The Very Large Array
Origin, Development, and Construction

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VLA Origin-
100 Years of Scientific and Technical Developments

Years	Key Person	Milestone
1930	Jansky	Discovery of galactic radio waves
1930-1945	Reber	Technolgy limited
1939-1945	Many	Development of microwave radar
1946-1960	Pawsey, Boltan, Ryle	Discovery of discrete sources, recognition of need for resolution in the arc second range
1967	Heeschen, Clark	VLA proposal
1960-	Many	Cryogenics, transistor LNAs, digital processing ala Moore's Law
1973-1980	Heeschen, Hvatum, Lancaster	VLA, exceded proposed sensitivity, bandwidth, frequency range, and spectral lines
1980	Many	Optical fiber technology
2002-2010	Many	JVLA, 1-50 GHz, increased sensitivity and bandwidth
1990-2020	Many	Spinnoff of communication industry give lower cost, high performance electroncs
2017-2030	Beasley	ngVLA, 10X expansion of sensitivity and resolution, 1.2 -116 GHz

VLA Origin - Strategic Events

Event	Year	VLA Relevance
David Heeschen, new Director of NRAO	1962	With input from Pawsey starts a 10 year campaign to develop and fund the VLA
Whitford 1	1962	Recommends high-resolution 3cm instrument
Whitford 2	1964	Recommends many radio telescopes
Dicke 1	1967	Recommends construction of 8 x 40m Caltech Array
VLA Proposal 1-4	1967	NRAO proposes 36 x 25m array in NM
Dicke 2	1969	Reversed VLA/Caltech array priority
Greenstein	1972	Priority to VLA over large dish and Arecibo upgrade
VLA Construction	74-'80	Completed in 1980 at $78M

Development Path

Item	VLA Proposal	VLA As Built	JVLA Addition	ngVLA Concept
Year	1967	1975	2005	2017
Cost	$40M	$78M	$75M	$1500M ?
Cost, $2017	$284M	$405M	$120M	$1500M ?
Antennas	36 x 25m	27 x 25m	27 x25m	214 x 18m
Transport	Tires	Rail	Rail	None
Signal Transmission	Cables	Waveguide	Fiber	Fiber
Frequency, GHz	2.7/8.1	1-23	1-50	1.2-116
Cryocoolers. Temp	None	1- 15K	8-15K	2 - 20K
Typical Tsys	100	50	30	25
Correlator	Analog	Digital	Digital	Digital
Bandwidth, MHz	20	200	2,000	20,000

Development Strategy

- During the 1960's electronics was in a transformational period due to the to introduction of transistors, digital computers, new data transmission methods

- The incorporation of this new technology required several highly competent up-to-date scientists and engineers for new designs of low noise amplifiers, cryogenic systems, long distance low loss waveguide, and digital correlators. NRAO was able to assemble a group of the order of 10-20 scientists and engineers to design the VLA from sources such as Australia, UK, Canada, Germany, Sweden, Polard, and Caltech

- The VLA did not have formal design reviews (PDR, CDR, etc), a NASA and ESA process which came later. Designs and decisions were made in small groups with the responsible engineer, Weinreb, and Hvatum. Lancaster and Hvatum did hold monthly cost reviews.

- The upper management (Director and NSF) had the courage and confidence in the engineering team to allow major changes from the proposal without delay.

Revisions of VLA Electronics Between Proposal (1967) and Construction (1973-1980)

Had the VLA been built has proposed as a 2.7/8.1 GHz continuum instrument much radio astronomy research would have been delayed by a decade

Major Electrnics Change Documents

- Introduced 4-band 1 -23 GHz cryogenic receiver to replace high noise 2.7/8.1 GHz
- Describes digital delay and correlator system
- Designed spectral line system
- Describes waveguide transmission to replace miles of coaxial cable system with less bandwidth and a repeater every 2km

VLA Electronics Memoranda

Memo Submission

Contact the Library via e-mail if you have any trouble with the scans posted here.

Memo Number	Title	Author(s)	Date	Original PDF
1	Sensitivity Measurements of Mixers for the VLA LO System	J. L. Dolan	02/28/67	
2	Consideration of a Microwave Link IF Transmission System	S. Weinreb	05/10/68	
3	VLA Correlator Design Studies	J. Rehr	09/15/67	
4	A Test Set for VLA Correlator Design Studies	J. Rehr	09/15/67	
5	Comparison of Modulation Systems for Transmission Through Dispersive Cables	S. Weinreb	11/29/67	
6	Prototype IF Transmission System	S. Weinreb	12/19/67	
7	Equalization and Signal-To-Noise Problems in the IF Transmission System	D. Buhl	02/06/68	
8	Interim Report on Prototype Local Oscillator System	H. Beazell	03/09/68	
9	Status of IF Transmission System	S. Weinreb	03/12/68	
10	Phase and Group Delay of Coaxial Cable	S. Weinreb	03/15/68	
11	Phase Equalization in the VLA IF System	D. Buhl	-	
101	Front End Options	S. Weinreb	4/10/72	
102	Waveguide Signal Transmission System	S. Weinreb	8/17/72	
103	Digital Delay System for the VLA	A. Shalloway, P. Camana	9/22/72	

http://library.nrao.edu/vlae.shtml 1/

Replacement of Prototyped Coaxial Cable with 1970 State-of-the-Art Lossless Mode Waveguide

- Waveguide developed by many years of research at Bell Telephone Labs. Would have been used for nationwide data transmission if optical fiber had not been developed
- NRAO purchased 63 km of the waveguide from Furukawa in Japan
- Waveguide must be installed with radius of curvature > 1km.

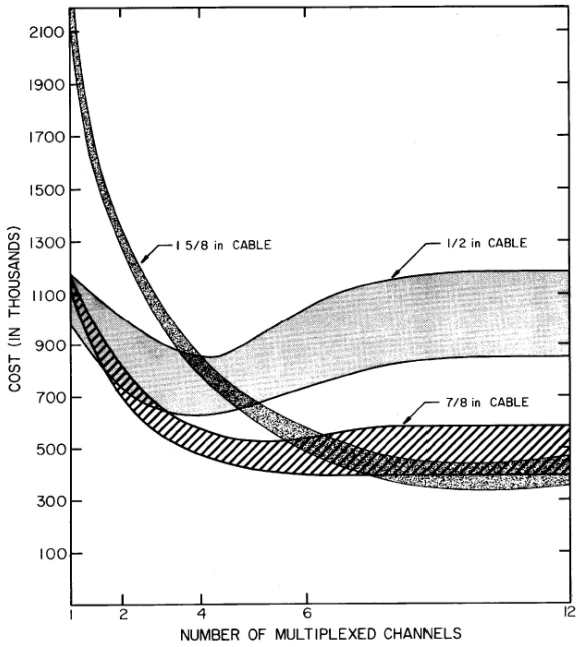
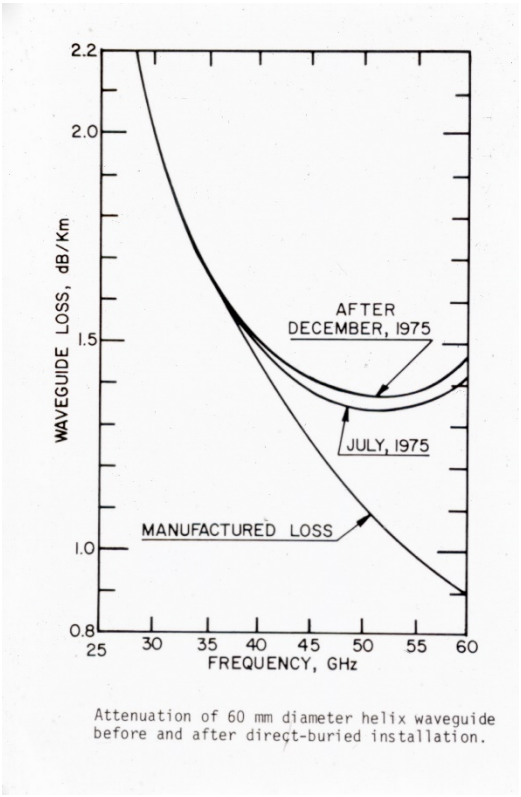


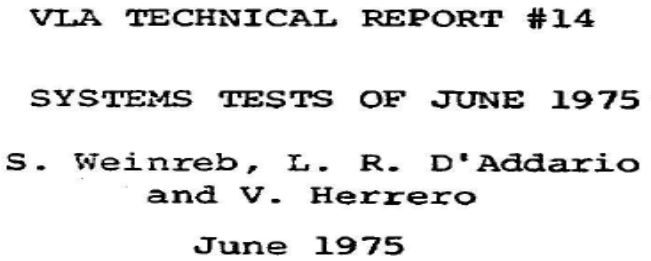
Figure 16 - 1. Cable and repeater costs for a 21 km arm with 12 antennas (includes LO cable).



Attenuation of 60 mm diameter helix waveguide before and after direct-buried installation.

Key Technical Documents

The VLA electronics system is documented in hundreds of memo. Many of these can benefit future radio astronomy array designs. Some samples are shown below.



VLA TECHNICAL REPORT #14

SYSTEMS TESTS OF JUNE 1975

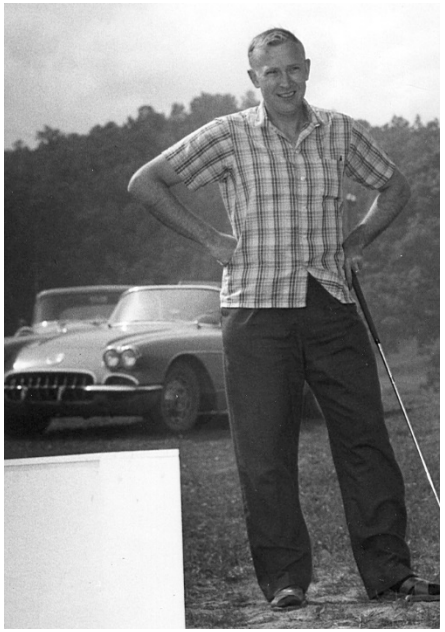
S. Weinreb, L. R. D'Addario and V. Herrero

June 1975

End to end test of electronics from one antenna to control room to find spurious signals, noise levels, and stability

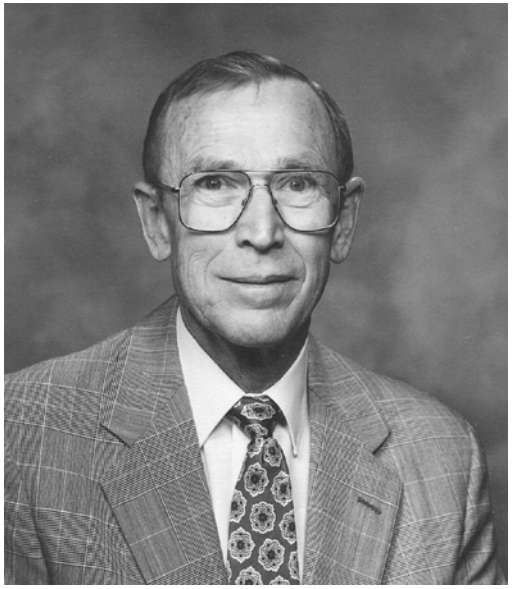
103	Digital Delay System for the VLA	A. Shalloway, P. Camana	9/2?/72
102	Waveguide Signal Transmission System	S. Weinreb	8/
101	Front End Options	S. Weinreb	4/
118	The Bandwidth Effect ('Delay Beam') for a Synthesis Array and Related Requirements for the IF Filter Characteristics	A. R. Thompson	11/1
124	The Design of the VLA Fringe Rotator System	A. R. Thompson	10/16/74
144	Cooled Mixers and Spurious Signals	M. Balister	8/15/74
145	VLA Circular Waveguide System	R. Predmore	9/25/74

147	Combining the VLA Continuum and Spectral Line Correlators	R. Escoffier	8/25/75
165	VLA Reliability and Maintenance - an Early Look	M. Ballister, J. R. Fisher, J. Payne, S. Weinreb	10/77
207	The Correlator System for the Very Large Array Radio Telescope	C. Broadwell, R. Escoffier	07/82
171	Closure - Some Examples	B. G. Clark	04/78



David S.Heeschen
1926-2012

NRAO Director
1962-1978



- Led the campaign for VLA funding for 10 years directed the scientific requirements, technical development, and construction.
- Distinguished by his vision, forcefulness, honesty, and Judgement of people and ideas. Initiated open skies policy for all NRAO observing instruments.
- Memorable quotations:

  Memo to managers: NRAO has contracted to build the VLA for $72M and there will be no overruns or cost expansion.

  "Let's not become another money grubbing organization."

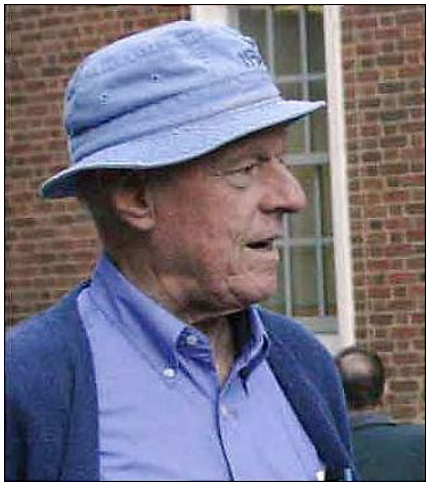
  "Let's stick to our knitting

  After dinner speech: "The bar is open"

Hein Hvatum

1925-1982

Associate Director of NRAO
Ph.D. EE Chalmers, Sweden
Protégé of Olef Rydbeck



- Responsible for construction of VLA: antennas, electronics, and computer
- Was a great communicator with everyone
- Wonderful sense of humor
- Ardent bicyclist, radio ham, and train buff
- Memorable quotations:

“Let’s see mistakes because of lack of paperwork; in that way we know we are not overdoing it”

“When you travel, do something for fun”

Jack Lancaster
1917-2013

From 1946 to 1972 he worked at Brookhaven National Laboratory as Chief Project Engineer involved in all large construction projects. From 1972 to 1981 he was Assistant Director of the National Radio Astronomy Observatory and **Project Manager for the Very Large Array** Radio Telescope in Socorro, NM.

Very capable manager of large projects. Tight cost control; a penny pincher. Provide compact monthly reports such as below:

The personnel changes as of March 31, 1979 are as follows:

Division	Budgeted 12/79 Level	2/28/79 Level	Additions	Reductions	3/31/79 Level
Site & Wye	9	9	1	1	9*
Antenna	17	14	0	1	13
Electronics	55	50	3	1	52**
Operations Management	3	3	0	0	3
Computer	14	12	0	0	12
Array Operations	11	9	0	0	9***
Program Management	28	27	0	0	27****
Totals	136	124	4	3	125

Barry Clark

Unofficial Project Scientist of the VLA. Project guru who we went to for hard questions. Wrote the original on-line Modcomp softwave for the VLA used for many years and did much of the scheduling of telescope time. Known for his brief, information packed, short answers such as the one below.

What the effect of water vapor on VLA phase?
Barry: 9
Sandy: What units?
Barry: No units, just 9.
Sandy: Why 9?
Barry: Square root of 80

10 years later through MIT Ph.D. thesis of Joe Waters we learned the increase in path delay due to each mm of precipitable water vapor in the path was 6mm/mm.

Other Major Contributors

Peter Napier - Led the optics design and on-site construction, 1977-1981
Richard Thompson - Much analysis and coauthor of the authorative reference book on radio astronomy arrays.
Larry D'addario – System engineering and trouble-shooer.
Art Shalloway – Early correlator and digital delay development
Ray Escoffier - Designed VLA correlator
Mike Balister – Responsible for cryogenic receiver
Ted Riffe – Assistand Director for business opeations – NSF business contact
Jay Marymor – Managed contracts
Bill Horne – Responsible for VLA antenna contract with E-Systems
Bob Burns – Computer division head during VLA development.
Jack Campbell – Led VLA electronics fabrication
Monroe Petty – Personnel manager

VLA Documents

Many documents from 1967 until the current (2017) are available at the NRAO library, at:

http://library.nrao.edu/vla.shtml

A concise history of radio astronomy leading up to the VLA construction is:
G.W. Swenson, "A Case Study of The Decision to Construct a Large Radiotelescope – The VLA" 1977

Next Generation Very Large Array Memos	2015-	Computing	1973-1996
Expanded Very Large Array Memos	EVLA, 1995-	Electronics	1967-
Very Large Array Memos	Original VLA Memo series, 1967-	HTRP	1983-1992
VLA Reports	1966	Interference	1992-2009
VLA Proposals	1967-1972	Scientific	1967-2003
VLA Progress Reports	1974-1981	Technical	1973-2001
VLA Publications	Various	Test	1974-2005
		Antenna	1967-1968

VLA Lessons Learned

Requirements – Know what the scientist wants but better yet, know what he/she needs

Think Ahead – The instrument will go into operation 15 years after proposed and last for 20 years.

New Technology – Use it wisely and carefully but take some risks.

Buy Smart – Know how to build what you are buying and what it costs to build.

Strong Engineering Staff - Import if necessary to get experienced expertise

Sponsor Relations – Two-way street; work on common goals. Have contact at high levels.

Operation Cost - Think ahead on how to diagnose and repair failures.