HERA-19 commissioning: radio frequency interference

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Abstract

In HERA memo #7 [3], I analyzed stacked RFI flags from 200 nights of PAPER-128 observations. Stacking the flags allowed me to identify 'repeat offender' RFI channels as a proxy set for what we could expect the HERA RFI environment to look like. In this memo I use HERA and PAPER data, taken at the same time as part of the HERA IDR1, to move from forecasts of the RFI environment to actual realizations of it. I find that HERA-19 picks-up many more narrow-band RFI channels, mainly at the low and high ends of the band, but is also sensitive to broadband RFI bursts. More data is required to understand whether or not this is 'normal' behaviour.

1 Introduction

The HERA-19 internal data release 1 (IDR1) consists of four subarrays: the HERA-19 hexagon of dishes (the 'HERA Hex'), a hexagon of 19 PAPER dipoles in the exact positions of not-yet-constructed HERA dishes (the 'PAPER Hex'), an imaging array and an experimental array for polarization measurements. I will concentrate on the two Hexes in this memo. Furthermore, I will be analyzing radio frequency interference (RFI) as flagged in the linear xx-polarization only. Asymmetric beams can in principle pick up different RFI events for different linear polarizations, but study of that is outside the scope of this diagnostic memo.

At the time of writing, IDR1 consists of one 'golden day', JD2457458. This runs from 6pm on March 10th 2016 to 6am the following day. This gives, per baseline, roughly 4000 integrations of 20 seconds each over 1024, 100 kHz frequency channels from 100 to 200 MHz.

In order to flag RFI I used the AIPY script `xrfi_simple.py`, which takes the derivative of the frequency axis of all baselines associated with a given antenna and flags any frequencies with a derivative $\geqslant 6\sigma$ above the mean, per integration. I took the union of all baseline flags as my data to analyze below. Unlike in my previous memo [3], these data did not have a-priori flagging of band edges, FM radio, etc., which allows me to make more identifications than last time. I do have to build-in flags in order to get more than a zeroth-order view of the RFI (since these will dominate the flagging routine unless they are flagged already), but I can now have a better idea of *what* I am flagging to get there.

In the sections below, I present measurements of high-power, mostly narrow-band RFI channels as flagged in HERA Hex data and PAPER Hex data separately. In both cases, I list any channels that are flagged for $\geqslant 1\%$ of the night. I can then compare the flagging Hex-to-Hex, and to PAPER-128. I conclude with my major findings.

2 HERA Hex RFI

Table 1 shows all narrowband frequency ranges flagged in HERA-19 visibilities, with columns of the frequency range in MHz, % flagging over time, plausible identification, whether or not it was reported in Memo #7, notes (often details of the ID) and finally the range that the South African Table of Frequency Allocations (SATFA, [5]) places those frequencies in, bounded by horizontal lines in the table. Frequencies with 100% flagging indicate manual flags required for `xrfi_simple` to work on the rest of the channels.

Clearly, the low-end of the band is swamped by FM radio broadcasts. One notable frequency is the 109.2±0.3 MHz band, which is heavily flagged in HERA visibilities, but was only flagged a few percent in Memo #7.

As seen before, the ORBCOMM satellite emissions spill out of their allocated 137-138 MHz band down to 136.3 MHz.

There are many narrowband RFI channels, across the band, that PAPER-128 did not pick-up. Most of these are flagged only at low levels, with two exceptions: 111.3±0.2 MHz and 113.5±0.1 MHz. Both of these like in the aircraft navigation band. There is some evidence [1] that 111.3 MHz band is an air force communications. The 113.5 MHz band is a known band for radionavigation beacons ('VOR navaids') [2].

A particularly annoying 'new' emitter is the 153.8±0.2 MHz one, which is close to the center of our nominal EoR band. It could correspond to mobile phones being used close to site.

3 PAPER Hex RFI

Table 2 has the same description as Table 1, but for the PAPER Hex. Clearly, there are far fewer RFI frequencies flagged in PAPER visibilities, almost all of which are seen by HERA. The only RFI seen by the PAPER Hex and *not* the HERA Hex is 123.5±0.1 MHz emission, which I cannot find a plausible identification for. I make more comparisons to HERA in the following section.

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Table 1: RFI as flagged by HERA

ν (MHz)	flagged (%)	ID (Possible)	Seen by PSA128?	Notes	SATFA [5]
100.7 ± 0.2	50	FM Radio	n/a	RSG "Dis Die Een" Prieska	
101.5 ± 0.3	36	FM Radio	n/a	RSG "Dis Die Een" Calvinia	
102.4 ± 0.1	100	FM Radio	n/a	RSG "Dis Die Een" Carnarvon	
102.8 ± 0.3	57	FM Radio	n/a	RSG "Dis Die Een" Pofadder	FM Radio
104.2 ± 0.1	100	FM Radio	n/a	SAfm Prieska	
105.1 ± 0.2	100	FM Radio	n/a	SAfm Calvinia	
106.2 ± 0.3	100	FM Radio	n/a	SAfm Carnarvon	
106.9 ± 0.1	15	FM broadcast	n/a	Sentech	
107.2 ± 0.1	18	FM Radio	Yes		
107.8 ± 0.2	15	FM Radio	Yes		
108.3 ± 0.1	31	FM Radio?	Yes		
109.2 ± 0.3	93	FM Radio?	Yes...	...but not to this degree	
111.3 ± 0.2	25	Air force?	No		
112.5 ± 0.1	5	?	No		Aeronautical
113.5 ± 0.1	21	Airplane Communications	No	VOR navaid	Radionavigation
115.5 ± 0.1	3	Navaids?	No		
115.9 ± 0.1	3	Navaids?	No		
116.6 ± 0.2	9	Airport Communications?	Yes	VOR-DME navaids	
120.1 ± 0.2	5	Aircraft	Yes	CPT< − >JNB	
125.0± 0.2	6	Aircraft	Yes	CPT< − >JNB	Aeronautical
130.0 ± 0.2	4	Aircraft	No	Air-to-air communication	Voice/data
131.6 ± 0.2	15	Aircraft	Yes	KLM OPS	communication
136.4 ± 0.1	9	ORBCOMM	Yes		
136.7 ± 0.1	10	ORBCOMM	Yes		
137.4 ± 0.4	100	ORBCOMM	Yes		
145.7 ± 0.4	18	ISS/Amateur Radio band	Yes		Satellite
149.9 ± 0.1	100	ISS	Yes		communication
153.8 ± 0.2	7	Single frequency mobile phones?	No		
175.0 ± 0.1	100	VHF TV	Yes	Channel 4 Video	
178.3 ± 0.2	8	VHF TV	No	Channel 7?	
181.2 ± 0.1	100	VHF TV	Yes	Channel 4 Audio	
182.2 ± 0.2	9		Yes		
183.5 ± 0.6	100	VHF TV	Yes	Channel 5 Video	
184.1 ± 0.1	2	VHF TV?	Yes	Channel 5?	VHF
184.7 ± 0.1	6		No		Broadcasting
187.8 ± 0.1	4		No		
189.1 ± 0.1	52	VHF TV	Yes	Channel 5 Audio	
190.1 ± 0.3	13		n/a		
191.1 ± 0.1	100	VHF TV	n/a	Channel 7	
197.2 ± 0.2	18		n/a		
199.4 ± 0.5	100	BAND EDGE	n/a		

Table 2: RFI as flagged by PAPER

ν (MHz)	flagged (%)	ID (Possible)	Seen by PSA128?	Notes	SATFA [5]
100.0 ± 0.1	100	BAND EDGE	n/a		
100.7 ± 0.1	11	FM Radio	n/a	RSG "Dis Die Een" Calvinia	
101.6 ± 0.2	6	FM Radio	n/a	RSG "Dis Die Een" Calvinia	
102.4 ± 0.1	100	FM Radio	n/a	RSG "Dis Die Een" Carnarvon	
102.7 ± 0.1	100	FM Radio	n/a	RSG "Dis Die Een" Pofadder	FM Radio
104.2 ± 0.2	100	FM Radio	n/a	SAfm Prieska	
105.1 ± 0.2	100	FM Radio	n/a	SAfm Calvinia	
106.2 ± 0.3	100	FM Radio	n/a	SAfm Carnarvon	
108.2 ± 0.1	3	FM Radio?	Yes		
109.1 ± 0.1	26	FM Radio?	Yes		Aeronautical
113.6 ± 0.1	2	Airplane Communications	No	VOR navaid	Radionavigation
120.2 ± 0.3	3	Aircraft	Yes	CPT< − >JNB	
123.5 ± 0.1	1		No	Not seen by HERA	
125.0 ± 0.2	6	Aircraft	Yes	CPT< − >JNB	Aeronautical
130.0 ± 0.3	3		No		Voice/data
131.7 ± 0.2	14	Aircraft	Yes		communication
136.4 ± 0.2	6	ORBCOMM	Yes		
136.7 ± 0.2	6	ORBCOMM	Yes		
137.4 ± 0.4	100	ORBCOMM	Yes		
145.8 ± 0.3	14	ISS/Amateur Radio band	Yes		Satellite
149.9 ± 0.1	100	ISS	Yes		communication
153.8 ± 0.2	3	Single frequency mobile phones?	No		
175.1 ± 0.2	100	VHF TV	Yes	Channel 4 Video	
178.3 ± 0.2	100	VHF TV	No	Channel 7?	
181.2 ± 0.1	100	VHF TV	Yes	Channel 4 Audio	VHF
183.2 ± 0.2	100	VHF TV	Yes	Channel 5 Video	Broadcasting
189.2 ± 0.1	100	VHF TV	Yes	Channel 5 Audio	
191.2 ± 0.1	100	VHF TV	n/a	Channel 7	
199.8 ± 0.2	100	BAND EDGE	n/a		

4 Comparisons

4.1 Hex to Hex

As mentioned above, the PAPER Hex sees far fewer narrowband RFI channels than HERA does. This highlights an interesting trade-off between dipoles and dishes: at first glance, one might expect PAPER dipoles to be more susceptible to RFI given their broader effective beams. However, HERA dipoles are lifted several meters above the ground, and this change in height may be the source of the greater susceptibility to RFI. RFI comes from the horizon, which is now more easily received in the far sidelobes of the beam.

Even for the RFI channels they do share, HERA flags more of it. Taking the difference in percentage-flagged for the common RFI channels (think of the left panel subtracted from the right panel for common channels in Figure 1), those channels have an average of 8% more flagging in HERA visibilities. The difference is particularly high in the aeronautical radionavigation band, where HERA has on average 38% more flagging than the PAPER Hex.

Figure 2 shows the flags on a sample basis (these were averaged over time to create Figure 1). Most apparent is the crowdedness of the HERA plot compared to the PAPER Hex one. An important component of this plot is the averages over frequency in the right-hand panels. We see that the average flagging for a given time sample is about 5% higher on HERA than on the PAPER Hex, mostly due to the higher flag occupancy in the FM band. But we also see something new - HERA appears to be much more sensitive to broadband bursts of RFI. The PAPER Hex catches one of these (around 1.30am SAST) at high significance, but most of them hardly rise above average flagging. HERA sees five to seven bursts across the night.

4.2 PAPER-128 stacked flags

Memo #7 looked at RFI flags stacked over 200 days of observations. This method washed-out single events that effect analysis on a single-night basis, but was sensitive to repeatedly offending frequencies. Due to the PAPER-128 analysis pipeline, many channels were automatically flagged (particularly large portions of the band edges), which artificially boosted the average flagging per time and did not allow for closer inspection of the ends of the band. There was some evidence of broadband emission (see Figure 1 of that memo) but the band was largely free of RFI in the middle of the night. Obviously, the data presented in this memo shows a less-clean band, but it also only concentrates on a single night's data, so it may be that this night is conspicuous compared to an 'average' night of observations.

Traits shared between the two memos are:

- Aircraft communications disrupting data until around local midnight.
- ORBCOMM spilling out of it's band.
- VHF TV frequencies emitting throughout the night in the high end of the band.

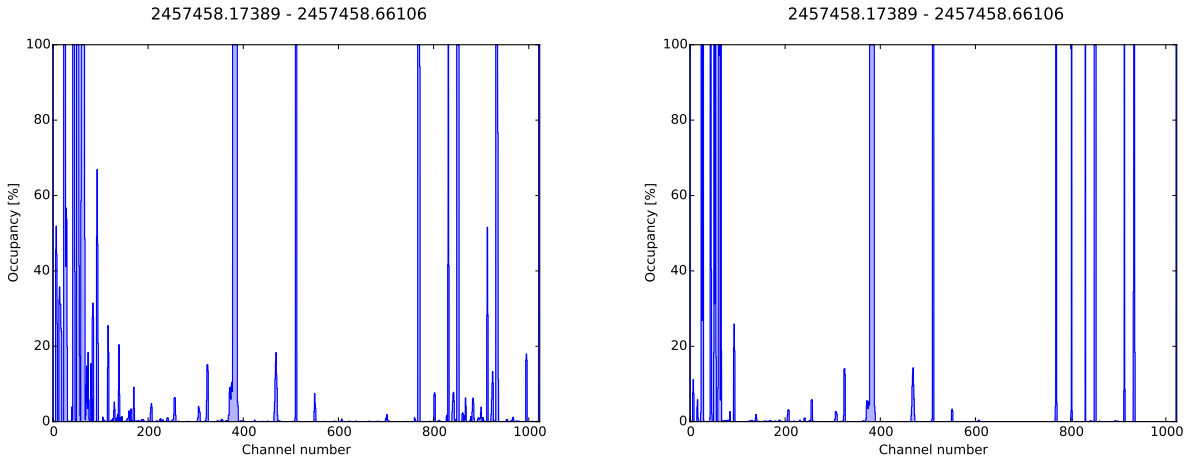

Figure 1: Frequency vs. percentage flagging for the HERA Hex (*left*) and PAPER Hex (*right*). Any band with greater than 1% flagging is reported in Tables 1 and 2.

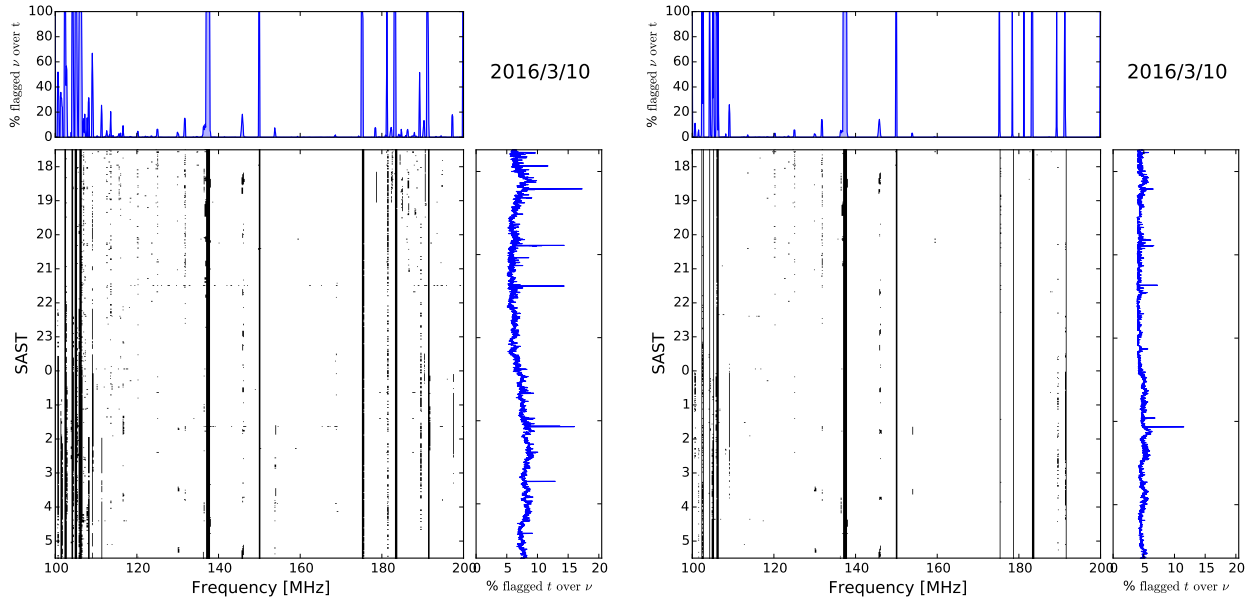

Figure 2: RFI flag 'waterfalls' of frequency vs. South Africa Standard Time (SAST) for the HERA Hex (*left*) and PAPER Hex (*right*). The top panels show the average over time (identical to Figure 1), while the right panels show the average over frequency.

Table 1 highlights many frequencies seen by HERA and not by PAPER-128. Again, given the fact I stacked flags in memo #7, these may not be 'new', but they might be. Particularly conspicuous are the emissions in the aeronautical radionavigation band.

5 Conclusion

I have presented a first look at RFI in HERA-19 Commissioning data. Probably due to the height of the receiving element on HERA versus PAPER dipoles, much more RFI is apparent, especially on the low and high ends of the band. Luckily, the EoR band is largely clean of RFI, except an emitter at about 154 MHz, which could correspond to single-frequency mobile phone communications. These are officially banned in the SKA Radio Quiet Zone [4], which HERA is at the center of.

Only looking at a single night of RFI flags limits the predictive power of this memo. More data is required to establish whether or not this is level of RFI is 'normal'. In particular, I think we need to investigate broadband RFI bursts more closely.

Efforts to extend the HERA band to lower and possibly higher frequencies are currently under way. The FM radio band extends to around 65 MHz, while the VHF TV band extends to around 230 MHz, so the RFI environment should be a consideration for these efforts.

Meanwhile, I should also note that the RFI flagging routine used here, `xrfi_simple`, is indeed simple. More advanced RFI flagging algorithms such as AOFlagger are going to be tested in later studies.

HERA collaborators with access to the `folio` cluster can find the data used in this memo in:
`folio:/data4/paper/HERA2015/2457458/RFI_{HH,PH}/*uvcR`

References

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[5] Staatskoerant. South african table of frequency allocations. Technical Report 31264, ICASA, `http://thornton.co.za/resources/31264_890_complete-1.pdf`, July 2008.