Parkes RFI Environment and Mitigation

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1. Introduction

An obvious issue with a low-frequency broad-band receiver is the degree to which the science data are affected by radio-frequency interference (RFI). RFI comes in two main classes: a) relatively narrow-band quasi-steady transmissions and b) broad-band transient signals. Very strong narrow-band signals can result in non-linear responses which dramatically spread the signal in frequency. Transient emissions are a particular problem for pulsar observations since observing systems have high time resolution.

Here we discuss strategies for estimating the current level of RFI at Parkes within and around the band of the proposed Ultra-Wideband Low-frequency (UWL) receiver (0.7 – 4.0 GHz), estimating likely future developments, and strategies for mitigating the effect of RFI signals.

2. The current Parkes RFI environment

We have a good knowledge of the Parkes RFI environment in the bands currently used for pulsar astronomy. Although the widths of the observed bands greatly exceed the widths of bands where radio astronomy has some regulatory protection, RFI within them is generally manageable and data quality is not seriously compromised. Outside of the observed bands we have limited knowledge of the radio spectrum. Existing surveys are of low sensitivity and are incomplete. Furthermore, we have no extensive survey of impulsive RFI, although pulsar surveys and the lunar neutrino detection (LUNASKA) project have shown that most impulsive RFI at 20cm is generated on-site and is strongly concentrated between 9am and 4pm local time.

To address this problem, specifically over the band of the UWL receiver, an RFI measuring system, similar to that to be used for ASKAP/SKA site monitoring, is being constructed by Ron Beresford, Aaron Chippendale, Aidan Hotan and Paul Roberts. This will consist of an unpolarised antenna and preamplifier covering the band 25 MHz to 6 GHz, to be located near the 12-m ASKAP antenna at Parkes, a Rohde & Schwarz FSU-26 programmable spectrum analyser with 50 MHz instantaneous bandwidth, the BEDLAM transient recorder developed for the LUNASKA project, and control and data recording software. We will use this to make a high-sensitivity survey of the RFI spectrum and transient activity over the band 50 MHz to 6 GHz. We plan to commission the system at Parkes and do a first survey in mid-2013, and then to repeat the survey at approximately six-monthly intervals to monitor long-term trends in the RFI environment. We expect that long-term trends in RFI at frequencies up to 3.5 GHz will also be monitored using a dedicated system based on a Rohde & Schwarz EB 500 spectrum analyser.

Known strong RFI bands affecting the Parkes enviromnent are listed in Table 1. Column 3 gives the flux density at the telescope of the in-band signal in dB(W m^{-2} Hz^{-1}). Where the transmitter power and location are known or can be estimated, this is given by

$$S_{\mathrm{dB(Wm^{-2}Hz^{-1})}} = P_{\mathrm{t,dBW}} + G_{\mathrm{t,dBi}} - 20\log d_{\mathrm{km}} - 10\log B_{\mathrm{t,MHz}} - 131 \tag{1}$$

where $P_{\mathrm{t,dBW}}$ is the isotropic transmitted power in dBW, $G_{\mathrm{t,dBi}}$ is the transmitter antenna gain relative to an isotropic radiator, d_{km} is the transmitter distance from the Parkes telescope in km, $B_{\mathrm{t,MHz}}$ is the transmitted bandwidth in MHz, and the −131 db comes from unit conversions (ITU-R P.525-2). Note that these estimates do not include terrain loss (usually at least a few dB) and so are conservative in that respect. On the other hand, atmospheric ducting and other anomalous propagation effects can lift RFI levels above nominal levels for distant terrestrial transmitters. However, this is relatively rare and so not a major issue. For satellite and other transmitters where the signal levels are not easy to estimate, observed signal levels from RFI monitoring are taken; this is indicated by "obs" in the Comments column. The next column gives the RFI power received at the preamplifier input in dBm, given by

$$P_{\mathrm{i,dBm}} = S_{\mathrm{dB(Wm^{-2}Hz^{-1})}} + 10\log B_{\mathrm{t,MHz}} - 20\log f_{\mathrm{MHz}} + 10\log N_{\mathrm{t}} + G_{\mathrm{r,dBi}} + 128.6 \tag{2}$$

where f_{MHz} is the signal frequency in MHz, N_{t} is the number of signals of bandwidth $B_{\mathrm{t,MHz}}$ and $G_{\mathrm{r,dBi}}$ is the effective gain of the telescope in the far sidelobes relative to an isotropic radiator. For the Parkes telescope, assuming an aperture efficiency of 0.7, the main-beam gain is approximately

$$G_{\mathrm{Pks(0,0)}} = 20\log f_{\mathrm{MHz}} - 5.1 \text{ dBi.} \tag{3}$$

At 1 GHz, this gives a forward gain of about +55 dBi. Taking an average sidelobe level of −50 dB relative to the main beam, the effective antenna gain in the far sidelobes is therefore about +5 dBi. This number is very approximate, neglecting systematic effects related to the feed-leg structure and other diffraction and reflection effects. Given the large uncertainties, we assume the same effective far sidelobe gain for all frequencies.

The amplifier input power levels may be compared with the receiver noise-floor power given by

$$P_{\mathrm{sys}} = kT_{\mathrm{sys}}B_{\mathrm{r}} \tag{4}$$

where P_{sys} is in Watts, T_{sys} is the system noise temperature in Kelvin and B_{r} is the receiver bandwidth in Hz. With the noise power expressed in dBm and with B_{r} in MHz, this is

$$P_{\mathrm{sys}} = 10\log T_{\mathrm{sys}} + 10\log B_{\mathrm{r,MHz}} - 138.6 \text{ dBm.} \tag{5}$$

For $T_{\mathrm{sys}} = 25$ K and a 4 GHz bandwidth, P_{sys} is about −89 dBm.

Signals can propagate over the edge of the dish directly into the feed. Given a normal primary beam taper, the feed gain at the edge of the dish is about +3 dBi. Therefore, these "spill-over"

Table 1: Known strong RFI bands affecting the Parkes environment

Source	Frequency Range/Bandwidth (MHz)	Flux Density (dB(W m^{-2} Hz^{-1}))	Amp-in Power (dBm)	Comments
Mt Coonambro ATV	412–419	−122	−50	9 × 0.01 MHz
Mt Canobolas DTV	582–637	−116	−23	5 × 7 MHz
Mt Ulandra DTV	652–693	−165	−72	obs, 5 × 7 MHz
GSM Mobile phone	880–915	−131	−56	0.1W @ 1 km, 5 × 0.2 MHz
GSM Mobile base	925–960	−133	−62.5	5W @ 20 km, 2 × 0.2 MHz
Parkes Airport DME	1018/0.1	−180	−116	
ADS-B air navigation	1090/1.2	−134	−57	10km range
GPS L2,L1	1227/2,1575/2	−190	−116	obs
Airborne Defence radar	1260–1335	−90	−20	obs, intermittent
DRCS links	1438/2,1499/2	−175	−98	obs
Thuraya-3	1534–1559	−170	−100	obs, modulated 0.5 MHz bands
Iridium/Globalstar	1610–1626	−180	−107	obs
3G Mobile phone	1920–1980	−145	−63	0.1W @ 1 km, 5 × 5 MHz
3G Mobile base	2110–2170	−147	−69	5W @ 20 km, 2 × 5 MHz

signals have very similar levels to those coming in through far sidelobes of the main beam and the levels given in Table 1 are relevant.

Within the UWL band, the strongest signals are likely to be the airborne Defence radar systems and the ADS-B air-navigation system at 1090 MHz. The former is very strong but only occasionally present. The latter is strong when equipped planes are in Parkes airspace. From 2014 its use will be mandatory on all new aircraft and so it can be expected to be present much of the time. A high-temperature superconducting (HTS) filter between the feed and the preamplifier may be required. Aside from these transmissions, mobile phones used by visitors near the Observatory are likely to be the most problematic. Mobile base stations are not as strong, but are always present. Satellite transmissions are ubiquitous but are usually relatively narrow-band and do not result in non-linear response. Consequently they are relatively easy to filter out in the signal processing system. The same is true for relatively narrow-band point-to-point links such as the Digital Radio Concentrator Service (DRCS) transmissions.

Digital television (DTV) signals are broadband (7 MHz/channel) and are the strongest continuous signals in the Parkes environment. Existing transmissions are just below the band proposed for the UWL receiver but may not be significantly attenuated by the feed response. An HTS filter between the feed and the preamplifier may be required.

3. Future developments

While we can access some information through the Australian Communications and Media Authority (ACMA) and other relevant agencies, it is very difficult to predict all future developments. For example, satellites can be launched by administrations where we have no control and little access to information. Under the Governments “Digital Dividend”, spectrum in the bands 694–820 MHz and 2500–2690 MHz is scheduled for auction from April 2013. It is most likely that they will be used for wireless access services, in particular, 4G+ mobile communications. In both bands, spectrum will be sold in paired 5+5 MHz bands separated by fixed offsets. Different regions will be auctioned separately — Parkes is in the Regional East Australia area. We do not know what effect users of this spectral space will have on Parkes operations or the timescale on which this may happen. Maintaining close contact with relevant people in ACMA and in the wider communications industry on such issues is essential. For example, over many years the ACMA RALI MS31 arrangements, originated by Tasso Tzioumis and implemented by Erik Lensson, have been successful in influencing the placement and radiated power of transmission towers in the Parkes area, including the recent NBN rollout planning.

Table 2 gives estimated specifications as in Table 1 for known future transmissions affecting Parkes operation. Galileo is the European global navigation system and plans for 30 satellites in mid-altitude orbits; currently three are launched and operating. Estimated levels are based on the observed signals in the central (E6) Galileo band as shown in Figure 1. Levels for other radio navigation systems known to be operating or planned are likely to be similar — in fact the the "Galileo" signals shown in Figure 1 may in fact come from the Chinese "BeiDou" radio navigation system (also known as "Compass") which has similar plans to Galileo and occupies the same spectral space. The levels for the NBN base station transmissions are estimates based on currently available broadband wireless technologies. Uplink signals from NBN wireless users in the vicinity of the telescope are comparable but likely to be a little stronger.

Table 2: Future RFI bands

Source	Frequency Range/Bandwidth (MHz)	Flux Density (dB(W m^{-2} Hz^{-1}))	Amp-in Power (dBm)	Comments
Galileo/BeiDou	1164–1214, 1260–1300, 1563–1591	−190	−107	15 × 1 MHz
NBN remote	2302–2382	−155	−73	1W @ 5 km, 2 × 20 MHz
NBN base	2302–2382	−160	−78	2 × 20 MHz

4. Mitigation strategies

Signals which are strong enough to result in a non-linear response at any point in the receiver chain are mixed with all other signals in the band. If the strong signal is modulated, this modulation is seen in all the mixed products. For example, the BPSR amplifier chain has very little headroom and the modulation of the Galileo/BeiDou signals shown in Figure 1 dominates the noise power over the entire receiver passband.

Front-end preamplifiers can be designed to avoid significant non-linearity for signals which increase the system noise by about 20 dB (100-fold increase). That is, signals with power at the amplifier input of more than about −69 dBm (see Tables 1 and 2) may result in a significantly non-linear response. Strong signals which would saturate the preamplifiers must be avoided by reduced feed gain or by using HTS filters ahead of the preamplifiers. Signals which are not strong enough to saturate the preamplifiers may still saturate subsequent stages of amplification. Such

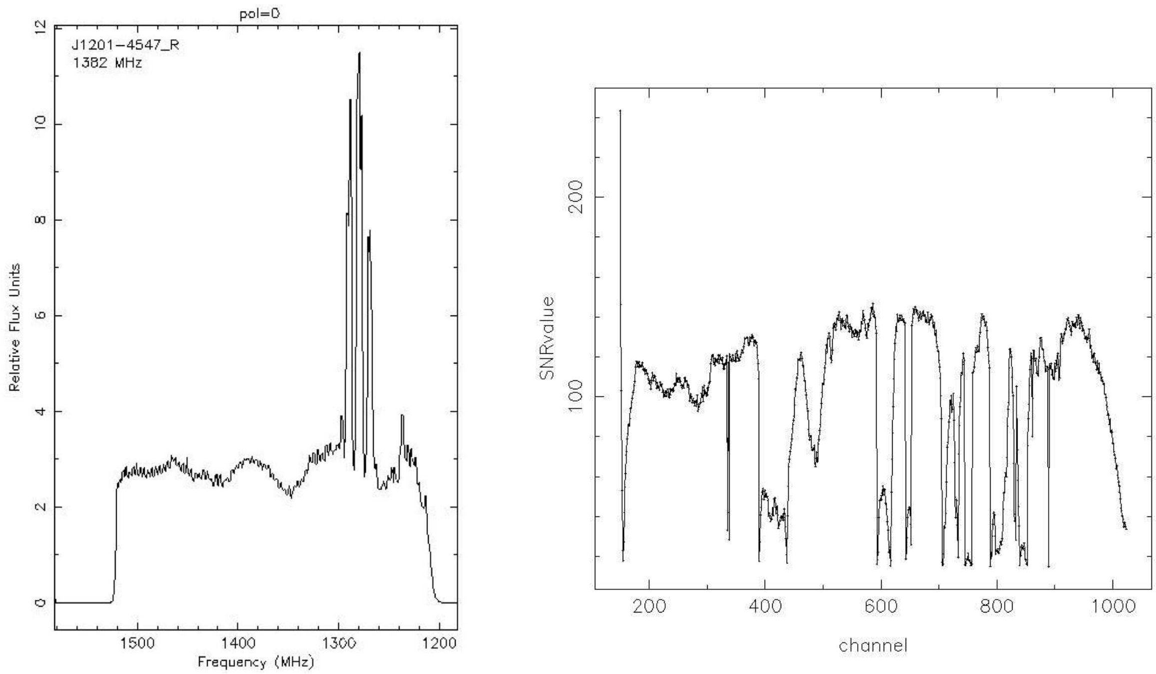

Fig. 1.— Left: BPSR bandpass spectrum recorded on 14 December, 2012 showing signals from three satellites (either Galileo or BeiDou) in the E6 (1260–1300 MHz) band. Right: Signal/noise ratio of the observed modulation across the same bandpass. Receiver non-linearity has spread the signal across the entire band. (M. Bailes)

signals can be removed with analogue filters after the first stage amplifiers. Weaker signals for which the system is linear can be filtered out post-digitisation either by excision or by adaptive filtering if a suitable reference signal is available.

A band-stop HTS filter suitable for use ahead of a first-stage preamplifier has been implemented at NRAO to reject satellite interference at 2.3 GHz (Pal et al. 2012). The filter has more than 40 dB attenuation in the 25 MHz stop band and an insertion loss of 0.15 dB at other frequencies. This insertion loss corresponds to a system temperature increment of 0.9 K at the filter operating temperature of 24 K. Similar filters could be developed for Parkes receivers. Since they can be designed with sharp cutoffs and high attenuation, their use after the first stage may also be advantageous.

The digitiser itself is a source of non-linearity because of the signal quantisation to a limited number of bits (Jenet & Anderson 1998). While 8-bit digitisation is adequate for most purposes, the very high level of some signals in the UWL band may require even more bits. Since very fast (e.g., 8 Gsamp/s) multi-bit digitisers are expensive, it may be worth considering splitting the band into two parts. This would allow use of say 12-bit digitisers and could be designed to avoid a very bad RFI band. For example, the lower band could cover 0.7 – 1.9 GHz and the upper band 2.4

– 4 GHz with two pairs of 4 Gsamp/s digitisers, thereby avoiding the 3G and NBN bands. With synchronised sampling, the data could be combined to allow (for example) quasi-real-time coherent dedispersion over the whole 0.7 – 4 GHz band.

Narrow-band signals which do not saturate the amplifier chain, e.g., those from the DRCS links, may be simply excised from the processed spectrum with no significant sensitivity loss. Other signals which cover a wide bandwidth and/or are time variable, e.g., mobile phone transmissions, may potentially be removed by adaptively filtering the digitised signal (Kesteven et al. 2010). This method, which requires an input reference signal containing the RFI, has been successfully applied to remove the Mt Ulandra DTV signals from the original 50cm band. After filtering, the RFI signal in the astronomy channel is reduced to approximately $1/S_r$ of its original strength, where S_r is the signal/noise ratio of the RFI signal in the reference channel. The underlying astronomy signal is unaffected. The filtering can be applied to both polarisations of the astronomy signal using the same reference signal.

For satellite and mobile phone signals, a near-isotropic reference antenna would have to be used. This would have a gain comparable to that of the far sidelobes, so any signal that has an input power of about -100 dBm or more in a 1-MHz channel and does not saturate the amplifier chain can effectively be removed from the data.

Impulsive RFI is by its nature broad-band and cannot be removed by spectral filtering. However, since such RFI normally has a very low duty cycle, it can be detected after digitisation and excised from the data stream without significant loss of sensitivity. A system that detects kurtosis in the distribution of digitised baseband voltages has been successfully implemented in the CASPSR recording system at Parkes. A similiar system could be implemented for the UWL receiver. It should be noted that a multibeam or PAF system is potentially advantageous in that locally generated RFI signals will not have a single-source far-field response, allowing discrimination against them.

5. Summary

Because of the very broad band and high sensitivity of the proposed UWL receiver, RFI poses a significant challenge to its successful operation. The RFI within the currently observed bands is reasonably well characterised but an extensive survey is required to examine the entire 0.7 – 4 GHz band of the proposed Parkes UWL receiver. Currently known and expected RFI signals will require a range of mitigation strategies to obtain high-quality astronomy data over the UWL band, but such strategies appear feasible with current technology.

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