MICROWAVE LINKS

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It has been proposed that the two antennas within New Mexico should be linked by microwave systems to the VLA site to allow real time correlation with the VLA and tape recording at the VLA site. The antennas in question would be located in northern NM at Bernal or Los Alamos, and south of the VLA site in the vicinity of Winston (see VLBA Memo 205). A site in the Rio Grande valley has also been considered for the southern antenna. To accommodate the signal bandwidth of 200 MHz required for maximum sensitivity in real-time correlation with the VLA, the links would have to be in the 18 GHz or 25 GHz regions of the spectrum. For computations in this memo 18 GHz will be used. Some preliminary considerations of the link requirements have been given in VLBA Memo 213.

The Northern New Mexico Antenna

In a preliminary study J. Coe considered implementing this link with repeaters on Sandia Crest and South Baldy. The distances involved are:

Bernal to Sandia Crest	107 km (66 miles)
Sandia Crest to South Baldy	151 km (94 miles)
South Baldy to VLA Site	40 km (25 miles)

Consider first the longest part of the link between Sandia Crest and South Baldy. One has to consider the effects of rain attenuation, multipath fading, and variation in the angle of arrival of the wave. To obtain some information on these phenomena I have talked to D.C. Hogg (NOAA, Boulder) and A. Vigants and S.H. Lin (Bell Labs). The rain attenuation is about 1.5 dB/km for 1" per hour rain rate, increasing in proportion to rate. This suggests attenuation of 5-10 dB during summer thunder-shower weather. The multipath fading is difficult to estimate, but Vigants told me that the average length between Bell telephone repeaters is 26 miles and 30-40 dB fading margin is allowed. Most experience is at 6 or 11 GHz, and design is for outages of no more than 10^{-4} of the time. However, we might tolerate 10^{-3} to 10^{-2}. The variation of angle of arrival depends upon variation in the gradient of refractive index. Vigants estimated a range of +80 to -157 n-units per km for the area concerned. (1 n-unit is a change of 10^{-6} in refractive index). This leads to the following formula:

$$\Delta\alpha \text{ (degrees)} = \frac{\text{distance in miles}}{92}$$

where $\Delta\alpha$ is the range of the angle of arrival. For the 94 mile distance this gives $\Delta\alpha = \pm \frac{1}{2}°$. However there is no information on how often these extremes would be reached. To remain within the half-power beamwidth the diameter of the receiving antenna cannot be greater than about 1.1 m and the transmitting antenna should be the same diameter. The propagation loss between two 1.1 m dishes spaced by the Sandia-South Baldy distance is as follows:

$\frac{A}{4\pi r^2}$	-116 dB
Antenna gain	45 dB
Rain	- 10 dB
Fading margin	- 30 dB
	-111 dB

Here A is the antenna collecting area and r is the distance. Consider transmitting a signal of bandwidth 200 MHz with 20 dB required signal-to-noise ratio and a receiving system temperature of 300°. The required transmitter power is 10 W*. The power could be reduced by using antennas with horizontally elongated apertures since the variation in angle of arrival is mainly vertical: this however would probably be breaking new ground in link technology. Thus the IF link with active repeaters is probably feasible, but we cannot really predict its performance on the basis of the above rough calculations. Vigants said that he would not build a link like the Sandia to South Baldy one without testing it first, which would involve making measurements over at least a year to determine seasonal effects. I conclude that the information upon which we could confidently design this link probably does not exist.

The preliminary study also considered the use of passive reflectors on Sandia Crest and South Baldy for the local oscillator link, to avoid the complexity of two-way repeaters. However, passive reflectors have the effect of passing on the variations in angle of arrival, so overall these would become ±1°. Suppose therefore that we use 0.5 m dishes and two 3 m x 5 m passive reflectors, one on each mountain. The signal-to-noise ratio for, say, a 180 MHz reference signal to get 0.2° per GHz rms phase accuracy is 64 dB. If we assume a 1 Hz noise bandwidth, the required transmitter power would be in the megawatt range (see Appendix). Clearly this is impractical.

Thus for the local oscillator we must use either two-way active repeaters or a maser at the antenna. The second possibility is expensive but may be more reliable. We would send back the 180 MHz maser reference signal to the VLA where it would provide a measure of the mean offset between the antenna maser and the VLA maser, and could also be used to monitor phase fluctuations on the link.

Conclusion. The above considerations suggest to me that the northern NM antenna should be put into operation using the maser and tape system. The possibility of a radio link may be reexamined later in the light of experience with the shorter link from the southern antenna.

*For comparison the Huntersville-Greenbank link uses 2 W from a travelling wave tube at 17 GHz

The Southern Antenna

It is hoped that this link can be implemented using only one repeater. We shall consider for the repeater site Oak Peak, 10 miles almost due west from Mt Withington. Then we have:

Winston to Oak Peak	50 km	(31 miles)
Oak Peak to VLA Site	24 km	(14.8 miles)

With a passive reflector the total distance indicates fluctuations in the angle of arrival of about $\pm\frac{1}{4}°$. Thus 2 m diameter antennas could be used. Oak Peak is almost in a straight line from Winston to the VLA site, so two reflecting surfaces would be necessary. In calculating the transmission loss it will be assumed that they can be sufficiently closely spaced that they act like a single reflector. Then for the IF signal with the same parameters used for the Sandia-South Baldy calculation the required transmitter power would be 24 dBW (250 W): see Appendix. This is a rather high power level for the 18 GHz range. It could be reduced by about 10 dB by using a cooled FET receiver. Also the calculation includes 40 dB for rain plus multipath fading which would not be required at all times. With no power on Oak Peak it would be possible in principle to use a solar-powered active repeater. The U.S. Forest Service use solar power supplies for some repeaters in NM and these include batteries and provide a power level of 16 amps at 24 volts. However with no road, service of such a repeater would be very difficult, especially in winter.

An alternative location for the southern NM antenna has been considered in the vicinity of Elephant Butte Reservoir, east of the San Mateo mountains from Winston. If we consider a site about 20 km north of Truth or Consequences and a repeater on South Baldy the distances are:

T or C site to South Baldy	75 km	(47 miles)
South Baldy to VLA site	40 km	(25 miles)

Probably we would only choose this site if the passive repeater link from Winston is judged to be too marginal. Then we would have to use an active repeater on South Baldy since the distances are longer than those of the Winston link. Power and a road are available to Langmuir Lab on the mountain but the road is not kept open in winter. The Forest Service have a link between South Baldy and Caballo Peak, about 20 km south of T or C, but this operates at 1.711 and 1.849 GHz so it is not very useful in estimating performance at 18 GHz. The distance from a site 20 km north of T or C to South Baldy is about 1/2 of that from Sandia Crest to South Baldy, so the comments made earlier about the latter path apply at a somewhat reduced level. The required transmitter power level for the IF link would be 250 mW (see appendix).

Conclusion. A passive-repeater link from the Winston area or an active-repeater link from the T or C area are both possibilities, although the former may be somewhat marginal. We do not yet have enough information on propagation effects to be able to estimate the reliability of either one. In particular we need a better estimate of the fading margin, for which 30 dB (plus 10 dB for rain) has been used in all of the above computations. J. Coe tells me he has not seen evidence of deep fading on the Greenbank 17 GHz links. However a study for a radio link at Westerbork (NFRA Report 133) includes 28 dB for rain plus fading margin for a maximum path length of 20 km at 11 GHz.

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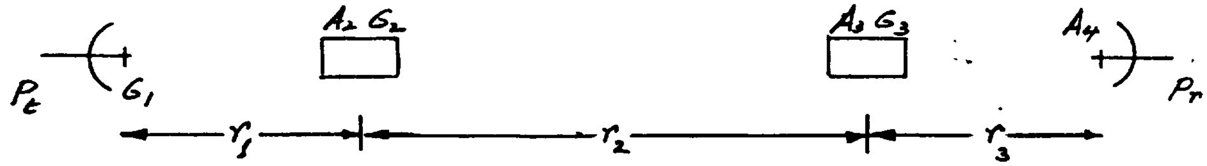
Appendix. Path Loss and Power Level Calculations.

Northern Antenna: Link with Passive Reflectors



$A_4 = 0.14 m^2$ $\quad G_1 = 6.3 \times 10^3$ (0.5m diam. dishes) $\quad (\lambda = 0.0167 m$, 18GHz)

$A_2 = A_3 = 9 m^2$ $\quad G_2 = G_3 = 4 \times 10^5$ (approx 3m×5m passive reflectors : assume subtended area = 3m×3m)

$r_1 = 1.07 \times 10^5 m$ $\quad r_2 = 1.51 \times 10^5 m$ $\quad r_3 = 4 \times 10^4 m$

$$\frac{P_r}{P_t} = \frac{G_1 A_2}{4\pi r_1^2} \cdot \frac{G_2 A_3}{4\pi r_2^2} \cdot \frac{G_3 A_4}{4\pi r_3^2} = -169 dB$$

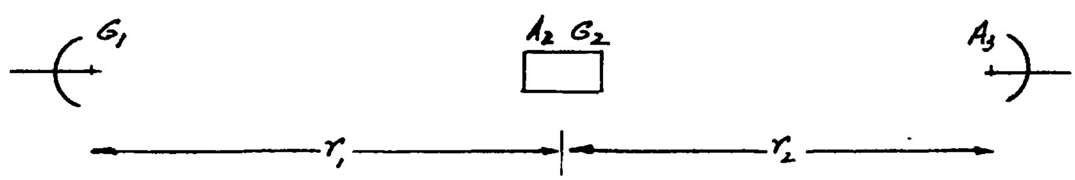
P_r/P_t	−169 dB
rain	−10 "
fading margin	−30 "
	−209 "

$k = 1.38 \times 10^{-23} J K^{-1}$
$T = 300 K$
$B = 1 Hz$ (LO loop bandwidth)

Required receive power (For LO signals) = 64dB above kTB
= −204dBW + 64dB
= −140dBW.

Required transmitter power = −140dBW + 209dB = 69dBW = 7.9 MW (!)

Southern Antenna: Winston to VLA Site with Passive Reflector on Oak Peak



$A_3 = 2 m^2$ $\quad G_1 = 10^5$ (2m diam. dishes)

$A_2 = 9 m^2$ $\quad G_2 = 4 \times 10^5$ $\quad r_1 = 5 \times 10^4 m$ $\quad r_2 = 2.4 \times 10^4 m$

$$\frac{P_r}{P_t} = \frac{G_1 A_2}{4\pi r_1^2} \cdot \frac{G_2 A_3}{4\pi r_2^2} = -85 dB$$

P_r/P_t	−85 dB
rain	−10
fading	−30
	−125 dB

Required receive power (For IF signals) = 20dB above kTB $\quad B = 200 MHz$ (IF signals)
receive power = −121 dBW + 20dB = −101dBW

Required transmitter power = −101dBW + 125dB = 24dBW = 250 W.

Site 20 km North of T or C to S. Baldy

$$\frac{P_r}{P_t} = \frac{G_1 A_2}{4\pi r^2} = -55.5\,dB$$

$A_2 = 2m^2 \quad G_1 = 10^5$ (2m diam dishes)
$r = 7.5 \times 10^4$ m

P_r/P_t	-55 dB
rain	-10
fading	-30
	-95 dB

Required receive power (IF signals) = 20 dB above kTB $\quad B = 2\times10^8$ Hz
$= -121$ dBW $+ 20$ dB $\quad T = 300$K
$= -101$ dBW.

Required transmitter power $= -101 + 95$ dBW $= -6$ dBW $=$ 250mW