# Spectrum efficient ranging method

# PN-Modulated Tone Ranging: Proof of Concept

Alexander Pawlitzki

e-mail: alexander.pawlitzki@timetech.de

web: www.timetech.de

TimeTech GmbH
Curiestrasse 2
D-70563 Stuttgart
Germany

Phone: +49-711-678 08-0
Fax: +49-711-678 08 99

# Table of contents

# 1. Introduction

Current situation

- Ranging PN coded signal with 2.5 Mchip/s
  allocating bandwidth of ~3.5 MHz on transponder

- Performance scales almost linearily with chiprate
  --> higher chipping rates desirable

but:

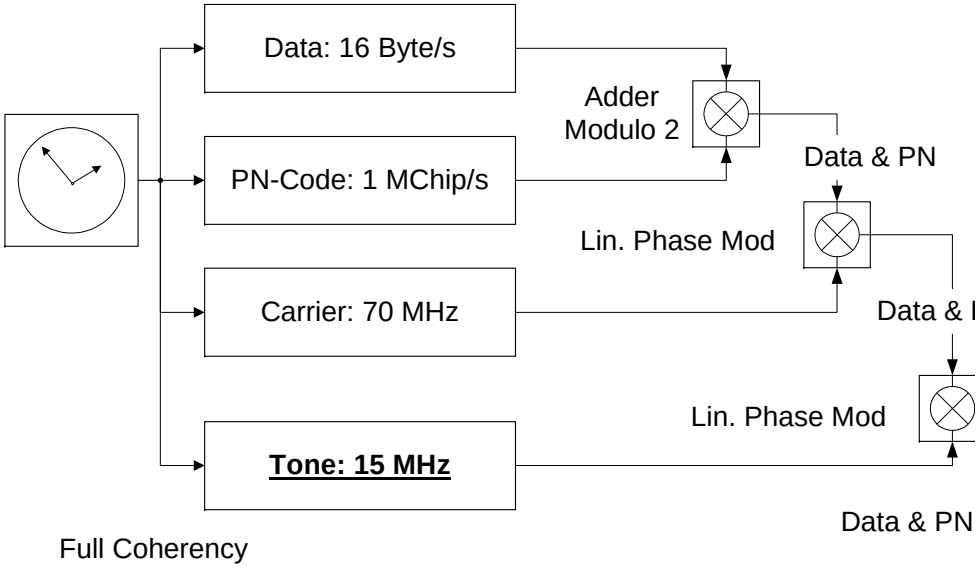
- We pay for bandwidth

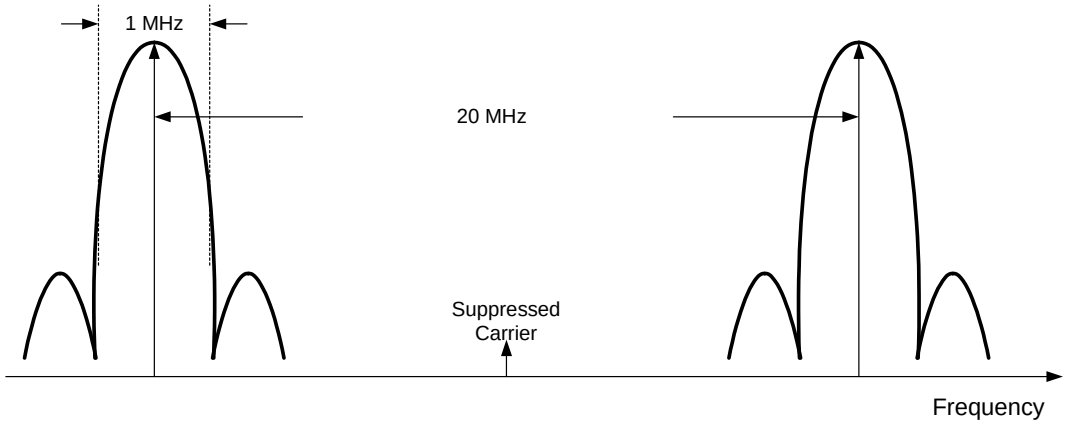
Method

- Combination of PN ranging with tone ranging to improve performance.

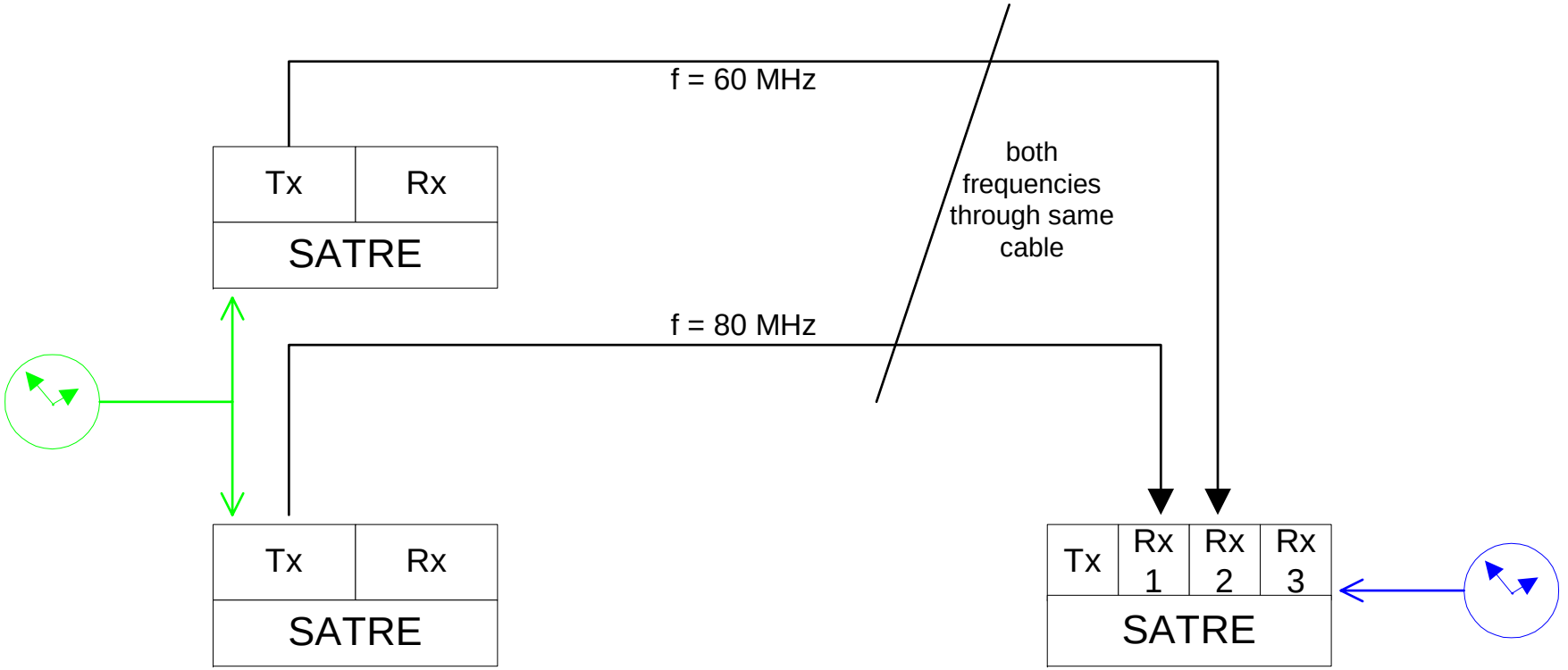
- Use PN code to resolve ambiguity of tone ranging

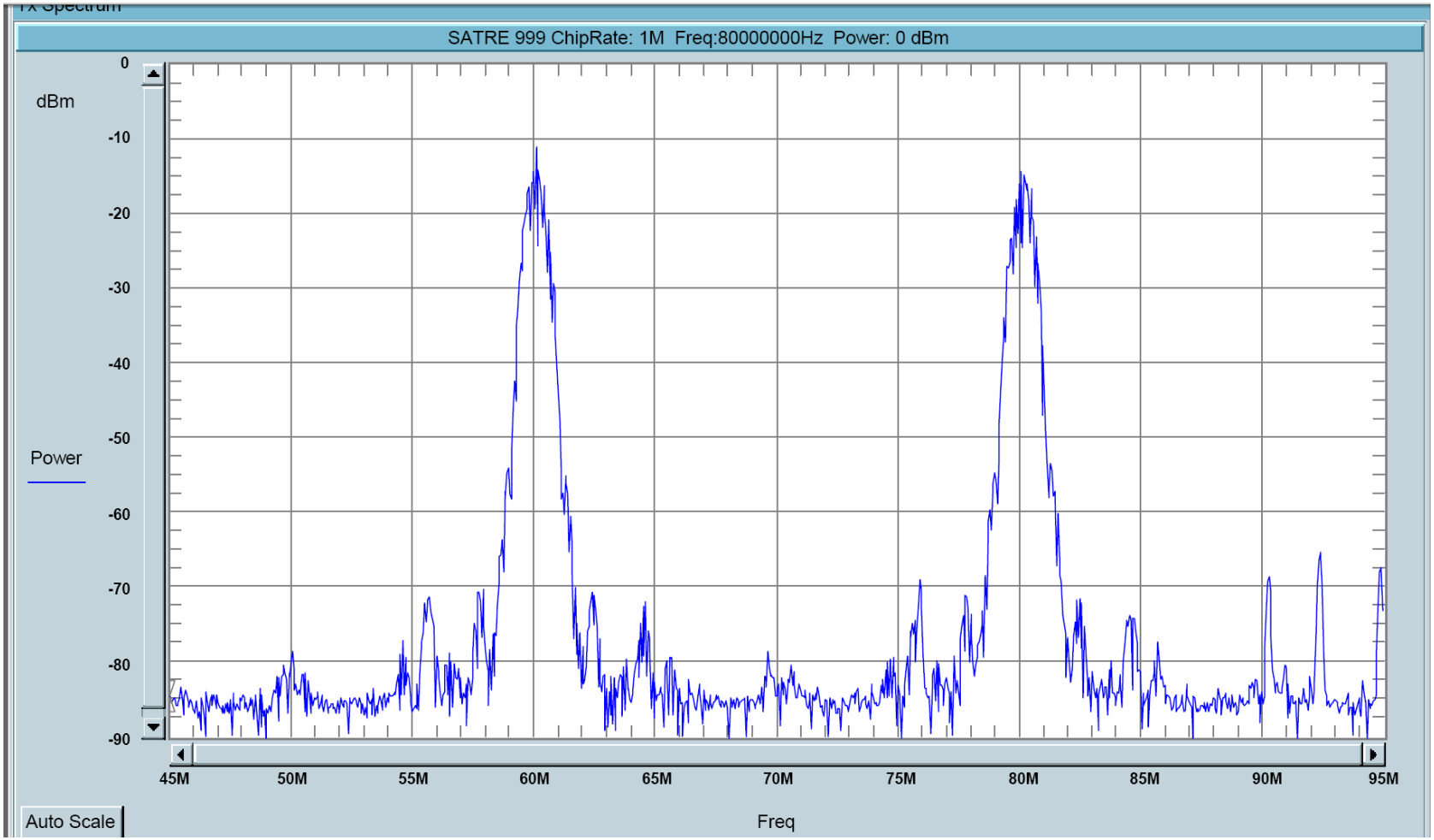
## 2. Signal structure: PN-Modulated Tone




Basic Idea: double sideband, suppressed carrier by modulating a PN signal with a Tone resulting in two PN sidebands. (quite old, **presented during PTTI 1999**)


f = 60 MHz
both
frequencies
through same
cable
Tx
Rx
SATRE
f = 80 MHz
Tx
Rx
SATRE
Tx
Rx
1
Rx
2
Rx
3
SATRE




Spectral plot: Two PN signals (1 MChip/s) at 60 and 80 MHz

## 3. Limitations of the current test set-up

SATRE is not designed for tone ranging.

Using a two-Tx / two-Rx setup for ‘proof of concept’. (3 modems used)

Fist setup used for frequency transfer only (to study noise).

In Rx chain, signal is processed in two different (but coherent) chains

--> phase relationship is more difficult.

SATRE Doppler-Counter can measure frequency only, not phase.

Any phase relationship is ‘destroyed’ by internal multiplication (x 1000).

--> for time transfer, different Rx setup has to be used !

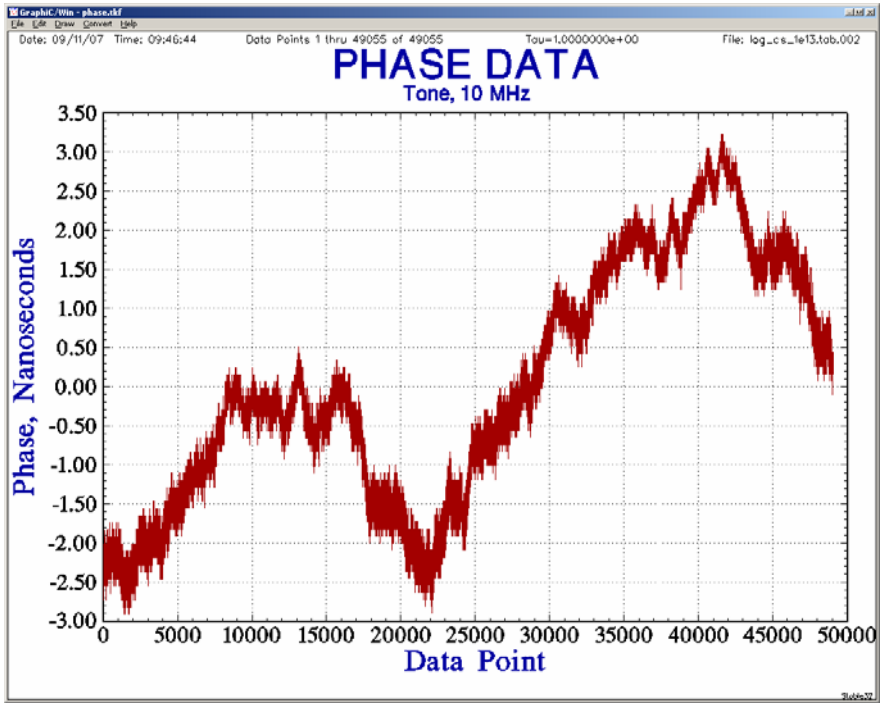
# 4. Performance measurements

## 4.1. Comparison of two Cs clocks

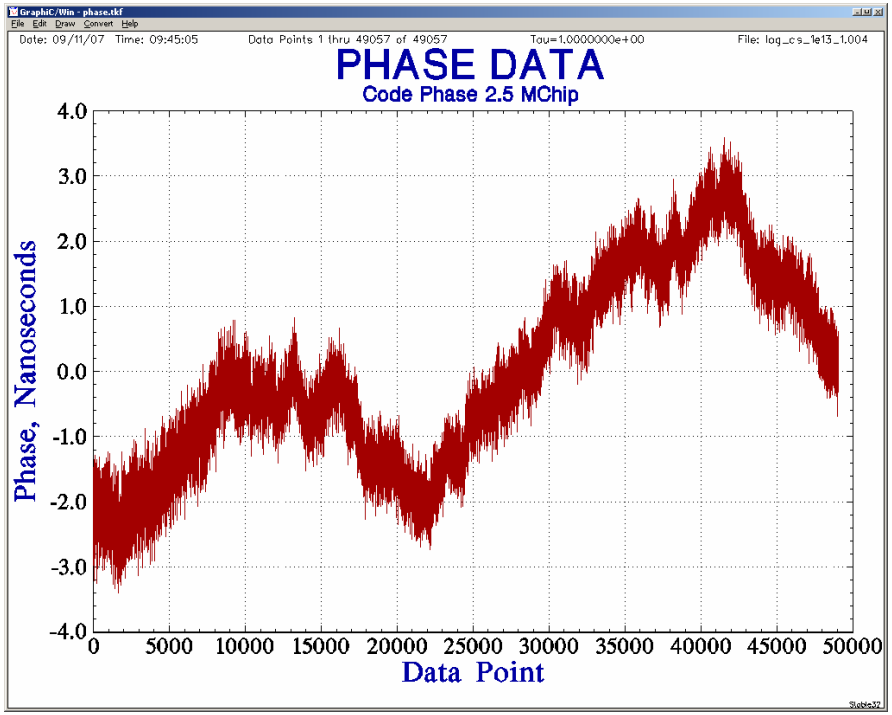
Two HP 5071 Cs clocks, frequency offset of 1E-13.

Two PN signals, 2.5 Mchip/s, separated by 10 MHz (giving a tone of 5 MHz)

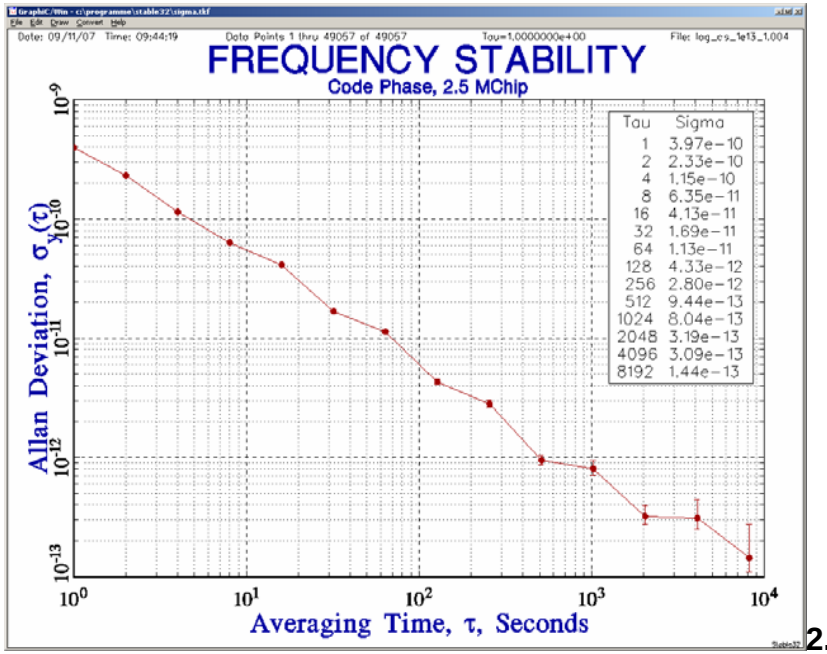
Measurement was **without additional noise**



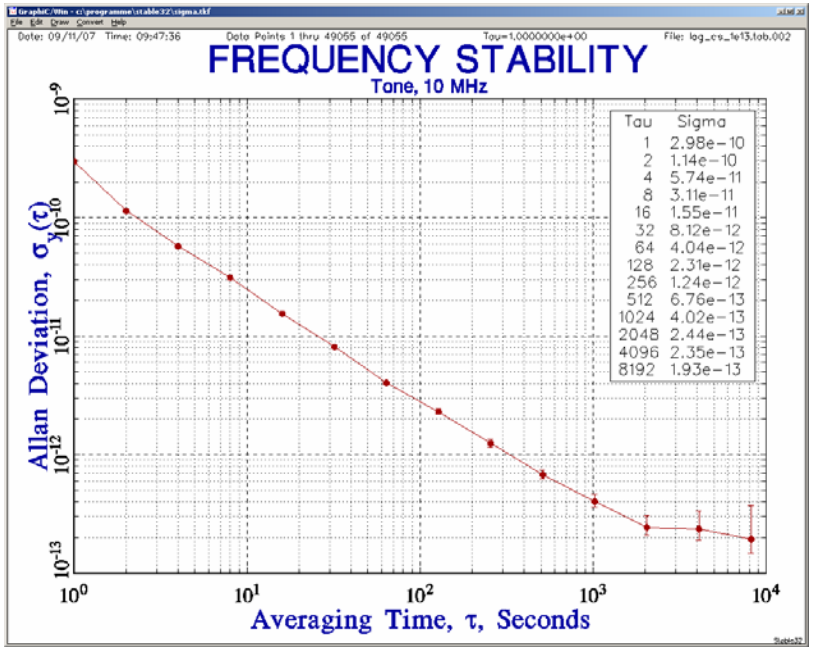

Occupied BW: approx **15 MHz**



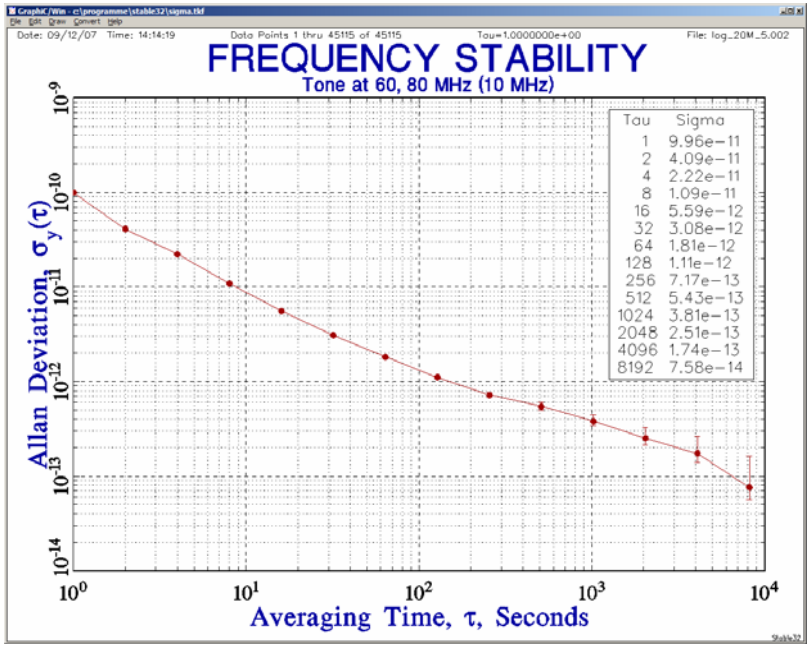

BW: approx **4 MHz**



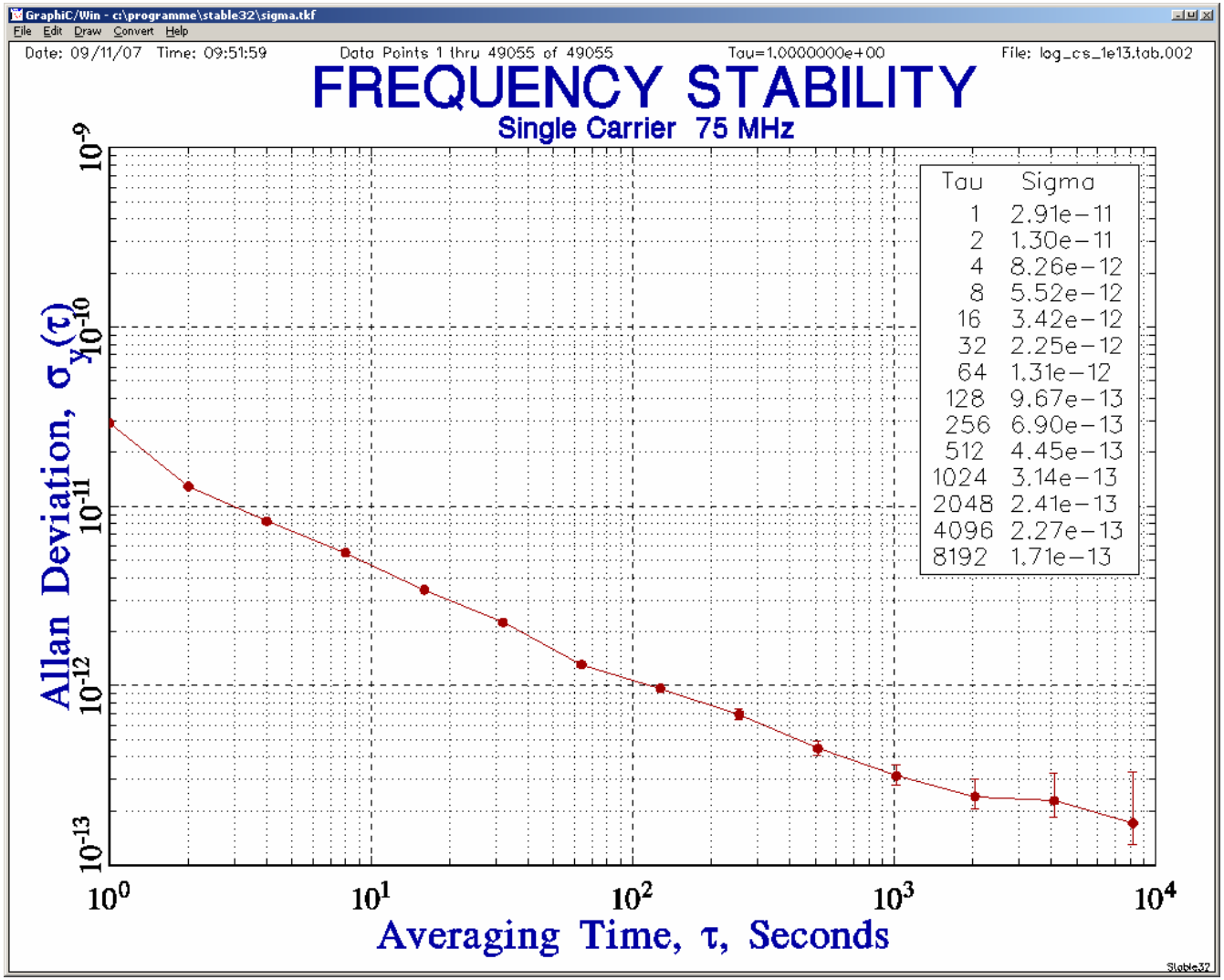

**2.5 MChip**




**5MHz**




**10 MHz**




100 sec to 1000 sec is noise floor (Cs clock against Cs clock)

“simple” set-up, cannot be used via satellite

## Comparison

| Tau | PN @ 2.5MChip | Tone @ 5MHz | Tone @ 10 MHz | Improvement |
|---|---|---|---|---|
| 10 sec | 5.0 E –11 | 2.5 E –11 | 9.0 E -12 | 2 / 5 |
| 100 sec | 6.0 E –12 | 3 E –12 | 1.3 E –12 | 2 / 5 |
| 1000 sec | ~6 E –12 | 4 E –13 | 3.8 E –13 (noise floor) | 2 / >2 |

## 4.2. 2nd set-up: offset oscillator as source

> Eliminate noise induced by reference Cs clocks

Offset oscillator including built-in USO, generating a frequency offset of 1E-13.

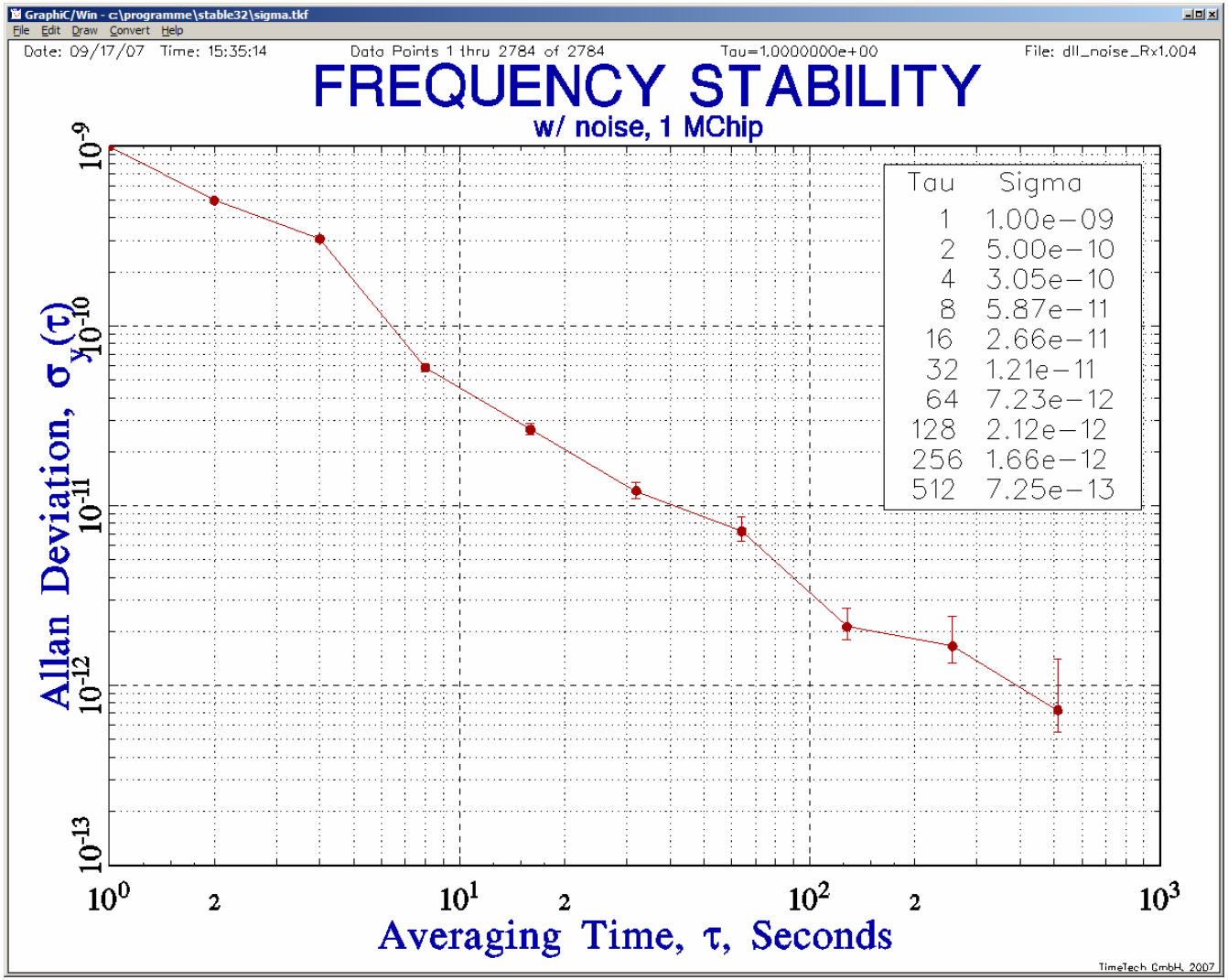
Reference connected to transmitters

Offset reference connected to receivers

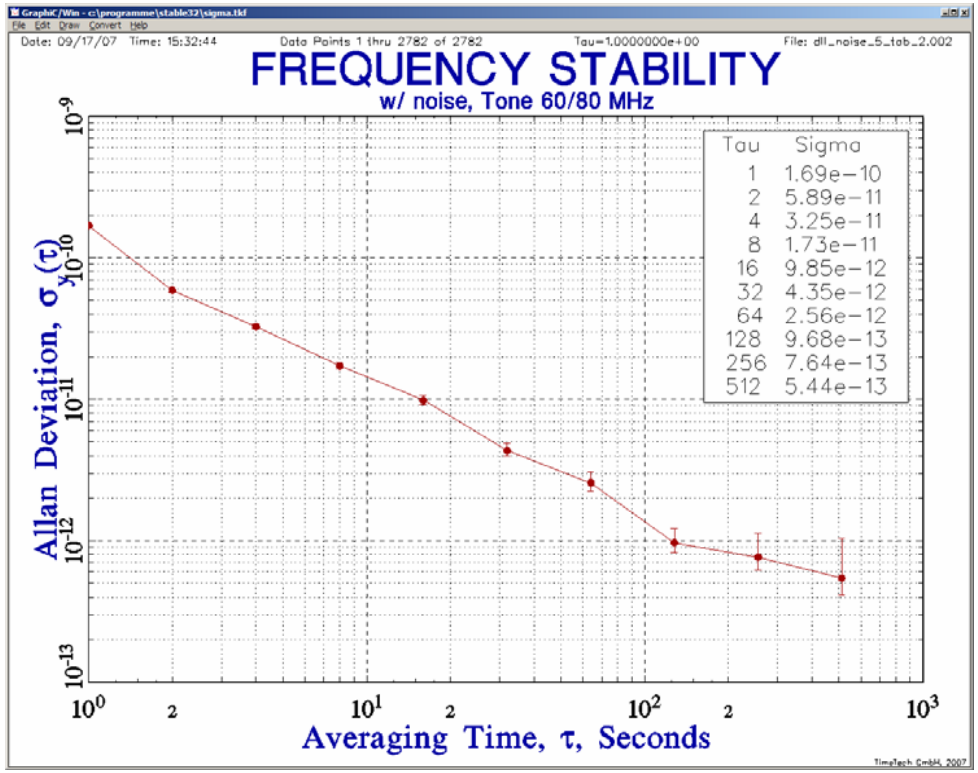
Two PN coded signals, separated by 20 MHz (at 60 MHz and at 80MHz)

-> resulting in a **tone of 10 MHz**

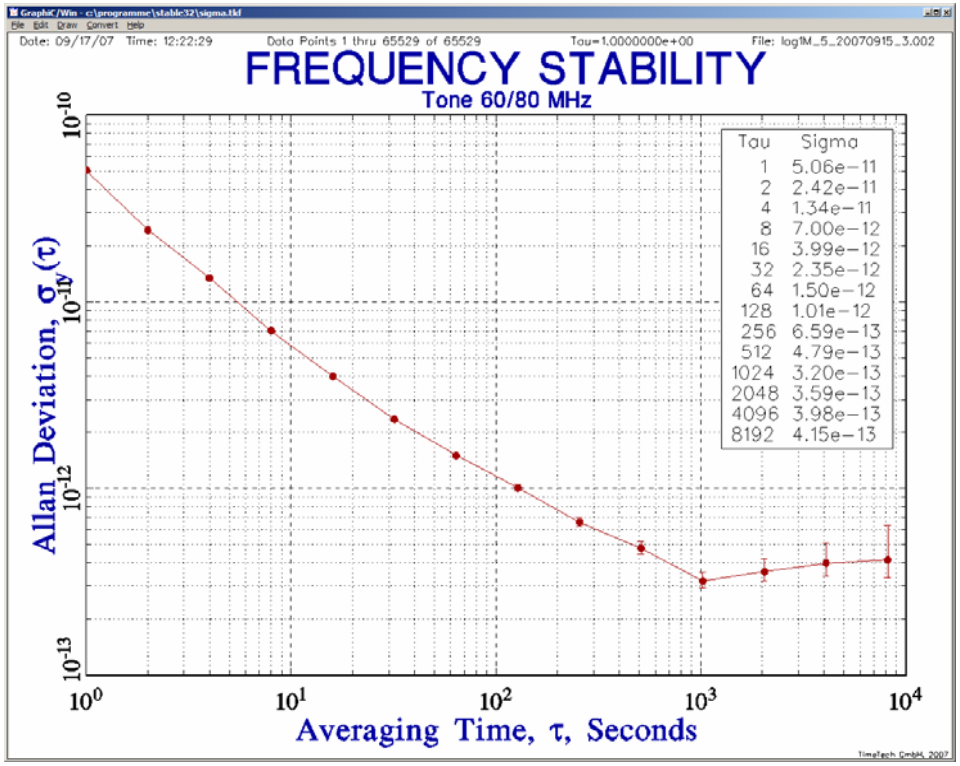
Measurement was **with noise**, C/No around 55 dBHz (not calibrated)




1 MChip/s, C/No ~ 55 dBHz




C/No ~ 55 dBHz




noise-free: noise floor reached after 100s

Comparison

| Tau | PN @ 1MChip | Tone @ 10MHz | **Improvement** |
|---|---|---|---|
| 1 sec | (1.0 E-9) | (1.7 E-10) | **5** |
| 10 sec | (6 E-11) | 1.5 E-11 | **4** |
| 100 sec | (4 E-12) | 1.5 E-12<br>(noise floor) | **3** |

Theoretical gain of ~10 not fully seen (only for small tau < 10 sec).

## 5. Next Steps

- Link via RF (Ku-Band)

  --> use 8 or 20 MHz frequency spacing
  --> use two SATRE channels in base-band to receive

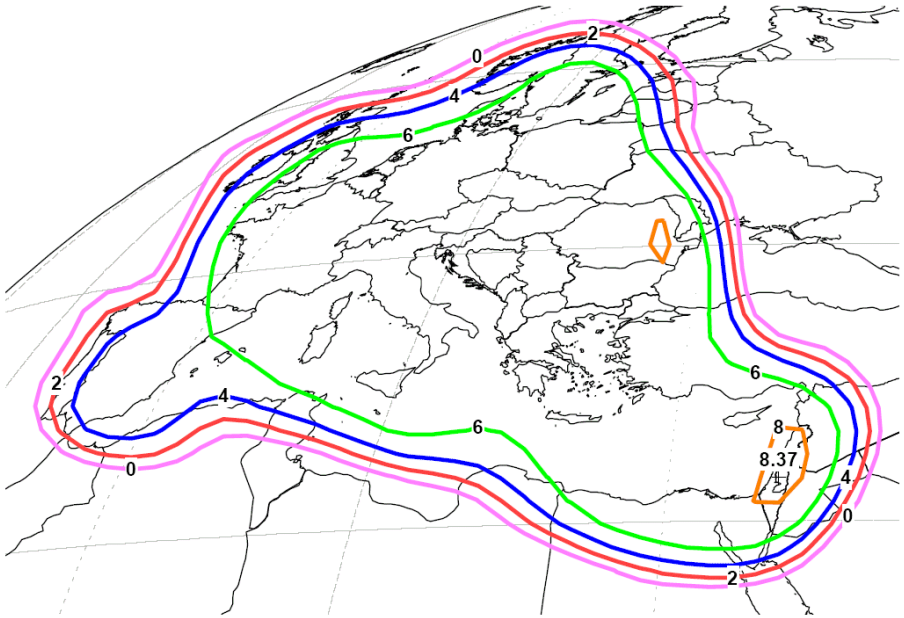
- Link via satellite to verify that algorithm is correct

  --> satellite movement
  --> doppler shift

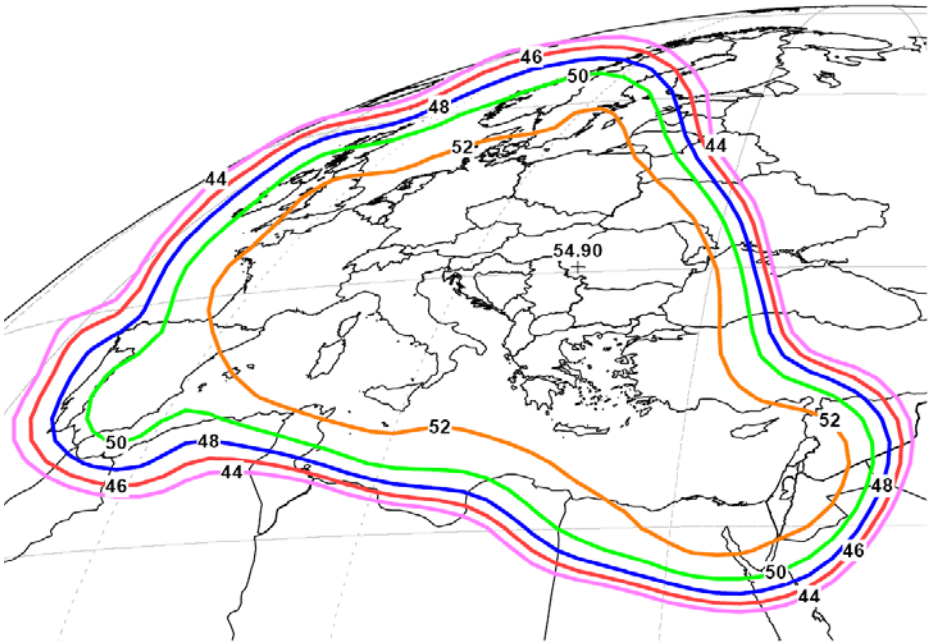
- Zero baseline / two clock experiment via satellite

- Full clock comparison over distances

## 6. Helassat Footprint



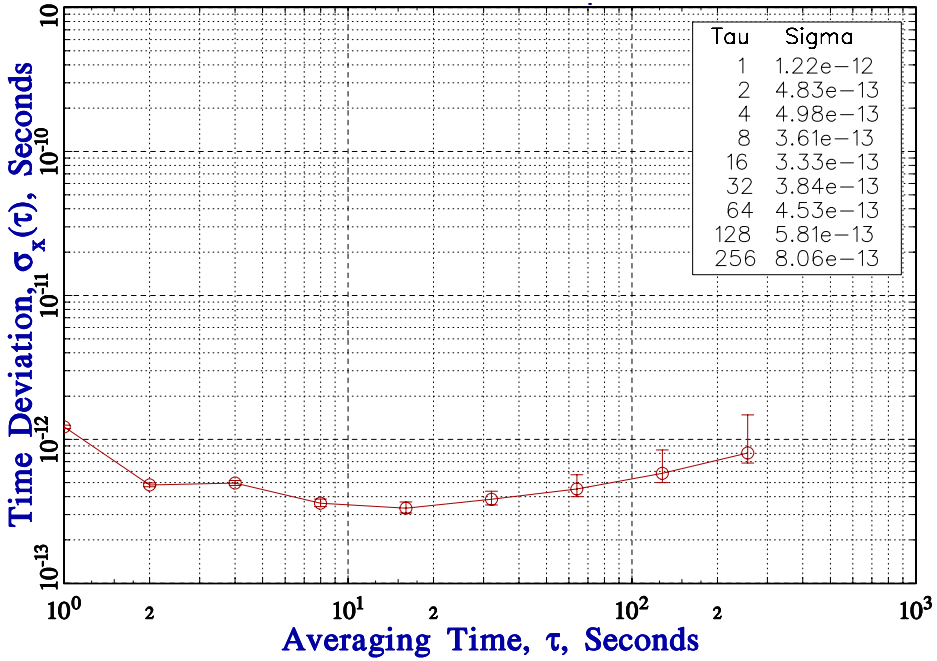

Uplink



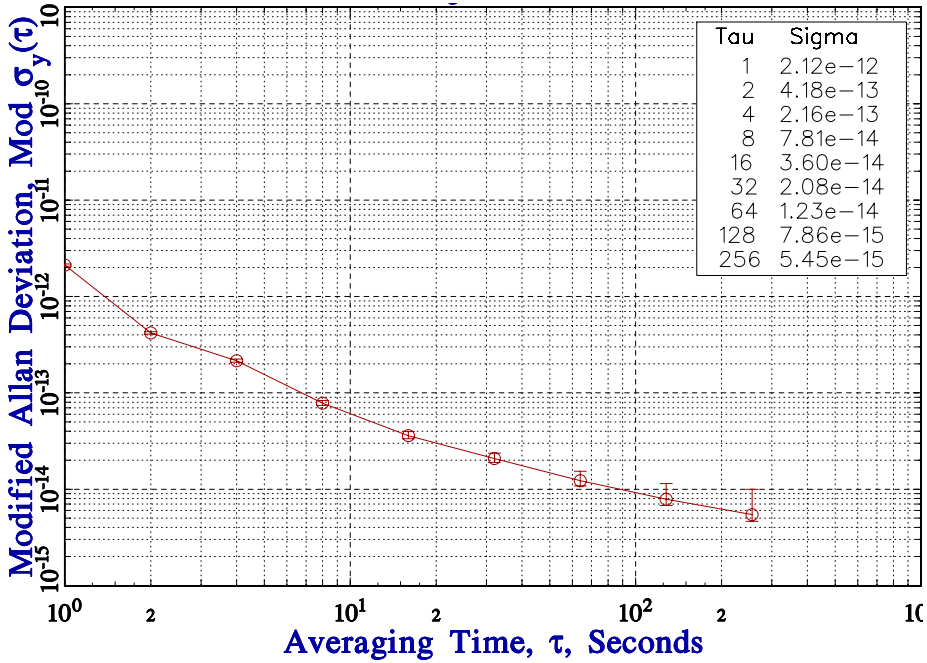

Downlink

- ESA leased Transponder
- 9 MHz BW
- Normally used for return-link systems and experimental VSAT applications

## 7. Results 2-way Carrier Phase (reminder)




Time Stability (TDEV)




Frequency Stability (MDEV)

- First results 1998 PTB/DLR and USNO/NIST (EFTF 1999 and PTTI 1999)
- But still experimental
- Future (?): we like to co-operate with anyone interested

## 8. Conclusion

- New methods exist
- Results promising
- But still experimental
- 2-way carrier phase needs rigorous data analysis and automated processing
- Modulated tone needs experiments via satellite (ESA shows great interest)
- Set-ups and stations need to be improved to take advantage of new methods