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M CHUSETTS INSTITUTE OF TECHNOLOGY

HAYSTACK OBSERVATORY

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AR102.90

18 October 1990

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Holographers

From: Alan E.E. Rogers AEER

Subject: Elimination of multiple reflections

Background

The problem was studied in 1978 and I have reviewed the old memos (see attachments) and I now think I understand the problem and its solution better.

There are multiple reflections between the subreflector and the feed, the front of the box and the annulus of the main dish shadowed by the subreflector. These reflections produce ripples in the spectral line baselines. While tests were done with "spoilers" to eliminate reflections the spectral line problem was solved by taking data at two subreflector positions a quarter wavelength apart.

Reflection from the feed

For spectral line the reflection from the feed is likely to be the most serious as it is the strongest (except in the case of a well matched feed). For holography this extra reflection is not important as it originates from the same focus as the primary signal and will produce an apparent offset in the entire surface. Actually even the constant offset will be calibrated out by the phase referencing on the beam center.

Reflections from the front of the box and annulus

The extra reflections are out of focus by the amounts illustrated in the attached Figure 1. The equivalent prime focus change is 0.2' (increased focal length) for the reflection from the front of the box and the reflections from the annulus are out of focus by 0.37'. These focus changes produce a path length decrease at the edge of the main reflector of 0.1' and 0.2' respectively. These distances are approximately proportional to radius squared and will produce Newton's rings with about one and three fringes respectively. If the feed is on axis and the antenna perfectly symmetrical the rings will be centered, however, the relative phase of the two ring systems depends on the exact distance between the front of the box and the vertex of the main dish. Also the centers of the ring systems will move with subreflector tilt. The amplitudes for the rings are approximately given by the fractional areas of the regions of multiple reflection. For example, the fractional area of the shadowed annulus (9.33' outer diameter, 8' inner diameter) is 0.6% in power or 8% in voltage - or 5 degrees of phase which will produce an apparent surface ripple of 14 mils peak-to-peak at a holography wavelength of 1000 mils. The ripple from the front of the box is smaller (10 mils p-p) but will beat the other ring structure. Figure 2 shows an example of a simulated ring system.

Spoiling the multiple reflections

Spoiling the center of the subreflector would work at short wavelengths, but is difficult at 12 GHz. While the geometrical size of a spoiler cone needed to prevent illumination of the box and shadowed annulus is only about 1' in base diameter, it would have to be increased in size by about another foot to overcome diffraction. A one-foot diameter cone has already been tried and doesn't work. Spoiling the front of the box and shadowed annulus is better because of the larger size of the spoiler. A rough reflector (on the scale of 1 inch) or an annular cone with an outer base diameter of 10.5'should do a good job. In practice it would be easier to make it in two pieces, a reflective annulus attached to the dish and an absorber on the front of the box. If the reflecting annulus has a tilt of 15 degrees (cone apex half angle of 75 degrees) the unwanted reflection will have an annular "beamwidth" of about 5 degrees (at 12 GHz) which misses the subreflector by about 20 degrees. At elevations below 30 degrees some of this reflection will start to pick up the ground -- at worst, this will add 2 degrees to the system temperature. An absorber would add about 4 degrees to the system at all elevations. The front of the box not covered by feeds is 30 square feet in area and using absorber here should add less than 1 degree.

xc: B.E. Corey
C.J. Lonsdale
A.R. Whitney
Astronomy Group

NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY

6 February 1978

TO: M.L. Meeks and J.C. Carter

FROM: Alan E.E. Rogers AEER

SUBJECT: Tests of the Spectral Line Baseline Ripple Problem Using the R2 Box at 10 GHz

I conducted a large number of different tests from which I can draw few conclusions but I found no simple fixes.

Definite Conclusions

A) Observing Cas A

1) The ripple depends on the polarization used for linear it runs ≈1.8% peak-to-peak at 10030.5 MHz. For circular it is considerably worse ≈4% peak-to-peak.

2) There are two or more periodicities involved. That is, the ripple is not a simple sine wave but consists of a component with a period of 11.3 MHz and another around 12.5 MHz. There is also a ripple component with a period of 80 MHz which is very strong when using circular polarization. The 80 MHz ripple component is probably the result of multiple reflections between the receiver and the front of the feed since this component doesn't change phase with subreflector motion.

3) Ripple obtained using RCP appears to be the same as that obtained using LCP.

4) The ripple varies across the beam. For linear polarization the ripple expressed as a fraction of the antenna temperature goes as high as 3% for an azimuth/cos El offset of 0.035°.

B) Observing Only Cold Sky

1) Ripple is quite evident in an observation where the signal run is made with the noise source on and the comparison with the noise source off. Using linear polarization the ripple is approximately 1.6% of Tcal.

2) Ripple also results if the subreflector is moved by $\lambda/4$ between signal and comparison runs. The ripple character is complex in this case but components around 12 MHz are dominant.

Tentative Conclusions

1) Putting a large conical annulus (10' outer diameter, 8' inner diameter) on the front of the box eliminated the 11.3 MHz component, but the higer frequency period components remain. The overall effect on the ripple was small. The ripple decreased from 1.8% to about 1.4% when using linear polarization.

2) Putting a small spoiler cone (1' diameter) on the subfeed point of the subreflector had little or no effect on the ripple.

3) Placing crinkled foil on flat surfaces around the feed to roughen any flat surfaces appears to further reduce ripple. Conversely putting a 10" square of flat foil on one side of the feed facing the subreflector increased the ripple.

Futher Tests Which Might Be Worthwhile

1) A test of the influence of the 300°K termination on the ortho-port of the feed to see if it contributes to the increased ripple observed with circular polarization. This load radiates 300°K to the subreflector which returns about 0.3°K (see Ruze's calculation of the subreflector reflection strength) to the receiver. In addition, a signal of about 3°K may be returned from the polarizer itself. The two reflections will beat to cause ripple which will become apparent if the total power level changes between signal and comparison runs.

2) I plan to order some broadband absorbing "carpet like" material which could be glued to flat surfaces around the feed. It might be interesting to see if this will reduce the ripple. A reduction of the large ripple observed using circular polarization might be brought about by covering the large ring which supports the polarizing slats with absorbing material.

AEER:bev
xc: R.P. Ingalls
P.B. Sebring

CALCULATIONS ON BASE-LINE Thermal Ripple

6/20/75

It is of interest to calculate the ripple in the received antenna temperature due to reflections from or interaction with the Cassegrain Sub-reflector and also any enclosing radome. Such ripples are basically caused by variations in antenna gain and may mask the detection of weak sources.

I) Feed - Sub-Reflector Interaction

The reflection into the horn feed from a sub-reflector is given by (Reference Rusch)

$$\Gamma = \frac{G_f}{4\pi M}\left(\frac{\lambda}{2c}\right) \qquad (1)$$

where

G_f = feed power gain
M = system magnification
$2c$ = distance between antenna foci

To evaluate the magnitude of this effect we shall work out an example with HAYSTACK parameters at 25.7 Gc ($\lambda = 0.5'' \approx 1.2$ cm).

W.V.T. Rusch & P.D. Potter "Analysis of Reflector Antennas." page 106 for HAYSTACK $2c = 42$ feet ; $M = 10.76$

The Gain of the feed horn can be estimated from

$$G_f = \frac{8a}{\theta_0^2}$$

where $a = 1.15$ for 10 db aperture taper
$\theta_0 = 6.7° = 0.117$ radians
(sub-reflector half angle).

hence

$$G_f = \frac{8 \times 1.15}{(0.117)^2} = 672 \; (28.3 \text{db})$$

Returning to (1)

$$\Gamma_s = \frac{672}{4\pi \, 10.76} \left(\frac{0.5}{42 \times 12} \right) = 0.005 \quad *$$

-46 dB

This means that only 2.5×10^{-5} power is returned to the horn from reflection by the sub-reflector.

We are really interested in the fluctuation of received energy caused by the beating of the sub-reflector reflection coefficient with the reflection coefficient of the horn itself.
We can write for the change of gain or collecting area

$$\frac{G}{G_0} = \frac{A}{A_0} = \left[1 - |\Gamma|^2 \right]$$

where $\Gamma = \Gamma_h + \Gamma_s e^{j\delta}$

Γ_h = horn reflection coefficient

Γ_s = sub-reflector reflection

δ = arbitrary phase due to path length difference

$$|\Gamma|^2 = |\Gamma_h|^2 + |\Gamma_s|^2 + 2|\Gamma_H||\Gamma_S| \cos\delta.$$

The variation or ripple will then be $\pm 2|\Gamma_H||\Gamma_S|$
We note that this will vanish if the horn is <u>perfectly matched</u>.

For a horn in which no great care is taken $\Gamma_H \approx 0.2$ corresponding to a VSWR ≈ 1.4
Using this figure

$$2|\Gamma_H||\Gamma_S| = 2 \times 0.2 \times 0.005 = 0.002$$

If the antenna temperature is 10°K we would have a ripple of ±0.02°K.
The periodicity of this ripple $f/\Delta f = \lambda/\Delta\lambda$ is

$$\frac{f}{\Delta f} = \frac{2L}{\lambda} = \frac{2(42' \times 12'' - 43'')}{0.5} = 1844$$

at 23,700 Mc

$$\Delta f = \frac{23{,}700}{1844}\text{ Mc.} = \underline{12.8\text{ Mc}}$$

2) Feed-RADOME Interaction

The parabolic reflector generates plane waves which are partially reflected from the transparent radome. The paraxial rays will focus at half the radius (37.5') of the radome and then will spread out again toward the feed. The HAYSTACK feed aperture is 20 feet from the radome center. We attempt to find the power density at the feed aperture, namely

$$S = \frac{2 P_T}{\frac{\pi}{4} D^2} \left(\frac{37.5}{17.5}\right)^2 \qquad (2)$$

where $\frac{\pi}{4} D^2$ is the normal parabola area ($D = 120'$) the factor $\left(\frac{37.5}{17.5}\right)^2$ is the increase in concentration due to the focussing action. The "2" is a factor added due to the illumination taper.

We must reduce (2) by the energy transmitted thru the radome. Assuming a 1 db membrane loss and a 1 db space frame loss – now all of the membrane loss is reflected energy but only one half of the space frame as it scatters in both backward and forward direction. Hence only (1.5 30% of the incident energy is reflected and we have

$$S = 0.3 \frac{2 P_T}{\pi/4 D^2} \left(\frac{37.5}{17.5}\right)^2$$

the horn received power is: $P_r = S A_H = S \dfrac{\lambda^2}{4\pi} G_f$

or

$$\frac{P_r}{P_T} = |\Gamma|^2 = \frac{0.6}{\frac{\pi}{4} D^2} \left(\frac{37.5}{17.5}\right)^2 \frac{\lambda^2}{4\pi} G_f$$

$$|\Gamma|^2 = 0.6 \left(\frac{37.5}{17.5}\right)^2 \left(\frac{\lambda}{\pi D}\right)^2 G_f$$

$$|\Gamma| = \sqrt{0.6} \left(\frac{37.5}{17.5}\right) \left(\frac{0.5}{\pi \times 120 \times 12}\right) \sqrt{672}$$

$$|\Gamma| = 0.00475$$

Therefore the radome reflection, in this case, is almost identical to that from the sub-reflector. For a better radome it would be less. The frequency of the ripple however will be larger as the path is much longer.

The radome calculations are, however, much more approximate as we have neglected the shielding of the feed by the sub-reflector. Rays will still be reflected from the shell over the sub-reflector. As we have neglected the sub-reflector shielding the radome calculations are pessimistic

John Ruze
MIT Lincoln Lab
June 20, 1973

5 Nov 77

Memo:
To: MLM
From: AEER
Subject: Multiple reflections on Haystack – Summary

The most obvious multiple reflection is that which arises from a reflection between the subreflector and the feed. The magnitude of this effect has been examined by Rage and Rusch. Very roughly this effect results in a baseline ripple of

$$4\left(\frac{\lambda M}{D}\right)\Gamma \approx 0.8\% \text{ peak to peak (worst case at } \lambda = 3\text{ cm)}$$

where
λ = wavelength
M = magnification ≈ 10
D = diameter of Haystack
Γ = Feed reflection coefficient (taking $\Gamma \approx .2$ as an example)

This is not likely to be our problem for 2 reasons

1) It should result in baseline ripple on cold sky – as the VSWR ripples.
2) For a well matched feed it vanishes and even for a poor feed it is smaller than observed.

Another fairly obvious multiple reflection for Haystack is that which arises between the inner annular portion of the main reflector (see accompanying notes) and the subreflector and out again to the outer annular portion of the main reflector. I have guestimated this multiple reflection to produce a ripple of very approximately

$$4\left(\frac{\lambda M^2}{D}\right)\left(\begin{array}{c}\text{fractional area of}\\ \text{annulus shadowed by subreflector}\end{array}\right)^{\frac{1}{2}}$$

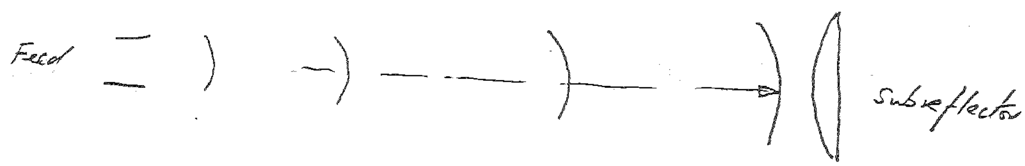
$$\approx 1.6\% \text{ at } 3\text{ cm.}$$

JCC
PBS
RPI

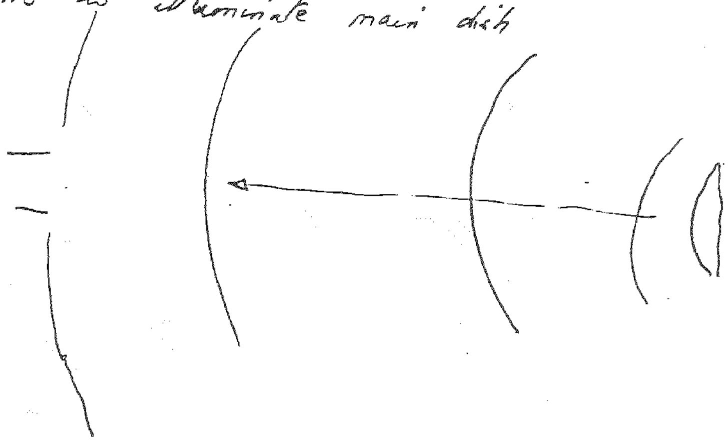
To: MLM
From: AEER
Subject: Multiple reflection problem on Haystack

After lunch I thought through reflection problem a little more. Imagine that we transmit a pulse from feed and follow it through the antenna system — using simple geometrical optics.

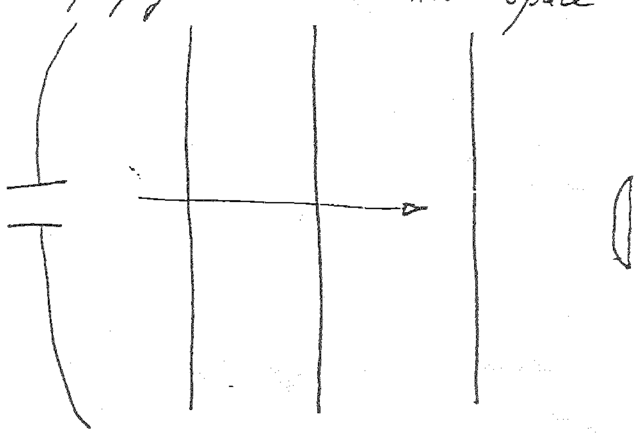
1) Pulse radiates out to subreflector



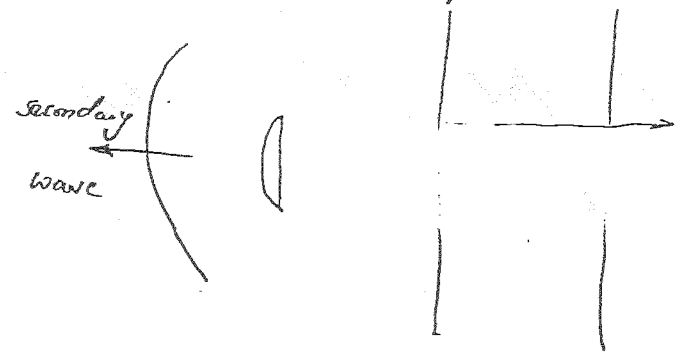
2) Pulse returns to illuminate main dish



3) Plane wave propagates out into space



4) But some energy is intersected by the subreflector



5) This secondary wave is returned to main reflector and reradiated – a little out of focus

Secondary pulse is delayed by $2(48' - 3.6') = 88.8'$ = 11.1 MHz

Strength of secondary wave is approximately

$$r_s^2 / r_m^2 = (0.6\% \text{ in power})\ (\text{or } 8\% \text{ in voltage})$$

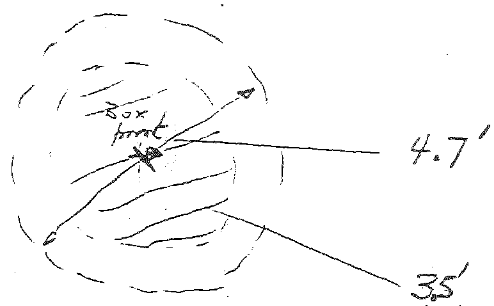
but it is defocussed so that it appears to be generated by feed at ∞ instead of at secondary focus. Because of the defocussing the secondary wave is further reduced – when viewed at ∞ so that the net predicted ripple effect is approximately

$$\frac{2\theta_B\, r_s M}{\left(\frac{13.4^\circ}{2}\right) r_m} \approx \frac{M \lambda r_s}{\left(\frac{13.4^\circ}{2}\right) r_m^2} \approx 2\% \text{ at X-band}$$

$$\approx 1\% \text{ at K-band}$$

r_s = subreflector radius
r_m = main antenna radius (effective)
λ = wavelength
13.4° = angle subtended by subreflector
M = magnification

If theory is OK – cure is to cover inner portion of dish and front of box out to a radius – at least equal to that of the subreflector (4.7') with absorbing material. – Neglecting diffraction effects



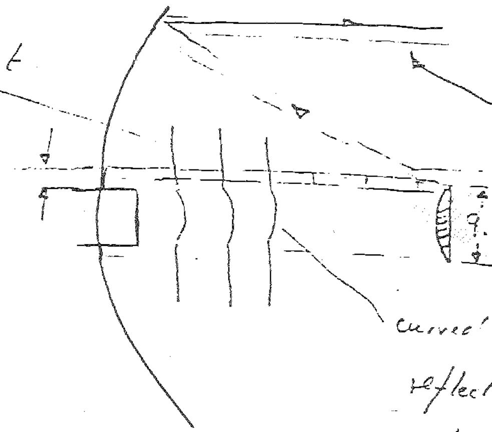
The only problem is that I would have expected that covering front of box would have at least some effect –

This analysis – may be all wrong

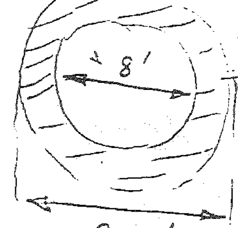
AEER

5 Nov 77

Litt – doing some further analysis – I think I understand why the reflection from the box front is not important – its because it is a plane surface –



Beam width of reflection from annulus $\simeq \frac{1}{M^2}$ radians $\simeq 0.6°$



Area of annulus 1.68 square meters
effective area of antenna ~ 730 m² i.e. approx .2%

ripple $(1+\alpha)^2 = 2\alpha$ α = voltage

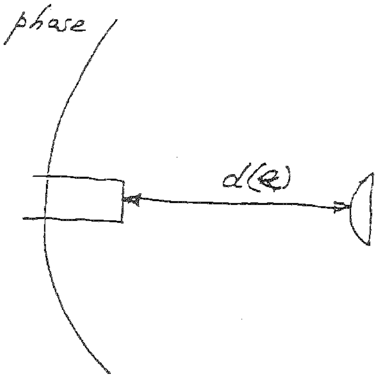
$$\text{p-p ripple} = 4\alpha = \left(\frac{4\lambda M^2}{D}\right)\left(\frac{\text{fractional}}{\text{area}}\right)^{1/2}$$

$$= \frac{4 \times 3 \times 10^2 \times 0.044}{2 \times 50 \times 12 \times 2.54} = 1.6\% \text{ at } \underline{3\text{ cm}}.$$

suggest conical deflection shield – perhaps made of foil covered eurethane sheet –

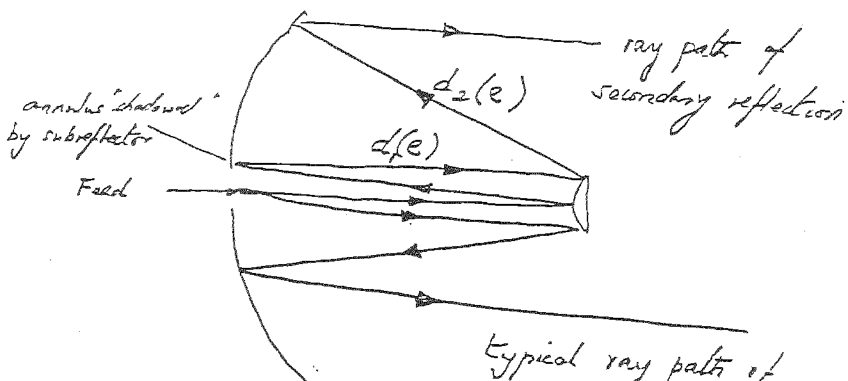
Elevation dependence of multiple reflection phase

1) For Feed reflection



$$\phi(e) = \frac{4\pi}{\lambda} d(e)$$

2) For annular reflection



$$\phi(e) \approx \frac{4\pi}{\lambda} d_2(e)$$

path length $d_1(e)$ is common to both main and secondary reflections and thus should have little or no effect.

I attach curve for $d_2(e)$ –

NORTHEAST RADIO OBSERVATORY CORPORATION
HAYSTACK OBSERVATORY

18 January 1978

TO: Haystack Scheduling Committee

FROM: A.E.E. Rogers AEER

SUBJECT: Study of "Baseline Ripple Effect" on Haystack

Understanding the baseline ripple studied by M.L. Meeks is important for both spectral observations and precise astrometric VLBI. Furthermore, the problem which results from multiple reflections is of general interest since there have been few studies outside those performed at Bonn and Kitt Peak. A complete understanding of the problem for antennas with and without radomes may be very valuable in reducing the multiple reflections on existing antennas and for the design of new antennas.

I propose to test theoretical model I proposed (informally to Litt, Joe and Dick) as a result of a luncheon meeting. Specially, I would like three 6-hour observing sessions at 8 or 10.7 GHz. During the first session I propose to measure the baseline ripple on

1) A strong continuum source like Cygnus
2) An extended source like the Moon

in order to see if the percentage baseline ripple is dependent on source size. My model for one of the multiple reflections which I believe important predicts an increased ripple on the edges of the beam+ and an increase of a factor of 2 on an extended source.

If the results of the first test tend to confirm the theory, I propose to place a "spoiler" around the opening in the main dish to inhibit reflection from the region shadowed by the subreflector. For this purpose I am constructing a very light foil covered eurethane conic annulus (10 feet in outer diameter and 8 feet inner diameter) which can be taped to the antenna surface between box changes.

For the second session, I propose to remeasure the ripple and look for components with other periods which may become more clearly visible if the spoiler is successful in reducing the multiple reflections between the subreflector and the main antenna surface. I expect that multiple reflections between the feed and the subreflector may now be important and I would propose to reduce these by placing a small cone (approx. 6 inches diameter at the base) at the subfeed point on the subreflector using tape and the crane for installation.

+Because the beam formed by this multiple reflection is broadened by defocussing (Joe has just brought to my attention a study at Meudon which mentions that Robinson (in Australia?) has observed a variation of "Chromaticity" over the beam).

If I am successful in greatly reducing the ripple due to multiple reflections from subreflector to main surface and subreflector to feed I would like to study the dependence of any ripple that might remain on source temperature to test for any non-zero intersept or ripple that remains on cold sky. Further, I would like to look for ripple resulting from reflections from the subreflector supports which may be visible when the sun is above the horizon. Thus, I would like the final session to be scheduled around sunrise or sunset.

I invite Joe, Litt, Dick, Bruce and Paul to join as coinvestigators if they wish as all have contributed to the ideas I propose to test.

AEER:bev

xc: J.C. Carter
R.P. Ingalls
B.G. Leslie
M.L. Meeks
P.B. Sebring

RCVD
5 July 77
M. L. Meeks

A Memo on the Baseline Ripple at Haystack and its Correction by Means of Subreflector Defocusing

The main problem that broad-band radiospectroscopy faces when observing sources with moderate or large continuum temperature ($T_c \gtrsim 1$ K) is the baseline ripple that appears because of reflections between the feed and other parts of the antenna structure.

Using data provided by Dr. M.L. Meeks as well as extensive observations taken by ourselves, we reached the following conclusions regarding the baseline ripple in the Haystack system.

1) The ripple can be roughly represented by a sinusoidal curve with period of ∿ 12.3 MHz. This implies that the distance involved in the reflection is 12.2 meters (40 ft.) which is consistent with our estimate of the distance between the feed and the sub-reflector.

2) The amplitude of the sinusoidal, T_{ripple}, increases linearly with T_c. Under total power operation we measured:

$$\frac{T_{ripple}}{T_c} \simeq 1.2 \times 10^{-2} \text{ (at 7.8 GHz)}$$ p-p ?

and

$$\frac{T_{ripple}}{T_c} \simeq 1.8 \times 10^{-2} \text{ (at 8.3 GHz)} .$$

The larger value of T_{ripple}/T_c at 8.3 GHz probably

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The larger value of T_{ripple}/T_c probably results from a degraded coupling between the feed horn and the incoming radiation, consequently producing more spillover and stronger reflections.

3) With the collaboration of Red Sellers, we started during our June run to use subreflector defocusing in an attempt to eliminate the ripple. Our preliminary tests were very encouraging and indicate that this technique significantly improves the baseline (See Figs. 1, 2, and 3).

Further testing is required to determine the optimal defocusing position. This technique should enable Haystack to take full advantage of its wide-band capabilities.

4) Within a few percent accuracy, there is no measurable change in the antenna gain because of the defocusing.

Luis

Luis F. Rodriguez

Eric

June 28, 1977 Eric J. Chaisson

FIGURE CAPTIONS

Figure 1. a) Cas A with normal focus position and Double Dicke technique. b) Cas A with the subreflector defocused by $\lambda/4$ units inwards. c) Mean of the two previous runs.

Figure 2. The same as in Fig. 1 but for W51A.

Figure 3. The same as in Fig. 1 but for W51A with total-power operation.

Fig. 1

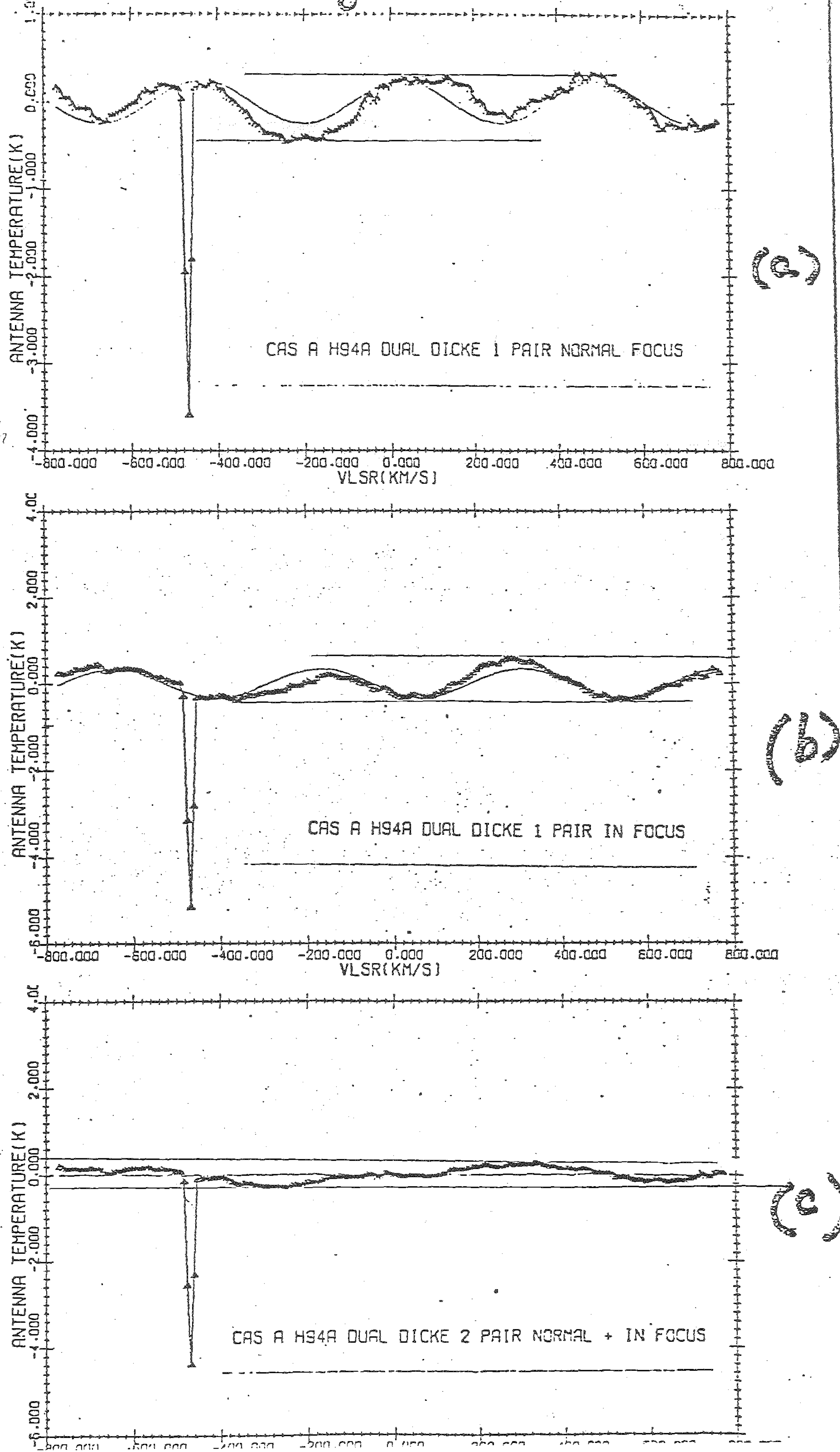
12.5 / 16 = .78 K

↑ average peak to peak 0.92 K ↓

8.5 / 8.0 = 1.06 K

5 / 8.

Peak to peak .63 K

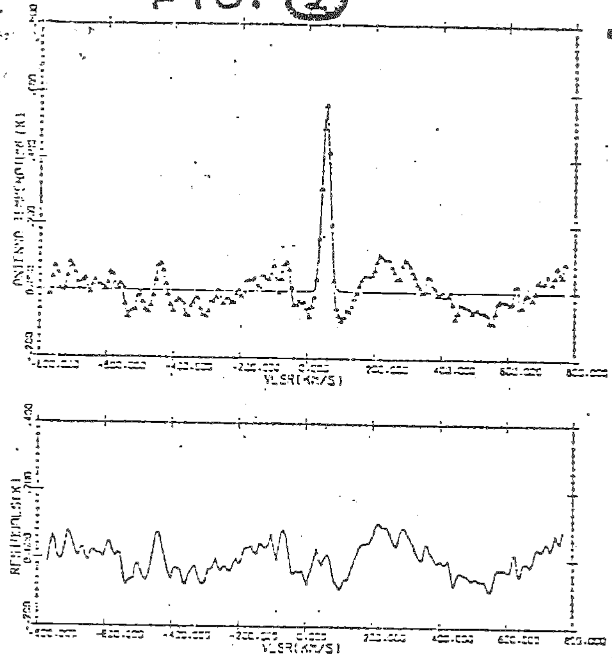


1600

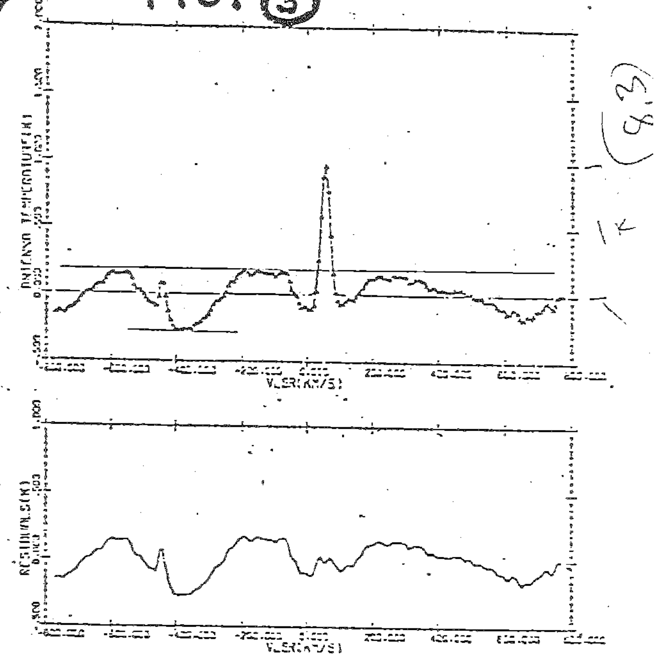
FIG. 2

FIG. 3

a

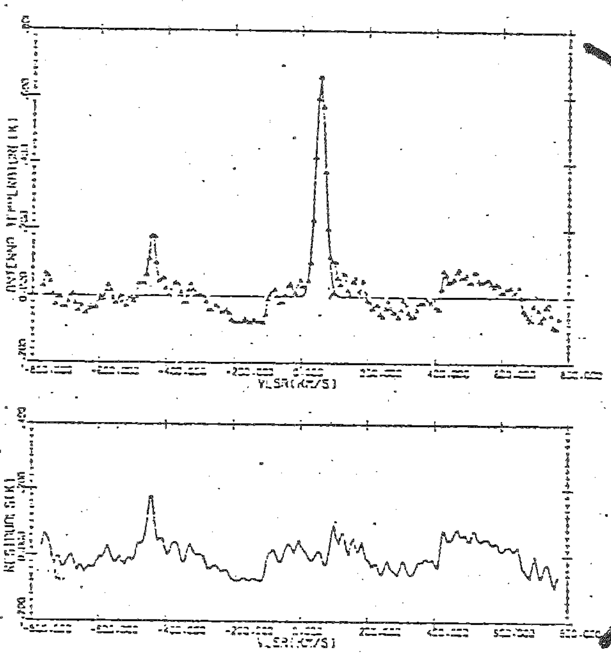


W51A H64A DUAL DICKE 1 PAIR NORMAL FOCUS

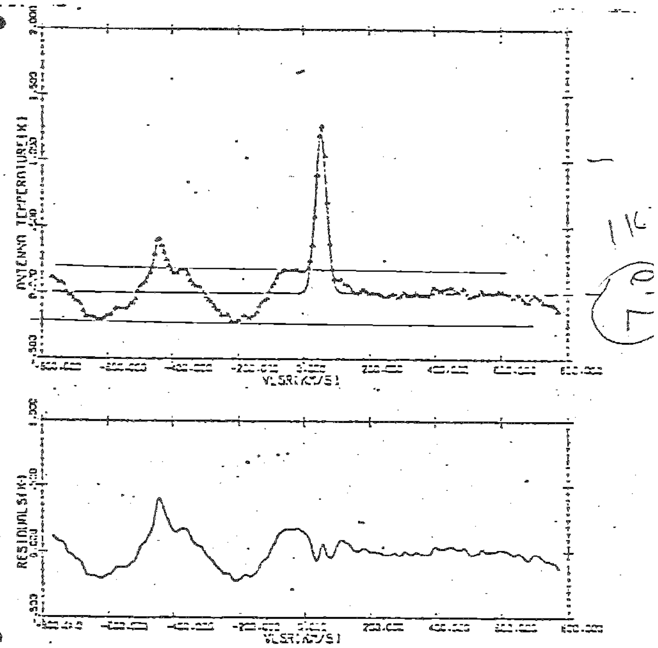


W51A H64A TOTAL POWER 1 RUN NORMAL FOCUS

b

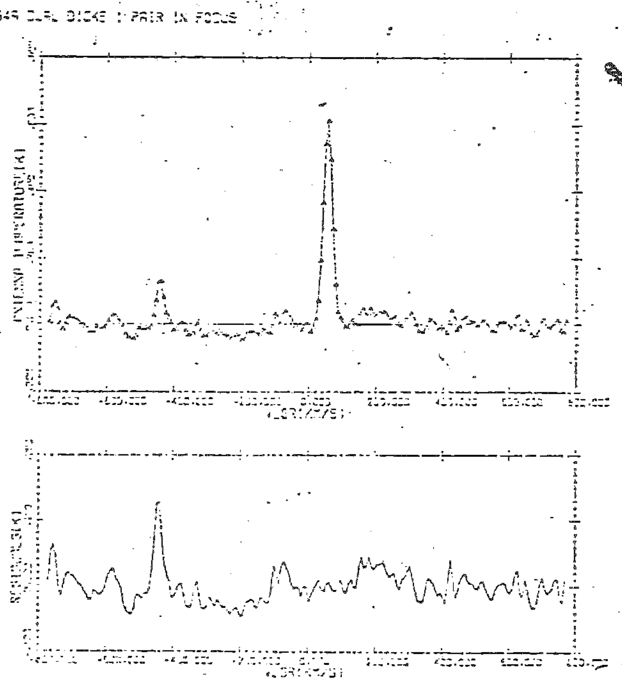


W51A H64A DUAL DICKE 1 PAIR IN FOCUS

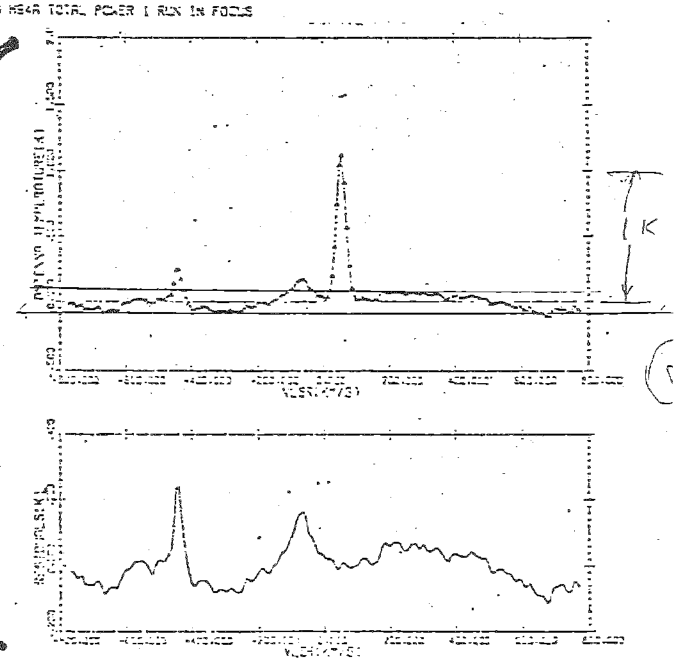


W51A H64A TOTAL POWER 1 RUN IN FOCUS

c



W51A H64A DUAL DICKE 1 PAIR IN + 1 PAIR NORMAL FOCUS



W51A H64A TOTAL POWER 1 RUN NORMAL + 1 RUN IN FOCUS