γnrw[i]]}, {i, 1, 201}],
  PlotStyle → {PointSize[0.01], RGBColor[0.7, 0.3, 0]},
  Joined → False,
  PlotLabel → StyleForm["|Γ(f)| vs. freq.", {"Helvetica", 12}],
  AxesLabel → {"f[GHz]", "Γ[f]"}, GridLines → Automatic]
```



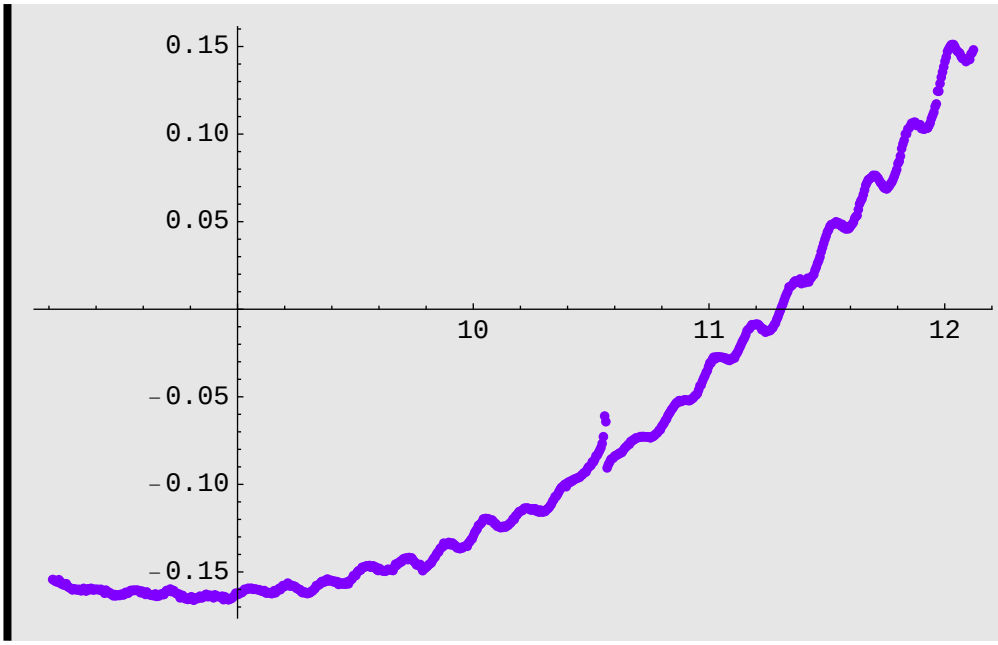
$$znrw[i\_] := \frac{1.0 + rnrw[i]}{1.0 - rnrw[i]}$$

IMPEDANCE NRW

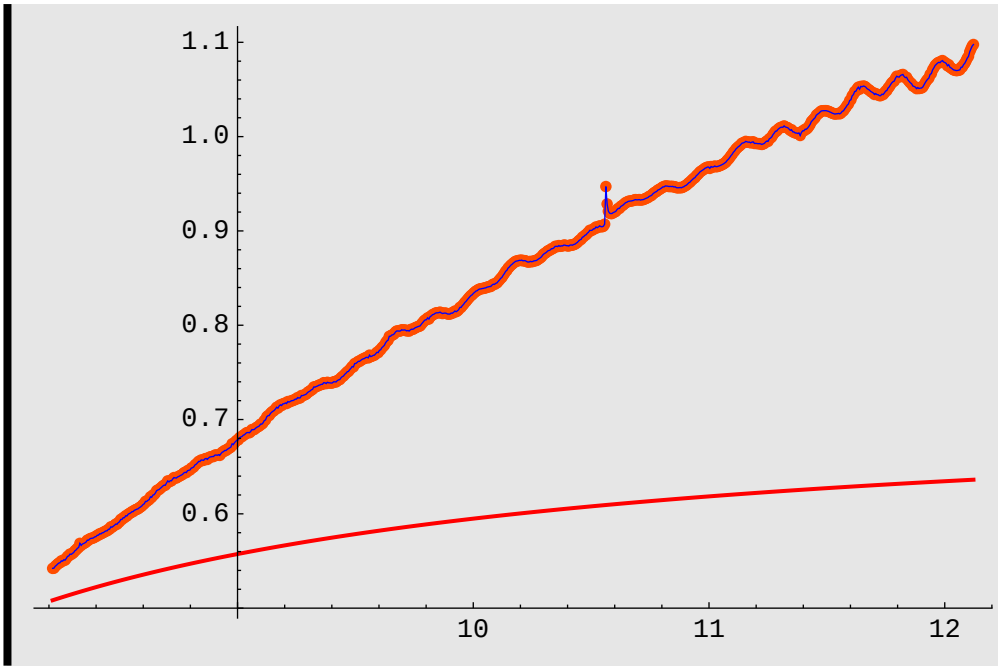
```
zre=ListPlot[Table[{f[i],Re[znrw[i]]},{i,1,745}],
PlotStyle→{PointSize[0.012],
    RGBColor[1,0.3,0]},Joined→False, PlotRange→All]
```



```
zim=ListPlot[Table[{f[i],Im[znrw[i]]},{i,1,745}],
PlotStyle→{PointSize[0.01],
    RGBColor[0.5,0,1]},Joined→False, PlotRange→All]
```




```
Show[zre,ZbRe,ZbanltRe]
```



TRANSMISSION COEFFICIENT

```
T[i_] := Exp[-γ[i] d]
```

```
d
```

```
0.01
```

SLAB THICKNESS

$$TZb[i\_] := \frac{S21C[i]}{1.0 - S11C[i]\,\frac{Zb[i]-1}{Zb[i]+1}}$$

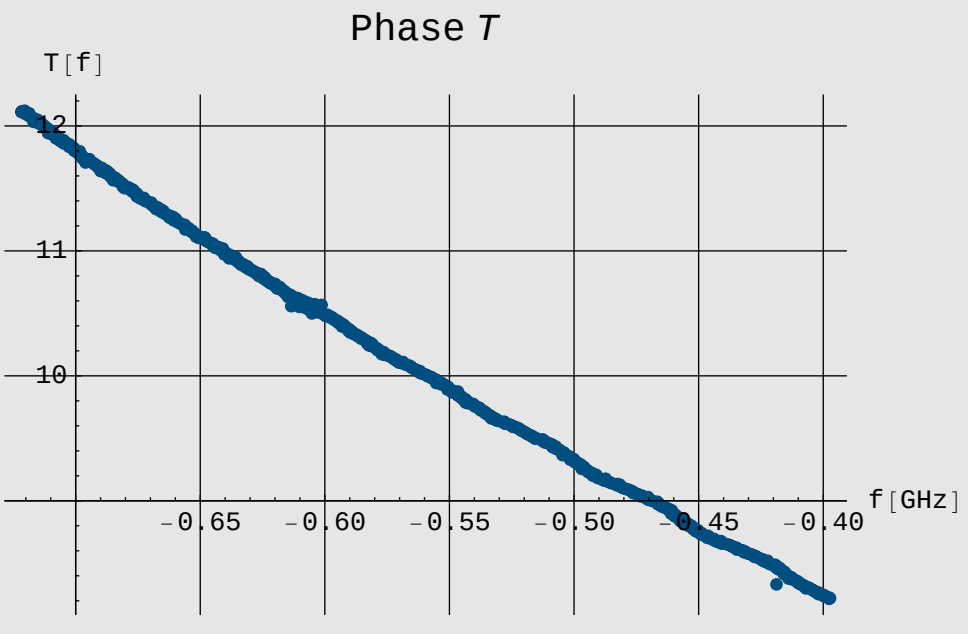
```
AbsTZb=Table[{f[i],Abs[TZb[i]]},{i,1,201}];
```

$$phTZb[i\_] := \frac{1}{\pi}\,ArcTan[Re[TZb[i]],\ Im[TZb[i]]]$$

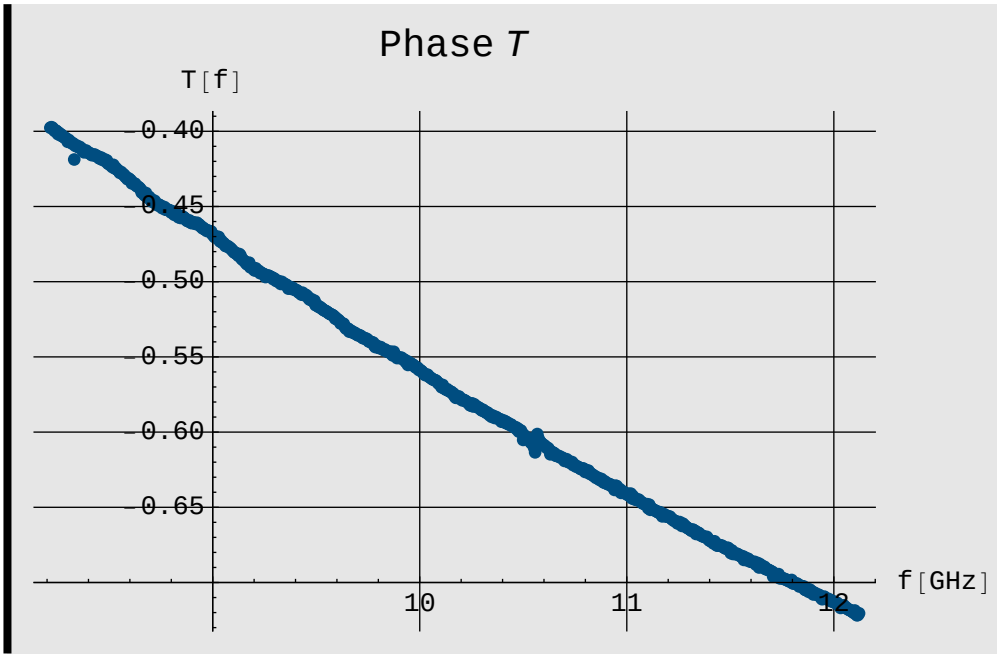
```
PhsTZb=Table[{f[i],phTZb[i]},{i,1,745}];
```

```
dispersion=Table[{phTZb[i],f[i]},{i,1,745}];
```

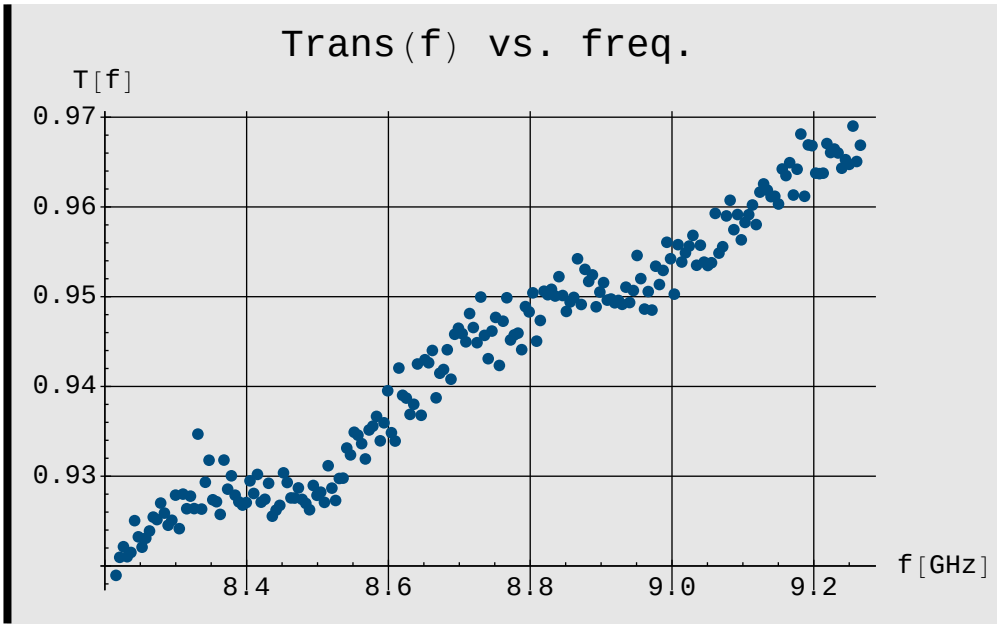
```
plotDisp=ListPlot[dispersion,Joined→False,
PlotStyle→{PointSize[0.015],
RGBColor[0.0,0.3,0.5]},
PlotLabel→Phase T, AxesLabel→{"f[GHz]","T[f]"}
,GridLines→Automatic]
```



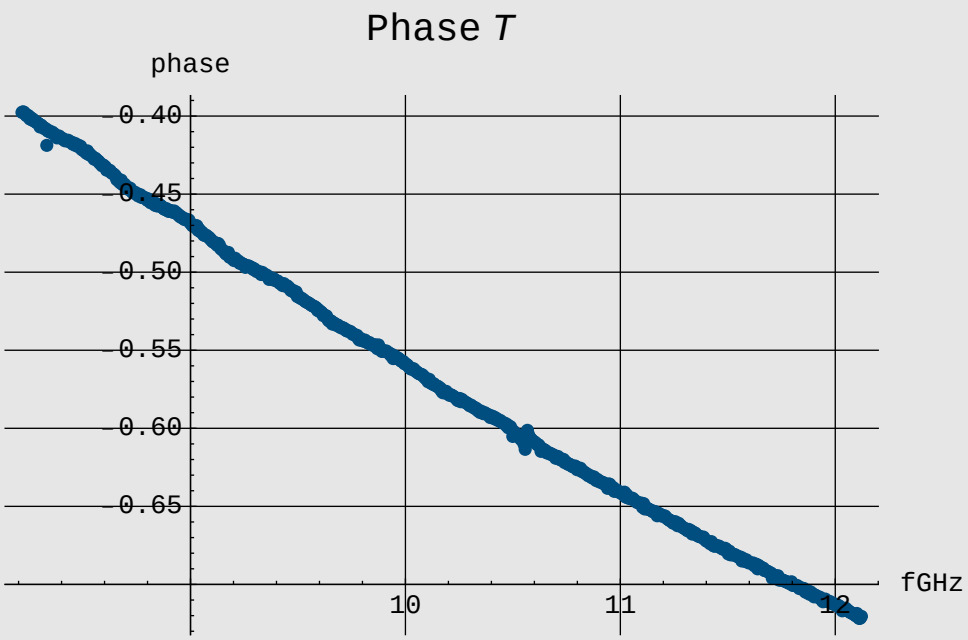
```
phsTZb=ListPlot[PhsTZb,Joined→False,PlotStyle→{PointSize[0.015],
RGBColor[0.0,0.3,0.5]},
PlotLabel→Phase T, AxesLabel→{"f[GHz]","T[f]"}
,GridLines→Automatic]
```




```
absTzb = ListPlot[AbsTZb, Joined → False,
  PlotStyle → {PointSize[0.015], RGBColor[0.0, 0.3, 0.5]},
  PlotLabel → "Trans(f) vs. freq.", AxesLabel → {"f[GHz]", "T[f]"},
  GridLines → Automatic]
```



```
phsTZb=ListPlot[PhsTZb,Joined→False,PlotStyle→{PointSize[0.015],
RGBColor[0.0,0.3,0.5]}
,GridLines→Automatic, PlotLabel-> Phase T,
AxesLabel->{fGHz, phase} ]
```



NEW T

```
Tnew[i_]:=Re[TZb[i]]+i Im[TZb[i]]*1
```

$$\text{phTnew}[i\_] := \frac{1}{\pi}\,\text{ArcTan}[\text{Re}[\text{Tnew}[i]], \text{Im}[\text{Tnew}[i]]];$$

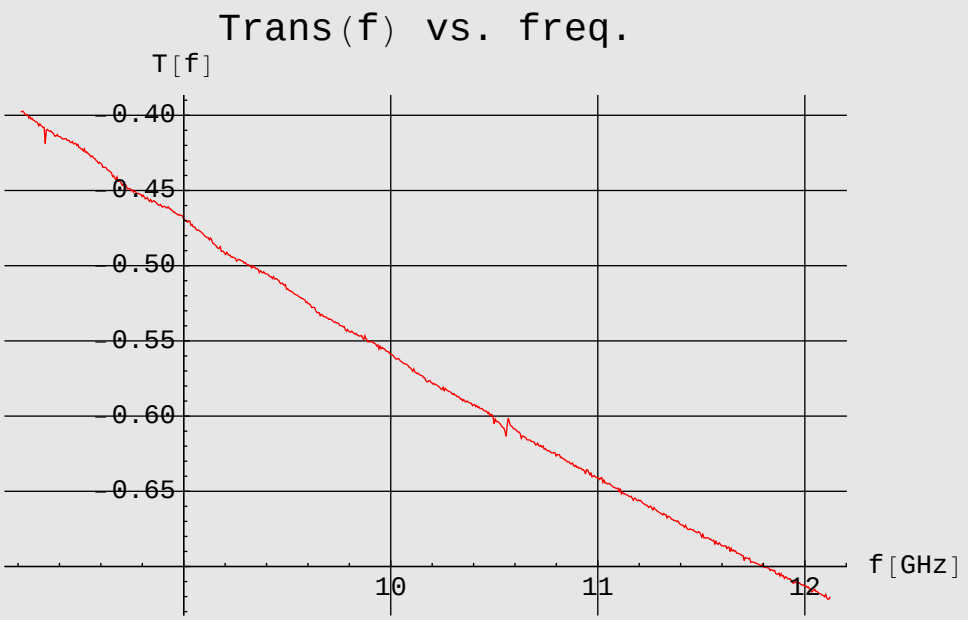
```
ix = 24
```

```
24
```

```
For[i = 0, i < ix, i = i + 1, phTnew[i] = 0];
```

```
PhsTnew=Table[{f[i],phTnew[i]},{i,1,745}];
```

```
phsTnew=ListPlot[PhsTnew,Joined→True,PlotStyle→{PointSize[0.015],
RGBColor[1.0,0,0]}
,PlotLabel→"Trans(f) vs. freq.",
AxesLabel→{"f[GHz]","T[f]"},GridLines→Automatic,PlotRange->All]
```




```
{x = 100; f1 = f[x], phTnew[x], y = x + 1; f11 = f[y], phTnew[y]}
```

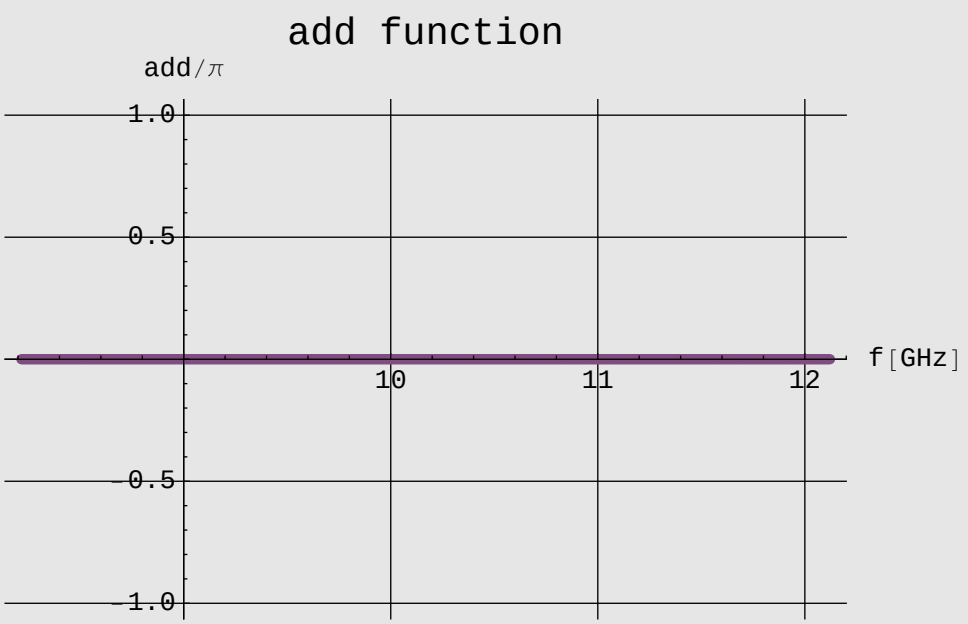
```
{10.279, phTnew[100], 10.3, phTnew[101]}
```

```
add[i_] := Which[f[i] < 7.5, 0 Pi, f[i] ≥ f[i], 0 Pi]
```

```
{f1, add[2]};
```

```
Tadd=Table[{f[i],add[i]/(2 Pi)}, {i,1, 745}];
```

```
ListPlot[Tadd,Joined→False,PlotStyle→{PointSize[0.012],
    RGBColor[0.5,0.3,0.5]},PlotLabel→
  "add function",AxesLabel→{"f[GHz]",
    " add/π "},GridLines→Automatic]
```



below: addex correcting phase factor

$$\text{inv}\Lambda 2[i\_] := \frac{i}{2\pi d}\,\text{Log}[\text{TZb}[i]] + \frac{1 * \text{add}[i]}{2\pi d}$$

```
TZb[100]
```

```
0.151693 − 0.933443 i
```

```
{f[100], Log[TZb[100]], add[100]}
```

```
{8.7355, −0.0558421 − 1.4097 i, 0}
```

```
d
```

```
0.007
```

$$\text{inv}\Lambda 1[i\_] := \frac{i}{2\pi d}\,\text{Log}[\text{TZb}[i]] + \frac{0 * \text{add}[i]}{2\pi d}$$

```
inv∧1[100]
```

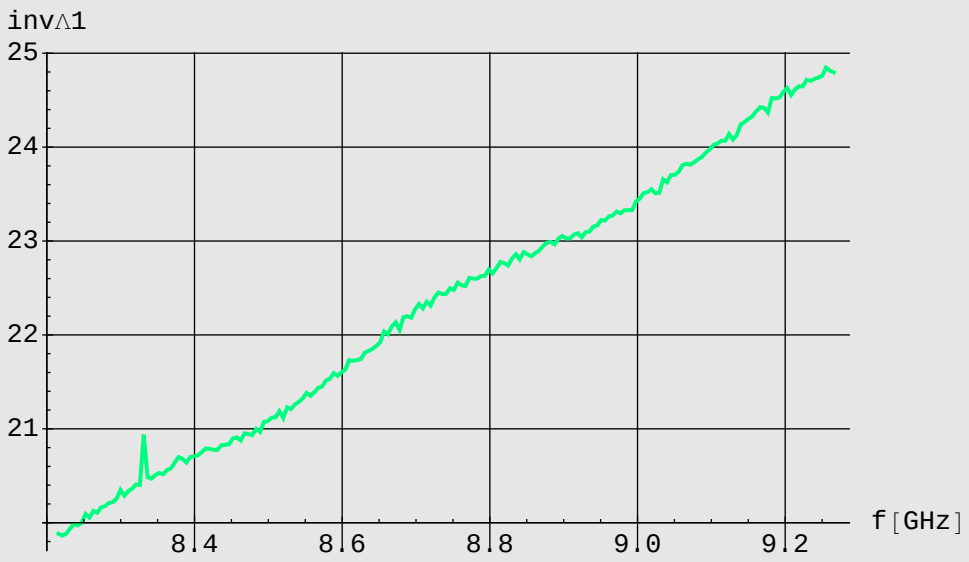
```
22.436 - 0.888754 i
```

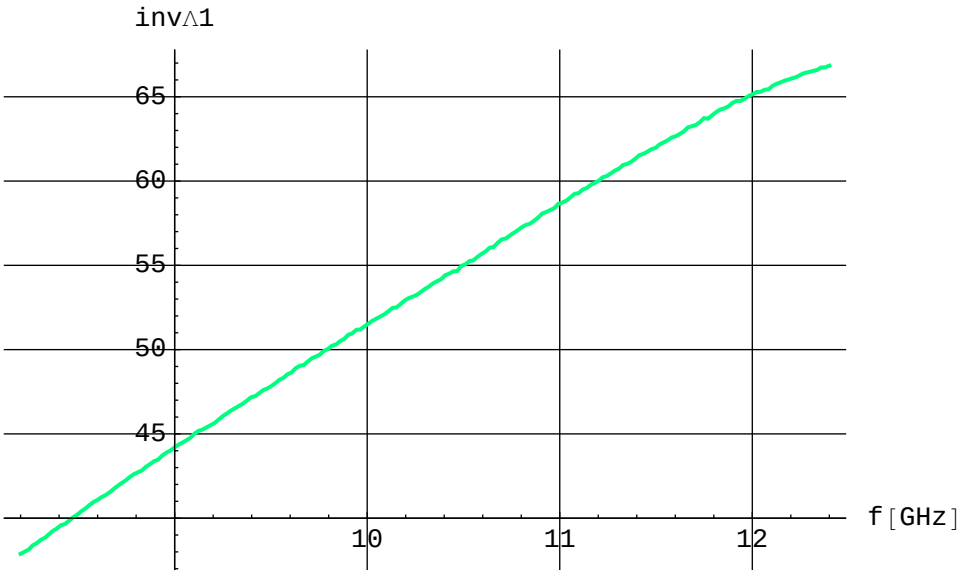
```
tab∧1=Table[{f[i], Re[inv∧1[i]]},{i,1,201}];
```

```
tab∧2=Table[{f[i], 1*Re[inv∧2[i]]},{i,1,201}];
```

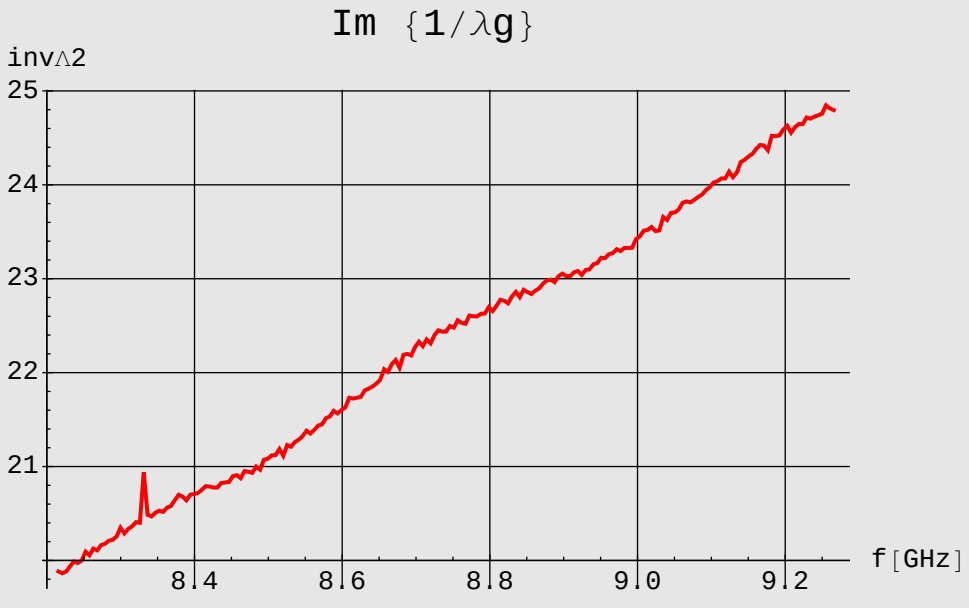
λ0[i] invΛ2[i] is the refractive index

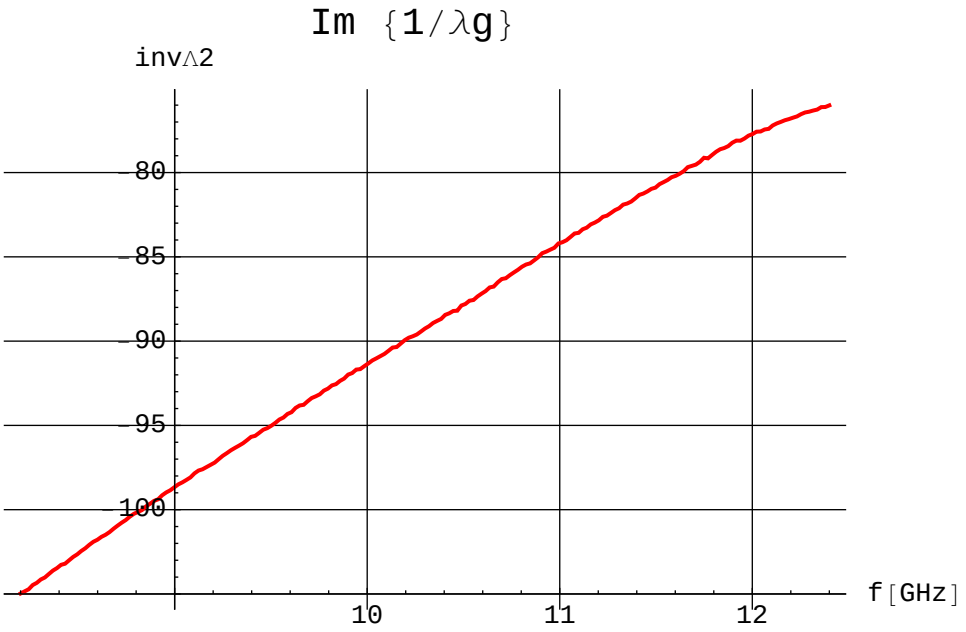
```
lam1 = ListPlot[tab∧1, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0, 1, 0.5]}, PlotLabel → StyleForm[" ", {"Helvetica", 12}],
  AxesLabel → {"f[GHz]", "inv∧1"}, GridLines → Automatic,
  PlotRange → All]
```






```
lam2 = ListPlot[tab∧2, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[1, 0, 0]}, PlotLabel → "Im {1/λg} ",
  AxesLabel → {"f[GHz]", "inv∧2"}, GridLines → Automatic,
  PlotRange → All]
```



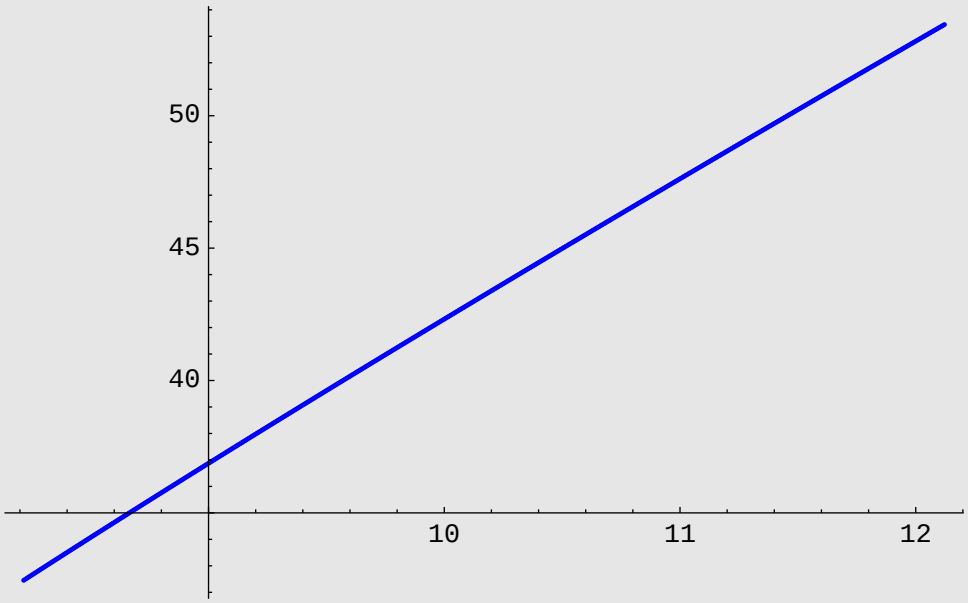


$$\lambda G[i\_] := \frac{2\pi}{-i\, gamaX[i]}$$

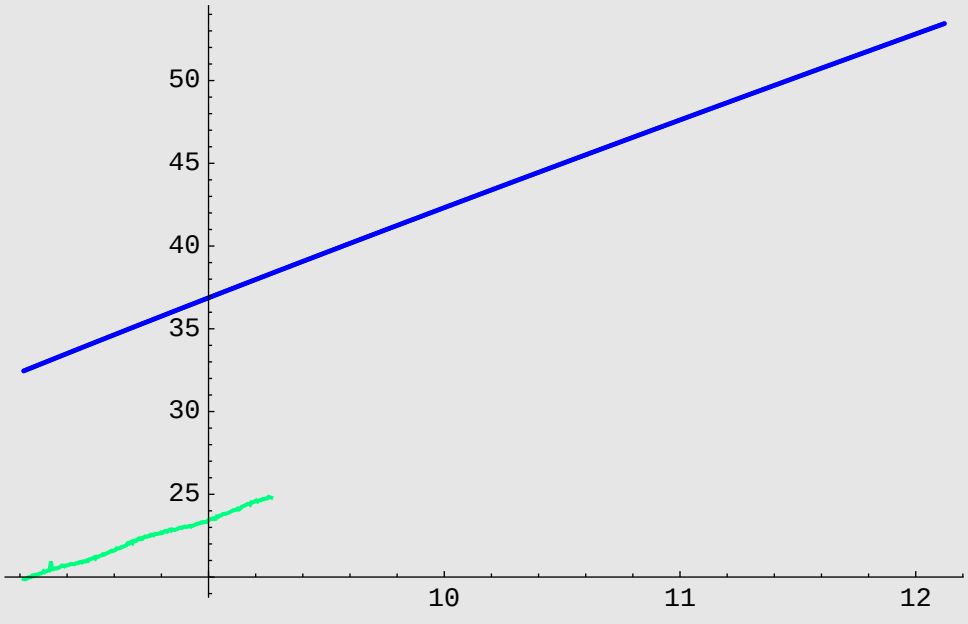
$$gamaX[i\_] := \frac{i\, 2\pi}{\lambda 0D[i]} \sqrt{\left(\epsilon a * \mu a - \frac{\lambda 0D[i]^2}{\lambda cDX^2}\right)}$$

```
lg = Table[{f[i], λG[i]}, {i, 1, 745}];
```

```
Plotlg = ListPlot[Table[{f[i], Re[1 / λG[i]] * 1}, {i, 1, 745}],
  PlotStyle → {PointSize[0.005], RGBColor[0, 0, 1]}, Joined → False,
  PlotRange → All]
```




```
Show[{Plotlg, lam1}]
```



REFRACTIVE INDEX

```
n[i_] := inv∧1[i] * λ0D[i]
```

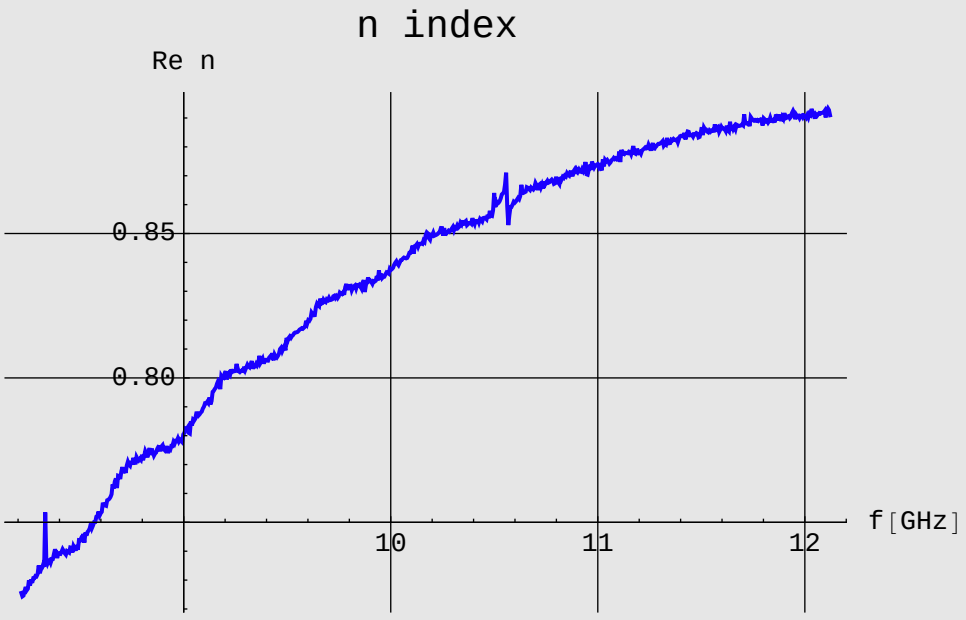
$$\lambda guide[i\_] := \frac{\lambda 0D[i]}{\sqrt{1 - \frac{\lambda 0D[i]^2}{\lambda cDX^2}}}$$

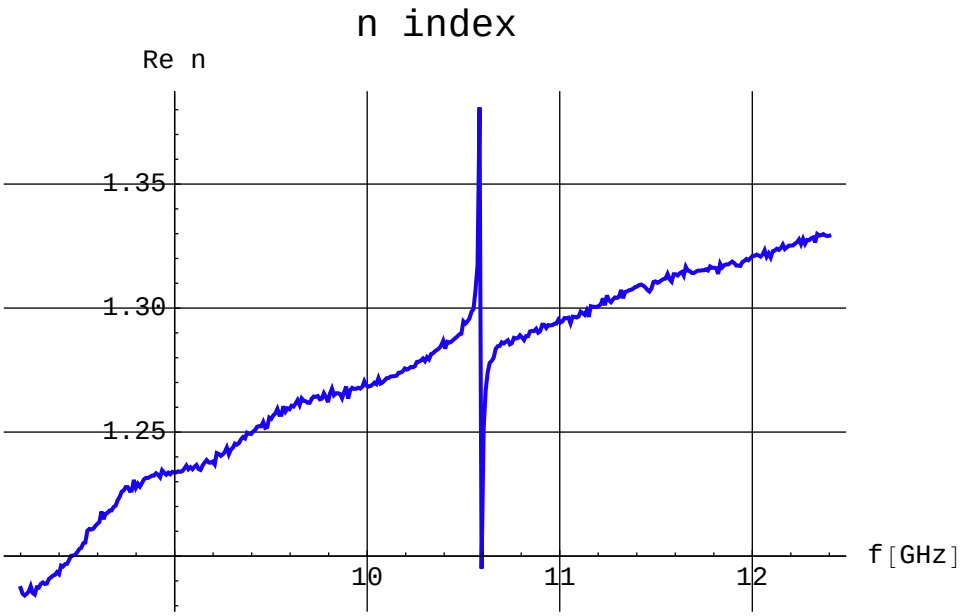
```
nguide[i_] := inv∧1[i] * λguide[i]
```

```
nr=Table[{f[i], Re[n[i]]},{i,1,745}];
```

```
ni=Table[{f[i], Im[n[i]]},{i,1,745}];
```

```
Realn = ListPlot[nr, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.1, 0, 1]}, PlotLabel → " n index",
  AxesLabel → {"f[GHz]", "Re n"}, GridLines → Automatic,
  PlotRange → All]
```

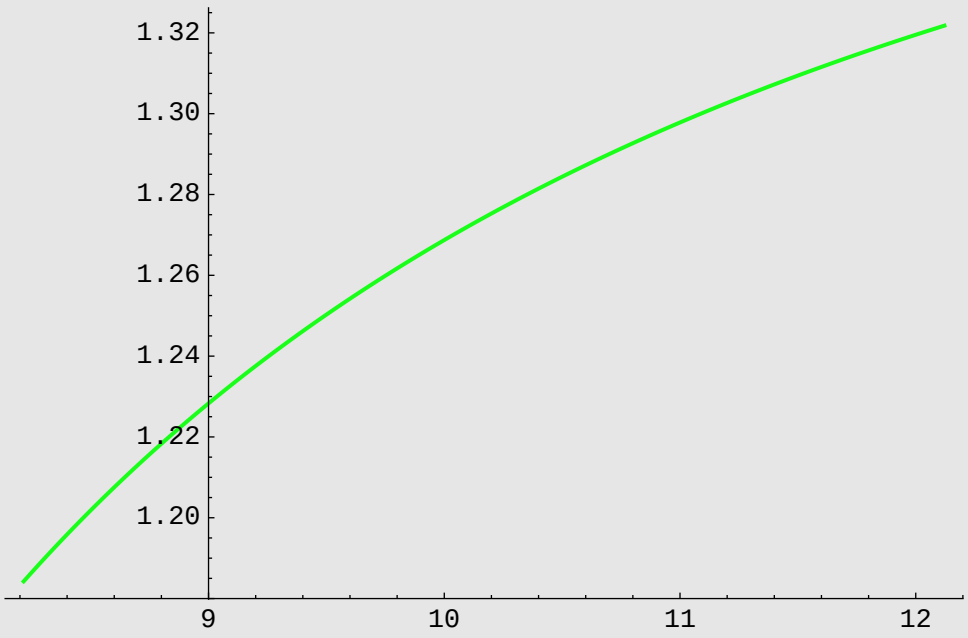




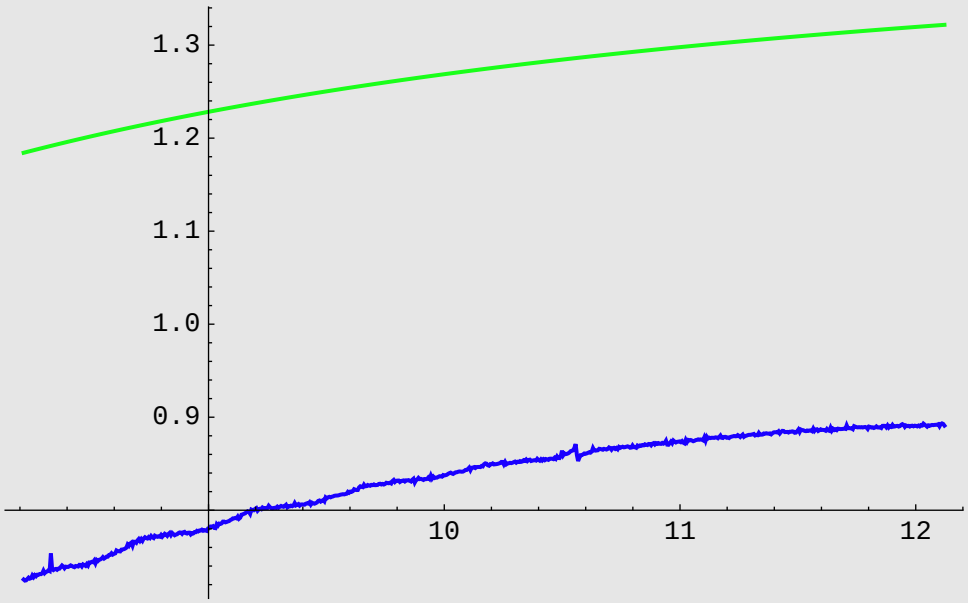
$$\text{indexanlt}[i\_] := \sqrt{\epsilon a * \mu a - \left(\frac{\lambda 0 D[i]}{\lambda c DX}\right)^2}$$

```
tabindex=Table[{f[i],Re[indexanlt[i]]},{i,1,745}];
```

```
plotindex = ListPlot[tabindex, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.1, 1, 0.1]}]
```

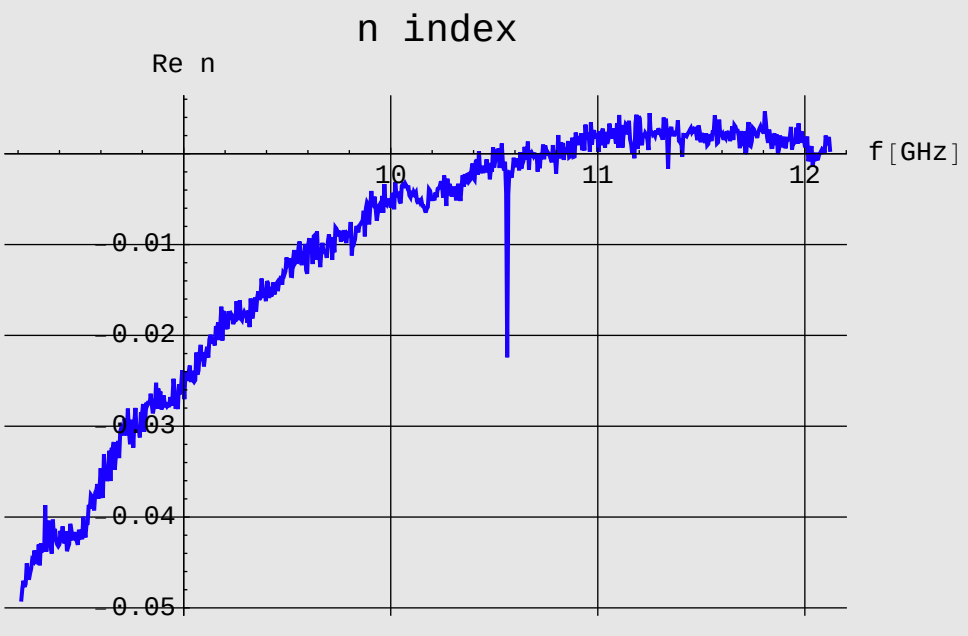


```
Show[plotindex, Realn]
```




```
Export[
  "C:\\Users\\Barroso\\Documents\\Miguel\\Results\\teflon\\3nexp.dat"
  , nr, "Table"];
```

```
Imn = ListPlot[ni, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.1, 0, 1]}, PlotLabel → " n index",
  AxesLabel → {"f[GHz]", "Re n"}, GridLines → Automatic,
  PlotRange → All]
```



Calculo de EPS and MU no guia de Onda

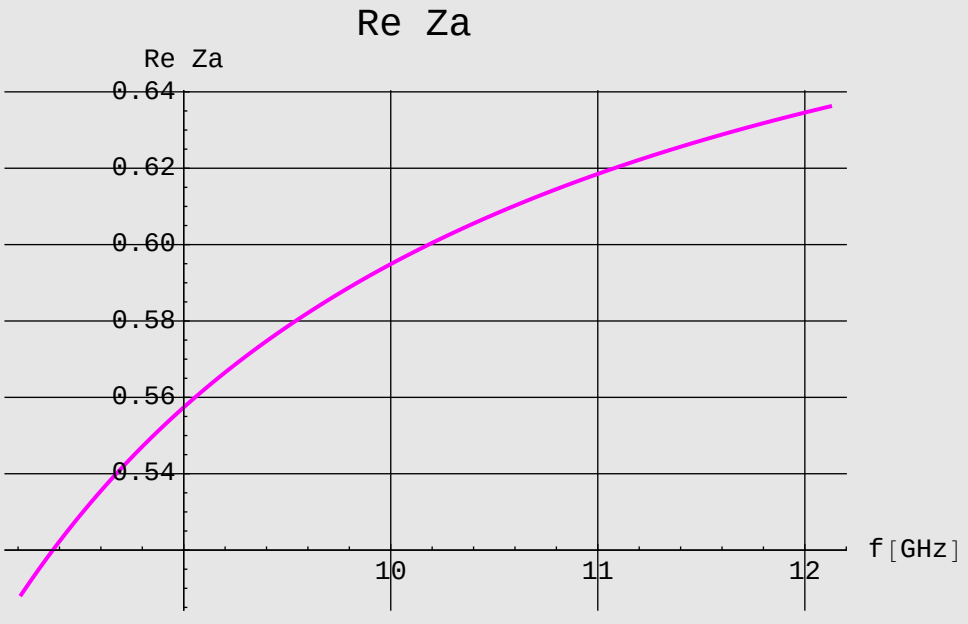
$$za[i\_] := \mu a \frac{\sqrt{1 - \left(\frac{\lambda 0D[i]}{\lambda cDX}\right)^2}}{\sqrt{\epsilon a * \mu a - \left(\frac{\lambda 0D[i]}{\lambda cDX}\right)^2}};$$

```
za[100]
```

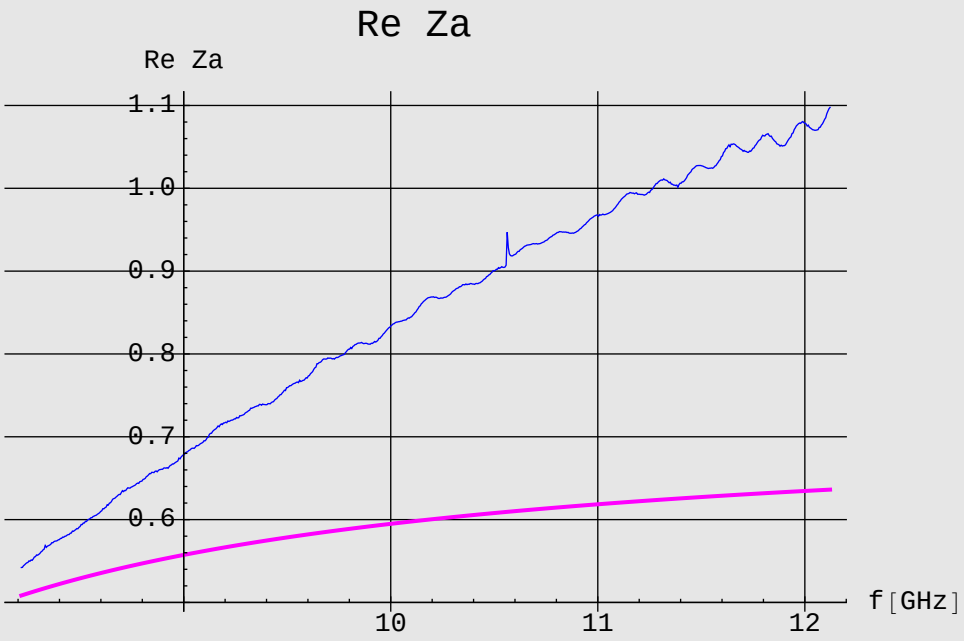
```
0.543527 + 0. i
```

```
Reza=Table[{f[i], Re[za[i]]},{i,1,745}];
```

```
PlotReza = ListPlot[Reza, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[1, 0, 1]}, PlotLabel → "Re Za ",
  AxesLabel → {"f[GHz]", "Re Za"}, GridLines → Automatic,
  PlotRange → All]
```



```
Show[PlotReza, ZbRe]
```



$$\beta 0z[i\_] := \sqrt{\left(\frac{2\pi}{\lambda 0D[i]}\right)^2 - \left(\frac{\pi}{aX}\right)^2}$$

$$\lambda 0g[i\_] := \frac{1}{\sqrt{\left(\frac{1.}{\lambda 0D[i]^2} - \frac{1}{\lambda cDX^2}\right)}}$$

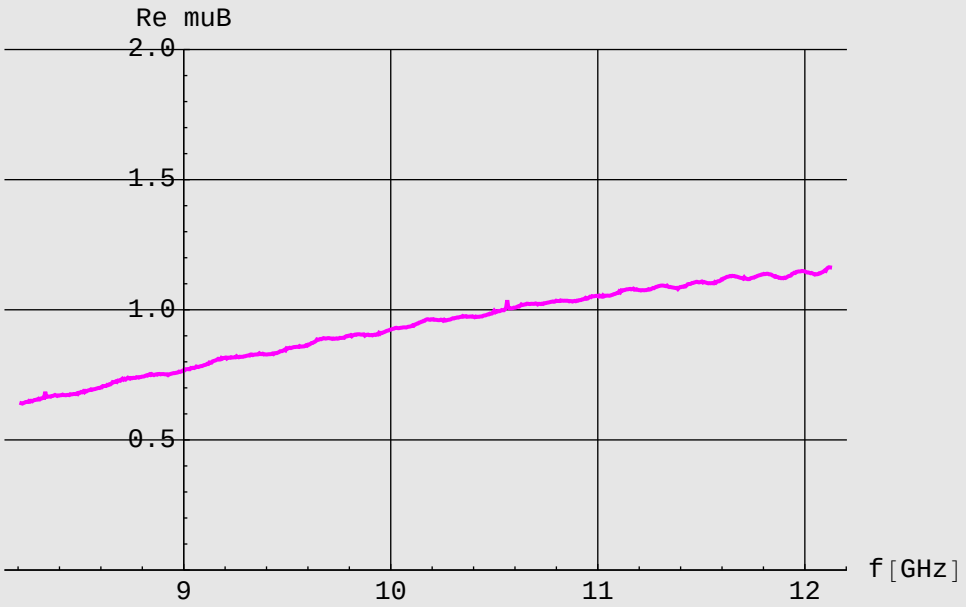
```
μB[i_] := Zb[i] * invΛ1[i] * λ0g[i];
```

```
μB[135]
```

```
0.752151 - 0.215073 i
```

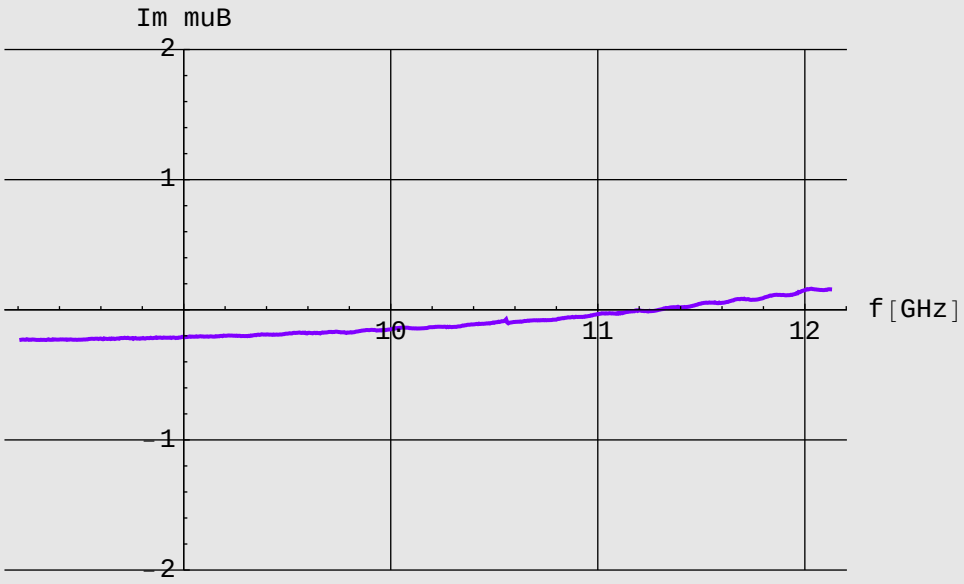
```
μBr=Table[{f[i], Re[μB[i]]},{i,1,745}];
```

```
ReμB = ListPlot[μBr, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[1, 0, 1]}, PlotLabel → " ",
  AxesLabel → {"f[GHz]", "Re muB"}, GridLines → Automatic,
  PlotRange → {0, 2}]
```




```
μi=Table[{f[i], Im[μB[i]]},{i,1,745}];
```

```
ImμB = ListPlot[μi, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → " ",
  AxesLabel → {"f[GHz]", "Im muB"}, GridLines → Automatic,
  PlotRange → {-2, 2}]
```



$$\epsilon mu[i\_] := \frac{\left(invA1[i]^2 + \frac{1}{\lambda cDX^2}\right)}{\mu B[i]}\, \lambda 0D[i]^2$$

```
ϵmu[10]
```

```
1.61904 + 0.471468 i
```

```
λ0D[100]^2
```

```
0.00117784
```

```
ϵmu[100]
```

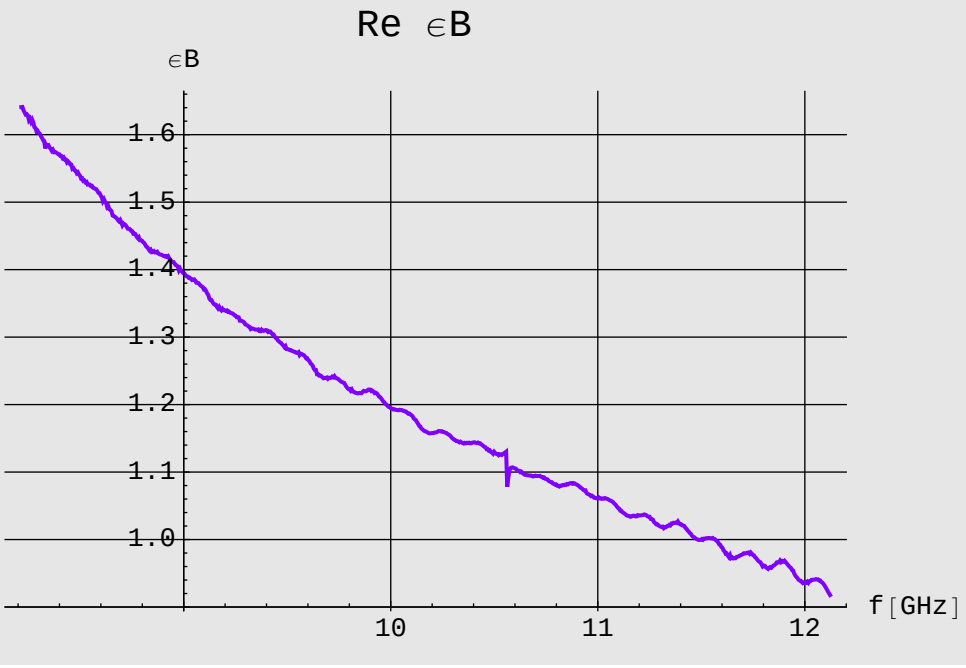
```
2.02963 - 0.0157828 i
```

```
ϵBtab=Table[{f[i], Re[ϵmu[i]]},{i,1,745}];
```

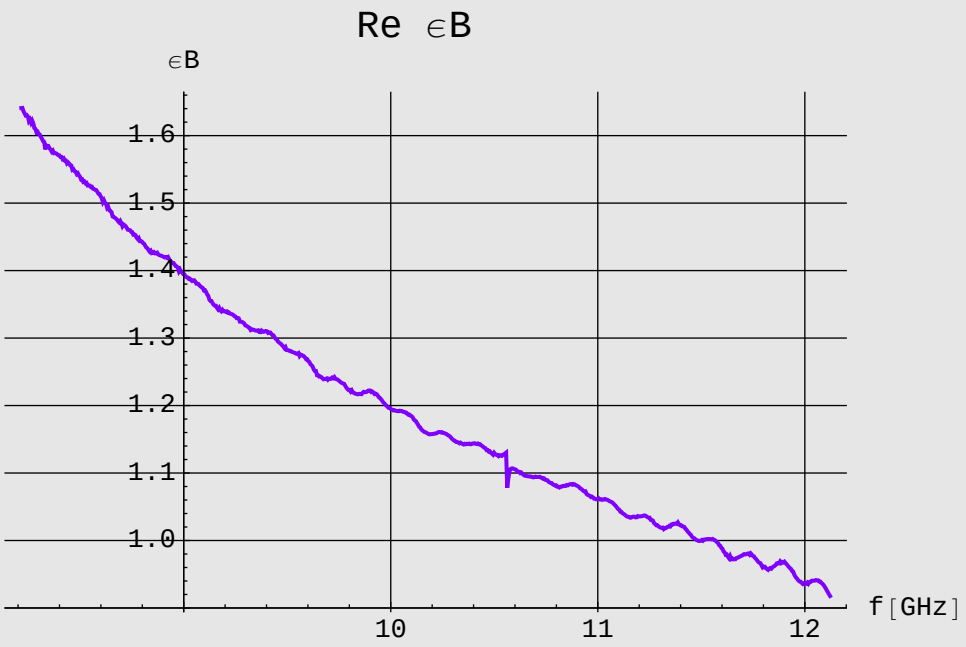
```
Re[ϵmu[20]]
```

```
1.3082
```

```
RealϵB = ListPlot[ϵBtab, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re ϵB ",
  AxesLabel → {"f[GHz]", "ϵB"}, GridLines → Automatic, PlotRange → All]
```

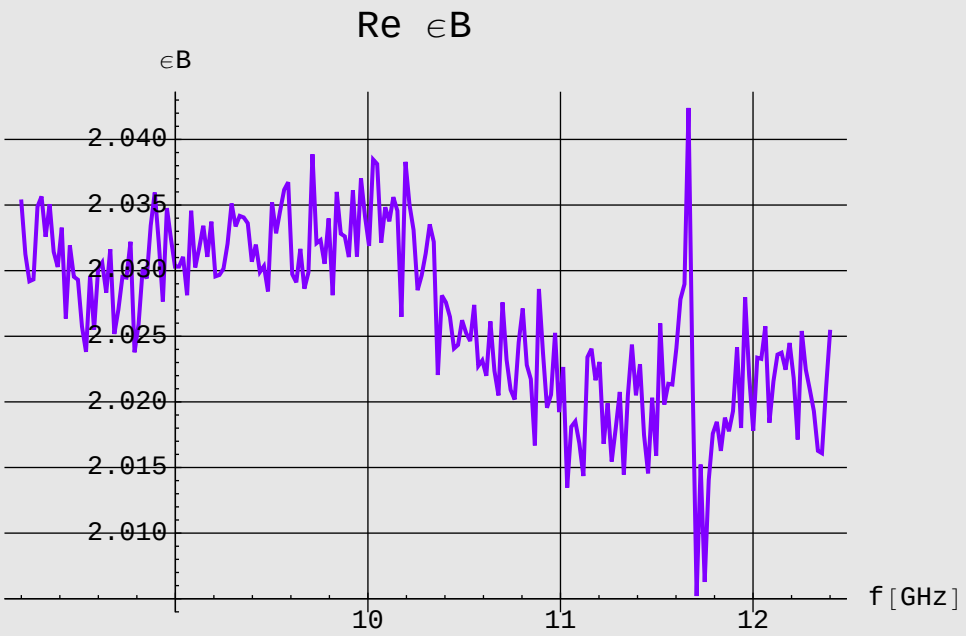


```
RealϵB = ListPlot[ϵBtab, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re ϵB ",
  AxesLabel → {"f[GHz]", "ϵB"}, GridLines → Automatic, PlotRange → All]
```



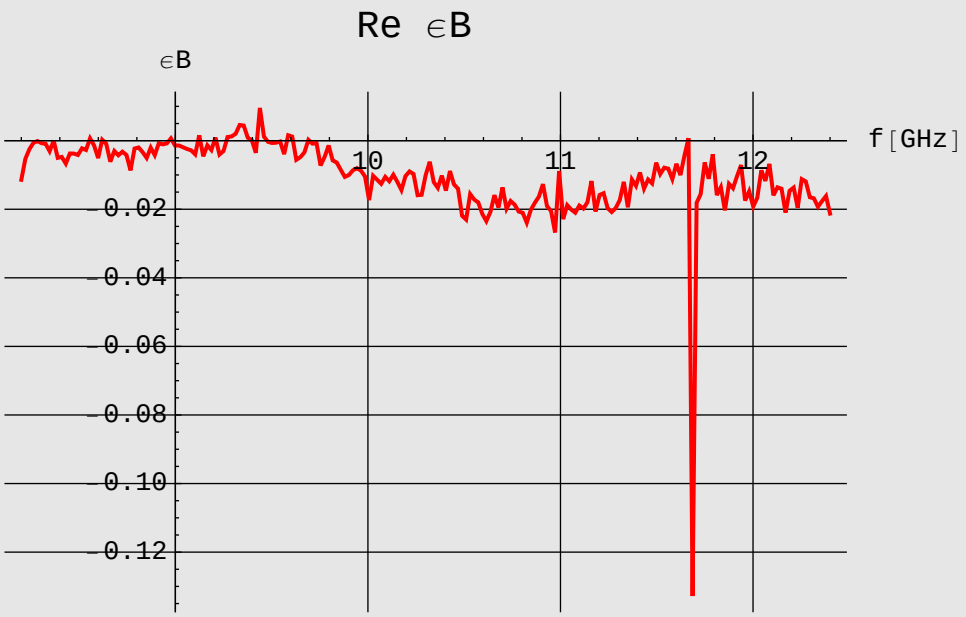

```
ϵmutab = Table[{f[i], Re[ϵmu[i]]}, {i, 1, 201}];
```

```
Real∈mutab = ListPlot[∈mutab, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re ∈B ",
  AxesLabel → {"f[GHz]", "∈B"}, GridLines → Automatic, PlotRange → All]
```




```
∈Bi = Table[{f[i], Im[∈mu[i]]}, {i, 1, 201}];
```

```
ImageϵB = ListPlot[ϵBi, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[1, 0, 0]}, PlotLabel → "Re ϵB ",
  AxesLabel → {"f[GHz]", "ϵB"}, GridLines → Automatic, PlotRange → All]
```



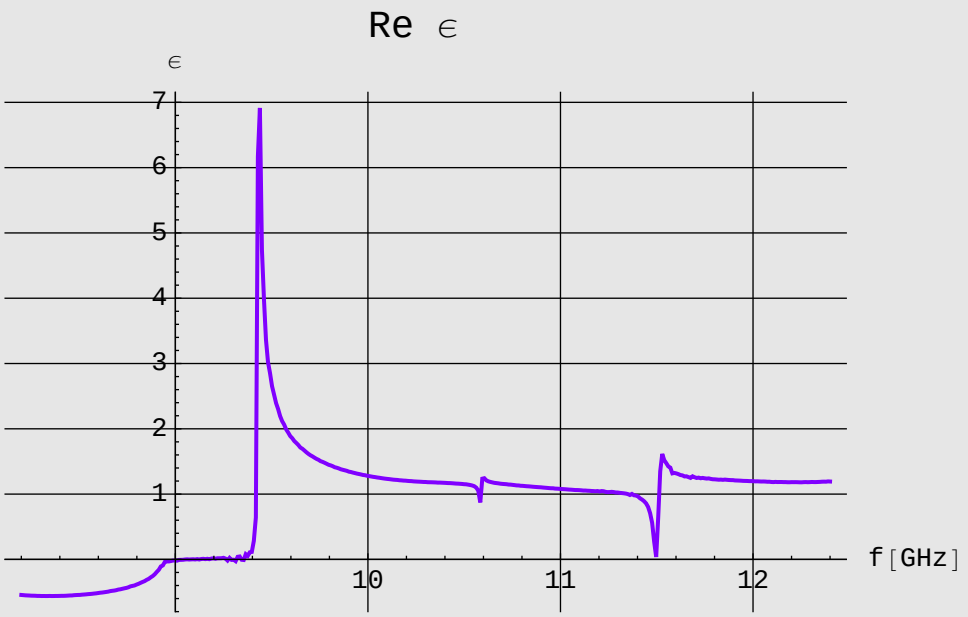
$$\text{Zrec}[i\_] := \frac{\mu B[i] * \text{gama0X}[i]}{\frac{i\,2\pi}{\lambda 0D[i]}\sqrt{\left(\epsilon mu[i] * \mu B[i] - \frac{\lambda 0D[i]^2}{\lambda cDX^2}\right)}}$$

```
Zrec[50]
```

$$-0.457681 - 0.0117704\,i$$

```
Zrecr=Table[{f[i], Re[Zrec[i]]},{i,1,401}];
```

```
RealZrecr = ListPlot[Zrecr, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re ϵ ",
  AxesLabel → {"f[GHz]", "ϵ"}, GridLines → Automatic, PlotRange → All]
```



EPS and MU

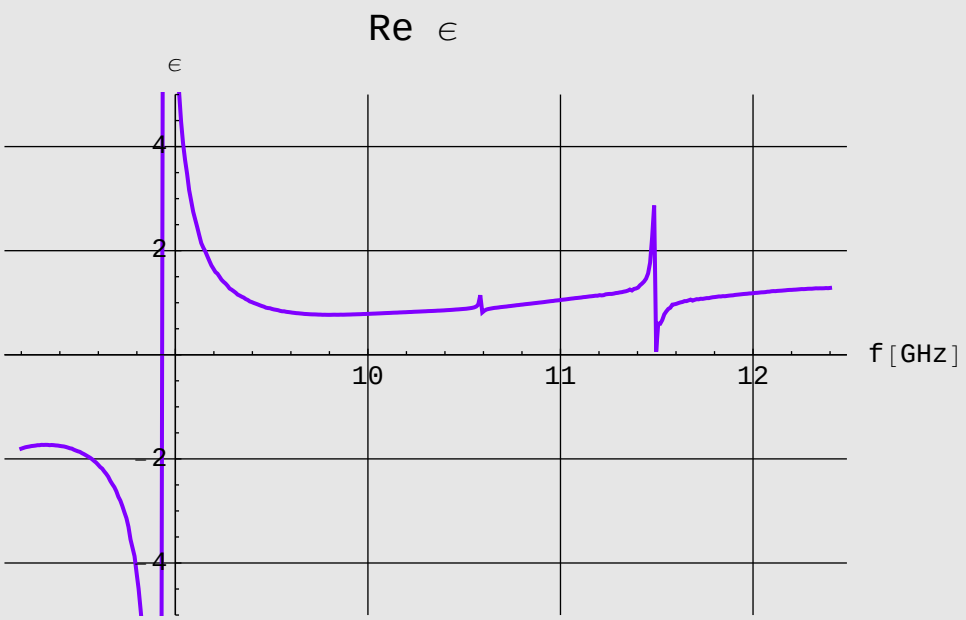
```
ϵr=Table[{f[i], Re[ϵmu[i]]},{i,1,401}];
```

```
ϵi=Table[{f[i], Im[ϵmu[i]]},{i,1,401}];
```

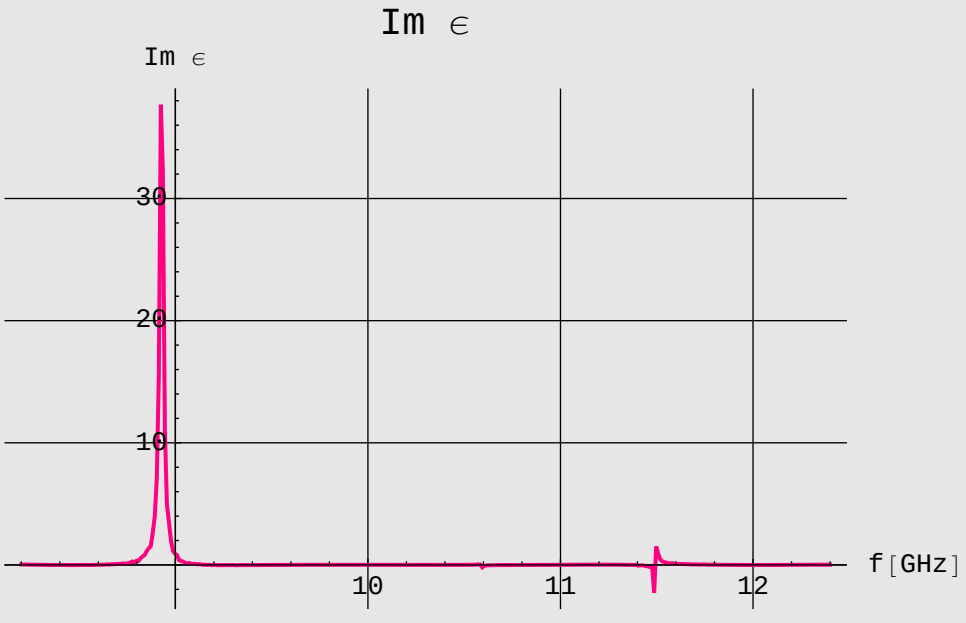
```
μr=Table[{f[i], Re[μB[i]]},{i,1,401}];
```

```
μi=Table[{f[i], Im[μB[i]]},{i,1,401}];
```

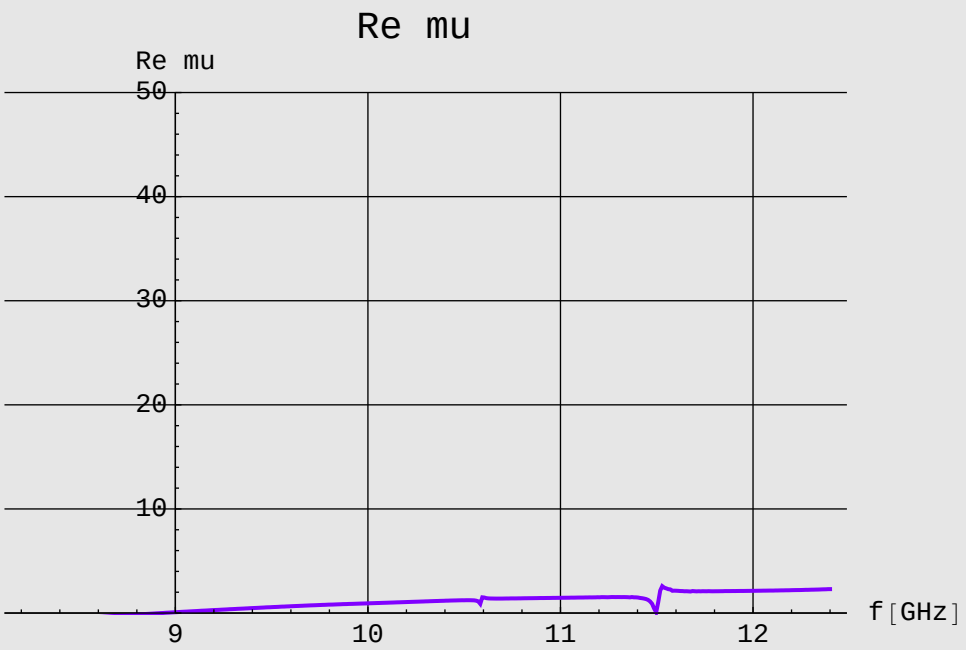
```
Realϵ = ListPlot[ϵr, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re ϵ ",
  AxesLabel → {"f[GHz]", "ϵ"}, GridLines → Automatic,
  PlotRange → {-5, 5}]
```



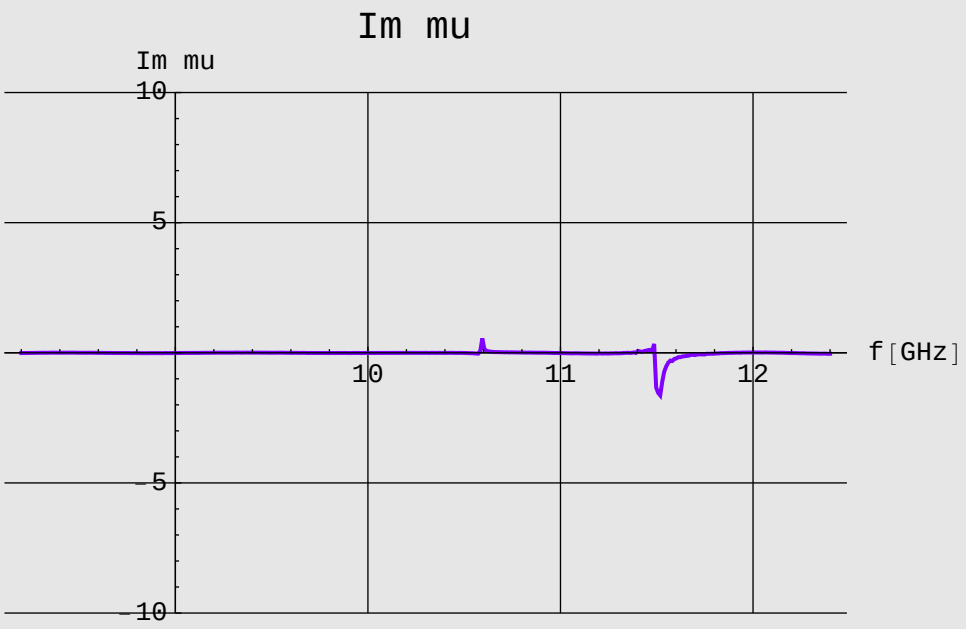

```
Imϵ = ListPlot[ϵi, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[1, 0.0, 0.5]}, PlotLabel → " Im ϵ ",
  AxesLabel → {"f[GHz]", "Im ϵ"}, GridLines → Automatic,
  PlotRange → All]
```



```
Reμ = ListPlot[μr, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Re mu ",
  AxesLabel → {"f[GHz]", "Re mu"}, GridLines → Automatic,
  PlotRange → {0, 50}]
```



```
Imμ = ListPlot[μi, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], PointSize[0.02],
    RGBColor[0.5, 0, 1]}, PlotLabel → "Im mu ",
  AxesLabel → {"f[GHz]", "Im mu"}, GridLines → Automatic,
  PlotRange → {-10, 10}]
```



INVERSE PARAMETERS

```
d
```

```
0.007
```

```
{d,λc}
```

```
{0.01, 0.0457}
```

```
Total[{6., 1. × 10^10}]
```

```
1. × 10^10
```

$$\gamma[i\_] := i\,\frac{2\pi}{\lambda 0D[i]}\sqrt{\epsilon mu[i]\,\mu B[i] - \left(\frac{\lambda 0D[i]}{\lambda c}\right)^2}$$

```
γ[10]
```

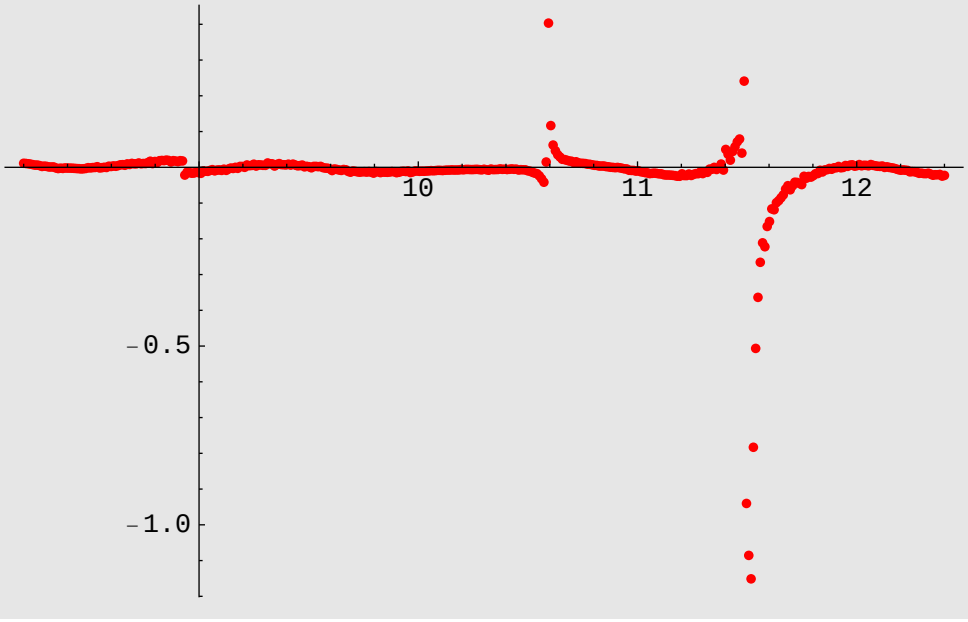
```
0.934022 + 149.195 i
```

```
Zout[i_] := √(μB[i] / ϵmu[i])
```

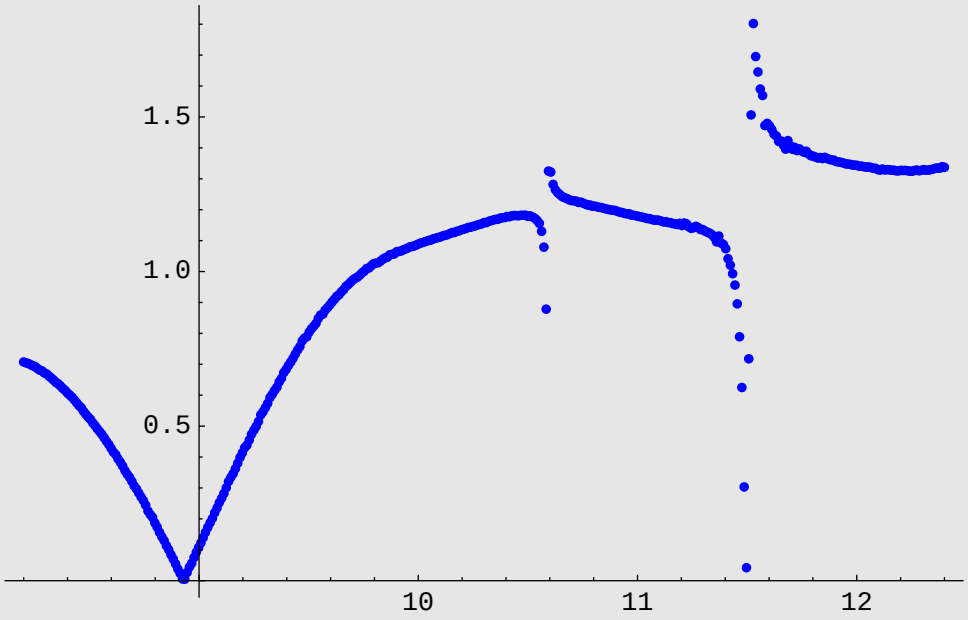
```
Zout[10]
```

```
0.671878 + 0.00336017 i
```

```
ZoutIm=ListPlot[Table[{f[i],Im[Zout[i]]},{i,1,401}],
PlotStyle→{PointSize[0.01],
    RGBColor[1,0,0]},Joined→False, PlotRange→All]
```



```
ZoutRe=ListPlot[Table[{f[i],Re[Zout[i]]},{i,1,401}],
PlotStyle→{PointSize[0.01],
    RGBColor[0,0,1]},Joined→False, PlotRange→All]
```



$$\text{aS11}[i\_] := \frac{(\text{Zb}[i]^2 - 1)\ \text{Sinh}[-\gamma[i]\ d]}{(\text{Zb}[i] + 1)^2\ \text{Sinh}[-\gamma[i]\ d] + 2\ \text{Zb}[i]\ \text{Exp}[\gamma[i]\ d]}$$

```
aS11[10]
```

```
-0.525277 + 0.0413965 i
```

$$\text{aS21}[i\_] := \frac{2\ \text{Zb}[i]}{(\text{Zb}[i] + 1)^2\ \text{Sinh}[-\gamma[i]\ d] + 2\ \text{Zb}[i]\ \text{Exp}[\gamma[i]\ d]}$$

$$\text{phaS11}[i\_] := \frac{1}{\pi}\ \text{ArcTan}[\text{Re}[\text{aS11}[i]],\ \text{Im}[\text{aS11}[i]]]$$

$$\text{phaS21}[i\_] := \frac{1}{\pi}\ \text{ArcTan}[\text{Re}[\text{aS21}[i]],\ \text{Im}[\text{aS21}[i]]]$$

```
InvS11=Table[{f[i], Abs[aS11[i]]},{i,1,401}];
```

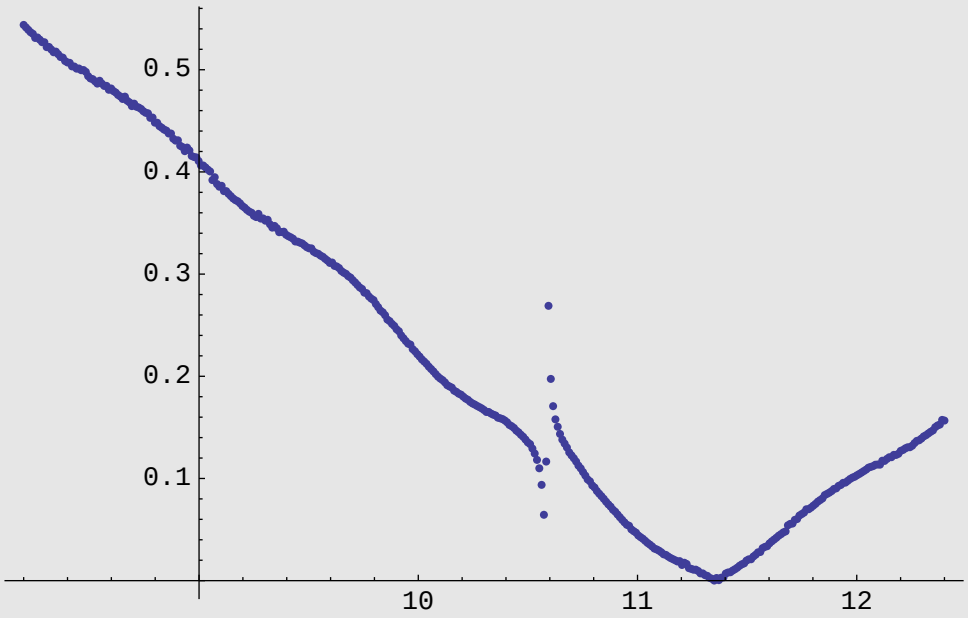
```
InvS11x=Table[{f[i], Abs[bS11[i]]},{i,1,401}];
```

```
InvS11fase=Table[{f[i], phaS11[i]},{i,1,401}];
```

```
InvS21=Table[{f[i], Abs[aS21[i]]},{i,1,401}];
```

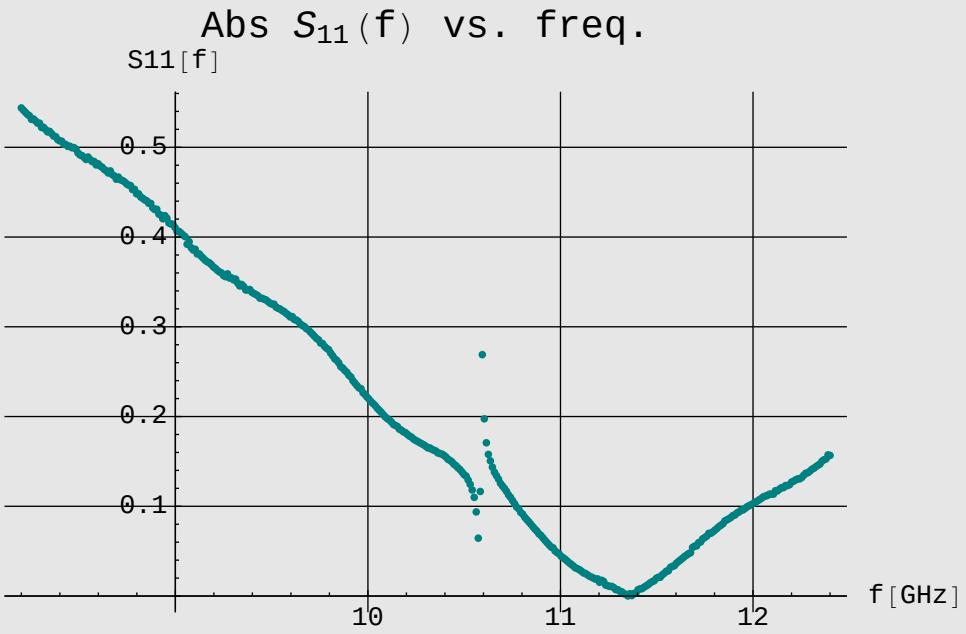
```
InvS21fase=Table[{f[i], phaS21[i]},{i,1,401}];
```

```
ListPlot[InvS11]
```

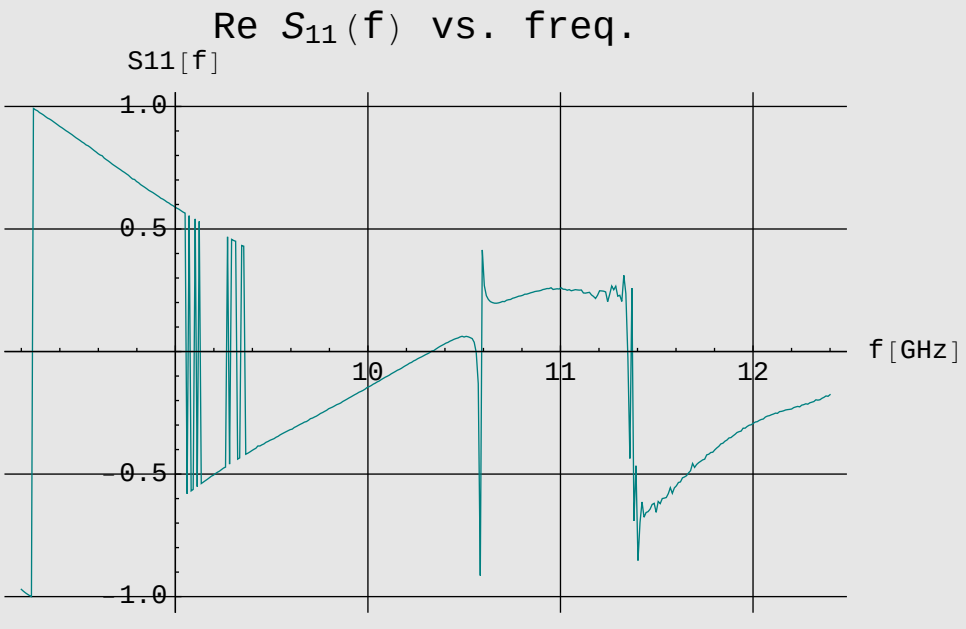



```
InvS21fase=Table[{f[i], phaS21[i]},{i,1,401}]
```

```
inS11 = ListPlot[InvS11,
  PlotStyle → {PointSize[0.009], RGBColor[0, 0.5, 0.5]},
  PlotLabel → "Abs S11(f) vs. freq.", AxesLabel → {"f[GHz]", "S11[f]"},
  GridLines → Automatic]
```

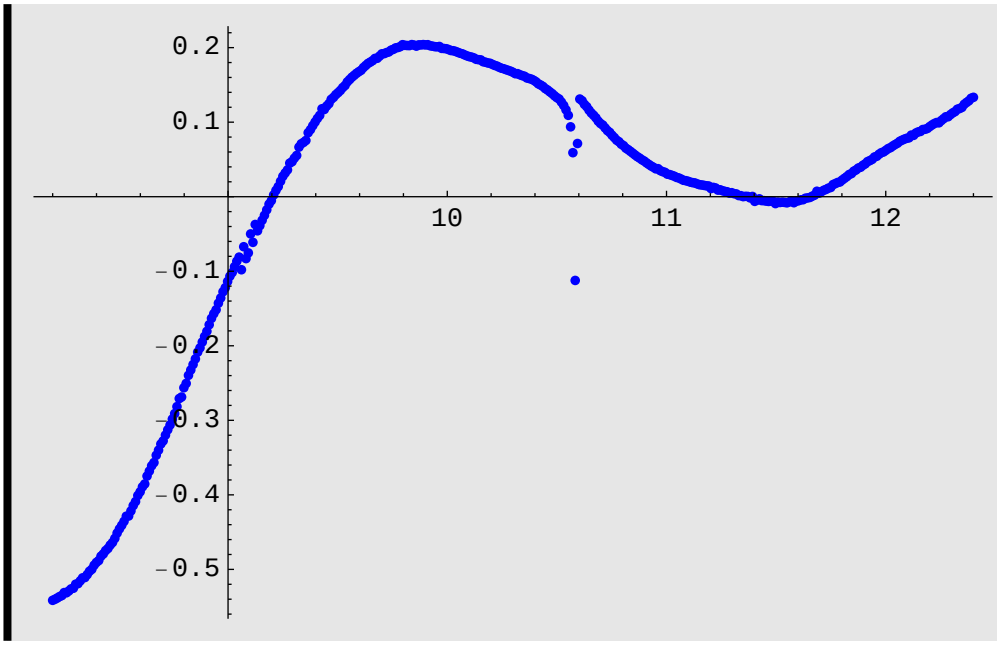



```
inS11fase = ListPlot[InvS11fase,
  PlotStyle → {PointSize[0.012], RGBColor[0, 0.5, 0.5]},
  PlotLabel → "Re S11(f) vs. freq.", AxesLabel → {"f[GHz]", "S11[f]"},
  GridLines → Automatic, Joined → True]
```

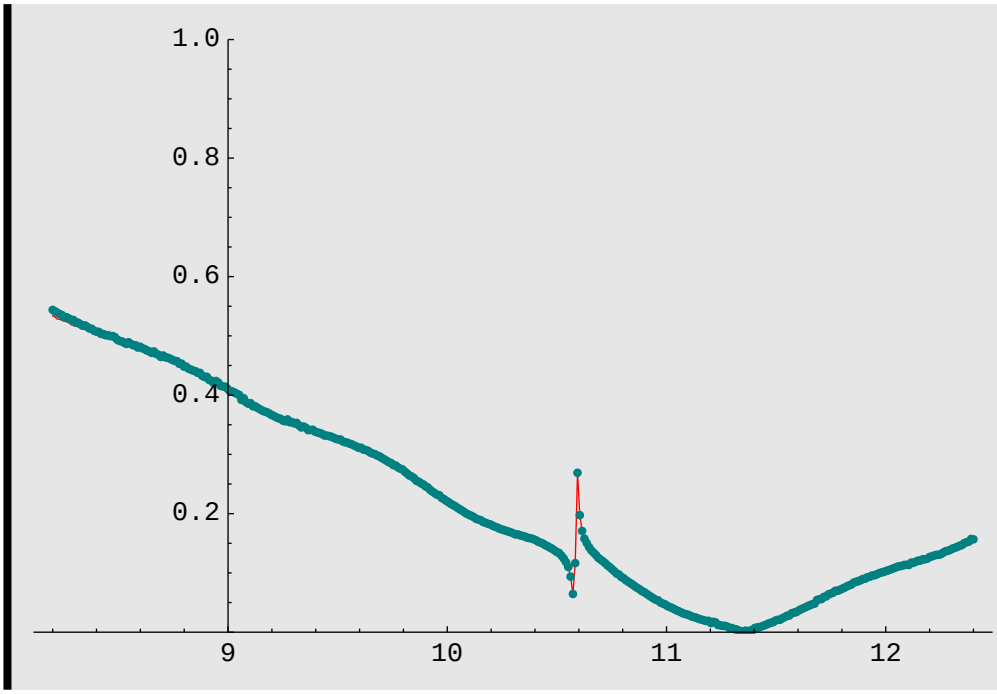


```
in11Re = Table[{f[i], Re[aS11[i]] }, {i, 1, 401}];
```

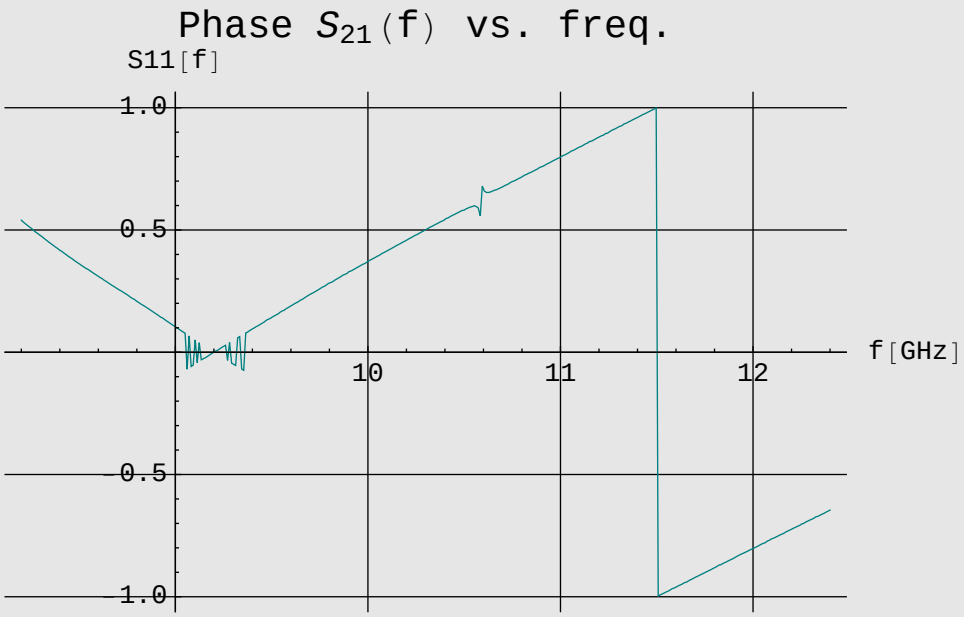
```
invRe11 =
 ListPlot[in11Re, PlotStyle → {PointSize[0.01], RGBColor[0, 0, 1]},
  Joined → False]
```



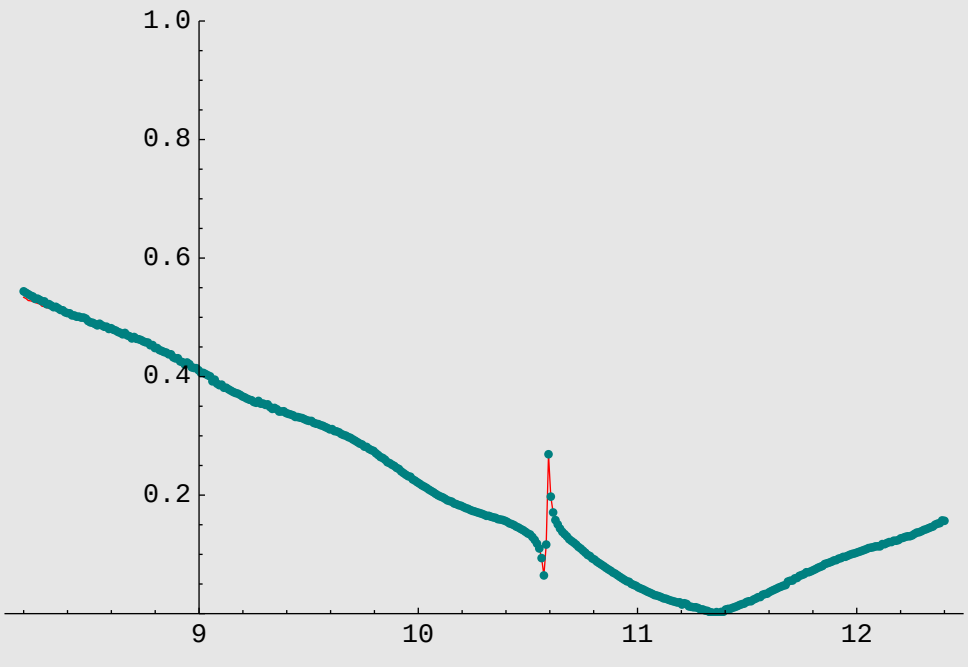

```
Show[Mod11,inS11]
```



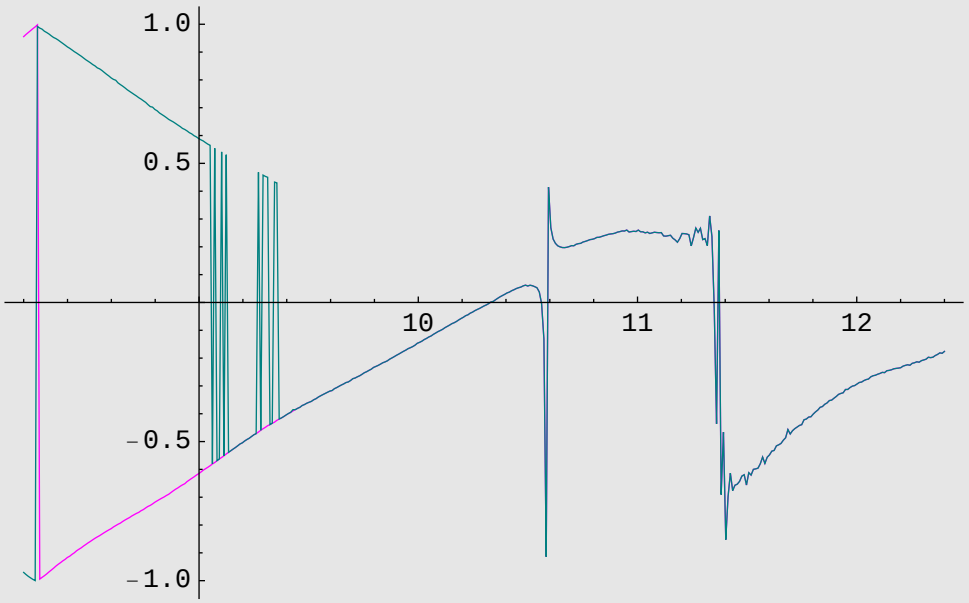
```
inS21fase = ListPlot[InvS21fase,
  PlotStyle → {PointSize[0.012], RGBColor[0, 0.5, 0.5]},
  PlotLabel → "Phase S21(f) vs. freq.",
  AxesLabel → {"f[GHz]", "S11[f]"}, GridLines → Automatic, Joined → True]
```



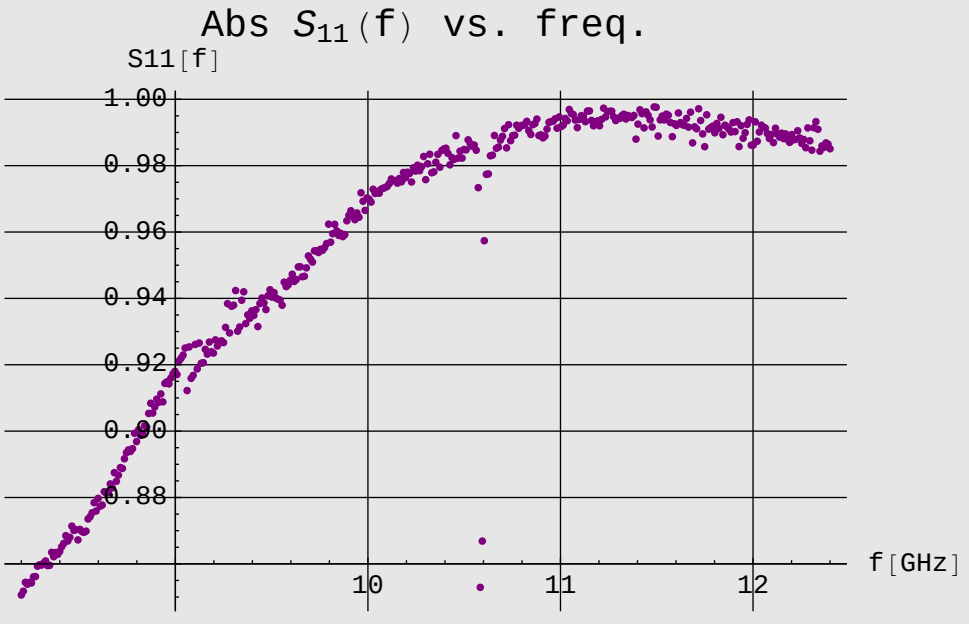

```
Show[Mod11,inS11]
```



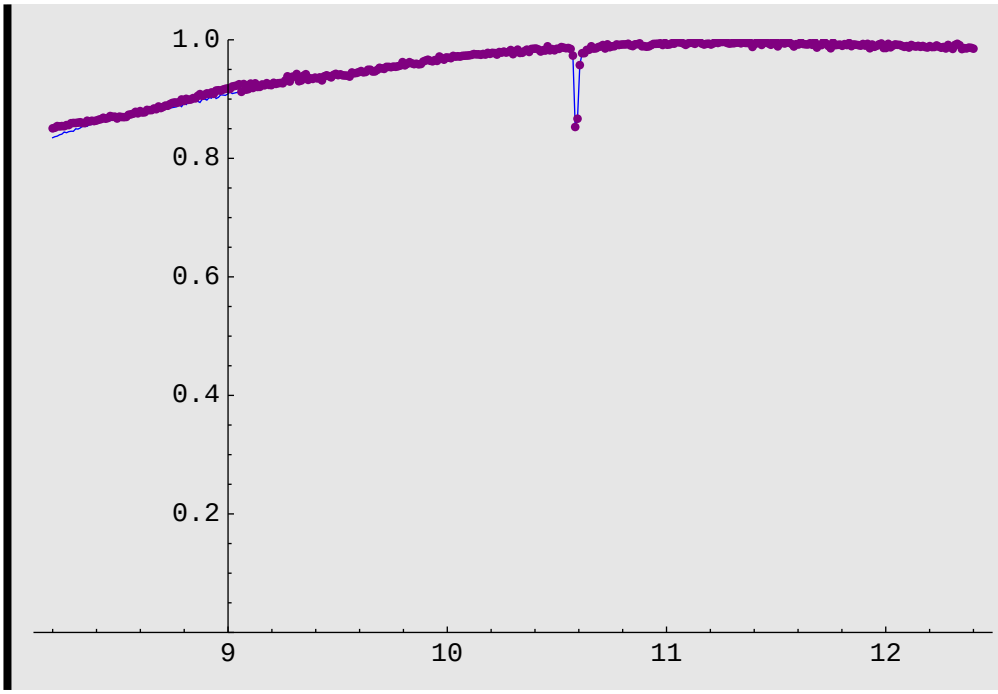
```
Show[Fase11,inS11fase]
```




```
inS21 = ListPlot[InvS21,
  PlotStyle → {PointSize[0.009], RGBColor[0.5, 0.0, 0.5]},
  PlotLabel → "Abs S11(f) vs. freq.", AxesLabel → {"f[GHz]", "S11[f]"},
  GridLines → Automatic]
```

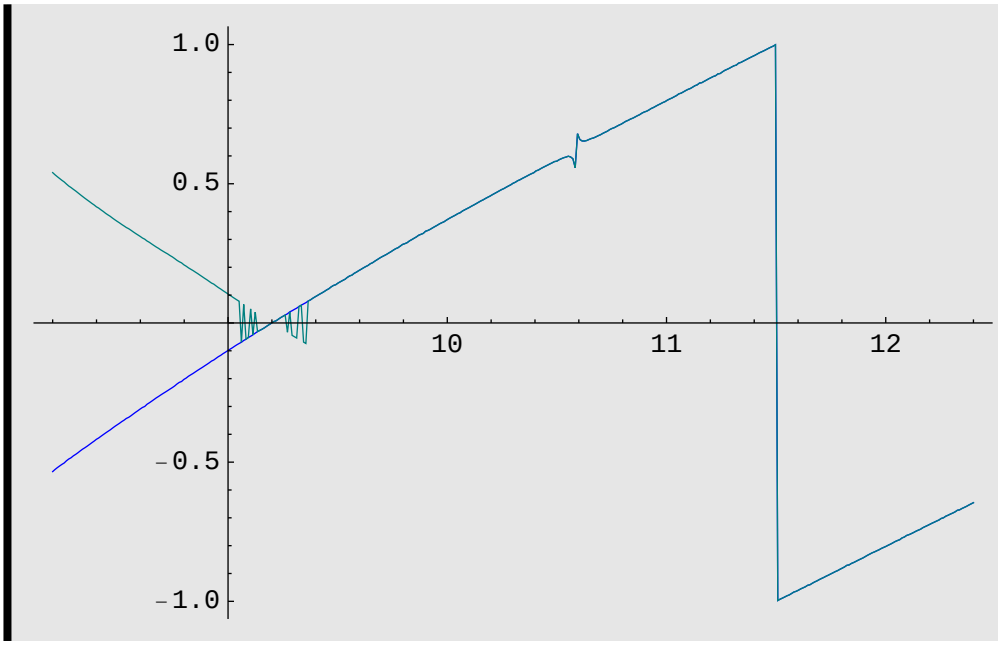


```
Show[Mod21,inS21]
```




```
Show[Mod21]
```

```
Show[Fase21,inS21fase]
```



RETRIEVED PARAMETERS

```
muNRW[i_] := λ0D[i] invΔ2[i] (1.0 + rnrw[i]) / (1.0 - rnrw[i])
```

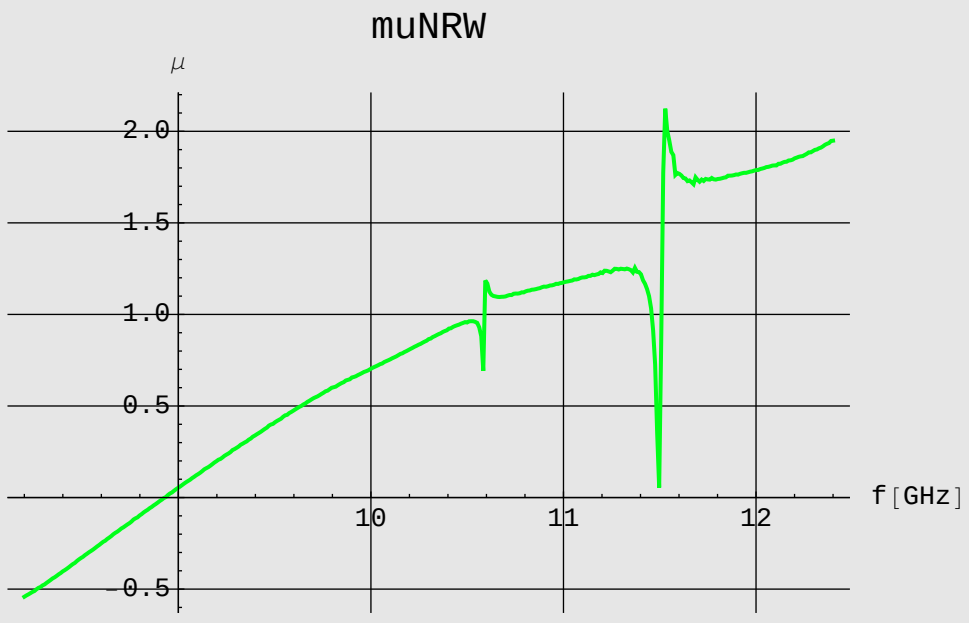
```
muNRW[10]
```

```
-0.479878 - 0.000775324 i
```

```
muTab=Table[{f[i], Re[muNRW[i]], Im[muNRW[i]]},{i,1,401}];
```

```
muTab=Table[{f[i], Re[muNRW[i]]},{i,1,401}];
```

```
muplot = ListPlot[muTab, Joined → True,
  PlotStyle → {AbsoluteThickness[1.5], RGBColor[0, 1, 0.1]},
  PlotLabel → "muNRW", AxesLabel → {"f[GHz]", "μ"},
  GridLines → Automatic, PlotRange → All]
```



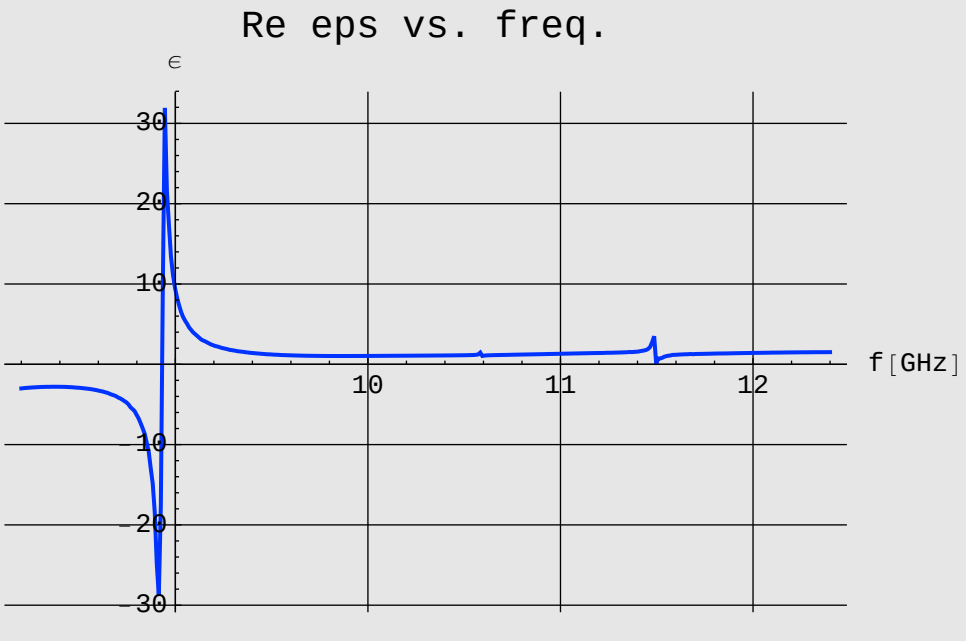

```
epsNRW[i_] := λ0D[i]^2 (invΔ2[i]^2 + (1/λcD)^2) / muNRW[i]
```

$$\text{epsNRW}[i\_] := \frac{\lambda 0D[i]^2 \left(\text{invA2}[i]^2 + \frac{1*1}{\lambda cDX^2}\right)}{\text{muNRW}[i]}$$

```
epsTab=Table[{f[i], Re[epsNRW[i]],Im[epsNRW[i]]},{i,1,401}];
```

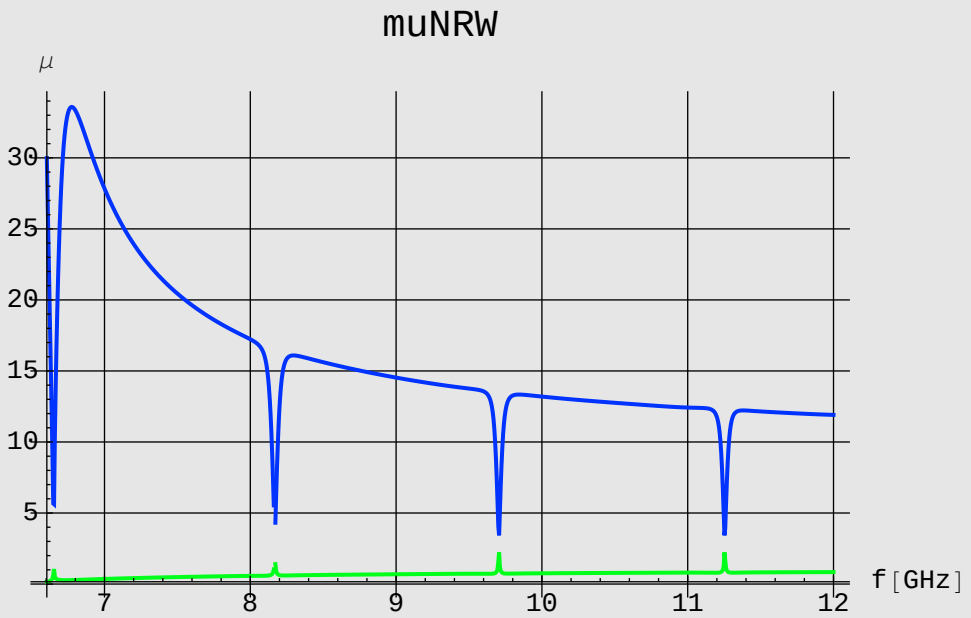
```
epsTab = Table[{f[i], Re[epsNRW[i]]}, {i, 1, 401}];
```

```
epsplot=ListPlot[epsTab,Joined→True, PlotStyle→{AbsoluteThickness[1.5],
RGBColor[0,0.2,1]},
PlotLabel→"Re eps vs. freq.",
AxesLabel→{"f[GHz]","ϵ"},GridLines→Automatic, PlotRange→All]
```




```
Show[Realμ,Realϵ,Realn]
```

```
comp=Show[{muplot, epsplot}]
```



REFRACTIVE INDEX

```
ny[i_] := √(Re[muNRW[i]] Re[epsNRW[i]])
```

```
np[i_] := √(muNRW[i] epsNRW[i])
```

```
nm[i_] := -√(muNRW[i] epsNRW[i])
```

```
sinal[i_] := Which [Im[np[i]] ≥ 0, 1, Im[nm[i]] ≥ 0, -1]
```

```
ListPlot[Table[{f[i],sinal[i]},{i,1,1001}]];
```

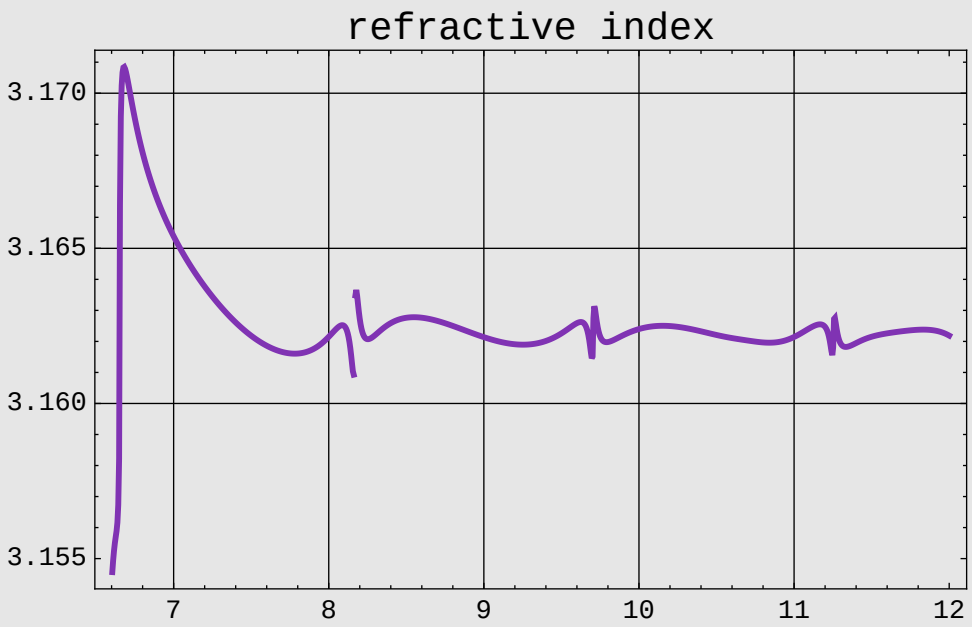
```
nx[i_] := sinal[i] √(muNRW[i] epsNRW[i])
```

```
indep = Table[{f[i], Re[np[i]]}, {i, 1, 1001}];
```

```
index = Table[{f[i], Re[nx[i]]}, {i, 1, 1001}];
```

```
indey = Table[{f[i], Im[nm[i]]}, {i, 1, 1001}];
```

```
indice1 = ListPlot[indep, Joined → True,
  PlotStyle → {AbsoluteThickness[2.2], RGBColor[0.5, 0.2, 0.7]},
  PlotLabel → "refractive index", AxesLabel → {"f[GHz]", "  "},
  GridLines → Automatic,  Frame → True, PlotRange → All]
```




```
indicex = ListPlot[index, PlotJoined → True,
    PlotStyle → {AbsoluteThickness[2.2], RGBColor[0.5, 0.2, 0.7]},
    PlotLabel → StyleForm["refractive index", {"Helvetica", 11}],
    AxesLabel → {"f[GHz]", "  "}, GridLines → Automatic,
    Frame → True, PlotRange → All];
```

```
xx=293;
{f[xx],ny[xx]}
```

```
{8.106, 3.0308}
```

```
ind2=Table[{f[i],Re[nx[i]]},{i,1,1001}];
```

```
indshort=Table[{f[i],Re[np[i]]},{i,285,450}];
```

```
indice2 = ListPlot[index, PlotJoined → True,
    PlotStyle → {AbsoluteThickness[1.8], RGBColor[0.8, 0.1, 0.0]},
    PlotLabel → StyleForm[" ", {"Helvetica", 11}],
    AxesLabel → {"f[GHz]", "  "}, GridLines → Automatic,
    Frame → True, PlotRange → {-0.01, 0.01}];
```

```
ListPlot[indshort, PlotJoined → True,
  PlotStyle → {AbsoluteThickness[1.8], RGBColor[0.8, 0.1, 0.0]},
  PlotLabel → StyleForm[" ", {"Helvetica", 11}],
  AxesLabel → {"f[GHz]", "  "}, GridLines → Automatic, Frame → True,
  PlotRange → {-0.01, 0.01}];
```

```
xx=200;
{f[xx],nn[xx]}
```

```
Show[{indice1, indice2}];
```

Above result for d= 2.5 cm

```
Show[joint];
```

```
epsplot = Plot[{Re[epsNRW[f]], -Im[epsNRW[f]]}, {f, 7, 30},
   PlotStyle → { {AbsoluteThickness[1.5], RGBColor[0, 0, 1]},
     {AbsoluteThickness[1.5], RGBColor[0.5, 0, 0.5] } },
   PlotLabel → StyleForm["eps) vs. freq.", {"Helvetica", 12}],
   AxesLabel → {"f[GHz]", "eps]"}, GridLines → Automatic];
```

OUTPUT TABLE

```
tabS=Table[{f[i],S11mag[i],S21mag[i],phS11[i],phS21[i]},{i, 1, 1001}];
```

```
tabZ=Table[{f[i],Re[Zb[i]],Im[Zb[i]]},{i,1,1001}];
```

```
tabn=Table[{f[i],Re[n[i]], Im[n[i]]},{i,1,1001}];
```

```
tabeps=Table[{f[i], Re[ϵ[i]],Im[ϵ[i]]},{i,1,1001}];
```

```
Zanlt=Table[{f[i],Re[Zbanlt[i]]},{i,1,201}];
```

```
Zbexp=Table[{f[i],Re[Zb[i]]},{i,1,201}];
```

```
tabeps=Table[{f[i], Re[∈mu[i]],Im[∈mu[i]]},{i,1,201}];
```

```
tabmu=Table[{f[i], Re[μB[i]],Im[μB[i]]},{i,1,201}];
```

```
dispersion=Table[{phTZb[i],f[i]},{i,1,1001}];
```

```
Export["C:\\Users\Barroso\Documents\Miguel\Data2\\teflon5mm-eps.txt",
  tabeps, "Table"];
```

```
Export["C:\\Users\Barroso\Documents\Miguel\Data2\\teflon5mm-mu.txt",
  tabmu, "Table"];
```

```
Export[
  "C:\\Users\Barroso\Documents\Miguel\Data2\\teflon5mm-Zbexp.txt",
  Zbexp, "Table"];
```

```
Export["C:\\Users\Barroso\Documents\Miguel\Data2\\teflon5mm-mu.txt",
  tabmu, "Table"];
```

```
Export[
  "C:\\metamaterials\\array new one\\Parametros S SRR new
    one\\ disp.txt", dispersion, "Table"];
```

```
Export[
  "C:\\metamaterials\\array new one\\Parametros S SRR new
    one\\ beta.txt", tab∧1inv, "Table"];
```