NATIONAL RADIO ASTRONOMY OBSERVATORY
SOCORRO, NEW MEXICO
VERY LARGE ARRAY PROJECT

VLA ELECTRONICS MEMORANDUM NO. 151

WAVEGUIDE SYSTEM FOR A VERY LARGE ANTENNA ARRAY*

November 11, 1976

Mikio Ogai

At this conference, many papers have been presented on different areas of millimetric waveguide systems. These are mainly concerned with the technique and hardware to establish the use of waveguide in the public communication systems.

Now I would like to show you a new application of millimeter waveguide transmission systems.

(SLIDE 1) - AEROVIEW OF THE VLA - 76-6-5 (5)

For years, radio astronomers have felt the need for an instrument that could provide high resolution radio "pictures" of cosmic sources rapidly and with great sensitivity.

This is the telescope that meets the requirements of astronomers. It is being built in the USA, in central New Mexico, by the National Radio Astronomy Observatory under contract from the National Science Foundation. It is called "The Very Large Array", shortly the VLA.

*This is the presentation at the IEE Conference on Millimetric Waveguide Systems, London, November 9-12, 1976.

(SLIDE 2) - ARTIST'S CONCEPT OF THE VLA - VLA-4

The VLA consists of twenty-seven antennas. These antennas are arranged along the arms of a "Y". Each arm is from 19 Km ~ 21 Km long and has nine antennas. Each antenna has a 25m diameter parabolic reflector and weighes more than 200 tons. They can be moved between 24 observing stations on each arm to achieve four array configurations.

The VLA requires a low-loss and wide-band transmission system between the central control building and each antenna.

After many considerations, the millimeter waveguide system was adopted.

(SLIDE 3)

This is the concept of the waveguide transmission system for the VLA. Each arm has an independent waveguide system. Through this system two local-oscillator phase-reference tones and antenna control signals are sent from the central control building to each antenna.

From each antenna, two local oscillator phase-reference tones, antenna monitor signals and four 50 MHz band analog IF signals are sent back. IF signals carry radio astronomical signals received by the antenna.

These signals are diplexed in the 1 ~ 2 GHz frequency range and sent through the waveguide system as amplitude modulation on a high frequency carrier.

The carrier frequency range used in the VLA waveguide system is from 27 to 53 GHz. This range is shared by 11 channels. Adjacent channels are 2.4 GHz apart and each channel has 1 GHz bandwidth.

This waveguide system can be divided into four main parts. Those are antenna waveguide, couplers, main trunk waveguide, and signal distributor.

Maximum allowable loss is 56 dB and variation in 10 MHz and 50 MHz must be less than .2 dB^{P-P} and 1.0 dB respectively.

I would like to show you more detail of each part.

(SLIDE 4)

The most important part is the Main Trunk Waveguide. 60 mm dia. helical waveguide developed in Japan is installed directly underground, without having any mechanical protection. Each piece is 5 m long and connected by a threaded coupling joint. Polyethlene coating with self-healing compound protects the waveguide from corrosion.

The biggest problem in the main waveguide is the deterioration of transmission loss. Even though direct burial installation was abandoned in almost all countries, after some studies, it was adopted for the VLA because it is the least expensive. The construction site is in a very flat plain and has no traffic over the waveguide, and the amount of rain is small. It is an almost ideal place for the waveguide installation.

Unfortunately we have not gotten a very good performance from the first section, but after some study and improvement on the compaction of the soil around the waveguide, performance has been improved. Compactions are made on a smoothed bed, at the bottom of the trench, on the soil at both sides of the waveguide, on the sandy soil cover of 30 cm thickness, and on the backfilled soil.

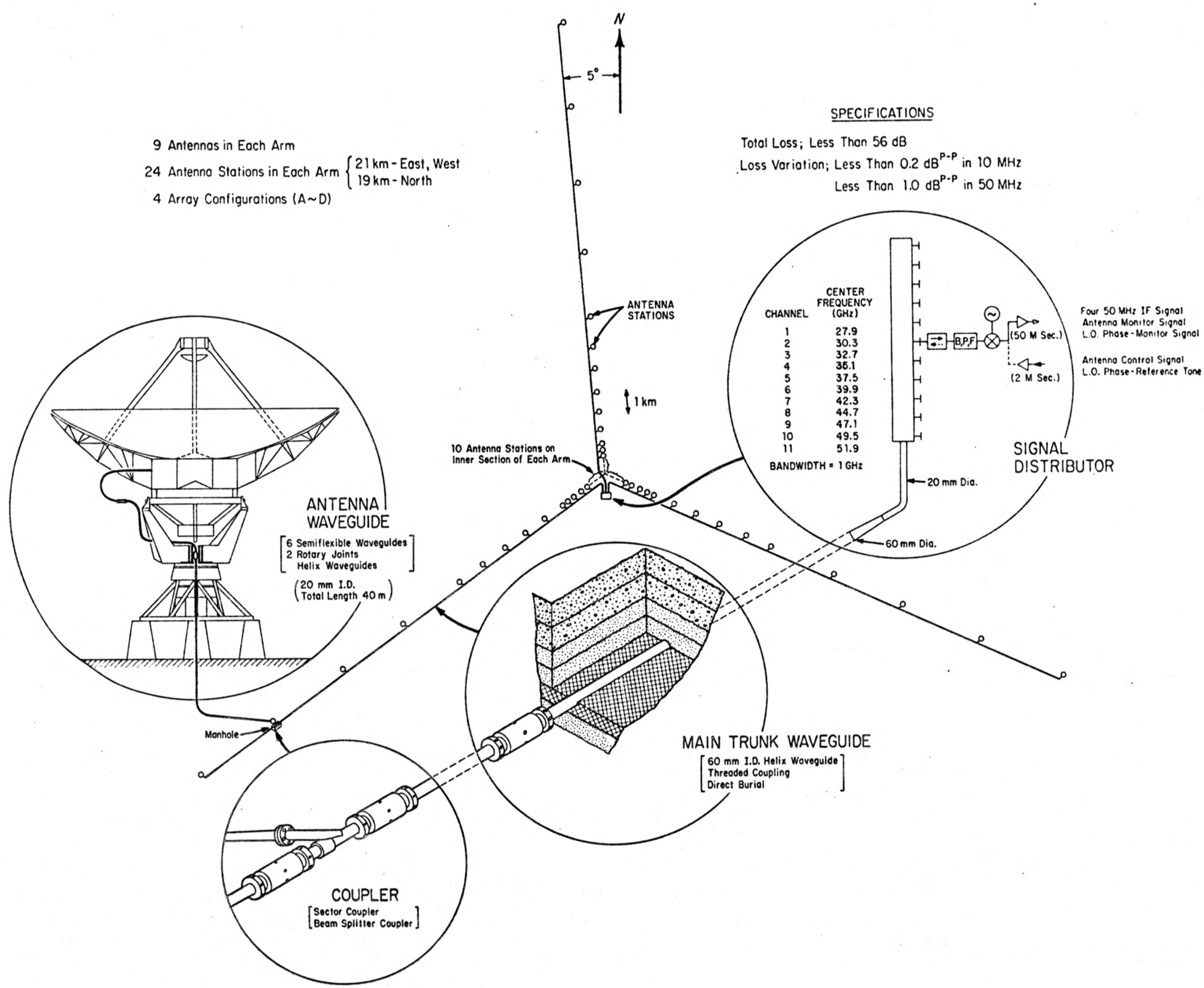
(SLIDE 5)

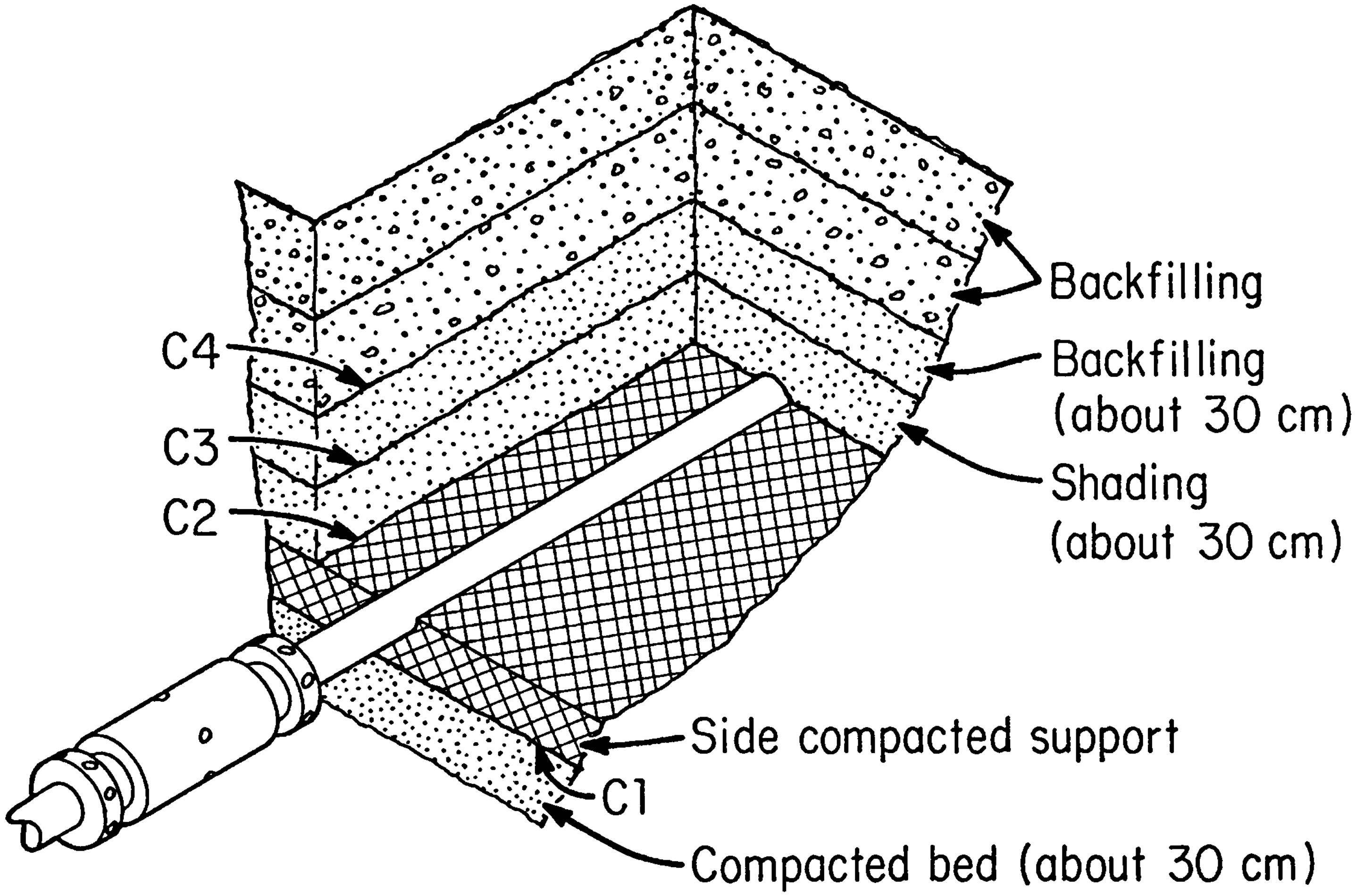
This is the transmission loss of the first section of waveguide. A large loss increase was found just after the backfilling, and one year later, another loss increase was found.

But with the improvement of the soil compaction method, the loss increase caused by backfilling has become smaller. The r.m.s. curvature now stays around 900 m even several months after installation.

These measurements were done by automatic test sets developed in NRAO. This is based on the single pulse reflection method and frequency is swept automatically. Pulses reflected from a shutter at the near end and a cover plate at the far end of the waveguide are integrated and compared with each other. Details are given in the technical paper.

VLA WAVEGUIDE SYSTEM

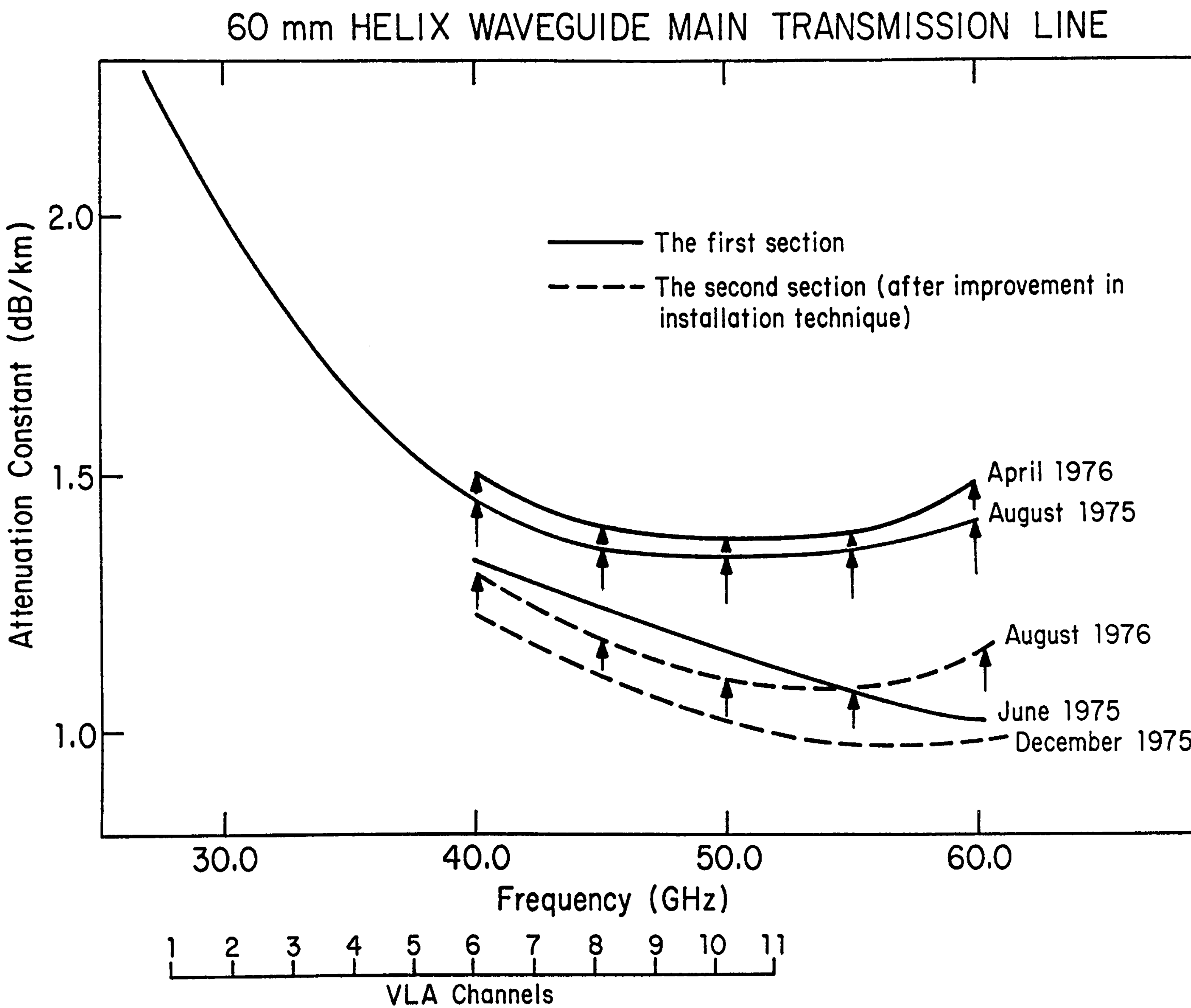




Note: C1 - C4 are compaction layers

Main Trunk Transmission Waveguide

Waveguide: 60 mm Dia. I.D. Helix Waveguide.
Connection: Threaded Joint.
Protection: Polyethylene Lining with Selfhealing Undercoat.
Installation: Direct Burial. (1~3 m deep)



60 mm HELIX WAVEGUIDE MAIN TRANSMISSION LINE
The first section
The second section (after improvement in installation technique)
April 1976
August 1975
August 1976
June 1975
December 1975
2.0
1.5
1.0
Attenuation Constant (dB/km)
30.0
40.0
50.0
60.0
Frequency (GHz)
1
2
3
4
5
6
7
8
9
10
11
VLA Channels

(SLIDE 6)

As twenty-three couplers are installed along each arm of the main trunk line, their performance is an important factor.

This slide shows the required coupling and allowable insertion loss. Regarding the coupling value, five models are required and one each of models A ~ D and 19 of model E are required in each arm.

(SLIDE 7)

These are the couplers that we have mainly evaluated at this time. Before we started our study on couplers, no suitable coupler that had 60 mm diameter was available. Reduced diameter couplers make the system very complicated. So, most of the efforts have been made on developing 60 mm diameter couplers.

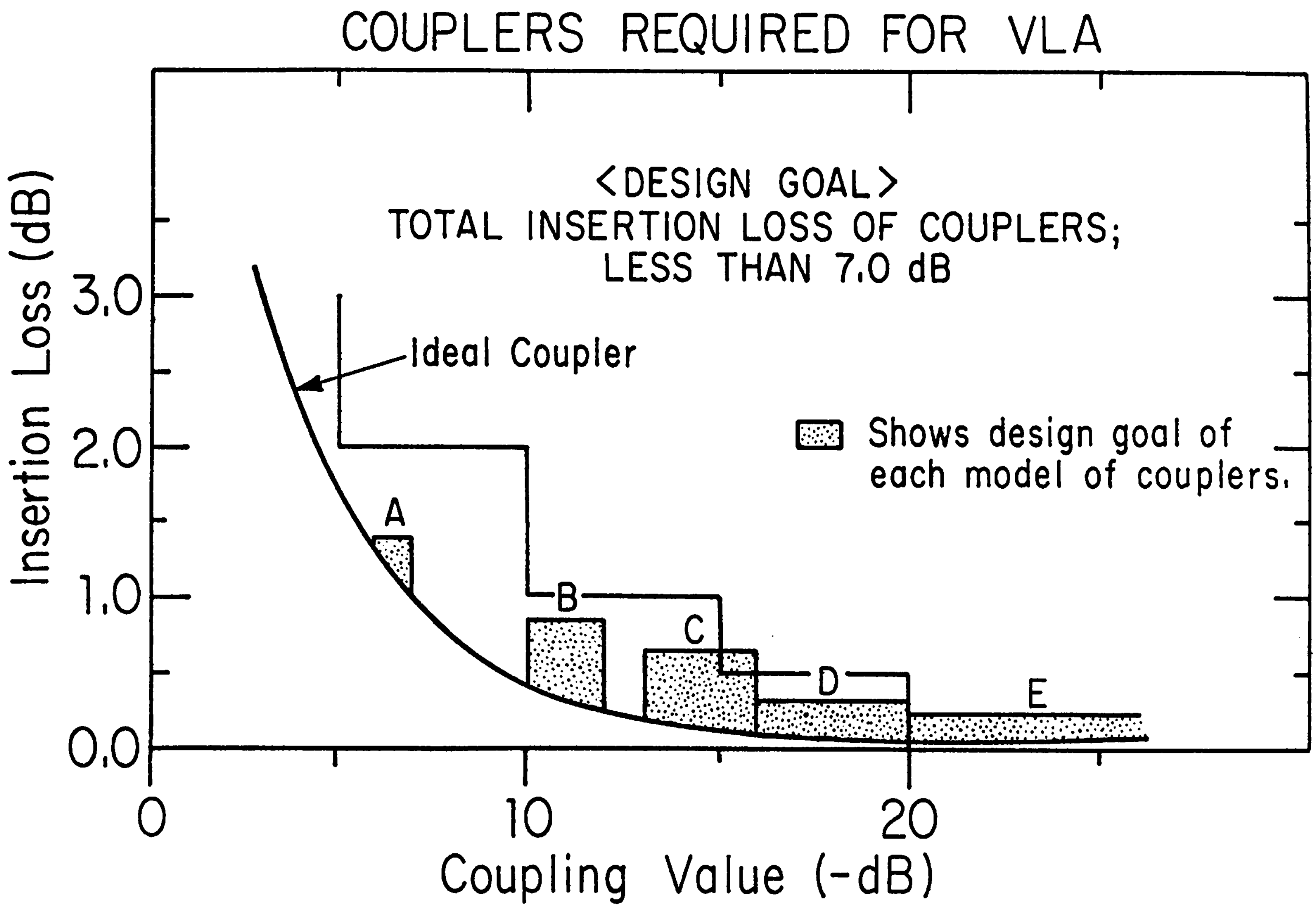
One of these is this one. We call this coupler a "helical coupler". It gets a coupling between a circular waveguide and a spiraled rectangular waveguide through coupling holes that are located on the common wall of two waveguides.

The lead of the spiral is determined so that the phase velocities of two waveguides become the same in the longitudinal direction of the circular waveguide at the specified frequency.

The problem in this coupler is poor mode discrimination between TE_{01} and TE_{02} mode. Coupling of TE_{02} mode is about 10 dB below TE_{01} mode when the frequency is .5 GHz away from the center design frequency.

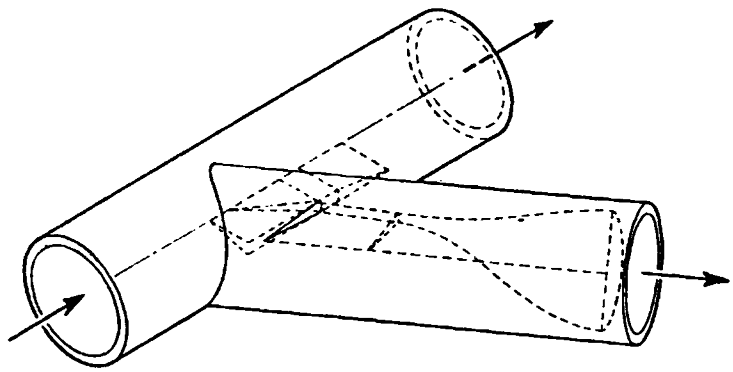
The beam splitter coupler has also been evaluated. By changing the dielectric material and its thickness, the coupling value can be controlled. But the insertion loss of the main line is too high and it generates too much TE on mode to be used at all the stations. These facts limit the number that we can have in one arm.

The coupler in which most of the developing efforts are concentrated is this one. We call it the "sector coupler". This seems to be the best at almost all the stations except the last few. It has a broadband coupling response and simpler configuration than the helical coupler.



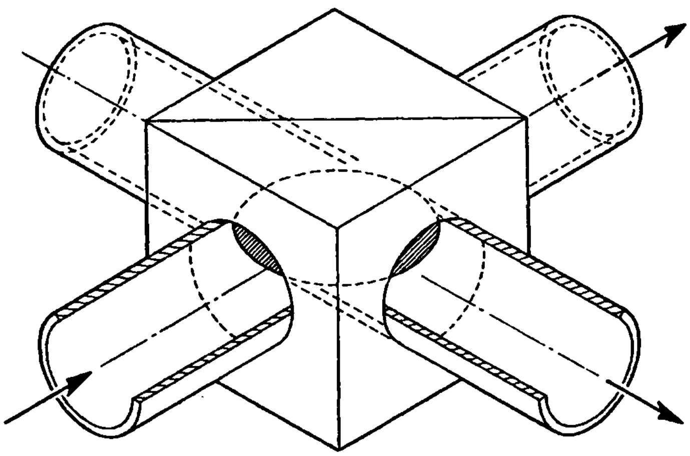
One of each models A~D and 19 of E model are required in one arm of "Y".

COUPLER EVALUATED FOR VLA



o Broad Band Coupling Response
o Easy To Get Required Coupling

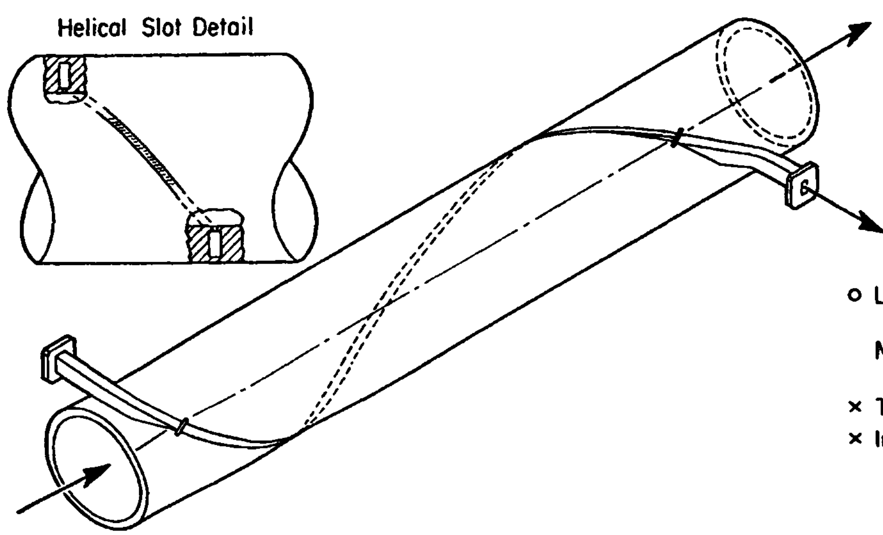
I SECTOR COUPLER



o Broad Band Coupling Response
o Easy To Get Required Coupling

× TE_{ON} ($N \geq 2$) Mode Coupling
× TE_{ON} ($N \geq 2$) Mode Generation
× Loss Too High To Get a Good Loose Coupler

II BEAM SPLITTER COUPLER



o Low Insertion Loss

Narrow Band Coupling Response

× TE_{ON} ($N \geq 2$) Mode Coupling
× Impossible To Get Tight Coupler

III HELICAL COUPLER

(SLIDE 8)

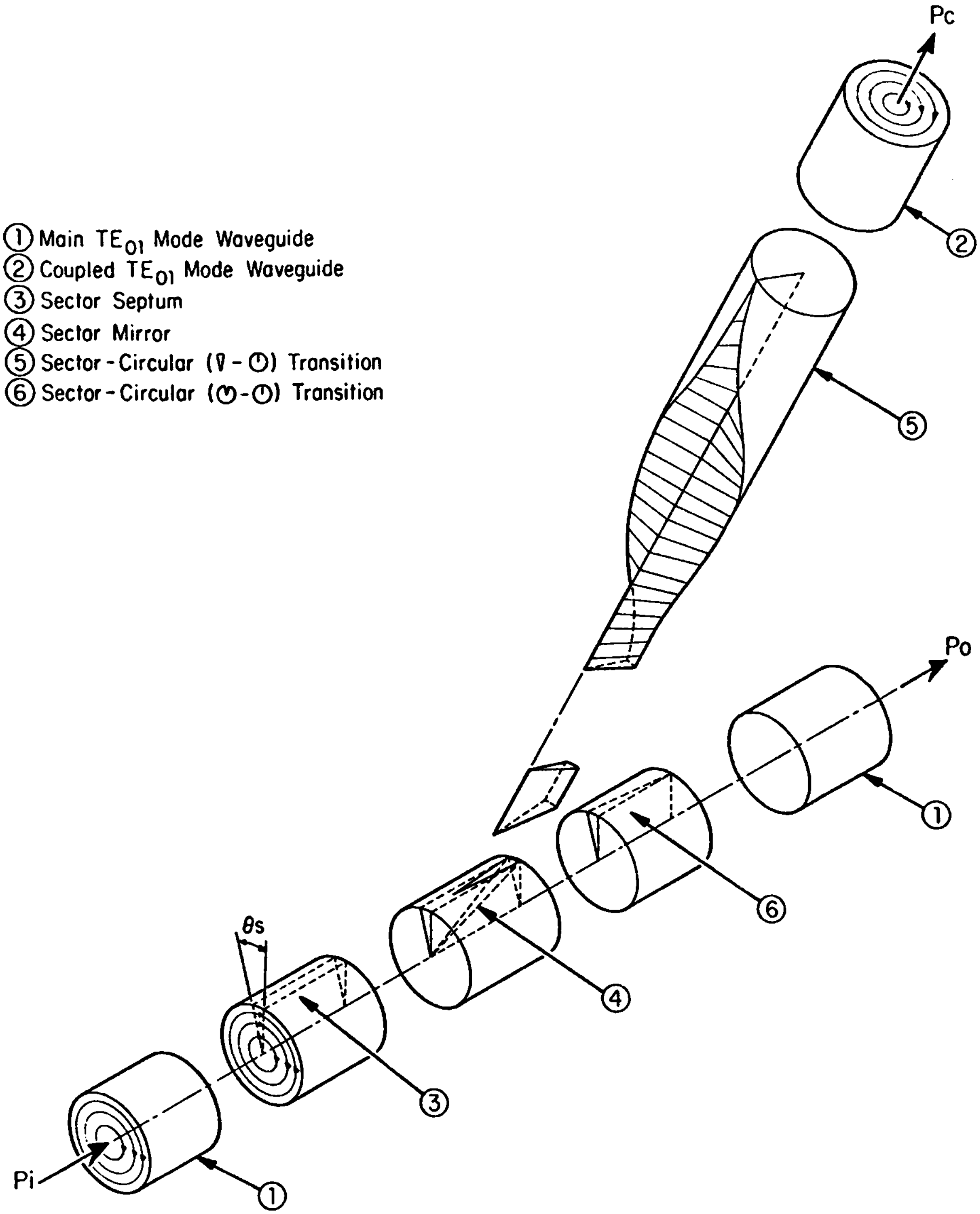
I would like to show you some more details of the sector coupler. As you know the TE_{on} mode waves in a circular waveguide have the electric field only in the circumferential direction. This means that a flat perfect conductor plate that contains the center line of circular cylinder does not disturb the TE_{on} mode field. When two sheets of plate exist like this, the TE_{on} mode wave from the circular waveguide goes into two waveguides smoothly. The amount of the wave is in proportion to the sector angle.

Several methods can be considered to take out the sector waveguide from the main waveguide. The most compact and powerful way in our applications, seems to be to change the direction by a sector mirror.

After that the sector is opened out gradually. The coupling loss can be expressed as follows:

Coupling = - { - - - - - - - - - } (shown in slide)

Insertion loss can be expressed as follows:



PRINCIPLE OF SECTOR COUPLER

$$\text{COUPLING}\left(\frac{Pc}{Pi}\right) = -\left\{-10\ \text{Log}\left(\frac{\theta s}{360}\right) + \text{Loss of sector mirror} + \text{Loss of sector-circular transition}_{(\nabla-\odot)}\right\}\ (\text{dB})$$

$$\text{INSERTION LOSS}\left(\frac{Pi}{Po}\right) = -10\ \text{Log}\left(\frac{360-\theta s}{360}\right) + \text{Loss of sector-circular transition } (◔-\odot)\ (\text{dB})$$

Insertion loss = { - - - - - } (shown in slide)

(SLIDE 9)

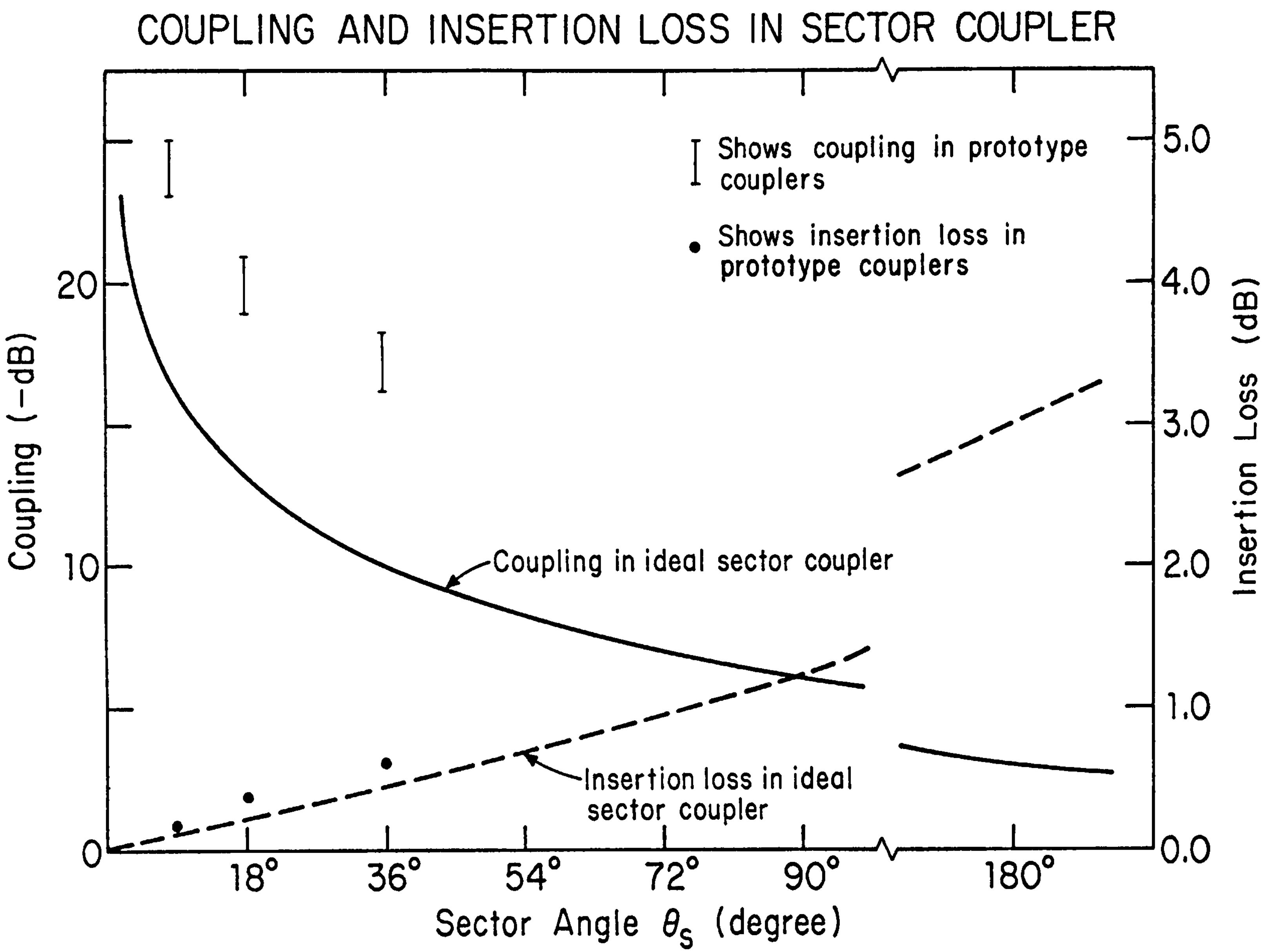
These are actual values that we got from the prototype sector couplers. The coupling difference between an ideal coupler and actual couplers is caused mainly by the insertion loss of the $\nabla - \theta$ transitions. There seems to be some possibility that we may be able to reduce this difference.

(SLIDE 10)

This is the present development status compared with design goals. Beam splitter couplers seem to be promising for tight coupling, and sector couplers with different angles are close to the design goals.

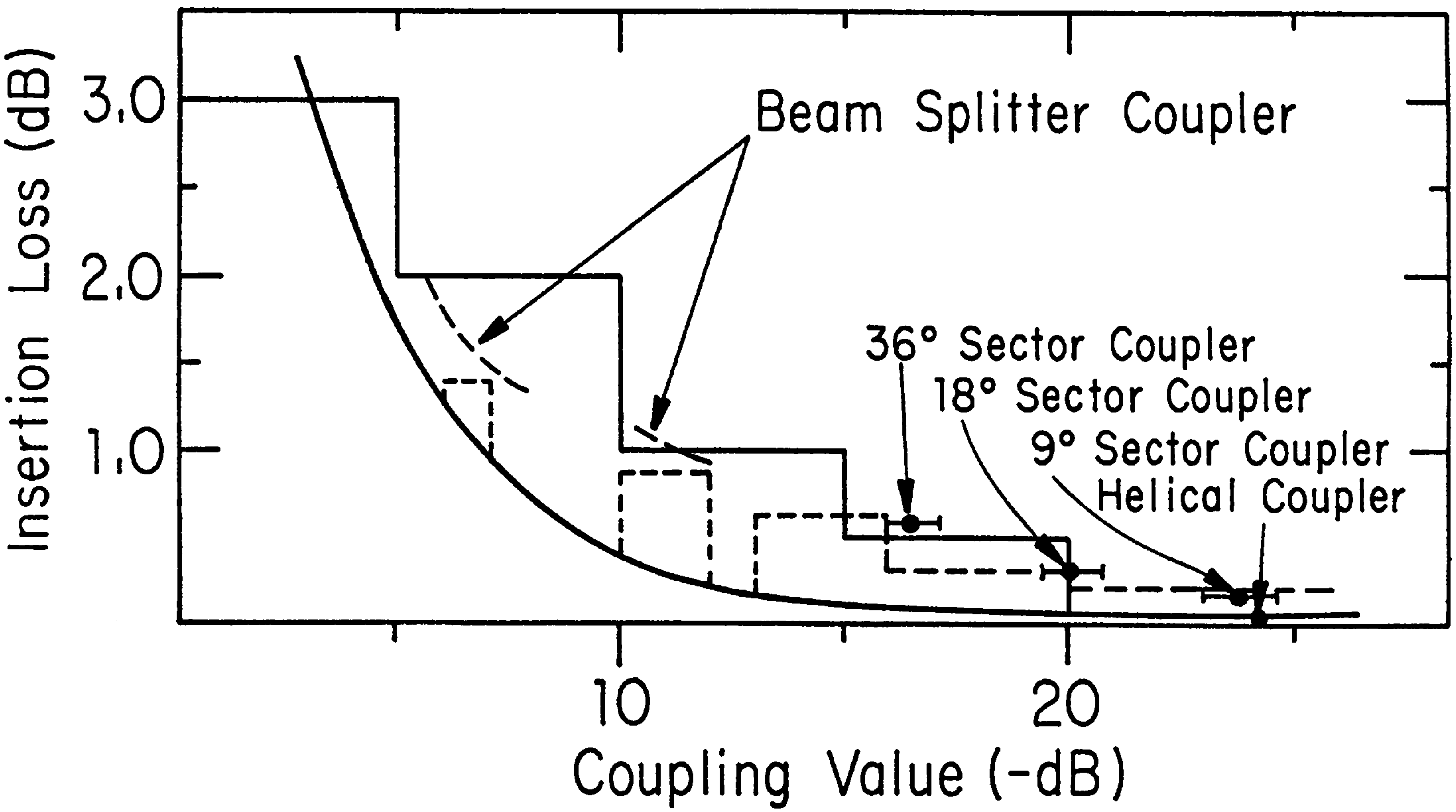
(SLIDE 11)

Between the coupler and the vertex equipment room of each antenna 20 mm diameter waveguide is installed. This run contains two rotary joints and 6 pieces of semi-flexible helix waveguide. The flexible waveguide is most critical



Ideal sector coupler; has no transition loss from sector to specified waveguide and no extra loss besides coupled power loss.

COUPLING-INSERTION LOSS
RESPONSE IN COUPLERS



(Evaluated For VLA Waveguide System Before Oct. 1976) in determining the overall performance. Sections are bent to 1 m radius and held in a PVC casement. The loss from P_1 to P_2 is shown on the following slide.

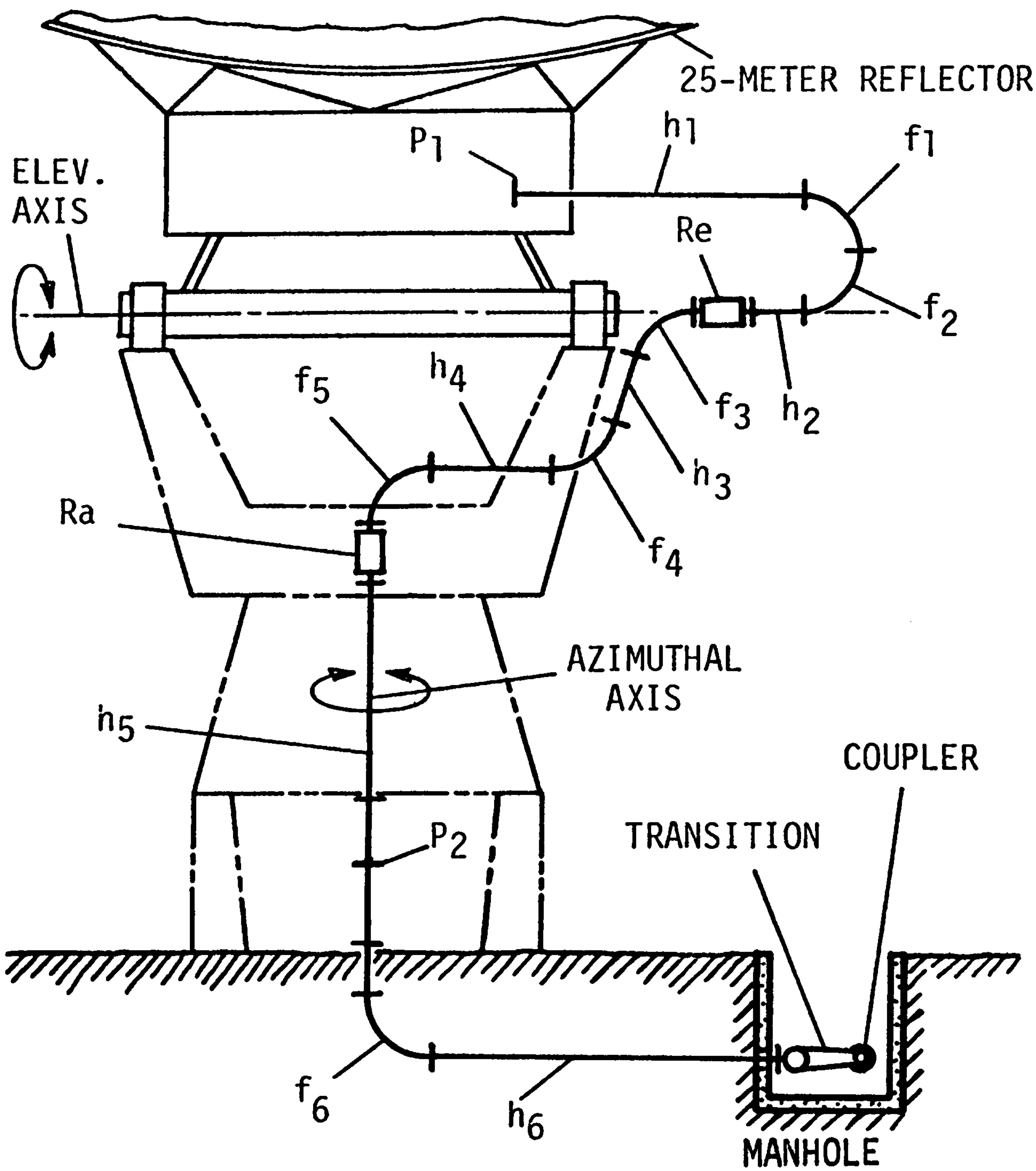
(SLIDE 12)

No. 1 and No. 2 antennas had different types of flexible waveguide. The difference was caused by the flexible waveguide. No. 1 had much better performance except around 30 GHz where the flexible waveguide had a loss peak. When the attenuation of the main trunk waveguide is considered, it is desirable to get the performance like No. 1 antenna.

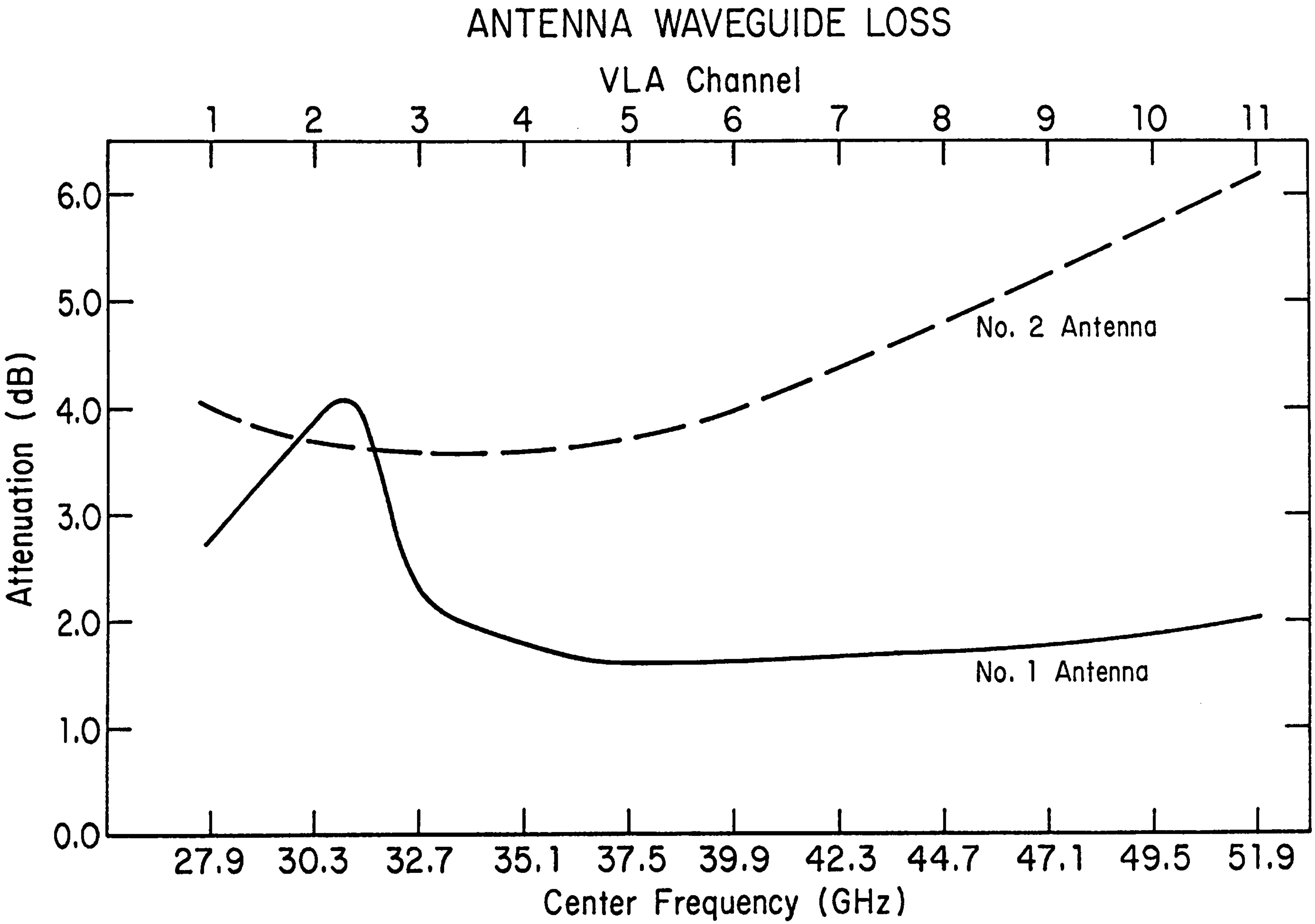
At the control building the waveguide is terminated by a branching network that consists of a cascade of high-pass and low-pass diplexers realized in semi-circular waveguide and rectangular waveguide. The distribution loss is less than 5 dB in almost all the channels.

(SLIDE 13) - VLA Site

Using one part of the waveguide system and several antennas, observations have been started and the



Antenna waveguide configuration. The 40 meter path from the manhole to equipment room at P_1 is bridged by 6 rigid 20 mm diameter waveguides (f_1 thru f_6). Ra and Re are azimuth and elevation rotary joints.


ANTENNA WAVEGUIDE LOSS
VLA Channel
1 2 3 4 5 6 7 8 9 10 11
Attenuation (dB)
6.0
5.0
4.0
3.0
2.0
1.0
0.0
No. 2 Antenna
No. 1 Antenna
27.9 30.3 32.7 35.1 37.5 39.9 42.3 44.7 47.1 49.5 51.9
Center Frequency (GHz)

waveguide system has been confirmed to work well.

As a conclusion, I would like to say that a new application of millimeter waveguide is possible which takes advantage of its low-loss and a large transmission capacity and techniques that have been developed.

I wish to acknowledge co-authors and many people who are supporting this work in NRAO, especially to Dr. Weinreb and Dr. Thompson for their direction of this work and their help in presenting this paper.