Ultra-Gaussian Horns for ClOVER – a B-Mode CMB Experiment

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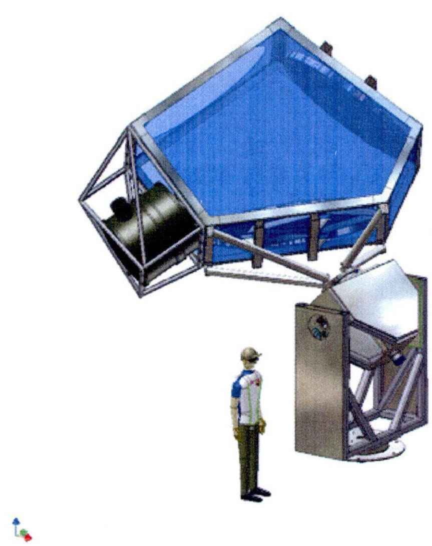
Abstract — **ClOVER is a UK funded experiment to be based in the Atacama Desert to measure the B-mode polarization of the Cosmic Microwave background between multipoles of 20 and 1000 down to foreground limited sensitivities. One of two telescopes will operate large focal plate arrays at 150 and 225 GHz, using TES bolometers.**

The feeds to these bolometers utilise corrugated horns with novel features which meet with two important performance requirements: very low sidelobes, to avoid uncontrolled signal contamination and high pass filtering to control the fields presented to the Radial Probe detectors.

The former is provide by a design, developed by Graham Smith in St.Andrews, to deliberately excite HE12 higher order modes in a sine-square profile section of the horn, followed by an extended parallel section designed to bring the HE12 mode into phase with the dominate HE11 mode. Surprisingly wide bandwidths – at the 30% level - with sidelobes well below minus 35dB are achieved. Analysis shows that close to 99.88% of the transmitted power (in a time reversed view) is in the fundamental Gaussian free space mode – hence the term, Ultra-Gaussian horn.

The later is provide by a filter section close to the transition into the detector module. The suppression of leaks well below the nominal HE11 cut-off provided an interesting computational and experimental challenge, requiring significant modelling effort in both HFSS and more traditional Mode Matching programs.

Special attention has been applied to the production engineering of these horns – given budgetary constraints and the large number required (100 in each band)



An image of the telescope with the horns places inside the black cryostat (Middle left of picture)

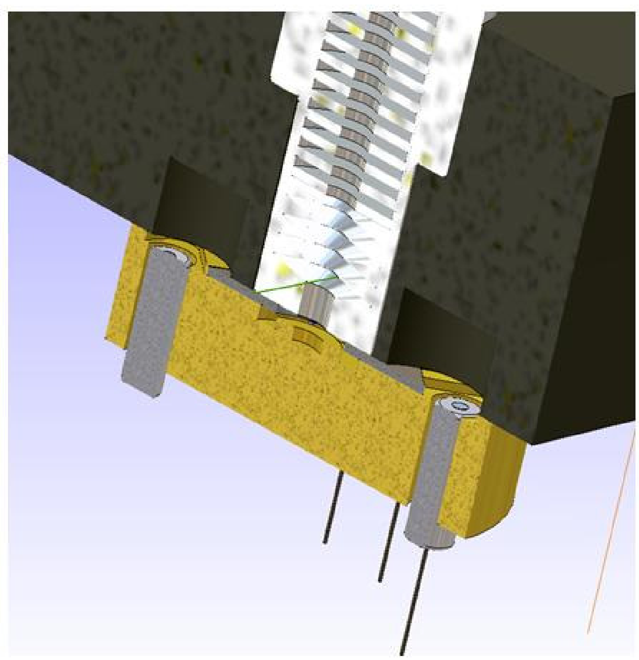
Introduction

ClOVER [1] is a UK funded experiment to be based in the Atacama Desert to measure the B-mode polarization of the Cosmic Microwave background between multipoles of 20 and 1000 down to foreground limited sensitivities. One of two telescopes will operate large focal plane arrays at 150 and 225 GHz, using a 4-probe Ortho-Mode Transducer (OMT) in circular waveguide with outboard TES bolometers to simultaneously detect the orthogonal polarizations.

Clover Horns

The form of a 150 GHz ClOVER focal plane module is shown in the two images below, indicating how a set of 8 closely packed horns are assembled to feed the 4-probe device which is supported on a silicon nitride membrane across the circular guide. A backshort behind the membrane enhances the probe absorption efficiency. Detail of the backshort design is presented in [2].

The horns mandrels are made on a modified Harding SuperPrecision lathe, and electroformed using a space-qualified process. To control costs, the outside form of the horn has been kept as simple as possible, allowing alignment to be provided by the assembly.



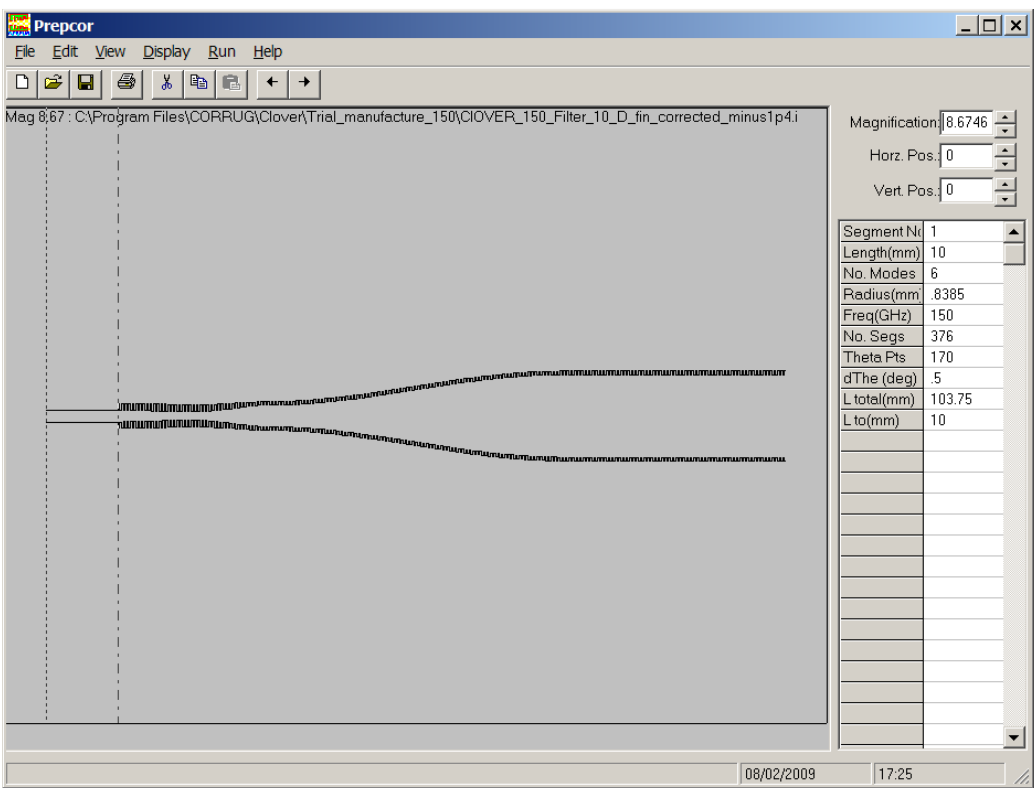
Sidelobes

A B-mode experiment requires critical control of the beam on the sky as any power contribution from strong polarized sources in the sidelobes will contamination the primeval signal. The cleanliness of the feed system is thus a crucial part of the design.

Traditionally, corrugated horns have be used for this task as they provide axially symmetric patterns over the wide spectral bandwidth needed for detection of the weak B-mode signature - but their sidelobes are typically at the –25 dB level.

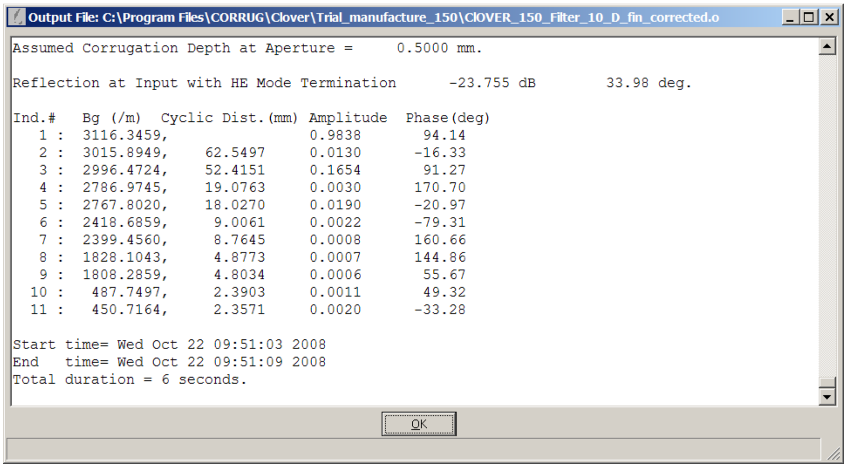
Recently however, Graham Smith of St. Andrews University, devised a way of deliberately adding a HE12 component to the standard HE11 mode formed at the throat of a corrugated horn and then - with a phasing section - allowing the two modes to come into phase [3]. In principle it is possible to move from having 98% of the power in the fundamental mode in a standard corrugated horn to something like 99.88%.

This is the approach that we have taken for the ClOVER horns. The form of the horn is shown below, with a cosine squared profile to generate the appropriate amount of HE12 mode and then a phasing section to bring this mode into phase with the HE11 fundamental mode.



In this cross section, the profile section generated the HE12 mode, and the parallel section brings it into phase with the HE11 mode

Soe Min Tun of SMT Ltd has devised an addition to his CORRUG mode matching program to help us design such "Ultra-Gaussian" horns by providing amplitude and phase of the HE1n and EH1m mode sets, to allow computational adjustments to be made.



Output File: C:\Program Files\CORRUG\Clover\Trial_manufacture_150\ClOVER_150_Filter_10_D_fin_corrected.o

Assumed Corrugation Depth at Aperture = 0.5000 mm.

Reflection at Input with HE Mode Termination -23.755 dB 33.98 deg.

Ind.#	Bg (/m)	Cyclic Dist.(mm)	Amplitude	Phase(deg)
1 :	3116.3459,		0.9838	94.14
2 :	3015.8949,	62.5497	0.0130	-16.33
3 :	2996.4724,	52.4151	0.1654	91.27
4 :	2786.9745,	19.0763	0.0030	170.70
5 :	2767.8020,	18.0270	0.0190	-20.97
6 :	2418.6859,	9.0061	0.0022	-79.31
7 :	2399.4560,	8.7645	0.0008	160.66
8 :	1828.1043,	4.8773	0.0007	144.86
9 :	1808.2859,	4.8034	0.0006	55.67
10 :	487.7497,	2.3903	0.0011	49.32
11 :	450.7164,	2.3571	0.0020	-33.28

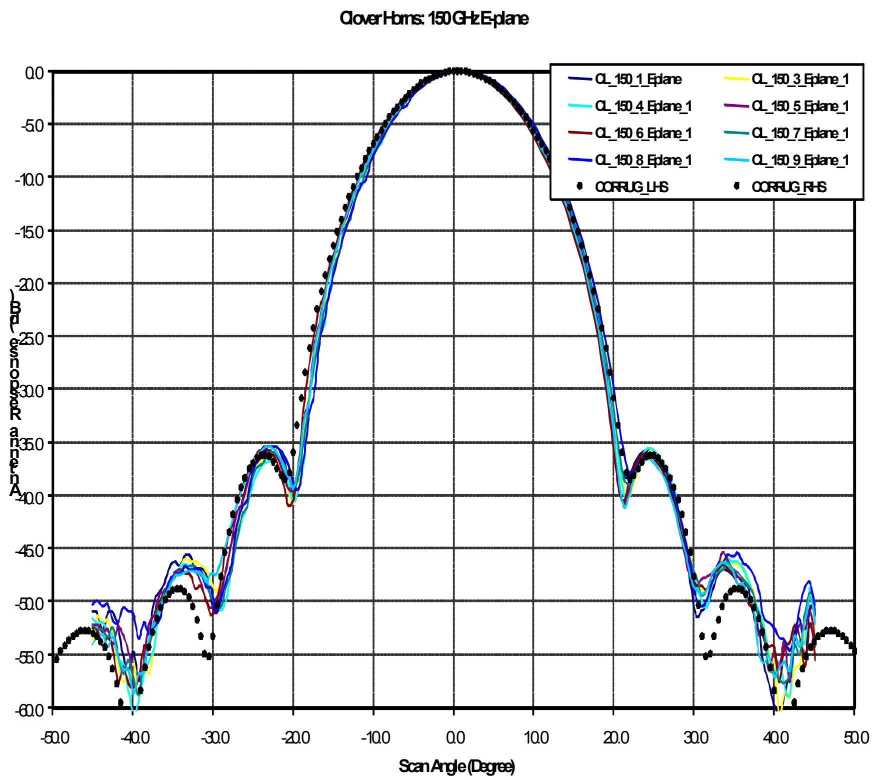
Start time= Wed Oct 22 09:51:03 2008
End time= Wed Oct 22 09:51:09 2008
Total duration = 6 seconds.

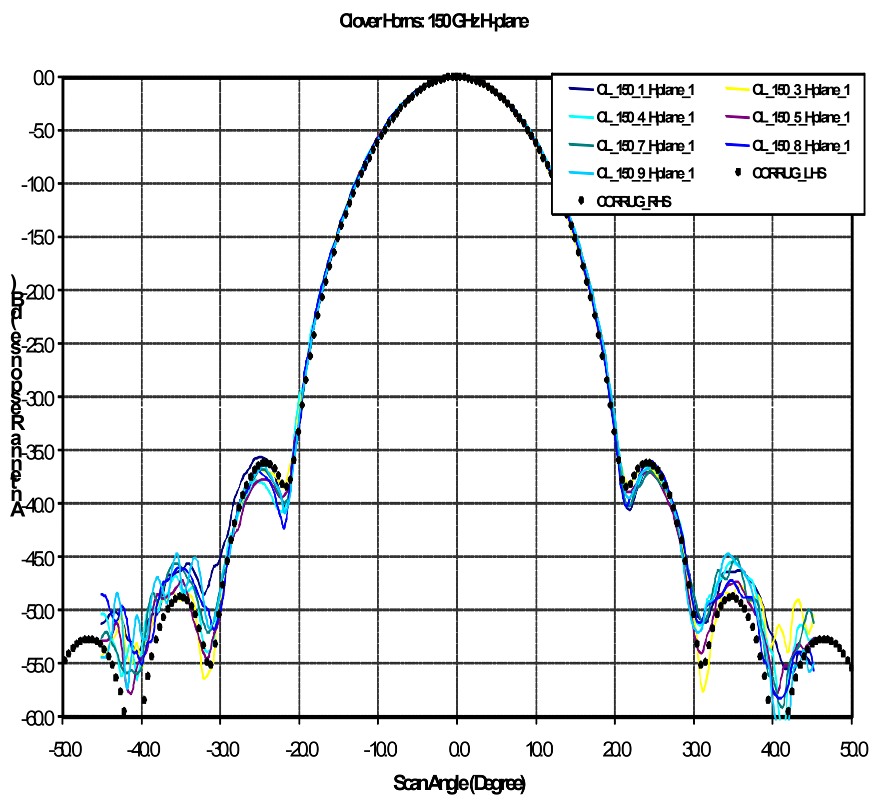
OK

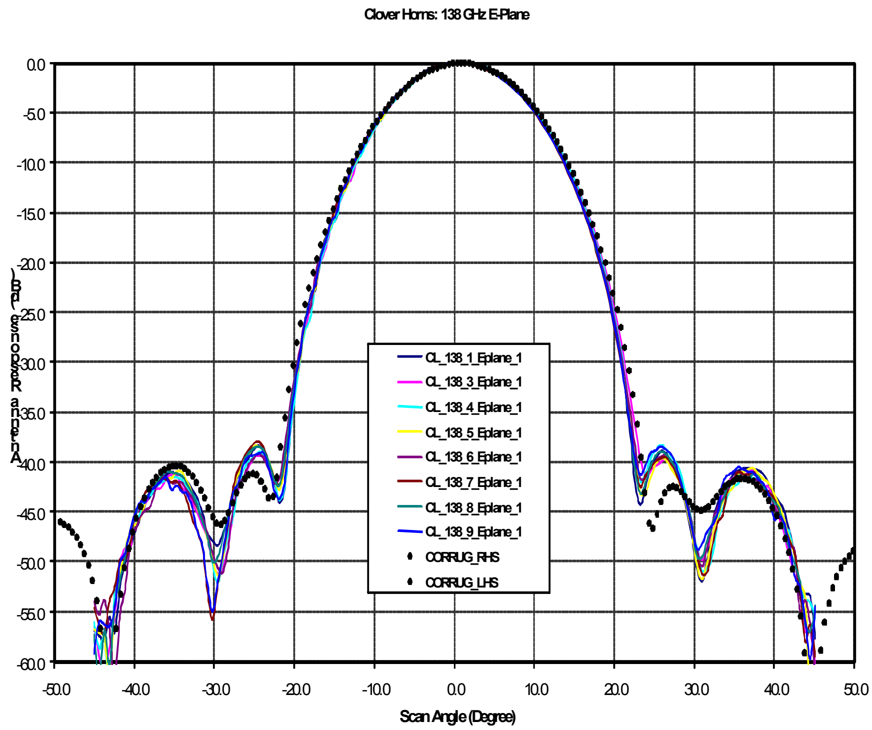
At the practical level one simply modifies the length of the cosine-square form to give the amplitude of HE12 mode desired and then adjusts the length of the parallel section to bring the modes into phase.

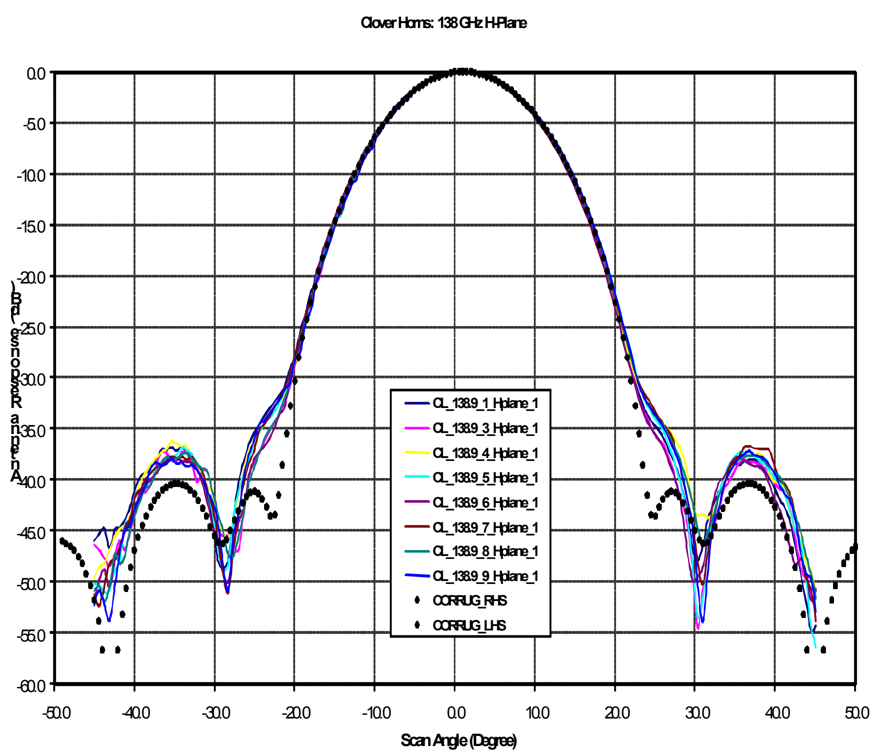
Performing this analysis over the wide band of frequencies detected, has shown that this technique is much more insensitive to changes in frequency than, for instance, Potter or Picket horns – which also rely upon the generation of higher order smooth wall modes to improve the antenna pattern.

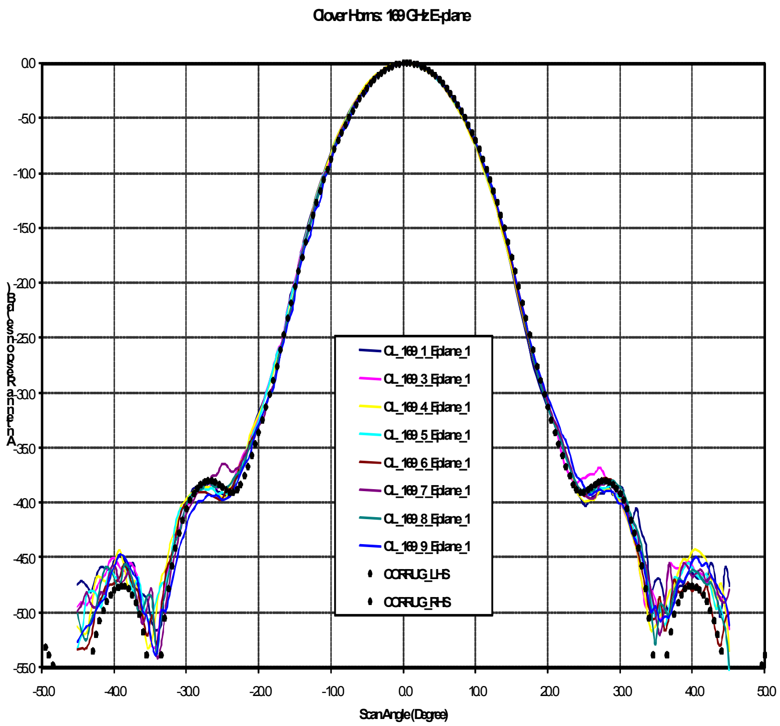
The outcome of this analysis can be seen in the following plots of E& H pattern measurements made on a set of ClOVER horns at the middle and band edge frequencies. The black dots are the CORRUG mode matching predictions, and provide ample proof that both the analysis and construction of the horn are working well.

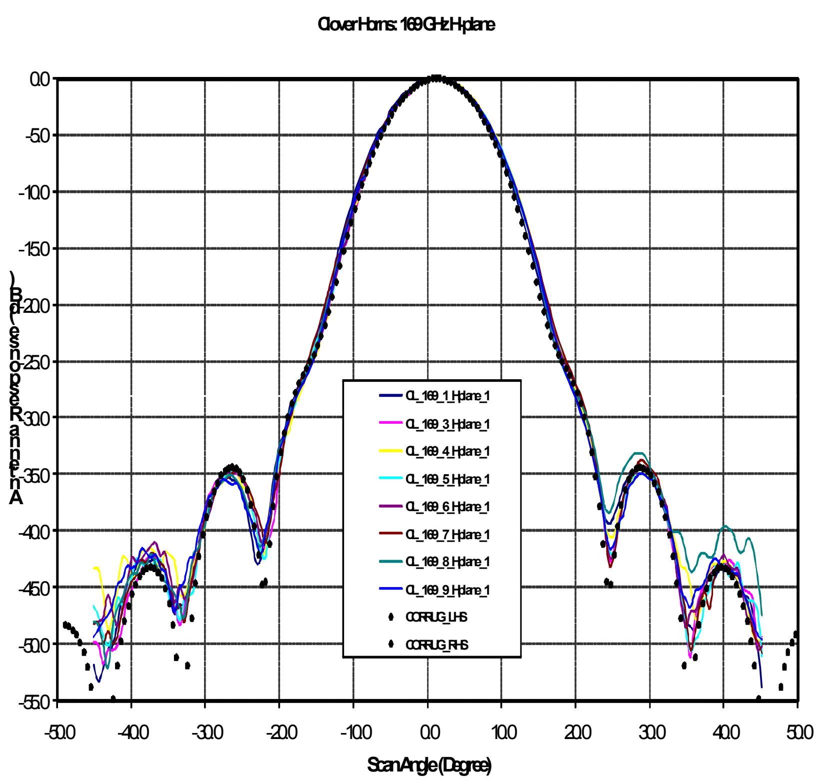

Clover Horns: 150 GHz E-plane
CL_150_1_Eplane
CL_150_3_Eplane_1
CL_150_4_Eplane_1
CL_150_5_Eplane_1
CL_150_6_Eplane_1
CL_150_7_Eplane_1
CL_150_8_Eplane_1
CL_150_9_Eplane_1
CORRUG_LHS
CORRUG_RHS
Antenna Response (dB)
Scan Angle (Degree)


Clover Horns: 150 GHz H-plane
CL_150_1_Hplane_1
CL_150_3_Hplane_1
CL_150_4_Hplane_1
CL_150_5_Hplane_1
CL_150_7_Hplane_1
CL_150_8_Hplane_1
CL_150_9_Hplane_1
CORRUG_LHS
CORRUG_RHS
Antenna Response (dB)
Scan Angle (Degree)


Clover Horns: 138 GHz E-Plane
Antenna Response (dB)
Scan Angle (Degree)
CL_138_1_Eplane_1
CL_138_3_Eplane_1
CL_138_4_Eplane_1
CL_138_5_Eplane_1
CL_138_6_Eplane_1
CL_138_7_Eplane_1
CL_138_8_Eplane_1
CL_138_9_Eplane_1
CORRUG_RHS
CORRUG_LHS

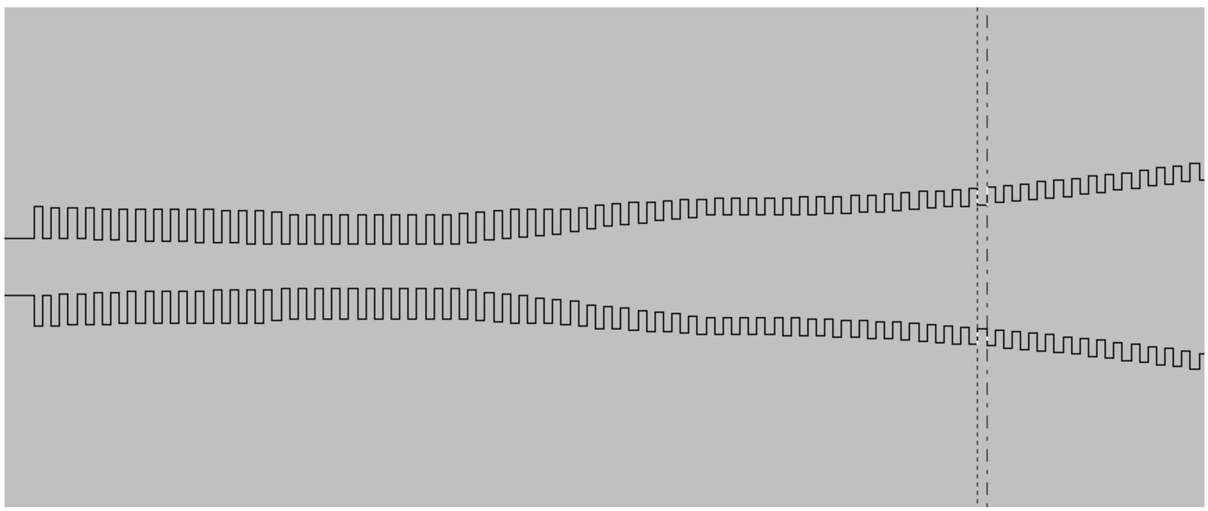

Clover Horns: 138 GHz H-Plane
Antenna Response (dB)
Scan Angle (Degree)
CL_138.9_1_Hplane_1
CL_138.9_3_Hplane_1
CL_138.9_4_Hplane_1
CL_138.9_5_Hplane_1
CL_138.9_6_Hplane_1
CL_138.9_7_Hplane_1
CL_138.9_8_Hplane_1
CL_138.9_9_Hplane_1
CORRUG_RHS
CORRUG_LHS


Clover Horns: 169 GHz E-plane
Antenna Response (dB)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
CL_169_1_Eplane_1
CL_169_3_Eplane_1
CL_169_4_Eplane_1
CL_169_5_Eplane_1
CL_169_6_Eplane_1
CL_169_7_Eplane_1
CL_169_8_Eplane_1
CL_169_9_Eplane_1
CORRUG_LHS
CORRUG_RHS
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
Scan Angle (Degree)


Clover Horns: 169 GHz H-plane
Antenna Response (dB)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
CL_169_1_Hplane_1
CL_169_3_Hplane_1
CL_169_4_Hplane_1
CL_169_5_Hplane_1
CL_169_6_Hplane_1
CL_169_7_Hplane_1
CL_169_8_Hplane_1
CL_169_9_Hplane_1
CORRUG_LHS
CORRUG_RHS
-50.0
-40.0
-30.0
-20.0
-10.0
0.0
10.0
20.0
30.0
40.0
50.0
Scan Angle (Degree)

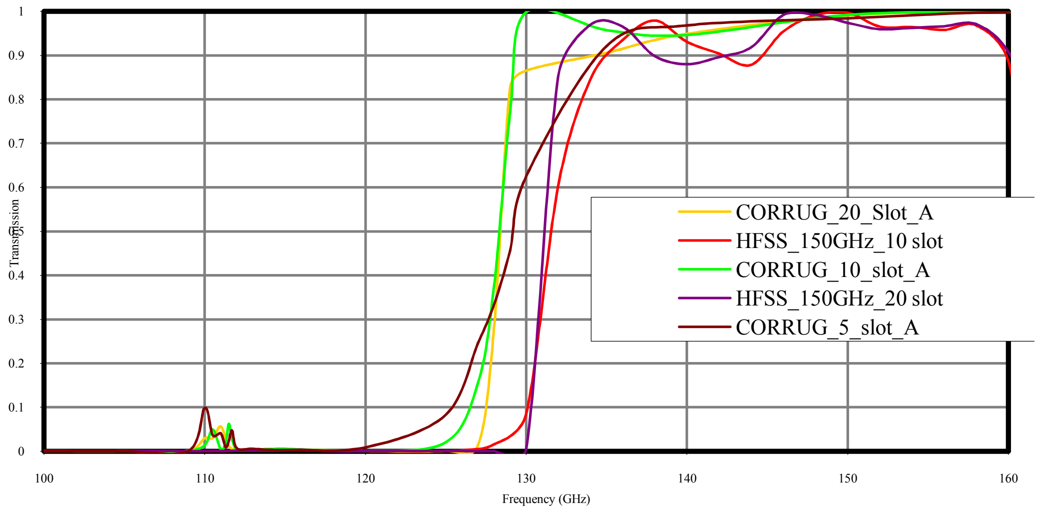
Filtering

In addition to the low-sidelobe patterns, the horns also need to provide a high pass cut on to the detectors. The presence of a section of parallel guide - see in this expanded section of the horn - provide the cutoff.



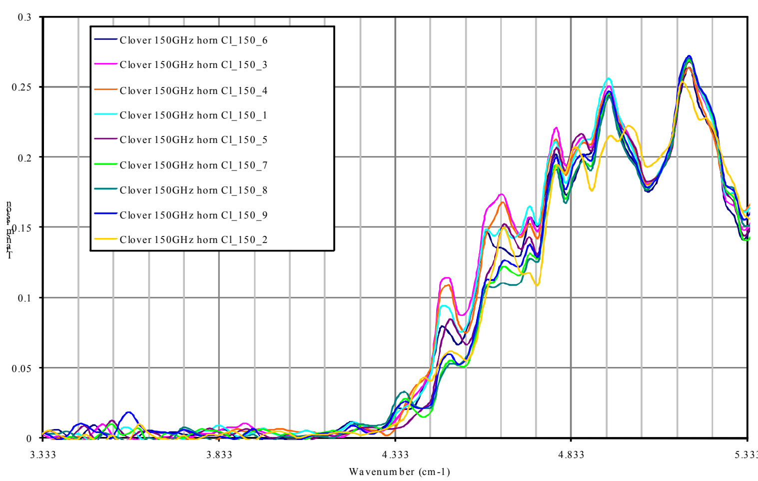
It turns out that the filtering action of HE11 guides is not a simple as one might expect. The dispersion curves for the structure are complex, and not at all intuitive. As other have found out [4], one can suffer leaks, often associated with slow wave propagation, at frequencies well below the nominal cut on.

We have used both HFSS and CORRUG to model the leakage below the cutoff band. The plot below gives details of the modeling results, showing the unwanted leakage around 110 GHz.



CORRUG and HFSS modeled Transmission from 100 to 160 GHz (3.33 to 5.33 wave numbers)

Filter sections of 5,10 and 20 slot were examined following a very careful heuristic design of the transition in and out of the filter section, with 10 slots proving to be sufficient. A set of trial horns was placed in the optical path of a long wavelength spectrometer to determine the spectral nature of the high frequency cut-on. As the presence of the horns modifies the optical matching to the spectrometer, the precise level of transmission is not important. These data show that the cut-on is occurring at the desired frequency and that low frequency leaks are absent.



Measured Transmission from 3.33 to 5.33 wave numbers (100 to 160 GHz)

Conclusions

The design of corrugated horns had been though of as a mature technology, but these ClOVER horns employ some unexpected new developments[1] to give the required sidelobes for CMB measurements. Though careful modeling, problems associated with sub-band leakage though the filtering section have been overcome.

References

[1] Clover – Measuring the CMB B-mode polarization. C.E.North et al. 18th Int. Symp on Space Terahertz Technology, Pasadena, California, USA
[2] "Clover Polarimetric Detector - A Novel Design of an Ortho-Mode Transducer at 150 and 225 GHz". Mauskopf P., Zhang J., Ade P.A.R., Withington S., Grime P., Progress In Electromagnetics Research Symposium, 24th-28th March 2008, Hangzhou, China.
[3] "Reducing Standing waves in Quasi-optical Systems by Optimal Feedhorn Design". Paul A.S. Cruickshank, David R. Bolton, Duncan A. Robertson, Richard J. Wylde and Graham M. Smith, in Digest of IRMMW-THz2007 conference, Cardiff 2007, Volume 2 pp941-942
[4] "Corrugated waveguide band edge filters for CMB experiments in the far infrared" E.Gleeson, J.A.Murphy, D.Maffei, W.Lanigan, J.Brossard, G.Cahill, E.Cartwright, S.E.Church, J.Hinderks, E.Kirby, C.O 'Sullivan in Infrared Physics and Technology 46 (2005) 493-505

[1] It turn out that similar mode sets – with high levels of HE12 modes - were used in the Planck HFI horns, but without a proper understanding of the process which gave rise to the good sidelobes performance