

Reflections on Engineering Developments in the EVN

Arnold van Ardenne

Retired ASTRON / ardenne@astron.nl



Pre-EVN: ODE-times 18cm VLBI 1976

New Observing role and new Involvement for ASTRON Lab



Opening Dwingeloo Telescope by the Queen 1956 with Prof. Oort

The 1956 crew with Prof. Muller



Upon Richard's 1976 arrival and Leiden discussions; Quick steps toward Europe's first "experiment", Preparations only took a few months:

Early 1976, no specific VLBI equipment:

- 25m Alt-Az Dwingeloo telescope
- Cooled 18 cm receiver
 - Linear pol./ 42K system noise

Required:

- (Interface to) VLBI IF- and Videoformatter
- 1- bit Taperecorders
- Time sync. e.g. through Long wave receivers
- Atomic clock
- (Access to-)Post-observing correlator and processing @ MPI, NRAO
- Adequate Surviving skills; observing inside Dwingeloo telescope, not sure about sleep

The Observing Team

Boudewijn Baud, George Miley, Richard Schilizzi, Me



Data collection

Mark II taperecording
(on loan from Onsala)

Time dissemination & Phase Coherency

LongWave RX (DCF77)

TV synchronisation

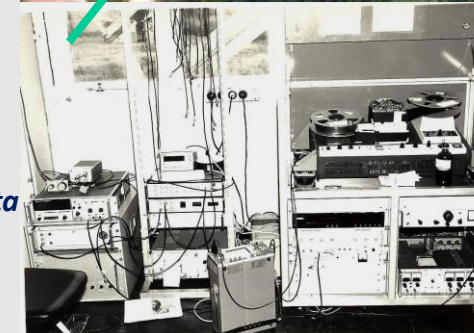
Rubidium clock

(on loan from
Nat. Bureau of Stds/VSL)

Signal conditioning and Data formatting

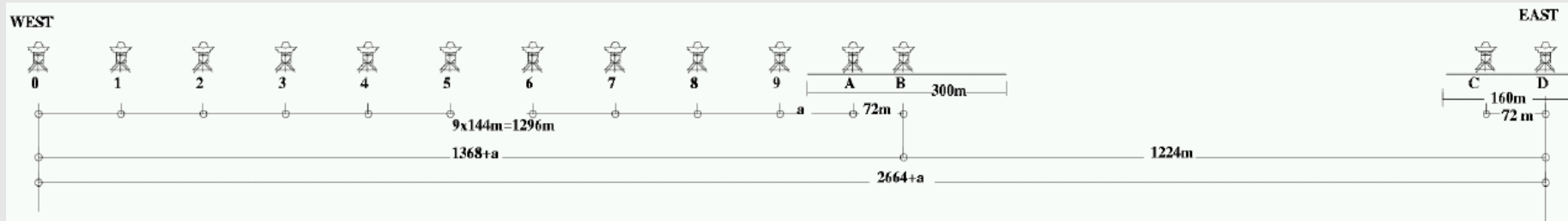
IF & formatter

(on loan from NRAO)



Early VLBI (1967) by NRAO and later in Europe in Onsala and MPI/Bonn (not necessarily in that order) for R.A. and Geodesy; Important (technical) assistance came from there!

Next step: Tied arraying with Westerbork; Emulating a single large telescope for VLBI



In-phase addition of all the signals from all telescopes



Equivalent Diameter max 93 m
i.e. $25 \times \sqrt{14}$

Westerbork Array (Neth.) East – West
configuration of 14 antennas;
Full synthesis & coverage in 4x12 hours

Analog- (1979) then
Digital Adding box
(1981)

Comparable diameter



Effelsberg Greenbank



Lessons learned with VLBI at Westerbork

- Calibration and other issues e.g.:
 - Correct VLBI “tied array position”
 - Effective Area: Different receiver temperatures (always) result in smaller area i.e. max. only with equal system temperatures/telescope (*Note: Initially only 4 cooled RX’s!*)
- Higher than 4 bit quantization required before further digital manipulation (e.g. filtering) and subsequent VLBI correlation, otherwise correlation loss*. With digital adding (beamforming) loss-effect is “only” a few percent for #bits>5-6

*A. van Ardenne, "Sensitivity loss with WSRT as digital tied array, ASTRON Note 289, 1979

*B. J. Korkeler, P. Fridman, A. van Ardenne,
 " Degradation due to quantization noise in radio astronomy
 phased arrays",
Journal for Experimental Astronomy , Vol 11, 33 – 56, Feb. 2001

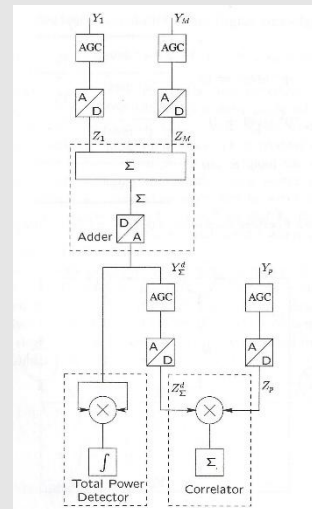
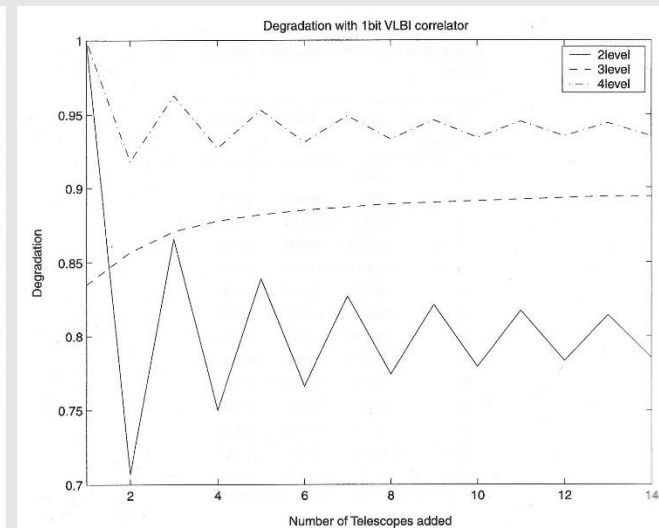


Figure 1. Generic blockdiagram of a Tied Array system



- “Spin-off”: VLBI Tied array activity in Westerbork kicked-off local pulsar work**

****Eds: R. Strom, A. van Ardenne, St. Torchinsky, "50 years Westerbork Observatory", ISBBN 978-90-805434-0-9, 2018**

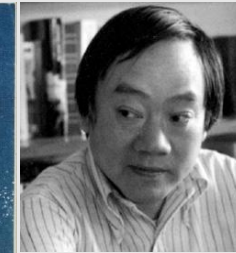
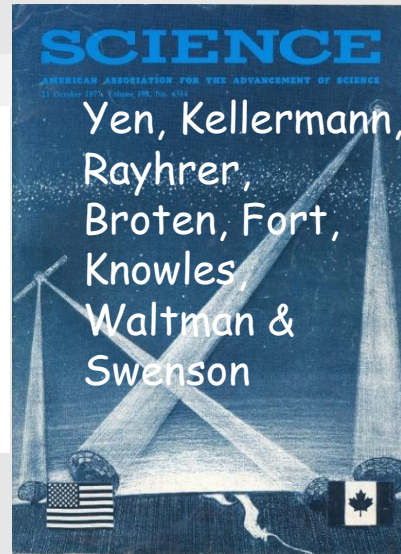
Magnetic recording cumbersome: Steps toward Satellite-linked VLBI, 1977-1982

US, Canada:

Hermes DataLink 1977

Real-Time, Very-Long-Baseline Interferometry Based on the Use of a Communications Satellite

Abstract. The Hermes satellite, a joint Canadian-American program, has been used to provide a communication channel between radio telescopes in West Virginia and Ontario, for very-long-baseline interferometry (VLBI). This system makes possible instantaneous correlation of the data as well as a sensitivity substantially better than that of earlier VLBI systems, by virtue of a broader observational bandwidth. With the use of a geostationary communications satellite it is possible to eliminate the tape recorders and the most troublesome part of the postobservational data processing. A further possibility is the development of a phase-coherent interferometer.



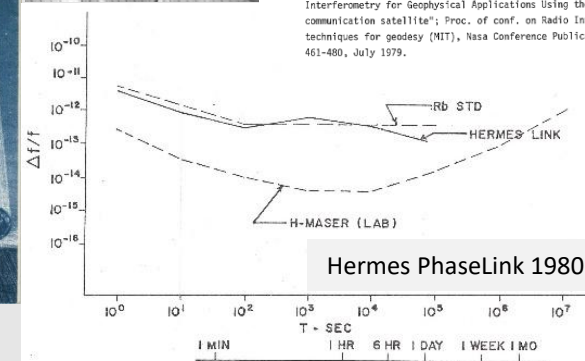
Yen, J.L.; Kellermann, K.I.; Rayhrer, B.; Broten, N.W.; Fort, D.N.; Knowles, S.H.; Waltman, W.B.; Swenson, G.W.: "Real-time Very Long Baseline Interferometry based on the use of the communications satellite", Science, 198, 289-291, 1977.

Waltman, W.B.; Knowles, S.H.; Yen, J.L.; Fort, D.N.; Swenson, G.W.; Cannon, W.H.; Galt, J.: "Phase coherent VLBI using a satellite Link", Proc. of Conf. on Radio Interferometry techniques for Geodesy (MIT), Nasa Conference Publication 2115, 90-94, July 1979.

Laroye, J.F.: "Phase Comparison via Satellite Link", Thesis Dept. El. Eng., University of Toronto, Canada, January 1979.

Yen, J.L.: Private Communication, July 1980.

Cannon, W.H.; Petrachenko, W.T.; Yen, J.L.; Galt, J.A.; Waltman, W.B.; Knowles, S.H.; Popelar, J.: "Plans for Phase Coherent Long Baseline Interferometry for Geophysical Applications Using the Anik-B communication satellite", Proc. of conf. on Radio Interferometry techniques for geodesy (MIT), Nasa Conference Publication 2115, 461-480, July 1979.



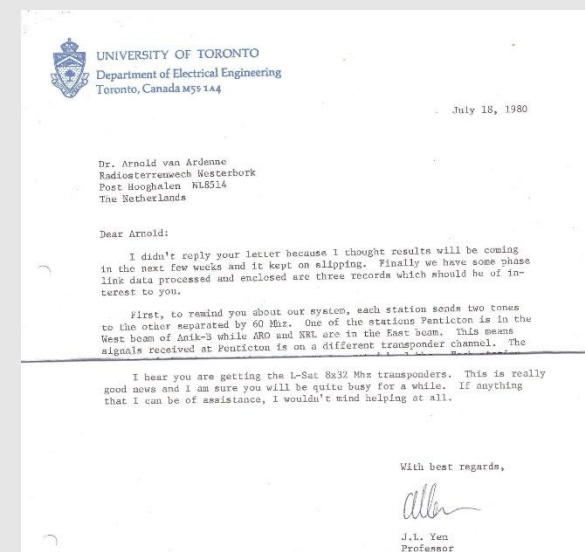
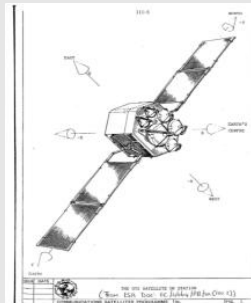
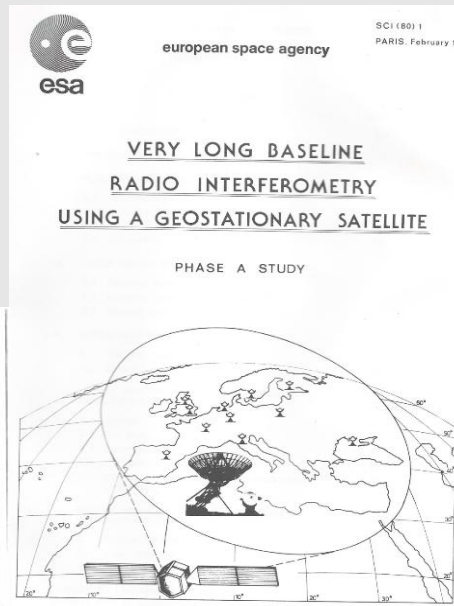
Hermes PhaseLink 1980

Europe:

1978: ESA Feasibility Study of satellite-linked VLBI

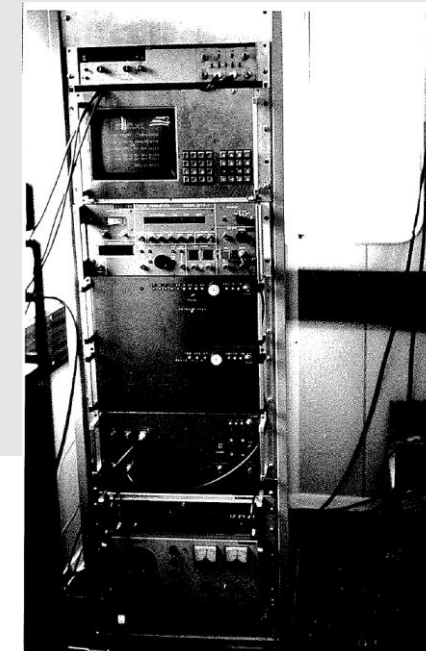
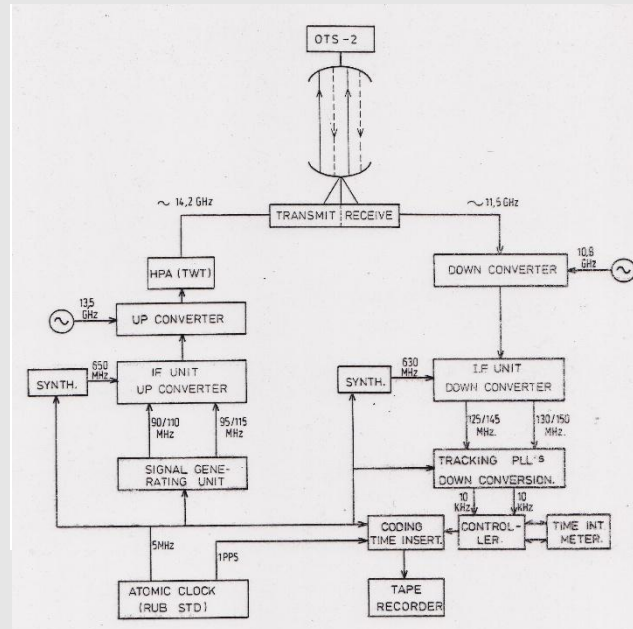
1981: ESA Phase A study of satellite-linked VLBI using L-SAT

1982: Phase transfer via ESA's Orbital Test Satellite 2



Toward Space VLBI and Quasat times : Time/phase transfer with OTS2 at ESTEC site, 1981

- Geostationary satellite
- Multi-tone transmission
- Phase noise from on-board translation oscillator is common to all tones and is cancelled via differential phase measurements between the tones
- Satellite motion and propagation delay cancelled by use of the 2-way up and down links at 11.5/14.2GHz

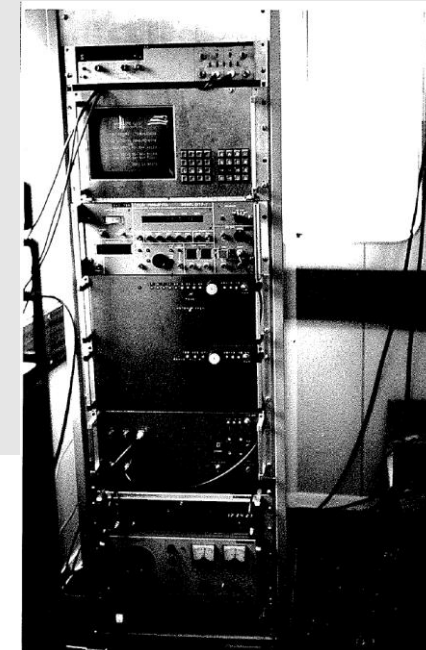
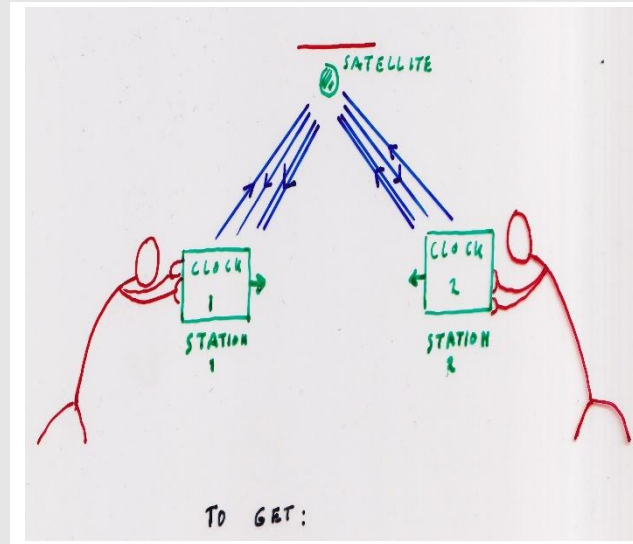


"Requirement" (from ESA report):

The ground system must be capable of supplying, via a two-way link, a stable radio tone that will allow a signal decorrelation loss due to phase transfer error of no more than 1% at 22 GHz for a 300 second integration time. This performance corresponds to an RMS phase error of 8° at 22 GHz (phase slope removed). If the link is dominated by white phase noise, the required square root Allan variance is 3.3×10^{-15} in 300 seconds.

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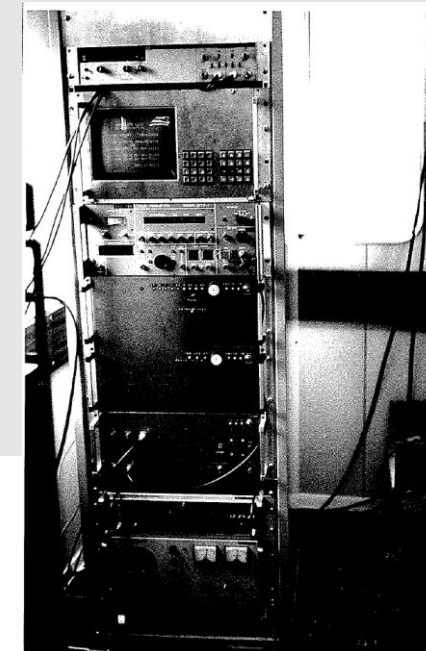
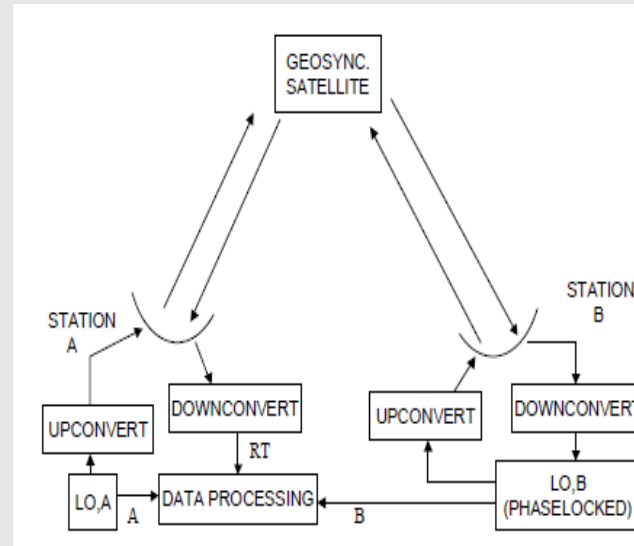


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Results of Phase/time transfer through satellite

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

[4] demonstrated the possibility of comparing high-stability atomic clocks to within an accuracy of 10 ns by means of a two-way satellite communication link. Other techniques potentially capable of even higher accuracies [5], [6]; the merits and merits of existing and planned methods are summarized by Lechitta [7]. There are a number of other applications

- A. van Ardenne, J.D. O'Sullivan, "VLBI clock phase comparison using a geostationary satellite", *Internat. Conference on VLBI Techniques*, CNES, Toulouse, 1982

- A. van Ardenne, J. D. O'Sullivan, A. de Dianous, "A High-Precision Phase-Comparison Experiment Using a Geostationary Satellite", *IEEE Trans. Instrum. and Measurement*, Vol IM-32, Nr.2, pp 370-376, 1983

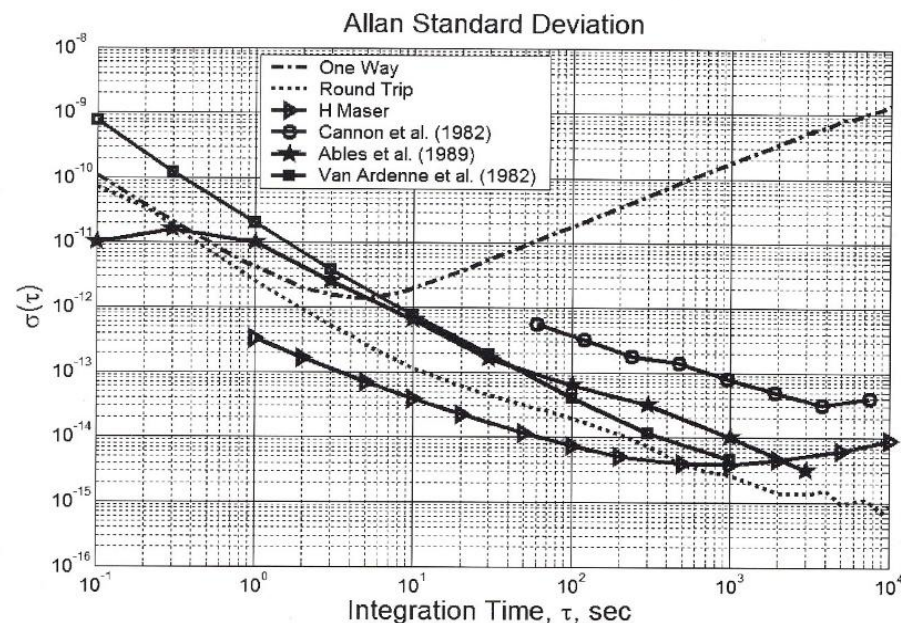


Figure 4. Measured Allan standard deviation (Cannon et al., 1982; Ables, 1989; Van Ardenne et al., 1983) one way refers to ϕ_B and round trip refers to ϕ_{residual} .

- S.T. Ables; Phase stability with the Aussat satellite, ATNF, 1989
- J. Bardin, S. Weinreb, and D. Bagri; "Local Oscillator Distribution using a Geostationary Satellite", *The SKA; an Engineering Perspective*, pp193-199, 2005

- Achieved order of magnitude improvement with OTS2 (1981)
- Comparable with H-maser after about 1000sec
- Result could improve with higher S/N
- 2005 result proves this (dashed line in figure left)
- comparable with H-maser after order 500sec

Harmonizing Engineering VLBI in Europe: EVN-TWG

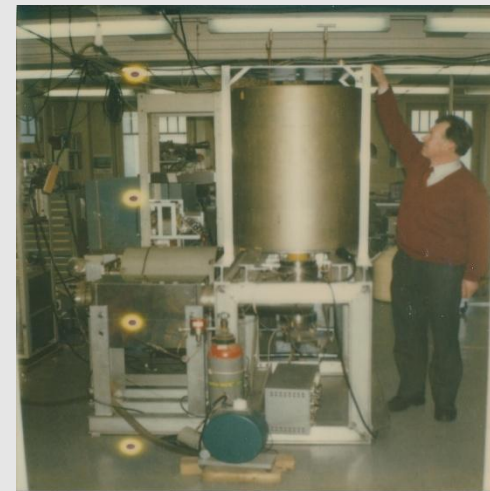
EVN Technical Working Group 1982 (MPIfR Bonn)- 1998, then “TWG” became “TOG”

- Participation representing all EVN institutes
 - *1st Chair Wolfgang Zinz (MPIfR) until 1986*
- Scheduling/Organizing time slots vis a vis observational readiness
 - *Observing frequencies, Scheduling software*
- Promoting technical knowledge and - exchange for VLBI e.g.:
 - *RX's, LNA's*
 - *(Implementing) Tape recorder developments (mostly originating in US)*
 - *Time keeping; synchronisation, H-maser clock developments,..*
 - *Resolving the Polarization mismatch left/right*



Idea generation and
Knowledge exchange:

Miller Goss, Richard
Strom and John
O'Sullivan.
VLBI Conference
Heidelberg 1978



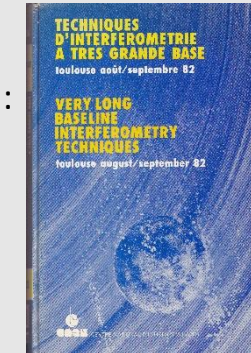
Lout Sondaar preparing
the first Westerbork
Hydrogen Maser
precision clock in the
Oscilloquarz Labs,
Neuchatel in early 1984

*Note: Lout was later
honoured with the Yuri
Gagarin medal for his
RadioAstron contribution*

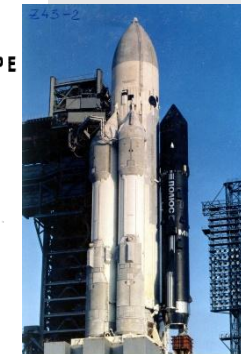
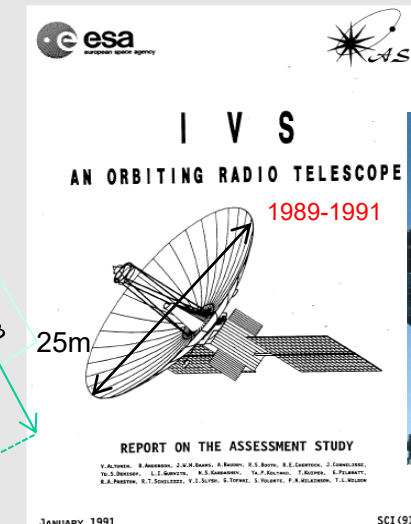
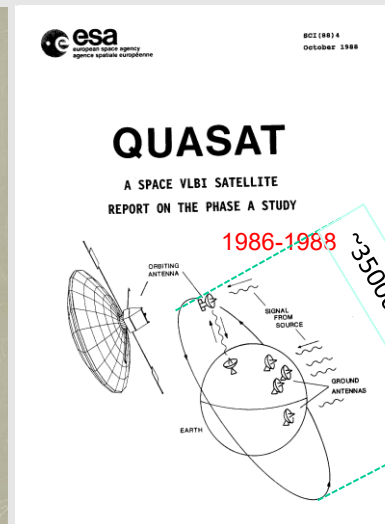
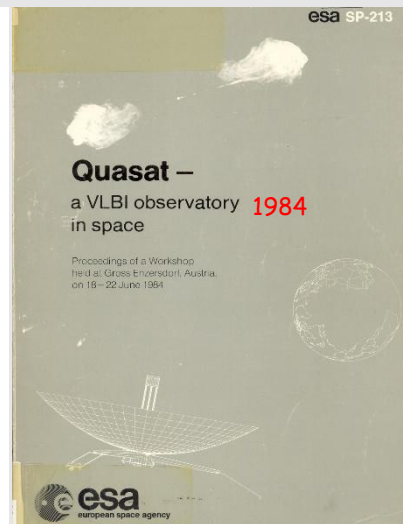
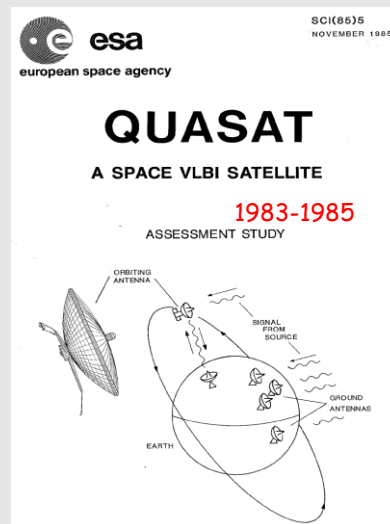
Increasing the resolution further:

In parallel, space VLBI 1982-1991

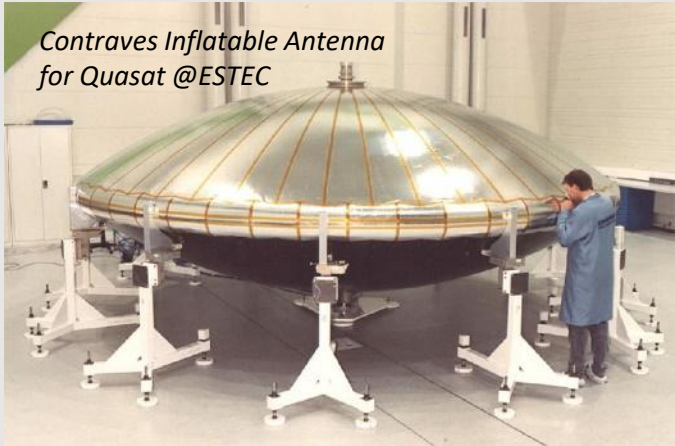
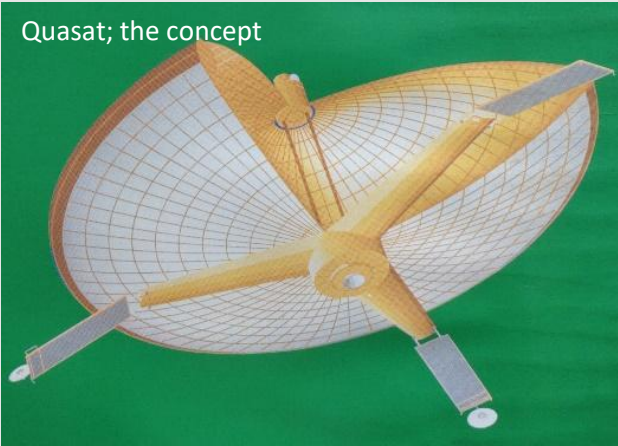
- 1982 QUASAT, ESA-NASA VLBI mission initiated at CNES VLBI meeting in Toulouse, France :
- 1983 1983-5 Assessment Study
- 1984 ESA conference at Gross Enzersdorf, Austria
- 1986-8 Phase A Study
- 1988 Nov. 1988 Demise of QUASAT in Bruges ; **too Expensive**
- 1989 International VLBI Satellite, ESA-Astro Space Center Russia



Not selected by ESA, Russian funding too risky



Quasat did not work out but generated relevant developments



Early QUASAT simulation work

QUASAT IMAGING SIMULATIONS
"COLLOQUIUM PACK"
A. Wells & P. Wilkinson, Jodrell Bank, U.K.

5 x 35mm slides showing computer simulations which illustrate the improvement in image quality to be expected if the EVN* ground array is operated with QUASAT in its standard orbit. These simulations are discussed in detail in the ESA Assessment Study report (ESA SCI(85)5) prepared by the European QUASAT Science Team. The relevant sections in the report are 5.1.1, 5.1.2, 5.1.3 and, especially, 5.1.4.

Feeds

Ames, H.; Bolton, S.; Burke, B. F.; Burks, S.; Christensen, C.; Dhawan, V.; Freland, B.; Grippi, D.; Hamilton, C.; Hansen, D.; and 40 coauthors,
"Quasat: technical aspects of the proposed mission", ESA Spec. Publ., ESA SP-213, p. 27 – 99, 1984

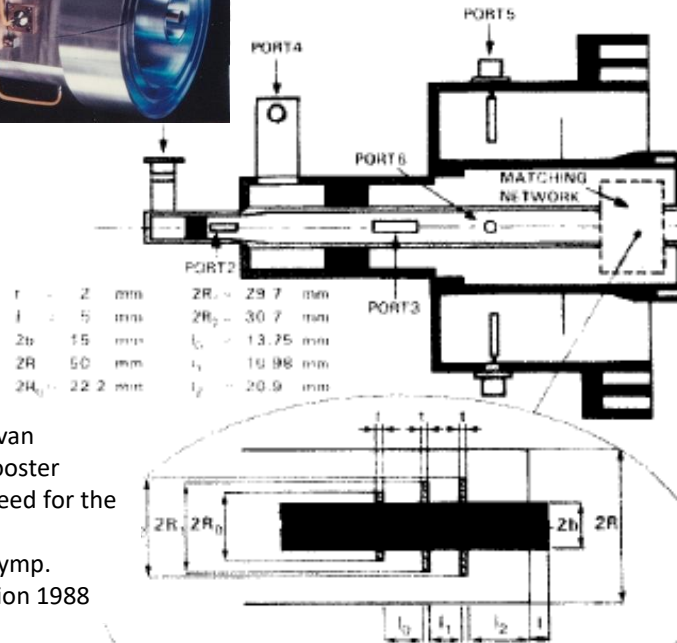
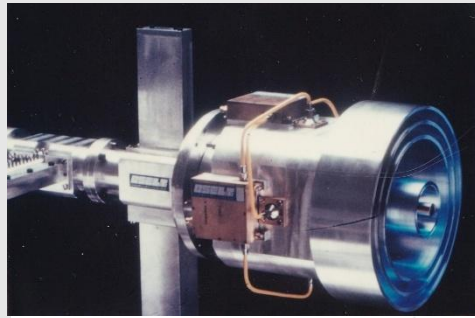
Defined: Four Frequency bands:

Table 1.1: Angular resolution, maximum source size that can be mapped, and sensitivity

λ (cm)	Angular resolution ¹ (micro-arcsec)	max source size (milli-arcsec)	RMS noise per pixel ² (continuum)	RMS noise per spectral channel ³	Frequency (GHz)
1.35	50	10	0.3 mJy	15 mJy	22.0-22.50
6	225	50	0.1	8	4.72-5.02
18	670	125	0.1	8	1.60-1.72
92	3410	675	0.6	-	0.324-0.328

Multi-Frequency Feeds (1987-1988)

Industrial Package: Collaborating with Arcetri/Bologna i.e. G. Tofani



D. Savini, G. Figlia, A. van Ardenne, K. van't Klooster
"A triple frequency feed for the QUASAT antenna",
IEEE AP-S Internat. Symp.
Antennas & Propagation 1988

Fig.1. QUASAT Triple Frequency Feed.

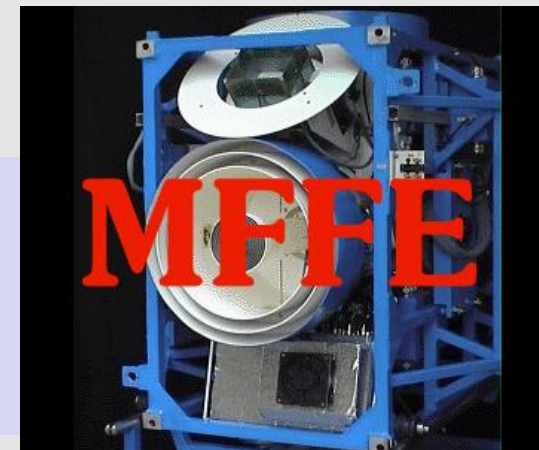


Different perspective; Kees van het Klooster, me in Florence (catching up with Gianni Tofani)



Lessons learned:

- Applied to new system in Westerbork Array i.e. MultiFreq. Frontends (MFFE, 1999-2020+, *G.H. Tan et al.*)
- Now: Korean triple freq. mm feed for Sardinia RT?



Increasing the resolution even further; RadioAstron

- 6cm RX ASTRON, MPIfR-Bonn(LNA):
- 18cm RX CSIRO; became operational RX

Lout Sondaar, Jan Buitter, Axel Schmidt (MPIfR), funded by the EVN.

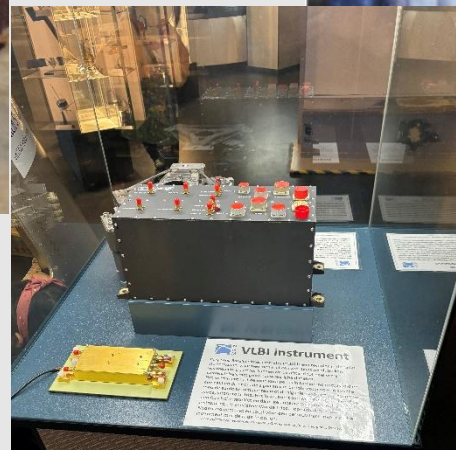
ESA supported the project by use of their anechoic chamber and vibration test facility for the Engineering Model.

RadioAstron workshop Moscow Dec.1985, (Lenin Hills, -20degC)

Ltr: RTS, IKI interpreters, AvA, Istvan Fejes, Sandy Weinreb,?



Ltr: Esko Valtaoja (University of Turku),
RTS, Jan Buitter, Rod Davies, Eugen
Preuss
(Moscow, 24Oct1991)

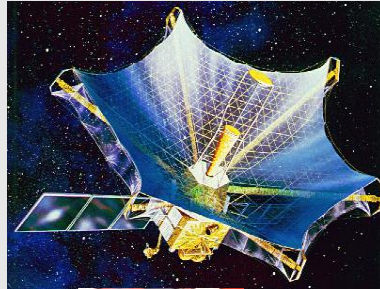


6cm Flightmodel, now at
National Space Museum,
Neth.
(Courtesy Leonid Gurvits)

No support for Satellite-linked VLBI by EVN Directors or ESA (paying for the telemetry stations at telescope sites was the main obstacle) **QUASAT** and **IVS** not funded however **VSOP** and **RadioAstron** carried on

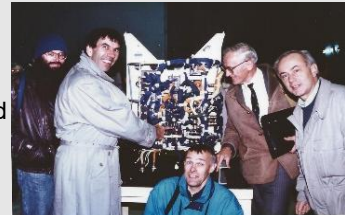
VSOP-HALCA

Operational 1997-2003



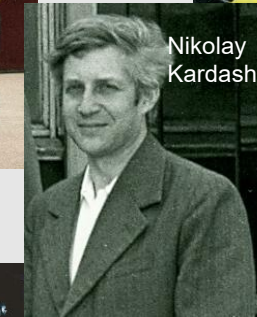
1986-1994

EVN 6 cm receiver built in Dwingeloo and Bonn, tested at ESTEC, and delivered to Moscow. But did not fly on RADIOASTRON



RadioAstron

Operational 2011-June 2019



Last but not least; Some personal Views

- Most rewarding times (scientifically, personally)
- From “experiments” to “standard observations” (including the WSRT) harmonized through EVN
- Developments of organizations and international perspectives while making enormous technological strides
- SKA provides platform for furthering links

End