VLBI – the pioneering years

Alan E. E. Rogers
MIT Haystack Observatory

AvA symposium 2013

FIRST FRINGES

- Canadian Group – DRAO-Algonquin 17 April 1967
- NRAO/Cornell – NRL-Green Bank 8 May 1967
- MIT – Haystack-Green Bank 5 June 1967

Canadian	NRAO	MIT
Broten	Bare	Moran
Legg	Clark	Barrett
Locke	Kellermann	Burke
McLeish	Cohen	Rogers
Richards	Jauncey	Carter
Chisholm		Crowther
Gush		Ball
Yen		Hyde
Galt		

American Academy of Arts and Science Rumford Award 1971

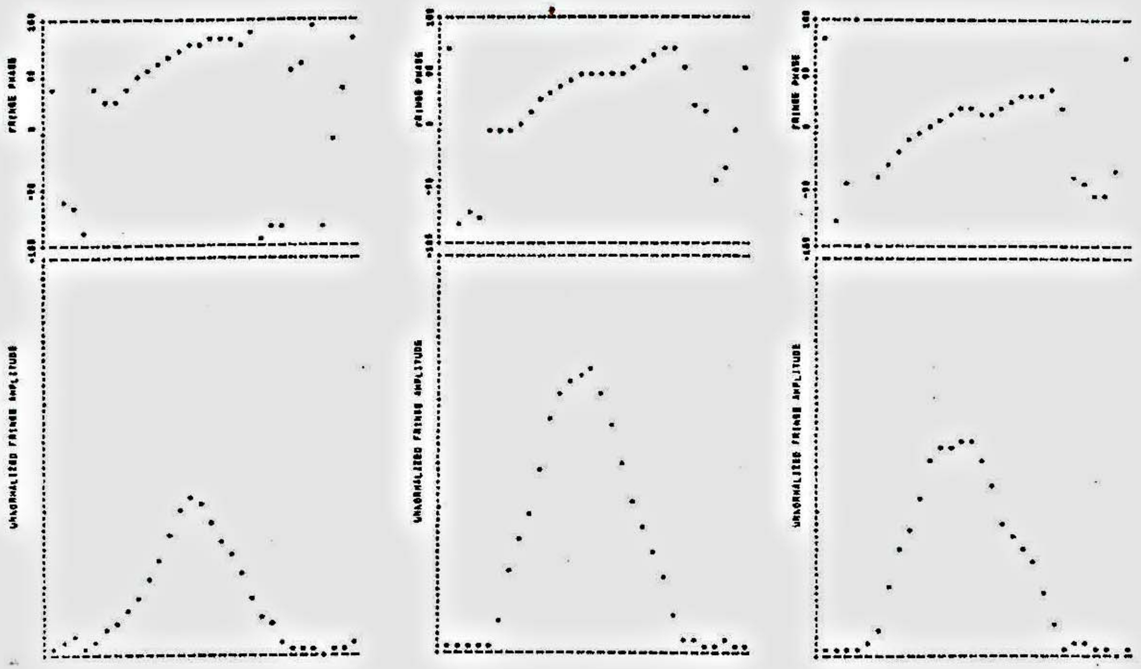


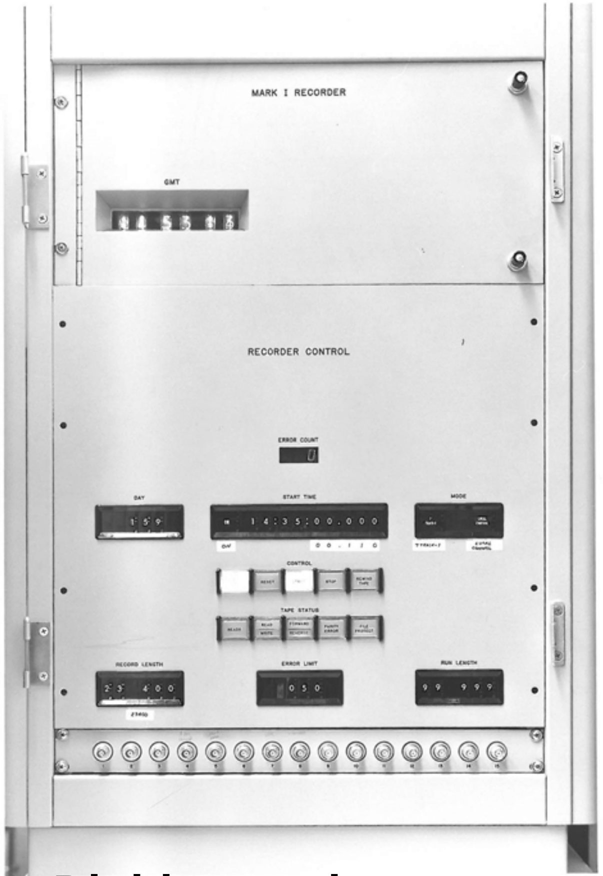
Fig. 1.— The first VLBI measurements of an OH maser, W3(OH), from data recorded on June 8, 1967 at 1665 MHz. The three panels show fringe amplitude and phase versus frequency across a 6-KHz band for different fringe frequency offsets. The resolution was 500 Hz and the integration time was 200 seconds. (Moran 1968)

First Fringes on OH – from “The Early Days of VLBI” from talk by Jim Moran – in celebration of Barry Clark’s 60 th. 1998

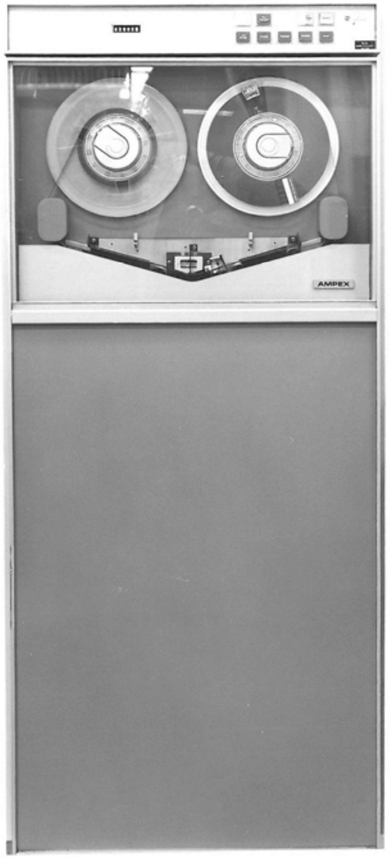
Video converter

Hewett-Packard 5065A
Rubidium clock

Varian H-10 hydrogen maser



Digitizer and
recorder controller



Recorder

VLBI equipment used at Haystack for first Fringes 8 June 1967

VLBI technology pre-cursors

- One-bit sampling theory – Van Vleck 1943
- Min. redundancy – Arsac 1955
- One-bit digital correlator – Weinreb 1961
- Rubidium clock – Hewlett-Packard 1964
- Hydrogen maser – Ramsey, Vessot 1964
- Video tape recorder – Ampex 1963
- IBM 6250 digital recorder 1964
- Loran C and traveling clocks for time sync

EARLY RESULTS

- Quasar brightness approaching Compton limit ~ 10^{13}K
- Superluminal Expansion in Quasars
- OH and H_2O Masers
- Contemporary plate motion

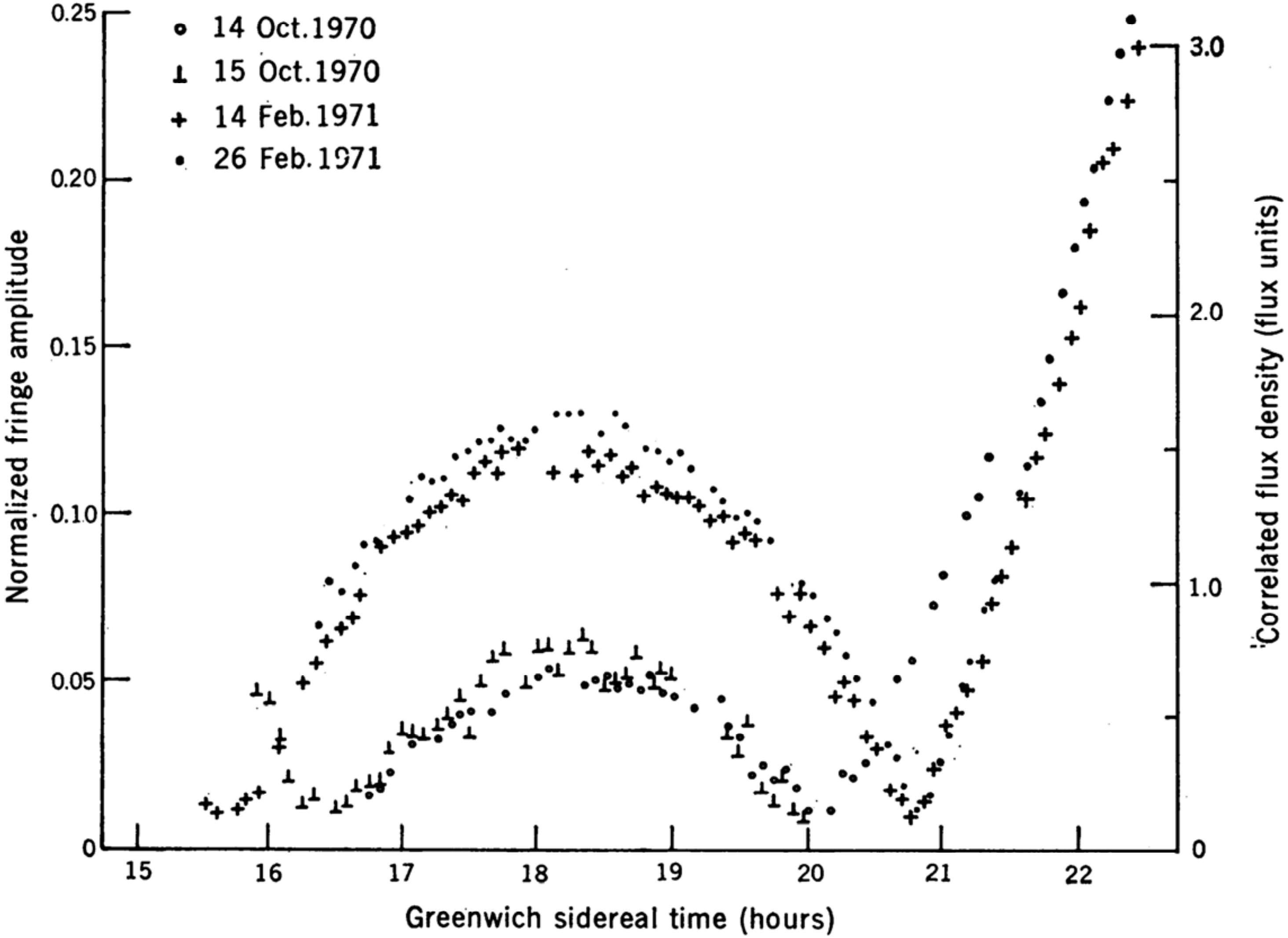
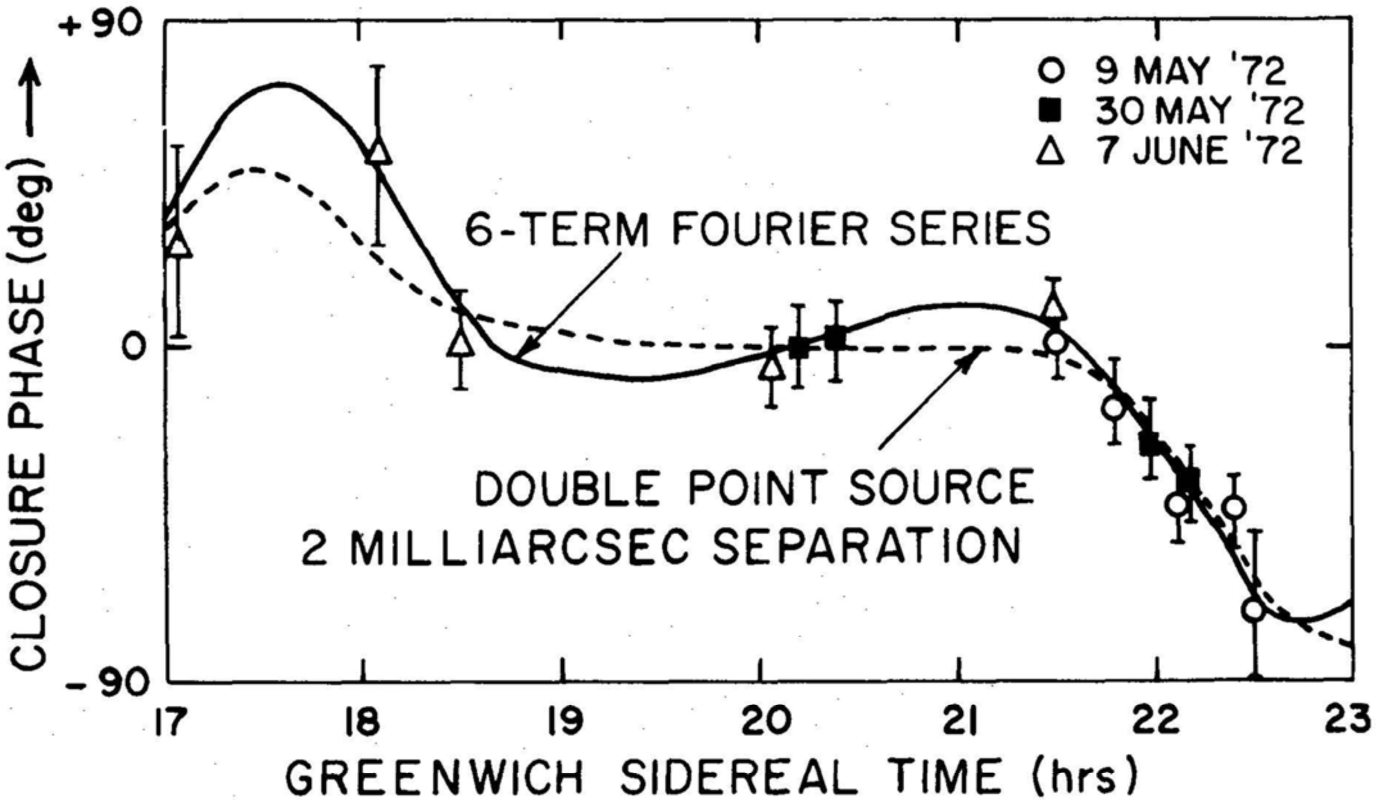


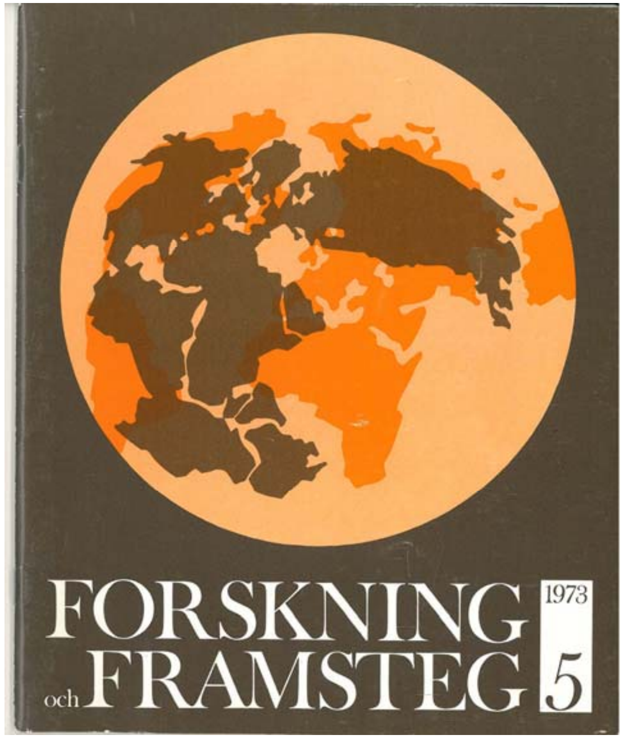
Fig. 1. Fringe-amplitude data from observations of 3C 279 with the Goldstone-Haystack interferometer. Each point is based on 110 seconds of integration.

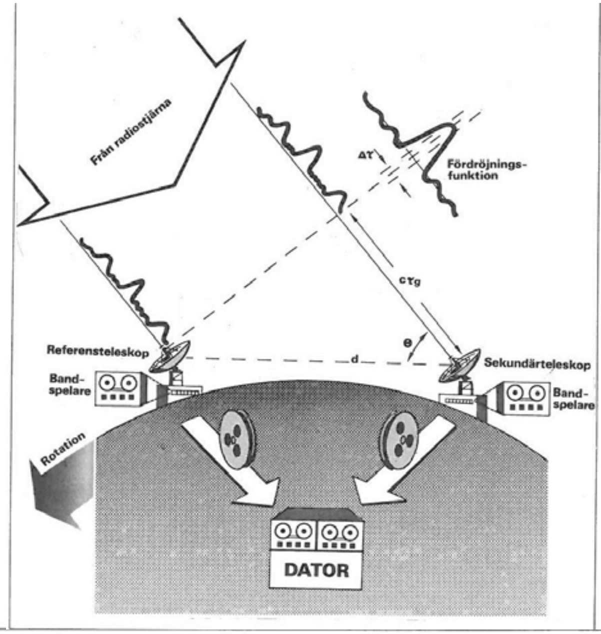
First use of “Closure phase” in VLBI

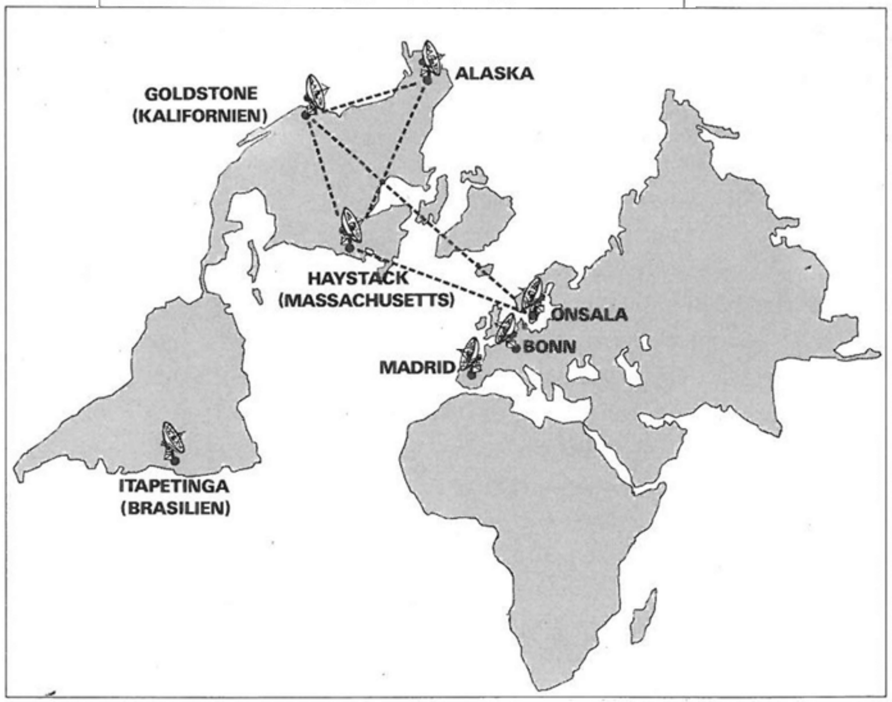
3C273B extended double source along
PA ~ 60º   Haystack-Goldstone-Alaska



Rogers et al. Astron.J 193:293-301, 1974

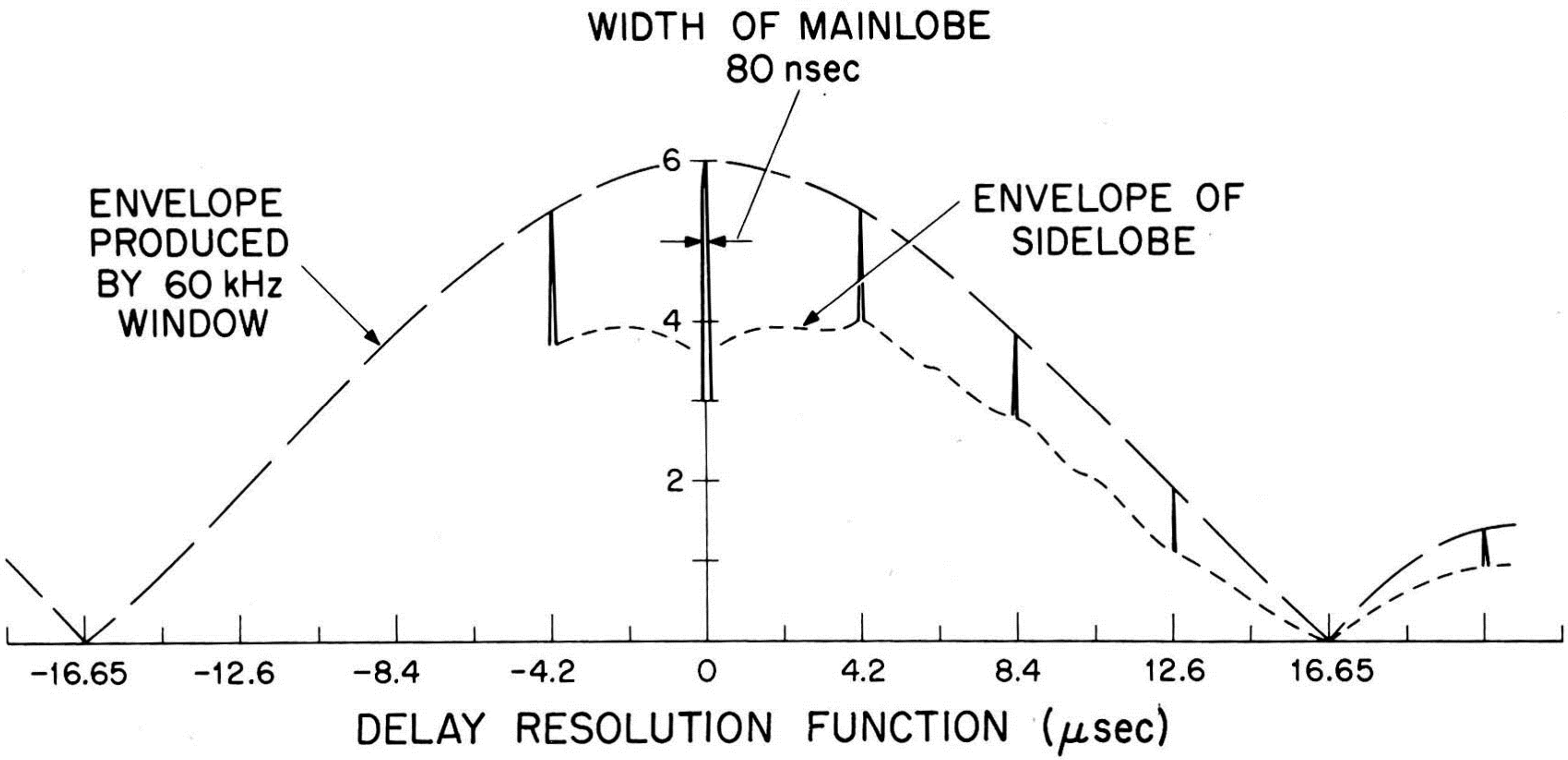






Goldstone

Onsala



Bandwidth synthesis (BWS) using “Arsac” array of frequencies

JGR 1986

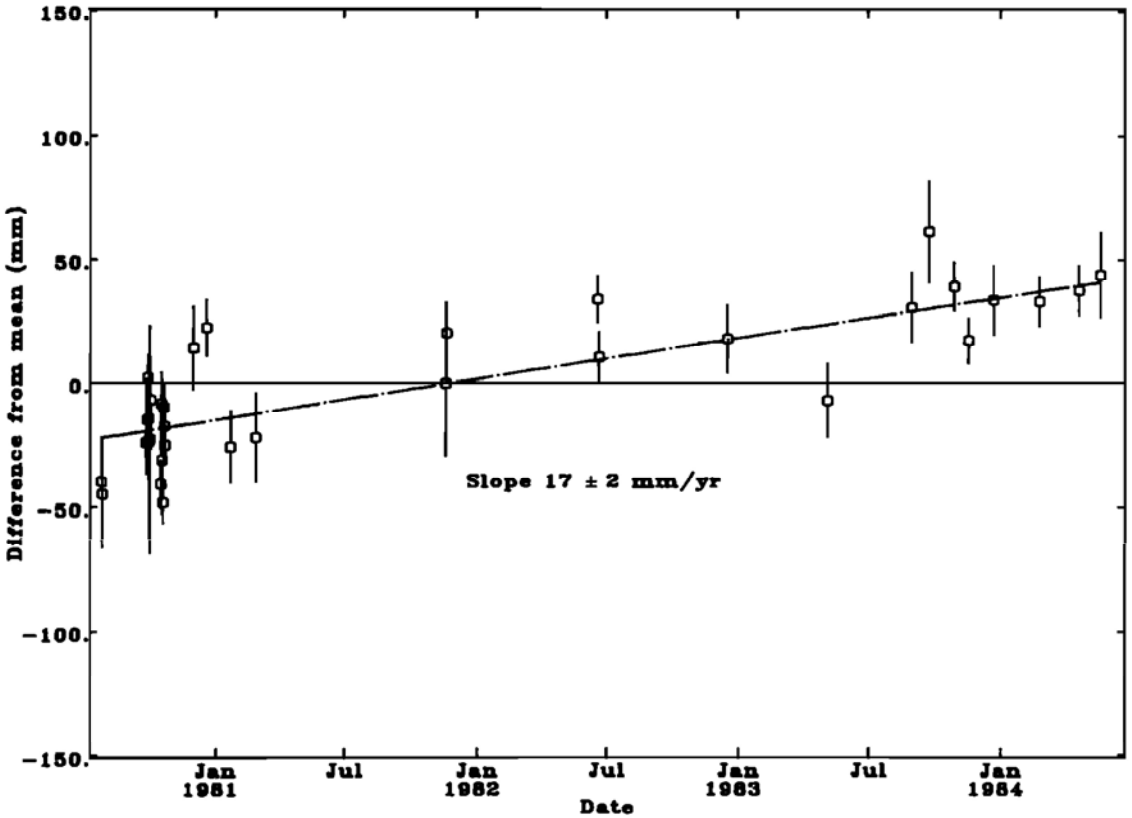


Fig. 1. Differences from a weighted mean value of 5,599,714.451 m for 34 measurements of the length of the HA–ON baseline. The WRMS and NRMS scatters (see Table 1) of the baseline length residuals about the "best fit" straight line are 17 mm and 1.4, respectively.

Some VLBI history papers

- Early VLBI in the USSR – Matveyenko
- The Early days of VLBI – Moran
- Thirty Years of VLBI: Early Days .. - Moran
- Long-Baseline Interferometry – Burke
- A Review of VLBI Instrumentation – Alef
- A History of the EVN: 30 Years of Fringes – Porcas
- A review of the History of VLBI - Clark

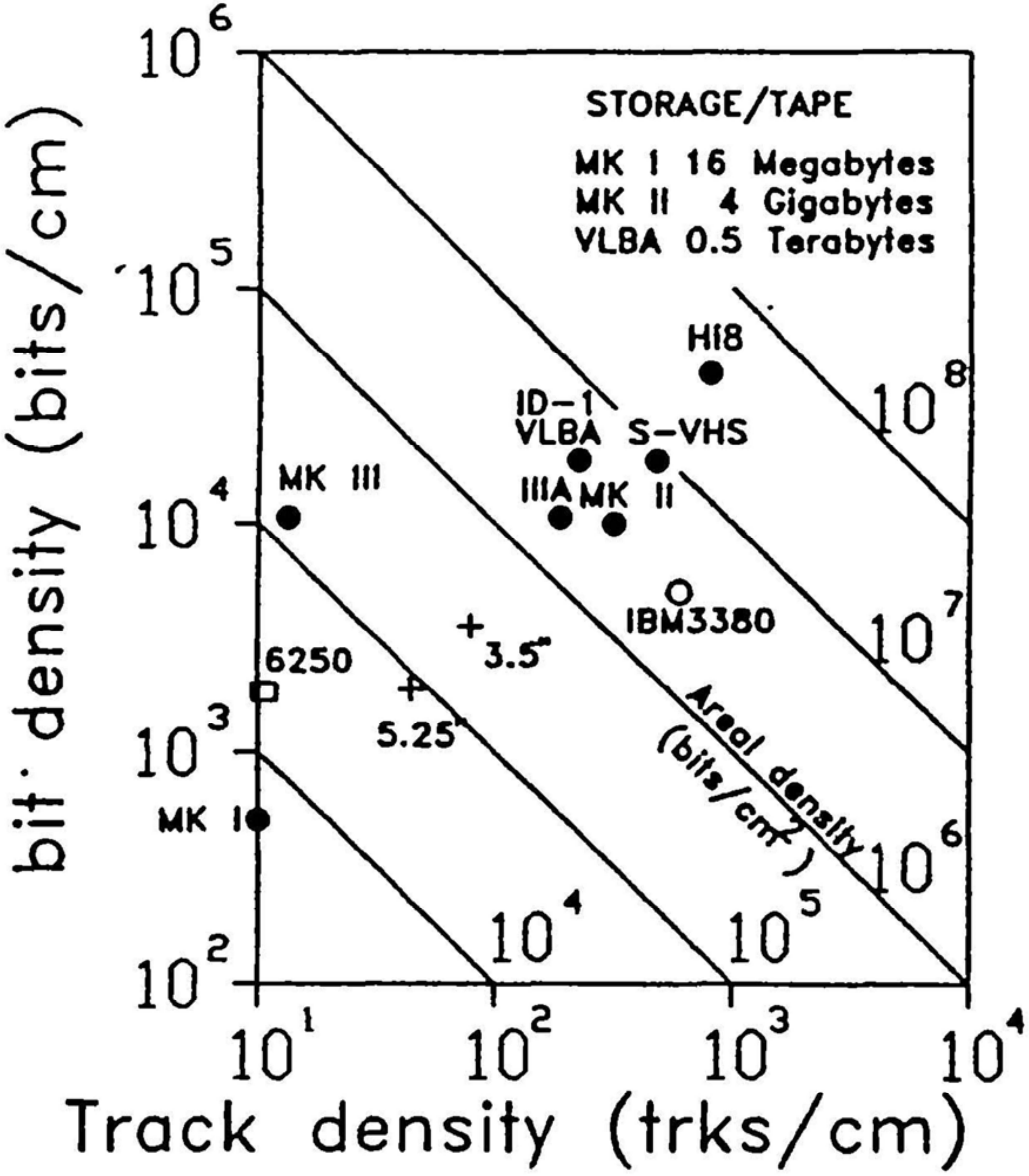
Data recording

- Mk I IBM 7-track 720 kb/s 1967 – 1971
- Mk II Video VR-660 4 Mb/s 1971
- Mk II VHS cassette 4 Mb/s
- Mk III 28 trk instrumentation 256 Mb/s1977
- Mk IV moving headstack 256 Mb/s 1991
- Mk V Computer disk 2 Gb/s 2003
- Mk 6 16 Gb/s 2013

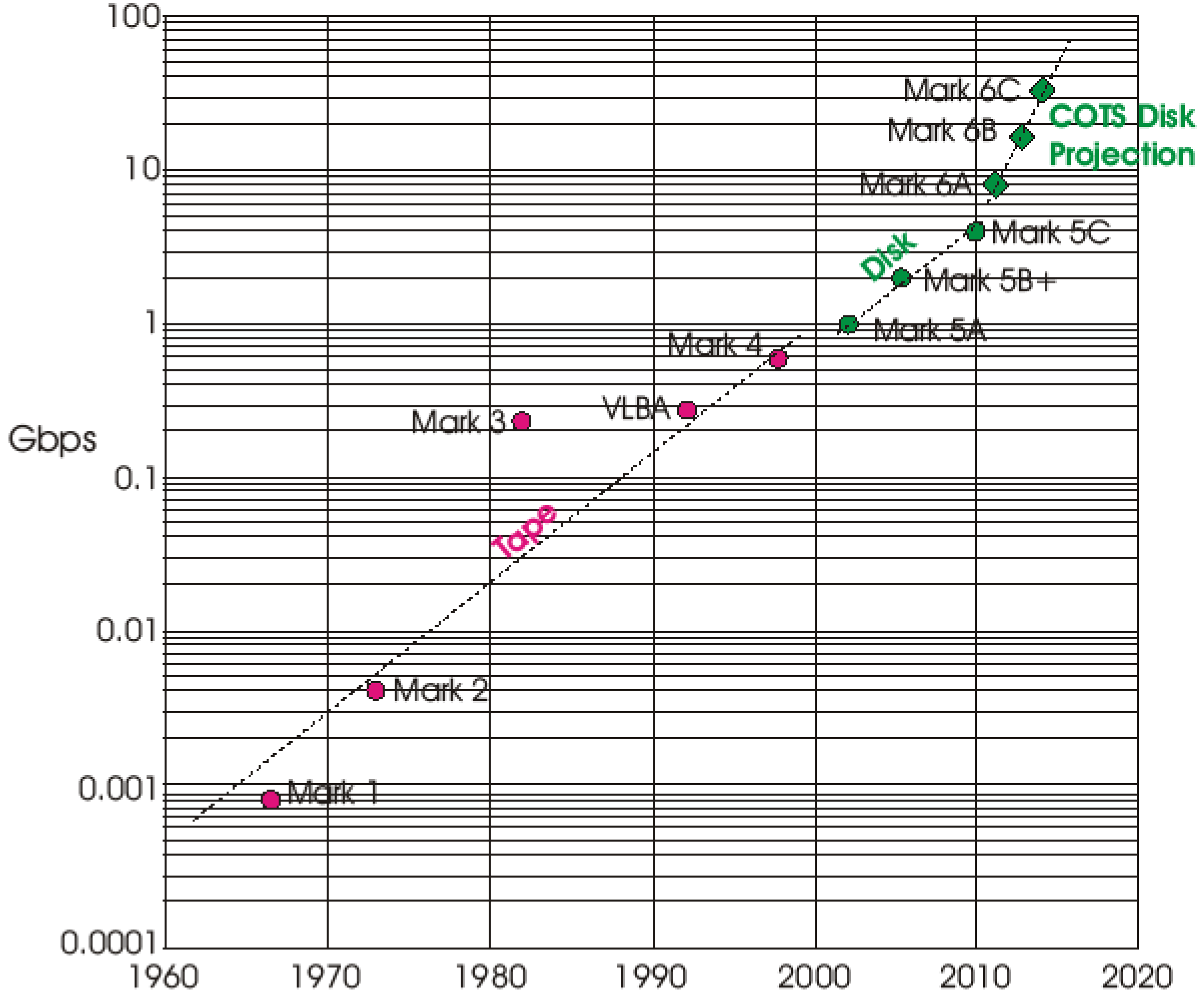
Mark I VLBI data recording system.

CDC 3300 Mk I software correlator at Haystack

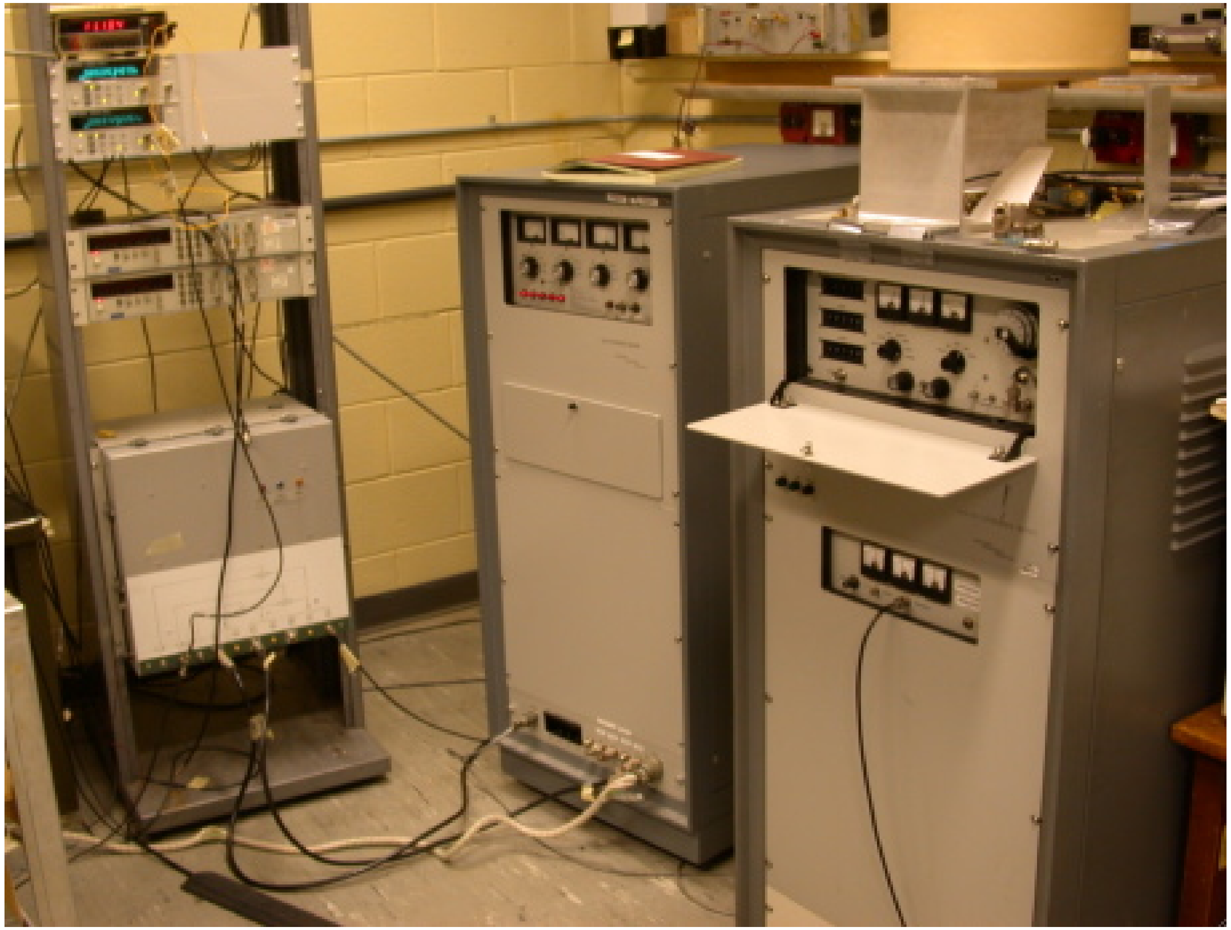
Mk II VR660



STORAGE/TAPE
MK I 16 Megabytes
MK II 4 Gigabytes
VLBA 0.5 Terabytes
HI8
ID-1
VLBA
S-VHS
MK III
IIIA
MK II
IBM3380
3.5"
6250
5.25"
MK I
Areal density (bits/cm²)
10^4
10^5
10^6
10^7
10^8
bit density (bits/cm)
10^2
10^3
10^4
10^5
10^6
Track density (trks/cm)
10^1
10^2
10^3
10^4



VLBI recording technology - recent plot from Alan Whitney

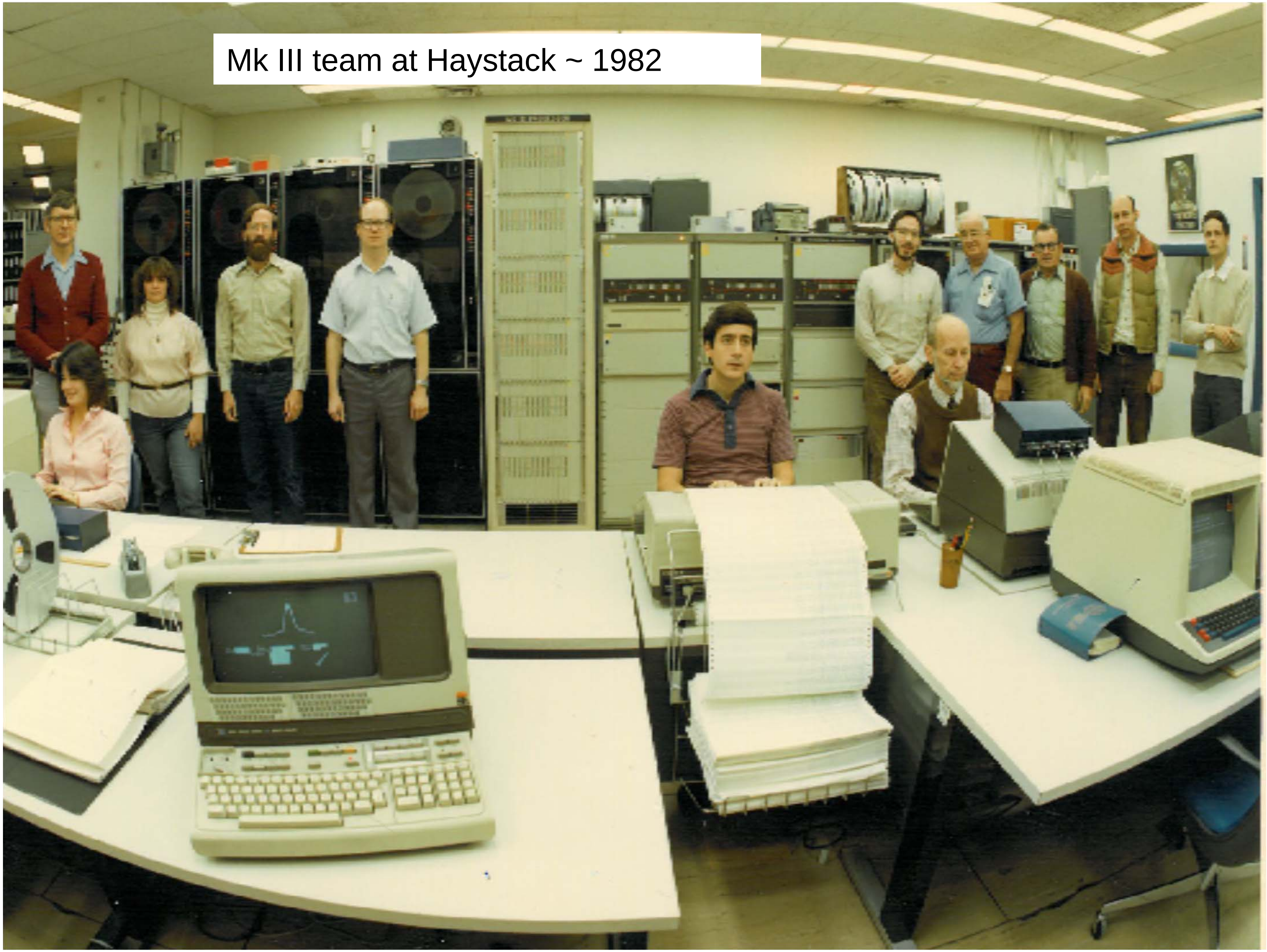


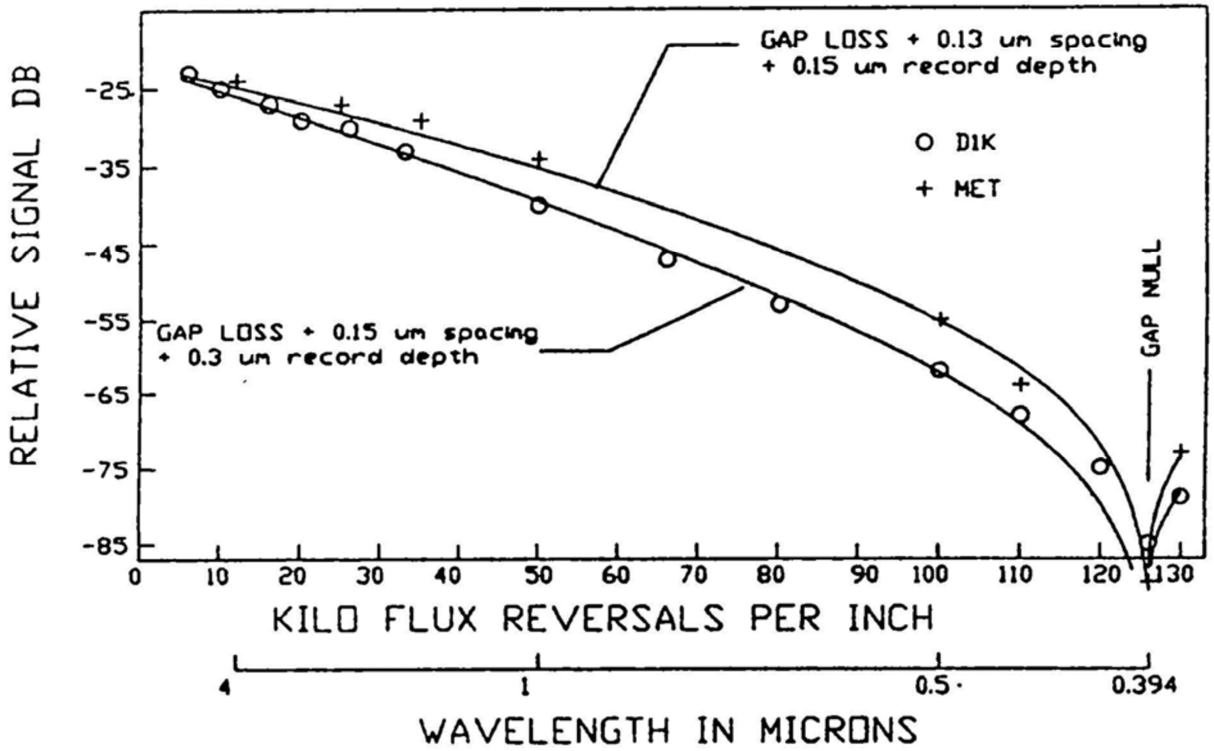
Vessot’s Harvard/CFA H-masers   Peters’ NASA H-maser and Mk I

VLBI Algorithms

- Digital fringe rotation
- Closure phase (actually already used in connected element interferometry – Jennison 1958)
- Bandwidth synthesis (Arsac array of frequencies used for geodetic VLBI)

Mk III team at Haystack ~ 1982





GAP LOSS + 0.13 um spacing
+ 0.15 um record depth
O DIK
+ MET
GAP NULL
GAP LOSS + 0.15 um spacing
+ 0.3 um record depth
RELATIVE SIGNAL DB
-25
-35
-45
-55
-65
-75
-85
0
10
20
30
40
50
60
70
80
90
100
110
120
130
KILO FLUX REVERSALS PER INCH
4
1
0.5
0.394
WAVELENGTH IN MICRONS

VLBI TIMING

- Loran C and traveling clocks - before GPS
- GPS since ~ 1990 (H-maser still needed to time scale < ~ 1 day)
- 2-way satellite link tested by Arnold van Ardenne in 1983 – could in principle provide better performance than H-masers or Superconducting cavity oscillators

IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, VOL. IM-32, NO. 2, JUNE 1983

A High-Precision Phase-Comparison Experiment Using a Geostationary Satellite

ARNOLD VAN ARDENNE, JOHN D. O'SULLIVAN, AND ALAIN DE DIANOUS

***Abstract*—A phase-comparison experiment using a two-way communication link at 14.2/11.5 GHz via a geostationary satellite and a single groundstation is described. Links of this kind can be used in applications where a high degree of phase synchronization is required between signals at frequencies of the order of gigahertz, which are derived from remotely located high-stability clocks, or where a high degree of fractional-frequency stability between remote clocks needs to be maintained.**

The link precision was found to be better than 10 ps over intervals in the range 10–1000 s. At these and longer timescales, the link is more stable than a rubidium standard. Present fractional-frequency stability capabilities are better than 10^{-14} in 1000 s and indicate better than 10^{-15} in 24 h. Improvements may lead to 10^{-15} in 1000 s and a few parts in 10^{-16} in 24 h. In the latter case, the link performance would exceed the capabilities of present H-maser in the region between a few times 10^3 and 10^4 s.

Preliminary estimates of the link performance for a multistation setup indicate that ionospheric variations may determine the overall fractional-frequency stability.

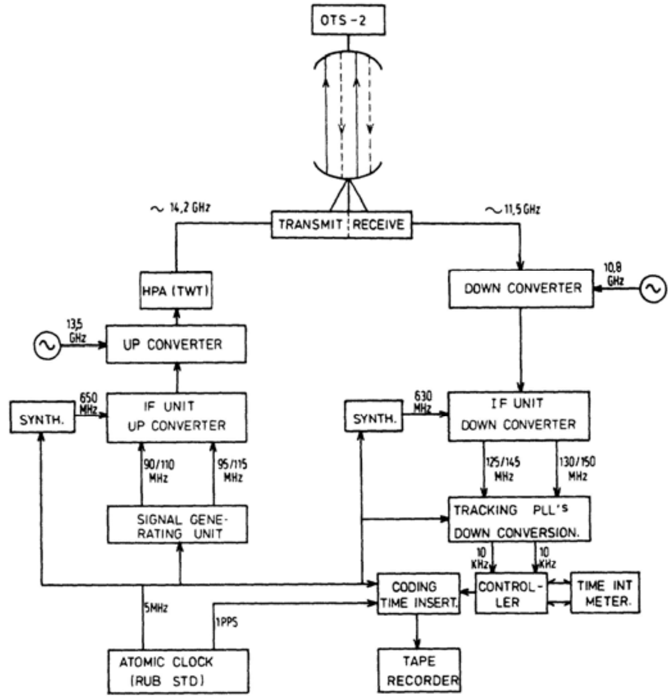


Fig. 2. Block diagram of the experimental system. The uplink part is the left part of the figure. Apart from the high-frequency up/downlink converters, all signals are derived from the station rubidium standard. The 1 pulse per second is used for the generation of a time label which is inserted in the data.

Arnold, we wish you all the very best for your retirement from

Haystack Observatory

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