COMPUTATION BOOK

NAME

Jack Welch

Course ATA #5

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143) Chalmers Y-factor vs. f measurements

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PD 126-131

9/5/2011

New mail address for Astronomy
B-20 Hearst Field Annex, Mail Code 3411
Astronomy Dept.

Doug Thornton phone (510) 655-4451

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[illegible] thickness accuracy requirement.

Noise tests with better Agilent Spectrum Analyzers 4/8/10

⇒ Tests with the old E4408B SA compared with N9020A

The absolute accuracy spec of the N9020A is ±0.23dB as compared with ±1.1dB for the E4408B. The excellent reproducibility of the N9020A is seen in the blue and black traces at about the same bias settings above. The low values of Y at low frequencies on the E4408B are probably just the inaccuracy of the E4408B. This same pattern, low Y at low frequencies and higher values near 7-8GHz, has been observed on other feeds.

It's really not the reproducibility. It's the gain errors in the SA that turn up on the screen.

4/28/10

The shortest 2 sets of standoffs on the feed are located in the active zones of the feed at 3.8 GHz and 5.5 GHz. The next two figures show Y factor measurements made with and without the standoffs for feed 5B-008. The difference is striking. The residual dips after the standoffs have been removed could be due to the remaining holes in the fins and the pyramid. Also there is copper tape near the active region at 5.5 GHz.

The accuracy of the E4440A is 0.19 dB

[STI "Saphire" 5 watt cooler] will be used (maybe) for the new feed.

SB-008-B(3), Y-pole, ABB-050, Test 15 Noise Ratio With Stand-Offs, 2010-03-31

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz	
048 Ratio	-0.97	0.71	1.59	60.9	3.77	3.20	2.04	(-33.09 dB @ 6 GHz) Attenu 5/5
049 Ratio	-0.97	0.61	1.60	55.2	3.84	3.34	2.12	(-33.40) PAM 5/5
050 Ratio	-0.97	0.79	1.59	65.7	3.74	3.16	2.07	(-32.97)
051 Ratio	-0.97	0.65	1.59	57.5	3.79	3.27	2.10	(-33.23)
052 Ratio	-0.97	0.61	1.60	55.2	3.91	3.34	2.13	(-33.46) removed 1st & 2nd stand-offs

SB-008-B(3), Y-pole, ABB-050, Test 15 Noise Ratio
Stand-Off Removed, 2010-04-01

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12	
Y1+ Ratio	-0.97	0.61	1.61	55.6	3.81	3.27	2.03	(-32.15 dB @ 6 GHz) PAM 05/05
Y4+ Ratio	-0.97	0.61	1.61	55.6	3.90	3.35	2.15	(-31.85)
0Y1 Ratio	-0.97	0.61	1.61	55.6	3.87	3.31	2.12	(-31.83) PAM 5/5
0Y2 Ratio	-0.97	0.69	1.60	60.0	3.80	3.21	2.07	(-31.38)

What plating on arms and pyramid to use? 4/09/10
polished (.03) or highly polished (.02) Copper looks as good as gold (.02 or .03)

Table of Total Emissivity

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These tables are presented for use as a guide when making infrared temperature measurements with the OMEGASCOPE® or other infrared pyrometers. The total emissivity (ε) for Metals, Non-metals and Common Building Materials are given.

Since the emissivity of a material will vary as a function of temperature and surface finish, the values in these tables should be used only as a guide for relative or delta measurements.
The exact emissivity of a material should be determined when absolute measurements are required.

METALS

Material	Temp °F (°C)	ε Emissivity
Alloys		
20-Ni, 24-CR, 55-FE, Oxid.	392 (200)	.90
20-Ni, 24-CR, 55-FE, Oxid.	932 (500)	.97
60-Ni , 12-CR, 28-FE, Oxid.	518 (270)	.89
60-Ni , 12-CR, 28-FE, Oxid.	1040 (560)	.82
80-Ni, 20-CR, Oxidized	212 (100)	.87
80-Ni, 20-CR, Oxidized	1112 (600)	.87
80-Ni, 20-CR, Oxidized	2372 (1300)	.89
Aluminum		
Unoxidized	77 (25)	.02
Unoxidized	212 (100)	.03
Unoxidized	932 (500)	.06
Oxidized	390 (199)	.11
Oxidized	1110 (599)	.19
Oxidized at 599°C (1110°F)	390 (199)	.11
Oxidized at 599°C (1110°F)	1110 (599)	.19
Heavily Oxidized	200 (93)	.20
Heavily Oxidized	940 (504)	.31
Highly Polished	212 (100)	.09
Roughly Polished	212 (100)	.18
Commercial Sheet	212 (100)	.09
Highly Polished Plate	440 (227)	.04
Highly Polished Plate	1070 (577)	.06
Bright Rolled Plate	338 (170)	.04
Bright Rolled Plate	932 (500)	.05
Alloy A3003, Oxidized	600 (316)	.40
Alloy A3003, Oxidized	900 (482)	.40
Alloy 1100-0	200-800 (93-427)	.05
Alloy 24ST	75 (24)	.09
Alloy 24ST, Polished	75 (24)	.09
Alloy 75ST	75 (24)	.11
Alloy 75ST, Polished	75 (24)	.08
Bismuth, Bright	176 (80)	.34
Bismuth, Unoxidized	77 (25)	.05
Bismuth, Unoxidized	212 (100)	.06
Brass		
73% Cu, 27% Zn, Polished	476 (247)	.03
73% Cu, 27% Zn, Polished	674 (357)	.03
62% Cu, 37% Zn, Polished	494 (257)	.03
62% Cu, 37% Zn, Polished	710 (377)	.04
83% Cu, 17% Zn, Polished	530 (277)	.03
Matte	68 (20)	.07
Burnished to Brown Color	68 (20)	.40
Cu-Zn, Brass Oxidized	392 (200)	.61
Cu-Zn, Brass Oxidized	752 (400)	.60
Cu-Zn, Brass Oxidized	1112 (600)	.61
Unoxidized	77 (25)	.04
Unoxidized	212 (100)	.04
Cadmium	77 (25)	.02
Carbon		
Lampblack	77 (25)	.95
Unoxidized	77 (25)	.81
Unoxidized	212 (100)	.81
Unoxidized	932 (500)	.79
Candle Soot	250 (121)	.95
Filament	500 (260)	.95
Graphitized	212 (100)	.76
Graphitized	572 (300)	.75
Graphitized	932 (500)	.71
Chromium	100 (38)	.08
Chromium	1000 (538)	.26
Chromium, Polished	302 (150)	.06
Cobalt, Unoxidized	932 (500)	.13
Cobalt, Unoxidized	1832 (1000)	.23
Columbium, Unoxidized	1500 (816)	.19
Columbium, Unoxidized	2000 (1093)	.24
Copper		
Cuprous Oxide	100 (38)	.87
Cuprous Oxide	500 (260)	.83
Cuprous Oxide	1000 (538)	.77
Black, Oxidized	100 (38)	.78
Etched	100 (38)	.09
Matte	100 (38)	.22
Roughly Polished	100 (38)	.07

Material	Temp °F (°C)	ε Emissivity
Polished	100 (38)	.03
Highly Polished	100 (38)	.02
Rolled	100 (38)	.64
Rough	100 (38)	.74
Molten	1000 (538)	.15
Molten	1970 (1077)	.16
Molten	2230 (1221)	.13
Nickel Plated	100-500 (38-260)	.37
Dow Metal	0.4-600 (–18-316)	.15
Gold		
Enamel	212 (100)	.37
Plate (.0001)		
Plate on .0005 Silver	200-750 (93-399)	.11-.14
Plate on .0005 Nickel	200-750 (93-399)	.07-.09
Polished	100-500 (38-260)	.02
Polished	1000-2000 (538-1093)	.03
Haynes Alloy C,		
Oxidized	600-2000 (316-1093)	.90-.96
Haynes Alloy 25,		
Oxidized	600-2000 (316-1093)	.86-.89
Haynes Alloy X,		
Oxidized	600-2000 (316-1093)	.85-.88
Inconel Sheet	1000 (538)	.28
Inconel Sheet	1200 (649)	.42
Inconel Sheet	1400 (760)	.58
Inconel X, Polished	75 (24)	.19
Inconel B, Polished	75 (24)	.21
Iron		
Oxidized	212 (100)	.74
Oxidized	930 (499)	.84
Oxidized	2190 (1199)	.89
Unoxidized	212 (100)	.05
Red Rust	77 (25)	.70
Rusted	77 (25)	.65
Liquid	2760-3220 (1516-1771)	.42-.45
Cast Iron		
Oxidized	390 (199)	.64
Oxidized	1110 (599)	.78
Unoxidized	212 (100)	.21
Strong Oxidation	40 (104)	.95
Strong Oxidation	482 (250)	.95
Liquid	2795 (1535)	.29
Wrought Iron		
Dull	77 (25)	.94
Dull	660 (349)	.94
Smooth	100 (38)	.35
Polished	100 (38)	.28
Lead		
Polished	100-500 (38-260)	.06-.08
Rough	100 (38)	.43
Oxidized	100 (38)	.43
Oxidized at 1100°F	100 (38)	.63
Gray Oxidized	100 (38)	.28
Magnesium	100-500 (38-260)	.07-.13
Magnesium Oxide	1880-3140 (1027-1727)	.16-.20
Mercury	32 (0)	.09
Mercury	77 (25)	.10
Mercury	100 (38)	.10
	212 (100)	.12
Molybdenum	100 (38)	.06
Molybdenum	500 (260)	.08
Molybdenum	1000 (538)	.11
Molybdenum	2000 (1093)	.18
" Oxidized at 1000°F	600 (316)	.80
" Oxidized at 1000°F	700 (371)	.84
" Oxidized at 1000°F	800 (427)	.84
" Oxidized at 1000°F	900 (482)	.83
" Oxidized at 1000°F	1000 (538)	.82
Monel, Ni-Cu	392 (200)	.41
Monel, Ni-Cu	752 (400)	.44
Monel, Ni-Cu	1112 (600)	.46
Monel, Ni-Cu Oxidized	68 (20)	.43

Material	Temp °F (°C)	ε Emissivity
Monel, Ni-Cu Oxid. at 1110°F	1110 (599)	.46
Nickel		
Polished	100 (38)	.05
Oxidized	100-500 (38-260)	.31-.46
Unoxidized	77 (25)	.05
Unoxidized	212 (100)	.06
Unoxidized	932 (500)	.12
Unoxidized	1832 (1000)	.19
Electrolytic	100 (38)	.04
Electrolytic	500 (260)	.06
Electrolytic	1000 (538)	.10
Electrolytic	2000 (1093)	.16
Nickel Oxide	1000-2000 (538-1093)	.59-.86
Palladium Plate (.00005 on .0005 silver)	200-750 (93-399)	.16-.17
Platinum	100 (38)	.05
Platinum	500 (260)	.05
Platinum	1000 (538)	.10
Platinum, Black	100 (38)	.93
Platinum, Black	500 (260)	.96
Platinum, Black	2000 (1093)	.97
" Oxidized at 1100°F	500 (260)	.07
"	1000 (538)	.11
Rhodium Flash (0.0002 on 0.0005 Ni)	200-700 (93-371)	.10-.18
Silver		
Plate (0.0005 on Ni)	200-700 (93-371)	.06-.07
Polished	100 (38)	.01
Polished	500 (260)	.02
Polished	1000 (538)	.03
Polished	2000 (1093)	.03
Steel		
Cold Rolled	200 (93)	.75-.85
Ground Sheet	1720-2010 (938-1099)	.55-.61
Polished Sheet	100 (38)	.07
Polished Sheet	500 (260)	.10
Polished Sheet	1000 (538)	.14
Mild Steel, Polished	75 (24)	.10
Mild Steel, Smooth	75 (24)	.12
Mild Steel, Liquid	2910-3270 (1599-1793)	.28
Steel, Unoxidized	212 (100)	.08
Steel, Oxidized	77 (25)	.80
Steel Alloys		
Type 301, Polished	75 (24)	.27
Type 301, Polished	450 (232)	.57
Type 301, Polished	1740 (949)	.55
Type 303, Oxidized	600-2000 (316-1093)	.74-.87
Type 310, Rolled	1500-2100 (816-1149)	.56-.81
Type 316, Polished	75 (24)	.28
Type 316, Polished	450 (232)	.57
Type 316, Polished	1740 (949)	.66
Type 321	200-800 (93-427)	.27-.32
Type 321 Polished	300-1500 (149-815)	.18-.49
Type 321 w/BK Oxide	200-800 (93-427)	.66-.76
Type 347, Oxidized	600-2000 (316-1093)	.87-.91
Type 350	200-800 (93-427)	.18-.27
Type 350 Polished	300-1800 (149-982)	.11-.35
Type 446, Polished	300-1500 (149-815)	.15-.37
Type 17-7 PH	200-600 (93-316)	.44-.51
Type 17-7 PH		
Polished	300-1500 (149-815)	.09-.16
Type C1020, Oxidized	600-2000 (316-1093)	.87-.91
Type PH-15-7 MO	300-1200 (149-649)	.07-.19
Stellite, Polished	68 (20)	.18
Tantalum, Unoxidized	1340 (727)	.14
"	2000 (1093)	.19
"	3600 (1982)	.26
"	5306 (2930)	.30
Tin, Unoxidized	77 (25)	.04
"	212 (100)	.05
Tinned Iron, Bright	76 (24)	.05
	212 (100)	.08

4/09/10

More on the issue of standoffs on the feed arms and their effect on the Y factor. Y-pole of SB-038-B(2)

I. The first Y factor plot is for SB-038-B(2) Y pole. The dips at 3.8 GHz and 5.5 GHz are quite pronounced. In this case the standoffs are in place. There are three bias settings

II. In the second plot the standoffs are removed. The dips at 3.8 GHz and 5.5 GHz are less pronounced, but they did not disappear as nearly completely as they did for SB-008. The bias settings are the same.

III In the third plot rexolite panels have been inserted where the cylindrical standoffs with .01" thick in place of the cylindrical standoff that produces the 5.5 GHz feature and .02" panel in place of the standoff that produces the 3.8 GHz feature. There appears to be no significant difference between this plot and the previous one, and the bias settings are the same.

These tests suggest that using the thin pieces of Rexolite rather than the cylindrical standoffs for the two sets of standoffs at the 3.8 GHz and 5.5 GHz active zones would give a more uniform Y factor across the band.

Final Test

SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio
Various Bias Settings, 2010-04-06 Plot 1

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz	
016 Ratio	-0.97	0.21	1.52	55.8	3.95	3.59	1.82	(-44.36 dB @ 6 GHz) PAM 10/10
017 Ratio	-0.97	0.30	1.51	60.7	3.96	3.61	1.82	(-44.05)
018 Ratio	-0.97	0.40	1.51	65.8	3.99	3.63	1.83	(-44.07)

Cold load less effective below 3.0 GHz

H

SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio
Various Bias Settings, 2010-04-06 Plot 1

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz	
019 Ratio	-0.97	0.21	1.52	55.9	3.98	3.59	1.84	(-44.17)
020 Ratio	-0.97	0.30	1.51	60.8	3.96	3.68	2.02	(-43.85)
021 Ratio	-0.97	0.38	1.51	65.0	3.99	3.69	2.01	(-43.78)

H.

10

SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio
Various Bias Settings, 2010-04-08 Plot 1

III

The next eight pages contain the memo describing transmission through the glass dewar and teflon layer over the dewar.

Signal TransmissionThrough the LP Feed Glass Dewar

Jack Welch[1] and Matt Fleming[2]
1. Radio Astronomy Lab, UCB; 2. Minex Engineering, Antioch CA

I. Abstract

We study the effect of the glass dewar on the transmission of signals to the feed. The tip of the dewar is a hemisphere and the extension to the low frequency part of the feed is approximately a cone. Because the feed pattern is largely confined to a cone toward the tip end, we can estimate the transmission using a complete sphere as a model. For this structure an exact EM calculation can be made, including a spherical layer of Teflon adjusted to minimize the reflection of the glass structure. For the conical part of the ~~feed~~ glass we use an approximate model which is a plane layer of glass with a parallel plane layer of Teflon. The EM solution in this case is formally the same as that for the spherical region, and we can use the sphere results for the cone. Reflection for two thicknesses of glass plus Teflon are examined in detail. For one the glass thickness for the spherical region is .020" corresponding to typical light bulb thickness, and for the other the glass thickness is .040". With the proper choice of the Teflon layer, reflections can be kept to less than a few percent over the band 1 < f < 15 GHz in both cases.

II. Introduction

The ~~One~~ next version of the cm wave Log Periodic Feed will be encased in a glass vacuum dewar so that both the feed and the attachments between the LNA and the feed terminals can be cooled to about 65K. Extrapolations from the operation of the present feed and LNA suggest that this cooling will result in overall system temperatures of about 30K in the frequency range 1-15 GHz. This development raises issues about both the cooling of the feed in the presence of the ~300K thermal infrared background and the signal transmission through the glass. The thermal problems were discussed in memo # 14, where it was concluded that the feed could be cooled by a refrigerator connected to the large end of the feed with no more than about a 10K temperature rise along the feed. In this memo we discuss the transmission through the glass dewar and the use of a Teflon anti-reflection layer surrounding the glass dewar to lower the reflection from the glass.

Reflection from the Glass

Figure 1 shows the planned log periodic feed with the glass dewar surrounding it. The feed directivity is in the direction toward which the pyramidal feed points, and the active receiving part of the feed at any particular wavelength is at a distance from the feed vanishing point which is about 1.5 wavelengths. Thus the shortwave sensitivity is close to the tip, and the longer wave sensitivity is at the larger end of the feed. For any particular glass thickness the shorter wavelength transmission is more of a problem near the tip. The diagram of Figure 2 shows the detailed shape and the plan for a thin hemispherical section around the tip connecting to a conical section which expands in

thickness toward the back part of the feed. The hemispherical region can be quite thin, e.g. ~.020", which is typical of an ordinary light bulb, and be structurally strong. The glass thickness is planned to be greater toward the large end of the feed for overall strength. Since the longer wavelengths are received at the larger end, it can be thicker there without producing a significant reflection. We can study the reflection problem from the sphere for the shorter wavelengths by calculating the reflection of a spherical wave originating at the center of the glass sphere.

Figure 1. The feed inside the glass dewar

Figure 2. Section view of the glass dome.

III. Transmission Through the Spherical Tip of the Glass Dome

Here is the basic plan. We first find the field radiated from an elementary dipole current source at the center of the glass sphere, obtaining, in particular, the transmission through the sphere as a function of wavelength. We then make the plausible assumption that if the source were moved a small distance from the center of the sphere the transmission would not change significantly. Then we note that the actual feed current distribution could be synthesized as a distribution of the elementary currents over a short section of

the feed at any particular wavelength. That is, the elementary solution is Green's function for the antenna problem, and we could use it to synthesize the pattern. With these assumptions, it is sufficient to study just the reflection for the elementary source to estimate the reflection of the antenna signal if it were transmitting. Because the final pattern is directed toward the tip, the complete sphere is a sufficient model for the hemisphere. Because of reciprocity, this calculation also gives the inward transmission from a distant source.

The elementary current distribution is a small source, and we put it at the center of the spherical coordinate system with its polarization oriented along a local z coordinate normal to the feed axis. For the log-periodic feed element two such sources on the two sides of the pyramid corresponding to the two arms will eventually be needed along with a distribution of sources distributed along a short length of the feed for a particular frequency and linear polarization. Again, it should be sufficient to study just the elementary source and field. The time dependence is $e^{i\omega t}$ so that the spatial part of an outgoing wave is $(1/r)e^{-ikr}$.

The Elementary Source and Its Field.

The vector current source is $\hat{a}_z\ I_o\,\Delta z$, and the field components for this source are well known (e.g., Stratton, 1941, p436).

$$E_\theta = I_o\,\Delta z\, e^{-ikr}\,\{i\omega\mu/4\pi r + \eta/4\pi r^2 + i\omega\varepsilon/4\pi r^3\}\,\sin\theta$$

$$E_r = I_o\,\Delta z\ e^{-ikr}\,\{2\eta/\,4\pi r^2 + 2/i\omega\varepsilon 4\pi r^3\}\,\cos\theta \qquad (1)$$

$$H_\varphi = I_o\,\Delta z\, e^{-ikr}\,\{ik/4\pi r + 1/4\pi r^2\}\,\sin\theta,$$

where ε is the permittivity, μ is the permeability, $\eta = \sqrt{(\mu/\varepsilon)}$, and $k=2\pi/\lambda$. The radius of the sphere is ~5 cm, and the leading terms in E_θ and H_φ dominate the field at the spherical surface for wavelengths shorter than ~5 cm. So we ignore the other terms in the matching of the boundary conditions at the spherical surface.

The Boundary Conditions

In addition to the glass layer extending from $r = r_1$ to $r = r_2$, we include a layer of Teflon above it which extends from $r = r_3$ to r_4, as shown in Figure 3. The thickness and radius of the Teflon will be adjusted so that the overall transmission will be maximized over the operating band 1 to 15 GHz. The form for the fields in the spaces between the bounding surfaces correspond to spherical TEM waves like the leading terms of the elementary source in equations (1). Both outgoing and incoming waves are included in every region except the outer most region where there must be only an outgoing wave. The tangential electric and magnetic fields, E_θ and H_φ, must be matched at each surface of discontinuity. These field terms are exact solutions to Maxwell's Equations for the simple spherical structure of the model. The diagram of Figure 3 outlines the five regions.

Figure 3: The spherical glass and Teflon layers

The field components of region 1, $r < r_1$, appear below with coefficients to be determined by the boundary conditions. The strength of the elementary outgoing field is normalized to unity for the electric field in this region.

$$E_\theta = (\mathrm{Sin}\Theta/r)\mathrm{Exp}(-i\gamma_o r) + (B\mathrm{Sin}\Theta/r)\mathrm{Exp}(i\gamma_o r);$$

$$H_\varphi = (\mathrm{Sin}\Theta/\eta_o r)\mathrm{Exp}(-i\gamma_o r) - (B\mathrm{Sin}\Theta/\eta_o r)\mathrm{Exp}(i\gamma_o r) \quad (2)$$

The subscripts on the wave numbers, γ_i, and characteristic impedances, η_i, correspond to the characteristics of the three regions: free space, glass, and Teflon. The characteristic impedances are defined above. The wave numbers defined in terms of the free space value k are given by $\gamma = k\sqrt{(k_e)}$, where k_e is the relative dielectric constant of the medium. Similar field components for the other regions are defined with initially undetermined coefficients: (C,D) for the outgoing and incoming components in region 2, $r_1 < r < r_2$, (E,F) for region 3, $r_2 < r < r_3$, (G,H) for region 4, $r_3 < r < r_4$ and I for the outgoing wave in region 5, $r > r_4$.

The boundary conditions, continuity of tangential electric field, E_θ, and tangential magnetic field, H_φ, must be satisfied at each boundary. This gives a pair of equations at each boundary. For example, at the boundary $r = r_3$: $E_{\theta 3} = E_{\theta 4}$ and $H_{\varphi 3} = H_{\varphi 4}$, require:

$$E\,\mathrm{Exp}(-i\gamma_o r_3) + F\,\mathrm{Exp}(i\gamma_o r_3) = G\,\mathrm{Exp}(-i\gamma_t r_3) + H\,\mathrm{Exp}(i\gamma_t r_3);$$

$$(E/\eta_o)\mathrm{Exp}(-i\gamma_o r_3) - (F/\eta_o)\mathrm{Exp}(i\gamma_o r_3) = (G/\eta_t)\mathrm{Exp}(-i\gamma_t r3) - (H/\eta_t)\mathrm{Exp}(i\gamma_t r_3) \quad (3)$$

In addition to these, there are similar equation pairs for the other boundaries: r_1, r_2, and r_4. The common (1/r) factors as well as the sinΘ factors in each of these equations cancel out in the equations which determine the coefficients B,C,D,E,F,G,H, and I. To find the

transmission from the central source through the glass and Teflon requires solving for the coefficient I for the amplitude of the outgoing wave. Since the amplitude of the outgoing electric field in region 1 is taken to be 1, I would be equal to 1 if the transmission through the glass and Teflon layers were perfect .The calculation is straight forward algebra, combining the equations in pairs to successively eliminate all the coefficients except I.

Here is the equation for I: (amplitude of E, not $|E|^2$)

$$
\begin{aligned}
16/I = {} & Q_A(1+\eta_g/\eta_o)(1+\eta_o/\eta_g)\mathrm{Exp}\{i[\gamma_o(r_1-r_2)+\gamma_g(r_2-r_1)]\} \\
& +Q_B(1-\eta_g/\eta_o)(1+\eta_o/\eta_g)\mathrm{Exp}\{i[\gamma_g(r_2-r_1)+\gamma_o(r_2+r_1)]\} \\
& +Q_A(1-\eta_g/\eta_o)(1-\eta_o/\eta_g)\mathrm{Exp}\{i[\gamma_o(r_1-r_2)+\gamma_g(r_1-r_2)]\} \\
& +Q_B(1+\eta_g/\eta_o)(1-\eta_o/\eta_g)\mathrm{Exp}\{i[\gamma_o(r_1+r_2)+\gamma_g(r_1-r_2)]\}, \text{ where}
\end{aligned}
$$

$$
\begin{aligned}
Q_A = {} & \{(1+\eta_t/\eta_o)(1+\eta_o/\eta_t)\mathrm{Exp}\{i[(\gamma_t-\gamma_o)(r_4-r_3)]\} \\
& +(1-\eta_t/\eta_o)(1-\eta_o/\eta_t)\mathrm{Exp}\{-i[(\gamma_o+\gamma_t)(r_4-r_3)]\}\}, \text{ and}
\end{aligned}
$$

$$
\begin{aligned}
Q_B = {} & \{(1+\eta_t/\eta_o)(1-\eta_o/\eta_t)\mathrm{Exp}\{i[(\gamma_t-\gamma_o)(r_4-r_3)-2\gamma_o r_3]\} \\
& +(1-\eta_t/\eta_o)(1+\eta_o/\eta_t)\mathrm{Exp}\{-i[(\gamma_t-\gamma_o)(r_4-r_3)+2\gamma_o r_4]\}\}. \qquad (4)
\end{aligned}
$$

A First Example: The glass thickness of a typical incandesant light bulb is about .020". We take this case for our glass sphere and work out its transmission properties as a function of frequency for $1 < f < 15$ GHz. Then we add the layer of Teflon and vary its thickness and radial distance to maximize the transmission. Since all of the γ_i factors have the frequency as a factor, the plotting vs frequency is straight forward. We take the relative permitivity of the glass to be 4 and that of Teflon to be 2. Fused quartz, probably the best choice for the glass, actually has a permitivity of 3.8, but 4 is close enough for the example.

Figure 4 shows several transmission curves. The one for (glass) only shows power transmission, $|I|^2 > .99$ up to about 7 GHz but dropping to .955 by 15 GHz. If the feed structure is at a physical temperature of ~70K, the 1 percent implied reflection at 7GHz would add ~0.7K to the feed system temperature, and the 4.5 percent at 15 GHz would add about 3K to the system temperature apart from the small radiated and reflected noise contribution from the LNA. These numbers would be about four times higher if the feed were not physically cooled to 70K. The other curves show the effect of a .35mm layer of Teflon at various heights above the glass layer. The 5mm separation appears to give about the best overall improvement, with the transmission at 15 GHz raised to .97 and generally better results at the lower frequencies. In Figure 5 we show transmission curves keeping the 5mm separation and varying the Teflon layer thickness to get the best transmission. The .8mm thickness appears to be about the best. The scale of Figure 5 is finer than that of Figure 4, and the transmission is .99 or better for much of the range. Further optimization will probably not make significantly further improvement.

It is important to keep in mind that the other effect of any transmission loss is the loss in antenna gain. Keeping that loss to a few percent or less from the transmission through the dewar is almost as important as lowering the system temperature.

Figure 4. Transmission through the .51 mm glass and Teflon

A Second Example for the Sphere: For the second case, we take the thickness of the glass sphere to be 1mm, about double that of the first case, and discuss only a limited optimization. For this case we use the relative permittivity of ~~4.8~~ 3.8 for the glass, which is appropriate for fused quartz. The results are shown in Figure 6. With just the glass, the transmission drops to 0.95 at 8 GHz and is .86 at 15 GHz. Based on the results of the first example, we put in a double thickness Teflon layer, 1.6mm, at the same 5.0 mm spacing that was used in Figure 5 with the 0.51mm thick glass. This makes a substantial improvement, raising the transmission to .97 or better out to about 11.5 GHz. Changing the Teflon layer thickness to 1.8 mm raises the transmission a little higher near 10 GHz and degrades it a little at the higher frequencies. Decreasing the Teflon layer spacing to 4.0 mm for the 1.6 mm thick layer provides a transmission of .95 or better out to 14 GHz with a minimum of .96 at 7 GHz. These are all interesting possibilities, and a detailed optimization can be developed for the finally chosen thickness of the glass.

Figure 5: Glass and Teflon transmission with different Teflon thicknesses

IV. Transmission through the conical part of the glass cover.

This part covers the lower frequency part of the feed. The feed is about 24 inches long, and the 1 GHz sensitivity is at the back end. The 2 GHz zone is at 12 inches, the 4 GHz zone is at 6 inches, and the 8 GHz zone is at about 3 inches. This latter region is close to the tip, and is covered largely by the sphere. For the low frequency transmission from the large, low frequency, part of the feed, we use an approximate model which is plane parallel sheets of glass and Teflon. Since the transmission is expected to be high, this approximate model is plausible. For transmission through plane layers at approximately normal incidence, the spherical model which we have studied for the tip of the feed is the same EM problem. In equations (3) for the matching of the boundary conditions for the sphere, the 1/r factors drop out at each boundary, and the equations for the continuity of the tangential components of E and H in the plane parallel case are the same. Thus we can use the same results, equations (3), for the corresponding rectangular field components. What matters is the transmission through the double layer given by equation (4). The important parameters are the phase delays between the layers and the discontinuities of the field components at the glass and Teflon boundaries.

We can study the transmission through the conical part of the glass/Teflon dewar by examining Figure 6 or Figures 5 and 4. The first point to notice is that whereas the addition of the Teflon improves the transmission for frequencies above about 6 GHz it

actually makes it slightly worse at the lower frequencies. This suggests that no Teflon be used over the conical part of the dewar. Because the thickness of the dewar is increasing toward the large end of the feed, it is necessary to include that effect in the scaling of the transmission to lower frequencies. Figure 6 shows large dots for the transmission at selected lower frequencies assuming that there is no Teflon and the thickness follows the dimensions of Figure 2. The model transmission is quite high at the lower frequencies which justifies the approximate model. Altogether the effect of the glass is small for the conical part of the dewar.

-.09 dB

-.18 dB

Figure 6: Transmission through the 1mm (.040") thick glass sphere and three different choices of Teflon thicknesses and separations. The three circles show the expected transmissions through the conical part of the feed with no Teflon at 2 GHz, 4 GHz, and 6GHz, where the cone and sphere thicknesses are the same.

V. Future Plans

We have found an experienced glass manufacturer who is confident about building the dewar. We have ordered tow units for a good price and expect delivery in about a month. The glass thickness will be 0.04" corresponding to the second example above. In he t meantime we will make a more detailed optimization of the required Teflon thickness and separation.

4/11/10

Ray paths through the glass for different angles and frequencies for the current glass dewar model.

For the low frequencies

Glass thickness is .040" on the sphere, .240 at the large end.

1 GHz 42° ray at the edge ray at A
normal to ray angle 48° · t Glass = .24" · $t_{eff} = \frac{1}{\cos 48°} \cdot .24 = .36"$
ray at B 18° from axis, 54° from normal, $\cos 54° = \frac{1}{1.7}$
normal t: .04 + .07 (.36 distance) = .11" · $t_{eff} = .11 \times 1.7 = .187"$
ray at C 61° from normal normal t = .04 · $t_{eff} = .04/\cos 61° = .08"$
Reading graph @ 1 GHz and .04" glass get .999 transmission
For .08" eff thickness .001 → .002 reflected, .998 transmitted
For .187" eff thickness .001 → $.001\left(\frac{.187}{.04}\right) = .0047$ reflected, .995 trans
For .36" " .001 → $.001\left(\frac{.36}{.04}\right) = .009$ reflected, .99 trans

2 GHz ray at B is 31° from normal · t = .11
effective $t = .11/\cos 11° = .128"$

ray at C is 47° from normal, t = .04, $t_{eff} = .04/\cos 47° = .0587$
From graph @ 2 GHz, .04 glass is .996 = 1 − .004 transmission
For $t_{eff} = .128"$, .004 → $.004\left(\frac{.128}{.04}\right) = .0128$ reflection (.0987)
For $t_{eff} = .0587"$, .004 → $.004\left(\frac{.0587}{.04}\right) = .0059$ reflection

4 GHz edge ray (42°) at C is 31° from normal
$t_{eff} = .04(1.166) = .0466"$ close to .04"
The graph shows transmission of .982, close to the open dot on the graph.

The open circles are close to the values for the worst case rays. The average should be better.

The best result will be 1.6 mm teflon at 4 mm spacing with the teflon not continued past the hemisphere.

What if ε = 2.36 for the "teflon"?

NB Glass spherical radius is 3" on final model

[610
24.016
[609.60
24.000
[7
.276OR
CAN BE THI
[330
12.992
.787
47°
61°
54°
48°
R3.000
.236
15.00°
R.125
A
.040 +.000 -.010 THICK AT TIP
31°
31°
B
C
42.00°
42
42
Axis1
1 GH1
2 GH2
4 GH3
8
16
[300
11.81 DIA
OUTSIDE
11.260DIA
Inside REF
[76
2.992RAD
1000.00RAD
OR STRAIGHT
5.230
Y
Z

4/18/10 (Final Fig 5)

Numerical experiments with layers of polyethylene ($\epsilon \approx 2.3$) instead of the teflon. This material is cheaper and more malleable than teflon. It's loss tangent is $\sim 10^{-4}$ at 11 GHz a little better than teflon.
The layer lowers the reflection above 8 GHz and raises it a little below. There will be a layer only over the hemispherical top. The overall power transmission is better than 0.96 all the way to 14 GHz and drops to .94 at 15 GHz. Since the feed structure will be @ ~20K, the 4% reflection will send .04×70 ~ 2.8K radiation at the feed near 8 GHz. At the higher and lower frequencies it will be ≤ 1.2K°. The glass reflection by itself is .18 @ 15 GHz. This is for a .04" (1.0mm) glass thickness.

?

G5.pdf

Transmission through glass dewar with a layer of polyethylene 4mm above the spherical tip region only. There are two candidate thicknesses for the polyethylene, 1.0 mm and 1.2 mm.

Gary's Hat Creek Power Measurements 5/5/10

These were made at the 480V 3φ power distribution panel down stream of the generator transfer switch.

Lab 1. p = 5.48 KVA
Lickert p = 8.86 KVA } = 63.7
SPR p = 26.8 KVA
array still p = 22.6 KVA
array slew p = 24.8 KVA plus first 3 = 65%
array peak air p = 37.4 KVA plus first 3 = 78.5

7/3/10

☆ Transmission through a glass sphere which is 3" in ~~diameter~~ radius and .080" thick (2mm). The trend from the 0.5mm (.02") and 1.0mm (.04") spheres shows that with a single layer of polyethelyne or Teflon the minimum in transmission is at wavelength and is equal to the glass only value — in this case 0.85, −0.7dB @ 7.5 GHz

test1.pdf

Effect of Pointing Errors on the achievable dynamic range of an SKA map 6/29/10 WSW

Assume the SKA has $10^6\ m^2$ area and $T_{sys} = 50$, an early spec

T_N for a 1000 second observation in 200 MHz band.

$$T_N = \frac{50}{\sqrt{10^8 \cdot 1000}} = .00016^\circ K$$

For a 6m dish get 150 Jy for 1K [60%] @ ~28.0 m^2
For $10^6\ m^2$ area, get $10^6/30 = 35{,}333$ times more area.
Sensitivity becomes, $150/35{,}000 = .0043$ Jy per K

For $.00016^\circ K$ Flux $= .00016 \times .0043 = 6.9 \times 10^{-7}$ Jy
This is the noise floor. Relative to 3C286 @ 10 Jy, the floor is $\sim 10^{-7}$ of the peak signal.

How small must the pointing errors be to achieve that dynamic range?

Assume: (a) a symmetrical Gaussian beam
(b) a normal distribution of the pointing errors during the observation.

The effect of the pointing errors will be to slightly enlarge the size of the beam.

If $g(x,y)$ is the antenna gain function, it's transform is $G_T(u,v)$

$$G_T(u,v) = \iint_{-\infty}^{\infty} g(x,y)\, e^{i2\pi(ux+vy)}\, dx\, dy$$

The true visibility function $V_T(u,v)$ is:

$$V_T(u,v) = \iint_{-\infty}^{\infty} T_B(x,y)\, e^{i2\pi(ux+vy)}\, dx\, dy$$

The observed visibility function: $V_o(u,v)$ is:

$$V_o(u,v) = \iint_{-\infty}^{\infty} T_B(x,y)\, g(x,y)\, e^{i2\pi(ux+vy)}\, dx\, dy$$

The erroneous visibility function with pointing errors in the gain function is:

$$V_E(u,v) = \iint_{-\infty}^{\infty} g(x+\delta x, y+\delta y)\, T_B(x,y)\, e^{i2\pi(ux+vy)}\, dx\,dy$$

$$G_E(u,v) = \iint_{-\infty}^{\infty} g(x+\delta x, y+\delta y)\, e^{i2\pi(ux+vy)}\, dx\,dy \; ; \; \text{let} \begin{cases} x+\delta x = q \\ y+\delta y = p \end{cases}$$

$$G_E(u,v) = \iint_{-\infty}^{\infty} g(q,p)\, e^{i2\pi\{u(q-\delta x)+v(p-\delta y)\}}\, dq\, dp$$

$$= \iint_{-\infty}^{\infty} g(q,p)\, e^{i2\pi(qu+pv)}\, dq\, dp\; e^{-i2\pi(u\delta x+v\delta y)}$$

$$= G_T(u,v)\, e^{-i2\pi(u\delta x+v\delta y)}$$

The Fourier Transform of a product is the ~~product~~ convolution of the Fourier Transforms.

So, $V_E(u,v) = V_T(u,v) * \left[G_T(u,v)\, e^{-i2\pi(u\delta x+v\delta y)}\right]$

The polar coordinates $\theta^2 = x^2+y^2$; $\beta^2 = u^2+v^2$

Transforms of Gaussians $F(x) = e^{-wx^2} \longrightarrow f(u) = \frac{1}{\sqrt{2pw}} e^{-u^2/4pw}$

$$FT\{e^{-wx^2} e^{-zy^2}\} = \frac{1}{\sqrt{2w}} e^{-u^2/4w} \cdot \frac{1}{\sqrt{2z}} e^{-v^2/4z}$$

$$FT\{e^{-w(x^2+y^2)}\} = \frac{1}{2w} e^{-(u^2+v^2)/4w} = \frac{e^{-\beta^2/4w}}{2w} \; ; \; w = \frac{2.76}{\theta^2}$$

$$FT\left\{e^{-2.76\frac{\theta^2}{\theta^2}}\right\} = \frac{1}{2\left[\frac{2.76}{\theta^2}\right]} e^{-\beta^2/4\left[\frac{2.76}{\theta^2}\right]} = \frac{\theta^2}{5.52} e^{-\frac{\beta^2\theta^2}{11.04}}$$

$$e^{-i2\pi(u\delta x+v\delta y)} = e^{-i2\pi\beta\sigma_\theta} \; ; \text{ For a normal distribution:}$$

$$Exp\{e^{-i2\pi\beta\sigma_\theta}\} = e^{-(2\pi\beta\sigma_\theta)^2} = e^{-2\pi^2\beta^2\sigma_\theta^2}$$

So $Exp\{V_E(u,v)\} = V_T * \left[G_T(u,v)\, e^{-2\pi^2\beta^2\sigma_\theta^2}\right]$

Then $Exp\{T_E(x,y)\} = FT\left\{V_T * \left[G_T(u,v)\, e^{-2\pi^2\beta^2\sigma_\theta^2}\right]\right\}$

The Fourier Transform of $G_T(u,v)\,e^{-2\pi^2\beta^2\sigma_\Theta^2}$:

$$G_T(u,v)\,e^{-2\pi^2\beta^2\sigma_\Theta^2} = \frac{\Theta^2}{5.52}\,e^{-\frac{\beta^2\Theta^2}{11.04}}\,e^{-2\pi^2\beta^2\sigma_\Theta^2} = \frac{\Theta^2}{5.52}\,e^{-\beta^2\left\{\frac{\Theta^2}{11.04}+2\pi^2\sigma_\Theta^2\right\}}$$

$$FT\left\{\frac{\Theta^2}{5.52}\,e^{-\beta^2\left\{\frac{\Theta^2}{11.04}+2\pi^2\sigma_\Theta^2\right\}}\right\} = F\left\{\frac{\Theta^2}{5.52}\,e^{-(\beta^2+v^2)\{\quad\}}\right\}$$

$$= \frac{\Theta^2}{5.52}\left\{\frac{e^{-x^2/4\{\}}}{\sqrt{2\{\}}}\;\frac{e^{-y^2/4\{\}}}{\sqrt{2\{\}}}\right\} = \frac{\Theta^2\;e^{-\Theta^2/4\{\}}}{(5.52)\,2\{\}}$$

Finally, $\mathrm{Exp}[T_E(x,y)] = T_B(x,y)\,\dfrac{\Theta^2\;e^{-\Theta^2/4\{\}}}{5.52\,2\{\}}$

$$\{\} = \frac{\Theta^2}{11.04} + 2\pi^2\sigma_\Theta^2 = \frac{\Theta^2}{11.04}\left\{1+(11.04)\,2\pi^2\left(\frac{\sigma_\Theta}{\Theta}\right)^2\right\}$$

$$\mathrm{Exp}\{T_E(x,y)\} = T_B(x,y)\,\frac{\cancel{\Theta^2}\;e^{-\Theta^2/4\,\frac{\Theta^2}{11.04}\left\{1+(11.04)\,2\pi^2\left(\sigma_\Theta/\Theta\right)^2\right\}}}{11.04\,\frac{\cancel{\Theta^2}}{\cancel{11.04}}\left\{1+(11.04)\,2\pi^2\left(\frac{\sigma_\Theta}{\Theta}\right)^2\right\}}$$

$$\mathrm{Exp}\{T_E(x,y)\} = T_B(x,y)\,\frac{e^{-2.76\,\frac{\Theta^2}{\Theta^2\left\{1+(11.04)\,2\pi^2\left(\sigma_\Theta/\Theta\right)^2\right\}}}}{\left\{1+(11.04)\,2\pi^2\left(\sigma_\Theta/\Theta\right)^2\right\}}$$

The normalization cancels some of the error in the exponential

The input filter for the new wideband feed 5/25/10

It's a Chebyshev low pass: $\rho = 10\%$ $A_m = 2$
Zero: ρ 175 $n = 3$
$L_1' = L_3' = .716$, $L_2' = .223$, $C_2' = .870$

For Bandedge = 16 GHz (above 15 GHz) and $R_r = 100\,\Omega$

$\omega_r = 2\pi f_r = 2\pi(16\times10^9) = 1\times10^{11}$ for 16 GHz band edge

$\omega_r/R_r = 1\times10^{11}/100 = \underline{10^9}$; $\omega_r R_r = 10$

$C = C'/\omega_r R_r = .870\times10^{-13} = .087\,pf$, close to 0.1 pf

$L_1 = L_1'/\frac{\omega_r}{R_r} = L_1'\times10^{-9} = .716\times10^{-9} = \underline{.716\,nH} = L_3$

$L_2 = L_2'\times10^{-9} = \underline{.223\,nH}$

There will be some series inductance in the commercial capacitor. The catalogue shows series resonance of 28 GHz for 0.1 pf cap.

$$2\pi(28\times10^9) = \frac{1}{[LC]^{1/2}} = \frac{1}{[L(.1\times10^{-12})]^{1/2}}$$

$$\sqrt{L} = \frac{1}{2\pi(28\times10^9)[.1\times10^{-12}]^{1/2}} = \frac{1}{55{,}605}\ ;\ \underline{L = .323\,nH} = L_2$$

about 45% higher than the L_2 in the above model for 16 GHz.

L_1 and L_3 are lengths of a single wire, the diameter of the UT-35 coax central conductor, .0028 inches.

Wire Inductance: $L = 2l\times10^{-7}\ln\left(\frac{2l}{er}\right)$ $\quad r = .0014'' = 3.6\times10^{-5}\,m$

For $l = \underline{\underline{.05''}} = .0013\,m$ $\quad L = 2(.0013)\times10^{-7}\ln\left(\frac{2(.0013)}{(2.7)(3.6\times10^{-5})}\right) = .26\times10^{-9}\ln[26.$

$= 0.85\,nH = L_1 = L_3$, close to the model above

The actual values for the filter: $L_1 = L_3 = 0.85\,nH$, $L_2 = .32\,nH$, $C = 0.1\,pf$

Calculate the bandshape for the actual values.

$$\text{Transfer function} = \left\{\frac{2Z_b}{j\omega L_1 + R + Z_b}\right\}\left\{\frac{R}{R + j\omega L_3}\right\}$$

$$\text{where } Z_b = \frac{(R + j\omega L_3)\left(j\omega L_2 + \frac{1}{j\omega C_2}\right)}{\left(R + j\omega L_3 + j\omega L_2 + \frac{1}{j\omega C_2}\right)}$$

For the calculation: $f_g = x$ in GHz

$\omega L_3 = \omega L_1 = 2\pi f_g \times 10^9 (.85\times10^{-9}) = 5.34 f_g$

$\omega L_2 = 2\pi f_g \times 10^9 (.32\times10^{-9}) = 2.01 f_g$

$\omega C_2 = 2\pi f_g \times 10^9 (.10\times10^{-12}) = .628\times10^{-3} f_g$

$f_1[x_] := (R + j\omega L_3) = 100 + I(5.34x)$

$f_2[x_] := j\omega L_2 + \frac{1}{j\omega C_2} = I(2.01x - 1/(.000628x))$

$f_3[x_] := R + j\omega L_3 + j\omega L_2 + 1/j\omega C_2 = 100 + I(7.35x - 1/.000628x)$

$Z_b = f_1[x] f_2[x]/f_3[x]$

$f_4[x_] := R/(R + j\omega L_3) = 100/(100 + I\,5.34x)$

$f_5[x_] := j\omega L_1 + R + Z_b = 100 + I\,5.34x + f_1[x] f_2[x]/f_3[x]$

Transfer voltage $= \frac{2 f_1[x] f_2[x]}{f_3[x] f_5[x]} f_4[x]$

For power transfer, Plot[Abs[$\frac{2 f_1 f_2 f_4}{f_3 f_5}$]^2, {x, 1, 15},

Frame → True, GridLines → Automatic]

The file is "filter.pdf" for the plot

Make the plot, also, leaving out the first inductor, L_1.

The only change is $f_5[x_] := 100 + f_1 f_2/f_3$

The rest is the same and the output file is "filter2.pdf"

see p. 30

Note that the scales are very different.

With $L_1 \neq 0$ but about $L_3/3$ $= 2\pi f_g \times 10^9 (.3\times10^{-9}) = 1.88 f_g$

and $f_5[x_] = 100 + I\,1.88x + f_1[x] f_2[x]/f_3[x]$

Plot {x, 1, 15} The $L_3/3$ case is approximately what we have for the current ATA field. The response is plotted as dots on p 30 on the filter2.pdf plot.

15GHpt is 0.93
in power

filter.pdf

filter2.pdf for new ATA feed
$L_1 = 0$ (no input inductor)

The dots are for $L_1 = L_3/3$

Final Test

SB-044-B(2), X-pole, ABB-156, Test 15 Noise Ratio
Various Bias Settings, 2010-08-03

Feed ready to be returned to Hat Creek: average/good

The dark line is data taken with the two smallest sets of standoffs out.

The cap, ~0.1pf, is in place at the input; the input inductance, L_1, is absent.

To get total Tsyp, add 10K everywhere; i.e. 64K → 74K

Leaving out the input inductance will have little effect up to 8-10 GHz

See the previous two plots.

8/22/10 Transmission through a glass sphere (fused quartz)
→ of 3" radius and .06" thickness

.06" = 1.5 mm thickness
→ outer sphere dimension: radius 3.0" = 7.62 cm
$r_1 = 7.62 - 0.15 = 7.47$ cm; $r_2 = 7.62$ cm
$\gamma_0 = .2094 f_g$, $\gamma_g = .4082 f_g$
$r_2 - r_1 = .15$ cm, $r_2 + r_1 = 15.09$ cm

$i\gamma_0(r_1 - r_2) + i\gamma_g(r_2 - r_1) = i(.2094 f_g)(-0.15) + i(.4082 f_g)(.15) = i(.0298 f_g)$
$i\gamma_g(r_2 - r_1) + i\gamma_0(r_1 + r_2) = (.4082 f_g)(.15) + i(.2094 f_g)(15.09) = i\,3.2211 f_g$
$i\gamma_0(r_1 - r_2) + i\gamma_g(r_1 - r_2) = i(.2094 f_g)(-.15) + i(.4082 f_g)(-.15) = -i(.0926) f_g$
$i\gamma_0(r_1 + r_2) + i\gamma_g(r_1 - r_2) = i(.2094 f_g)(15.09) + i(.4082 f_g)(-.15) = i(3.0988 f_g)$

$(1 + \eta_g/\eta_0)(1 + \eta_0/\eta_g) = 4.463$ (copied)
$(1 - \eta_g/\eta_0)(1 - \eta_0/\eta_g) = -.463$
$(1 - \eta_g/\eta_0)(1 + \eta_0/\eta_g) = 1.437$
$(1 + \eta_g/\eta_0)(1 - \eta_0/\eta_g) = -1.437$

$x = f_g$

Glass only case: $Q_A = 4$, $Q_B = 0$

$$I = \frac{4}{\{4.463 e^{i(.0298x)} - .463 e^{-i(.0926x)}\}} = \frac{4}{f_1[x]}$$

Plot [Abs [4/f1[x]]^2, {x, 1, 15}, Frame → True, GridLines → Automatic]

final plot is Test2.pdf

This looks discordant with respect to IV p. 146 but it is probably just the extra phase term left off on p. 146 (IV).

The next page shows SB-044-B(2), X pol noise ratio with the new Thin standoffs in place as well as with no standoffs.

The surprise is that y-factor is better with the new thin standoffs in place. The y-factor is ~.25 dB better overall and much smoother at high frequencies.

Final Test

SB-044-B(2), X-pole, ABB-156, Test 15 Noise Ratio
Stand-off Evaluation, 2010-08-(03+11)

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz		
032 Ratio	-0.96	0.67	1.71	60.4	4.16	3.73	1.58	(-47.74 dB @ 6 GHz)	Thin Stand-offs 1st + 2nd
018 Ratio	-0.96	0.67	1.71	60.8	4.05	3.66	1.47	(-47.67 dB @ 6 GHz)	1st + 2nd stand-offs removed
015 Ratio	-0.96	0.67	1.71	60.8	4.06	3.69	1.56	(-47.86)	
017 Ratio	-0.96	0.67	1.71	60.8	4.03	3.65	1.51	(-47.85)	

9/16

G6.pdf

This is the transmission through a spherical glass shell of .06" (1.5) thickness with and without a plastic shell around it. The shell around the glass is 1.8 mm thick and spaced 4.0 mm from the glass. It's close to the optimum for a single layer. A separation of ~ 3.8 mm would probably work a little better (be the optimum).

.06" glass = 1.5 mm

How about a double layer? Difficult algebra, which might be possible using mathematica.

11/5/10

Thermal transmission of the fiber glass standoffs used to hold the feed.

$K = 0.16$ watts/m°c for fiber glass

The diameter is 1/2", so $R = 1/4" = (.25)\frac{2.54}{100} = .0064$ m

$\Delta T = 280 - 70 = 210$

$$H = KA\frac{\Delta T}{\Delta Z} = \frac{(.16)[\pi(.0064)^2]\,210}{.0254} = \underline{0.17 \text{ watts}} \text{ per peg}$$

<u>0.68 watts total</u> For a length of .866, it's .79 watts

The following three pages show Y-pole return loss as a function of frequency for various offsets of the feed with respect to the glass dome. Height 0.00 is the initial spacing of the feed, 1.0" at the bottom end. The red line is fixed in every panel. It corresponds to a smoothed version of the curve for 0.00 height. The best choice for the offset appears to be height 0.134. This choice has been implemented. It required removing 0.134 inches from the 1.0 inch standoffs.

Posted in 12/23/10

No correction for cable loss has been made for these measurements. The good results at 10–15 GHz are important for the corrected return loss to be $\lesssim 10$ db everywhere.

Plots for glass dome at various positions
(rotate dome 90° no difference)

TDP Feed 5C, Return loss (base line)
Y pole, Glass dome, Height 0.000, 2010-11-04

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 0.134, 2010-11-04

the choice

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 0.270, 2010-11-04

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 0.460, 2010-11-04
Gain (dB)
Frequency (GHz)
4
4. 101104-15 Y pole, F, gates on, space 0.460, dome 1, hat 1.

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 0.738, 2010-11-04
Gain (dB)
Frequency (GHz)
1
6. 101104-17 Y pole, F, gates on, space 0.738, dome 1, hat 1.

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 0.940, 2010-11-04
Gain (dB)
Frequency (GHz)
1
7. 101104-18 Y pole, F, gates on, space 0.940, dome 1, hat 1.

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 1.074, 2010-11-04
Gain (dB)
Frequency (GHz)
7. 101104-19 Y pole, F, gates on, space 1.074, dome 1, hat 1.
1

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 1.200, 2010-11-04
Gain (dB)
Frequency (GHz)
9. 101104-20 Y pole, F, gates on, space 1.200, dome 1, hat 1.
1

TDP Feed 5C, Return loss
Y pole, Glass dome, Height 1.490, 2010-11-04
Gain (dB)
Frequency (GHz)
10. 101104-21 Y pole, F, gates on, space 1.490, dome 1, hat 1.
1

12/23/10 This out-of-order figure shows that the current LO1 amp made with Rogers 3003 board and coax-to-μstrip line connectors have a match that is ≤ -20dB up to 18 GHz

LO1 amp; box made with Rogers 3003 board. Gate set past the knee.

12/23/10 This plot compares ~~return~~ transmission loss with no glass bottle with ~~return loss~~ transmission with the glass bottle and layer of polyethelene, over 6-16 GHz. Differences are mostly ≲ a few tenths of a dB. No correction for cable losses and reflections. $\tau = \delta_F \delta_H \left(\frac{\lambda}{4\pi R}\right)^2 = \delta_F A_H / 4\pi R^2$ // Also, there's motion of the feed point.

NO GLASS 1 / GLASS 1 HAT 1

42 12/23/10 (pasted in)

Corrected return loss, passive baluns in place

12/23/10 Uncorrected Return loss with and without the input filter in place.

12/23/10 Choice of absorber for new LN load. The absorber will be backed by metal plate which doubles the absorption. 10 dB one-way (= 20 dB) is the minimum acceptable attenuation. Not acceptable!

This is ok for f ≥ 3GHz & (It's marginal)

This is S12 for f ≳ 3 GHz

This is OK for f ≥ 3GHz

12/23/10 Patterns of New Feed at SRI

Raw Data

Problems here with scale
scale is wrong

Principal Plane Patterns with gate applied.

no amplitude calibration done here

This is from ATA_feed_X000_7.0000GHz
in the big folder that ends with ....\SRI_Anechoic_Chamber\2010_12_09_ATAfeed.

It looks like the 2 columns are for the two transmitted polarizations

various band very noisy

Gated results (problem with gear)

more gated results and scale wrong

and more gated pattern data
and wrong scale

From IV p. 67 and I p 134 for the New LN load

ϕ	n_s	θ_c	
	.085	90°	(8.26 2.0GHz perpendicular)
		90°	8.26 2.0 GHz
96°	.064	104	6.60 2.5GHz
68°	.058	112	5.50 3.0GHz
54°	.043	126	3.30 5.0GHz
48	.037	132	2.00 8.0GHz
46°	.032	134	1.65 10.0GHz
45°	.031	135	1.40 12.0GHz

For $n = 1.2053$ (LN)

$$\left|\frac{n-1}{n+1}\right|^2 = .0087$$

[How about a mean angle of incidence correction?]

Cooling the ATA PLP Feed in the Vacuum Dewar

Jack Welch and Matt Fleming

Summary

It is practical to cool the entire ATA PLP feed in a dewar to a temperature of the order of 70K with a modest refrigerator connected just to its large end. The thermal conductivity of both the pyramid and the feed arms is adequate to maintain a small temperature difference between the feed tip and the refrigerator in the presence of the 300 Kelvin infrared environment. The total infrared thermal load on the refrigerator is estimated to be about 2.5 watts.

Introduction

In an earlier memo, we proposed to use small capacitors made from AlN in the input matching circuit to transfer heat between the feed arms and the pyramid. While this material has high enough thermal conductivity to transfer the heat, its dielectric properties are highly dispersive and not suitable to serve as a high frequency capacitor. Here we investigate heat transfer along the pyramid and feed arms and find that with reasonable dimensions in the pyramid and feed arm fins heat transfer along the feed is adequate to maintain a small temperature drop between the feed and the refrigerator connected to the back end of the feed.

We consider the pyramid and the feed arms separately.

I. The pyramid. Figure 1 shows one face of the pyramid. The heat flow will be the same for all four of its faces. The pyramid angle is 10 degrees. x=0 is the vanishing point. The tip begins at .674" (1.712 cm) and is .118" (.300 cm) wide. The big end is at x= 21.973" (55.81cm). The half width of the pyramid face at a point x is y = ax, where a = .0875 radians. The pyramid is made of high thermal conductivity copper with a clean surface.

Figure 1 -

The distribution of the infra red flux incident on the pyramid is complicated by the presence of the feed arms above it. A detailed calculation of the flux strength is not simple because the high reflectivity of the copper on both the pyramid and the feed arms implies many bounces of the radiation before it is absorbed. Because of the many bounces, it could be close to the incident value of 300 Kelvin, and we simplify the discussion by assuming it to be exactly the 300 Kelvin, even though it may be somewhat less. $H_0 = \sigma T^4 = 5.7\text{x}10^{-12}(300)^4 = .045$ watts/cm^2. For clean copper, the absorption coefficient is $\varepsilon = .03$, or less with gold plating. The infrared heat absorbed in the strip of length dx and width 2y is $dH = \varepsilon H_0\, 2\, ax\, dx$. The total heat absorbed for $x < X$, which must be flowing in the positive x direction at $x = X$ toward the cold refrigerator is:

$$H(X) = \int \varepsilon H_0\, 2\, ax\, dx = \varepsilon H_0\, a X^2 \qquad (1)$$

Starting the integral at x=0 simplifies the formula and causes only a small error. The total power absorbed by all four faces of the pyramid, which has a surface area of 1074 cm^2, is about 1.7 watts, and this must be taken up by the refrigerator.

The heat flow along the face of the pyramid toward the refrigerator must have an associated temperature gradient, dT/dx, at X.

$$H(X) = k\ (\text{cross-section area})\ dT/dx = k\ 2aX\ t\ dT/dx \qquad (2)$$

t is the thickness. For the range 15cm < x < 55.8cm, t = 1/8" = .318cm. For x < 15cm, the pyramid is essentially solid so that the heat can flow with very little temperature gradient. For x > 15 cm, there will be a finite gradient. Equating (1) and (2), we can solve for the temperature gradient:

$dT/dx = -[\varepsilon H_0\ X]/\ 2kt$. For pure copper, k = 6.5 watts/cm k^0 at 70K, and $dT/dx = -.0003x$. The total temperature drop over the outer part of the pyramid.is:

$$\Delta T = -\int (.0003x)\, dx = .00015[(55.8)^2 - (15)^2] = -.5\text{ K}.$$

There is very little temperature drop between the pyramid tip and the refrigerator.

II. The feed arms. Here there is more temperature drop, because all of the heat must flow along the small fin of the feed arm. Figure 2 is an outline of a feed arm with a cell with one pair of tines. One triangular tine on one side has half the area of the approximately rectangular area that contains it. It is the same for the tine on the other side, and from the figure it is evident that the tines occupy one forth of the area of each cell. Because the 300K infrared radiation is absorbed on both sides, the overall absorbing area is half of the arm area.

Figure 2 -

The opening angle of the arm is 20^0 as compared with the 10^0 of the pyramid. The width at a point x is w=.349x, for the 20^0 angle. The element of absorbing area is w/2 dx. The element of heat absorbed is $dH=\varepsilon H_0 .175 x dx$, and the total absorbed for $x < X$ is:

$$H(X) = \int \varepsilon H_0 .175 x dx = \varepsilon H_0 (.087)X^2 \quad (3)$$

Figure 3 –

Figure 3 is a cross section of the feed showing the position of the arm next to the pyramid. The fin is along the center line of the feed and expands beneath the arm with an angle of 2.25^0. Its thickness is .01"(.0254cm) for the small end which extends up to about 6"(15.24cm). For the longer range out to 55.8 cm, its thickness is .03"(.076cm). The height of the fin with its angle of 2.25^0 is h = .0402x, and, with its thickness of .0254cm in the small region its cross sectional area is A = (.0402x)(.0254). The heat flow at x=X is:

$$H(X) = - k \text{ Area } dT/dx = - k(.001) X dT/dx \quad (4)$$

Equating (3) and (4) as before, we find $dT/dx = -\varepsilon H_0 (.087)X/ k(.001) = -(.020)X$. With $dT = -.020 x dx$, the temperature drop between x= 1.71 cm and 15.24 cm is:

$$\Delta T = \int -.020 x dx = -.010 [(15.24)^2 - (1.71)^2] = -2.29 \text{ K}.$$

For the long section of the feed, the main difference is the fin thickness which is now .030"(.076cm) which reduces the gradient by a factor of three. The total temperature drop in this case is:

$$\Delta T = \int -.0066\ x\ dx = -.0033[\ (55.8)^2 - (15.24)^2\ ] = -9.5\ K$$

Adding to this the -2.3 K from the short section, we get a total of -11.8K temperature drop from the feed tip to the refrigerator. The total area of the feed arms is half that of the pyramid, and the thermal load of the arms is half that of the pyramid, .85 watts. The total thermal load on the refrigerator is about 2.5 watts. The Sunpower Crystal GT cooler will easily have the capacity for this, and the STI Sapphire unit also might work.

The temperature drop along the arms is acceptable, but there appears not to be as much margin as one would like. The assumption that the space between the pyramid and the feed arms is filled with 300K radiation is conservative. More than half of the bounding surface of this region is at about 70K and the remaining surface is at 300K. So the radiation absorbed by the bottom surface of the feed arms may be closer to one half of the amount assumed in the calculation above. In this case, a smaller temperature drop for the feed arms would be expected. We consider the -11.8K calculation as conservative.

Figure 4- Details of the feed within the dewar. The glass is very thin near the tip and much heavier near the back end. It is largely transparent to the feed radio waves.

1/18/11

Expected Reduction in overall Tsys with lowering of the physical Temperature of the feed.

Transmission losses scale as R_s, surface resistance, for the copper of the feed lines and the pyramid. (?) (really?)

For the ATA feed (SB-0044-B4 Xpole), except for dip in Y factor @ 5.5 GHz
$\langle T_{rcvr} \rangle \cong 4.2$ dB up to 7 GHz : 4.2 dB = 54K
This is probably one of the better LNA's, ~ 12K is the LNA temp.
So 54 - 12 K = 42 K is from resistive losses

For lower physical temperature (~ 75K):
2 effects:
(a) lower R_s and (b) lower BB temperature (radiation)

(b) For the lower-radiation temperature @ 75K: 75/283 = .2650 (factor)

(a) lower R_s from I p. 118 : ρ (74K) = .189 ($\mu\Omega$ cm)
: ρ (283K) = 1.65 ($\mu\Omega$ cm)

$R_s = \sqrt{\frac{\omega\mu\rho}{2}} \propto \sqrt{\rho}$ $R_s'/R_s = \sqrt{.189/1.65} = .32$ (factor)

Both effects (.265)(x .32) = .0848 ≈ 1/12 ← ☆ ☆?

Then (42)(x .0848) = 3.6°K, new resistive contribution

With the same LNA, new T_{rcvr} = 3.6 + 12 = 15.6 K

Y(16K) ≅ 5.20 dB for feed and receiver

Adding in the antenna back ground of ~12K gives 27.5 °K total
about half of the ATA number.

Suppose the new physical temperature were 85K instead of 75K:
$\frac{85}{283} = .3004$; $R_s'/R_s = \sqrt{\frac{242}{1.65}} = .383$
.3004 x .383 = .1150 , x 42 = 4.8K , + 12 = 16.8K
+ 12 for the antenna back ground → 28.8 K total system

Note: $R_s \propto \sqrt{\omega}$

Mounts: Get new towers for the old BIMA pads

Hitite amplifier chips

MMC 460LC5 Qty 4 cost: $82.19 each
Hitite Microwave Corp. (978) 250-3343

4/28/011 Setting up for new feed noise Temperature

Use the EXA N9010A Spectrum Analyzer as detector

Estimate its noise temperature at input.

DANL at 1GHz with minimum Resolution Band Width is −150 dBm with no preamp, and −162 dBm with the optional preamp. Our unit has no preamp.

$KTB = 1.4\times10^{-23}$ (with $B = 1\,Hz$) $= -150$ dBm $= -180$ dB watts.

$10\log(1.4\times10^{-23}) = -228.5 \quad +180 = -48.5$

$KTB = +48.5$ with $B = 1$, and K multiplied in.

Hence $T = 70{,}294K$ for the SA.

The LNA has a mean gain of 28 dB and a noise temperature (average) of ~18 K

Relative to 300 K, it's noise figure is:

$(n_{LNA}-1)300 = 18K$ and $n_{LNA} = \frac{18}{300}+1 = 1.06$

Connecting a single Hittite amp. with $n = 2.5$ dB $\Rightarrow 1.8$ (240K) (G=15) and with an LNA gain of 28 dB (630),

$g \quad N \to [N_1] \xrightarrow{g_1} [N_2] \xrightarrow{g_2}$

overall $N = N_1 + \frac{N_2-1}{g_1} = 1.06 + \frac{1.8-1}{630} = 1.0613$

for $n = 1.0613$

$T = (1.0613-1)300 = 18.4K$ only 0.4K higher.

The combination gives a gain of $g_1 g_2 = 28+15 = 43$ dB and $n = 1.0613$ (18.4K)

43 dB → ~20,000

If we connect this up to the SA with its $T = 70{,}000$

Relative to 300 K, $(n_{SA}-1)300 = 70{,}000$, and $n_{SA} = 234$

It's effective input noise is $N_{LNA} + \frac{N_{SA}-1}{20{,}000} = 1.0613 + \frac{234-1}{20{,}000}$

$= 1.0613 + .0117 = 1.0747$

$(1.0747-1)300 = 22.4K$ ~ 4K higher than the LNA and Hittite together is 18.4K

If we include the cable loss of ~ 5dB. (7dB) max @ 20 GHz)

get $1.0613 + .0390 = 1.1003$; 30K

5/12/011
Gain of Cabin's 2 Hittite box

The Hitite evaluation board is difficult to use since it has no input and output capacitors.
← We should be able to manage with just Calvin's 2 chip box

Two problems: (a) The −10dB input setting of the SA has been in place
(b) The cable losses to get to the SA outside the room are as high as 20dB at 18GHz

Fixing the first problem is easy.
By putting the SA inside the screen room it's possible to get a shorter cable from the output of the hitite box to the SA ~3-4dB only

We are able to use a coaxial LN load for the noise figure measurement of the system, including hittite box, cable, and SA.

Y factor: $Y = \frac{T_R + 292}{T_R + 77.6} \Rightarrow T_R = \frac{292 - Y\,77.6}{Y-1}$ ← heating, ← LN — for LN reference

The ambient load is a small 50Ω coax load.

For the Hitite amps expect $N = 2.5\,dB$ (mod band) $\Rightarrow 1.8$ 190K

For the Hittite amp box, ~~cable, and SA~~ we measured ~ zero K.

For the SA, the expectation is $N \sim 233$, ~70,000 K

The 2 Hittite box has 23dB gain at 20GHz, and 30dB @ 100

The actual cable loss is ~3dB average for the shorter cable, which lowers the effective PAM to 23dB on average. So SA, cable, and PAM should have:

$$N \rightarrow N_{PAM} + \frac{N_{SA} - 1}{G_{PAM}} = 2.17 + \frac{233-1}{200} = 3.33$$

For the LNA: Gain is 28 dB → 27dB (500) with internal cable losses

$$\text{Final } N_{rec} = N_{preamp} + \frac{N_{PAM}}{G_{preamp}} = N_{preamp} + \frac{3.33}{500} = 1.06 + .0067 = \underline{1.0667}$$

With the 2 Hittite stage amps from Calvin connected to the SA with the shorter cable in the screen room, we get Y = 2dB with amb./LN loads at lower freqs and 1dB at higher freqs {There was also a large square wave modulation present – possibly the cryo cooler} Is this big problem?

6/1/011

This should work for Testing the LNAs

Final $N_{rec} = N_{preamp} + \frac{N_{PAM}}{G_{preamp}}$

If $T_{preamp} \sim 18K$ on the average, $N_{preamp} = 1.06$

$N_{rec} = 1.06 + \frac{3.33}{500} = \underline{\underline{1.0667}}$

A main problem here is that the single short piece of workhorse cable required that the SA be in the screen room with the feed. The SA will probably cause interference in the feed, so we must keep it outside of the screen room. Two improvements: (1) Add a Hitite evaluation board to the PAM; (2) Use the short length in the screen room and a very short piece of cable outside. This eval board has capacitors added to be it's input and output so that the chip amp will not have its DC biasing affected by, say, a 50Ω termination put at its input.

Some Noise Figures and Y factors

Y(dB)		T_R	N
2.5	(1.78)	198	1.68
2.25	(1.68)	238	1.815
2.00	(1.585)	292	2.00
1.75	(1.506)	352	2.205
1.50	(1.413)	364	2.25
1.25	(1.334)	562	2.925
1.00	(1.259)	747	3.56
0.75	(1.1885)	1050	4.60
.50	(1.12)	1709	6.85

Transmission of the cable: 6' workhorse for the screen room, 24" of silver cable for the run to the SA outside, 14" of blue cable at the input of the PAX Box

File Trace/Chan Response Marker/Analysis Stimulus Utility Help

Trace 2 Marker 1 15.0107000000 GHz

Tr 1 S12 LogM 10.00dB/ 0.00dB Tr 2 S12 LogM 10.00dB/ 0.00dB

> 1: 15.010700 GHz -5.4860 dB

2011-06-01 Loss 6' workhorse + 14" blue + 24" silver cables

50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00

1 >Ch1: Start 100.000 MHz Stop 18.0000 GHz

Print
Print...
Page Setup...
Print to File...
Transform

Cont. CH 1: S12 &Mem No Cor LCL

Final set-up 6/1/07

Y-factor measurements on the PAX case and connecting cables. There is a 14" cable run at the input which is roughly the run on the assembled new feed. The PAX is made up of Calvin's 2 Hilite box and a Hilite evaluation board with input and output added capacitors.

Y-factor measurements on the second stage:
with 14" of blue coax at the input of the PAX box. Between the PAX output to the SA is @ 6' piece of workhorse cable and 24" piece of silver coax. The 6' piece will be in the screen room and the silver will go from the wall to the SA outside the screen room.

$\Longrightarrow$

Y ≅ 2dB up to 9GHz, 1.75dB up to 14 GHz, and a slow drop to ~ 0.5'– 1.0 dB at 15GHz

Y factors, T_R, and N for the set up

Y(dB)		T_R	N
2.5	(1.78)	198	1.68
2.25			
2 dB	(1.58)	292	2.00
1.75dB	(1.506)	352	2.205
1.50			
1.25			
1.00	(1.259)	747	3.56
0.75			
0.5	(1.12)	1709	6.85

With 30dB LNA gain, Y(2.0dB) $\Longrightarrow \frac{292}{1000} = .29$K add on.
Y(1.0)dB) $\Longrightarrow \frac{747}{1000} = .75$K add on

With 28dB LNA gain, Y(2.0 dB) $\Rightarrow \frac{292}{631} = 0.46$K add-on
Y(1.0 dB) $\Rightarrow \frac{747}{631} = 1.18$K add-on

VACUUM
DRIVE

FAN
RIMBOX
CRYO
THERM
GAUGE
DIAPHRAGM
PUMP
VACUUM
DRIVE
OUT
ADJ
GND
IN
EN
(R5)
(C5)
NO
COM
NC
GND
GND
+24V
+48V
NO
NC
K1
(D2)
(diode +)
C
24V
(Q1)
Antonio Feed Monitor and Control (v 1.0)

Rob Ackermann

ackermann@seti.org (not working)
rob@ackrman.net (tried 9/10/2018)
510-936-8632 (sent text 9/10)
510-713-7146 (sent text 9/10)

Note on Possible Common Failure Type in New Feeds

Some of the Antonio feeds found to be nonfunctional share common features in the power spectrum. These are a repeating (broad) power comb at approximate harmonics of 530 MHz. A sampling of these are shown below. It is not immediately obvious whether this indicates a cause or just are a symptom of the failure.

Note that the iBobs were level-set to 11 counts RMS prior to taking the measurements, so it is likely that the signals near the peaks were clipping the ADCs. However, it is noted that these artifacts were still observed on a spectrum analyzer connected to the Rack-PAM, so are believed to be legitimate features of these failed feeds.

ATA Antonio Feed Comb Summary

Billy Barott/ 2018-08-20 Rev 01: Initial document

Summary

The beamformer was used in single-antenna mode to perform signal scans on the operational feeds at the ATA. Scans were created between about 550 MHz and 4500 MHz. A significant 8-MHz comb is present in all of the (usable) Antonio feeds. Additionally, some common wideband periodicity was seen in the nonfunctional feeds, which might indicate the failure mechanism. Key observations are:

- The comb is present on all Antonio feeds, but absent in the legacy feeds.
- The comb is visible on a spectrum analyzer using the Rack-PAM, so is not a SPR/DSP effect.
- No hypothesis is offered at this time for the origin of the comb.

For comparison, two antennas are shown side by side below. The left (1a) is a legacy feed. The right (2a) is a new feed. The comb is evident between 1 GHz and 2 GHz.

The table below summarizes the results. "Type" indicates the new (Antonio) feeds. "Comb" indicates whether the 8 MHz comb was observed. "Good" indicates results from the beamformer health check. Dashes indicate that the feed is bad or was not measured. The pages that follow contain individual spectra for each feed. A summary of the code is contained at the end of this report.

Ant	Type	Comb?	Good?	Ant	Type	Comb	Good?	Ant	Type	Comb	Good?
1a		No	XY	2e	New	Yes	XY	3j		No	-Y
1b		No	XY	2f		No	-Y	3l	New	Yes	XY
1c	New	---	--	2g		---	--	4e		No	X-
1d		No	XY	2h	New	(Bad)	--	4f		---	--
1e	New	---	--	2j	New	Yes	XY	4g		No	XY
1f		No	XY	2k		No	X-	4h		---	--
1g	New	Yes	-Y	2l		No	X-	4j	New	Yes	XY
1h	New	Yes	X-	2m	New	(Bad)	-Y	4k		No	XY
1j		---	--	3c	New	---	--	4l		No	-Y
1k	New	---	--	3d	New	(Bad)	--	5b	New	---	--
2a	New	Yes	XY	3e		No	XY	5c		No	XY
2b	New	Yes	XY	3f		No	--	5e		No	XY
2c		No	--	3g		---	--	5g		No	XY
2d		No	-Y	3h		---	--	5h		No	XY

It's Rob Ackerman's control board

2a (Antonio Feed)
Power (dB-Arbitrary)
85
80
75
70
65
60
55
50
500
1000
1500
2000
2500
3000
Freq (MHz)

(V)

LNA - Base 14" .085 - 1.46db/ft. @ 75K? no

60" of 141 to PAM amplifier at room temp.

10 GHz 141 .42db/ft at Room temp. | Take 3.8 dB for both (? temp) the .085 is at 70K

Call in to SETI's SETI telecon Thursday @ 1:00 PM

coax table IV p-89 Room temp. attenuation

a) .085 @ 75K 1.46db/ft @ room temp. {db = 10 log10(ratio)}

all at 10 GHz

Loss goes as $\sqrt{T}$

for the .085 cable @ 70K: 1.46 db/ft @ 300K.

14" length: 1.70db?

$\frac{db}{10} = \log_{10}(\text{ratio})$

e.g. $\frac{3}{10} = \log_{10}(\text{ratio})$; $.3 = \log_{10}(2)$ ✓ i.e. $3db \Rightarrow 10\log_{10}(2)$

12" of (085) has 1.46db loss. 1.46 db → 1.3996 (ratio)

12": -1.46 db → .715 (ratio)

14": .613 ratio at room temp.

@ 75K, not 300K, get a factor of $\sqrt{\frac{75}{300}}$ less loss. i.e. $\frac{1}{2}$ the loss rate

i.e. 0.306 for the loss part, or 1-.3 = .7 for the transmission

The cable absorption of a factor of .3 is at 75K, which gives an addition of 25K of noise to the signal (It seems high)

It has to depend on the gain in front of the absorbing cable, which is the LNA.

Agilent Spectrum Analyzer - Swept SA
50 Ω
AC
SENSE:INT
ALIGN AUTO
01:26:18 PM Jun 01, 2011
Marker 1 15.001750000000 GHz
Input: RF
PNO: Fast
IFGain:High
Trig: Free Run
#Atten: 0 dB
Avg Type: Log-Pwr
TRACE 1 2 3 4 5 6
TYPE A A W W W W
DET S S f N N N
Export Data
Amplitude Correction 1
Trace All
Limit 1
Meas Results Peak Table
Save As ...
Mkr1 15.00 GHz
-65.45 dBm
2 dB/div
Log
Ref -62.00 dBm
-64.0
-66.0
-68.0
-70.0
-72.0
-74.0
-76.0
-78.0
-80.0
Trace 2023 noise pre amp with workhorse, blue + silver cables
Center 9.050 GHz
#Res BW 5 MHz
#VBW 10 kHz
Span 17.90 GHz
#Sweep 300 ms (401 pts)
MSG
File <Trace_2023 noise pre amp wh_blue_silver cables .csv> saved
STATUS
Meas Uncal

Test of ATA LNA in the new feed ~6/15/2011

$\Longrightarrow$

The LNA is unstable. However, with I_d set at 50.4 mils with $V_d = 1.72$ and $V_g = 0.86$ and $V_m = -0.88$, we get an intriguing Y factor measurement. Instability is evident near 4-6 GHz and 14-15 GHz. In between Y = 4.5 - 5.0 dB 40°K - 22°K. This is in the range of real interest. At higher I_d, it breaks up.

5C, X-pole, ABB-031, Test 15 Noise Ratio
Various Bias Settings, 2010-06-04

oscillating

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz	
024 Ratio	-0.98	0.86	1.72	50.4	9.41	6.68	4.61	(-55.30)
025 Ratio	-0.98	0.86	1.72	50.4	6.39	4.76	4.38	(-65.46 dB @ 6 GHz)
026 Ratio	-0.98	0.86	0.57	32.3	1.47	2.05	0.68	(-69.08)
027 Ratio	-0.98	0.86	0.73	35.4	5.05	3.35	2.55	(-64.63)
028 Ratio	-0.98	0.86	0.61	33.1	2.60	2.54	1.06	(-64.58)
029 Ratio	-0.98	0.86	0.64	34.2	3.44	3.02	1.53	(-60.52)

JPL LNA tested in the new feed.
Both pols show some gain. One is very weak.
Neither pole showed better than Y ≅ 0dB.

6/25/2011

The glass thickness, .055 ≅ 1.5mm, is substantial and will cause significant reflections @ 15GHz.

<u>Estimate the reflection</u>

The waves

$$E_{r_1} = \frac{1}{r\ln(b/a)}\left\{V_+^1 e^{-jk_g z} V_-^1 e^{jk_g z}\right\}$$

$$H_{\phi_1} = \frac{1}{r\ln(b/a)\eta_g}\left\{V_+^1 e^{-jk_g z} - V_-^1 e^{jk_g z}\right\}$$

in the glass

$$E_r^2 = \frac{1}{r\ln(b/a)}\left\{V_+^2 e^{-jk_t(z-l)}\right\}$$

$$H_\phi^2 = \frac{1}{r\ln(b/a)\eta_t}\left\{V_+^2 e^{-jk_t(z-l)}\right\}$$

in the teflon

The Input voltage due to the LNA output is $V_{in} = \int_a^b E_{r_1}\Big|_{z=0} dr$

$$V_{in} = \int_a^b \left\{\frac{1}{r\ln(b/a)}\left[V_+^1 + V_-^1\right] dr\right. = V_+^1 + V_-^1$$

$$\boxed{V_{in} = V_+^1 + V_-^1}$$

<u>leaving out the source impedance</u>

Continuity of E_r and H_ϕ at $z = l$

$$\boxed{V_+^1 e^{-jk_g l} + V_-^1 e^{jk_g l} = V_t^2}$$ for tangential E

$$\boxed{\frac{V_+^1 e^{-jk_g l} - V_-^1 e^{jk_g l}}{\eta_g} = \frac{V_t^2}{\eta_t}}$$ for tangential H

With some algebra find

$$\boxed{V_t^2 = \frac{2V_{in}e^{jk_g l}}{\left[\left(1+\frac{\eta_g}{\eta_t}\right)\left(1+e^{2jk_g l}\right) - \left(\frac{\eta_g}{\eta_t}\right)\right]}}$$

The source voltage and input impedance are not included. If the match is good $V_{in} \cong \frac{1}{2}V_o$, the source voltage, and

$$V_t^2 \cong \frac{V_o e^{jk_g l}}{\left[\left(1+\frac{\eta_g}{\eta_t}\right)\left(1+e^{j2k_g l}\right)-\left(\frac{\eta_g}{\eta_t}\right)^2\right]}$$

The phase term $e^{2jk_g l}$ is significant.

$$2k_g l = 2k_o\sqrt{\epsilon_g}\, l = 2\{\omega\sqrt{\mu_o\epsilon_o}\}2l = 4k_o l$$

$k_o = .2095 f_g \ \text{cm}^{-1}$

At 15GHz, $2k_g l = 2\cdot 2\cdot k_o l = 4(.2095 f_g)(0.15\ \text{cm})$
$= 0.1257 f_g$

At 15GHz, $2k_g l = 1.885$ radians.

A more self consistent solution that largely ignores the problem of exciting the input to the glass from the microstrip line from the mimic gives the following.

$\epsilon_2 = 2$, $\epsilon_1 = 4$ (glass)

This should minimize the effect of the glass

$$\eta = \sqrt{\frac{\mu}{\epsilon}}$$

Similar algebra as above produces:

$$V_t^2 = \frac{4A}{\left\{e^{jk_g l}\left(1+\frac{\eta_g}{\eta_t}\right)\left(1+\frac{\eta_t}{\eta_g}\right)+e^{-jk_g l}\left(1-\frac{\eta_g}{\eta_t}\right)\left(1-\frac{\eta_t}{\eta_g}\right)\right\}}$$

For $l = 1.5$ mm and $f_g = 15$ GHz

$\left|V_t^2/A\right|^2 = 0.67$ $\underline{-1.7\text{dB}}$ This is optimistic since it ignores the problem of coupling the stripline to the glass bead in the transmission line.

7/20-21

We skip the idea of replacing (or not using) the hermetic output connection on the LNA board.

Next, we just use 044B LNA (a really good one with lot of gain) and both Hitite units in the PAX box.

First try keeps the separate bias wires up to the base plate of the dewar and then runs unshielded wires to a connector on a standoff from the baseplate from the outside connector baseplate connector.
Instabilities are observed at full LNA gain

Interim: the Hitite interconnection RF cables are checked out and some SMA connections are switched out.
Instabilities are still observed at high LNA gain.

Next steps: Shield all LNA bias and temp. sensor cables in the dewar and from the back of the backplate up to the power supply connections.

Next cool down 7/28-29

a) Second stage gain adjusted to keep out the strong oscillations. Only the first IF amp in the PAX box is kept. No oscillations are observed at best bias settings.
b) Cool down: LNA appears very weak. Something failed. Again come on the spiral antenna using the Agilent NA shows about 30dB less signal than had been observed.

⇒ NB In the warm-up at ~ 190K, the full transmission curve in the test with the NA reappeared!

Further tests made with 044B LNA It works most of the time.

Major improvement in the feed operation and Testing when the Workhorse cable in the screen room is replaced with a length of semi-rigid .141 coax. All the instabilities vanish. Both second stage units can be used. A second improvement is bringing the output from the PAX box out at the top, away from the dewar.

Published results from EVLA memos for Tsyp

memos: #128, #137, #152 [Background is included]

There is a range of temperatures over all (or most) of the EVLA ants.
They use 3C286 and Baars et al (1977) paper

L-band Teff = 60K-80K ⇒ X 0.4 (eff) ⇒ 24K - 32K ; ave = 28 K
60K-100K

#128 C-band Teff range = 45K-65K ⇒ X 0.6 ⇒ 27K-39K ; ave = 33K
4700 - 4900

X-band Tsyp range = 50-65K ; ave = 57K = Tsy/ε ; Tsy ≈ 30-40K
#128

K-band Tsyp = 150-240 ; ave = 195K

Y factor measurements of Tsyp using LN with .25dB correction

$$T_{syp} = \frac{292 - 77.6\left[10^{Y/10}\right]}{\left[10^{Y/10} - 1\right]}$$

Further tests near end of August show good results except for a drop out in YF at ~ 0.9 GHz intervals. There is also quite a lot of structure in the noise spectra for both the low and high temperature. One possibility is that the two noise measurements are made with the dewar moved. To avoid this problem, the tests are repeated with the hot and cold loads moved up to the feed, so that no cables are flexed. This made no difference. Also, leaving out the second amp. stage in the PAM box made no difference.

The Y-factor of the PAM with both amplifiers is shown here →

The peak-peak in the spectral fluctuations is ~1dB, probably due to cable connections in the PAM box. They cancel nicely in the Y-factor

PAM Tfactor

Agilent Spectrum Analyzer - Swept SA

50 Ω | AC | SENSE:INT | ALIGN AUTO | 05:00:30 PM Aug 04, 2011

[redacted]

Input: RF | PNO: Fast | IFGain:High | Trig: Free Run | #Atten: 0 dB | Avg Type: Log-Pwr

TRACE 1 2 3 4 5 6
TYPE A A W W W W
DET S S f N N N

2 dB/div Log | Ref -58.00 dBm

-60.0
-62.0
-64.0
-66.0
-68.0
-70.0
-72.0
-74.0
-76.0

Trace 2075 X backend noise

Center 9.050 GHz
#Res BW 5 MHz
#VBW 10 kHz
Span 17.90 GHz
#Sweep 300 ms (401 pts)

Trace/Det
Select Trace
Trace 2
Clear Write
Trace Average
Max Hold
Min Hold
View/Blank
View
More
1 of 3

MSG | STATUS ! Meas Uncal

The "hot" and "cold" spectra overall and the Y factor

Labeled Y factor test with EVLA results shown.

(See pp 126–131 for the cure to this problem)

8/31 p. 135 shows new NF results; also p. 85

The main problems on the previous pages are (a) the sharp drop outs at ~0.9 GHz intervals and (b) the complicated noise spectra. The periodicity in the noise spectra match the periodicity in the drop outs. One possibility is the lack of a good ground at ☆ the top of the ~~[illegible]~~ straining for the coaxial cables.
Whereas the p-p fluctuations in the PAH cancel, giving a relatively smooth result, those in the overall, including the front end, do not. The positive excursions cancel whereas the negative ones do not!?

One problem is the open stub due to propagation down the outside of the small coax from the tip. There is absorber near the bottom of the small coax. It should have eliminated the effect of this mode.

A more important problem is the lack of a ground of the small coax up at the tip. That is, the small coax lengths being not grounded leaves their length as an open stub in series with the connection between the antenna and the LNA. ☆

There is now just a small amount of capacitance to ground near the tip. The transmission to the LNA from the feed shows periodic structure.

This is in addition to the sharp drop outs with about the same period of about ~1 GHz.

9/10 Putting the ground in did not help. It did not make any difference. It appears that there is a bad connection to the LNA.

12/00/2011

None of the above changes in the grounding made any difference. A look at the antenna input match on p 42 shows that the match is good ≤-10dB, and should not cause the Y-factor problems of p 78 and 79.

Some steps that did help were (a) using semi-rigid cable on the 2nd IF input, which suppressed the oscillation in the screen room! There seemed to be feedback between the "work horse" cable and the feed; and (b) leaving the semi-rigid cable fixed in it's connections and the feed position fixed and moving the hot and cold loads up around the feed rather than moving the feed. At this point there were stable, repeatable, measurements and no dropouts.

Greg suggested that using a Fluke Ohmeter to test continuity of the LNA hook-up could damage the LNA. He had found such problems. In view of this, we began to suspect that we were damaging the LNA's and this was the reason that, e.g. 044 no longer worked well and showed a bad input match

---

12/05 We then borrowed another LNA from the ATA for testing; SB-081. It's last test (previous test) had been made before the new SA was in use. It showed the characteristic low Y values at lower frequencies and Y ≥ 4dB near 6-7 GHz, which became Y ≥ 4 dB over the whole range with the ~~HP~~ SA. We assumed that it was a good LNA with Y ≥ 4dB over the whole range. We also were very careful in installing on the new feed: no Fluke tests, minimal soldering changes.

The gain curve using the spiral transmitter antenna is on the next page. Gain curves for a range of bias levels appear on the next page.

File Trace/Chan Response Marker/Analysis Stimulus Utility Help
Channel 1
Power Level -10.00 dBm
Tr 1 S12 LogM 10.00dB/ -30.0dB
Tr 2 S21 LogM 10.00dB/ -30.0dB
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
X pole 300K -081
Y pole 300K -044
Meas
S11
S21
S12
S22
Receivers...
Measurement Class...
Transform
Cont. CH 1: S21
No Cor
LCL

Power -10 dB
Tip to spirol gap 5"
5C, X-pole, ABB-081
Test 14 Gain, 2011-12-05
Gain (dB)
Frequency (GHz)
20
10
0
-10
-20
-30
-40
-50
0
1
2
3
4
5
6
7
8
9
10
11
1
File Temp Vm Vg Vd Id
2120 81K -0.98 0.82 1.70 73.4
2121 81K -0.98 0.82 1.51 69.5
2122 81K -0.98 0.75 1.51 64.6
2123 81K -0.98 0.65 1.52 58.7
2124 81K -0.98 0.65 1.42 56.7
2125 81K -0.98 0.55 1.43 51.3
2126 81K -0.98 0.46 1.43 46.4
2127 81K -0.98 0.45 1.34 44.5
2128 81K -0.98 0.36 1.34 40.1
2129 81K -0.98 0.35 1.25 38.6
2130 81K -0.98 0.27 1.25 34.8
2131 81K -0.98 0.17 1.25 31.6
2132 81K -0.98 0.37 1.34 40.8
2133 81K -0.98 0.37 1.44 42.5

The following two graphs show the effect of the cylindrical standoffs, no stand-offs at positions 1 and 2, and the thin rexolite stand-offs on two different feeds. The thin rexolite panels largely remove the K factor dips at 3.8 and 5.0 GHz. Also shown are the projected Y factor curves for the new feed.

The third graph shows the measured Y-factor on SB-081 mounted in the new feed and cooled down. Also shown on the right is the expected total Tsyp, assuming a 10% background addition. The addition is 12K in the first slide).

~~The third slide shows the measured Y-factor with SB-081~~
The specified error, ±.23dB, for the #2010A Agilent Spectrum Analyzer is shown as an error flag (±.23dB) in the upper right corner.

In the forth slide the new feed Y factor is shown with a projected noise factor superimposed. The agreement is striking.

An interesting point about the new feed measurement is that the LNA temperature was 80K, not the 70K expected from earlier measurements. Getting to 70K for the LNA could mean lowering the feed noise temperature by a few Kelvin.

DI CAPS

PART NUMBER: D35 CF 0R5 A 1 P X

Size 35

W =	0.0350	+/- 0.0050
L =	0.0300	+/- 0.0100
T =	0.0070	+/- 0.0020

◉ in ○ mm

Material CF

Cap (pF) 0.5

Voltage 100

Tolerance A: ± 0.05pF

Termination P: TiW/NiV/Au (Sputter plated)

Test Code X: Commerial

Series Model

Rs(Ω)	0.198
Rp(KΩ)	49.0
Ls(nH)	0.05
C(pF)	0.5
Fs (GHz)	31.878

Series/Parallel Model

Rs(Ω)	0.198		
Rp(KΩ)	49.0		
Ls(nH)	0.066		
Cs(pF)	0.38		
Cp(pF)	0.12		
Fs (GHz)	31.878	Fp (GHz)	64.418

Add Lead Inductance

Inductance (nH): 0.0

Fs (GHz) 31.831

Graphing Links: Series Shunt T-Line

Acceptable Temp Range -55 to 125 (°C)

Temp (°C) 25

Frequency 1.000 (GHz)

SETI / ATA D Eng 1 / 30-28 Cryo Cooler / Reference Info / Tsys Equation.xls

$$Tsys = \frac{(292) - (77.6)10^{Y/10}}{10^{Y/10} - 1}$$

Tsys = (292 - 77.6*10^(Y/10)) / (10^(Y/10) - 1)

Yg / b (dB)	77.6 Tsys LN (Kelvin)	10.0 Tsys Sky (Kelvin)
1.00	750	1079
1.50	442	674
2.00	289	472
2.20	247	418
2.40	213	372
2.60	184	334
2.80	159	301
3.00	138	273
3.20	119	249
3.40	103	227
3.60	88	208
3.80	76	192
4.00	64	177
4.20	54	163
4.40	45	151
4.60	36	140
4.80	29	130
5.00	22	120
5.20	15	112
5.40	9	104
5.60	4	97
5.80		91
6.00		85
6.20		79
6.40		74
6.60		69
6.80		64
7.00		60
7.20		56
7.40		53
7.60		49
7.80		46
8.00		43
8.20		40
8.40		38
8.60		35
8.80		33
9.00		31
9.20		29
9.40		27
9.60		25
9.80		23
10.00		21
10.20		20
10.40		18
10.60		17
10.80		16
11.00		14
11.20		13
11.40		12
11.60		11
11.80		10
12.00		9
12.20		8
12.40		7
12.60		6
12.80		6
13.00		5
13.20		4

Measured and Expected Feed/Receiver Performance

Noise Ratio, System Temperature vs Frequency
Current ATA Feed 4 and Projected ATA Feed 5

Final good Y-factor results for the new cooled feed!

5C, X-pole, ABB-081, Test 15 Noise Ratio
Various Bias Settings, 2011-12-05
+.25 dB for load emmisivity
SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio
2010-04-08
Analyzer error spec
ATA Tsys = 16.5°K
ATA Tsys = 32°K
ATA Tsys = 50°K
ATA Tsys = 74°K
ATA Tsys = 105°K
ATA Tsys = 148°K
ATA Tsys = 208°K
NOTES
Cold load less effective below 3.0 GHz
Used PAX / PAM & EXA N9010A Spectrum Analyzer
Ratio (dB)
Frequency (GHz)
6.5°K
22°K
40°K
64°K
95°K
138°K
198°K
Vm Vg Vd Id
120 73.4
121 Ratio
122 Ratio -.98 5 1.51
123 Ratio -.98 .35 1.52
124 Ratio -.98 .65 1.42 56.7
125 Ratio -.98 .55 1.43 51.3
126 Ratio -.98 .46 1.43 46.4
127 Ratio -.98 .45 1.34 44.5
128 Ratio -.98 .36 1.34 40.1
129 Ratio -.98 .35 1.25 38.6
130 Ratio -.98 .27 1.25 34.6
131 Ratio -.98 .17 1.25 31.6
132 Ratio -.98 .37 1.34 40.8
133 Ratio -.98 .37 1.44 42.5

12/15/2011

The current location and recent upgrade status of feeds at Hat Creek. There are 9 feeds at Minex being repaired. Three are about ready to get back

ANT #	ANT NAME	FEED #	STATUS	
0	00			
1	1A	SB-017	*	*
2	1B	SB-039	*	* ?
3	1C	SB-029		
4	1D	SB-028		
5	1E	SB-025		
6	1F	SB-043		
7	1G	SB-010	*	
8	1H	SB-021		
9	1J	NO FEED		
10	1K	SB-008		
11	2A	SB-030		
12	2B	SB-036	*	*
13	2C	SB-012		
14	2D	NO FEED		
15	2E	SB-046	*	
16	2F	SB-019		
17	2G	SB-0027		
18	2H	NO FEED		
19	2J	SB-040		
20	2K	SB-041		
21	2L	NO FEED		
22	2M	SB-045	*	
23	3C	NO FEED		
24	3D	SB-015	*	
25	3E	SB-031	*	*
26	3F	SB-044	*	*
27	3G	SB-003	*	* ?
28	3H	SB-005	*	
29	3J	SB-007		
30	3L	SB-032		
31	4E	NO FEED		
32	4F	NO FEED		
33	4G	NO FEED		
34	4H	SB-037	*	
35	4J	SB-016	*	
36	4K	SB-023		
37	4L	SB-014		
38	5B	SB-013	*	
39	5C	SB-038	*	
40	5E	SB-024	*	
41	5G	SB-022		
42	5H	NO FEED		
			Caps and Loops Installed	New Standoffs Installed

The good pattern data is in the Desktop folder:
"\Desktop_\ATA_feed". There are many other useful files and the New ATA feed, including Greg's pattern calculations and the ppt describing all the parts that need to be upgraded for the new feed.

"Delay_corrected_feed_patterns" contains both X and Y pol patterns for 2000, 5000, 6000, 7000, and 12,000 for 0°, 45°, 90°, 135°, +180°

There are also No Bottle Patterns for the Y-pole (180°)

EVLA memos for comparison

Friday PM for alarm system upgrade (Also page 74)

#152 (May 2, 2011) .95 - 2.0 GHz — 3C286 used — using Baars et al (1977)

They had new OMT and 4th cryogenic compressor.
0.93 efficiency of Wider correlator
SEFD is ~325 for 1250 - 1420, ~400 up to 1800.

$$RMS(Jy) = \frac{1}{\eta_c K_{ks}} \frac{SEFD(Jy)}{\sqrt{\beta \tau}}$$

#137
x-band { eff. Tsyp vs. freq: (eff Tsyp/ε) 8200 - 8600 MHz
range from 50 - 65K for VLA, about the same for EVLA.
K-band 150 - 240K for VLA and about the same for EVLA
Q-band (42.8 - 44.8) 300 - 700 K for VLA, a little tighter (300 - 600) for EVLA

#128 (?) @ 60% = η_A at x-band $\frac{50-65}{\eta_A}$ ⇒ 30K - 40K <35K>

K-band: (150 - 240) × .6 = 90 - 144K

Lband (from #128) Teff: 60K - 80K ⇒ × 0.4 ⇒ 24K - 32K <28>K

Cband (EVLA) Teff range: 45K - 65K × 0.6 ⇒ 27K - 39K <33>K

for Y = 3.0 dB $T_{sy} = \frac{292 - 77.6\,[10^{Y/10}]}{10^{Y/10} - 1}$

$10^{.3} = 1.995 \cong 2.0$

$T_{sy} = 137$ ✓

C-band 5-8 averages

33K

for Y = 5.2 dB, T = 15.16 ✓
for Y = 6.0 dB, T = negative!

Long Baseline Study (Dave Deboer)

In order to increase the spatial resolution of the ATA it would be possible to exploit the existing infrastructure to add additional longer baselines. The infrastructure in this instance is the foundation work, fiber connectivity and available power at the 6 former BIMA stations to the east and north of the ATA. The map below shows the BIMA locations. The purple lines are the underground fiber lines.

Each pad could hold up to two ATA antennas, so if new antennas were built, the array would comprise 54 antennas. The study here focuses on moving 6 of the ATA antennas to the locations keeping the total at 42.

The table below lists some key parameters for the proposed new baselines, which are discussed more fully in the subsequent text.

Table I: Overall parameters of the proposed new stations.

#	Longest Baseline [m]	F/O Delay [m]	Pad	Fiber
2200E	1864	690	IMG_3281	IMG_3282
1500E	1656	450	IMG_3290	IMG_3287
1740N	1049	600	IMG_3294	IMG_3297
2700N	1170	980	IMG_3298	IMG_3302
3270N	1307	1190	IMG_3303	IMG_3306

4320N	1864	2005	IMG_3310	IMG_3312

The Figure below shows a histogram of the difference without the outer stations (top) and with the outer stations (bottom). It is on a log plot to highlight the inclusion of the long baselines. For the bottom plot, an essentially arbitrary six antennas were removed from the original ATA-42. An optimized study with several figures-of-merit was conducted on which six to remove, which has relatively little effect on the plot.

The principle expenses for the proposed reconfiguration are: new pedestals, preparation of the new foundation, air-handling, additional fiber to equalize the signal path, labor, wastage/contingency. These are briefly discussed below, and Table II contains a summary of costs.

1 – Pedestals

The most effective way to move the antennas is to remove the antenna structure at the turning, which is the reverse of the assembly process (see picture). The pedestals themselves are grouted into the foundation and will remain in place. There currently exists a spare pedestal assembly, so only five new assemblies are needed. The estimated delivered cost per pedestal for quantity five is $8,000.

If two new antennas are put at each pad for an array total of 54 antennas, the baseline distribution is shown below.

Or linear... hmmm maybe not keep?

2 – Foundations

The BIMA pads upon which the antennas will be relocated is a solid reinforced concrete surface which can be utilized to minimize the foundation cost. One of the ATA tripod legs will be bonded directly into the deep BIMA mounting pad and the other two will tie into the surrounding apron. Estimated cost per foundation for quantity six is $5000.

3 – Air-handling

The ATA antennas incorporate a novel underground-coupled air-cooling system in order to minimize O&M costs. Each antenna location will need a blower, housing and up to 100 feet of underground PVC. Estimated cost per antenna for quantity six is $2000.

4 – Fiber-optics

The existing ATA system is designed to handle the inherent delay of the existing antennas. Since the new baselines are long baselines, a fiber equalization path must be installed on the remaining 36 antennas not being moved, as well as onto the some of the shorter five new locations. Note that for the existing array, the average fiber run is about 450m, with a maximum length of 610m and a minimum length of 250m. Bringing all of the fiber run lengths to 2000 m will require the purchase of 130 km of fiber. These will remain on spools and installed in a thermally controlled chamber adjacent to the ATA Signal Processing Room. The cost of the fiber is estimated at $30/km plus connectors etc. and the cost of the installation/chamber/etc. is estimated at ZZZ.

5 – Labor

The installation would be done by existing RAL staff in a "campaign" mode after a short design period. If the site has been shut down but the existing Hat Creek staff are available they would also be brought in.

6 – Wastage/contingency

Inevitably in any process of moving equipment there is the prospect for damage or destruction of some components in the process. Additionally, it is desired to retain the infrastructure for the existing locations intact. This means that a larger than usual contingency is required for a project of this sort.

Item	Unit cost	Total
Pedestals	$8,000 ea	$40,000
Foundations	$5,000 ea	$30,000
Air-handling	$2,000 ea	$18,000
Fiber-optics	$30 fiber /km $YY /connector $ZZZ chamber ea	$3,900
Labor		
	Contingency	
	Overhead	
	TOTAL	

Added fiber needed (CWDM specifications)

single mode fiber, the last time purchased, was $50/km.
link loss is ≈ 0.4dB/km at 1550 nm of wavelength

For lab3 run to be compensated will require ~1.5dB loss worth of cable. That amount adds to connector losses, and the total adds to the link noise figure.

How about head room in the Link?

For redundancy we need 4 single mode fibers/antenna.

What else?

Fan for airconditioning

A. Underground PVC pipe (out and back) at each remote station
~ 100 foot round trip at each pad.

B. provision for two antennas per pad.

C. The cost of new antenna towers at each distant pad.
~~with~~ They can probably share the underground existing pipes at each pad

D. Painting all of the antennas. (what is said about this in our agreement with USFS?)

E. Move the antennas out, leaving the towers behind for newly built (whenever) antennas/feeds/rcvrs

---

Additional Cable in front of every antenna.
Assume 4km of fiber length for each polarization. Total is 8km. @ $50/km, that's $400 worth of cable for each old antenna. That's a small addition to the cost of each antenna. With 2 ants at each of 6 pads, that's 12 being moved and 30 remaining
Total cost is $400 x 30 = $12,000 total.

8mi @ 1/2 power

Calvin's current price is $30/km for a minimum order.

Defocus curves for the new feed.

from IV 63, 64, 70

Phase error will be quadratic

$$E(\theta) \propto \int_0^{3m} e^{-i\Phi_{max}(r/3)^2}\left[0.211+.786\left(1-(r/3)^2\right)\right]^{1.9} J_0\left[\frac{2\pi}{\lambda} r \sin\theta\right] r\,dr$$

$$\Phi_{max} = \frac{2\pi}{\lambda}\,\frac{2\Delta X}{1+(4F)^2} = \frac{\Delta X}{\lambda}\,1.62 \text{ for } F = .65$$

ΔX is the offset between the focal point at any given wavelength and the focal position actually chosen for the feed.

$G \propto |E(\theta)|^2$ It is the peak gain that is of interest here. So we can put $\sin\theta \Rightarrow 0$ and $J_0(0) = 1$.

Focal positions are measured w.r.t. the vanishing point of the feed $s_0 = 1.44\lambda_0$ is fixed; x is the actual focal point at each wavelength: $x = 1.44\lambda$

$$\Phi_{max}^{(f)} = 1.62(1.44)(s_0 - c/f) \text{ for each fixed focal length } s_0$$

$$f_1[r] = \left[.211+.786\left(1-(r/3)^2\right)\right]^{1.9} r$$

$$f_3[r] = e^{-i\Phi_{max}(r/3)^2}$$

For the gain calculate $\left(\text{Abs}[\text{NIntegrate}][f_1[r]\,f_3[r]]\right)^2$ ~~[illegible]~~

The integrals are over $0 \le r \le 3$

The gains are relative to the peak values.

GAIN CURVES FOR HIGH FREQUENCY ATA FEED

F in GHz	12 GHz focus	10 GHz focus	6 GHz focus	2 GHz focus
15	0.974	0.905		
12	1	0.994	0.68	
10	0.995	1	0.84	
8	0.97	0.984	0.96	
6	0.905	0.938	1	0.195
4	0.836	0.866	0.96	0.667
2	0.756	0.771	0.84	1
1	0.71	0.741	0.75	0.905

Transmission test through the new EMI absorber

The absorption is quite uniform in frequency
It's ~ 22dB at 1 GHz
It should work well for the low frequency load on the ATA rear test.

File Trace/Chan Response Marker/Analysis Stimulus Utility Help
Trace 1
Marker 1 1.0000000000 GHz
Memory
Tr 1 S21 LogM 10.00dB/ -60.0dB
Tr 2 S21 LogM 10.00dB/ -60.0dB
> 1: 1.000000 GHz -45.909 dB
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
-90.00
-100.00
-110.00
Target no absorber
AEMI
AEC-4 Convuluted Absorber
with
Data->Mem
Normalize
Data Math
Off
Data Trace
Memory Trace
Data and Memory
Transform
1 >Ch1: Start 750.000 MHz
Stop 2.00000 GHz
Cont. CH 1: S21 &Mem No Cor
LCL

Transmission through the cover materials used for the Denver airport.

At 10 GHz no absorption exceeding ~1% could be detected for either piece. The limitation was that any motions near the setup caused variations ≳ 1% to be observed. Getting a better limit will require a much better setup. $\boxed{\lesssim 1\%}$

Measure at lower frequencies

$$Y(T_{rec} + T_{ref}) = T_{rec} + T_{amb} \qquad Y = \frac{T_{rec} + T_{amb}}{T_{rec} + T_{ref}}$$

$$T_{rec}(Y-1) - YT_{ref} = T_{amb}$$

Two comparison temperatures: T_{amb} and T_{ref}.

Receiver temperatures for the new cooled receiver measured on antenna 3F at Hat Creek

The feed is mounted in place with the horns set for low frequencies. The radome is in place. A cylindrical absorber is used for accurate Tamb. aluminum

the absorber from p. 100.

The antenna is set at its lowest elevation angle, 18°, to allow placing and removing the absorber. With the absorber removed, the antenna remains pointed at elevation = 18° for the cold sky reference.

The feed is cooled down. It has an input LNA with 30-35dB and low noise temperature. The second stage, with gain of 40-45dB is also mounted close to the feed. A semi-rigid piece of coax couples the feed to the spectrum analyzer. The spectrum analyzer [EXA 9010A] shows spectra on a log scale. Thus, the difference of 2 spectra, for the Tamb load around the feed and the absorber absent, gives a Y-factor measurement in dB of the Trecvr. The warm load was measured to be 304K, close to the air temperature. The reference load Tref, is made up of the atmospheric brightness emission, the 2.7 BG and the antenna spillover coupling to the ground.

$$Y = \frac{T_{rec} + T_{amb}}{T_{rec} + T_{ref}}$$

Contributions to Tref:

Geometrical optics spillover: $\sim 3K(1 - \frac{z}{90})$

Diffraction spillover [I p. 132]: $\sim 8K/\sqrt{f_g}$

CMB: 2.7 K

atmos. emission: $\sim 3K \sec z$ (but see the plots)

(?) We are mainly interested in the low frequencies, $\lesssim 4GHz$, so the atmospheric optical depth, even at $z = 72°$, is modest.

File Trace/Chan Response Marker/Analysis Stimulus Utility Help

Trace 1 Marker 3 6.2619100000 GHz

Tr 1 S12 LogM 10.00dB/ -20.0dB Tr 2 S12 LogM 10.00dB/ -20.0dB

1: 631.040000 MHz -3.0815 dB
2: 14.015600 GHz -26.751 dB
> 3: 6.261910 GHz -3.2756 dB

30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00

1 >Ch1: Start 10.0000 MHz Stop 18.0000 GHz

Anti-aliasing filter

Transmission

~~f_LO is 14.06 GHz~~ (?)

-18

14.9

10.8

14.9

Marker
Marker 1
Marker 2
* Marker 3
Reference
More Markers
Turn Off Markers
Properties
Marker Functions
Favorites

Cont. CH 1: S12 &Mem No Cor Works only up to ≅ 2 GHz; Transmission = -26.7 dB at f_LO ? LCL

Film's no. is 14.9 GHz for LO2

104

ATA upgrade to 15GHz DG: doc

5C, X-pole, ABB-081, Test 15 Noise Ratio Various Bias Settings, 2011-12-05 With SB-038-B(2), Y-pole, ABB-169, Test 15 Noise Ratio 2010-04-08

11/31/2012

Possible (not done)

Calibration of the New LNA's from Niklas

We have proposed to do the RF tests: the measurement of T_{LNA} over 0.9–15GHz for each LNA from Niklas. The basic idea is to connect a balun to the balanced input of the LNA, put the balun in LN so that no heat goes into the LNA which is also in LN. Then the load at the 50 ohm terminal will be either ambient (~280) or LN 77K. The balun will lie in a trough which is filled with LN. Then one load/source will be a 50Ω load in foam bucket filled with LN. The other load will be 50Ω at room temperature with a short length of the Cu/stainless to keep the 50Ohm load (in a block to keep it at ambient) at 280K. A Y-factor measurement can be made with the SA.

Calibration of the balun

Measure the loss in 2 baluns back-to-back at room temperature

The loss in one balun is half of the total measured.
The one balun will be used at LN temperatures.
The expected loss ~~comb~~ at 77K can be found by extrapolating from the ambient temperature measurement.
In II p.59 the effect of cooling the feed to 77K from ~300K (ambient) was discussed. There are two effects

1. The lower copper losses @ 77K
2. The lowering of the black body radiation at going from ~300K to ~77K is a factor ~4 in the emission from the balun
   $75/283 = .265$
1. The effect of lowering the copper losses is large:
   $R_s \propto \sqrt{\rho}$ $\quad R_s'/R_s = \sqrt{.165/1.65} = .32$

Considering both effects: $(.265)(.32) = .085 \cong 1/12$.

Given the measured loss of the balun, we can calculate it's noise at ambient. Then, applying the factor 1/12, we can scale down the calculated noise to what it must be with the balun in LN.

11/31/12

Characteristic Impedance of a coaxial line (for the connectors)

Freespace impedance: $\eta = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0}{\epsilon_0 K_e}}$ (MKS)

$\epsilon_0 = \frac{10^{-11}}{36\pi}$, $\mu_0 = 4\pi \times 10^{-9}$

$$\eta_0 = \sqrt{\frac{4\pi \times 10^{-9}}{(1/36\pi)10^{-11}}} = \sqrt{(4\pi)(36\pi)10^{2}} = 377\,\Omega$$

Coax impedance

$$Z_0 = \frac{\eta_0}{\sqrt{K_e}} \frac{1}{2\pi} \ln\left(\frac{r_o}{r_i}\right) = \frac{60}{\sqrt{K_e}} \ln\left(\frac{r_o}{r_i}\right)$$

For PTFE, $K_e = 2.1$ (Google look-up) Wikipedia

The table IV p. 89; UT34-95 has $2r_i = .0028''$ and $2r_o = .027''$

so $Z_0 = \frac{60.0}{\sqrt{2.1}} \ln\left(\frac{.027}{.0028}\right) = \underline{\underline{93.8\,\Omega}}$

The tabular value is $95 \pm 4.0\,\Omega$, good agreement.
So the formula should be accurate for other dimensions as long as PTFE is used.
With just a connector in free space, use the above formula with $\sqrt{2.1} \to 1$.

Measurement of cable losses as a function of frequency.

From I p. 11-12 $\quad V = V_0 e^{-R_s x}$ $\quad R_s \propto \sqrt{f}$ for simple Cu losses.

$V = V_0 e^{-a x \sqrt{f}}$ $\quad dB \propto \ln(V/V_0) \propto -x a \sqrt{f}$; i.e. $dB \propto -x a \sqrt{f}$

Cable loss is measured with Network analyzer

In terms of squares on the measured loss graph

$dB = -a\sqrt{f}$ $\quad$ f in squares

It looks like $DB = -1\sqrt{f/9}$

One square is 1.55 mm

f	DB	x 1.55 mm
1	-.333	-.516
2	-.471	-.730
3	-.577	-.894
4	-.667	-1.034
5	-.745	-1.16
6	-.816	-1.26
7	-.882	-1.37
8	-.943	-1.46
9	-1.00	-1.55
10	-1.05	-1.63

This agrees with the tabular data of Precision Tube for IN5085 which is 304 SS/Cu

see III 7

File Trace/Chan Response Marker/Analysis Stimulus Utility Help
Channel 1
Power Level 12.52 dBm
Tr 1 S21 LogM 2.000dB/ 0.00dB
Tr 2 S21 LogM 2.000dB/ 0.00dB
14-1/2" SR Cable Test (w/cal)
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
-12.00
-14.00
1 >Ch1: Start 10.0000 MHz
Stop 15.0000 GHz
Memory
Data->Memory
Normalize
Data Math
Off
Data Trace
Memory Trace
Data and Memory
Favorites
Cont. CH 1: S21 &Mem CΔ 2-Port
LCL LVL

LNA Noise Temp Test & Calibration

File Trace/Chan Response Marker/Analysis Stimulus Utility Help
Channel 1
Power Level -5.00 dBm
Memory
Tr 1 S22 LogM 10.00dB/ 0.00dB
Tr 2 S22 LogM 10.00dB/ 0.00dB
Maury Cold Load with 36" silver/gold cable + 2 adapters, S22 Test 2013-01-30
30.00
20.00
10.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
Data->Memo
Normalize
Data Math
Off
Data Trace
Memory Trace
Data and Memory
Favorites
1 >Ch1: Start 10.0000 MHz
Stop 15.0000 GHz
Cont. CH 1: S22 &Mem C 1-Port
LCL

The input to the calibration tool will be a length of JN 50085 coax. [.085 coax]. Some heat will be absorbed in the input room temperature block due to heat passing along the JN 50085. This will cause some evaporation of the LN that cools both the LNA and the balun. Calculate the heat flowing along the .085 coax connecting the ambient block and the LN bath. The thermal transfer coefficient varies with temperature. Start by using a mean value:

$\langle k \rangle = .130$ watts/cm°k

Area of the coax:

OD = .085"
dielectric OD = .066"

$$\text{Area} = \frac{\pi}{4}(.085)^2 - \frac{\pi}{4}(.066)^2 = .0023\,\text{in}^2 = .0023\,(2.54)\,\text{cm}^2 = .0148\,\text{cm}^2$$

For stainless, 304 SS, II p. 66 shows $\langle K \rangle = .183\,(T/300)^2 = .130$ watts/cm°k

At 200 K $\quad K = .130 \dfrac{\text{watts}}{\text{cm °K}}$

$$\text{Heat} = (.0148)\,\text{cm}^2\,\frac{(.130)}{\text{cm °K}}\,\frac{dT}{dx}$$

$dT \cong 280\text{K} - 70\text{K} = 210\text{ K}$
$\Delta x = 10$ cm (~4 in)

$$H = (.0148)\left(\frac{.130\text{ watts}}{\text{cm °K}}\right)\frac{210°}{10\text{ cm}} = \underline{.04\text{ watts}}$$

Heat of vaporization for LN is $99\text{ J/gm} = \dfrac{99\text{ watt-seconds}}{\text{gm}}$

How much is boiled off in 30 min = 1800 seconds.
Total heat is $(.04)(1800) = 72$ watt seconds, which 99 watt-seconds releases 1 gm. Get $\frac{72}{99}$ gms = .73 gms of LN

LN is .807 gm/mL $\quad$ get $.807 \times .73 = .589$ mL $\cong \frac{1}{2}$ mL released.

Photonics Inc. (978) 670-4980
ext 231

Planned

Conversation with Douglas Dillon @ Photonics, Inc.

The model 2601 is available for ~ 10K in large quantity. The packaging is large because of the laser and optical modulator. It could be modified to fit the PAX box into a larger a Thorlabs package 3/13/2013 upper freq. edge is 20 GHz

1. 1dB compression output power → +12dBm @ input?
2. The link noise flow. Is that in N = 32dB? ✓
3. Get drawing for RCVR box which we would take apart. e-mail to wwelch@astro.berkeley.edu
4. How about a rough cost? 20K → 10K for 84 units Is that still about right? (no answer yet) probably close

84 × 10K = 840k $

ATA Down Converter

PHOTONICSystems, Inc.®
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PSI-2600 SERIES MICROWAVE PHOTONIC LINKS

PRODUCT DESCRIPTION

The PSI-2600 series is a family of high-performance microwave photonic links intended for antenna remoting or RF/IF signal distribution in military systems, satellite communications, radio astronomy, optical delay lines, cellular/wireless base stations or other applications. The PSI-2601 is an amplifierless link with wide spur-free dynamic range and high input intercept point for difficult RF environments. Also available are amplified versions; the PSI-2602 includes amplification at the TX side to optimize noise figure the PSI-2603 employs amplification only at the RX module and the PSI-2604 includes amplification at both link ends, yielding 27 dB of insertion gain. All links feature very wide bandwidth of up to 20 GHz and low power consumption. This performance is achieved through a transmitter employing a precisely controlled lithium niobate modulator and a low noise DFB laser. The separate receiver module (identical to the module used in PSI-1600 series links) contains a sensitive, microwave bandwidth InGaAs photodiode. All modules are constructed in laboratory-grade housings and shipped with AC power supplies. Custom packaging and gain configurations are also available. For more information, please contact us at info@photonicsinc.com.

PSI-2600 Features	Benefit
High performance fiber optic link	Enables replacement of lossy, heavy copper transmission lines
Lithium niobate modulator with precision bias control	Long service life
High input power tolerance	Will not overload when close to high RF sources
Compact, low power consumption and high reliability	Low total cost to install and operate

Applications

- **Radio over fiber**
- **Radio astronomy**
- **Remote antenna distribution**
- **Phased array radar**
- **Cellular antenna farms**
- **Optical delay lines**
- **SATCOM**
- **ELINT/EW**

Typical Performance, 25°C @ mid-band

Parameter	PSI-2601 Link	PSI-2602 Link w/ pre-amp	PSI-2603 Link w/ post-amp	PSI-2604 Link w/ pre & post-amp
Operating bandwidth	.045-20 GHz	.1-20 GHz	.1-20GHz	.1-20 GHz
Noise figure	32 dB	5 dB	32 dB	5 dB
Gain	-21 dB	11 dB	11 dB	43 dB
1-dB compression output power	-9 dBm	-10 dBm	20 dBm	20 dBm
IP3 output power	0 dBm	-2 dBm	26 dBm	26 dBm
Spur-free dynamic range (in 1 Hz)	108 dB	104 dB	104 dB	101 dB
VSWR	<2:1	<2.2:1	<2.2:1	<2.2:1
Bias power, TX module	<20 W	<23 W	<20 W	<23 W
Bias power, RX module	35 mW	35 mW	4 W	4 W

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978-670-4990
www.photonicsinc.com

Photonic Systems, Inc. (PSI) is a recognized expert in the design, analysis development and production of high performance fiber optic systems.

With decades of collective experience, the PSI team offers comprehensive fiber optic engineering solutions to government, military and commercial customers.

Revised 3/10/2008 Subject to change without notice

Referred to the input, the 1-dB compression point is +12 dBm

Current ATA system

Dynamic Range

			3.7×10^6 K	Link noise figure and associated spectral density
EIN	-132.98	dBm/Hz	41.0 dB NF	
P1dB	10.00	dBm	3650594 K	Link 1dB compression point
Link loss	28.00	dB		Link insertion loss
BW	12.00	GHz	1.38E-23	Noise bandwidth
EIN power	-32.19	dBm		Total link noise (EIN*BW)
Tsys	45.00	K		System temperature
Power	-182.07	dBm/Hz		k*Tsys
	-81.28	dBm		k*Tsys*BW
Noise margin	19.50	dB		Desired noise margin of link (want Tsys noise that much greater than EIN noise)
added T	0.50	K		Contribution of EIN to Tsys (EIN/kG)
input noise	-113.48	dBm/Hz		EIN + Noise margin (this is where we want the Tsys to be)
	-12.69	dBm		Input noise over entire band (input noise)*BW
upstream gain	68.59	dB		Amount of gain we need to get Tsys to desired input noise level
Headroom	**22.69**			P1dB - (input noise)*BW

7

For 30db in LNA, need 38.6db in the PAM. If PAM is 47db, an 8db pad should be switched in.

For link loss of 28db, RFCB needs 40db to get to 0 DBM.

Call (D Dill) about 2600 – box drawing and cost
213

(2)

Dynamic Range for the $\boxed{2600}$ photonic Link

32 dB NF = 1584 ; $T_s = (F-1)300K = 4.75\times10^5$ K.

BW = 1 GHz = 1.5×10^{10} Hz

Link loss : 21 dB

P1dB : 12 dBm

EIN: $K_B T = (1.38\times10^{-23})(4.75\times10^5) = 6.6\times10^{-18}$ watt-seconds

$= 6.6\times10^{-18}$ joules

Input noise power: $K_B T_s (BW) = (6.6\times10^{-18})(1.5\times10^{10}) = 9.8\times10^{-8}$

EIN $= 9.8\times10^{-5}$ mwatts $\Rightarrow$ -40.04 dBm ✓

P_{1dB} – EIN power : $12.00 - (-40.04) = 52.04$ dB

The head-room total.

For only 1% contribution of background noise, set the link level @ 20dB above the EIN Power. That leaves 32dB headroom above that in the link!

PHOTONICSystems, Inc.
WE LIGHT THE WAY

PSI-2600 Series Microwave Photonic Links

RF and Electrical Characteristics

Parameter	Min	Max	Units
Bandwidth	0.10	20	GHz
RF port impedance	50, all ports		Ohms
Receiver input equivalent noise		20	pA/Hz
Amplitude flatness, any 100 MHz		± 0.5	dB
AC power (60 Hz)	100	240	VAC

Absolute Maximum Ratings

Parameter	Min	Max	Units
Operating Temperature (within specs)	0	50	°C
Operating Temperature (no damage)	-20	60	°C
Storage Temperature	-40	80	°C
Humidity	0	95	%
RF input (Amplified TX at max gain)		-6	dBm
RF input (Unamplified TX)		+25	dBm
Optical power into receiver		+13	dBm

Optical Characteristics

Parameter	Min	Max	Units
Wavelength	1520	1575	nm
TX optical power	0.5	10	mW
RX optical input power	0	20	dBm
Receiver responsivity	0.85		A/W
Connector return loss		-40	dB
Fiber type between TX and RX (user supplied)	Single mode; Corning SMF-28 or equivalent		–
Fiber span @ 1dB degradation in noise figure	6		km

Physical Characteristics

Parameter	Attribute
RF Connectors, all ports	SMA Female
DC connector	9 pin D-sub
Fiber optic connector	FC/APC

PSI-1600 & 2600 Series Receiver Module-
This module is used for both families of photonic links, including amplified and amplifierless versions.

PSI-2600 Series Transmitter Module-
This module is used for all PSI-2600 transmitters.

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$T_{eq} = (F-1)300 \cong F300$

Comparison of Some Commercial Photonic Links (no amps)

0) PSI-1601
1. current ATA
2. PSI-2601
3. Finisar
4. Optilab (20 GHz)

$10 \log 2\times10^{11} = 10[11+.3] =$

$20\,GHz = 2\times10^{11}\,Hz$

NF
0. 47.0 dB
1. 41.0 dB ~~12,500 K~~ 3.7×10^{6} K
2. 32.0 dB ~~1500 K~~? 4.8×10^{5} K
3. 46.0 dB ~~39,800~~ K 1.2×10^{7} K
4. RIN is −145 dB/Hz (max) ~~−420 dB~~ ~~−145 + 135 = −10 dB~~ NO

Gain Flatness (important)
1. ? ± 20 dB over narrow range
2. ± 0.5 dB up to 15 GHz, the whole range
3. −36.6 dB @ 1.000 GHz; −42.2 dB at 18 GHz
4. −18 dB @ 2 GHz; −23 dB @ 20 GHz

Link Gain (loss) 0) −32. dB
1. −28 dB
2. PSI 2601: −21 dB
3. −39 dB
4. −18 to −23 dB

1 dB compression
1. +10 dBm
2. −9 dBm output → +12.00 dB input, applying gain
3. ~~+20 dBm~~
4. +10.0 dBm

5/9/2013

The plastic Correction layer for the nonplastic bottle

Material from Tencate, provided by Rich Rand.
cyanate ester, two possible cases
ⓐ "neat" $D_K = 2.7$ @ 10 GHz
ⓑ with quartz laminate $D_K = 3.0$

⟹ Use the quartz laminate with $D_K = 3.0$ cgs
1 mm thickness is available. (.04")

Geometry

$r_2 - r_1 = .04'' = 0.1016$ cm
$r_4 - r_3 = 0.12$ cm {polyethelyne layer

These dimensionless numbers are a first guess based on previous calculations

Radius:
$r_1 = 6'' = 15.240$ cm
$r_2 = r_1 + 0.1016 = 15.3416$ cm
$r_3 = r_2 + 0.4$ cm $= 15.7416$ cm
$r_4 = r_3 + 0.12$ cm $= 15.8616$ cm

$r_1 + r_2 = 30.5816$

Parameters
IV(146)

$\gamma_0 = .2095 f_g$
$\gamma_g = \omega\sqrt{\mu_0 (3.01\epsilon_0)} = .3629 f_g$
$\gamma_t = \omega\sqrt{\mu_0 2.3\epsilon_0} = .3177 f_g$ (polyethelyne)
$\eta_0 = 377\ \Omega$ $\sqrt{\frac{\mu_0}{\epsilon_0}}$
$\eta_g = \sqrt{\frac{\mu_0}{3.0\epsilon_0}} = 217.6674$ ok
$\eta_t = \sqrt{\mu_0/2.3\epsilon_0} = 248.5864$

Finally (after much algebra) IV(148)

$$\frac{16}{I} = Q_A\left(1+\frac{\eta_g}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_g}\right)e^{i\gamma_0(r_1-r_2)+i\gamma_g(r_2-r_1)} + Q_B\left(1-\frac{\eta_g}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_g}\right)e^{i\gamma_g(r_2-r_1)+i\gamma_0(r_2+r_1)}$$

$$+Q_A\left(1-\frac{\eta_g}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_g}\right)e^{i\gamma_0(r_1-r_2)+i\gamma_g(r_1-r_2)} + Q_B\left(1+\frac{\eta_g}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_g}\right)e^{i\gamma_0(r_1+r_2)+i\gamma_g(r_1-r_2)};$$

— where

$$Q_A = \left\{\left(1+\frac{\eta_t}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_t}\right)e^{i[(\gamma_t-\gamma_0)(r_4-r_3)]} + \left(1-\frac{\eta_t}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_t}\right)e^{-i[(\gamma_0+\gamma_t)(r_4-r_3)]}\right\}$$

and

$$Q_B = \left\{\left(1+\frac{\eta_t}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_t}\right)e^{i[(\gamma_t-\gamma_0)(r_4-r_3)-2\gamma_0 r_3]} + \left(1-\frac{\eta_t}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_t}\right)e^{-i[(\gamma_t-\gamma_0)(r_4-r_3)+2\gamma_0 r_4]}\right\}$$

The various factors in the above equations

$\frac{\eta_g}{\eta_0} = .5774$; $\frac{\eta_0}{\eta_g} = 1.7320$

$$\left(1+\frac{\eta_g}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_g}\right) = 4.3094$$

$$\left(1-\frac{\eta_g}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_g}\right) = 1.1545$$

$$\left(1-\frac{\eta_g}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_g}\right) = -.3093$$

$$\left(1+\frac{\eta_g}{\eta_0}\right)\left(1-\eta_0/\eta_g\right) = -1.1547$$

$$\left(1+\frac{\eta_t}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_t}\right) = 4.1760$$

$$\left(1-\frac{\eta_t}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_0}\right) = -.1760$$

$$\left(1+\frac{\eta_t}{\eta_0}\right)\left(1-\frac{\eta_0}{\eta_t}\right) = -.8572$$

$$\left(1-\frac{\eta_t}{\eta_0}\right)\left(1+\frac{\eta_0}{\eta_0}\right) = .8572$$

$$\frac{\eta_t}{\eta_0} = \frac{248.5864}{377} = .6594$$

$$\frac{\eta_0}{\eta_0} = 1.5166$$

The exponential factors (for 6" bottle) ☆!!!

① $i\gamma_0(r_1-r_2)+i\gamma_g(r_2-r_1) = (.0156)i f_g$

② $i\gamma_g(r_2-r_1)+i\gamma_0(r_2+r_1) = i(6.4437)f_g$

③ $i\gamma_0(r_1-r_2)+i\gamma_g(r_1-r_2) = -i(.0582)f_g$

④ $i\gamma_0(r_1+r_2)+i\gamma_g(r_1-r_2) = i(6.3699)f_g$

⑤ $i[(\gamma_t-\gamma_0)(r_4-r_3)] = i(.0130)f_g$

⑥ $-i[(\gamma_0+\gamma_t)(r_4-r_3)] = -i(.0635)f_g$

⑦ $i[(\gamma_t-\gamma_0)(r_4-r_3)-2\gamma_0 r_3] = -i(6.5827)f_g$

⑧ $-i[(\gamma_t-\gamma_0)(r_4-r_3)+2\gamma_0 r_4] = -i(6.6590)f_g$

Summary for the components:

a) vacuum bottle: tip radius of curvature: 6" thickness: 0.102cm (.04")
b) dense polyethelyne layer: 0.12cm thick (.05"), 6" radius as well
c) separation between the bottle and this layer: .4cm (0.16") ~~thick~~
d) The layer could be either outside or inside.

Do the ~~glass~~ plastic bottle only case first, case (a), and then add the corrective layer: from p. 146 (IV)

$$4 = E\left\{\left(1+\frac{\eta_g}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_g}\right)e^{-i\gamma_g(r_1-r_2)} + \left(1-\frac{\eta_g}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_g}\right)e^{i\gamma_g(r_1-r_2)}\right\}$$

$\gamma_g(r_1-r_2) = -.0369 f_g$; and $\left(1+\frac{\eta_g}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_g}\right) = 4.3094$; $\left(1-\frac{\eta_g}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_g}\right) = -.3094$

Define: $g_6(x) = 4.3094\,\mathrm{Exp}[I(.0369)x] - .3094\,\mathrm{Exp}[-I(.0369)x]$

The factors

$$f_1 = \left(1+\frac{\eta_g}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_g}\right)e^{i\gamma_g(r_1-r_2)+i\gamma_g(r_2-r_1)} = 4.3094\,e^{i(.0156)f_g}$$

$$f_2 = \left(1-\frac{\eta_g}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_g}\right)e^{i\gamma_g(r_2-r_1)+i\gamma_o(r_2+r_1)} = 1.1545\,e^{if_g 6.4437}$$

$$f_3 = \left(1-\frac{\eta_g}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_g}\right)e^{i\gamma_o(r_1-r_2)+i\gamma_g(r_1-r_2)} = -.3093\,e^{-i(.0582)f_g}$$

$$f_4 = \left(1+\frac{\eta_g}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_g}\right)e^{i\gamma_o(r_1+r_2)+i\gamma_g(r_1-r_2)} = -1.1547\,e^{i6.3700f_g}$$

$$f_5 = \left(1+\frac{\eta_t}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_t}\right)e^{i(\gamma_t-\gamma_o)(r_4-r_3)} = 4.1760\,e^{i(.0130)f_g}$$

$$f_6 = \left(1-\frac{\eta_t}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_t}\right)e^{-i[(\gamma_o+\gamma_t)(r_4-r_3)} = -0.1760\,e^{-i(.0633)f_g}$$

$$f_7 = \left(1+\frac{\eta_t}{\eta_o}\right)\left(1-\frac{\eta_o}{\eta_t}\right)e^{i[(\gamma_t-\gamma_o)(r_4-r_3)-2\gamma_o r_3]} = -.8572\,e^{-i6.5827f_g}$$

$$f_8 = \left(1-\frac{\eta_t}{\eta_o}\right)\left(1+\frac{\eta_o}{\eta_t}\right)e^{-i[(\gamma_t-\gamma_o)(r_4-r_3)+2\gamma_o r_4]} = 0.8572\,e^{-i6.6590f_g}$$

Combining Various factors and defining the g_i factors

$g_1 = f_1+f_3$, $g_2 = f_2+f_4$, $g_3 = f_5+f_6$, $g_4 = f_7+f_8$

$g_1[x]: = 4.3094\,\mathrm{Exp}[I(.0156)x] - .3093\,\mathrm{Exp}[-I(.0582)x]$

$g_2[x]: = 1.1545\,\mathrm{Exp}[I(6.4437)x] - 1.1547\,\mathrm{Exp}[I(6.3700)x]$

$g_3[x]: = 4.1760\,\mathrm{Exp}[I(.0130)x] - 0.1760\,\mathrm{Exp}[-I(.0633)x]$

$g_4[x]: = -.8572\,\mathrm{Exp}[-I(6.5827)x] + 0.8572\,\mathrm{Exp}[-I(6.6590)x]$

Finally: $$I = \frac{16}{g_1[x]\,g_3[x] + g_4[x]\,g_2[x]}$$

The total Plot with both the curves, one with and one without

G = Plot[{Abs[16/(g1[x] g3[x] + g4[x] + g2[x])]^2, Abs[4/g6[x]]^2},
{x,1,15}, Frame → True, GridLines → Automatic] (Intensity)

```
In[1]:= g1[x_] := 4.3094 Exp[I (.0156) x] - .3093 Exp[-I (.0582) x]

In[2]:= g2[x_] := 1.1545 Exp[I (6.4437) x] - 1.1547 Exp[I (6.3700) x]

In[3]:= g3[x_] := 4.1760 Exp[I (.0130) x] - 0.1760 Exp[-I (.0633) x]

In[4]:= g4[x_] := -.8572 Exp[-I (6.5827) x] + .8572 Exp[-I (6.6590) x]

In[5]:= g6[x_] := 4.3094 Exp[I (.0369) x] - .3094 Exp[-I (.0369) x]

In[6]:= G = Plot[{Abs[16 / (g1[x] g3[x] + g4[x] g2[x])]^2, Abs[4 / g6[x]]^2},
          {x, 1, 15}, Frame → True, GridLines → Automatic]
```

Out[6]=

N.B

6 inch bottle radius !?

Yes

This looks good enough, so that no further optimization seems necessary.

Multiplication — checked

It should also work with a 3" radius of curvature and with the lens inside the bottle. [Check this out.] ??

6/24/13

The problem of the NF dropouts (in frequency) for the new (Antonio) feed

Measurements from last summer when the suspicion was that there was interference from either vacuum pump or the cryocooler. At the installation of the new feed with the cryo-cooler and vacuum pump fully installed and shielded, these same drop-outs appeared. With the connection to these two components briefly disconnected, the drop-outs were still evident as shown in the next figure →

These are measurements through the whole system including the Optical fiber link. Except for the dropout points the Y-factor agrees with the results on the left page, which were done at the antenna. There was very heavy overcast which probably accounts for the lower Y-factors at higher frequencies

ARRIVAL | FINAL TEST

ABB-000-x, X-pole, ABB-000, Test 15 Noise Ratio
Various Bias Settings, 2010-00-00

MESSAGE

Data file	Vm	Vg	Vd	Id	| 3-6	| 6-9	| 9-12GHz |
0X1 Ratio	-0.97	0.47	1.44	49.8	6.56	6.31	6.57
0X2 Ratio			0.25	0.25	0.25		
0X3 Ratio			0.25	0.25	0.25		
0X4 Ratio			0.25	0.25	0.25		
0X5 Ratio			0.25	0.25	0.25		

Are the plots of the final observations

128

4.040" COAX END TO CLAMP

This shows the LNA and connection to the coaxial cables to the feed point.

4.040"

Based on the distance of the clamp at the LNA, the expected length of the outside transmission line: tip to LNA. The outside surface, the pyramid, is not shown.

null	observed frequency	free space calculated from 4.04" = L	scaled to length which is shorter by 1.11
1	.72 GHz	.731 GHz	.82
2	1.29	1.46	1.62
3	2.14	2.19	2.43
4	3.05	2.92	3.24
5	3.90	3.65	4.06
6	4.80	4.4	4.88
7	5.70	5.12	5.69
8	6.50	5.84	6.48
9	7.40	6.60	7.33
10	8.25	7.31	8.11
11	9.15	8.04	8.94
12	10.00	9.04	9.79

NB: These do not line up with peaks in the reflection coefficient on p. 42.

Note: the input connector for the ref. coefficient measure is different from the LNA connection, which has the feed resonances to the LNA.

The scaling to a shorter length by a factor of 1.11 is reasonable in view of the irregularities of the 1/4 stub length. The agreement with the observed null frequencies is now quite good, and this fact argues in favor of the mode to explain the drop-outs. The agreement is particularly good at the higher frequencies. The null spacings correspond to 1/4 wavelengths.

Peak Y is 8.0 dB (6.3)

$$T_{rec} = \frac{T_{amb} - Y T_{ref}}{Y-1} \qquad T_{amb} = 80F\ (27°C) \Rightarrow 300°K$$

$$\left\{ Y = \frac{T_{rec} + T_{amb}}{T_{REC} + T_{ref}} \right\}$$

For $T_{ref} = 10k$ (probably low), $T_{rec} = 44.7k$

for el = 20°: For $T_{ref} = 20k$ (probably high), $T_{rec} = 33k$ (but note the overcast)

Splitting the difference: $T_{rec} \cong 40k$

Note the weather: thunderstorm forecast, no actual rain but sky very dark; ambient temperature and humidity are high. The weather is probably the source of lower Y at the higher frequencies, and also at the lower frequencies as well.

CHALMERS

.25 dB added

Ant 1 K

5C4-012-A, X-pole, LNA 0037a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

5C4-012-A, Y-pole, LNA 0056a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

Ant 1h

5C4-013-A, X-pole, LNA 0053a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

5C4-013-A, Y-pole, LNA 0072a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

Ant 2m

5C4-015-A, X-pole, LNA 0083a, 2017-02-02
Noise Ratio, Various Bias Settings

CHALMERS

.25 dB added

5C4-015-A, Y-pole, LNA 0084a, 2017-02-02
Noise Ratio, Various Bias Settings

CHALMERS

.25 dB added

Ant 3c

5C4-016-A, X-pole, LNA 0021a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

5C4-016-A, Y-pole, LNA 0019a
2017-06-14, Noise Ratio

CHALMERS

.25 dB added

Ant 3d

5C4-017-A, X-pole, LNA 0024a, 2017-02-01
Noise Ratio, Various Bias Settings

CHALMERS

.25 dB added

5C4-017-A, Y-pole, LNA 0073a, 2017-02-01
Noise Ratio, Various Bias Settings

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New Cooled Feeds for the Allen Telescope Array

Wm. J. Welch[1], Matthew Fleming[2], Chris Munson[3,4], Jill Tarter[3], G. R. Harp[3], Robert Spencer[2], and Niklas Wadefalk[5]
[1] Professor in the Graduate School, UCB, Berkeley CA, USA Emeritus Prof. Astronomy & EECS
[2] Minex Engineering Corporation, Antioch CA, USA
[3] SETI Institute, Mountain View CA, USA
[4] Millennium Engineering and Integration Company, Moffett Field CA, USA
[5] Low Noise Factory, Mölndal, Sweden
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Abstract

We developed a new generation of low-noise, broadband feeds for the Allen Telescope Array at the Hat Creek Observatory in Northern California. The new feeds operate over the frequency range 0.9 to 14 GHz. The noise temperatures of the feeds have been substantially improved by cooling the entire feed structure as well as the low-noise amplifiers to 70 K. To achieve this improved performance, the new feeds are mounted in glass vacuum bottles with plastic lenses that maximize the microwave transmission through the bottles. Both the cooled feeds and their low-noise amplifiers produce total system temperatures that are in the range 25–30 K from 1 GHz to 5 GHz and 40–50 K up to 12.5 GHz.

Key words: extraterrestrial intelligence – instrumentation: detectors – instrumentation: interferometers – telescopes – low noise amplifiers (LNA) – antenna feeds

1. Introduction

We describe the development of new low-noise feeds to upgrade the receiver systems on the Allen Telescope Array (ATA) (Welch et al. 2009). The array consists of 42 antennas distributed over a few acres of land at the Hat Creek Radio Observatory in Northern California. Each antenna utilizes a 6.1 meter diameter primary reflector and a 2.4 meter secondary with offset Gregorian optics to minimize the interference scattered into the system. Figure 1(a) is a drawing showing the placement of the wideband feed in the 2.2% of the area of the primary reflector that is shadowed by the secondary mirror, and the metallic shroud that shields the feed from thermal ground emission. Figure 1(b) is a photograph of one of the antennas, showing the Sunbrella fabric radome cover that protects the feed from the weather. The ATA is currently capable of synthesizing images with wide bandwidths, modest sensitivity, and good angular resolution. To achieve this bandwidth, we use log-periodic antennas, members of the class of frequency-independent antennas (Rumsey 1966) as the antenna feeds. The ATA feed is pyramid shaped and receives orthogonal linear polarizations from pairs of feed arms on opposite sides of the pyramid. At any wavelength, the feed's active region is located where the width of the pyramid is about one half wavelength; this is near the wide end of the feed for long wavelengths and near the narrow end for short wavelengths. For this class of antenna, signals are received from the direction of the tip of the feed, where the input terminals are located. Received signals travel up to the tip on the feed arm structure and then onto coaxial cables down to the low-noise amplifier (LNA) within the feed. Figure 2 shows a photograph of the first generation (uncooled) feed mounted in the antenna. A cutout drawing of the feed interior shows one polarization of the LNA cooled in a dewar to 70 K.

An important feature of the feed and reflector system is its inherent wide bandwidth. At any wavelength, the optimum sensitivity is achieved when the active region of the feed is placed at the fixed focus of the Gregorian optics. For observations at a single frequency, the feed is translated into position for maximum sensitivity. Figure 3 shows the variation of relative system sensitivity of the current log-period feed as a function of frequency for a number of different focus positions. The performance has a rather broad maximum; thus, a single focus position can be chosen for observations covering a wide range of frequencies. For example, if the feed is set at the 10 GHz focal point, the relative gain is >0.9 over the range of 4.5 GHz to 15 GHz, an unusually wide bandwidth.

2. The Upgrade

Welch et al. (2009) described the motivations behind construction of the current wideband feeds on the ATA and their expected performance. Since their installation, these feeds have proven to be less robust than forecast, with a number of the feeds now in need of repair and performance of some of the others degrading over time. The new feeds have been redesigned to alleviate the initial shortcomings as well as extend the highest frequency and improve noise performance at all frequencies.

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Figure 1. (a) The two-mirror offset Gregorian optics with the feed and its mounting bracket and the metal shroud between the two mirrors at the bottom. The metal shroud protects the optical system from background radiation from the ground. (b) The Sunbrella radome cover that protects the feed from the weather. Laboratory measurements show that this fabric has a nearly frequency-independent absorption of just one percent. Image adapted from Figure 2 in Welch et al. (2009).

A major improvement follows from the entire feed structure being cooled to a temperature close to the temperature of the LNA, 70 K. In addition, the coaxial cables between the feed tip and the LNA are also cooled to 70 K. At this lower physical temperature the resistive losses in both the feed structure and cables are much lower as is their emitted blackbody radiation. The resistivity of copper at low temperatures can be approximated as $\rho = .67\ (\mathrm{T} - 20/132)^{1.35} \times 10^{-6}\ \Omega\,\mathrm{cm}$. Going from 300 K to 70 K lowers the resistivity of copper from 1.85×10^{-6} to $0.18 \times 10^{-6}\ \Omega$ cm. The resistive losses scale as the surface resistance Rs, and Rs $\sim \sqrt{\rho}$. Thus, the resistive losses will be a factor of 0.31 smaller. The blackbody radiation scales linearly with temperature and is thus reduced by a factor of 0.23. The product of these two temperature effects lower the received background noise at each LNA by a factor of $\sim$14. Laboratory measurements of the receiver temperature average 30 K from 1 to 10 GHz. Measurements of the LNA noise temperature contributions from LNA ABLNC1_15A rise from 10 to 15 K over the frequency range. Thus, the contribution from the cooled feed structure and coax cables ranges from 12 to 7 K from 1 to 10 GHz.

Lowering the physical temperature of the entire feed from ambient temperature (about 300 K) to 70 K, is a major challenge. Prototyping and final implementation for the Antonio Feeds was carried out at Minex Engineering in Antioch, California. The lowest frequency of the feed was moved from 0.5 to 0.9 GHz to significantly shorten its physical size. As a result, the entire feed structure can be readily contained within a vacuum vessel that is largely transparent to radio waves. This allows the cooled feed to couple well to wideband incoming signals. After testing several possible materials for the transparent dewar, we chose pyrex glass because of its very low radio frequency loss, mechanical strength, and availability, despite its rather large dielectric constant of 5.1.

The glass vacuum bottle is a hemisphere at the tip of the feed and continues as a cone and then a cylinder past the large base of the feed as can be seen in Figure 4. In addition, to improve radio transparency at the higher frequencies, we added a thin hemispherical layer of plastic, effectively a lens, with a dielectric constant of 2.3 and thickness .127 cm covering the tip of the pyrex bottle. The pyrex bottle thickness is .100 cm over the hemispheric region, with inner and outer radii at 7.620 cm and 7.720 cm respectively. The thickness of the glass grows to .500 cm at the base of the feed.

Figure 5 shows a picture of the feed antenna in the vacuum bottle with the hemispherical polyethylene lens over its tip. The optimum lens thickness and separation of the glass from the lens were found from a large number of trial calculations of the transmission of radio waves through the glass bottle and lens to

Figure 2. Current log-periodic feed, with operational bandwidth from 0.5 to 10 GHz. The cryogenic dewar and LNAs are cooled to ~70 K by a commercial refrigerator mounted internal to the pyramid. Image adapted from Figure 4 in Welch et al. (2009).

Figure 3. Change in relative sensitivity as a function of frequency for a range of different focus settings.

the feed. For frequencies below about 5 GHz, the incoming signal goes past the edge of the plastic lens and proceeds directly to the feed through the lower part of the bottle.

Figure 6 shows the calculated radio wavelength transmission into the feed as a function of frequency from about .9 GHz up to 14 GHz for three different lens outer radii: 8.247 cm, 8.267 cm, and 8.287 cm. For operations up to 14 GHz, the limit of the receiver, the mean radio frequency power transmission factor is .93 for the chosen radius of 8.287 cm. The magenta line in Figure 6 shows the significant loss of transmission at high frequencies in the absence of any lens.

The new Antonio feeds incorporate cryogenic amplifier MMIC chips (part number LNF-ABLNC1_15A) fabricated by Low Noise Factory as part of a research collaboration with Chalmers University and mounted on custom blocks designed to fit within the feed pyramid. Figure 7 shows the test results demonstrating excellent gain and noise temperature for this LNA over a wide range of frequency from 0.9–14 GHz when cooled to cryogenic temperature.

Figure 4. Upgraded feed mounted in an ATA antenna, with geometry of the glass bottle clearly visible.

Figure 5. Upgraded feed with plastic lens.

2.1. Connection Between the Feed and the Low-noise Amplifiers

The input terminals of the two orthogonal, balanced, linearly polarized, log-periodic feeds are at the four sides of the tip of the pyramidal structure. Electromagnetic transmission simulations of the original feed gave a frequency-independent balanced feed impedance of 207 ohms for each linearly polarized feed (Engargiola & Welch 2004). We use two pairs of small diameter coaxial 90 Ohm cables to connect the tip terminals to the LNAs that are located well down within the feed structure. The 180 Ohm impedance of each of the two pairs of small cables provides an adequate match for each of the two 207 Ohm orthogonal polarizations. The magnitude of the power reflection from this mismatch is 0.5%. Although small, this mismatch is responsible for the fine frequency structure, ~0.5 GHz wide, in the final feed system temperature measurements.

Figure 6. Transmission through the glass and plastic lens for the three different outer radii. The magenta curve shows the transmission in the absence of any lens.

There remain the inductances in the long leads that connect the coaxial cable centerlines to the tip terminals at the apex of the pyramid. To avoid the effect of this inductance, we absorb it by halving it for both leads of each polarization and adding a capacitance to ground at each mid point. By design, these inductances and added capacitances form low-pass filters that have an upper band edge at 15 GHz for each polarization. The tip region, which is very compact, is shown on the right side of Figure 8. The circuit diagram for these structural parasitic components and their selected values are shown at the bottom of Figure 8; they provide a well-matched Chebychev low-pass filter (Zverev 1967) for the connection between each feed polarization and its corresponding LNA at the end of each coaxial cable pair.

Also shown in the upper left of Figure 8 are two of the four planar rexolite support structures that attach the feed arms to the central pyramid. Near the tip of the pyramid, the high frequency region, the standoff thicknesses are .25 mm, and near the large end, the low-frequency region, they are 2.5 mm.

Figure 7. Measured gain (solid white curve) and noise temperature in °K (dashed white curve) of LNF-ABLNC1_15A at cryogenic temperature. Red curves refer to an older LNA design manufactured by Fraunhofer IAF.

Figure 8. Details of arm support and the tip area for the log-periodic feed. Visible are the rexolite standoffs connecting the feed arms to the pyramid, details of the feed tip with coax cables, and capacitors that comprise the low-pass filter circuit described (Zverev 1967).

Calculated reflections from these standoffs are less than −30 dB, and they have little detrimental effect on the operation of the feed.

The efficacy of this low-pass filter mounting at the tip is illustrated in Figure 9 that shows the calculated transmission of the low-pass filter circuit model yielding an excellent result up to 14 GHz.

2.2. *Protection for Ultra-wideband LNAs*

In the presence of strong transmitters on aircraft, in orbit, and incorporated into ground-based electronic products, it is necessary to protect these ultrasensitive, wideband LNAs (LNF-ABLNC1_15A) from being damaged during observations. Independent of the particular frequency band being selected by the observer, the LNAs are sensitive to strong signals at all frequencies within their frequency range, all the time. The new Antonio feeds contain a pair of back to back Schottky diodes mounted to ground across each of the two input terminals as part of the custom mounting block for the LNA. The diodes clamp when the voltage they experience exceeds 0.7 volts, corresponding to a power of 2.5 mW. These diodes are clearly visible in Figure 10. As an example; a typical avionics transponder used in general aviation aircraft flying through the antenna main beam, at an altitude of 1000 m, will produce a power flux of 0.02 mW/m^2, or a 0.4 mW peak pulse focused directly onto the LNA in an antenna. This power level will not engage the Schottky diodes, but a CAL FIRE helicopter flying over the array at much lower altitudes during fire season (a not infrequent event) would do so. A live cell phone in the pocket of a member of a film crew, when the bomb bay doors of the shroud are opened for better viewing (also a not infrequent event), poses a threat as well.

2.3. *The Cryocooler*

It is essential to bring the physical temperature of the feed down to near 70 K so that its thermal noise contributes very little to the receiver noise of the system. With the feed in the vacuum bottle, connecting the base of the feed to the same cryocooler that cools the LNA will work if it has adequate capacity. The heat that must be removed is the general 300 K infrared background radiation around the bottle and the feed. This radiation will transmit through the bottle readily and illuminate the feed.

Figure 9. Transmission factor in the feed tip as a function of frequency.

Figure 10. Micrograph of a portion of the mounting block for the new amplifiers. Two pairs of back to back Schottky diodes combine with the inductances of the strip line segments to produce a wideband, low-pass filter with an upper band edge at 15 GHz, to protect the LNF-ABLNC1_15A LNA.

It is practical to cool the entire feed in the dewar to a temperature to between 65 K and 70 K with a modest refrigerator connected just to its large end. The thermal conductivity of both the pyramid and the feed arms is adequate to maintain a small temperature difference between the feed tip and the refrigerator in the presence of the 300K infrared environment. The total infrared thermal load on the refrigerator is calculated to be about 2.5 Watts. The Sunpower CryoTel GT cooler was selected, and the temperature of the feed in operation is measured to be close to 70 K as expected.

During the 12 months following the installation of the first ten new feeds on ATA antennas, the physical temperatures of their LNAs have been measured daily. The LNA temperatures have remained steady and close to 65 K. These are important measurements because a reservoir of ambient cooling air is blown through buried plastic conduits from the node buildings and across the cryocoolers at each antenna, to keep them from overheating. In the summer, when the soil is very dry, the heat exchange between the colder ground and the warmer air is less efficient. Nevertheless, the performance of the cryocooler system has been adequate to maintain stable regulation of the physical temperature of the LNAs throughout every season.

Because the feed operates cantilevered from the primary dish, at the antenna focus, it is critical to control any structural vibrations within the unit. An additional vibration isolation mechanism was designed and built at Minex Engineering and integrated into the Sunpower CryoTel GT cryocooler (Fleming, private communication 2014). The residual peak to peak vibration measured at the tip of the feed is <0.″001.

3. Measured Receiver System Noise Temperatures

The receiver system temperatures are measured with the receivers installed on the antennas. The two reference loads used for these Y-factor measurements are the atmosphere and an ambient absorber that can be placed over the entire feed. The ambient load is a metal cylinder with AEMI Broadband Convoluted absorber AEC-4 covering its inner walls and end plate. This material shows a power reflection coefficient less than .001 and a one-way absorption greater than 25 db at all frequencies in the range 0.9 to 15 GHz. The atmospheric brightness is based on an accurate model for the Hat Creek site that uses the known atmospheric properties and the 20° elevation angle at which the measurements are made. The azimuthal angles of all test measurements were chosen to avoid any background contribution from the Milky Way Galaxy at low frequencies. The ambient load temperature is measured

Figure 11. Upgraded feed mounted on antenna. Inset shows the hot load that surrounds the feed during measurement of system noise temperature.

Figure 12. Model radio brightness in the terrestrial microwave window (Morrison et al. 1977). The lowest background region is 1–15 GHz at a mean galactic latitude. The measured ATA background in Figure 13 shows system temperatures slightly above these limiting values, as discussed above.

with an accurate electronic thermometer, a typical value being 298 +/− 0.1 K.

Figure 11 shows the upgraded feed mounted inside the antenna, covered by a bag made of Sunbrella fabric, that provides additional safety in the event of a failure in the pyrex vacuum bottle. Also shown is the ambient load that is placed around the entire feed during measurements of the system noise temperature to provide an excellent blackbody.

A major design goal for these new feeds is to enable observation of the entire, quiet, terrestrial microwave window from 0.9 GHz to 14 GHz with as little added instrumental noise as possible. Figure 12 shows how emission from the O_2 and H_2O vapor in the atmosphere must add to the measured receiver temperatures in Figure 13 at the higher frequencies and synchrotron emission from the galaxy at lower frequencies as well. Measured system temperatures for both polarizations for ten feeds installed during 2015 October and December appear in Figure 13.

It is a pleasure to acknowledge the philanthropic support from Franklin Antonio that enabled this upgrade. The research and manufacturing of the LNAs (LNF-ABLNC1_15A) used

Figure 13. System temperatures measured at the ATA on ten new feeds during 2015 October and December, including both polarizations. An atmospheric model was used to correct the 20° elevation measurements to zenith. The spikes at the low frequencies are satellite transmissions (XM, Glonass, GPS, Inmarsat) and air traffic responses to ARTC from aircraft . The small vertical fluctuations that have a period of about 0.5 GHz are consistent with the small mismatch between the coaxial cables (180 ohms) and the feed (207 ohms) discussed above. The performance of 4J-X is unacceptable; that feed is scheduled for repair.

in this upgrade was carried out at the GigaHertz Centre in a joint project financed by Swedish Governmental Agency of Innovation Systems (VINNOVA), Chalmers University of Technology, and Low Noise Factory, Omnisys Instruments, SP and Wasa Millimeter Wave. The SETI Institute provided scientific staff to analyze the measurement results and SRI International provided on-site staff to assist with the installation and physical measurements on the antennas.

References

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Rumsey, V. H. 1966, Frequency Independent Antennas (New York: Academic Press)

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Zverev, A. I. 1967, Handbook of Filter Synthesis (New York: John Wiley & Sons, Inc.), 175

How to eliminate the dropouts.

1. Solder small wires between the top end of the pirami and the ring around the coaxial cables at the top. This will provide a good ground at the tip. Easy disconnect for the wires
2. Put absorber between the coax cable and the Piramid, as much as can be squeezed in.
3. The ground at the tip should largely kill the quarter wave resonances (and all odd quarter wavelengths).
4. The absorber should kill the multiple half wavelength resonances of the parasitic resonant cavity. This cavity is formed by the coax cables clamped at the LNA and the walls of the piramid.

[One gnd wire seems to work] 8/12/03 (NB)

This worked. !

How high can the input band frequency be?
BF filter: 15.2 – 15.8 GHz [600 MHz]

→ LO2: 14.9 GHz fixed gives a fixed output band of 600 MHz centered @ 600 MHz {15.2 – 14.9 = 300, 15.8 – 14.9 = 900}

LO1 for 15.2 – 15.8 GHz filter
LO1 must be added to the signal band frequencies:

for 1 GHz – 1.6 GHz band	f_{LO1} = 14.2 GHz
0.5 GHz – 1.1 GHz band	f_{LO1} = 14.7 GHz
10.0 GHz – 10.6 GHz band	f_{LO1} = 5.2 GHz
14.4 GHz – 15.00 GHz	f_{LO1} = 0.8 GHz

To keep the 600 MHz output center frequency and go to 17 GHz it would require moving the band cent frequency up and the LO2 up. 17.2 – 17.8 GHz for the band pass filter, and 16.9 for the second LO ~~used~~ should work. The LO's, mixers, and LO amps would all have to be changed. (?)

{ν > 15 GHz should be possible)

Calvin's prototype PAM with the new Hittite

Photonics Inc. Model 2600,
see pp. 117-121

V. Following the PAM is the wide band optical fiber link. The current link covers the frequency range 0.5 – 12.5 GHz, transmitting this entire band as an analog signal from the antenna to the central control room. To reach 15 GHz, a wider band link is necessary. The same company that provided our current link, PHOTONICSystems, Inc. manufactures a link that covers 0.45 – 20 GHz, that is now available. Figure 13 shows the summary specification page. It claims a slightly better dynamic range than the current link, and should work well over the desired .9 – 15 GHz band.

VI. The Radio Frequency Converter Boards (RFCB) contain the remaining analog components. Each board accepts two optical fibers corresponding to the two linear polarizations from each antenna. There are at present 42 such boards in the same relay rack. Figure 14 contains a block diagram of the RFCB and an image of one of the current units. The fiber for each polarization is fed to a diode detector that puts out the overall RF band into a power splitter unit with four copies of the overall band. These copies are separately up/down converted to four different 600 MHz bands, each of which can be drawn from any part of the overall input spectrum. The conversions are partly effected by first mixers and first local oscillators that can be tuned from16.0 GHz to 27.0 GHz in the current system. The heterodyned (mixed) signals then pass through narrow band fixed frequency filters covering 15.2 GHz - 15.8 GHz. The output of this filter then goes to a second mixer with a fixed local oscillator at 14.9 GHz, and the result is a band of 600 MHz width centered at 630 MHz. Following the down converted signal at 600 MHz in the current system is a 200 MHz anti-aliasing filter which then drives the A/D converter. This output band is the same for every tuning of the first local oscillator. From the input of the 15.2 – 15.8 GHz filter on, no changes are required for the upgrade.

see p. 116

The required changes for the 15 GHz upgrade are an increase of (a) the bandwidth of the signal power splitter, (b) the range of the first local oscillator, and (c) the range of the first mixer. The planned new optical link can use the existing photodiode receiver. The required increased range of the first local oscillator, from a maximum of 27.00 GHz to 30.5 GHz, can be accommodated by the current first oscillator units. The amplifiers that now distribute the first LO to the various RFCB units have enough bandwidth to operate up to the required new higher frequency. The first mixer will need to be changed for the newer higher frequency, and the signal power splitter unit will also have to be modified. The present power splitter uses the same amplifier chips that are used in the PAM. For the upgrade, we must make the same change in the amplifier chips that are needed for the PAM. The passive signal dividers that enable the four identical outputs will also have to be redesigned. The present signal power splitter unit also has low pass filters, cutting off at 11.5 GHz, in each of its outputs. These filters are used to avoid crosstalk between the different channels. These will have to have their upper band edges increased to 15.0 GHz. The same circuit boards and box cable connectors will work here as well as for the PAMs.

probably not
It's ≤ 12.5 GHz

Changing the first mixers in the RFCB requires using a different mixer chip from the one that is now in service. Hittite has a device that appears capable of serving as the new first mixer chip: model HMC292LC3B. To test this possibility we ordered two units for test purposes, along with an evaluation board. We have received the units and have tested the mixer chip over the desired range of 16 – 30.5 GHz. They should work well for the upgrade. Are the amplifiers ok? I think they are tested by Calvin

Did we?

Figure 14. Block diagram of the RFCB along with an image of one of the current units.

VII. Expected system temperatures with the upgrade. The new system will operate over 0.9 to 15 GHz. We have conducted Y-factor measurements of the gain of the prototype feed in the lab using liquid nitrogen as the cold load contrasted to ambient temperature load. The Y-factor is the ratio of the total power output spectra when the feed is at ambient temperature (300K) and liquid nitrogen temperature (77K). Note that b) Because of the length of the feed and its vacuum bottle, it is not possible to fully immerse the feed in a liquid nitrogen bath, therefore Y-factor measurements have been made at frequencies above 2 GHz. A feed that works well at the higher frequencies is expected to perform well at the lowest frequencies. Figure 15 is an image of the test setup; note that for safety during these tests, the feed and its vacuum bottle have been covered with an RF-transparent bag made from the Sunbrella® material that is currently used in the ATA radome covers.

The measured Y-factors have been converted to predicted system temperature values on the antenna when looking at cold sky by assuming an additional 10K will be contributed by the antenna and sky. Figure 16 shows a series of test results up to 18 GHz, made to find the optimal bias settings for the LNAs. Also shown in Figure 16 is the performance of the current feed up to 10 GHz. The performance of the prototype feed at the best bias setting is identical with the theoretical curve predicting feed performance, shown as a dashed line. The improvement in system temperature over the range of frequencies covered by the current feed is better than a factor of two (closer to three)

Figure 15. Test setup for making Y-factor measurements in anechoic chamber. The output power spectrum of the prototype feed (covered by a white safety bag) can be measured at ambient temperature (300K), or with the front half of the feed immersed in a liquid nitrogen bath (77K).

Figure 16. Measured Y-factors and inferred system temperatures for the prototype cooled feed and the current ambient ATA feed as a function of frequency. The dashed curve is the theoretical prediction for the feed performance. Different color curves correspond to different bias settings for the cooled feed LNAs. Best results require the best bias choices; the results are reproducible.

Noise vs temperature for the three contenders

They all meet at 110K!

Early Noise temperature measurements. The NGST measurements should be the closest to the Chalmers or Fraunhofer LNAs. The data are sparse but show the effect of increasing temperature from 20K to 85K.

SRI 1(886) 519-2802

pc 126970 #

Cryo cooler Sumpower & T
Vacuum Felfer Hipase 80 not CTI.

Tomorrow

A layer of material to be put on the plastic bottle to reduce possible molecular diffusion of atmospheric gases into the interior of the bottle. It's properties: $\epsilon \sim 10$
loss tangent $\sim 3\times10^{-4}$ } @ 15 GHz

The layer thickness is 1μ (10^{-6} m)

The previous reflection calculations e.g. p122 are for layer thicknesses ~ 1 mm (10^{-3} m). Even though $\epsilon \sim 10$ for the thin layer, it's thickness is smaller by 10^{-3}. The reflection should be negligible. The attenuation with loss tangent of 3×10^{-4} should also be negligible. Compare with the figure on p. 125

LOW NOISE FACTORY
www.lownoisefactory.com

LNF-ABLNC1_15A s/n 0001A

1-15 GHz Cryogenic Low Noise Amplifier

FRAUNHOFER

Oct 31, 2013

Absolute maximum ratings

Parameter	Min	Max
V_{ds}	-0.5 V	3 V
I_{ds}		150 mA
V_{gs}	-12 V	+12 V
V_m	-2.0 V	+0.5 V
I_m	-80 mA	
RF Input drive level		0 dBm

Nominal bias @ 296 K

Parameter	Value
V_{ds}	1.70 V
I_{ds}	90 mA
V_{gs}	-0.21 V
V_m	-1.20 V
I_m	-58 mA

Nominal bias @ 65 K

Parameter	Value
V_{ds}	1.40 V
I_{ds}	60 mA
V_{gs}	
V_m	-0.75 V
I_m	≈ -38 mA

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F

Measured data, Tamb=296 K

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LNF-ABLNC1_15A s/n 0002A

1-15 GHz Cryogenic Low Noise Amplifier

CHALMERS

Oct 31, 2013

Absolute maximum ratings

Parameter	Min	Max
V_{ds}	-0.5 V	3 V
I_{ds}		150 mA
V_{gs}	-12 V	+12 V
V_m	-2.0 V	+0.5 V
I_m	-80 mA	
RF Input drive level		0 dBm

Nominal bias @ 296 K

Parameter	Value
V_{ds}	2.60 V
I_{ds}	90 mA
V_{gs}	-0.13 V
V_m	-1.70 V
I_m	-57 mA

Nominal bias @ 65 K

Parameter	Value
V_{ds}	1.20 V
I_{ds}	25 mA
V_{gs}	
V_m	-0.50 V
I_m	≈ -17 mA

LOW NOISE FACTORY
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LNF-ABLNC1_15A s/n 0002A

1-15 GHz Cryogenic Low Noise Amplifier

C

Measured data, Tamb=296 K

EX-1515 Radome

5C2, X-pole, 0001A(Fraunhofer), Test 15 Noise Ratio
Various Bias Settings, 2014-06-10

0.25 dB added

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz
X1 Ratio	-0.75	0.47	1.40	60.1	4.62	4.56	4.41
X2 Ratio	-0.75	0.47	1.40	60.2	4.66	4.63	4.47
X3 Ratio	-0.75	0.52	1.40	60.9	4.69	4.68	4.51
X4 Ratio	-0.75	0.55	1.40	61.3	4.67	4.64	4.48

small dependence on bias setting here

EX-1515 Radome

5C2, Y-pole, 0002A(Chalmers), Test 15 Noise Ratio
Various Bias Settings, 2014-06-10

0.25 dB added

Data file	Vm	Vg	Vd	Id	3-6	6-9	9-12GHz
Y1 Ratio	-0.50	0.10	1.20	25.0	4.57	4.51	4.35
Y2 Ratio	-0.50	0.16	1.20	25.7	5.36	5.48	5.32
Y3 Ratio	-0.50	0.16	1.20	25.9	4.95	5.00	4.88
Y4 Ratio	-0.50	0.19	1.20	26.3	4.72	4.65	4.48
Y5 Ratio	-0.50	0.07	1.20	24.6	4.81	4.81	4.69

This one shows a significant improvement with the optimum bias. (?)

AS LNA

Expected overall input system noise temperatures with the Fraunhofer and Chalmers LNAS. Right now the PAM input temperatures are ~ 1000K

<u>Fraunhofer LNA:</u> Input LNA ~ 35-40K
Gain is ~ 25dB (320)
The second stage add-on is 1000/320 ~ <u>3K</u> <u>38-43</u>

<u>Chalmers LNA</u> Input LNA is ~10-15K at opti mum, gain ≥ 30 dB
The second stage add-on is ≤ $\frac{1000}{1000}$ ≤ <u>1K</u>. <u>10-15</u> + 1 = <u>11-16</u>

<u>Gain Issue:</u> The cable losses between the LNA and the PAM amplifier are about 3dB. This has to be subtracted from the LNA gain. There is no effect (or little) for the Chalmers LNA. For the Fraunhofer, the gain at 10GHz is closer to 22dB than 25dB.

[SRI: 1-866-519-2802]
126970 #

notes

Cooled Feed Cooldown 2014-04-10 Thur 2014-05-18

889 hrs.

225° 22

11:04 bias #1080

13:40 #1236 [plain Plastic Bottle]

notes

Cooled Feed Cooldown 2014-02-(26-30)

BIASING started 11:04 to 13:40

The effect of looping the wires of the feed input wires: p. 27-29 shows the model filter with the straight wires. To exaggerate the effects of looping the leads we replace the straight wires on each side of the capacitors by semi-circles.

length is now $\frac{\pi}{2} d \cong$ i.e. $1.5d$, same diameter $r = .001''$

this is for both leads.

$$L = 2\ell \times 10^{-7} \ln\left(\frac{2\ell}{e r}\right)$$

original values are = 0.85 nH

With the greater lengths of the loops, $L_1 = L_3 = 1.5$ nH, almost double the original lengths. Other values stay the same. The planned upper band edge is still 16 GHz. The calculation formula is the same as on pp. 24-28.

```
In[11]:= f1[x_] := 100 + I (9.42 x)

In[12]:= f2[x_] := I (2.01 x - 1 / (.000682 x))

In[13]:= f3[x_] := 100 + I (11.43 x - 1 / (.000628 x))

In[14]:= f4[x_] := 100 / (100 + I (9.42 x))

In[15]:= f5[x_] := 100 + I (9.42 x) + f1[x] f2[x] / f3[x]

In[16]:= G = Plot[Abs[2 f1[x] f2[x] f4[x] / (f3[x] f5[x])]^2, {x, 1, 15},
           Frame → True, GridLines → Automatic]
```

Out[16]=

Compared with p. 29, the new roll-off is much worse.
very large

Is the skin effect a problem for the feed lead wires?

From Ramo and Whinnery:

skin depth (planar): $\delta = .0642/\sqrt{f}$ meters for silver.

f is in Hz.

for $f = 1\ \text{GHz} = 10^9\ \text{Hz}$, the planar skin depth is:

$$\delta = .0642/\sqrt{10^9} = 2.14\times10^{-6}\ \text{m}$$

For a wire that is 3 thousands of an inch in diameter, $\delta = 35$ skin depths at the lowest frequency. The current should be uniform accross the wire. That is, the skin effect is unimportant.

The planar surface Resistivity is $2.52\times10^{-7}\sqrt{f}$ ohms.

For $f = 1\ \text{GHz}$ near the lower end of the band,

$R_s = 2.52\times10^{-7}\sqrt{10^{10}} = 2.52\times10^{-2}$ ohms. This is small compared to the 100 Ω impedance level of the components in the filter.

The actual looping of the wires left the first loop intact and approximately doubled the length of the second loop. The transmission in this second case is shown below.

```
In[1]:= f1[x_] := 100 + I (10.78 x)

In[2]:= f2[x_] := I (2.01 x - 1 / (.000628 x))

In[3]:= f3[x_] := 100 + I (12.69 x - 1 / (.000628 x))

In[4]:= f4[x_] := 100 / (100 + I (10.68 x))

In[5]:= f5[x_] := 100 + I (5.34 x) + f1[x] f2[x] / f3[x]

In[6]:= G2 = Plot[Abs[2 f1[x] f2[x] f4[x] / (f3[x] f5[x])]^2,
          {x, 1, 15}, Frame -> True, GridLines -> Automatic]
```

Out[6]=

The transmission through a 6" bottle of 0.07" (.178 cm) thickness. The calculation is based on the formula of ☒ 146.

$\gamma_0 = \omega\sqrt{\mu_0\epsilon_0} = .2095 f_j$; $\gamma_g = \sqrt{\epsilon_r}\,\gamma_0 = .4083 f_g$

$$E = \frac{4}{4.462 e^{i(.01467x} - .463 e^{-i(.0146x)}}$$

```
In[4]:= f1[x_] := 4.462 Exp[I (.0725 x)]

In[5]:= f2[x_] := -.463 Exp[-I (.0725 x)]

In[6]:= G3 = Plot[Abs[4 / (f1[x] + f2[x])]^2,
          {x, 1, 15}, Frame → True, GridLines → Automatic]
```

Out[6]=

Compare with similar calculations on p 12-19 (.04") p. 22 (.04") p. 23 (.08") p. 32 (.06") p. 35 (.06") These are all glass; p. 122 for plastic bottle.

The transmission through a .06" thickness bottle of glass with a fairly high dielectric constant: 5.1. The bottle is 6" diameter.

```
In[7]:= f1[x_] := 4.701 Exp[I (.0753) x]

In[8]:= f2[x_] := -.7011 Exp[-I (.0753) x]

In[9]:= G4 = Plot[Abs[4 / (f1[x] + f2[x])]^2, {x, 1, 15}, Frame → True, GridLines → Automatic]
```

Out[9]=

The thickness is .06". The glass is pyrex with $\epsilon = 5.1$.
The transmission at 7.5 GHz is 0.8. Expect average transmission of 0.86 with lens. (average in frequency)

Expect average transmission of 0.93 with fused quartz.

Transmission through a .04" bottle with the high dielectric constant, 5.1 (6" diameter)

```
In[10]:= f1[x_] := 4.7065 Exp[I (.048 x)]

In[11]:= f2[x_] := -.7065 Exp[-I (.048 x)]

In[12]:= G5 = Plot[Abs[4 / (f1[x] + f2[x])]^2, {x, 1, 15}, Frame → True, GridLines → Automatic]
```

Out[12]=

A I

7.5 GHz the transmission is 0.90 giving a mean transmission across the band of 0.93 (estimated)

Required accuracy of the glass and plastic lenses

For a lens with one way transmission with RMS thickness σ variation across the lens, the phase scattered signal loss is:

$$e^{-\left(\frac{2\pi\sigma}{\lambda}\right)^2} \; ; \; e^{-.1} = 0.90 \text{ (e.g.)}$$

10 percent loss; Go for 5% loss or less

The shortest wavelength is 2cm (15 GHz) ; $e^{-.1} = 0.905$

So, $\left(\frac{2\pi\sigma}{\lambda}\right)^2 = .1$ and $\frac{2\pi\sigma}{\lambda} \le 0.3$; $\sigma \le \frac{0.3\lambda}{2\pi} = 0.1$, at the shortest λ

So the lens must have $\sigma < 0.1$ cm, or $\sigma \le 1$ mm [.04"] for ~~maximum~~ gain loss at 2cm (15 GHz) equal to .1