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Minimizing Noise-Temperature Measurement Errors

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[redacted] of system temperature measurement errors of low-noise amplifiers has

$$Y = \frac{(T/L) + (Tn/L) + TL + Te}{(T/L) + TL + Te} \qquad (1)$$

and

$$Te = \frac{Te}{} - (T/L) - Tn(1 - 1/L) \qquad (2)$$

calibrated more accurately by a standards laboratory. The approximate value of L, dB, resulting in the minimum Te-rms measurement error, is indicated for each case, except case 5.

A comparison of cases 1 and 2 with cases 3, 4, and 5 shows that with the accuracies assumed, two loads are

References

[1] C. Stelzried, *The Deep Space Network—Noise Temperature Concepts, Measurements, and Performance*, JPL Publication 82-33, Jet Propulsion Laboratory,

[2] C. Stelzried, R. Clauss, W. Rafferty, and S. Petty, "DSN G/T_{op} and Telecommunications System Performance," *TDA Progress Report 42-108*, vol. October–December 1991, Jet Propulsion Laboratory, Pasadena, California, pp. 271–278, February 15, 1991.

[3] C. Stelzried, "Corrections of High-Frequency Noise-Temperature Inaccuracies," *TDA Progress Report 42-111*, vol. July–September 1992, Jet Propulsion Laboratory, Pasadena, California, pp. 169–277, November 15, 1992.

Table 1. Summary of Supercalc 4 computer programs NOISE1ND and NOISE1LD analysis of an LNA noise-temperature measurement delta or error (*DTe*).

Case	Figure	Method	Configuration	L, dB	DTe (rms), K
1	3, 4	1 input load and noise source	$T = 300$ K $Tn = 1000$ K $DYG = 0.01$	20	1.0
2	5, 6	1 input load and noise source	$T = 300$ K $Tn = 60{,}000$ K $DYG = 0.02$	20	1.1
3	7, 8	2 input loads	$T1 = 80$ K $T2 = 300$ K $DYG = 0.01$	10	0.7
4	9, 10	2 input loads	$T1 = 2$ K $T2 = 300$ K $DYG = 0.02$	0	0.3
5	11, 12	2 input loads	$T1 = 2$ K $T2 = 300$ K $DYG = 0.01$	10	0.5

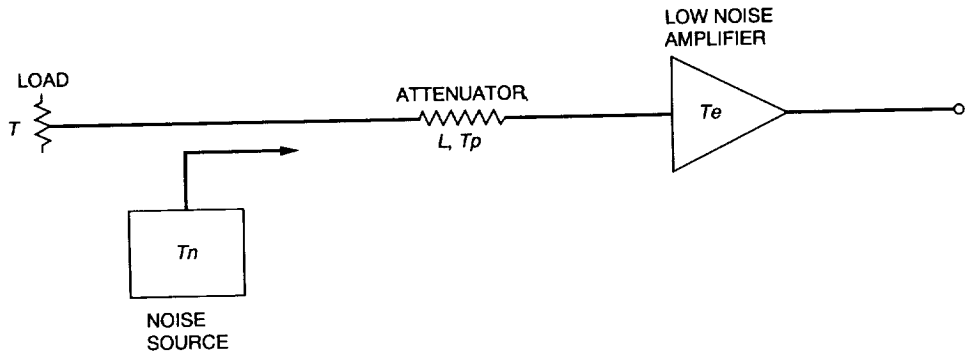

Fig. 1. Low-noise amplifier measurement scheme using a load at temperature *T*, a noise source, and a fixed attenuator.

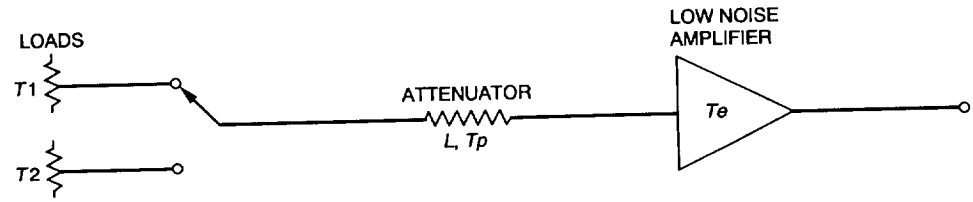

Fig. 2. Low-noise amplifier measurement scheme using two loads at temperatures *T*1 and *T*2 and a fixed attenuator.

INPUT								
T=	300	Tn=	1000	Tp=	2			
DT=	.1	DTn=	50	DTp=	.1	Te=	4	
DYLDB,A=	.01	DLDB,A=	.01	B,MHZ=	50	DYG=	.01	
DYLDB,B=	.01	DLDB,B=	.03	T,SEC=	1			
L,DB		0	3	10	15	20	23	30
L		1	1.995	10	31.62	100	199.53	1000
RESULTS		----------		Te ERROR,K		----------		
DL		.013800	.1366	.4133527	.6030	.7862374	.89317	1.1342
DT	.1	.1	.0501	.01	.0032	.001	.00050	.00010
DTn	50	15.2	7.768	1.79	.7712	.449	.37468	.3149
DTp	.1	0	.0499	.09	.0968	.099	.09950	.0999
DYL		6.59566	3.356	.7500375	.3047	.1645480	.13678	.16922
DYN		.112082	.0575	.0137455	.0065	.0048182	.00528	.01297
DYG		7.72680	3.966	.9466179	.4457	.3284142	.35618	.80217
SUM		29.7483	15.38	4.013754	2.231	1.833018	1.8661	2.5335
RMS		18.2830	9.347	2.200452	1.122	.9821036	1.0458	1.4380
NOMINAL CALC								
TL		0	.9976	1.8	1.937	1.98	1.9900	1.998
Y		4.28947	4.226	3.793296	3.050	2.113586	1.6688	1.1588
YDB		6.32404	6.259	5.790167	4.843	3.250199	2.2241	.64001
Te		4	4	4	4	4	4	4
ERROR CALC								
L,DB		.01	.3	1	10.31	15.46	20.61	23.7	30.91

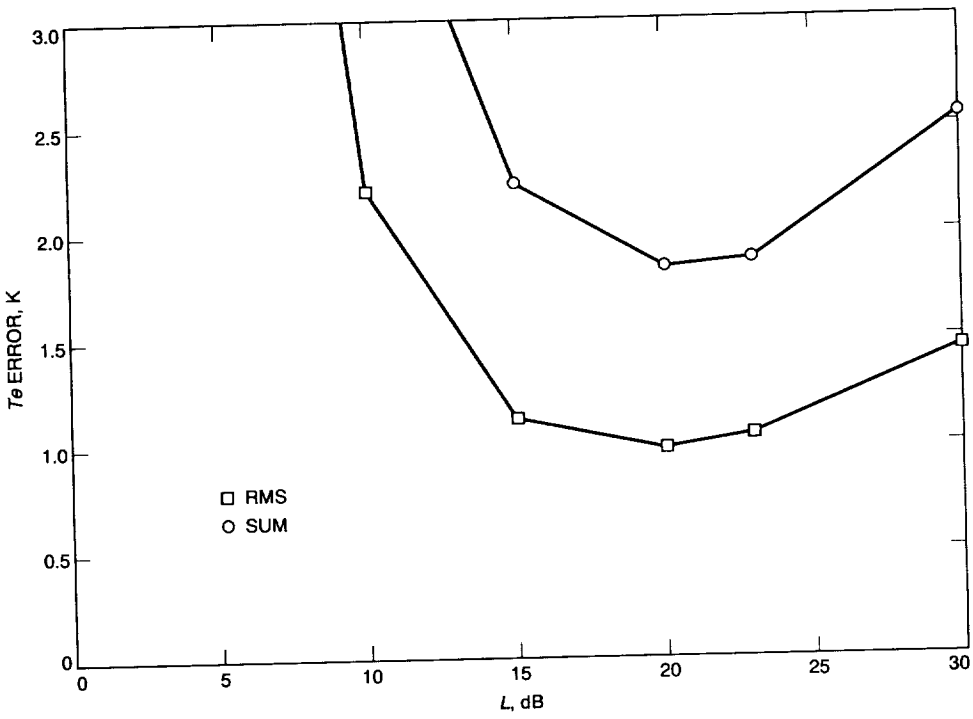

Fig. 4. Plot of the data in Fig. 3.

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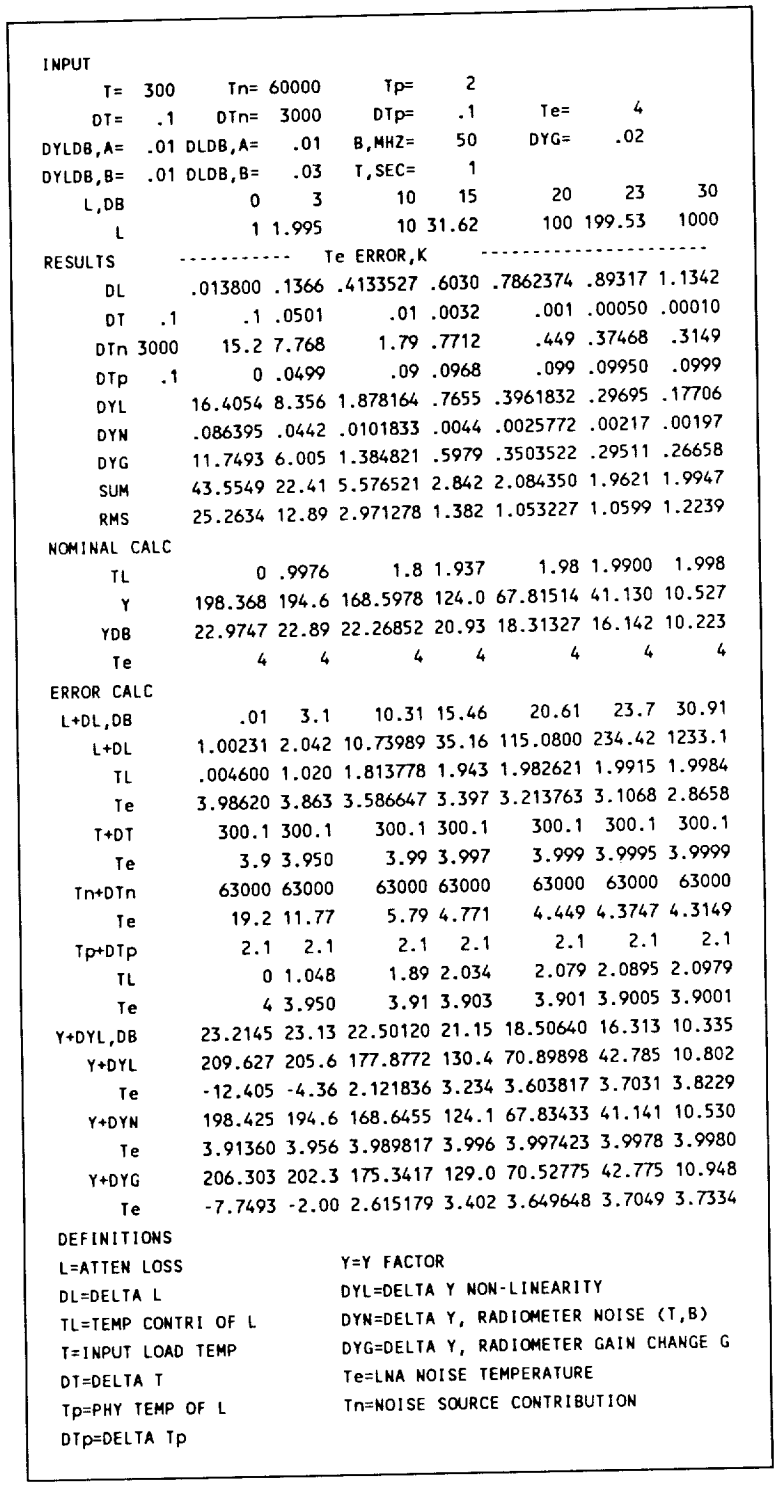

```
INPUT
      T=  300      Tn= 60000      Tp=     2
     DT=   .1     DTn=  3000     DTp=    .1      Te=      4
DYLDB,A=  .01 DLDB,A=    .01   B,MHZ=    50     DYG=    .02
DYLDB,B=  .01 DLDB,B=    .03   T,SEC=     1
    L,DB             0     3       10    15       20      23      30
       L             1 1.995       10 31.62      100  199.53    1000
RESULTS       ----------    Te ERROR,K     ----------
      DL      .013800 .1366 .4133527 .6030 .7862374 .89317 1.1342
      DT   .1       .1 .0501      .01 .0032     .001 .00050 .00010
     DTn 3000    15.2 7.768      1.79 .7712     .449 .37468  .3149
     DTp   .1       0 .0499       .09 .0968     .099 .09950  .0999
     DYL      16.4054 8.356 1.878164 .7655 .3961832 .29695 .17706
     DYN      .086395 .0442 .0101833 .0044 .0025772 .00217 .00197
     DYG      11.7493 6.005 1.384821 .5979 .3503522 .29511 .26658
     SUM      43.5549 22.41 5.576521 2.842 2.084350 1.9621 1.9947
     RMS      25.2634 12.89 2.971278 1.382 1.053227 1.0599 1.2239
NOMINAL CALC
      TL             0 .9976       1.8 1.937     1.98 1.9900  1.998
       Y      198.368 194.6 168.5978 124.0 67.81514 41.130 10.527
     YDB      22.9747 22.89 22.26852 20.93 18.31327 16.142 10.223
      Te             4     4         4     4        4      4       4
ERROR CALC
 L+DL,DB           .01   3.1     10.31 15.46    20.61   23.7   30.91
    L+DL       1.00231 2.042 10.73989 35.16 115.0800 234.42 1233.1
      TL       .004600 1.020 1.813778 1.943 1.982621 1.9915 1.9984
      Te       3.98620 3.863 3.586647 3.397 3.213763 3.1068 2.8658
    T+DT         300.1 300.1     300.1 300.1    300.1  300.1  300.1
      Te           3.9 3.950      3.99 3.997    3.999 3.9995 3.9999
  Tn+DTn         63000 63000     63000 63000    63000  63000  63000
      Te          19.2 11.77      5.79 4.771    4.449 4.3747 4.3149
  Tp+DTp           2.1   2.1       2.1   2.1      2.1    2.1    2.1
      TL             0 1.048      1.89 2.034    2.079 2.0895 2.0979
      Te             4 3.950      3.91 3.903    3.901 3.9005 3.9001
Y+DYL,DB       23.2145 23.13 22.50120 21.15 18.50640 16.313 10.335
   Y+DYL       209.627 205.6 177.8772 130.4 70.89898 42.785 10.802
      Te       -12.405 -4.36 2.121836 3.234 3.603817 3.7031 3.8229
   Y+DYN       198.425 194.6 168.6455 124.1 67.83433 41.141 10.530
      Te       3.91360 3.956 3.989817 3.996 3.997423 3.9978 3.9980
   Y+DYG       206.303 202.3 175.3417 129.0 70.52775 42.775 10.948
      Te       -7.7493 -2.00 2.615179 3.402 3.649648 3.7049 3.7334
DEFINITIONS
L=ATTEN LOSS                  Y=Y FACTOR
DL=DELTA L                    DYL=DELTA Y NON-LINEARITY
TL=TEMP CONTRI OF L           DYN=DELTA Y, RADIOMETER NOISE (T,B)
T=INPUT LOAD TEMP             DYG=DELTA Y, RADIOMETER GAIN CHANGE G
DT=DELTA T                    Te=LNA NOISE TEMPERATURE
Tp=PHY TEMP OF L              Tn=NOISE SOURCE CONTRIBUTION
DTp=DELTA Tp
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Fig. 5. Supercalc 4 computer program NOISE1ND printout of the analysis of Fig. 1, showing the measurement error as a function of attenuator loss *L*, dB, and assumed input parameter errors; noise source = 60,000 K. The higher gain change (*DYG*) than that in Fig. 3 is appropriate for *L* = small attenuation.

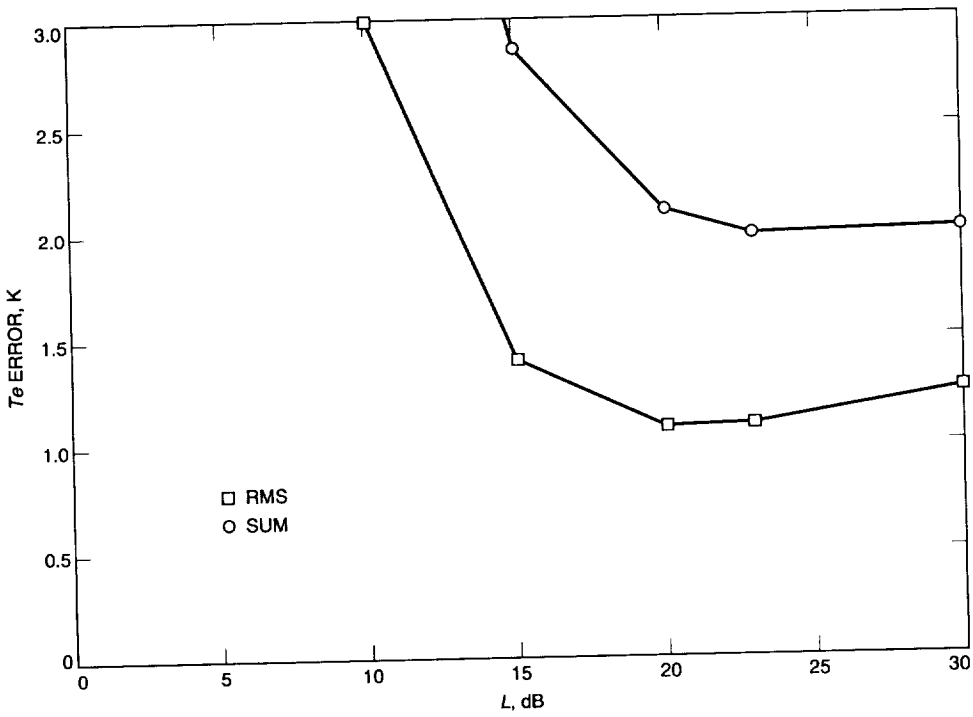


Fig. 6. Plot of the data in Fig. 5.

INPUT

T2=	300	T1=	80	Tp=	2			
DT2=	.1	DT1=	1	DTp=	.01	Te=	4	
DYLDB,A=	.01	DLDB,A=	.01	B,MHZ=	50	DYG=	.01	
DYLDB,B=	.01	DLDB,B=	.03	T,SEC=	1			
L,DB		0	3	10	15	20	23	30
L		1	1.99526	10	31.6228	100	199.526	1000

RESULTS — Te ERROR ,K

DL		.013800	.136577	.4133527	.603015	.7862374	.893172	1.13423
DT2	.1	.038182	.020497	.0062727	.003848	.0030818	.002905	.002763
DT1	1	1.38182	.706154	.1627273	.070107	.0408182	.034062	.028627
DTP	.01	0	.004988	.009	.009684	.0099	.009950	.00999
DYL		1.73695	.919911	.2622773	.153609	.1389508	.165092	.430334
DYN	.00014	.032817	.017963	.0063487	.005306	.0078186	.012261	.048818
DYG	.01	2.25902	1.23585	.4349709	.359467	.5117196	.764731	2.21293
SUM		5.46259	3.04194	1.294950	1.20504	1.498526	1.88217	3.86769
RMS		3.16738	1.70048	.6749003	.722143	.9492989	1.18796	2.52429

NOMINAL

L	NOM	1	1.99526	10	31.6228	100	199.526	1000
TL	NOM	0	.997626	1.8	1.93675	1.98	1.98998	1.998
Y	NOM	3.61905	3.44522	2.594203	1.82170	1.324484	1.17253	1.03620
YDB	NOM	5.58594	5.37217	4.140039	2.60478	1.220466	.691231	.154420
Te	NOM	4	4	4	4	4	4	4

ERROR CALC

L+DL,DB		.01	3.1	10.31	15.46	20.61	23.7	30.91
L+DL		1.00231	2.04174	10.73989	35.1560	115.0800	234.423	1233.10
TL		.004600	1.02044	1.813778	1.94311	1.982621	1.99147	1.99838
Te		3.98620	3.86342	3.586647	3.39699	3.213763	3.10683	2.86577
T2+DT2	300.1							
Te		4.03818	4.02050	4.006273	4.00385	4.003082	4.00290	4.00276
T1+DT1	81							
Te		2.61818	3.29385	3.837273	3.92989	3.959182	3.96594	3.97137
TP+DTP	2.01							
TL		0	1.00261	1.809	1.94644	1.9899	1.99993	2.00799
Te		4	3.99501	3.991	3.99032	3.9901	3.99005	3.99001
Y+DYL,DB		5.65180	5.43589	4.191440	2.64082	1.242671	.708144	.165964
Y+DYL		3.67435	3.49614	2.625089	1.83689	1.331273	1.17710	1.03895
Te		2.26305	3.08009	3.737723	3.84639	3.861049	3.83491	3.56967
Y+DYN		3.62007	3.44619	2.594937	1.82222	1.324858	1.17286	1.03649
Te		3.96718	3.98204	3.993651	3.99469	3.992181	3.98774	3.95118
Y+DYG		3.69143	3.51412	2.646087	1.85814	1.350973	1.19598	1.05692
Te		1.74098	2.76415	3.565029	3.64053	3.488280	3.23527	1.78707

DEFINITIONS

L=ATTEN LOSS
DL=DELTA L
TL=TEMP CONTR OF L
Y=Y FACTOR
DYL=DELTA Y FACTOR NON-LINEARITY
DYN=DELTA Y, RADIOMETER NOISE (T,B)
Tp=PHY TEMP OF L
DTp=DELTA Tp
Te=LNA NOISE TEMP
T1=COLD LOAD TEMP
DT1=DELTA T1
T2=HOT LOAD TEMP

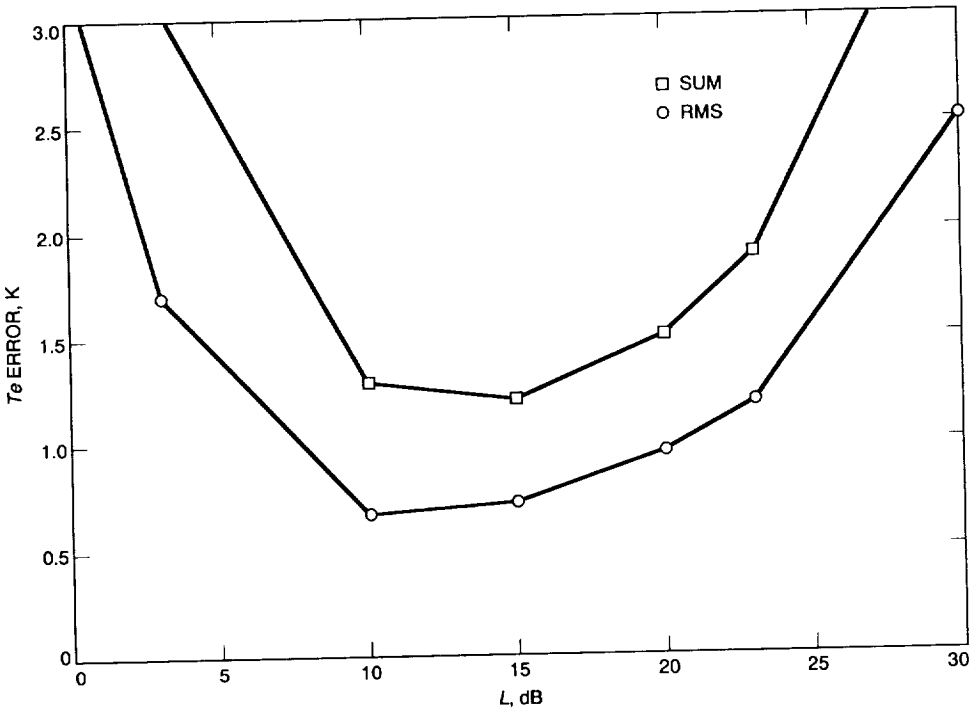
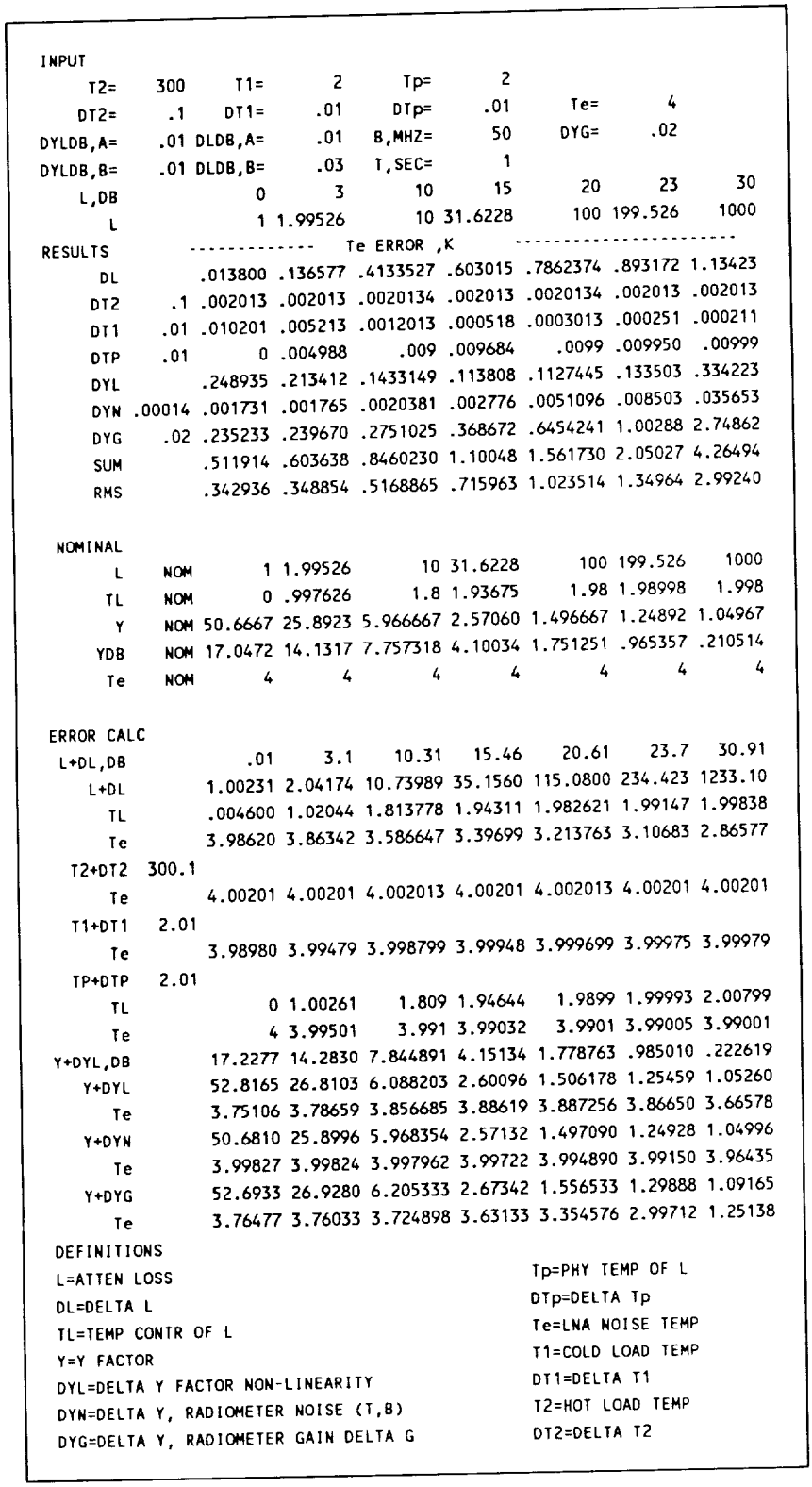


Fig. 8. Plot of the data in Fig. 7.



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INPUT
     T2=   300     T1=       2      Tp=       2
    DT2=    .1    DT1=     .01     DTp=     .01      Te=       4
DYLDB,A=    .01 DLDB,A=     .01    B,MHZ=      50     DYG=     .02
DYLDB,B=    .01 DLDB,B=     .03    T,SEC=       1
   L,DB              0       3        10       15       20       23       30
      L              1 1.99526        10 31.6228      100 199.526     1000
RESULTS         -------------   Te ERROR ,K   ----------------------
     DL         .013800 .136577 .4133527 .603015 .7862374 .893172 1.13423
    DT2     .1 .002013 .002013 .0020134 .002013 .0020134 .002013 .002013
    DT1    .01 .010201 .005213 .0012013 .000518 .0003013 .000251 .000211
    DTP    .01       0 .004988     .009 .009684    .0099 .009950  .00999
    DYL         .248935 .213412 .1433149 .113808 .1127445 .133503 .334223
    DYN .00014 .001731 .001765 .0020381 .002776 .0051096 .008503 .035653
    DYG    .02 .235233 .239670 .2751025 .368672 .6454241 1.00288 2.74862
    SUM         .511914 .603638 .8460230 1.10048 1.561730 2.05027 4.26494
    RMS         .342936 .348854 .5168865 .715963 1.023514 1.34964 2.99240

NOMINAL
      L    NOM       1 1.99526       10 31.6228      100 199.526     1000
     TL    NOM       0 .997626      1.8 1.93675     1.98 1.98998    1.998
      Y    NOM 50.6667 25.8923 5.966667 2.57060 1.496667 1.24892 1.04967
    YDB    NOM 17.0472 14.1317 7.757318 4.10034 1.751251 .965357 .210514
     Te    NOM       4       4       4       4       4       4       4

ERROR CALC
 L+DL,DB             .01     3.1   10.31   15.46   20.61    23.7   30.91
    L+DL         1.00231 2.04174 10.73989 35.1560 115.0800 234.423 1233.10
      TL         .004600 1.02044 1.813778 1.94311 1.982621 1.99147 1.99838
      Te         3.98620 3.86342 3.586647 3.39699 3.213763 3.10683 2.86577
  T2+DT2  300.1
      Te         4.00201 4.00201 4.002013 4.00201 4.002013 4.00201 4.00201
  T1+DT1   2.01
      Te         3.98980 3.99479 3.998799 3.99948 3.999699 3.99975 3.99979
  TP+DTP   2.01
      TL               0 1.00261    1.809 1.94644    1.9899 1.99993 2.00799
      Te               4 3.99501    3.991 3.99032    3.9901 3.99005 3.99001
Y+DYL,DB        17.2277 14.2830 7.844891 4.15134 1.778763 .985010 .222619
   Y+DYL        52.8165 26.8103 6.088203 2.60096 1.506178 1.25459 1.05260
      Te        3.75106 3.78659 3.856685 3.88619 3.887256 3.86650 3.66578
   Y+DYN        50.6810 25.8996 5.968354 2.57132 1.497090 1.24928 1.04996
      Te        3.99827 3.99824 3.997962 3.99722 3.994890 3.99150 3.96435
   Y+DYG        52.6933 26.9280 6.205333 2.67342 1.556533 1.29888 1.09165
      Te        3.76477 3.76033 3.724898 3.63133 3.354576 2.99712 1.25138
DEFINITIONS
L=ATTEN LOSS                                    Tp=PHY TEMP OF L
DL=DELTA L                                      DTp=DELTA Tp
TL=TEMP CONTR OF L                              Te=LNA NOISE TEMP
Y=Y FACTOR                                      T1=COLD LOAD TEMP
DYL=DELTA Y FACTOR NON-LINEARITY                DT1=DELTA T1
DYN=DELTA Y, RADIOMETER NOISE (T,B)             T2=HOT LOAD TEMP
DYG=DELTA Y, RADIOMETER GAIN DELTA G            DT2=DELTA T2
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Fig. 9. Supercalc 4 computer program NOISE1LD printout of the analysis of Fig. 2, showing the measurement error as a function of attenuator loss *L*, dB, and assumed input parameter errors; *T*1 = 2 K and *T*2 = 300 K.

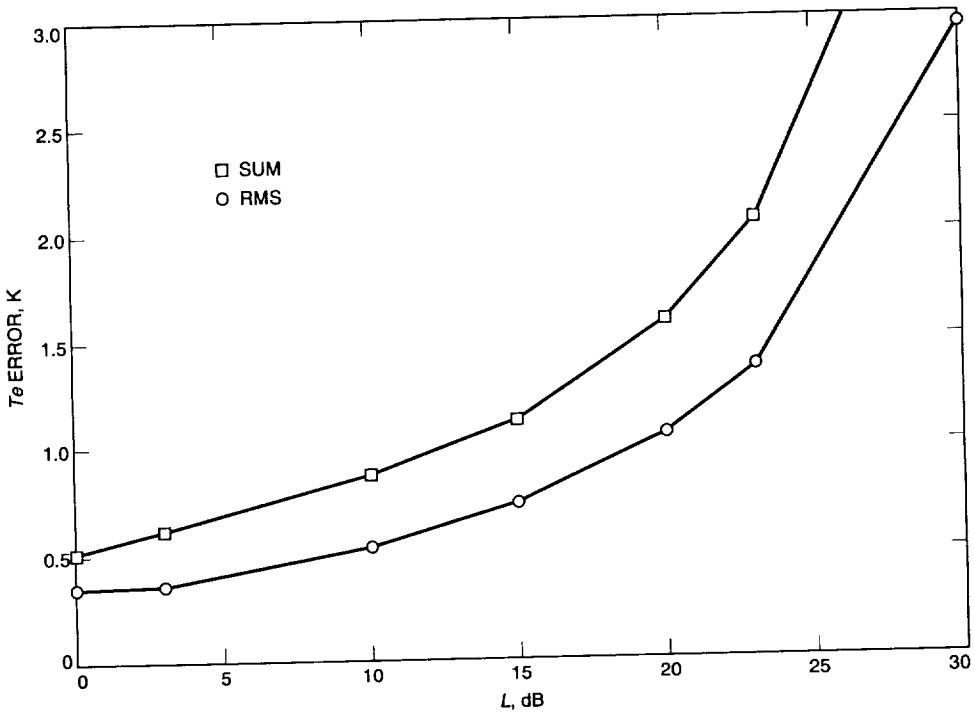
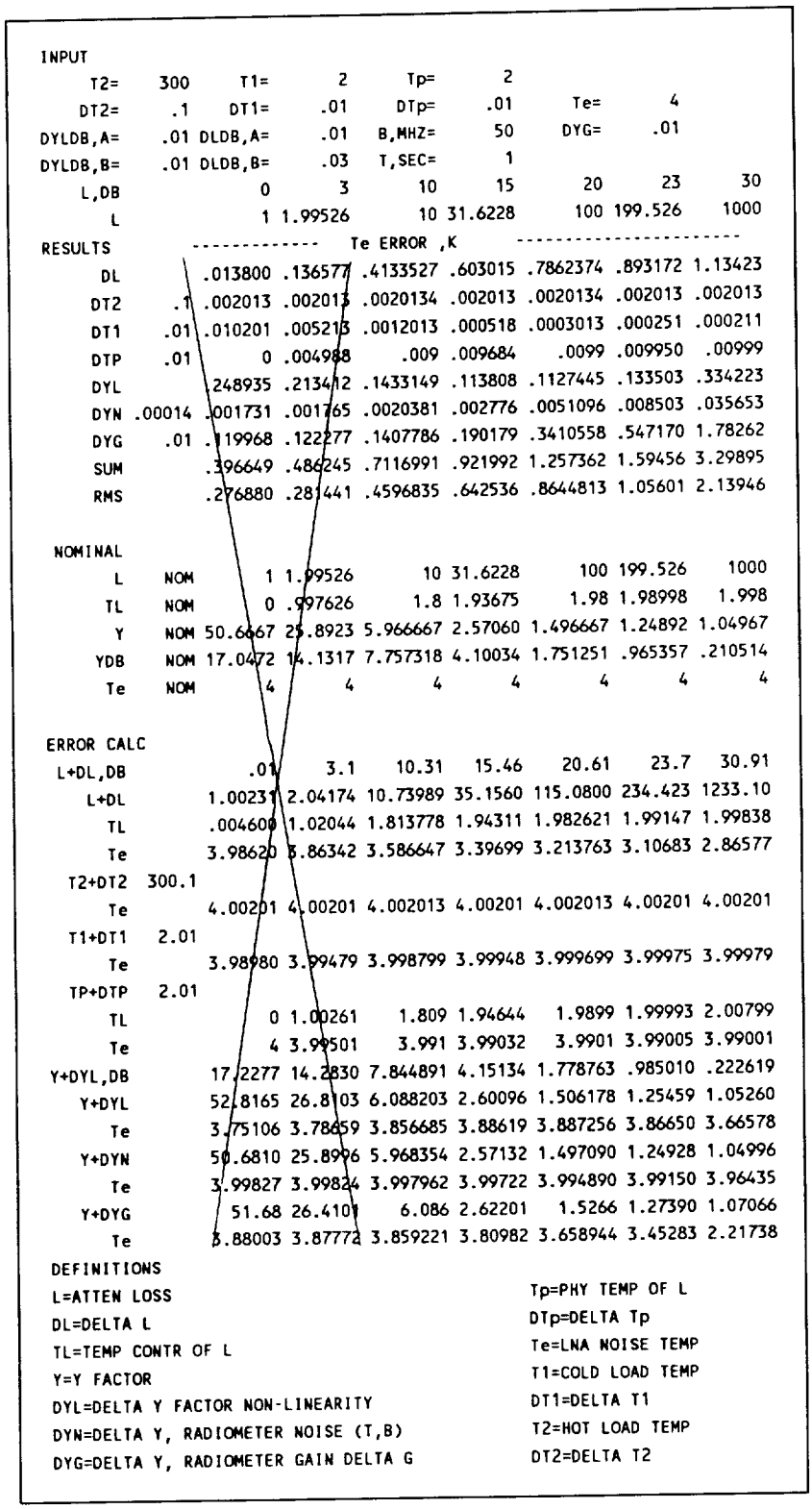


Fig. 10. Plot of the data in Fig. 9.



INPUT

T2=	300	T1=	2	Tp=	2			
DT2=	.1	DT1=	.01	DTp=	.01	Te=	4	
DYLDB,A=	.01	DLDB,A=	.01	B,MHZ=	50	DYG=	.01	
DYLDB,B=	.01	DLDB,B=	.03	T,SEC=	1			
L,DB		0	3	10	15	20	23	30
L		1	1.99526	10	31.6228	100	199.526	1000

RESULTS — Te ERROR ,K

DL		.013800	.136577	.4133527	.603015	.7862374	.893172	1.13423
DT2	.1	.002013	.002013	.0020134	.002013	.0020134	.002013	.002013
DT1	.01	.010201	.005213	.0012013	.000518	.0003013	.000251	.000211
DTP	.01	0	.004988	.009	.009684	.0099	.009950	.00999
DYL		.248935	.213412	.1433149	.113808	.1127445	.133503	.334223
DYN	.00014	.001731	.001765	.0020381	.002776	.0051096	.008503	.035653
DYG	.01	.119968	.122277	.1407786	.190179	.3410558	.547170	1.78262
SUM		.396649	.486245	.7116991	.921992	1.257362	1.59456	3.29895
RMS		.276880	.281441	.4596835	.642536	.8644813	1.05601	2.13946

NOMINAL

L	NOM	1	1.99526	10	31.6228	100	199.526	1000
TL	NOM	0	.997626	1.8	1.93675	1.98	1.98998	1.998
Y	NOM	50.6667	25.8923	5.966667	2.57060	1.496667	1.24892	1.04967
YDB	NOM	17.0472	14.1317	7.757318	4.10034	1.751251	.965357	.210514
Te	NOM	4	4	4	4	4	4	4

ERROR CALC

L+DL,DB		.01	3.1	10.31	15.46	20.61	23.7	30.91
L+DL		1.00231	2.04174	10.73989	35.1560	115.0800	234.423	1233.10
TL		.004600	1.02044	1.813778	1.94311	1.982621	1.99147	1.99838
Te		3.98620	3.86342	3.586647	3.39699	3.213763	3.10683	2.86577
T2+DT2	300.1							
Te		4.00201	4.00201	4.002013	4.00201	4.002013	4.00201	4.00201
T1+DT1	2.01							
Te		3.98980	3.99479	3.998799	3.99948	3.999699	3.99975	3.99979
TP+DTP	2.01							
TL		0	1.00261	1.809	1.94644	1.9899	1.99993	2.00799
Te		4	3.99501	3.991	3.99032	3.9901	3.99005	3.99001
Y+DYL,DB		17.2277	14.2830	7.844891	4.15134	1.778763	.985010	.222619
Y+DYL		52.8165	26.8103	6.088203	2.60096	1.506178	1.25459	1.05260
Te		3.75106	3.78659	3.856685	3.88619	3.887256	3.86650	3.66578
Y+DYN		50.6810	25.8996	5.968354	2.57132	1.497090	1.24928	1.04996
Te		3.99827	3.99824	3.997962	3.99722	3.994890	3.99150	3.96435
Y+DYG		51.68	26.4101	6.086	2.62201	1.5266	1.27390	1.07066
Te		3.88003	3.87772	3.859221	3.80982	3.658944	3.45283	2.21738

DEFINITIONS

L=ATTEN LOSS
DL=DELTA L
TL=TEMP CONTR OF L
Y=Y FACTOR
DYL=DELTA Y FACTOR NON-LINEARITY
DYN=DELTA Y, RADIOMETER NOISE (T,B)
DYG=DELTA Y, RADIOMETER GAIN DELTA G
Tp=PHY TEMP OF L
DTp=DELTA Tp
Te=LNA NOISE TEMP
T1=COLD LOAD TEMP
DT1=DELTA T1
T2=HOT LOAD TEMP
DT2=DELTA T2

Fig. 11. Supercalc 4 computer program NOISE1LD printout of the analysis of Fig. 2, showing the measurement error as a function of attenuator loss *L*, dB, and assumed input parameter errors; *T*1 = 2 K and *T*2 = 300 K. The lower gain change (*DYG*) than that in Fig. 9 is appropriate for case 5, *L* = 10 dB.

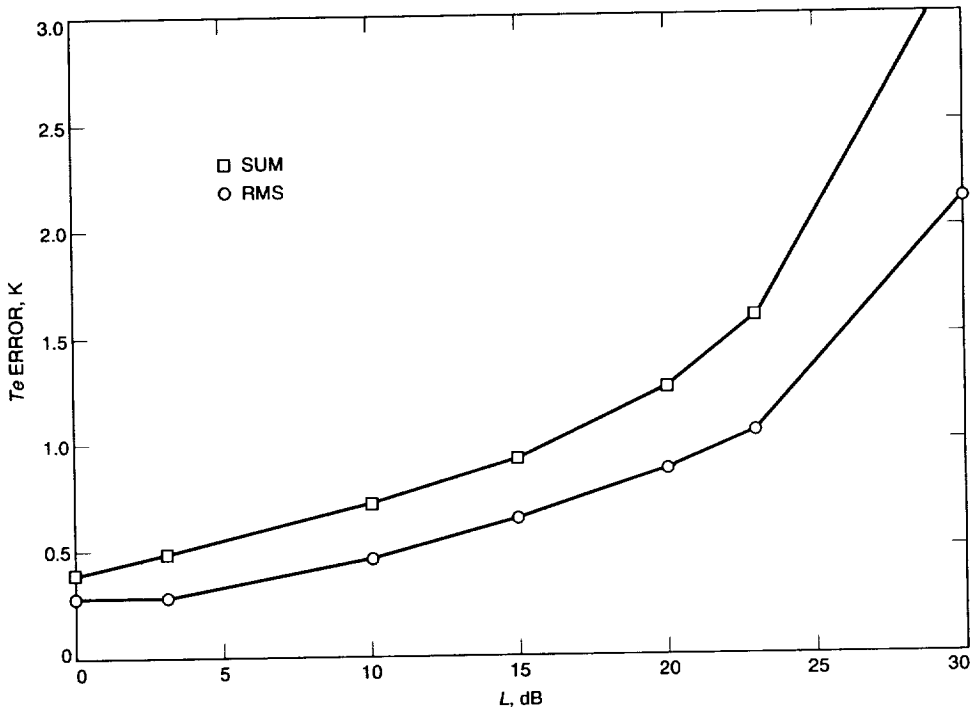


Fig. 12. Plot of the data in Fig. 11.