Dispersion-Power Relation Code (dp)
(T=7.5ps,   40Gb/s,   5000/50km)

1999. 6. 8   last   revised
2001. 11. 19   slightly revised

```
(*-----Initial Conditions-----------------------------*)
(* LD parameters *)
tfw=7.5    ;PdB=+13    ;GHz=40     ;
wl =1552   ;dGz=200    ;ch =+0.0   ;

(* Fiber parameters *)
s  =50.0   ;aa =0.20   ;Sl =0.07   ;Rt =5.0    ;
Dav=+0.03  ;dDp=0.0    ;kd =5      ;
Dc =+30    ;Nc =1      ;n2 =2.24 10^-20       ;

(* Amplification parameters *)
ka =10     ;NF =+5.0   ;fw =6      ;
Rfil=1.4   ;Rthr=0.3   ;Rdec=0.6   ;

(* Calculation parameters *)
h  =5000   ;dt =1      ;NM =16     ;ym =1.0    ;
kmax=1000  ;kw =100    ;

(* Graphics Array *)
Array[ dp1,{10,21,21}];
Do[ dp1[i,j,k] = 0, {i,10},{j,21},{k,21} ];

Print[ Date[ ]];
Pm = 10 ^ (0.1 PdB);
dm = 1000/GHz/dt;
M  = 2 Quotient[NM dm,2];
dl = 3.34 10^-6 ( wl^2 /(M dt) );
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(*----Pulse shape definition-------------------------*)

 (* Chirped Gaussian *)
kt= 1.665 ; t0= tfw /kt ;m= 1.0    ;
dth=(2 Pi dt dGz)/1000  ;dn =dm/NM ;

EE0=Table[(Exp[ -.5(1 + ch I)((t+7.5dm) dt/t0) ^(2m)]  *0
          +Exp[ -.5(1 + ch I)((t+6.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t+5.5dm) dt/t0) ^(2m)]  *0
          +Exp[ -.5(1 + ch I)((t+4.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t+3.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t+2.5dm) dt/t0) ^(2m)]  *0
          +Exp[ -.5(1 + ch I)((t+1.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t+0.5dm) dt/t0) ^(2m)]  *1

          +Exp[ -.5(1 + ch I)((t-0.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t-1.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t-2.5dm) dt/t0) ^(2m)]  *0
          +Exp[ -.5(1 + ch I)((t-3.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t-4.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t-5.5dm) dt/t0) ^(2m)]  *1
          +Exp[ -.5(1 + ch I)((t-6.5dm) dt/t0) ^(2m)]  *0
          +Exp[ -.5(1 + ch I)((t-7.5dm) dt/t0) ^(2m)]  *0)

          *(+Exp[ +2t dth I ]  *0
          +Exp[ +1t dth I ]  *0
          +     1          *1
          +Exp[ -1t dth I ]  *0
          +Exp[ -2t dth I ]  *0)
                                  ,{t,-M/2,M/2-1} ];

E0 = EE0;
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```
(* Dispersion length -----------------------*)
Lt = kmax h/1000;
La = ka h/1000;
att= 10^( -aa h /40000);
Dp = Dav - ( 1000 Dc )/( 2 h ka Nc );

Ld = t0^2 /Abs[ 5.31 10^-7 wl^2 Dp ];
Lq = t0^3 /Abs[ 2.82 10^-13 wl^4 Sl ];
Ls = 1.571 * Ld;
Print["Dp, dDp    = ",Dp," +- ",dDp,"( ps/nm/km )"];
Print["Dc, Nc     = ",Dc," ( ps/nm ) ",Nc];
Print["Dav,       = ",Dav," ( ps/nm/km )"];

Print["Ld, Lq      = ",Ld,"( km )  ",Lq,"( km ) "];
Print["Lt, Lt/Ls    = ",Lt,"( km )  ",Lt/Ls];
Print["La, La/Ld    = ",La,"( km )  ",La/Ld];

(* Initial width & power -------------------*)
uu = Table[ t ,{t,-M/2,M/2-1} ];
EET= Interpolation[ Re[ E0 ] ];
   Plot[ EET[t],{t,1,M},PlotRange-> {-ym,ym},
              AxesLabel ->{"time","E-field"}];
AE0= (Abs[E0])^2;
EEU= Interpolation[ AE0 ];
TEU= Interpolation[ uu * AE0 ];
TEV= Interpolation[ uu^2 * AE0 ];

IEU= NIntegrate[ EEU[t],{t,1,M},AccuracyGoal->3];
ITU= NIntegrate[ TEU[t],{t,1,M},AccuracyGoal->3];
ITV= NIntegrate[ TEV[t],{t,1,M},AccuracyGoal->3];
Pow= IEU Pm dt GHz /(1000 NM);
trms= Sqrt[ (ITV/IEU) - (ITU/IEU)^2 ] * dt;

Print["W(FWHM),chirp = ",tfw,"( ps )  ",ch ];
Print["Peak Power    = ",Pm,"( mW ) ",
                 N[ 10 Log[10,Pm]],"( dBm )"];
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```
Print["Average Power = ",Pow,"( mW ) ",
                    10 Log[10,Pow],"( dBm )"];

(* Dynamic soliton parameters -------------*)
P0 = 2.63 10^-28 wl^3 s Dp/(n2 tfw^2) *2;
Ga = 10^(aa ka h/10000);
gam= Ga Log[Ga]/(Ga-1);
Pam= P0 * gam;
Ne = Sqrt[ Pm /P0 ];
Nt = Sqrt[ gam ];
Print["P0, Pa, gam  = ",P0,"( mW )  ",Pam,"( mW )  "
     ,gam];
Print["N-exp,N-th   = ",Ne,"   ",Nt ];
Print[" "];

(* Spectrum parameters ---------------------*)
F0 = InverseFourier[ E0 ] ;
tt = Table[ If[ t <= M/2,(t+M/2),(t-M/2)],{t,1,M}];
AF0= Part[ Abs[F0],tt ]^2 ;
FFU= Interpolation[ Reverse[ 10 Log[10,AF0] ] ];
ff = Table[ If[ t <= M/2,(t-1),(t-M-1) ],{t,1,M} ];
fr = ff /(M dt);

(* Dispersion slope -----------------------*)
Dpl= Table[ Dp +Sl(t dl),{t,-M/2,M/2-1} ];
ltf= Table[ -t+M+1,{t,1,M} ];
Ddf= Part[ Dpl,ltf ];
DDT= Interpolation[ Reverse[ Ddf ] ];

(* Initial shape drawing--------------------*)
Plot[ DDT[t],{t,1,M},PlotRange-> {-2,+2},
            AxesLabel ->{"W.L.","D( ps/nm/km )"} ];
Plot[ EEU[t],{t,1,M},PlotRange-> {0,ym},
            AxesLabel ->{"time","Intensity"}];
Plot[ FFU[t],{t,1,M},PlotRange-> {-30,20},
            Frame -> True,GridLines -> Automatic];
```

```
(*---- Pulse propagation by S.S.F.------------------*)

(* y-axis : pulse peak power *)
Do[
  Pm = 10 ^ ( 0.1( 1.0(np-1) + 0 ));
  Print["Peak  =  ",Pm," ( mW )  ",
          10 Log[10,Pm],"( dBm )---------------"];

(* x-axis : fiber dispersion *)
Do[
  Dp = 0.005 (nd-1) - 1000 Dc/(2 ka h Nc) -0.02;
  Ld = t0^2 /Abs[ 5.31 10^-7 wl^2 Dp ];
 (*Print["Dp =  ",Dp,"  ( ps/nm/km )" ];*)

Ei = E0;
Do[
  Dpx= Dp + If[ EvenQ[ Quotient[k,kd]],+dDp,-dDp];

  gm = -1.05 10^-8 wl^2 Dpx fr^2
       +1.16 10^-14 wl^4 Sl fr^3;
  A  =  att Exp[ -(gm h/2)I ];
  B  = -( 3.1416*10^18 (n2/wl) (Pm/s) )I;

  F0 = InverseFourier[Ei];
  E1 = Fourier[A * F0];
(*
(* Raman *)
  AE1= (Abs[E1])^2;
  DE1= Append[ Rest[AE1],First[AE1] ];
  RAM= ( DE1 - AE1 ) * 0.001 Rt/dt ;
  B1 = Exp[ h B ( AE1 - RAM ) ];
  E2 = B1 * E1;
  F2 = InverseFourier[E2];
*)
  B1 = Exp[ h B (Abs[E1])^2 ];
  E2 = B1 * E1;
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  F2 = InverseFourier[E2];

  F3 = A * F2;
  E3 = Fourier[F3];

(*------------Dispersion Compensation-------------*)
If[ Mod[k,ka*Nc] == 0 && OddQ[Quotient[k,ka*Nc]],
  A3 = Exp[ 1.05 10^-5 wl^2 fr^2 Dc I ];
  E3 = Fourier[A3 * F3];
  F3 = InverseFourier[E3]
  ];

(*------------Amplification and Filtering----------*)
If[ Mod[k,ka] == 0,

(* Filter *)
  ktf= 0.6931   ;fm = 1     ;
  fc = dGz M dt/1000;
  fwt= fw / dl;

  FIL= Table[
          +Exp[-ktf Abs[2(f+4fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f+3fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f+2fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f+ fc) /fwt]^(2fm)] *0

          +Exp[-ktf Abs[2f/fwt]^(2fm)] *1

          +Exp[-ktf Abs[2(f- fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f-2fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f-3fc) /fwt]^(2fm)] *0
          +Exp[-ktf Abs[2(f-4fc) /fwt]^(2fm)] *0

                             ,{f,-M/2,M/2-1}];
  FIL= FIL / Max[FIL];
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    F4 = F3 * Sqrt[ Part[FIL,tt] ];
    E4 = Fourier[ F4 ];

(* Amplifier *)
    dAp= 0.0;
    GE4= Interpolation[ (Abs[E4])^2 ];
    IE4= NIntegrate[ GE4[t],{t,1,M},AccuracyGoal->3];
    dmp= If[ EvenQ[ Quotient[k,ka] ]
                       ,10^(-dAp/10),10^(dAp/10)];
    AMP= IEU/IE4 * dmp;
    F5 = F4 * Sqrt[ AMP ];
    E5 = Fourier[ F5 ];

(* Noise *)
    ASE= 0.994 10^-4 * 10^(NF/10) * AMP * (2 GHz/wl);
    WNE= Table[ ( ASE/Pm ) * Exp[6.28 Random[] I],{M}];
    E3 = E5 + Sqrt[ WNE ];
    F3 = InverseFourier[ E3 ];
    ];


(*---- Q-factor Calculation ----------------------------*)
If[ Mod[k,kw] == 0,

(* E-filter *)
    ktf= 0.6931  ;fm = 1  ;
    fwR= Rfil * GHz ( wl^2 10^-8 /2.998 );
    fwQ= fwR / dl;
    FIE= Table[ Exp[ -ktf Abs[ 2f/fwQ ]^(2fm) ]
                              ,{f,-M/2,M/2-1}];
    F4 = F3 * Sqrt[ Part[ FIE,tt ] ];
    E4 = Fourier[ F4 ];

    AE4 = (Abs[ E4 ])^2;
    Ymax= Max[ AE4 ];
    GE4 = Interpolation[ AE4 ];
```
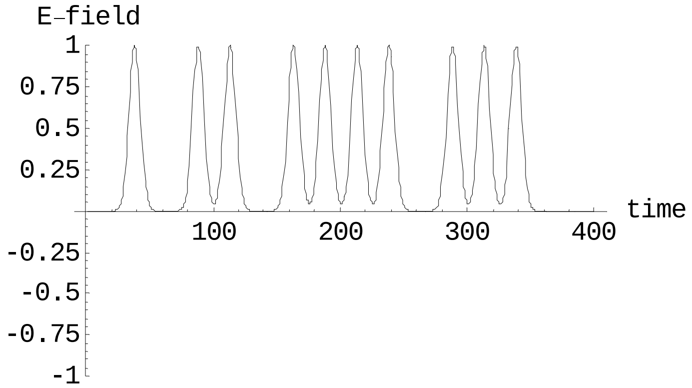

```
(* Auto Search ------------*)
  ww  = AE4;
  AEF = 0;
  Do[
    AEF = AEF + Take[ ww, dm ];
    ww  = Drop[ ww, dm ]
  ,{t,1,NM}];

  GEF = Interpolation[ AEF ];
  IX  = NIntegrate[ GEF[t],{t,1,dm},AccuracyGoal->3];
  AMAX= Max[ AEF ];

  Do[
    CEN = t;
    If[ Part[ AEF,t ] > 0.99 AMAX, Break[ ]]
  ,{t,1,dm} ];

  ww  = AE4;
  If[ CEN > dm/2, ww = Drop[ ww, Round[CEN -dm/2] ]
              , ww = Drop[ ww, Round[CEN +dm/2] ]];
 (*
(* eye-pattern -----------*)
  nn  = Table[ t,{t,1,M} ];
  cn1 = Table[ Mod[(t +dm -CEN), 2dm],{t,1,M} ];
  yey1= { Part[cn1,nn], Part[AE4,nn] };
  eye1= Transpose[ yey1 ];

  cn2 = Table[ Mod[(t -CEN), 2dm],{t,1,M} ];
  yey2= { Part[cn2,nn], Part[AE4,nn] };
  eye2= Transpose[ yey2 ];

  eye = Join[ eye1,eye2 ];
  ListPlot[ eye, Prolog->AbsolutePointSize[3]
             , PlotRange->{0,Ymax}
             (*PlotJoined -> True*) ];
*)
```

```
 (* Q-factor --------------*)
  iww= Interpolation[ ww ];

(* energy
  WD = Rdec * dm;
  PWD= Table[ NIntegrate[ iww[t],{t, (n-.5)dm -WD/2,
                 (n-.5)dm +WD/2}] ,{n,1,NM-1}];*)

(* level *)
  PWD= Table[ iww[(n-.5)dm ] ,{n,1,NM-1}];
  PWE = Sort[ PWD ];
(*Print[ PWE ];*)
  thr = Rthr * Max[ PWE ];

  For[ i=1, PWE[[i]] <thr, i++ ];
  zer = Take[ PWE, i-1];
  one = Drop[ PWE, i-1];
  n0  = Part[ Dimensions[ zer ],1] +0.001;
  n1  = Part[ Dimensions[ one ],1] +0.001;

  zrm= Apply[Plus,zer] /n0;
  zrd= (zer-zrm)^2;
  zrs= Sqrt[ Apply[Plus,zrd] /n0 ];

  oem= Apply[Plus,one] /n1;
  oed= (one-oem)^2;
  oes= Sqrt[ Apply[Plus,oed] /n1 ];

  soz = zrs + oes + 0.0001;
  Qfac= Abs[ (oem-zrm)/soz ];

dp1[ k/kw,np,nd ]= Qfac;
If[ Qfac < 5, Break[] ];
```

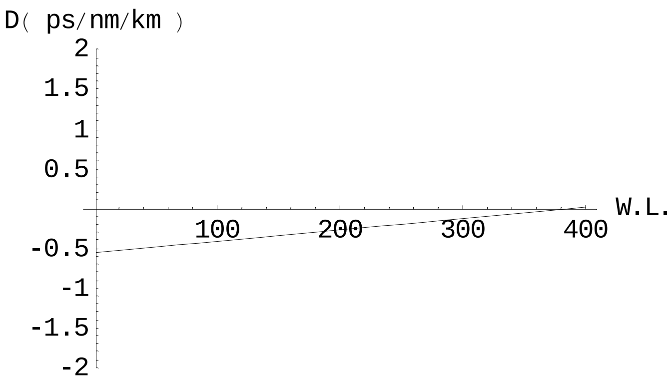
```
(*
(*---- Pulse Shape Drawing ------------------------------*)
   L   = k h /1000;
   AE3 = (Abs[ E3 ])^2;
   Pmax= Max[ AE3 ];
   GE3 = Interpolation[ AE3 ];
   IE3 = NIntegrate[ GE3[t],{t,1,M},AccuracyGoal->3];
   Po3 = IE3 Pm dt GHz /(1000 NM);

   AF3 = Part[ Abs[F3],tt ]^2;
   GF3 = Interpolation[ AF3 ];
   LF3 = Interpolation[ Reverse[ 10 Log[10,AF3] ] ];

   Print[" "];
   Print["L, L/Ls      = ",L,"( km )  ",L/Ls];
 (*Print["Peak Power    = ",Pmax * Pm,"( mW )  ",
                 N[ 10 Log[10,Pmax*Pm]],"( dBm )"];
   Print["Average Power = ",Po3,"( mW )  ",
                        10 Log[10,Po3]"( dBm )"];*)

   Plot[ GE3[t]/Pmax,{t,1,M},PlotRange->{0,ym},
                 AxesLabel ->{"time","Intensity"}];
   Plot[ LF3[t],{t,1,M},PlotRange->{-30,20},
              Frame -> True,GridLines -> Automatic];
*)
   ];

  Ei= E3

,{k,1,kmax} ];
,{nd,1,21} ];
,{np,1,21} ];

Array[ dp1,{10,21,21}] >> C:¥soliton¥dp1.m   ;
Print[ Date[ ]]
(*--------------------------------------------*)
```

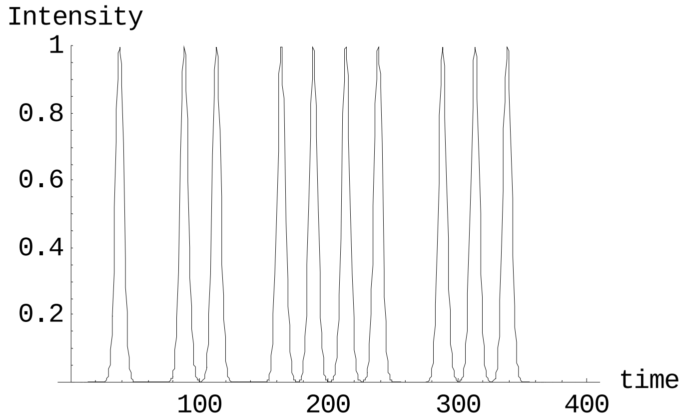
{2001 , 9, 17, 10, 26, 24}

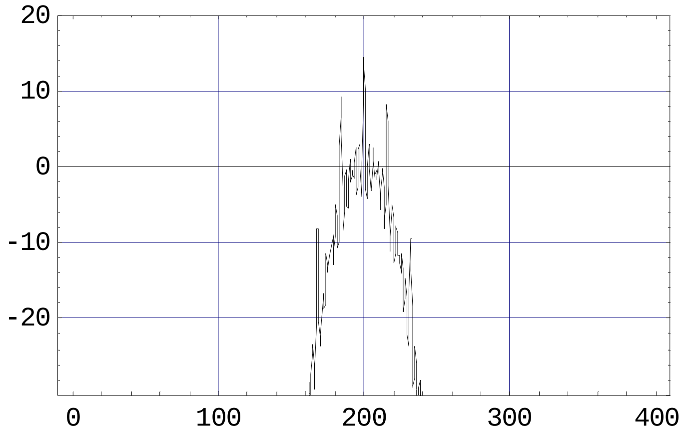
Dp, dDp = −0.27 +− 0. (ps / nm / km)
Dc, Nc = 30 (ps / nm) 1
Dav, = 0.03 (ps / nm / km)
Ld, Lq = 58.756 (km) 798.044 (km)
Lt, Lt / Ls = 5000 (km) 54.1678
La, La / Ld = 50 (km) 0.850977



W (FWHM) ,chirp = 7.5 (ps) 0.
Peak Power = 10. (mW) 10. (dBm)
Average Power = 1.99706 (mW) 3.0039 (dBm)
P0, Pa, gam = −10.534 (mW) −26.9505 (mW) 2.55843
N−exp , N−th = 0. + 0.974323 ⅈ 1.59951







Peak = 1 (mW) 0 (dBm) ---------------

Peak = 1.25893 (mW) 1. (dBm) ---------------

Peak = 1.58489 (mW) 2. (dBm) ---------------

Peak = 1.99526 (mW) 3. (dBm) ---------------

Peak = 2.51189 (mW) 4. (dBm) ---------------

Peak = 3.16228 (mW) 5. (dBm) ---------------

Peak = 3.98107 (mW) 6. (dBm) ---------------

Peak = 5.01187 (mW) 7. (dBm) ---------------

Peak = 6.30957 (mW) 8. (dBm) ---------------

Peak = 7.94328 (mW) 9. (dBm) ---------------

Peak = 10. (mW) 10. (dBm) ---------------

Peak = 12.5893 (mW) 11. (dBm) ---------------

Peak = 15.8489 (mW) 12. (dBm) ---------------

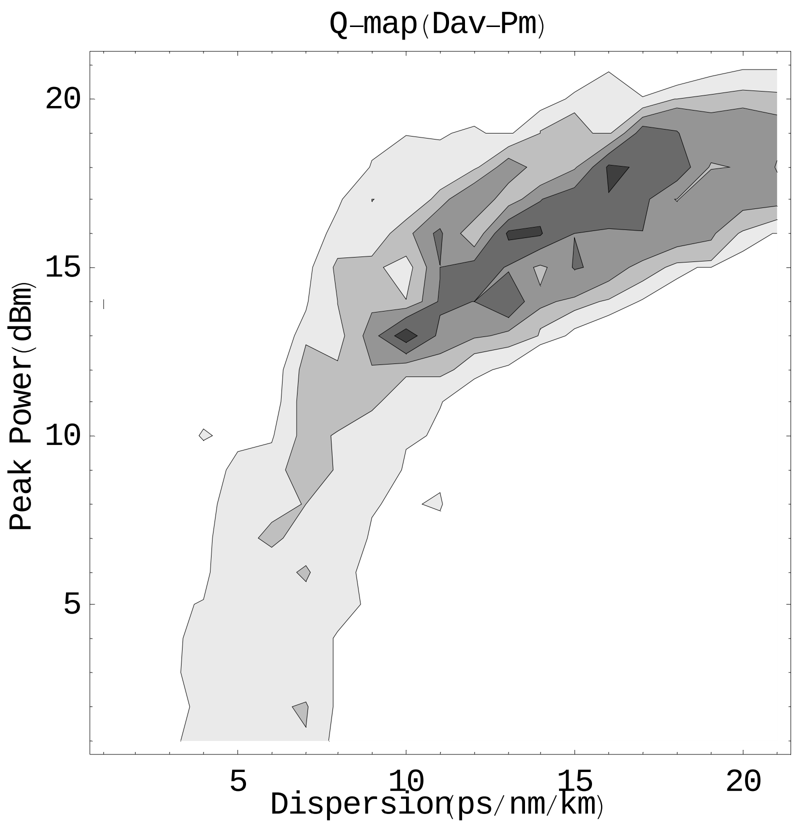
Peak = 63.0957 (mW) 18. (dBm) ---------------

Peak = 79.4328 (mW) 19. (dBm) ---------------

Peak = 100. (mW) 20. (dBm) ---------------

{2001 , 9, 17, 14, 7, 49}

```
(*  T=7.5 ps, 5000/50 km, Fil:6 nm, NF=+5 dBm,
    Dc=+30 ps/nm, h=5000 ,dt=1, NM=16,
    Dav[-0.02,+0.08 ps/nm/km], PdB[+0,+20 dBm] *)
dp1 = << C:\soliton\dp1.m;
Do[
k6  = Part[ dp1, k ];
k7  = Sqrt[k6];
k8  = 20 Log[10, k7];
ListContourPlot[ -k7, PlotLabel -> " Q-map(Dav-Pm) "
, FrameLabel -> {"Dispersion(ps/nm/km)", "Peak Power(dBm)"}
, PlotRange  -> {-4, -16}
, Contours -> {-4, -6, -8, -10, -12, -14, -16}
(*,ColorFunction -> Hue *) ];
, {k, 1, 10} ]
```



```
dp1 = << C:¥soliton¥dp1.m;
Do[
k6  = Part[ dp1,k ];
k7  = Sqrt[k6];
k8  = 20 Log[10,k7];

ListPlot3D[ k7,ViewPoint -> {0,-2,2}
,PlotRange -> {0,7} ]
,{k,1,10} ]
```