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CONSIDERATION OF A MICROWAVE LINK IF TRANSMISSION SYSTEM

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In this memorandum the following factors concerning the use of a microwave link for VLA IF transmission are examined:

A. Cost Comparison of Cable and Microwave Link Systems
B. Blockage of the Array
C. RF Interference to the Array
D. Cross-Talk
E. Rainfall Attenuation
F. Path-Length Variations
G. Frequency Allocation

A layout sketch of a possible system suggested by these factors is shown in Figure 1. A cable system is used for the inner 2.33 km of the Wye because array blockage and cross-talk make a link system difficult. Frequency bands of 11.5-12.7 and 13.7-14.3 Gc/s would be used. The receiving antennas are 1 meter x 3 meter paraboloids (narrow beam in azimuth) mounted on 65 meter towers. These towers are 800 meters from the nearest array antenna to avoid blockage. Each transmitting antenna would be a 2-meter paraboloid having a half-power beamwidth of 0.9°.

The transmission loss from the most distant antenna is approximately 50 dB. With 0 dBm transmitted power and a 7 dB receiver noise figure, 40 dB of signal-to-noise is achieved. This will be degraded by less than 20 dB by a 12.5 mm/hr. rainfall which will occur less than 15 hours a year at the sites of interest.

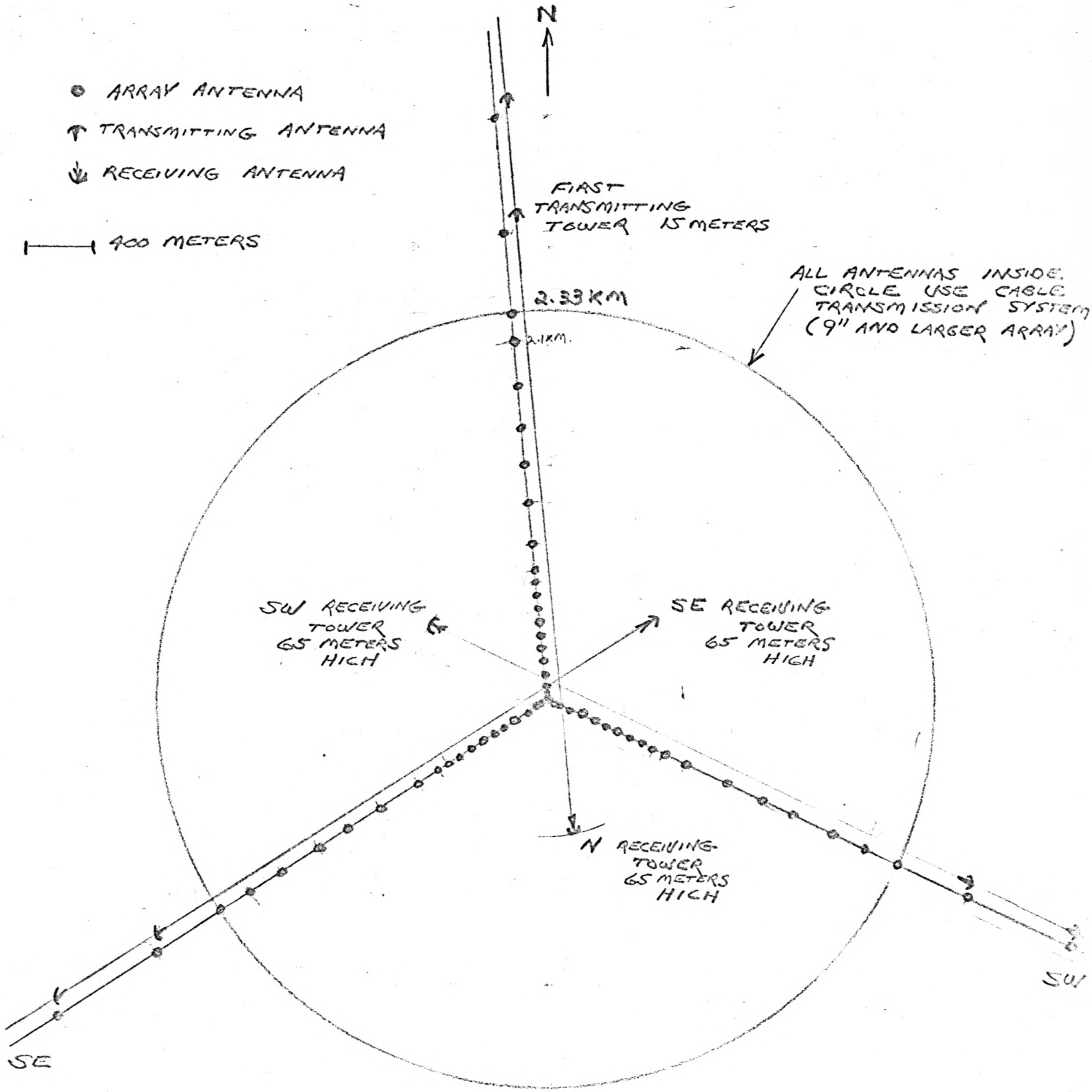

FIGURE 1 — A POSSIBLE VLA IF TRANSMISSION SYSTEM.

A. Cost Comparison of Cable and Microwave Link Systems

The current estimate of the cost of a cable IF and cable LO system is as follows:

IF TRANSMISSION ELECTRONICS ---	$ 781 K
IF CABLE AND REPEATERS -------	1070 K
LO ELECTRONICS -----------------	691 K
LO CABLE ----------------------	320 K
CABLE BURIAL COST --------------	750 K
TOTAL CABLE IF AND CABLE LO SYSTEM --------	$3612 K

(These figures are based upon the VLA Proposal with adjustments of cable prices and cable trenching cost to consider more recent figures. The 7/8" cable cost is computed at $0.70 per foot instead of $0.93 per foot, the 1 5/8" cable is computed at $1.50 per foot instead of $2.25 per foot, and cable burial cost is figured at $2.00 per foot instead of $4.00 per foot. The cable burial cost includes $252 K for manholes.)

If a microwave link system is used for IF transmission, the cost of IF transmission electronics would not differ appreciably. An IF cable system would most likely be necessary for the inner 2.1 km of each arm of the Wye so IF cable is priced at 1/10 of the previous cost. Transmitting and receiving antennas and towers are priced at 36 x $4 K + $56 K = $200 K. Finally, $300 K is added to cover the cost of cable transmission electronics needed for the inner 2.1 km. The result is as follows:

IF TRANSMISSION ELECTRONICS ----	$ 781 K
IF CABLE ------------------------	108 K
LINK ANTENNAS AND TOWERS ------	200 K
LO ELECTRONICS ----------------	691 K
LO CABLE -----------------------	320 K
CABLE BURIAL COST --------------	750 K
IF CABLE ELECTRONICS FOR INNER 2.1 KM ----------------	300 K
TOTAL MICROWAVE IF AND CABLE LO SYSTEM ---------	$3150 K

Finally, the cost of a system utilizing microwave links for both IF and LO on all but the inner 2.1 km of each arm is as follows:

IF TRANSMISSION ELECTRONICS -------	$ 781 K
IF CABLE ----------------------------	108 K
LINK ANTENNAS AND TOWERS ---------	200 K
LO ELECTRONICS -------------------	691 K
LO CABLE ----------------------------	32 K
IF AND LO CABLE ELECTRONICS FOR INNER 2.1 KM ---------------	600 K
TOTAL MICROWAVE IF AND MICROWAVE LO SYSTEM -------	$2412 K

B. Blockage of the Array

The link antennas must be mounted on towers in order to provide line-of-sight paths in spite of earth's curvature and local topography. These towers will block the array antennas if they fall in front of the aperture. The most serious effect of a small amount of blockage will be on anomalous phase shift of the incoming signal at some antenna positions.

To remove any possibility of this anomalous phase shift we must require that the link tower and antenna be outside of a 25-meter diameter column extending from the array antenna in the direction of the observed source. (This does not rule out scattering from the tower into the aperture but this will be a very small effect.) The array antennas can point to a minimum elevation of 5°. Since tan 5° = 1/11.4, each tower must then be located a minimum of 11.4 tower-heights from the array (assuming the lip of the array antenna is nearly at ground level at 5° elevation).

To preserve line-of-sight conditions over a 21 km path, receiving and transmitting towers must be $\sim$ 7 meters high in the absence of local deformations. This would require the towers to be located 80 meters from any antenna. Alternatively, a 30-meter central receiving antenna and nearly ground level transmitting antennas would fulfill the same condition.

The specification of the tower-height and location must, of course, take the earth's profile into account. An initial look at profile maps of site Y-15 has indicated that 35-meter and 70-meter towers will be required on the last two stations of the SE branch; all other stations at this site will probably require towers of less than 10-meter height. Site Y-23 is more hilly and will probably require several 70-meter towers.

The use of 70-meter towers for transmitting antennas is probably not too serious a problem. The cost of the tower is probably under \$5 K and the 800-meter path to the tower can be accommodated with 7/8" cable at ~ \$5 K including burial cost (the requirement for burial is marginal for IF cable of this length).

The most serious blockage problem arises for a receiving tower at the center of the array. The tower must be offset from the center to eliminate blockage of the large cluster of antennas which arises at the center for compressed configurations. This offset means that spatial separation of transmission channels cannot be used in order to conserve frequency allocation requirements. (If transmitters on each arm of the Y are isolated by directive antennas, 1800 Mc/s of bandwidth is required; if spatial isolation cannot be used, 5400 Mc/s of bandwidth is required. This is probably too much unless a very high frequency (~ 30 Gc/s) is used; rainfall attenuation is then a problem).

Two possible solutions to this problem are: (1) Use a cable transmission system for the inner 1 km or 2 km of the array; (2) use a repeater station mounted on a tower ~ 2 km from the center on each arm of the Y.

The blockage of the link paths by array antennas is not a serious problem except at the center of the array, where, as stated above, another solution is required anyway.

C. RF Interference to the Array

The frequency of the microwave links must be chosen above the maximum frequency of operation of the array. The antennas are not designed to operate well above 10 Gc/s. It is most likely that the maximum frequency of operation of the array is 4 x 2695 Mc/s = 10,780 Mc/s. Allowing for receiver bandwidth and a guard band, 11,400 Mc/s is chosen as the lowest allowable link frequency.

The effect of fairly large (of the order of -40 dBm) signals at frequencies > 11.4 Gc/s on the array receivers must be determined. This can be done best experimentally but some theoretical predictions are given below to obtain some feeling for the problem. The rejection to insertion loss ratio of suitable rejection filters also needs to be determined.

The first restriction upon interfering signals is that, irreguardless of frequency, they do not change the gain or noise temperature of the input paramp. An estimate of the maximum out-of-band signal level which can be tolerated is -20 dBm. Since a 0 dBm link transmitter power will be sufficient and a 20 dB path loss can be obtained with a small amount of care, this type of overload will probably not be a problem.

A second effect will be the beating of the interfering signal with pump harmonics to produce a signal in the receiver passband. If degenerate paramps with pump frequencies which are multiples of 2695 Mc/s are used, the following "forbidden" link frequencies are produced; a 200 Mc/s receiver bandwidth is assumed:

13,475 ± 100 Mc/s
16,170 ± 100 Mc/s
18,865 ± 100 Mc/s

These frequencies are forbidden because the receiver will be very sensitive to them and it will be difficult to obtain sufficient filtering to reject them.

A third method that the interference can effect the receiver is through beating of two interfering signals to produce a difference frequency in the receiver passband. It is difficult to estimate this effect; for two signals of the order of -40 dBm the beat note produced in the input varactor or mixer crystal is probably of the order of -80 dBm. This would be a large signal if in-band and the situation must be avoided either through selection of frequencies or input filtering.

The tolerable level of an in-band interfering signal depends, of course, on whether it appears correlated and is in the delay passband or the two antennas. (This could occur if the array antennas are looking at low elevation down one of the arms of the Y.) If the interference is uncorrelated, it must be well below receiver noise (50 °K in 50 Mc/s bandwidth = -105 dBm); a maximum level of -120 dBm is appropriate. If the interference is correlated for 1 hour, the receiver sensitivity is increased by 56 dB so that a maximum level of -176 dBm is appropriate for correlated interference.

In conclusion, it appears that interference caused by the links on the array needs careful consideration; however, it does not appear to be an unsolvable problem.

D. Cross-Talk

It appears that it will be necessary to share frequency bands among the arms of the Wye in order to limit the bandwidth requirements. Directive antennas would then be used to obtain isolation between links. With a small amount of care it should be possible to obtain > 25 dB isolation between links at similar frequencies. This degree of isolation will be sufficient unless the cross-talk signal is coherent with the signal in another link and is at a proper time delay to produce a correlator output. There is a small probability that the time delay will be correct. However, the correlation can be eliminated completely by putting a small frequency offset ($\sim$ 1 Mc/s) between the links operating in a common band.

It is fairly certain, then, that cross-talk can be made to have a negligible effect upon the array.

E. Rainfall Attenuation

An excellent article concerning atmospheric propagation at frequencies > 10 Gc/s has recently appeared (Weibel and Dressel, Proc. IEEE, April 1967, pp. 497-512). This article gives rainfall attenuation figures of 20 dB and 60 dB for frequencies of 15 Gc/s and 30 Gc/s and a 12.5 mm/hr. rainfall over a 21 km path. The 12.5 mm/hr. rainfall rate appears to be the maximum rainfall rate for which we must require the link to be operational. Since the prospective sites have yearly rainfall of about 250 mm, 20 hours per year would be lost at most.

The attenuation figures indicate that a 15 Gc/s link is quite feasible; a 20 dB margin in S/N can be achieved with 2-meter antennas and 1 mW transmitters. The 30 Gc/s link, however, would require 25 watt transmitters and is not feasible.

E. Path-Length Variations

A requirement of ± 2 ns time delay stability is appropriate for the VLA IF transmission system over a 24-hour period. A ± 30 N-unit change in the atmospheric index of refraction will cause this much time delay variation. This large a change in refractive index is possible but is not very probable. Whatever changes that do occur could be corrected by fairly simple meteorological measurements and thus this effect is not a serious problem.

Multi-path signals can cause "ghost" signals to appear at different delay times. However, spurious paths within the main beams of receiving and transmitting antennas will only be longer by less than 0.6 ns. With reasonable care in layout of the array and by using low back-lobe and side-lobe link antennas, it should be possible to reduce the "ghost" signals which differ by more than ± 2 ns to at least 25 dB below the direct signal.

Variations in multi-path within the main beams (ground reflection) will cause fading of the signal, However, at 2 cm wavelength the ground reflection should not be very strong and fading will not be very deep. A ± 3 dB variation is expected and this will be corrected by an AGC loop operating on the carrier.

G. Frequency Allocation

The interference and rainfall attenuation requirements dictate a frequency of operation between 11.4 Gc/s and $\sim$20 Gc/s with avoidance of harmonics of 2695 Mc/s. The frequency allocations within this range which may be usable are roughly as follows:

10.7 - 11.7 Gc/s — Fixed common carrier.
11.7 - 12.2 Gc/s — Land mobile common carrier.
12.2 - 12.7 Gc/s — Fixed common carrier.
12.7 - 13.2 Gc/s — Mobile television links.
13.4 - 14.3 Gc/s — Radio location and navigation.
14.4 - 15.25 Gc/s - Fixed and mobile, government.
15.7 - 17.7 Gc/s — Radio location.
17.7 - 19.3 Gc/s — Fixed and mobile, non-government.

A band of 1.8 Gc/s is required assuming that each IF channel is put into a 75 Mc/s band and 24 channels are allowed per arm of the Wye.

The FCC has been contacted and has unofficially given the opinion that it will not be difficult to obtain the required allocation. The licensing and investigation of possible interference to the link obviously need additional work. The outlook is fairly optimistic because of the frequency range involved and remote location of the sites.