Long and Short term PHASE STABILITY measurements of microwave Synthesizers for VLBI and RADIO SCIENCE with Cassini

Roberto Ambrosini, Mauro Roma, Sergio Mariotti

Istituto di Radioastronomia, CNR, Bologna (Italy)

IRA 237/97

RAPPORTO INTERNO

CONSIGLIO NAZIONALE DELLE RICERCHE

ISTITUTO DI RADIOASTRONOMIA

Via P. Gobetti, 101 - 40129 BOLOGNA (Italy)

Introduction

One of the most critical condition needed to perform Very Long Baseline Interferometry (VLBI) is to maintain the phase stability of the local oscillator (LO) within less than a radiant over the integration time of the observations. It is easy to show that at our highest operating frequency of 22GHz and along 10 000 seconds, this means a fractional frequency stability or an Allan Deviation of less than 10^{-14}.

An H-Maser frequency standard is at present the most convenient phase reference source for the chain of the local oscillators which allow to downconvert each operating VLBI band into the IF (Intermediate Frequency) accepted by the MarkIII or MarkIV backends.

Because at the time of the LO design for the VLBI bands from 1.4GHz to 22GHz, the upper frequency of commercially available synthesizers was 1.3GHz, it was decided to develop in house only the multipliers [1] and to select the best synthesizers for the long term phase stability performance.

This configuration has been proved to be reliable, versatile and easy to maintain in the past 13 years. In spite of the fact that it cannot give the best short term phase noise, it has been verified that its performance is satisfactory, at least up to 22GHz, for the long integration times typical of VLBI work. Because the Allan Variance of the synthesizer simply enters in a simple sum of the variances of all the other contributors (where the main one is the H-Maser), its value is not multiplied up, regardless of any following multiplier.

Now the Radio Science experiments, planned between an Italian station on the ground and the KaT transponder on board of the Cassini spacecraft, require an overall stability (for the ground segment) of $3*10^{-15}$ @ 1000s to Doppler track the probe downlink at 32GHz.

This tighter specification suggest to revise the local oscillator design for this particular application and all the previous measurements to compare performance versus operational constraints of multifrequency radiotelescopes.

Our measurement setup of the Phase Stability

In order to measure both the short and long term phase stability of different synthesizers we have simply modified the original setup developed for the characterization of H-Masers [2].

The system uses a double balanced mixer as the phase comparator. This is followed by a proper termination and a low-noise preamplifier, whose output is applied, for measurements of the short term phase noise, to a conventional FFT analyzer, while for the long term instabilities (Allan Variance), to a programmable A/D interface and a personal computer to record, at each second, the differential phase between the mixer inputs. An original software code for the PC, build the statistics needed to compute the Allan Variance at 1,2, 5 seconds of the four decades from 1s up to 100 000s.

We compare in phase to equal units or, when available, the unit under test against a "perfect" one. For example we have assumed as perfect, the internal multiplier chain of the H-Maser between 5 MHz and 1.3Ghz (both these signals are available externally). This has been chosen as the standard setup for all our tests of the synthesizers, because they usually lock into and generate these two frequencies.

While the measuring procedure is pretty straightforward, the initial calibration can be cumbersome. In fact to avoid systematic effects we use the same (slow) A/D converter also for the measurement of the K_v factor (the voltage to phase conversion factor of the mixer and its following conditioning amplifier).

With most of the microwave synthesizers, we had to use an independent Rb frequency standard to generate the very low beat note (less than 0.1 Hertz) needed by the A/D to accurately determine K_v.

For every new measuring setup, we have also checked the proper "linear" operation of the mixer as a phase detector, by selecting the mixer terminations and input power levels which gave a sufficiently low harmonic content, when there was a beat note between the two units (unlocked condition). Another computer program has been written to predict the worst case effect of any achieved set of harmonic levels and then fix their maximum acceptable level.

The measurements

We present here the Allan Variance measurements of HP8662A, HP8664A, Racal-Dana 9087, MI 2041, Wiltron 68159 and HP83711B, we had available in our laboratory, at different times over the last ten years.

Typically a measuring session lasts 50 000s (14 hours, i.e. one night) and is divided in batches of 5000s each (1.4 hours). This choice gives good statistical confidence for the Allan deviation at 1000s and reasonable estimates of the 10 000s values. The single batches allow to identify anomalous or sporadic behaviors. Overnight there is the quietest environment and is the most convenient arrangement also for the operator: one starts the session, after an all day of verifications and calibrations and gets the results, as the first thing in the morning of the following day.

After each batch, a full page is printed:

- the first six rows show the main input parameters and the maximum excursions in ambient temperature and differential phase, over that particular batch;
- in the following table field, the left one, called "Last Batch", reports for each integration time the number of data points used and the measured Allan Deviations over the last batch; the right table instead reports, in the same format, the cumulative statistics since the beginning of the measuring session;
- the first central plot, which follows, is the time history, over the last batch, of three different quantities: the Allan Deviation at 1s (a small square), the

ambient temperature (segmented line) and the differential (output) phase (a small cross);

- the final plot shows the cumulative Allan Deviations, as measured at each integration time. The actual result figures are plotted with a cross symbol, while the error bars with two squares. As an absolute reference all over the measurements, the typical H-Maser performance specifications are shown as the segmented line in the middle of the plot.

For the sake of simplicity we show here only the final page of the last batch, for each synthesizer. The intermediate pages have been extremely useful to diagnose failures or perturbations over the unattended periods of the measuring sessions and verify the consistency from one batch to the other.

Most of the synthesizers have been measured both in the quietest possible environment and with an ambient temperature gradient.

It is well known that the ambient temperature variations are the primary responsible for the deterioration of the Allan Variance at long integration times (with respect to the "white phase noise" τ^{-1} slope).

Because the synthesizers will operate in a real thermal environment, with a typical excursion of +/- one degree C, we have tried to simulate these conditions by cycling the ambient temperature of a similar amount during the measurement sessions.

For each synthesizer we generally present a chart recorder printout (noise bandwidth of a few Hertz) and the final pages of two measuring session: one under optimum (laboratory) temperature environment and one with a temperature cycling. The signs E4 (E5) stands for Efos4 (Efos5), which are the serial names of our H-Masers. In this particular case, we refer to their internal multipliers from 5MHz to 1260 or 1440MHz.

An example of the system noise floor is shown in the last file. To simulate the worst case conditions, the ambient temperature was varied of almost five degrees, during this test. The results are 4E-15 @ 1s and 3E-16 @ 100s.

Conclusions

Until now we have been using, in the vertex cabin of the Medicina and Noto radiotelescopes, a single synthesizer which drives all the local oscillators for the 1.4GHz, 1.6GHz, 5GHz, 6GHz, 12GHz and 22GHz band receivers, located either in the cassegrain or in the primary focus. The dual band S/X receiver, in the primary focus box, uses instead a dedicated PLL unit, which is directly locked to the 5MHz of the H-Maser and has two outputs at 2020MHz and 8080MHz.

At first we have used for this synthesizer the HP8667A, then we selected the Racal-Dana 9087 for its better performance at longer integration times (100 - 1000s) over the temperature gradients typical for our vertex cabin. Unfortunately this instrument has been proven to be unreliable and with poor repair capability (at least in Italy). Now we use the HP8664A mainly for its extended frequency range up to 2GHz.

For completeness we report here also the results for the MI2041 and the Wiltron sweeper we use in the scalar network of the laboratory.

Looking ahead in the future, our Institute has planned to rebuild all the receivers with a quasi continuous coverage from 1.4GHz up to 43GHz. From the operational convenience it comes out that the best solution should be a full microwave synthesizer from 1GHz up to 18GHz. This is the reason why we have recently measured the HP83711B.

Unfortunately, at the time of measurement, we did not have a sufficiently good source to make a phase comparison around 18GHz, where we plan to have the first LO for the higher bands, so we have duplicated our usual scheme against the internal multiplier of the H-Maser.

As a not essential feature but very convenient for our present distribution of the H-Maser reference, we have been able to verify experimentally that, in spite of the declared 10MHz input, the HP83711B can easily lock also to a 5MHz input, showing the same phase stability.

Compared to the new tighter specification of the 32GHz receiver which will be dedicated to the Radio Science experiments with Cassini, the HP83711B shows only a marginal performance at τ = 1000s, even when it is kept in the best possible thermal environment (the Maser room, which has a double thermal control within +/-0.1°C).

Moreover it is not clear how our measurements at 1.4GHz can be converted for a typical output of 18GHz, mainly because it seems impossible to know (at least in Italy) what is the frequency synthesis scheme of that instrument.

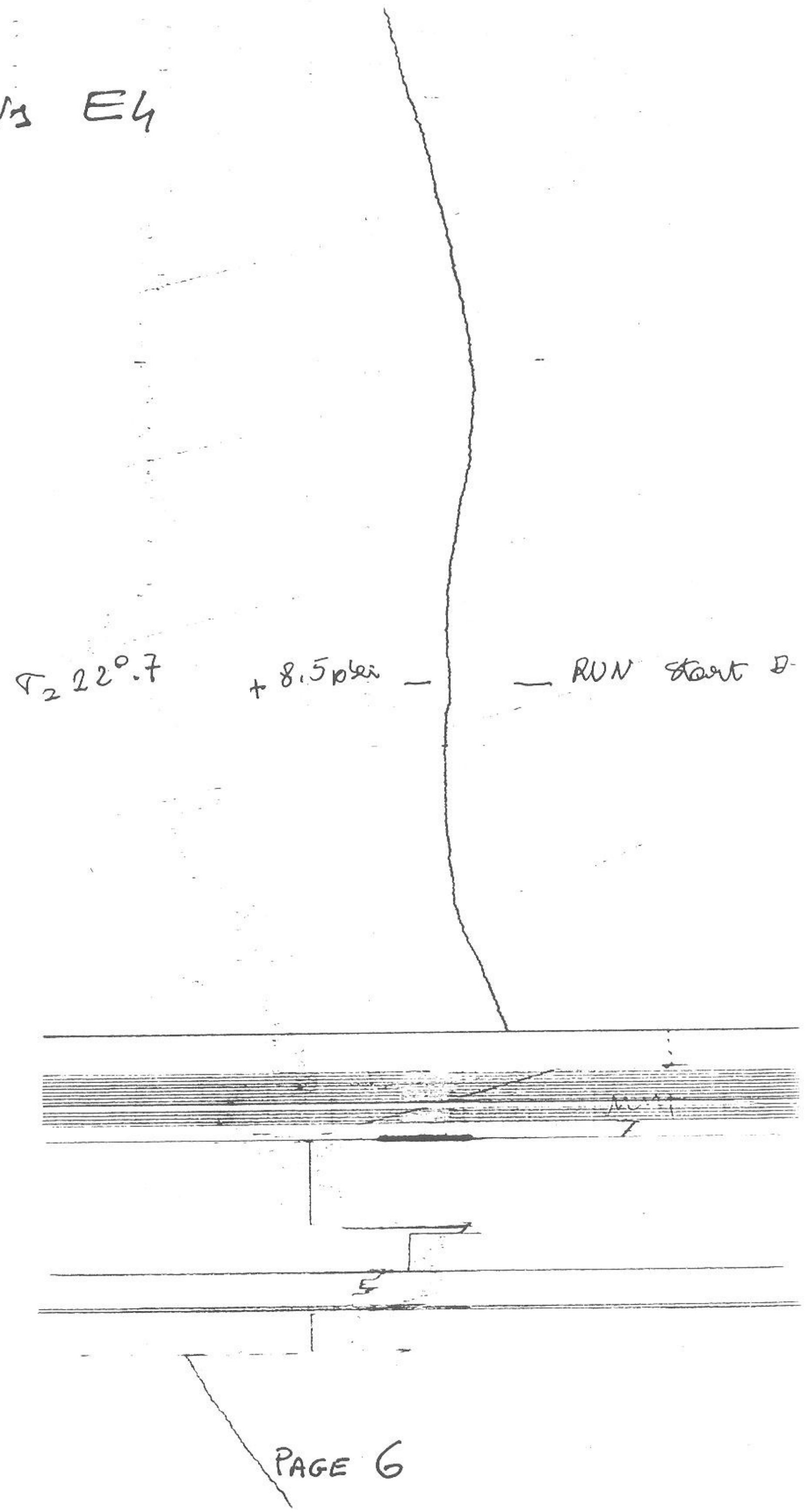
On the other end, because at the longer integration times the dominant elements to the (slow) phase variations of the radiotelescope are the coaxial cables which are exposed to the outside ambient temperature and because to compensate for this it is required a "Phase Calibrator" anyway, it can be expected that also the Allan Variance at 1000s could be improved by a fast calibration cycle every 60s or so. In this case the contribution of the synthesizer should be minimized.

References

[1] G. Tomassetti, "I moltiplicatori di frequenza a Mesfet come oscillatore locale per i ricevitori VLBI di Medicina", Rapporto Interno, IRA 61/84

[2] R. Ambrosini, M. Caporaloni, "A simple and versatile phase comparison method can accurately measure long term instability", IEEE-Transactions on Instrumentation and Measurements, IM-37, 127 (1988).

RD#4 vs E4

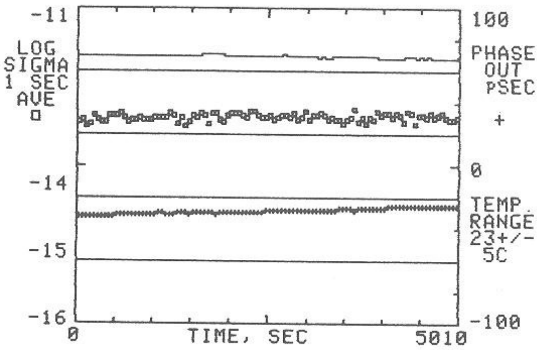


RD#4 vs E4 -high temp- RUN#2

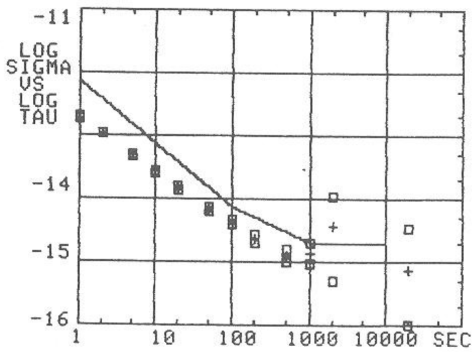
PNA program of 17/3/86
Mixing Frequency=1260MHz
Phase detector SLOPE=7047mV/Rad
RUN START 14:30.7 17/03/86
BATCH START 04:17.4 18/03/86
BATCH END 05:41.1 18/03/86

Reference is assumed PERFECT
PH-max=-25.2 PH-min=-33.3
OFFSET=1623mV
TLOW=26.36C, THIGH=26.5C
TEMP=26.46C PHASE=-32.5PS
TEMP=26.4C PHASE=-25.6PS

TAU (Sec.)	LAST BATCH DATA PTS	LAST BATCH SIGMA (E-15 units)	CUMULATIVE DATA PTS	CUMULATIVE SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	183.2	53468	190.7	0.2
2	2503	106.3	26723	109.8	0.2
5	1000	46.3	10676	48.8	0.2
10	499	27.3	5327	26.8	0.3
20	249	13.0	2658	14.7	0.3
50	99	5.7	1056	6.8	0.3
100	49	3.8	522	4.3	0.4
200	24	2.5	255	2.3	0.5
500	9	1.1	95	1.3	0.7
1000	4	0.3	42	1.4	1.4
2000	0	0.0	3	3.7	7.5
5000	0	0.0	0	0.0	0.0
10000	0	0.0	0	0.0	0.0
20000	0	0.0	1	0.7	14.2
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



No
Temp. grad

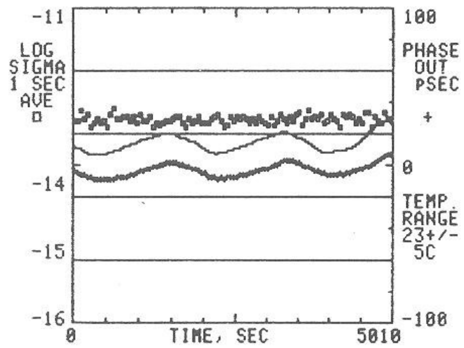


RD#4 vs E4 1260MHz

PNA program of 24/3/86
Mixing Frequency=1260MHz
Phase detector SLOPE=6508mV/Rad
RUN START 17:02.2 15/05/86
BATCH START 05:45.0 16/05/86
BATCH END 07:08.7 16/05/86

Reference is assumed PERFECT
PH-max=5.9 PH-min=-10.7
OFFSET=-1672mV
TLOW=23.23C, THIGH=24.4C
TEMP=23.64C PHASE=-4.4PS
TEMP=24.33C PHASE=5.4PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	165.2	50080	167.7	0.2
2	2503	85.1	25030	89.4	0.2
5	1000	40.1	10000	41.5	0.2
10	499	21.6	4990	22.3	0.2
20	249	10.5	2490	11.7	0.2
50	99	5.4	990	5.6	0.3
100	49	5.3	490	4.9	0.5
200	24	6.6	240	6.3	1.3
500	9	12.2	90	10.8	5.4
1000	4	6.7	40	9.7	9.7
2000	3	1.3	24	2.1	4.2
5000	1	0.7	9	3.3	16.7
10000	1	1.4	4	2.7	26.8
20000	0	0.0	1	2.0	40.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0

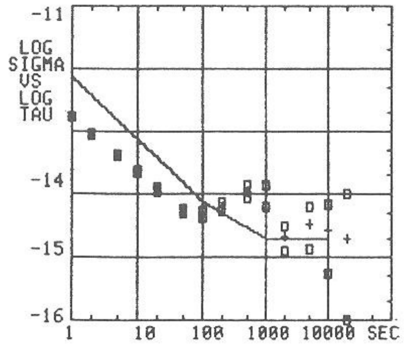


Tcool = 15.6

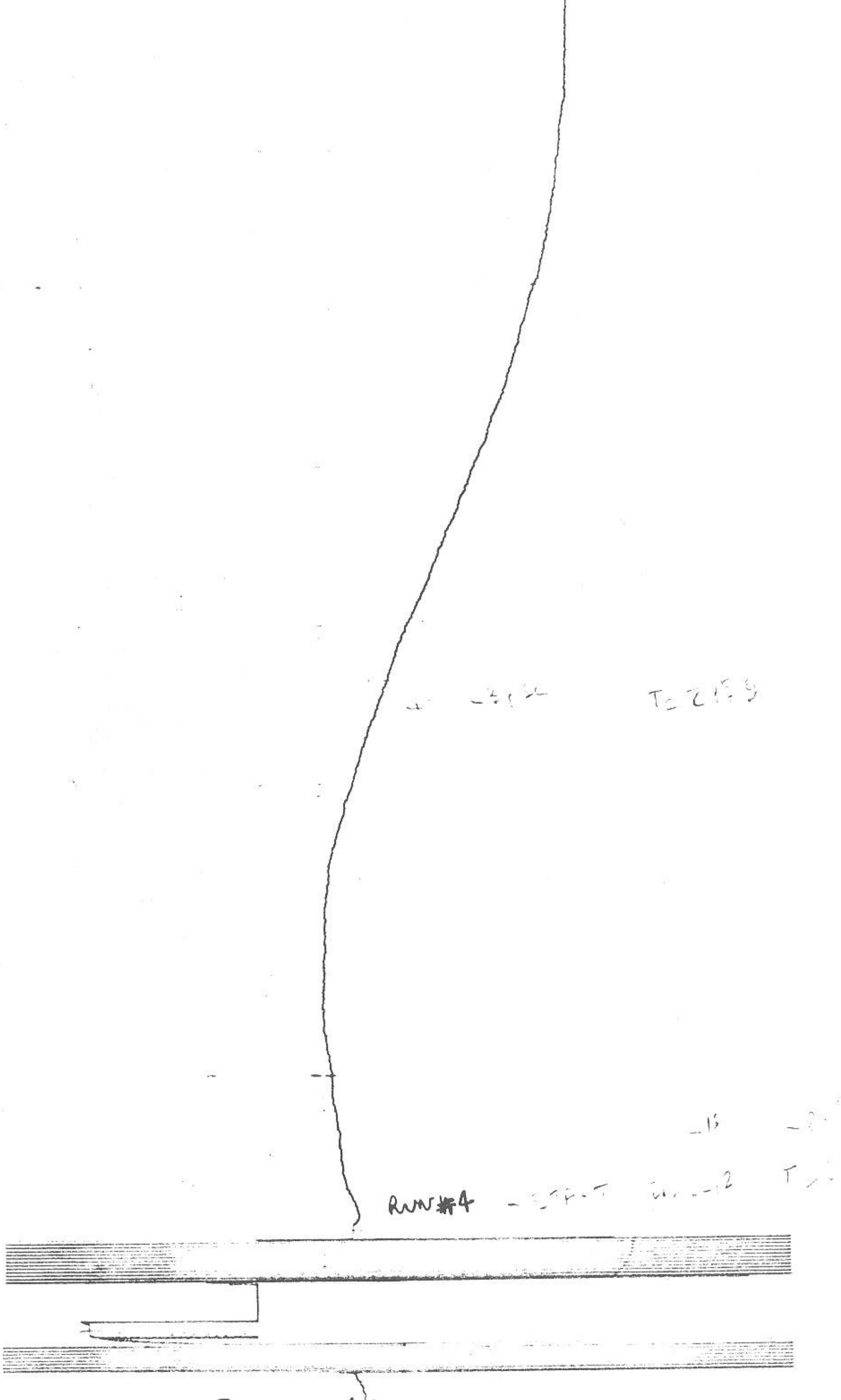
Kvemer = 6510
OF = -1709

ΔT = 1°.2

Δp = 17ps



HP 8662A Vs E5



CARTA =
5cm/h

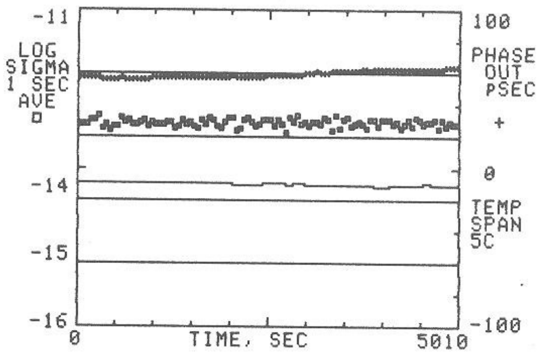
HP 8662A vs E5 @ 1260 MHz RUN#4

PNA1 program of 5/3/86

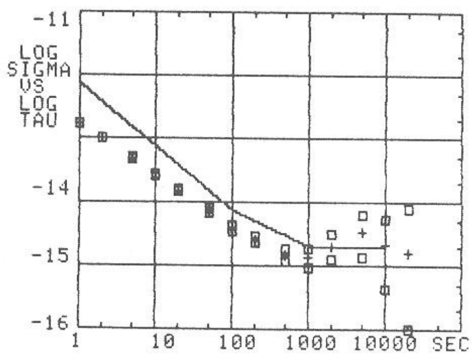
Phase detector SLOPE=7020mV/Rad
RUN START 15:09.2 05/03/85
BATCH START 05:23.1 06/03/85
BATCH END 06:46.7 06/03/85

Reference is assumed PERFECT
Mixing Frequency=1260MHz
OFFSET=2479mV
TLOW=21.69C, THIGH=21.79C
TEMP=21.76C PHASE=56.3PS
TEMP=21.72C PHASE=62.8PS

TAU (Sec.)	LAST BATCH DATA PTS	LAST BATCH SIGMA (E-15 units)	CUMULATIVE DATA PTS	CUMULATIVE SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	162.4	55088	169.5	0.2
2	2503	92.9	27533	99.4	0.2
5	1000	45.8	11000	47.4	0.2
10	499	25.2	5489	26.8	0.3
20	249	14.9	2739	15.0	0.3
50	99	7.1	1089	7.2	0.4
100	49	3.6	539	3.9	0.4
200	24	2.5	264	2.6	0.5
500	9	1.2	99	1.4	0.7
1000	4	1.0	44	1.4	1.4
2000	2	1.5	26	2.0	4.0
5000	1	2.6	10	3.4	16.9
10000	0	0.0	4	2.1	20.8
20000	0	0.0	1	1.6	31.1
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



NO Temp. gradient

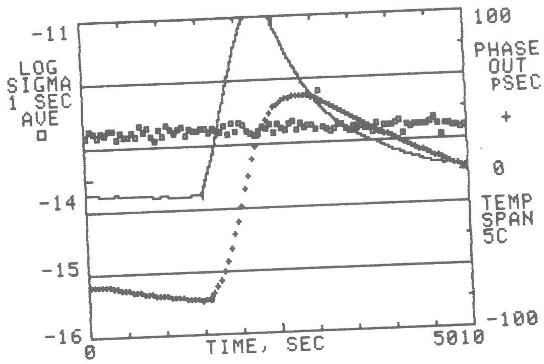


Temp steps HP vs E5 RUN#6

PNA1 program of 7/3/86
Mixing Frequency=1260MHz
Phase detector SLOPE=7030mV/Rad
RUN START 00:09.4 07/03/86
BATCH START 01:34.8 07/03/86
BATCH END 02:58.6 07/03/86

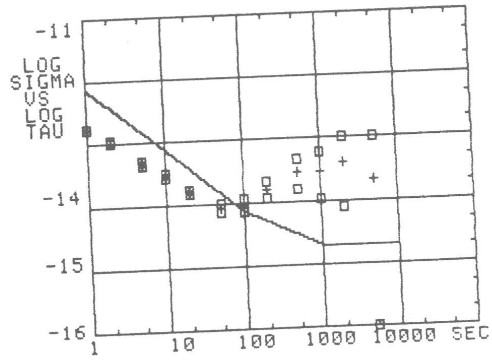
Reference is assumed PERFECT
PH-max=49.2 PH-min=-79.2
OFFSET=2493mV
TLOW=22.05C, THIGH=~~0~~C 25.13
TEMP=22.2C PHASE=-66.5PS
TEMP=22.49C PHASE=1PS

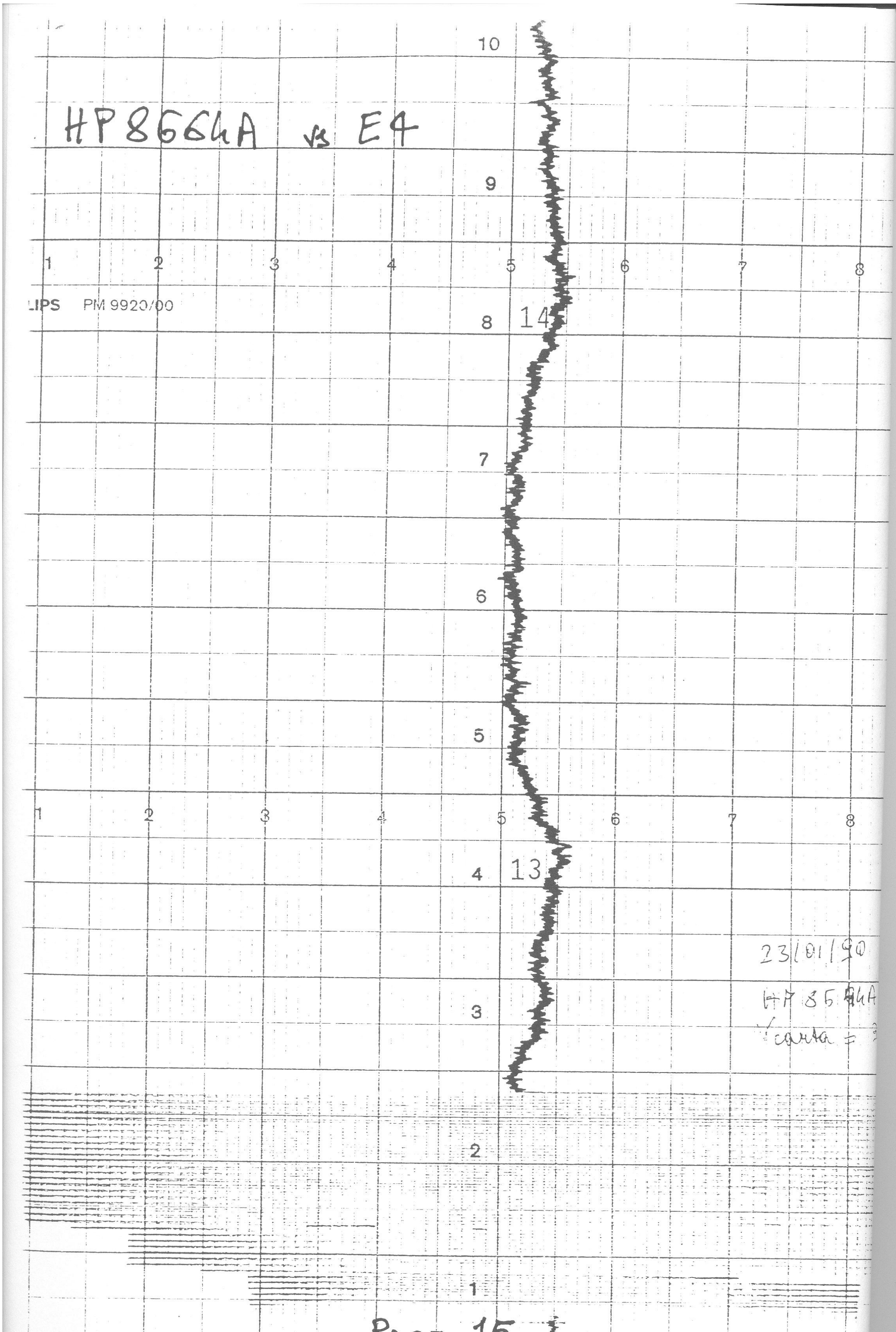
TAU (Sec.)	LAST BATCH DATA PTS	LAST BATCH SIGMA (E-15 units)	CUMULATIVE DATA PTS	CUMULATIVE SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	173.9	10016	168.9	0.2
2	2503	105.3	5006	101.1	0.2
5	1000	46.4	2000	46.4	0.2
10	499	29.1	998	28.4	0.3
20	249	15.2	498	15.9	0.3
50	99	9.7	198	8.7	0.4
100	49	12.5	98	9.5	0.9
200	24	22.7	48	16.2	3.2
500	9	41.6	18	29.4	14.7
1000	4	41.5	8	29.4	29.4
2000	3	46.1	4	40.0	79.9
5000	1	20.9	1	20.9	104.5
10000	0	0.0	0	0.0	0.0
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



ΔT = 3°

ΔP = 13[illegible]



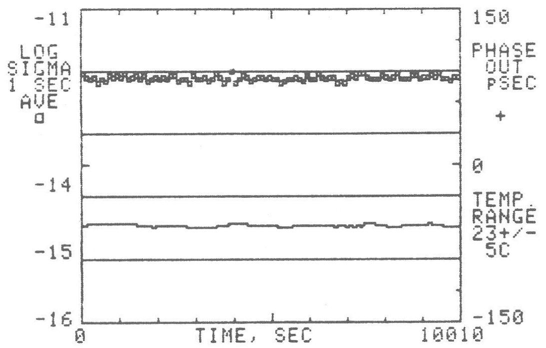

HP8664A vs E4
LIPS PM 9920/00
14
13
23/01/90

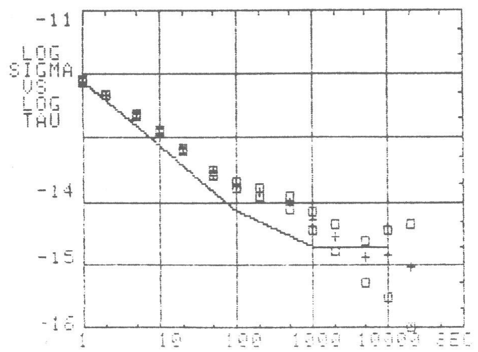
HP8644A vs E4 @ 1440 MHz (T=Lab)

PNA program of 1/4/86
Mixing Frequency=1440MHz
Phase detector SLOPE=5946mV/Rad
RUN START 90:16.4 23/01/86
BATCH START 90:03.5 24/01/86
BATCH END 90:06.3 24/01/86

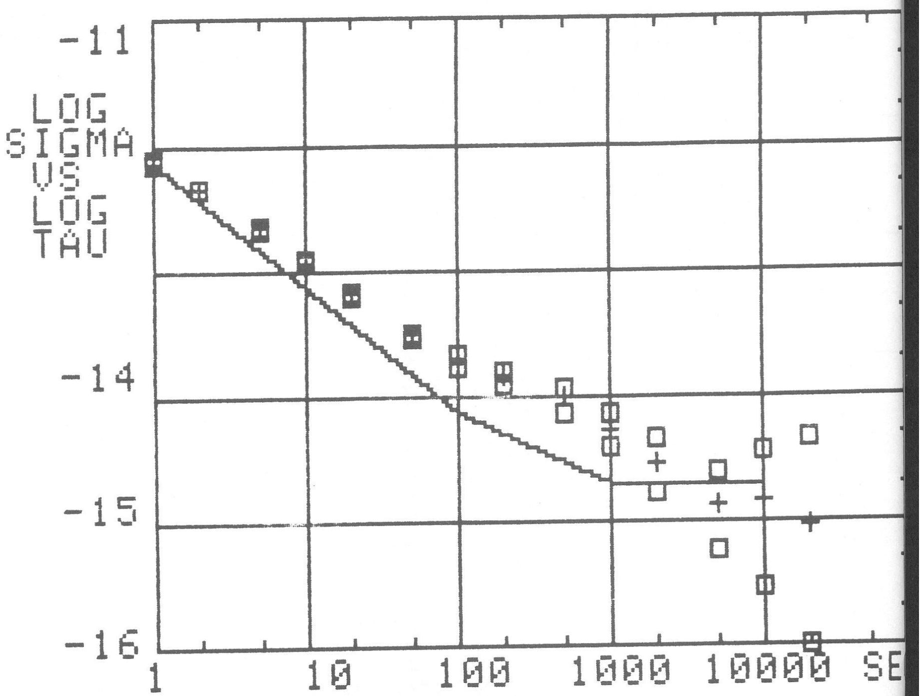
Reference is assumed PERFECT
PH-max=-16.6 PH-min=-41.5
OFFSET=1477mV
TLOW=20.94C, THIGH=21.14C
TEMP=21.06C PHASE=-35.8PS
TEMP=20.98C PHASE=-28.4PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	10008	748.2	50040	759.4	0.8
2	5003	461.3	25015	474.5	0.9
5	2000	224.0	10000	227.6	1.1
10	999	119.1	4995	118.1	1.2
20	499	61.7	2495	66.0	1.3
50	199	32.4	995	30.3	1.5
100	99	20.6	495	19.7	2.0
200	49	15.6	245	14.5	2.9
500	19	11.9	95	10.0	5.0
1000	9	5.6	45	5.6	5.6
2000	4	4.4	20	3.0	5.9
5000	2	1.7	9	1.3	6.6
10000	1	1.4	4	1.4	14.2
20000	0	0.0	1	0.9	18.5
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0





HP8644A vs E4 @ 1440 MHz (T=Lab)

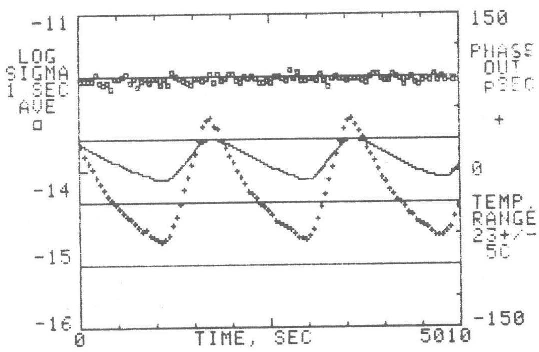


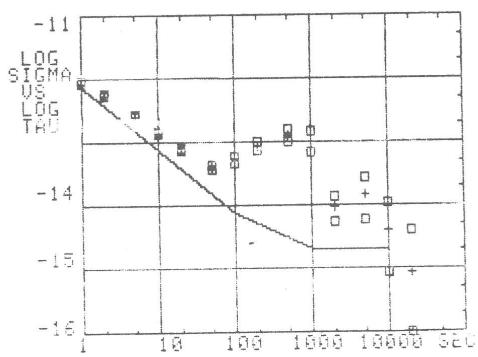
HP8644A vs E4 (Temp. gradients)

PNA program of 24/01/90
Mixing Frequency=1440MHz
Phase detector SLOPE=5949mV/Rad
RUN START 18:42.7 24/01/90
BATCH START 07:17.6 25/01/90
BATCH END 08:41.1 25/01/90

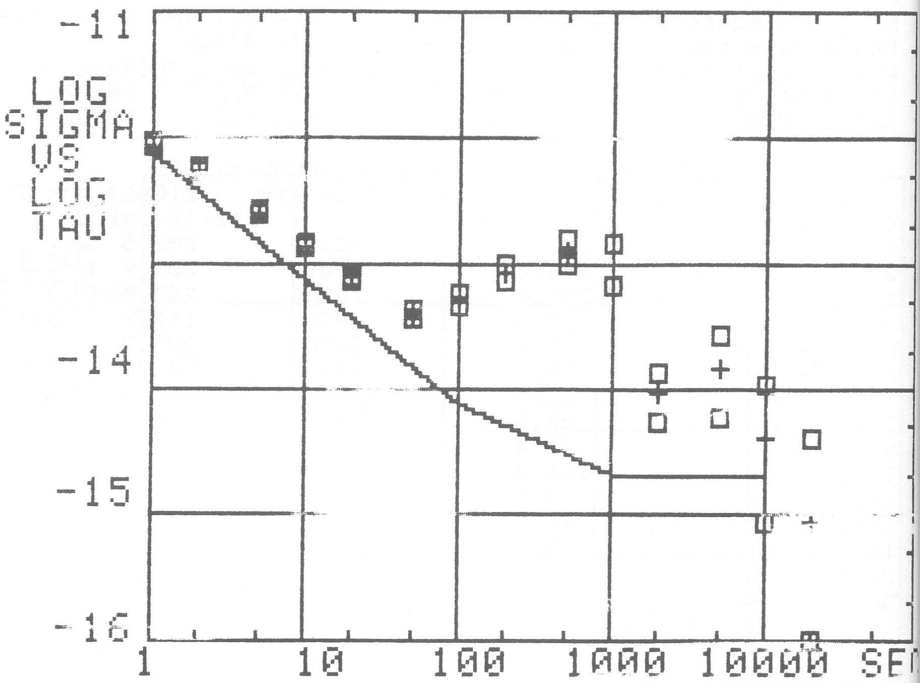
Reference is assumed PERFECT
PH-max=50.7 PH-min=-70.8
OFFSET=1477mV
TLOW=22.68C, THIGH=24.01C
TEMP=23.92C PHASE=31PS
TEMP=23.13C PHASE=-33.1PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	881.7	50080	882.3	0.9
2	2503	566.4	25030	559.9	1.1
5	1000	255.0	10000	260.8	1.3
10	499	137.3	4990	139.7	1.4
20	249	75.4	2490	76.9	1.5
50	99	39.9	990	41.0	2.0
100	49	51.2	490	52.5	5.3
200	24	80.6	240	86.4	17.3
500	9	118.4	90	129.2	64.6
1000	4	101.4	40	102.7	102.7
2000	3	3.9	24	9.1	18.2
5000	1	21.9	9	14.5	72.6
10000	1	2.5	4	4.1	41.1
20000	0	0.0	1	0.8	16.7
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0





HP8644A vs E4 (Temp. gradients)

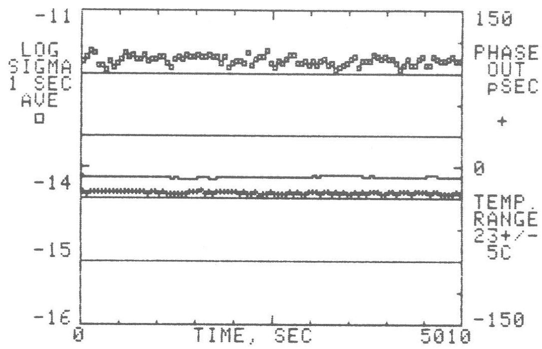


MARCONI 2041 Noise normal

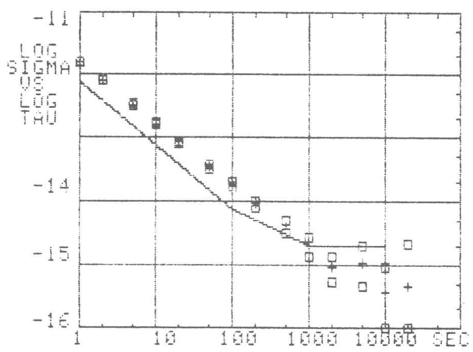
PNA program of 24/01/90
Mixing Frequency=1440MHz
Phase detector SLOPE=7406mV/Rad
RUN START 16:05.3 12/11/91
BATCH START 06:04.1 13/11/91
BATCH END 07:27.6 13/11/91

Reference is assumed PERFECT
PH-max=-22.2 PH-min=-30.3
OFFSET=920mV
TLOW=22.31C, THIGH=22.71C
TEMP=22.74C PHASE=-25.9PS
TEMP=22.63C PHASE=-26PS

TAU (Sec.)	LAST BATCH DATA PTS	LAST BATCH SIGMA (E-15 units)	CUMULATIVE DATA PTS	CUMULATIVE SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	1610.7	55088	1596.2	1.6
2	2503	805.4	27533	802.0	1.6
5	1000	336.2	11000	324.1	1.6
10	499	149.7	5489	164.2	1.6
20	249	69.4	2739	83.4	1.7
50	99	37.1	1089	35.1	1.8
100	49	16.2	539	18.4	1.8
200	24	9.6	264	9.0	1.8
500	9	1.9	99	4.2	2.1
1000	4	1.0	44	2.0	2.0
2000	2	0.6	26	0.9	1.8
5000	1	0.2	10	1.1	5.4
10000	0	0.0	4	0.4	3.7
20000	0	0.0	1	0.4	9.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



NO Temp. gradient

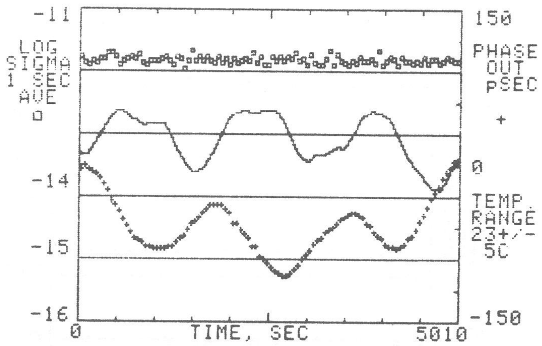


MI 2041 vs E4; Normal (Temp. Grad)

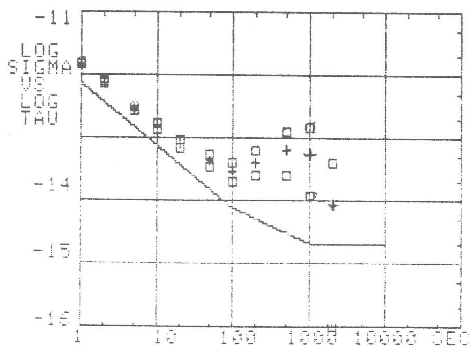
PNA program of 24/01/90
Mixing Frequency=1440MHz
Phase detector SLOPE=7406mV/Rad
RUN START 09:16.5 13/11/91
BATCH START 09:16.6 13/11/91
BATCH END 10:40.1 13/11/91

Reference is assumed PERFECT
PH-max=6.9 PH-min=-109
OFFSET=920mV
TLOW=22.18C, THIGH=24.71C
TEMP=23.42C PHASE=-2.5PS
TEMP=23.13C PHASE=5.7PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	1496.3	5008	1496.3	1.5
2	2503	750.7	2503	750.7	1.5
5	1000	293.4	1000	293.4	1.5
10	499	154.9	499	154.9	1.5
20	249	80.9	249	80.9	1.6
50	99	42.3	99	42.3	2.1
100	49	29.1	49	29.1	2.9
200	24	41.3	24	41.3	8.3
500	9	64.7	9	64.7	32.3
1000	4	55.7	4	55.7	55.7
2000	1	8.3	1	8.3	16.6
5000	0	0.0	0	0.0	0.0
10000	0	0.0	0	0.0	0.0
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



ΔT= 2°5

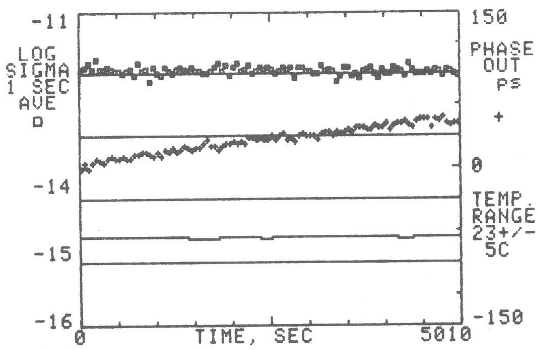


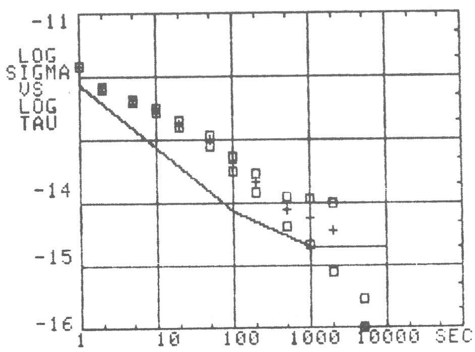
Wiltron vs E4

HP83711 program of 22/07/97
Mixing Frequency=1440MHz
Phase detector SLOPE=1148mV/Rad
RUN START 08:56.2 25/07/97
BATCH START 10:20.1 25/07/97
BATCH END 11:43.6 25/07/97

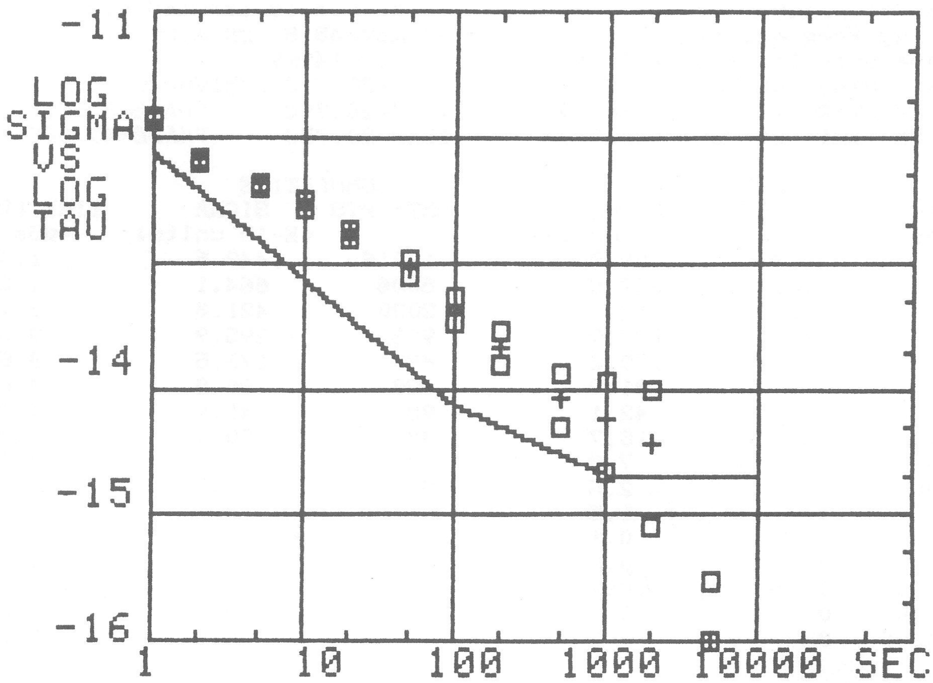
Reference is assumed PERFECT
PH-max=48.8 PH-min=-5.3
OFFSET=149mV
TLOW=20.71C, THIGH=20.78C
TEMP=20.79C PHASE=5.5PS
TEMP=20.75C PHASE=40.8PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	1088.9	10016	1449.6	1.4
2	2503	667.8	5006	664.1	1.3
5	1000	364.2	2000	421.3	2.1
10	499	234.9	998	295.9	3.0
20	249	170.2	498	175.5	3.5
50	99	81.9	198	96.8	4.8
100	49	42.1	98	41.9	4.2
200	24	18.7	48	20.8	4.2
500	9	7.2	18	7.8	3.9
1000	4	2.6	8	5.9	5.9
2000	3	1.5	4	3.8	7.6
5000	1	0.1	1	0.1	0.3
10000	0	0.0	0	0.0	0.0
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0





Wiltron vs E4

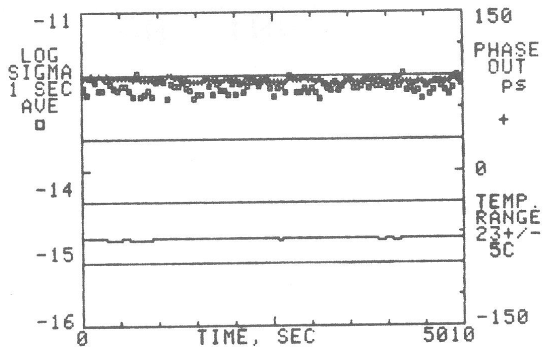


HP83711B vs E4

HP83711 program of 22/07/97
Mixing Frequency=1440MHz
Phase detector SLOPE=1150mV/Rad
RUN START 17:06.8 24/07/97
BATCH START 05:41.7 25/07/97
BATCH END 07:05.2 25/07/97

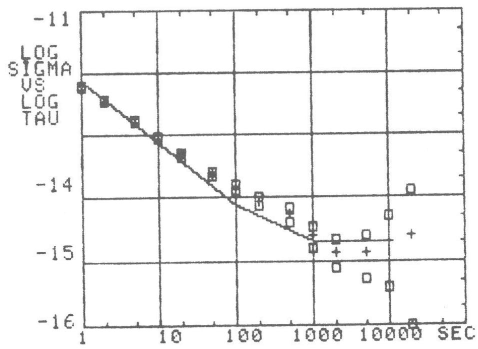
Reference is assumed PERFECT
PH-max=91.4 PH-min=80.4
OFFSET=152mV
TLOW=20.72C, THIGH=20.77C
TEMP=20.78C PHASE=87.6PS
TEMP=20.75C PHASE=85PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	656.1	50080	608.9	0.6
2	2503	376.7	25030	352.1	0.7
5	1000	176.0	10000	162.5	0.8
10	499	99.9	4990	87.7	0.9
20	249	49.4	2490	46.2	0.9
50	99	22.8	990	22.6	1.1
100	49	16.2	490	14.1	1.4
200	24	11.1	240	8.9	1.8
500	9	5.1	90	5.3	2.6
1000	4	2.5	40	2.4	2.4
2000	3	0.5	24	1.4	2.7
5000	1	0.2	9	1.3	6.7
10000	1	0.9	4	2.0	20.1
20000	0	0.0	1	2.6	51.8
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0

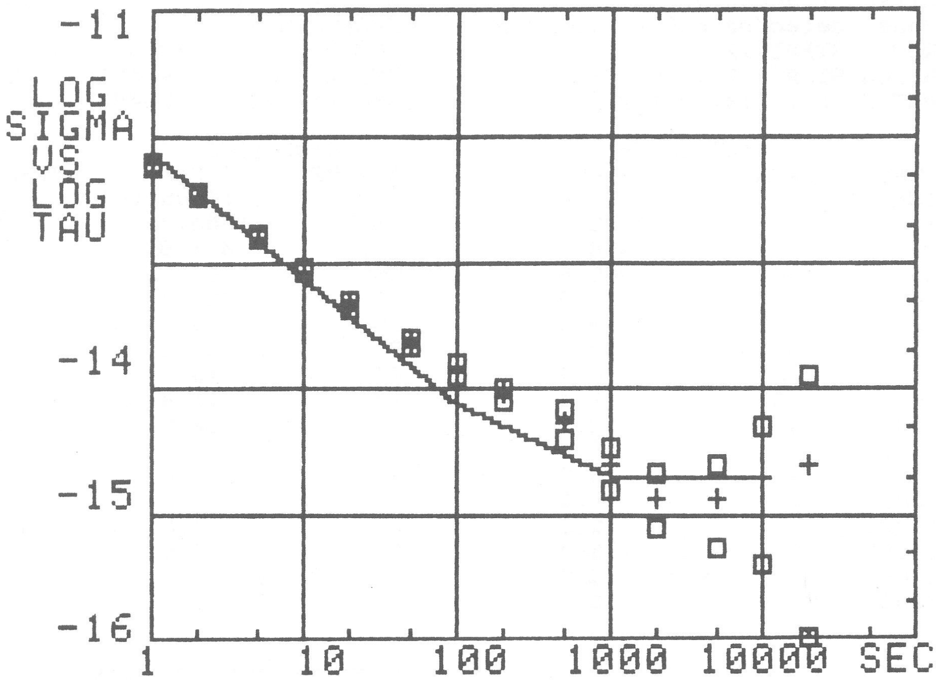


X°

NO Temp. gradient



HP83711B vs E4

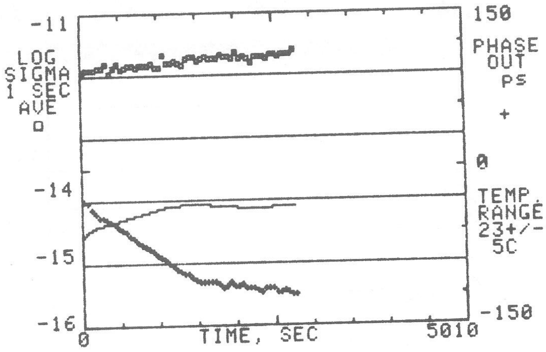


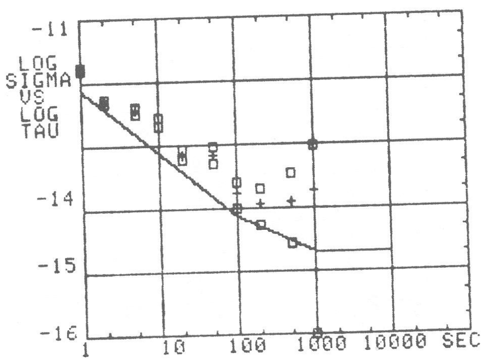
HP83711B vs E4 (Temp. grad)

HP83711 program of 22/07/97
Mixing Frequency=1440MHz
Phase detector SLOPE=1150mV/Rad
RUN START 12:43.5 25/07/97
BATCH START 12:43.5 25/07/97
BATCH END 14:59.1 25/07/97

Reference is assumed PERFECT
PH-max=-26.1 PH-min=-123.6
OFFSET=152mV
TLOW=20.75C, THIGH=21.84C
TEMP=20.76C PHASE=-27.5PS
TEMP=21.78C PHASE=-121.9PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	2805	1685.4	2805	1685.4	1.7
2	1402	498.8	1402	498.8	1.0
5	560	360.8	560	360.8	1.8
10	279	229.0	279	229.0	2.3
20	139	69.6	139	69.6	1.4
50	55	67.5	55	67.5	3.4
100	26	16.9	26	16.9	1.7
200	13	11.4	13	11.4	2.3
500	4	12.9	4	12.9	6.5
1000	1	18.1	1	18.1	18.1
2000	0	0.0	0	0.0	0.0
5000	0	0.0	0	0.0	0.0
10000	0	0.0	0	0.0	0.0
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0





SYSTEM NOISE FLOOR @ 1260 MHz

PNA1 program of 7/3/86
Mixing Frequency=1260MHz
Phase detector SLOPE=7018mV/Rad
RUN START 14:43.8 10/03/86
BATCH START 14:43.8 10/03/86
BATCH END 15:59.6 10/03/86

Reference is assumed PERFECT
PH-max=-13.6 PH-min=-14.6
OFFSET=2152mV
TLOW=21.66C, THIGH=26.24C
TEMP=26.26C PHASE=-14.5PS
TEMP=21.69C PHASE=-13.6PS

TAU (Sec.)	LAST BATCH DATA PTS	LAST BATCH SIGMA (E-15 units)	CUMULATIVE DATA PTS	CUMULATIVE SIGMA (E-15 units)	TIME ERROR (pSec.)
1	4529	4.1	4529	4.1	0.0
2	2264	2.2	2264	2.2	0.0
5	905	0.9	905	0.9	0.0
10	451	0.6	451	0.6	0.0
20	225	0.4	225	0.4	0.0
50	89	0.3	89	0.3	0.0
100	44	0.3	44	0.3	0.0
200	21	0.3	21	0.3	0.1
500	8	0.3	8	0.3	0.1
1000	3	0.1	3	0.1	0.1
2000	1	0.1	1	0.1	0.3
5000	0	0.0	0	0.0	0.0
10000	0	0.0	0	0.0	0.0
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0