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VERY LARGE ARRAY
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87 Oct 14

VOYAGER MEMO

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From: W. Brundage WB

Subject: VLA Implementation Plan for Voyager at Neptune

This PLAN (attached) is the NRAO commitment to JPL for implementing our part of the VLA-Goldstone Telemetry Array for Voyager 2 at Neptune, April - September, 1989.

Now we have to deliver a fully operational system by January 1, 1989, fine-tune it by April 1, 1989, and run it flawlessly thru September 30, 1989.!!!

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# VLA IMPLEMENTATION PLAN
# VLA-GOLDSTONE TELEMETRY ARRAY
# VOYAGER 2 AT NEPTUNE

SEPTEMBER 29, 1987

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The feed, supplied by JPL, sits on the VLA cassegrain antenna feed circle along with feeds for L, C, Ku, and K bands. The hyperbolic subreflector axis lies on the virtual cone "connecting" the prime-focus with the feed circle. Rotating the subreflector about the antenna axis selects the feed for the band in use.

The cooled front-end (CFE), with ultra-low-noise HEMT amplifiers, bolts directly onto the throat of the feed. RCP and LCP outputs from the CFE connect to the LO / MIXER Module-F12 in Rack-F.

Rack-F also contains power supply and control / monitor modules.

The first intermediate frequency (IF) outputs at C-band connect to the pair of bandswitches in Module-F9 of Rack-A. The bandswitches select the front-end for the band in use. Rack-A also contains the L, C, Ku, and K band front-ends.

C-band output from the bandswitches passes into the band-independent receiver system which filters, frequency converts, and modulates four receiver IFs and control / monitor data into the array waveguide. The waveguides, one on each arm of the wye array, connect all antennas to the control center electronics and computers.

## 1 INTRODUCTION

The Very Large Array (VLA) will be arrayed with the Goldstone Deep Space Communications Complex (GDSCC) during the Voyager 2 spacecraft encounter with Neptune in 1989, in order to increase the received telemetry rate at X-band. This document describes the implementation by the National Radio Astronomy Observatory (NRAO) of the VLA Goldstone Telemetry Array (VGTA). It provides brief descriptions of the major deliverables designed, fabricated, tested and installed by NRAO, and also the project implementation schedule. Implementation culminates in VGTA system testing, training, and VGTA Project utilization planned for 1988 and 1989.

JPL has responsibility for the overall project planning and management of the VGTA Project (ref. Management Plan). At JPL, an Interagency Arraying Project Manager (D. W. Brown) and an Implementation Manager (K.Bartos) have responsibility for all work undertaken by JPL. In parallel, the NRAO VLA Deputy Site Manager (R. A. Sramek), VLA-Voyager Preparation Manager and Project Engineer (W. D. Brundage), and Central Development Laboratory Manager (M. Balister) have responsibility for work undertaken by NRAO-VLA.

Installation of the X-band front end system and back-end systems on the VLA must be smoothly integrated into the system with minimal disruption to normal operations. Consequently, this implementation plan is compatible with:

* mechanical and electronic systems,

* system maintenaince (scheduled and unscheduled),

* system upgrades, and

* observing schedules.

VLA observing will be scheduled to include normal testing of X-band as a standard VLA observing band and periodic VGTA performance testing.

Implementation conforms to the Management Plan for the VGTA.

## 2 X-BAND FRONT-END SYSTEM

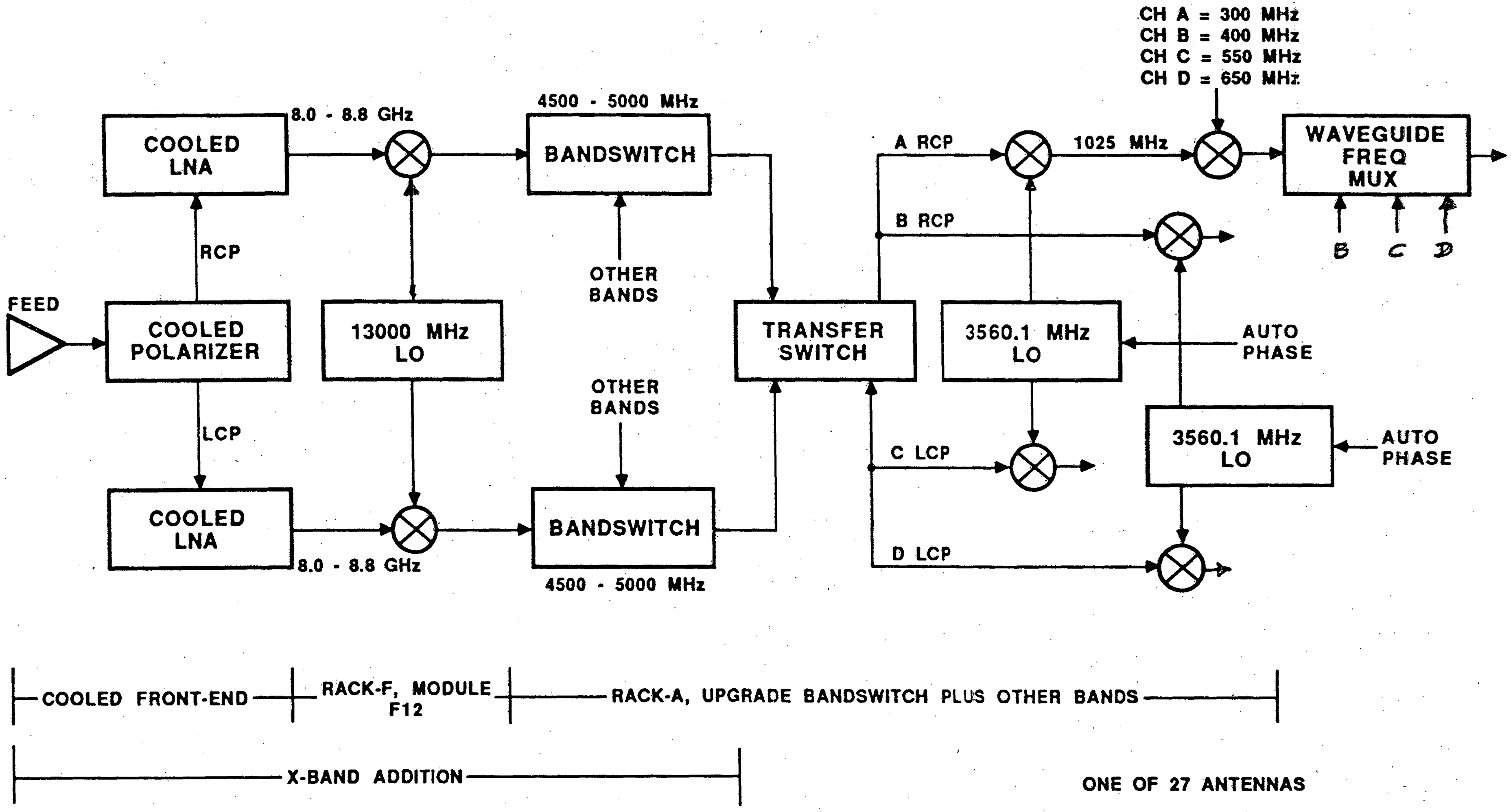
### 2.1 Description

The X-band receiver front-end add-on to the VLA multi-band receiver system is somewhat complex. It is best described in sequence of signal flow thru the system on each 25 meter antenna.

# NRAO IMPLEMENTATION

## FRONT-END SYSTEM

## BLOCK DIAGRAM



2.2 FIGURE 1

# 3 FEEDS

## 3.1 Delivery from JPL

JPL has delivered to VLA twenty eight X-band (8.0 - 8.8 GHz) corregated feed horns optimized for maximum G/T on the VLA cassegrain antennas (ref. Management Plan). F. Manshadi, JPL, was the responsible person.

## 3.2 Installation on VLA Antennas

The antenna group installs the feed horns and radiant heaters on antennas during scheduled antenna overhaul in the Antenna Assembly Barn (AAB). Each feed mounts inside a specially fabricated support tower.

The last prototype system was replaced in September 1987. As of October 1987, all 14 antennas operating at X-band have production feeds. VLA will install the last (28th) feed in November 1988.

R. Stidstone is responsible for feed installations.

# 4 COOLED FRONT-ENDS

## 4.1 Construction by NRAO-CDL

The NRAO Central Developement Laboratory (CDL) in Charlottesville, VA, constructs the X-band (8.0 - 8.8 GHz) dual channel cooled front-ends (CFE) and ships them to the VLA in groups of two or three. CDL will construct thirty front-ends, which include two spare units.

All production front-ends have HEMT amplifiers in the right-circular polarization (RCP) and left-circular polarization (LCP) channels. CFE's with HEMT's typically have receiver noise temperatures at the feed flange of 18K vs 32K for the FET's.

The reference document is VLBA Tecnical Report No. 1, "Low-noise, 8.4 GHz, Cryogenic GASFET Front-end".

M. Balister is responsible for construction of CFE's by CDL .

## 4.2 Delivery to VLA

As of September 1987, VLA has received 23 cooled front-ends from CDL. The remaining 7 will be shipped by January 1988.

Two prototype CFE's and one production CFE with FET amplifiers have been replaced by HEMT CFE's.

On receiving a CFE, the cryogenics group checks for vacuum leaks, modifies the cryo-refrigerator for improved reliability, and checks for proper cryogenic temperatures. R. Latasa is responsible for these checks and modifications.

Then, the front-end group checks the CFE gain and noise performance. P. Lilie is responsible.

In order to acquire more reliability statistics, all CFE's continue operating cold until installed on an antenna.

### 4.3 Installation on VLA Antennas

After a feed installation on an antenna, VLA installs the CFE on the feed via an adjustable mount. Then VLA purges the feed with dry nitrogen, so the feed interior will stay dry (above the dew point) by breathing thru a dessicant connected via small plastic tubing and valves.

R. Latasa is responsible for installing the CFE and feed dessicant on the antennas.

## 5 CRYOGENICS

### 5.1 Cryo Lines & Vacuum

After feed installation in an antenna, the cryo group installs the helium refrigerant lines for the CFE. After the Rack-F installation in an antenna, they install the vacuum pump and vacuum hose to the CFE.

R. Latasa is responsible for all cryogenic work.

### 5.2 Refrigerator Modifications

CTI Model 22 cryogenic refrigerators in all CFE's cool the HEMT amplifiers to 15 Kelvin. Several of the refrigerators operating in the array have failed (temperature > 25K) recently after about 3000 hours of accumulated running time. Section 14.4 on Reliability describes the VLA modification program to improve the MTBF.

### 5.3 Compressors

Back-up cryogenic helium compressors will be installed on all 28 antennas (ref. Management Plan).

Before installation, the cryo group modifies each compressor internally for improved performance and reliability. These modifications were also made on all existing VLA compressors.

Two back-up compressors have been purchased and modified. When, in August, NSF received the additional funds requested for 1987, VLA ordered twenty more . The remaining 6 will be ordered when NSF receives FY88 NASA funds. All 28 will be modified and installed on antennas by January 1989.

## 6 RACK-F

### 6.1 Rack

Located in the antenna vertex room, Rack-F contains several modules dedicated to the X-band front-end system. These include the LO / Mixer Module-F12, control and monitor Modules-C1 and -M1, power supply Modules-P9 and -P10, and critical power Module-P11. This rack also supports the vacuum pump for the CFE. Twenty nine racks will be built, and thirty sets of modules will be built.

The reference document is VLA Technical Report No. ___, "X-Band Receiver System".

P. Lilie is responsible for Rack-F.

### 6.2 Power Modules-P9,-P10,-P11

Power supply Module-P9 provides +5 VDC and +28 VDC to Rack-F and the CFE.

Power supply Module-P10 provides +15 VDC and -15 VDC to Rack-F and the CFE.

Critical power supply Module-P11 provides 120 VAC, +15 VDC, and -15 VDC to Module-C1 and the cryogenic controls on the CFE. The critical power AC voltage source, from the antenna transporter generator or site emergency generators, keeps the cryogenics cold during antenna power failures. All other AC loads disconnect. Until the new 1.4 MW generators can provide emergency power to all antennas, the current 0.5 MW emergency generators supply only critical power to the antennas.

Reference documents are VLA Tecnical Report No. ___, "Power Supply Modules P9 and P10", and VLA Technical Report No. ___, "Critical Power Supply P11".

P. Lilie is responsible for these modules.

## 6.3 LO/Mixer Module-F12

Frequency conversion of both RCP and LCP polarizations from X-band to the VLA first intermediate frequency (IF) of 4.5 - 5.0 GHz occurs in the LO / Mixer Module-F12. The LO group will build 30 modules. Signals pass thru 8.4 / 1.0 GHz bandpass filter and a double-balanced mixer without amplification. One yig-tuned local-oscillator (LO) phase-locks to coherent reference frequencies of 600 MHz and 200 MHz. The LO drives both mixers in the RCP and LCP channels. The LO generates commanded frequencies of (600 * N +/- 200) MHz in the range of 11.8 to 15.2 GHz, where N is an integer from 20 to 25. The LO frequency for receiving Voyager telemetry is 13.0 GHz.

The reference document is VLA Technical Report No. ___, "11.8 to 15.2 GHz LO / Mixer Module-F12".

L. Beno is responsible for Module-F12.

## 6.4 Control / Monitor Module-C1

The VLA receiver control and monitor system connects from the data-set Module-M1 to the X-band receiver subsystem thru the Control / Monitor Module-C1. It contains analog and digital multiplexers, and analog-to-digital converters. Module-C1 remains powered and active via the critical-power system in order to keep the cryogenics cold during emergency power situations. The front-end group will build 30 modules.

The reference document is VLA Technical Report No. ___, "The Control and Monitor C1 Module".

P. Lilie is responsible.

## 6.5 Data Set Module-M1

Data Set Module-M1 connects the Rack-F and CFE command and monitor functions (mostly via module-C1) to the antenna serial command and monitor data stream via modules in Rack-B. M1 is a standard VLA system module. The VLA control and monitor system addresses the X-band receiver thru this module as "data set 4". The DCS group will build 30 modules.

The reference document is VLA Technical Report No. 58, "The Data Set, Module Type M1".

D. Weber is responsible for Module-M1.

## 6.6 Cables

Three-eighths inch foam-dielectric "Heliax" coaxial cables carry RF from the CFE to Rack-F and the C-band IF from Rack-F to the bandswitches in Rack-A. Semi-rigid coaxial cables carry RF within Rack-F and also connect LO reference signals from Rack-B to Rack-F. Assorted shielded pair and multiconductor cables carry analog and digital signals amoung CFE, Rack-F, and Rack-B.

P. Lilie is responsible for cables between the CFE and Rack-F, and also between Rack-F and Rack-A. L. Beno is responsible for the LO reference coax between Rack-F and Rack-B. D. Weber is responsible for the other cables between Rack-F and Rack-B.

# 7 BANDSWITCHES

## 7.1 Rack-A and L,C,U,K-band Front-ends

The on-going VLA program to up-grade the L, C, U, K-band front-ends in Rack-A couples closely to the installation of the X-band receiver system. The only reasonable time to install the bandswitches, which connect the X-band IF into the VLA C-band first IF, occurs during the scheduled up-grade of the other VLA front-ends.

P. Lilie is responsible for the up-grade.

## 7.2 Diode Bandswitches

The initial X-band receiver system plan included 8-position diode coaxial bandswitches to connect the X-band IF into the VLA first-IF. After a 6-month delayed delivery of the first diode switches, they proved unreliable. The manufacturer cancelled the order rather than correct the problem. Then, in December 1986, VLA changed the design to a pair of 8-pole electromechanical coaxial switches mounted in Module-F9 of Rack-A.

If a diode bandswitch fails, the antenna will be retrofitted with electromechanical switches in Module-F9.

P. Lilie is responsible.

### 7.3 Module-F9

For the reasons given above, VLA installs the production receiving-band switches in Module-F9 in Rack-A. Besides extensive mechanical and electronic changes in Module-F9, installation also requires changes in the mechanics, semirigid coax, and coaxial connectors in Rack-A. Retrofitting bandswitches into Module-F9 occurs as part of the scheduled up-grade of receiver front-ends in Rack-A.

The reference document is VLA Technical Report No. ___, "Front-end Module-F9".

P. Lilie is responsible.

## 8 ANTENNA SYSTEM

### 8.1 Operations

In February 1987, VLA declared X-band to be a standard VLA operational band. Consequently, as each antenna acquires a complete X-band receiver system, VLA Operations gives it the standard focus setting, delay setting, "finding", and pointing procedures to make it fully operational. These procedures also catch most control and monitor bugs.

Thereafter, all antennas get a routine start-up check at X-band as well as all other bands following maintenance days. X-band also gets other routine checks.

Array Operations Head, C. Bignell, is responsible.

### 8.2 Performance

As of March 1987, the seven antennas with production feeds had measured aperture efficiencies of 62 +/- 3 %. The two preliminary (non-optimized) feeds had measured aperture efficiencies of 53 +/- 5 %.

# 9 BACK-END SYSTEM

## 9.1 Description

Buried low-loss large-diameter circular waveguides connect each arm of the wye to the central receiver back-ends at the control building. A frequency multiplexer converts an antenna sub-band in the 27 to 53 GHz wavequide band to the 1 - 2 GHz range where mixers at 1200 and 1800 MHz convert each IF channel to a 100 - 250 Mhz IF. Then Fluke synthesizers having high frequency resolution convert each IF to a baseband range of 100 kHz to 50 MHz.

Special bandpass filters (supplied by JPL) in each of the four baseband IF's pass the telemetry modulation sidebands of the Voyager signal. After 3-level 2-bit 100 MHz complex sampling of each antenna baseband IF, the signal is digitally delayed and split into two paths: one into the complex cross-multipliers and the other into the summing unit.

The correlator measures complex cross-products for each of the 351 antenna-pair baselines for each of the 4 intermediate frequency signals. After averaging by an array processor, the on-line system derives the autophasing parameters from the cross-products. It also passes the products to the off-line system for processing into astronomical images.

An analog summing unit for each of the 4 baseband IF outputs converts each selected antenna input to an analog voltage and sums all voltages. The on-line control system can remove any failed antenna from each of the four analog sum units. It also monitors total output powers.

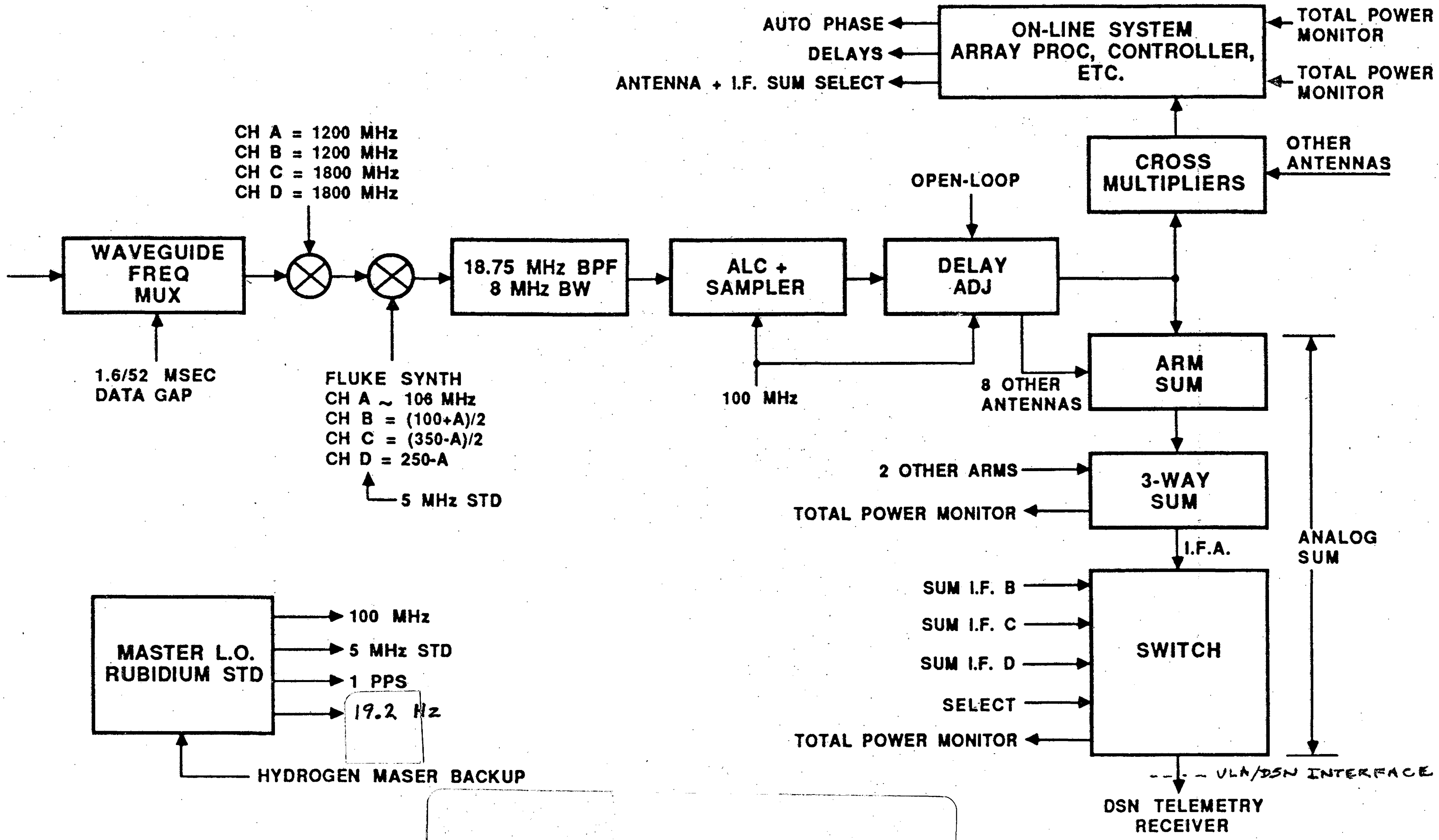
A switch will connect the one IF analog sum output containing the Voyager signal to the input of the DSN telemetry receiver. The special IF filters band-limit the input and output spectra of a summer and thereby provide image rejection for the upconverter input of the DSN receiver.

# NRAO IMPLEMENTATION

## BACK-END SYSTEM

JPL

## BLOCK DIAGRAM



AUTO PHASE

DELAYS

ANTENNA + I.F. SUM SELECT

ON-LINE SYSTEM ARRAY PROC, CONTROLLER, ETC.

TOTAL POWER MONITOR

TOTAL POWER MONITOR

CH A = 1200 MHz
CH B = 1200 MHz
CH C = 1800 MHz
CH D = 1800 MHz

CROSS MULTIPLIERS

OTHER ANTENNAS

OPEN-LOOP

WAVEGUIDE FREQ MUX

18.75 MHz BPF
8 MHz BW

ALC + SAMPLER

DELAY ADJ

1.6/52 MSEC DATA GAP

FLUKE SYNTH
CH A ~ 106 MHz
CH B = (100+A)/2
CH C = (350-A)/2
CH D = 250-A

5 MHz STD

100 MHz

8 OTHER ANTENNAS

ARM SUM

2 OTHER ARMS

3-WAY SUM

TOTAL POWER MONITOR

I.F.A.

ANALOG SUM

SUM I.F. B

SUM I.F. C

SUM I.F. D

SELECT

TOTAL POWER MONITOR

SWITCH

MASTER L.O. RUBIDIUM STD

100 MHz

5 MHz STD

1 PPS

19.2 Hz

HYDROGEN MASER BACKUP

VLA/DSN INTERFACE

DSN TELEMETRY RECEIVER

9.2 FIGURE 2

## 9.3 Master LO System

The master LO (MLO) system provides to the DSN receiver a 5 MHz standard frequency (stability +/-1*10^-11/day) and 1 pulse per second UTC (+/-2 microsec). A rubidium clock (HP 5065B), or a hrydrogen maser clock, provides a 5 MHz reference to the MLO. This system also provides 5 MHz, 19.2 Hz monitor/control sync, and 1 pps UTC to the IAT clock in the on-line system. Also, this system contains the two sets of four Fluke synthesizers which fine-tune the VLA received frequency.

## 9.4 Baseband Filters

JPL supplies special baseband bandpass filters for reception of Voyager telemetry. The LO group installs the filters in each of the four baseband IFs of each antenna.

Each antenna has a rack of electronics (Rack-D) in the Central Electronics Room of the Control Building which extracts the antenna communications from the wye waveguide and applies the antenna control communications to the wye waveguide. Modules-T3 convert RCP IFs A and B, and LCP IFs C and D to baseband with fine frequency control from the Fluke synthesizers. Module-T4C in each IF selects one of seven baseband lowpass filters or the externally connected Voyager filter.

The Voyager butterworth 6-pole bandpass filters have an 18.75 MHz center frequency and an 8.0 MHz 3dB bandwidth. Attenuators of 8dB each on input and output of each filter provide the total 16.5dB insertion loss required by the VLA system.

The LO group has mounted a filter in the A IF only for all 27 antennas. When JPL supplies the balance of filters, one will be installed in each of the 3 remaining IFs of each antenna over a period of three months.

The reference document is VLA Technical Report No. 48, "Module T4C Baseband Filter".

L. Beno is responsible for filter installation.

# 10 ANALOG SUM

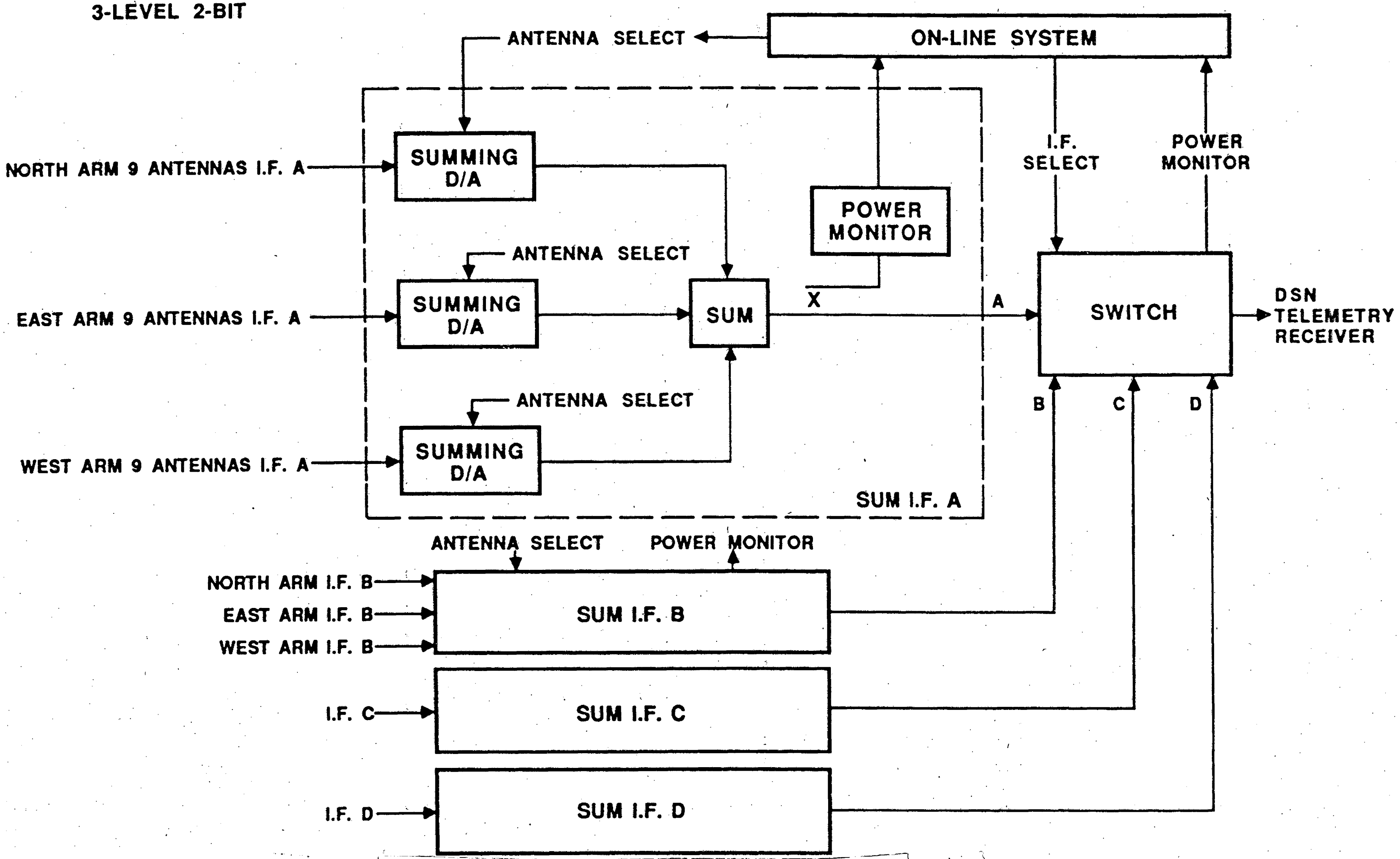
# NRAO IMPLEMENTATION

## ANALOG SUM

JPL

## BLOCK DIAGRAM

DELAYED 100 MHz SAMPLES,
3-LEVEL 2-BIT



ON-LINE SYSTEM
ANTENNA SELECT
NORTH ARM 9 ANTENNAS I.F. A
SUMMING D/A
POWER MONITOR
I.F. SELECT
POWER MONITOR
ANTENNA SELECT
EAST ARM 9 ANTENNAS I.F. A
SUMMING D/A
SUM
X
A
SWITCH
DSN TELEMETRY RECEIVER
ANTENNA SELECT
WEST ARM 9 ANTENNAS I.F. A
SUMMING D/A
B
C
D
SUM I.F. A
ANTENNA SELECT
POWER MONITOR
NORTH ARM I.F. B
EAST ARM I.F. B
WEST ARM I.F. B
SUM I.F. B
I.F. C
SUM I.F. C
I.F. D
SUM I.F. D

10.1 FIGURE 3

## 10.2 Sums

The Analog Sums provide the analog output signal from the VLA digital signal combiner for all 27 antennas in the array. Its output, containing the Voyager signal in the 14.75 to 22.75 MHz range (defined by the baseband passband filter), feeds the JPL phase-locked receiver and signal conditioner.

Any antenna may be added to and removed from the sum by command from the VLA Operator. This transition will occur during data invalid (the data gap).

A total output power detector in each sum provides a monitor point to the VLA On-line Computer System .

The analog sum taps the digitized input to the 2-bit three-level complex correlator for each antenna, forms the analog sum of selected antennas in an arm of the wye, and then forms the analog sum of the three arms.

Each of the four VLA IF channels has its own analog sum unit. The DCS group will provide a fifth analog sum as a spare.

Reference documents are Management Plan, section III, C, (7), and VLA Tecnical Report No.___, "Baseband Analog Sum and Switch".

D. Weber is responsible.

## 10.3 Switch

The analog sum switch selects the individual IF A, B, C, or D output sum for connection to the JPL receiver. The VLA Operator commands the selection via the On-line Computer System. The switching will occur during data-invalid (the data gap).

Output from the switch at the DSN interface will be nominally -16 dBm in the 8 MHz bandpass with 25 X-band antennas connected into the analog sum.

The switch will be located in the VLBI area near the JPL receiver system where manual selection will be possible and the indicators for the selected IF will be visible.

The reference document is VLA Tecnical Report No.___, "Baseband Analog Sum and Switch".

D. Weber is responsible.

### 10.4 Tests

The digitized signal at the correlator inputs is always sampled at a 100 MHz rate. The analog sum output contains the frequencies passed by the VLA IF baseband filter, as well as spurious signals in the 0 to 100 MHz range. Consequently, tests of the old VLA analog sum revealed spurious signals at frequencies and levels incompatible with the JPL receiver.

The DCS group built a prototype analog sum which met the JPL requirements of max spurious level of -94 dBm in the range from 14 to 24 MHz.

On completion of each sum unit, VLA will verify satisfactory spurious levels and satisfactory operation thru the output selector switch. The DCS group will issue memos reporting test results. JPL will also test spurious levels and operation of the summers in conjunction with the JPL receiver to verify that performance is adequate for VGTA.

R. Ferraro and H. Winchell are responsible for VLA tests.

## 11 ON-LINE SYSTEM

### 11.1 Description

A long-planned upgrade of the VLA on-line system, which controls and monitors the entire array system, will be completed in time for VGTA operations. In fact, the new system is necessary for VGTA because the current system is memory- and speed-bound even without the X-band and VGTA requirements. All new system hardware, including a third computer for backup, is in place and operating independently of the array. Sufficient software is being written and debugged to allow changeover in November 1987.

New capabilites necessary for VGTA include global autophasing, where global means minimizing RMS phase differences on all 351 antenna pair combinations. Global autophasing is more sensitive than single-reference autophasing by a factor of 3.67 in SNR for the determination of each antenna phase. This is especially important in wet weather with Voyager at low elevation angles where the troposphere can induce large phase fluctuations across the array.

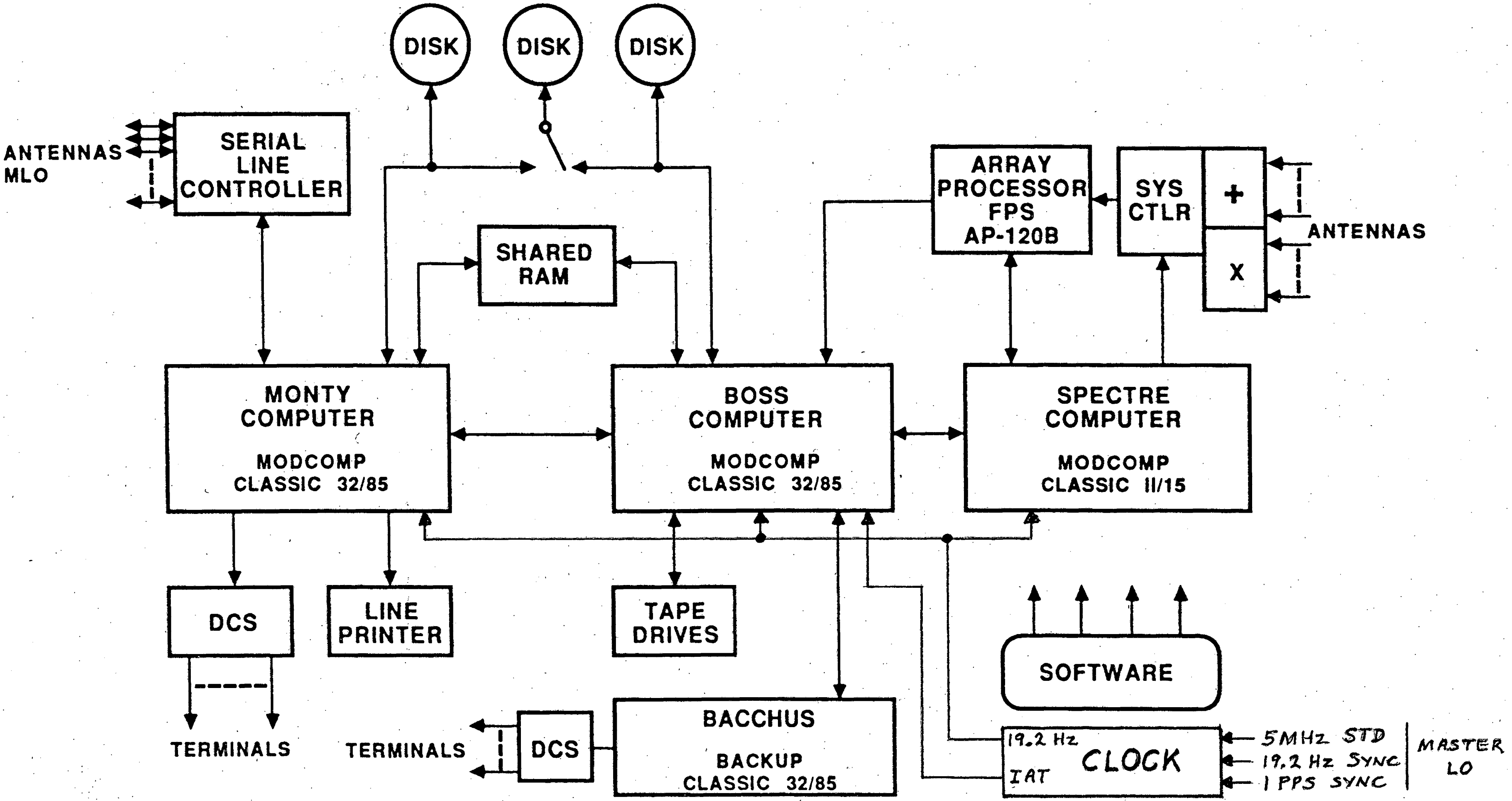
Three Modcomp computers, an array processor, and peripherals constitute the new on-line system . Two new Classic 32/85 32-bit computers perform the control (BOSS) and monitor (MONTY) functions. The Classic II/15 16-bit computer (SPECTRE) controls the array processor and correlator system controller as directed by BOSS. Shared RAM speeds communications between BOSS and MONTY. One of three disks is dual-ported between the computers. A Serial Line Controller connects MONTY to all antennas and the receiver back-end system. Terminals connected to MONTY provide the array operator control and monitor displays. A third Modcomp 32/85 computer (BACCHUS) provides backup at the cable-plug or board levels as well as real-time monitoring and software development. All new real-time software runs the system.

The on-line system clock receives the 5 MHz standard, 19.2 Hz sync, and 1 pps sync from the Master LO and provides 19.2 Hz sync and International Atomic Time (IAT) to the BOSS, MONTY, and SPECTRE computers. VLA Operations resets this clock by inputting UTC from a WWV receiver and the current IAT - UTC offset (currently +23 seconds).

# NRAO IMPLEMENTATION

## NEW ON-LINE SYSTEM

## BLOCK DIAGRAM



11.2 FIGURE 4

### 11.3 Implementation Plan for New On-line System

"Voyager Considerations for the VLA On-line System", VLA Computer Memo No. 177, September 1987, outlined all major performance features and tasks for hardware and software. It cites software features and performance goals. Some details will wait for joint VLA and JPL decisions following more testing and operating experience.

This Plan, by including special monitor, control, and operation features, expands the scope of the "Management Plan for the VGTA", Section II. F. and G., which states that NRAO will provide "normal" monitor, control, and operation of the VLA.

G. Hunt is responsible for implementing this Plan.

### 11.4 Autophasing

Autophasing refers to the VLA capability to use the correlator output to periodically adjust the phase of each antenna's baseband IF input to the correlators and analog sum so that the coherent component of celestial noise or of the Voyager signal is in phase. Consequently the Voyager signal voltages from each antenna add coherently while the incoherent noise voltages from each antenna add as the square root, thus improving the signal-to-noise power ratio (SNR).

Of course, errors in adjusting antenna phases cause imperfect coherency in the sum signal, and consequently degrades the summed SNR. Phase errors arise from atmospheric phase fluctuations in time and space and from thermal noise fluctuations. Errors also come from receiver phase drifts and jumps. The autophasing algorithm only partially corrects these errors because of finite integration time, global phase calculation time, and delay in updating phase corrections.

JPL will continue to test performance of autophasing algorithms, will suggest improvements, and will test them.

The reference document is "Autophasing algorithm in the on-line system".

K. Sowinski is responsible for implementing the algorithm.

### 11.5 Control

The control function of the VLA on-line system operates the VLA system including the antennas, the receiver front-end and back-end, signal processor system (correlators), and the data coming out of the on-line computers. The VLA Array Operator controls the system operation via terminals and observing files prepared by the user.

The observing file contains parameters for radio sources, receiver setups for each source, and times for observing each source. For Voyager 2, parameters include celestial coordinates and time derivatives. Receiver setups include LO frequencies, autophasing mode, and IF channel selection.

JPL will prepare the startup test files and the Voyager observing files. The JPL operator will coordinate with the VLA Array Operator.

The reference document is "An Introduction to the NRAO Very Large Array", 4/83.

K. Sowinski is responsible for the on-line software.

### 11.6 Monitor

The on-line system also contains many monitor functions, including a variety of displays of system monitor data in real time. It logs monitor data on tape for later retrieval. The system monitors hundreds of receiver voltages and operating states from the front ends and LOs in each antenna and from the backend IFs, LOs, samplers, correlators, array processor and analog sums. If critical parameters go out of range, a program called CHECKER alerts the VLA Operator.

The new on-line system will provide special JPL/Voyager monitor displays on dedicated terminals in the VLA control area and also in the JPL Operations area.

The reference document is VLA Technical Report No. 44, "An Overview of the Monitor and Control System".

K. Sowinski is responsible for the on-line software.

### 11.7 Software Freeze

Although Voyager will require over 400 hours of VLA observing time from January thru September 1989, NRAO must continue to develop on-line software and utilize it with monthly updates. Therefore, an early software freeze in January 1989 would require software support for and array operator use of two observing systems. That would aggravate human errors. Consequently, NRAO prefers a late freeze of one operating system from June thru September 1989 when there would be no updates except for fixing bugs.

### 11.8 Backup Computer

With NASA/JPL funds, VLA ordered, in December 1986, a backup on-line computer (Modcomp Classic 32/85). Since installation in April 1987, it (BACCHUS) serves as a plug-compatible backup for either of the two Modcomps in the new on-line system. Also it could provide backup at the board level.

This backup is essential for reliable VGTA performance in 1989, as the on-line system exclusively controls and monitors the VLA operation. The VLA cannot provide any Voyager signal while this system is down.

After the new on-line system becomes fully operational in late 1987, the backup computer will continue to be used as a test bed for software development.

G. Hunt is responsible.

### 11.9 Tests

Only after the new on-line system passes all tests for normal VLA operations will it become operational in late 1987 . Then the on-line group will test it for functions and performance unique to Voyager. These will include stability and continuity of phase solutions, flagging due to low sensitivity or closure errors, analog sum operation, half-correlator independence, and operational procedures.

After the new on-line system has run for several months, BACCHUS will be tested as a backup by substituting it for each of the two on-line computers.

K. Sowinski is responsible for the on-line software and testing.

## 12 POWER GENERATION SYSTEM

### 12.1 Implementation Plan

Installation of two 1400 KW diesel engine driven generators will provide a power system of high quality and reliability. It will have adequate usable and reserve capacity to supply total VLA power requirements during VGTA Voyager Neptune encounter operations during 1989. The commercial power source for VLA operation has inadequate reliability for VGTA operations, especially during the southwestern thunder storm season of July - August - September.

The Management Plan specified that JPL would provide a temporary power generation system, but in late 1986 JPL concluded that a permanent system would expedite installation, enhance compatibility and operations, and reduce costs.

Implementation will be according to the reference document "Very Large Array Power System Facilities Voyager/Neptune Encounter - 1989, Implementation Plan".

The Implementation Plan specifies the system operational performance, JPL installation and training tasks, VLA installation, training, and operational tasks, and implementation schedule. The entire system will remain at VLA, as NSF property, when the VGTA project ends.

W. del Giudice has the VLA responsibilities for the power generation system.

## 12.2 Installation

Installation of the generator system began in April 1987 and will end in June 1988. JPL and VLA share procurement and installation responsibilities as specified by the Implementation Plan.

A permanent building houses the diesel generators, control panels, and synchronizing gear.

JPL will provide nearly all of the generator system hardware and building. VLA, using NASA funds, will provide the foundations, building plumbing and electrical hardware, and some labor.

## 12.3 Tests

During May and June 1988, JPL and VLA will jointly test and debug the system according to a JPL test plan.

## 12.4 Operation

During May and June 1988, as part of testing, JPL will provide training for VLA operators in running and maintaining the system.

In June 1988, after succesfull testing, VLA will become responsible for operating the system.

For VGTA operations in 1989, the system will synchronize with commercial power, take up full site load, disconnect from commercial power, power the entire VLA during VGTA operations, then re-synchronize with commercial power, connect commercial power, shed load, and shut down. VLA will provide a generator technician during all VGTA operations.

# 13 SYSTEM TESTS

## 13.1 Antenna Checkout

Following X-band receiver installation on each antenna, VLA routinely checks the reciver in two steps.

First, front-end technicians exercise the receiver via the command simulator. This checks all command, read-back, and monitor functions.

Second, VLA Operations "finds" the antenna by observing calibrator radio sources to set delays for each IF channel, set focus, and find pointing offsets. On-line system program STUPID "finds" antennas with some intelligent intervention by the array operator.

Documentation is "ANTENNA MOVE MASTER CHECKLIST" and "SYSTEM CHECKOUT PROCEDURES".

P. Lilie is responsible for the front-end checkout.

P. Hicks is responsible for antenna checkout by Operations.

## 13.2 Performance Tests

VLA does only two performance tests beyond the antenna checkouts described above.

Usually monthly, or when an upgraded antenna enters the array, VLA Operations runs SYSTEST, which measures various analog offset and operating voltages and measures system temperatures at mid-, lower, and upper-frequencies of each operating band. The X-band mid-frequency is 8414.9 MHz at 50 MHz bandwidth.

At 4 to 6 week intervals, Operations runs TCAL DETERMINATION, which interferometrically derives an equivalent noise cal temperature for each IF channel by observing a calibrator source. These values become the Cal Temperatures in the SYSXIF system observing files.

Documentation is "TCAL DETERMINATION".

P. Hicks is responsible for these tests.

By monthly scheduled test observing, JPL determines VLA performance for purposes of receiving Voyager telemetry. The "Management Plan for the VGTA" II. D. puts this responsibility on JPL: "JPL will also be responsible for periodically testing the operation of the of the equipment and ensuring that it meets Project requirements".

Documentation for performance parameters of system temperature, aperture effeciencies and G/T ratios is in Ulvestad et. al..

### 13.3 Operational Tests

JPL periodically conducts tests for VGTA operations.

Documentation is "VGTA System Test Requirements".

## 14 RELIABILITY

### 14.1 Goals

JPL set the goals for VLA reliability as:

1. AVAILABILITY of the Voyager signal at the VLA analog sum output to the DSN receiver should be .98, excluding weather.
2. AVAILABILITY OF AT LEAST 25 OUT OF 27 ANTENNAS contributing Voyager signal to the VLA sum output should be .99.
3. MEAN TIME TO RECOVER (MTTR) from loss of the Voyager signal at the VLA sum output or from less than 25 operational antennas should be 4 hours or less for equipment failures, and less than 10 minutes for on-line system crashes.
4. DATA GAPS, other than control cycle gaps of 1.6 ms, should be less than 1 millisec.

VLA will provide system monitor displays optimized to quickly indicate problem areas, failures, and diagnostic aids.

During the hour before Voyager rise at each telemetry pass, JPL will test the X-band system by observing radio sources. VLA will make a best effort attempt to diagnose and fix problems according to JPL's priority.

Documentation is "VGTA SYSTEM REQUIREMENTS AND DESIGN".

Although the "Management Plan for the VGTA" does not mention reliability (other than HEMTs) or availability, the VLA accepts the above goals.

## 14.2 Weather

One significant factor affecting reliability is weather, especially during the southwestern thunderstorm season of July thru September -- the months of near encounter with Neptune. Winds over 40 mph will cause the array operator to stow all antennas. Each antenna will auto-stow at 50 mph. Lightning could disable one or more antennas. More frequently, rain cells will degrade phase coherence across the array and also attenuate the Voyager signal.

VLA and JPL will minimize phase degradation by developing a robust autophasing algorithm. K. Sowinski and J. Ulvestad (JPL) are responsible.

## 14.3 Power Cables

Buried power cables feeding the wye and control building are another significant relibility factor. They have been failing because of the aging characteristics of the cable. Utility experience indicates the failure rate of the HMWP type cable increases with age, and VLA has experienced 9 failures in 1986 and 1987. VLA submitted a replacement schedule and cost estimate to the National Science Foundation (NSF). VLA funds for 1987 allowed replacing only the control building feeder. NSF funds for 1988 are uncertain.

If special funding arrives by December 01, 1987, VLA can complete cable replacement by December 1988 at least to the end of the C-array, which will be used during most of the Voyager telemetry reception in 1989. Also, installing fused disconnects would protect all antennas from failures beyond the C-array.

VLA gave JPL a cost estimate and schedule for the above. JPL and NASA will consider special funding.

If the cable replacement program described above cannot be completed, the VLA will make a best effort to provide a track-mobile 500 kW generator for rapid recovery of antennas affected by a cable failure.

W. del Giudice is responsible.

### 14.4 Cryo-refrigerators

CTI Model 22 cryogenic refrigerators in cooled front-ends also pose a reliability problem. Many have failed after only 3000 hours running time. This experience indicates unreliable VGTA operations in 1989. However, five refrigerators had 8100 hours MTBF in a 2-year test .

Therefore, in March 1987, the cryogenics group began a program of modifying all Model 22 refrigerators to extend the MTBF. When each CFE arrives from CDL, the cryo group replaces carbon bushings in each refrigerator with Envex or Vespel polyamide bushings. Two refrigerators recently had VLA-designed scotch yokes installed. Soon two others will get a VLA-designed displacer-shaft connector. If these yoke and connector designs prove effective, all 30 refrigerators will be upgraded.

R. Latasa is responsible for all cryogenics.

### 14.5 Antenna Systems

Loss of Voyager signal from antenna systems degrades the SNR linearly (disregarding effects of autophasing). The JPL "VGTA System Requirements and Design" specifies a goal of .99 availability for at least 25 out of 27 antennas.

In each antenna, failure in any one of many receiver subsystems (modules) or antenna positioning subsystems can cause loss of Voyager signal. No redundancy exists for the antenna positioning subsystems, only backup modules and boards. Two IF channels in each polarization and a front-end polarization transfer switch provide redundancy for much, but not all, of the front-end system.

Presently, the cryo-refrigerators probably are the least reliable subsystem on each antenna, but should be much improved by 1989.

### 14.6 Common Systems

The common systems, where any "single point failure" causes loss of the Voyager signal, are the most critical areas. These include

electrical power source (new generator system),
electrical power distribution (replace buried cables),
waveguide,
wye-com system,
master LO system (redundant racks, no backup rubidium),
correlator system (half-correlator redundancy),
on-line system (backup computer, spare boards),
serial line controller (spare boards),

array processor (spare boards),
analog sum and switch (redundant sums, spare switch),
air conditioners for computers and back-end, and
array operator errors.

Failures of the Wye-com system, such as water penetration of buried cable or a control chassis fault, can take out 1, or 9, or 27 antennas under certain conditions.

Multiple IF channels provide redundancy only between part of the front-end, part of the delay/multiplier, and an analog sum output.

The on-line system computers are most critical, so VLA purchased a backup computer with JPL funds. Subsystem failure modes and recovery methods will be analyzed.

The LO group will install coaxial switches and cable to allow Fluke "set 2" to backup "set 1".

## 14.7 VLA Statistics

The VLA Maintenance Coordinator routinely keeps array downtime and maintenance statistics based on the array operating log and maintenance forms issued by the array operator and completed by the repairing technician. He issues monthly, quarterly, yearly, and arbitrary summaries of array downtime as a percentage of operational antenna observing hours (usually assumed equal to operational antenna calendar hours). Downtime does not include time for scheduled tests and maintenance.

For VGTA purposes, VLA produced a reliability review in May 1986, which will be updated by March 198~~9~~8. VLA will provide to JPL downtime statistics for analysis and estimation of VGTA availability. VLA will make a best effort to improve subsystem availability according to JPL priorities.

Documents are "Summary of downtime for ..." and "VLA RELIABILITY REVIEW NO. 1".

D. Van Horn documents maintenance and provides statistics.

## 15 FUNDING

Revised budgetary estimates thru March 1987 brought the total NASA funding for NRAO VGTA implementation to $6304k, up $771k from the 1985 Management Plan estimate of $5503k.

NRAO has received 1985 thru 1987 funds, and expects 1988 and 1989 funding and spending according to this schedule (in $k):

| CATEGORY | 1985 | 1986 | 1987 | 1988 | 1989 | TOTAL |
|---|---|---|---|---|---|---|
| <u>VERY LARGE ARRAY</u> | | | | | | |
| WAGES | 79 | 203 | 238 | 242 | 230 | 992 |
| BENEFITS | 22 | 55 | 64 | 66 | 62 | 269 |
| COMMON COSTS | 75 | 193 | 226 | 232 | 219 | 945 |
| TRAVEL | 20 | 10 | 30 | 20 | 6 | 86 |
| OFFICE LAB ADDITION | 0 | 28 | 0 | 0 | 0 | 28 |
| 2 DEV'L RECEIVERS | 92 | 62 | 0 | 0 | 0 | 157 |
| CRYOGENICS & VACUUM | 0 | 31 | 20 | 20 | 1 | 72 |
| CRYO COMPRESSORS | 0 | 3 | 158 | 162 | 1 | 324 |
| INSTALLATION M & S | 26 | 249 | 186 | 196 | 9 | 666 |
| EQUIPMENT | 8 | 59 | 48 | 5 | 5 | 125 |
| BACKUP COMPUTER | 0 | 250 | 0 | 0 | 0 | 250 |
| RELIABILITY IMPROV'T | 0 | 0 | 5 | 10 | 15 | 30 |
| POWER GENERATION | 0 | 0 | 73 | 3 | 1 | 77 |
| CONTINGENCY | 0 | 0 | 10 | 15 | 15 | 40 |
| TOTAL VLA | 325 | 1143 | 1058 | 971 | 564 | 4061 |
| <u>CENTRAL DEV'T LAB</u> | | | | | | |
| WAGES | 117 | 285 | 252 | 60 | 20 | 734 |
| BENEFITS | 35 | 91 | 81 | 15 | 5 | 227 |
| COMMON COSTS | 75 | 185 | 163 | 39 | 13 | 475 |
| TRAVEL | 6 | 15 | 15 | 5 | 0 | 41 |
| MATERIALS & SERVICES | 113 | 258 | 84 | 19 | 8 | 482 |
| EQUIPMENT | 220 | 0 | 59 | 5 | 0 | 284 |
| TOTAL CDL | 566 | 834 | 654 | 143 | 46 | 2243 |
| TOTAL NRAO | 891 | 1977 | 1712 | 1114 | 610 | 6304 |
| NASA FUNDS | 891 | 1977 | 1712 | 1114 | 610 | 6304 |

In order to complete the receiver installation on the VLA by the end of 1988, NRAO has requested that NASA transfer to NSF either the full $1114k for FY 1988 in FY Quarter 1, or $709k in FY Quarter 1 plus $135k in each of FY Quarters 2, 3, and 4.

## 16 SCHEDULES

# FIGURE 5 X-BAND SYSTEM INSTALLATION

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| | 1987 | | | | | | | | | 1988 | | | | | | | | | | | | 1989 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| 1 ANT 24 | ← | 86 | 04 | 30 | OP | | | | | | | | | | | | | | | | | BS | △2 | | | | | | 24 ↓ | |
| 2 ANT 03 | ← | 86 | 08 | 20 | OP | | | | | | | | | | | | | | | | | | BS | △1 | VGTA | | | | | |
| 3 ANT 25 | ← | 86 | 08 | 21 | OP | △1 | BS | | | | | | | | | | | | | | | | | | | | | | ↑ NEPTUNE | |
| 4 ANT 11 | ← | 86 | 09 | 26 | OP | | | | | | | | | | | | | | | | | | BS | △28 | | | | | | |
| 5 ANT 26 | ← | 86 | 11 | 17 | | △3 | BS | OP | | | | | | | | | | | | | | | | | | | | | | |
| 6 ANT 10 | ← | 86 | 12 | 29 | OP | | | | | | | | | | | | | | | | | | | BS | △25 | | | | | |
| 7 ANT 28 | ← | 87 | 02 | 27 | OP | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 ANT 06 | △13 | OP | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 ANT 01 | | △21 | OP | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 ANT 20 | | | △18 | OP | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 ANT 09 | | | | △14 | OP | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 ANT 08 | | | | | △20 | OP | | | | | | | | | | | | | | | | | | | | | | | | |
| 13 ANT 02 | | | | | | △24 | OP | | | | | | | | | | | | | | | | | | | | | | | |
| 14 ANT 21 | | | | | | △25 | OP | | | | | | | | | | | | | | | | | | | | | | | |
| 15 ANT 12 | | | | | BS | RF | △26 | △16 | FD | CF | OP | | | | | | | | | | | | | | | | | | | |
| 16 ANT 14 | | | | | | BS | RF | △30 | △28 | FD | CF | OP | | | | | | | | | | | | | | | | | | |
| 17 ANT 16 | | | | | | | | | | | △15 | OP | | | | | | | | | | | | | | | | | | |
| 18 ANT 17 | | | | | | | | | | | | △21 | OP | | | | | | | | | | | | | | | | | |
| 19 ANT 18 | | | | | | | | | | BS | RF | △29 | △25 | FD | CF | OP | | | | | | | | | | | | | | |
| 20 ANT 19 | | | | | | | | | | | | BS | RF | △24 | △13 | FD | CF | OP | | | | | | | | | | | | |
| 21 ANT 07 | | | | | | | | | | | | | BS | RF | △20 | △25 | FD | CF | OP | | | | | | | | | | | |
| 22 ANT 13 | | | | | | | | | | | | | | | | | △29 | OP | | | | | | | | | | | | |
| 23 ANT 15 | | | | | | | | | | | | | | | | BS | RF | △12 | △03 | FD | CF | OP | | | | | | | | |
| 24 ANT 23 | | | | | | | | | | | | △21 | FD | | | | RF | △09 | △10 | | CF | BS | OP | | | | | | | |
| 25 ANT 04 | | | | | | | BS | RF | △28 | | | | △25 | FD | CF | OP | | | | | | | | | | | | | | |
| 26 ANT 27 | | | | | | | | | | | BS | RF | △26 | | △25 | FD | CF | OP | | | | | | | | | | | | |
| 27 ANT 22 | | | | | | | | | | | | | | BS | RF | △18 | △29 | FD | CF | OP | | | | | | | | | | |
| 28 ANT 05 | | | | | | | FD | △09 | | | | | | | | | | | | △07 | BS | CF | RF | OP | | | | | | |
| IF BANDPASS FILTERS | IF A | | | | | | | | | | | | IF B,C,D | | | | | | | | | | | | | | | | | |

BS = BANDSWITCH, F9
(UPGRADE RACK-A)
CF = COOLED FRONT-END
FD = FEED
RF = RACK-F
OP = OPERATIONAL AT X-BAND
△xx = MILESTONE, xx = DAY

WDB 87 09 23

# FIGURE 6: BACKUP CRYO-COMPRESSOR INSTALLATION

| | 1987 | | | | | | | | | 1988 | | | | | | | | | | | | 1989 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| PURCHASE 2 COMP + MODIF MAT'L | ← 87 02 | | | | | | | | | | | | | | | | | | | | | | | | | | | | 24 | |
| MODIFY + TEST 2 COMP | | | 01 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL ON 2 ANTENNAS | | | | | | | 01 | | | | | | | | | | | | | | | | | | | | | | | |
| PURCHASE MODIF MTR'L 26 COMP | | | | | 14 | | | | | | | | | | | | | | | | | | | | | | | | | |
| REQUISITION 20 COMP | | | | 31 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| RECEIVE 10 COMP | | | | | | 15 | | | | | | | | | | | | | | | | | | | | | | | | |
| RECEIVE 10 COMP | | | | | | | | 02 | | | | | | | | | | | | | | | | | | | | | | |
| MODIFY + TEST 5 COMP | | | | | | | | 30 | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL 5 COMP ON 5 ANT | | | | | | | | | | 15 | | | | | | | | | | | | | | | | | | | | |
| MODIFY + TEST 5 COMP | | | | | | | | | | 29 | | | | | | | | | | | | | | | | | | | | |
| INSTALL 5 COMP ON 5 ANT | | | | | | | | | | | | 01 | | | | | | | | | | | | | | | | | | |
| MODIFY + TEST 5 COMP | | | | | | | | | | | | 15 | | | | | | | | | | | | | | | | | | |
| INSTALL 5 COMP ON 5 ANT | | | | | | | | | | | | | | 02 | | | | | | | | | | | | | | | | |
| MODIFY + TEST 5 COMP | | | | | | | | | | | | | | 15 | | | | | | | | | | | | | | | | |
| INSTALL 5 COMP ON 5 ANT | | | | | | | | | | | | | | | | 01 | | | | | | | | | | | | | | |
| REQUISITION 6 COMP | | | | | | | | 02 | | | | | | | | | | | | | | | | | | | | | | |
| RECEIVE 6 COMP | | | | | | | | | | 15 | | | | | | | | | | | | | | | | | | | | |
| MODIFY + TEST 6 COMP | | | | | | | | | | | | | | | | 15 | | | | | | | | | | | | | | |
| INSTALL 5 COMP ON 5 ANT | | | | | | | | | | | | | | | | | | | | 07 | | | | | | | | | | |
| INSTALL COMP, ELEC, HE ANT23 | | | | | | | | | | | | | | | | | | | 10 | | | | | | | | | | | |

VGTA

NEPTUNE

FIGURE 7; ANALOG SUMS AND SWITCH

WJB 87 09 23

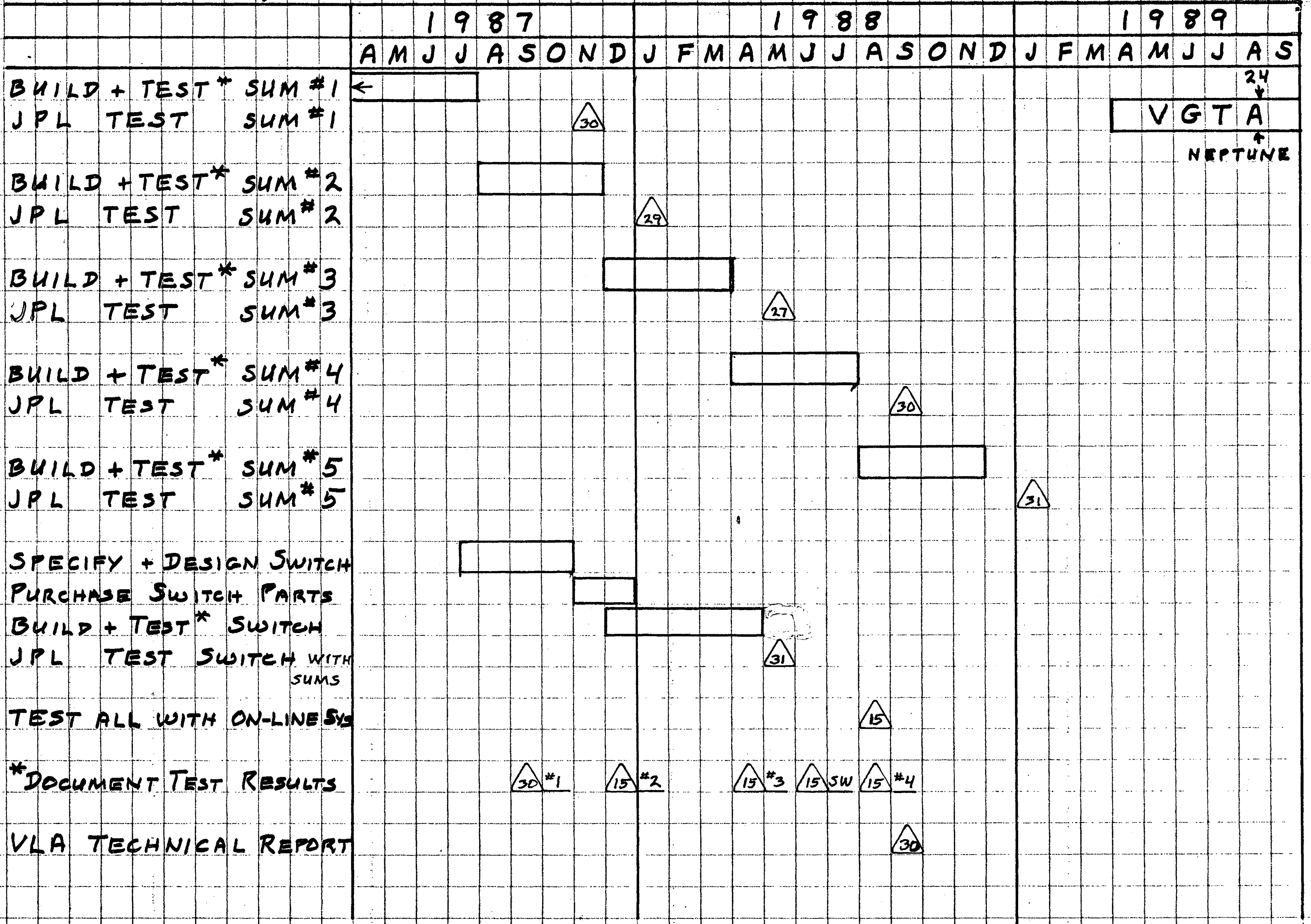
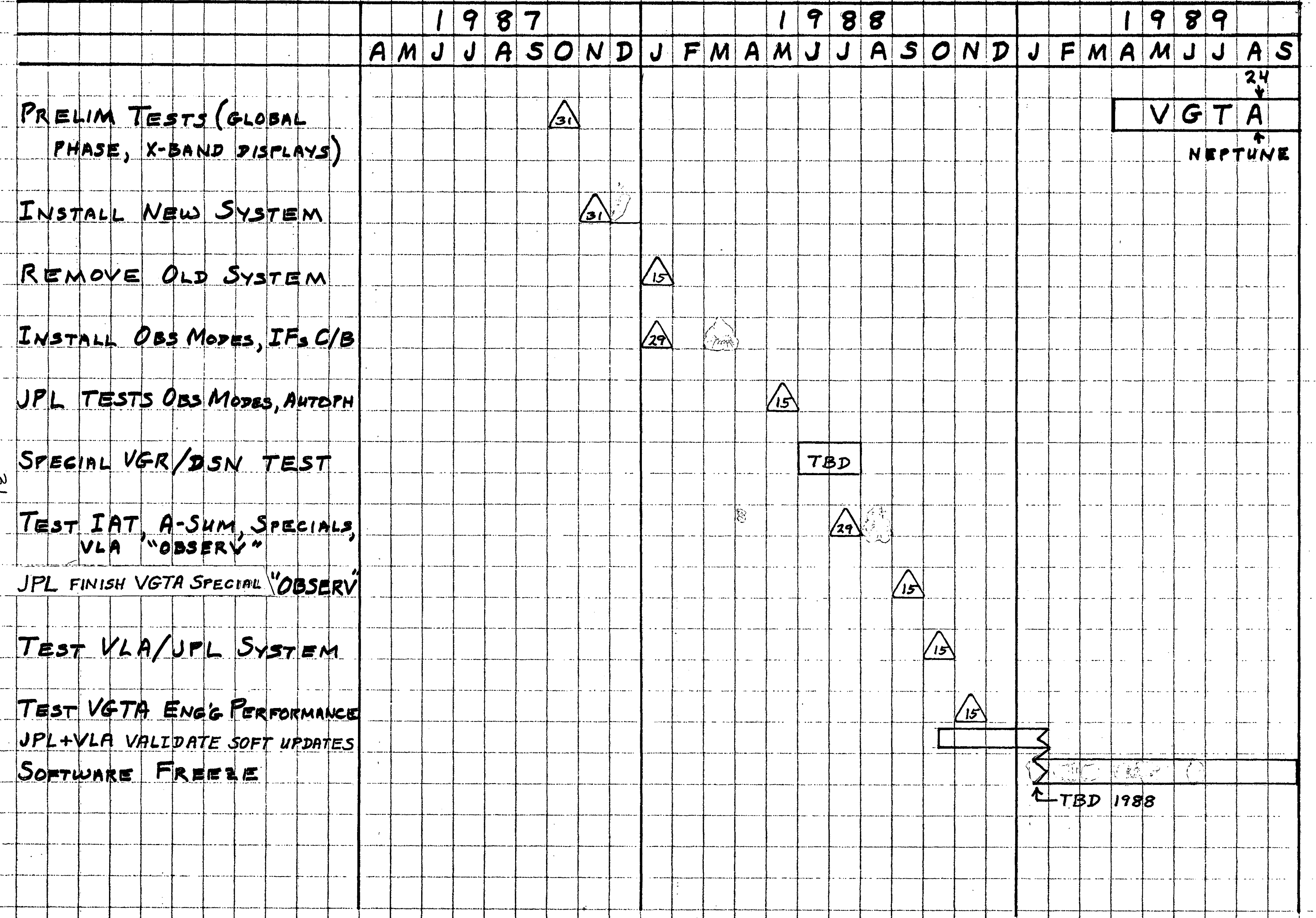


FIGURE 8: NEW ON-LINE SYSTEM

WDB 87 09 23



# FIGURE 9: POWER GENERATION SYSTEM

WDB 87 09 23

| | | 1987 | | | | | | | | | 1988 | | | | | | | | | | | | 1989 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S | O | N | D | J | F | M | A | M | J | J | A | S |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 24 ↓ | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | V | G | T | A | |
| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | ↑ NEPTUNE | |
| INSTALL GENERATORS | JPL | | △ | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL BUILDING | JPL | | | △ | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL BLDG ELECTRICAL | VLA | | | | | | | △ 30 | | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL FUEL TANKS | VLA | | | | | | | △ 16 | | | | | | | | | | | | | | | | | | | | | | | |
| INSTALL SPRINKLER SYS | JPL | | | | | | | | | | | | △ 23 | | | | | | | | | | | | | | | | | | |
| SET TRANSFORMER | JPL | | | | | | | | | | | △ 24 | | | | | | | | | | | | | | | | | | | |
| INSTALL SYNCRO INTERFACE | JPL | | | | | | | | | | | △ 26 | | | | | | | | | | | | | | | | | | | |
| PREPARE TEST PLAN | JPL | | | | | | | | | | | △ 26 | | | | | | | | | | | | | | | | | | | |
| INSTALL 480V INTERFACE | JPL | | | | | | | | | | | | △ 01 | | | | | | | | | | | | | | | | | | |
| INSTALL 12 KV INTERFACE | JPL | | | | | | | | | | | | △ 15 | | | | | | | | | | | | | | | | | | |
| CONNECT 12 KV | JPL | | | | | | | | | | | | | △ 08 | | | | | | | | | | | | | | | | | |
| SYSTEM CHECKOUT | JPL | | | | | | | | | | | | | △ 22 | | | | | | | | | | | | | | | | | |
| TRAIN OPERATORS/STARTUP | JPL-VLA | | | | | | | | | | | | | | △ 06 | | | | | | | | | | | | | | | | |
| SYSTEM TESTS | JPL-VLA | | | | | | | | | | | | | | | △ 20 | | | | | | | | | | | | | | | |
| ENVIRONMENTAL IMPACT | VLA | | | | | | △ 28 | | | | | | | | | | | | | | | | | | | | | | | | |
| STATEMENT APPOVED BY NM | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| AIR QUALITY PERMIT #692 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| NOTIFY NM ESTIMATED STARTUP DATE | VLA | | | | | | | | | | | | | | △ | 30-60 DAY PRIOR | | | | | | | | | | | | | | | |
| NOTIFY NM ACTUAL STARTUP DATE | VLA | | | | | | | | | | | | | | | △ | ≤ 15 DAY AFTER | | | | | | | | | | | | | | |

FIGURE 10: POWER CABLE REPLACEMENT

WDB 87 09 24

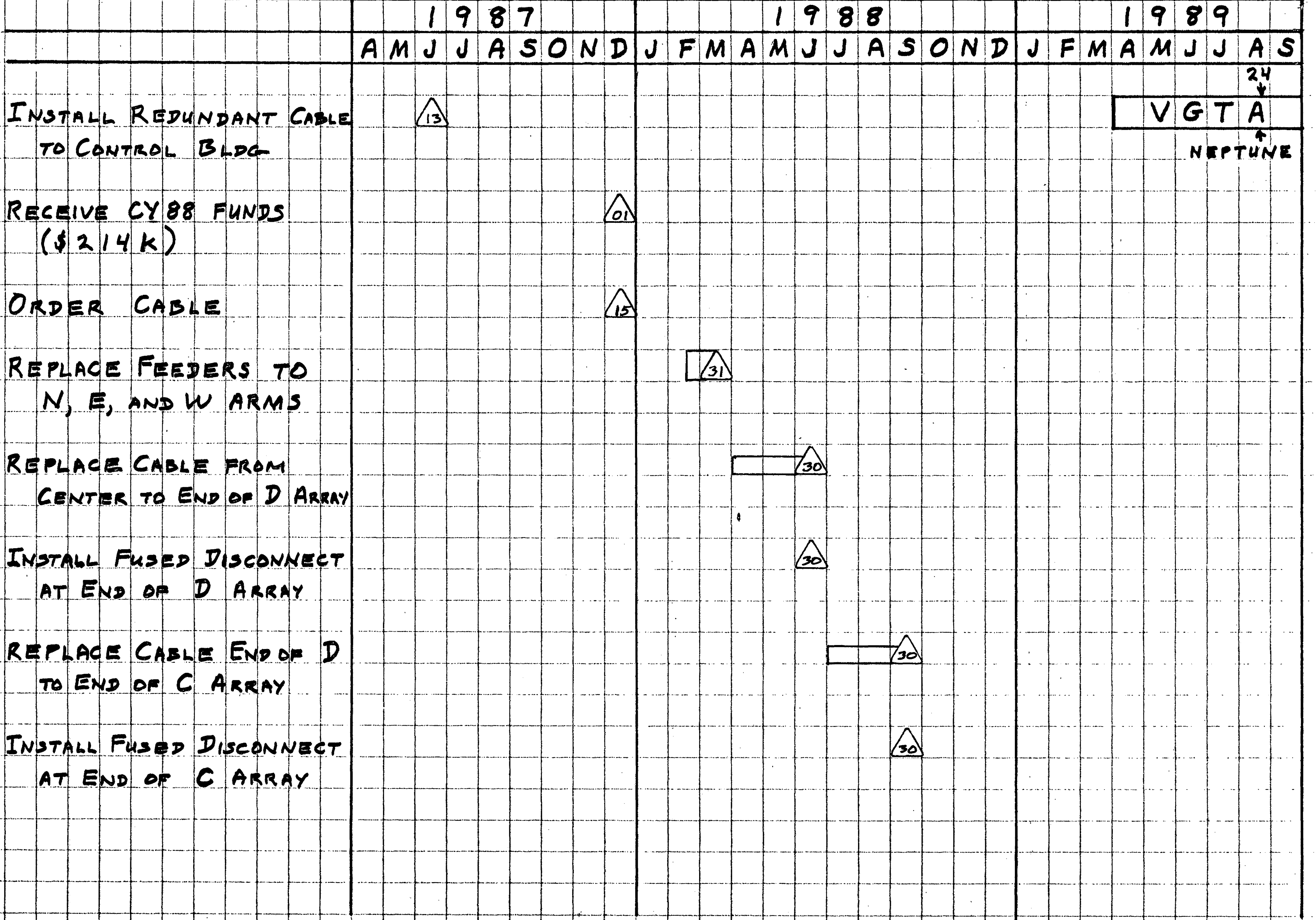
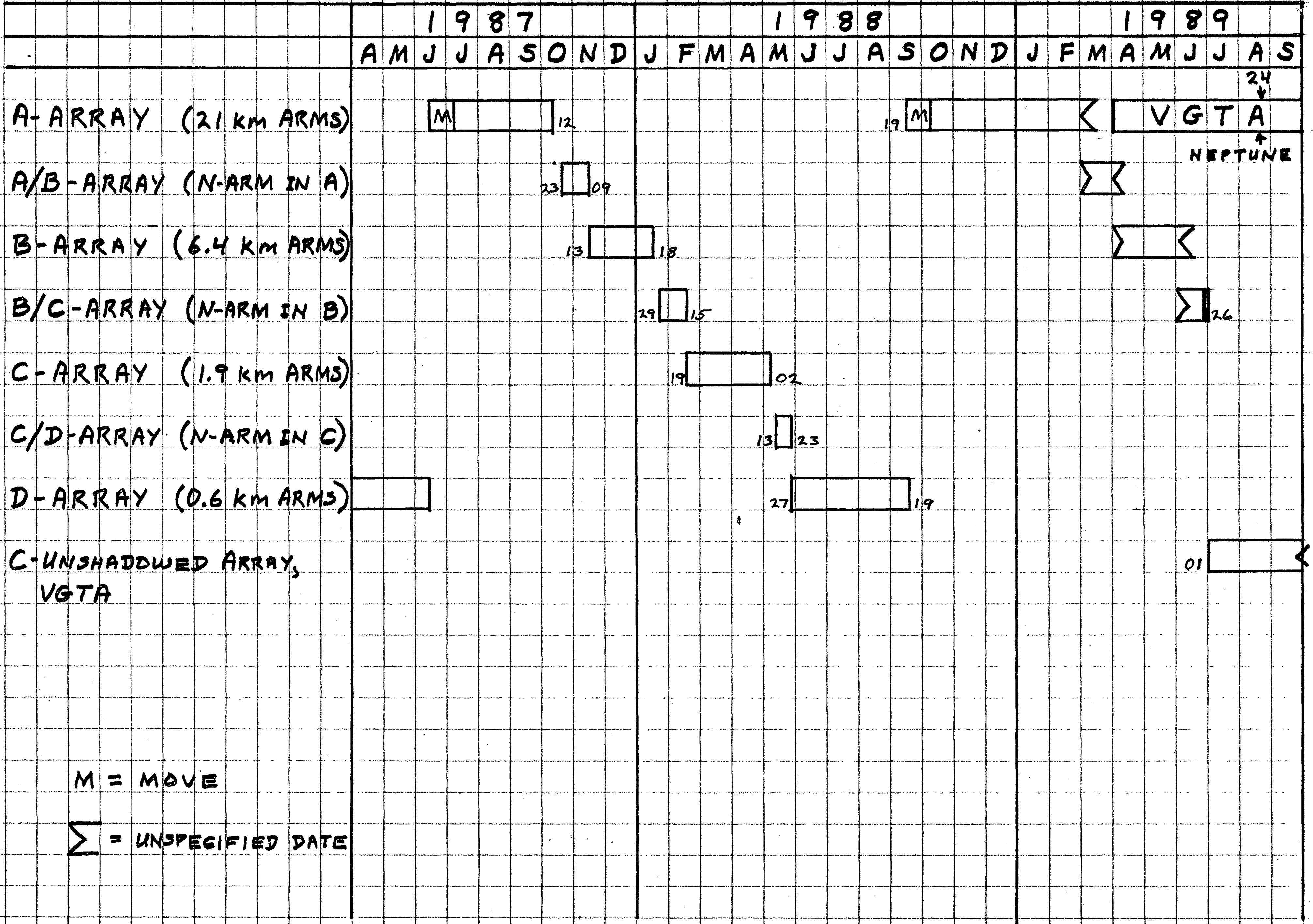


FIGURE 11: CONFIGURATION

WDB 87 09 01



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