RFI2004

P E N T I C T O N   C A N A D A

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CONTENTS

WORKSHOP COMMITTEE

Members of the *Workshop Committee* include:

Albert-Jan Boonstra (ASTRON)
Frank Briggs (MSO/ANU; Co-Chair)
Simon Ellingson (Virginia Tech; Co-Chair)
Donna Morgan (NRC/HIA/DRAO)
Neel Smuts (South Africa)
Ken Tapping (NRC/HIA/DRAO)
Tasso Tzioumis (ATNF)
Wim van Driel (Obs. de Paris; IUCAF liason)
P. Zarka (Obs. de Paris)

If you have any questions or comments please feel free to talk to any of them at any time. Other DRAO personnel in attendance may also be approached for assistance if needed.

The Committee was assisted by the LOC for the SKA 2004 meeting that follows RFI 2004:

Dave Del Rizzo
Sean Dougherty (Chair)
Cindy Furtado
Tony Hoffmann
Donna Morgan
Tom Landecker
Ken Tapping
Bruce Veidt

The Committee would like to acknowlege the considerable contributions of Jason Shrivell, Kathy Gibbard, Amy Fink, and Andrew Gray in the organization of this workshop.

IMPORTANT INFORMATION

The **workshop venue** is the Covington Building at the Dominion Radio Astrophysical Observatory (DRAO; phone 250-493-2277, fax 250-493-7767), located a 20 minute drive south of Penticton, about 8 km off Highway 97 on White Lake Road (look for the blue sign on the right just after the Highway 3 junction).

In what follows, the Penticton Lakeside Resort, at 21 Lakeshore Drive W (at the junction with Main Street), is referred to as "The Lakeside".

When	What	Where
July 16, 0745	Transportation to DRAO	The Lakeside
July 16, 0815	Arrive DRAO and pick up participant packages	DRAO Foyer
July 16, 1730	Tour of DRAO (refreshments and appetizers provided)	DRAO
July 16, 1930	Transportation to The Lakeside	DRAO
July 17, 0745	Transportation to DRAO	The Lakeside
July 17, 1700	Transportation to The Lakeside	DRAO
July 18, 0815	Transportation to DRAO	The Lakeside
July 18, 1100	Transportation to The Lakeside	DRAO

Transportation to DRAO will be provided to those without access to private or rental vehicles. Unless notified otherwise, the pick up and drop off location is the main entrance of The Lakeside.

Computer/Internet access will be available at DRAO for checking email, etc. There are two computer terminals outside the main meeting room and six Internet stations in the screened room on the second floor, near the reception area.

Posters will be on display in the foyer outside the main meeting room for the duration of the workshop.

Refreshments will be made available in the foyer each morning and afternoon.

Lunch will be provided for registered workshop participants on the patio outside the lunch room.

A **tour of DRAO** is scheduled for 1730 on Friday, July 16, following the day's session. The tour will be conducted mainly outdoors so you will need shoes suitable for walking on unpaved areas. Daytime temperatures in mid-July are typically $\sim 30°$C ($\sim 86°$F) and it is usually very dry. Refreshments will be available, including appetizers and beverages (beer, juices, and water).

A reminder for those registered for the **SKA2004 Conference**, there is a Registration/Reception at the Art Gallery of the South Okanagan (located immediately east of The Lakeside, at 199 Front Street), 1900 to 2200 on Sunday, July 18.

P A R T I C I P A N T S A – I

Ambrosini, Roberto	IRA - CNR
Ananthakrishnan, S.	NCIR/TIFR
Baan, Willem	ASTRON
Barnes, David	The University of Melbourne
Beresford, Ron	CSIRO
Bhat, Ramesh	MIT/Haystack
Bissell, Robert	Industry Canada
Boonstra, Albert-Jan	ASTRON
Bower, Geoffrey	UC Berkeley
Bregman, Jaap D.	ASTRON
Bretteil, Stephanie	LESI/Polytech'Orleans
Briggs, Frank	ANU-RSAA/CSIRO-ATNF
Bunton, John	CSIRO, ICT Centre
Chippendale, Aaron	CSIRO, ATNF
Chung, HyunSoo	Korea Astronomy Observatory
Colom, Pierre	Observatoire de Paris
Corbett, Greg	Industry Canada
Cornwell, Tim	NRAO
Davis, Michael M.	SETI Institute
DeBoer, David	SETI Institute
Deshpande (desh), Avinash	Arecibo Observatory/NAIC and RRI
Dewdney, Peter	NRC/HIA/DRAO
Diaz, Marcos	MIT Haystack
Dodson, Richard	ISAS
Dreher, John	SETI Institute
Drew, Dave	ICASA – South Africa
Dumez-Viou, Cedric	LESI / Observatoire de Paris
Ekers, Ron	CSIRO, ATNF
Ellingson, Steven	Virginia Tech
Fisher, Rick	NRAO
Fridman, Peter	ASTRON
Galt, John	NRC/HIA/DRAO
Gazaille, Chantal	Industry Canada
Gergely, Tomas	NSF
Gray, Andrew	NRC/HIA/DRAO
Hall, Peter	ISPO
Harp, Gerry	Allen Telescope Array
Horiuchi, Shinji	Swinburne University of Technology
Horell, Jasper	Saratoga Software (Pty) Ltd
Hyunh, Tam C.	Industry Canada

PARTICIPANTS J – Z

Je, Do-Heung	Korea Astronomy Observatory
Jeffs, Brian	Brigham Young University
Jonas, Justin	HartRAO
Kant, Dion	ASTRON
Kawai, Eiji	Kashima Space Research Center, NICT
Kesteven, Michael	Australia Telescope, CSIRO
Kim, HyoRyoung	Korea Astronomy Observatory
Kogan, Leonid	National Radio Astronomy Observatory
Kramer, Michael	University of Manchester/Jodrell Bank
Landecker, Tom	NRC/HIA/DRAO
Lane, Wendy	Naval Research Lab
Lewis, (Brian) Murray	NAIC (Arecibo)
Millenaar, Rob	ASTRON
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Tingay, Steven	Swinburne University of Technology
Tzioumis, Tasso	ATNF,CSIRO
van der Tol, Sebastiaan	TU Delft
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Veidt, Bruce	NRC/HIA/DRAO
Wijnholds, Stefan	ASTRON
Willis, Tony	NRC/HIA/DRAO

PROGRAMME

FRIDAY JULY 16

Introductory Session — Chair: S. Ellingson (Virginia Tech)

0830 Welcome and Introductions

0845 **The Future of our Radio Window on the Universe (Invited)**
Ron Ekers (ATNF)

0915 *Overview of Technical Approaches to RFI Mitigation*
F. Briggs (ANU/MSO)

0945 **Getting RFI Mitigation into the Workplace (Invited)**
J. R. Fisher (NRAO)

1015 *coffee break*

Regulatory Session — Chair: S. Ellingson (Virginia Tech)

1030 *Quiet Please – Introduction to Regulatory Protection*
Wim van Driel (Obs. de Paris)

1100 *SKA and ITU Regulations*
Tomas Gergely (NSF)

1130 *Radio Quiet Zones – Past, Present, and Future*
Tasso Tzioumis (ATNF)

1200 *lunch (provided on DRAO patio)*

Radar and Iridium — Chair: F. Briggs (ANU/MSO)

1330 *Examination of a Simple Pulse Blanking technique for RFI Mitigation*
N. Niamsuwan, J. T. Johnson (Ohio State), S. Ellingson (Virginia Tech.)

1355 *Kalman Tracking and Bayesian Detection for Radar RFI Blanking*
W. Dong, B. D. Jeffs (Brigham Young), J. R. Fisher (NRAO)

1420 *Iridium: Characterization and Countermeasures*
P. McDougle, S. Ellingson (Virginia Tech.)

1445 *RFI Mitigation and Burst etection with a Digital Receiver*
R. Weber (LESI/Polytech'Orleans), L. Denis (SRN), C. Dumez-Viou (LESI/SRN)

1510 *coffee break*

Applications — Chair: F. Briggs (ANU/MSO)

1530 *Ten Years of RFI – Project Phoenix at Parkes, Green Bank, and Arecibo*
M. M. Davis, P. R. Backus, J. Tarter (SETI)

1555 *Post-Correlation RFI Excision at Low Frequencies*
W. Lane, A. Cohen, N. Kassim, J. Lazio (NRL), R. Perley, W. Cotton, E. Griesen (NRAO)

1620 *Adaptive Filters Revisited – RFI Mitatgation in Pulasr Observations*
M. Kesteven, G. Hobbs (ATNF), R. Clement

1645 *RFI Mitigation for the Deuterium Experiemnt*
G. C. Bower (UC Berkeley)

1710 *RFI Mitigation Strategies for LOFAR and SKA*
W. A. Baan, A.-J. Boonstra, P. Fridman, R. Millenaar (ASTRON)

1735 DRAO Tour, with appetizers and refreshments.

1930 Tour ends.

SATURDAY JULY 17

Precorrelation Array Techniques — Chair: B. Jeffs (BYU)

0830 *RFI Mitigation at Westerbork: algorithms, test observations, system implementation*
W. Baan, P. Fridman, R. Millenaar (ASTRON)

0855 *RFI mitigation for tied-array configuration with phase-only adaptive beamforming*
P. Fridman (ASTRON)

0920 *Spatial Filtering of Interfering Signals at the Initial LOFAR Phased Array Test Station*
A.-J. Boonstra, S. van der Tol (ASTRON)

0945 *Design Constraints for RFI Nulling at the ATA*
G. R. Harp (SETI)

1010 coffee break

Postcorrelation Techniques — Chair: B. Jeffs (BYU)

1030 *Reference Antenna Techniques for Cancelling Interference from Moving Sources*
D. A. Mitchell (U. Sydney)

1055 *Correlations of Spectral Intensity Fluctuations; Application to RFI Mitigation*
A. A. Deshpande (NAIC/RRI)

1120 *Post-Correlation Ripple Removal and RFI Rejection for Parkes Telescope Survey Data*
D. G. Barnes (Melbourne), F. H. Briggs (ANU), M. R. Calabretta (ATNF)

1145 *Post-Correlation RFI Excision with the VLA and the EVLA*
R. Perley, T. Cornwell, S. Bhatnagar, K. Golap (NRAO)

1210 lunch (provided on DRAO patio)

Characterization and Algorithms — Chair: A.-J. Boonstra (ASTRON)

1400 *RFI Identification and Mitigation Using Simultaneous Dual Station Observations*
R. Bhat (MIT/Haystack), J. Cordes (Cornell), S. Chatterjee (NRAO), J. Lazio (NRL)

1425 *Cyclostationary Detectors for RFI Mitigation in Radio Astronomy*
S. Bretteil, R. Weber (LSI/Polytech'Orleans)

1450 *Another Algorithm for Phased Array Null Formation*
L. Kogan (NRAO)

1515 *The Effect of Amplifier Gain Compression in Correlation Coefficient*
R. Perley, R. Hayward (NRAO)

1540 coffee break

Mitigating RFI at RF — Chair: A.-J. Boonstra (ASTRON)

1600 *Interference Mitigation Using an Array Feed*
C. Hansen, K. F. Warnick, B. D. Jeffs (Brigham Young), J. R. Fisher, R. Bradley (NRAO)

1625 *RFI Mitigation at a 2 GHz band by using a wide-band high-temperature superconductor filter*
E. Kawai, J. Nakajima, H. Takeuchi, H, Kuboki, T. Kondo (NICT)

1650 *Suppression of Self-generated RFI Emissions for the EVLA*
S. Durand, R. Ridgeway, J. Jackson, R. Perley (NRAO)

1715 *Determination, control, and improvement of an SKA radio environment in South Africa*
N. Smuts (South Africa)

1740 end of session

SUNDAY JULY 18

Workshop Recap and Discussion — Chair: W. van Driel (Obs. de Paris)

ABSTRACTS

INTRODUCTORY

The Future of our Radio Window to the Universe

Ron Ekers
ATNF

This will be a very broad overview of issues related to the future use of the radio spectrum for astronomy. I will cover international activities, sharing use of the spectrum, impact of new technology, requirements for new telescopes, regulation versus mitigation, environmental credits, and other social issues.

Getting RFI Mitigation into the Workplace (Invited)

J. R. Fisher
NRAO

Over the past few years we have seen some impressive demonstrations of excision of RFI from radio telescope data. The techniques used include parametric signal synthesis and subtraction, adaptive filtering, post correlation subtraction, and pulse blanking. However, relatively little of this work has made its way into astronomical use. The distance between a demonstrated algorithm and devices that are useful to routine observing may be greater than we tend to imply.

The signal processing power required for RFI excision will be roughly in the range of one tenth to ten times the power required to do signal processing without excision, depending on the complexity of the RFI environment and the types of signals being removed. Hence, we will be directly competing for resources with astronomers' desire for wider bandwidths and higher time resolution. This calls for a careful match between the state of our art and the RFI problems that astronomers want solved. Thus far, there is not much overlap. Full implementation of RFI mitigation means that it must be usable by the non-expert. We tend to forget how much hand tweaking has gone into the optimization of our algorithms.

In this presentation I suggest that we take a very science-driven approach to RFI mitigation starting with simple solutions that have the highest ratio of scientific impact to effort required. Even the simplest algorithms can require a lot of work to make useful to the average observer. Experience in the entire implementation process will be a valuable guide to more sophisticated development. Continued funding for RFI mitigation research must and will depend on scientifically useful products. Designers of new radio telescopes are faced with a conundrum: systems are not easily retrofitted to RFI mitigation, but a lot of experience is still needed to confidently design excision algorithms into the instruments currently on the drawing boards. Some caution is required to avoid wasting resources.

Overview of Technical Approaches to RFI Mitigation

Frank Briggs
RSAA-ANU and ATNF-CSIRO

The goal of this introductory presentation will be to explore the commonality of different approaches to RFI mitigation, in order to help build intuition on some of the conditions under which interfering signals can be cancelled or subtracted without damaging the celestial signals that radio astronomers strive to receive.

Some of the methods can be visualized in much the same way that astronomers treat gain closure information and aperture synthesis. Cancellation of multiply scattered RFI appears at first glance to be a complex problem but can be treated very simply. Adaptive filters applied in the time-domain have precise analogs in the post-correlation frequency domain.

REGULATORY

Quiet, please – an introduction to regulatory protection strategies for the SKA

W. van Driel
IUCAF/Observatoire de Paris

The saying that "Prevention is better than a cure" also applies to the RFI situation for the SKA—the quieter its RFI environment, the higher the sensitivity that could be achieved and the easier it will be to mitigate residual RFI problems. An introduction will be given to the astronomical spectrum management situation, focused on different possible strategies for regulatory means to limit the levels of various kinds of RFI at the SKA site. In two related presentations, the role of the International Telecommunication Union (T. Gergely) and the implementation of Radio Quiet Zones (T. Tzioumis) will be discussed in further detail.

SKA and ITU Regulations

Tomas Gergely
National Science Foundation

The International Telecommunication Union (ITU) provides the international regulatory framework that governs the uses of the radio spectrum that the SKA will cover. The primary instrument used by the ITU to accomplish its task is the Radio Regulations (RR), an international treaty. Below the RR in hierarchy, but still at an important level, are the set of ITU-R Recommendations. For radio astronomy, the most important is Recommendation ITU-R RA.769, which lists the thresholds levels of interference harmful (or, in ITU-speak, detrimental) to observations in various bands allocated to radio astronomy. At a still lower level in this hierarchy are ITU Reports and the Rules of Procedure (ROPs), an interpretation of the Radio Regulations internal to the ITU that allows it to proceed with practical work.

I examine what provisions of the Radio Regulations cover radio astronomy, and how they may be applied to the SKA. I then discuss how the set of ITU-R radio astronomy recommendations, in particular Recommendation ITU-R RA.769, could be modified to cover the SKA. I discuss some of the assumptions that go into the calculation of threshold levels in and how they may change under the SKA scenarios envisioned.

Radio Quiet Zones - past, present and future

Tasso Tzioumis
ATNF, CSIRO

The first step of RFI mitigation should always be avoidance of RFI to the maximum practicable extent. One way to do this is to attempt to define the RF characteristics in the environment around our observatories, and that is the basic concept of a “radio quiet zone” (RQZ).

In this contribution, I will review the past and present instances of RQZs and their operational characteristics. However, as we move into the SKA era there is a need to define more precicely what ”radio quiet” means and what the new generation telescopes will need. I will review recent attempts at the OECD and ITU-R to progress the idea of RQZs. Finally, it is important that at these meetings we discuss possible paths to future RQZs and how to get there.

R A D A R A N D I R I D I U M

Examination of a simple pulse blanking technique for RFI mitigation

N. Niamsuwan, J. T. Johnson
Ohio State University

S. W. Ellingson
Virginia Tech

Radio frequency interference (RFI) mitigation is very important for spectroscopy at L-band due to the presence of numerous interference sources, including strong pulsed RFI from ground-based aviation radars (GBARs). A simple strategy for reducing pulsed RFI is to remove incoming data whose power exceeds the mean power by a specified number of standard deviations. It may also be advantageous to remove data within a specified time region before and after this “trigger” data, to ensure that any pre- and post- “pulse” information is successfully removed. Such an algorithm has been implemented in a fully-digital radiometer developed at the Ohio State University ElectroScience Laboratory; the process is termed “asynchronous pulse blanking” (APB) because no periodic properties of the interference source are assumed.

This paper presents results from a simulation of the APB algorithm on data obtained from the L-Band Interference Surveyor/Analyzer (LISA), an airborne instrument developed for observing the RFI in the region 1200–1800 MHz. The LISA instrument included a digital receiver capable of capturing 20 MHz of incoming data; this 20 MHz channel was tuned through the 1200–1800 MHz band throughout system flights. During Jan–Feb 2003, LISA was deployed on NASA’s P3-B aircraft to observe RFI in flights in the US and Japan. This data set is very useful for assessing the APB algorithm, since many RFI environments were observed that include multiple sources of interference. Several aspects of algorithm performance will be reported in the presentation, including the robustness of the method as the RFI environment is varied. Effects of the blanking process on the final output, which is now partially blanked if any pulse is detected, are also examined. Finally, alternate algorithms for the suppression of continuous wave (CW) interference will be discussed.

Kalman Tracking and Bayesian Detection for RADAR RFI Blanking

Weizhen Dong, Brian D. Jeffs
Brigham Young University

J. Richard Fisher
National Radio Astronomy Observatory

L-Band observations at the Green Bank Telescope (GBT) and other radio observatories are plagued with interference from pulsed aviation RADAR transmissions. Several researchers have studied the problem and proposed time gated blanking and parametric signal subtraction as mitigation strategies [Zhang, Fisher et al Ast. Jour. 126][Ellingson, URSI N. Amer. Mtng. 2003]. One remaining problem is that even when strong direct path pulses and nearby fixed clutter echoes are removed, there are still weaker aircraft echoes present which can corrupt the data. These echoes cannot be excised using fixed time-window blanking synchronized to the RADAR antenna rotation period because they can occur at any time due to the mobile nature of the aircraft. They must be detected before they can be removed, but low echo signal levels which make detection difficult can still corrupt astronomical signal observation. In this paper we present an algorithm which improves aircraft echo blanking by forming a Kalman filter tracker to follow the path of a sequence of echoes observed on successive RADAR antenna sweeps. The tracks developed for each aircraft can be used to predict regions (in bearing and range) for the next expected echoes, even before they are detected. The data in these regions can then be blanked in real time without waiting for the pulse peak to arrive. Additionally, we present a new Bayesian algorithm which combines tracker and pulse detector operations to enable more sensitive weak pulse acquisition. The developed track information is used to form a spatial prior probability distribution for the presence of the next echoes. Regions with higher probability are processed with a lower detection threshold to pull out low level pulses without increasing the overall probability of false alarm detection. Experimental results using real data collected at the BGT are presented.

Iridium: Characterization and Countermeasures

Patrick McDougle
Virginia Tech

Steve Ellingson
Virginia Tech

RFI from the Iridium satellite communication system complicates observations in 1610–1630 MHz band. In this paper, we present a detailed analysis of Iridium downlink signal observed at 1624 MHz using coherently-sampled data from Argus, a 24-element array of broadbeam antennas capable of instantaneous all-sky field of view, currently operating on the campus of the Ohio State University. We consider the performance of blanking algorithms using single- and multi-element detection techniques. Because Argus provides fully-coherent array data, we are also able to explore the performance of spatial nulling.

RFI Mitigation and Burst Detection with a Digital Receiver

Rodolphe Weber
LESI / Polytech'Orleans

Laurent Denis
Station de Radioastronomie de Nanay

Cedric Dumez-Viou
LESI / Station de Radioastronomie de Nanay

RDH (Reconquest of Radio Spectrum) is a high dynamic receiver currently developed at the Nançay Observatory in France. It is currently connected to 2 instruments that observe 10 to 30 cm long wavelength for the Nançay Radio Telescope (NRT) and 3 to 30 m long for the Nanay Decameter Array (NDA). The NRT is aimed for weak radio sources such as galaxies, comets, pulsars, etc. The NDA is mainly used to study radio emission of the Sun and Jupiter.

Algorithms are currently being implemented to allow those instruments to provide scientists with data free of RFI. Clear reobservation of the IIIZW35 MegaMaser has been made under Iridium interferences (a satellite constellation that uses TDMA-FDMA) and H1 radicals from galaxies start to appear when national airports radar pulses are removed. The other potential of RDH is the detection and recording of brief signals received from the Sun and Jupiter. Simulation and hardware tests are driven to allow future full time survey of radio emissions at a high frequency and time resolution.

APPLICATIONS

Ten Years of RFI—Project Phoenix at Parkes, Green Bank, and Arecibo

Michael M. Davis, Peter R. Backus, Jill Tarter
SETI Institute

Between 1995 and 2004 Project Phoenix detected and recorded narrowband, drifting CW and pulsed signals between 1200 and 3000 MHz, in a search for extraterrestrial intelligence. The observations were carried out at three major radio observatories, with frequency resolutions of 1 kHz, 1 Hz and, for candidate signals, a few mHz. No narrow bandwidth signals originating beyond the solar system were detected. Each of the millions of candidate signals were analyzed in near real time, and their characteristics stored in a database. Analysis of that database provides a unique snapshot of the radio frequency interference at each observatory, and the longer term evolution of terrestrial and satellite spectrum occupancy over the decade. The data permit comparison of the RFI status within and outside the protected radio astronomy bands in this frequency range.

Post-Correlation RFI Excision at Low Frequencies

W. Lane, A. Cohen, N. Kassim, J. Lazio
Naval Research Lab

R. Perley, W. Cotton, E. Greisen
NRAO

We describe some RFI excision schemes which are currently being used in low frequency (< 1 GHz) radio astronomy. We present examples from our experience with editing of single dish and interferometric data, and discuss specialized procedures employed for targetted observations, as well as broader brush, pipe-line schemes developed for surveys such as the VLA Low Frequency Sky Survey (VLSS). We will elaborate on the strengths and weaknesses of currently employed procedures, with an eye to providing useful guidance to those developing future, more sophisticated post-detection data editing algorithms. Our experience with RFI excision below 1 GHz should be of interest in the context of future SKA studies of Dark Energy and the Epoch of Reionization, as well as the development of other low frequency instruments such as the LWA and LOFAR.

Adaptive Filters Revisited - RFI Mitigation in Pulsar Observations

Michael Kesteven
Australia Telescope National Facility

George Hobbs
Australia Telescope National Facility

Ryan Clement

Pulsar detection and timing experiments are applications where adaptive filters seem eminently suitable tools for RFI mitigation. We describe a novel variant which has worked well in field trials—with observations at 700 MHz, 64 MHz bandwidth, 2-bit sampling.

Adaptive filters have generally received bad press for RFI mitigation in radioastronomical observations; the most serious drawback is the spectral echo of the RFI which is locked into the filtered signal. Pulsar observations are intrinsically less sensitive to this as they operate in the (pulsar period) time domain. The field trials have allowed us to identify issues which could limit the effectiveness of the adaptive filter.

RFI Mitigation for the Deuterium Experiment

Geoffrey C. Bower
UC Berkeley

One of the first scientific goals of the Allen Telescope Array is the detection of interstellar deuterium through the D I transition at 327 MHz. This is a novel experiment for RFI mitigation since we accumulate the astronomy signal from autocorrelations from each antenna but also compute cross-correlations. These cross-correlations can be used for RFI migitation since they resolve out the deuterium signal. We describe measurements of the interference environment at long wavelengths at the Hat Creek site and our early attempts at measuring the deuterium signal with the ATA.

RFI Mitigation Strategies for LOFAR and SKA

W. A. Baan, A.-J. Boonstra, P. Fridman, R. Millenaar
ASTRON

The leap in sensitivity of the new generation telescopes and the intensifying commercial and public use of the spectrum warrant a new and innovative approach towards RFI Mitigation. An RFI Mitigation strategy using multiple layers of applications during the data-processing flow is found to be optimal. This approach can be partially implemented at the WSRT and will be used for LOFAR and also for SKA. We will consider the actual implementation of these schemes for these telescopes and review results from ASTRON activities.

PRECORRELATION ARRAY TECHNIQUES

RFI mitigation at WSRT: algorithms, test observations, system implementation

W. Baan, P. Fridman, R. Millenaar
ASTRON

An RFI mitigation subsystem (RFIMS) based on real-time digital signal processing is proposed here for the Westerbork Synthesis Radio Telescope (WSRT). RFIMS is based on a powerful field programmable gate array (FPGA) processor Altera Stratix S80. In this system the radio astronomy signals polluted by RFI are “cleaned” with the RFIMS before the routine backend correlation processing takes place. The high temporal and frequency resolution of the RFIMS allows the detection and excision of RFI better than do standard radio telescope backend configurations.

For WSRT the minimum number of channels is 28 with 14 antennas and 2 polarizations. In the first instance, just one of the eight 20 MHz-bandwidth frequency channels will be processed before correlation. The full system consists of 28 separate processing channels (ADC -¿ FPGA -¿ DAC). The structure of RFIMS, the used RFI mitigation algorithms and some results of radio astronomy observations made with RFIMS are given. Eventually the system could be expanded up to 224 channels up to cover eight 20 MHz frequency bands from each antenna.

RFI mitigation for tied-array configuration with phase-only adaptive beamforming

P. Fridman
ASTRON

There are several specific features of large aperture synthesis radio interferometers (ASRI) like (WSRT, VLA, GMRT) which make a straightforward application of RFI mitigation adaptive beam-forming difficult and different from classic phased arrays: 1) ASRI are the highly sparsed arrays; 2) they are the correlation arrays, not additive; 3) direction-of-arrival (DOA) of a signal of interest (SOI) is a known and time dependant vector; 4)there is an auxiliary tied-array (TA) facility which is used during VLBI and pulsar observations. This mode is similar to the conventional phase-array: coherent adding of signals from array elements. This mode will also be a basic one for LOFAR stations. 5) there is no computer-controlled amplitude weighting before correlator or tied-array adder in the existing ASRI backend hardware; 6) noiselike radio astronomy SOI are usually much weaker than system noise (antenna + receiver) and RFI. An RFI mitigation beamformer should satisfy the following two requirements:

a) SOI must be protected, that is the response of the array is maintained constant for a prescribed direction, no matter what values are assigned to the weights;

b) the effects of RFI should be minimized.

Phase-only weights can be found as a solution of the corresponding system of nonlinear equations. The construction of the weight vector requires the knowledge of RFI's DOA, which may be known beforehand, or could be obtained from the observed correlation matrix. But it is necessary to have a special correlator for this purpose to follow all rapid scintillations of RFI, which are usually averaged by the main radio interferometer correlator. So, in principle, the system of nonlinear equations can be solved, and the phase corrections can be introduced into the phase control system. A more simple method of calculating the phase corrections in the tied-array mode is proposed. The tied-array total power detector (TPD) output is used as a cost function in a multi-variable optimization problem. To overcome the multimodality problem for the required small phase corrections a global maximum can be found using evolutionary programming (EP) method. The output of TPD is continuously measured and used to supply the EP algorithm with new data (cost function samples) which monitor performance of the tied-array with respect to RFI. The EP algorithm uses these data to calculate new phases which are introduced into the phase control subsystem after each iteration and a new value of the TPD output signal is used for the next step. Computer simulation results are given to illustrate the effectiveness of this method of RFI mitigation for different array configurations.

Spatial filtering of interfering signals at the initial LOFAR phased array test station.

A. J. Boonstra
ASTRON

S. van der tol
Delft University of Technology

The Low Frequency Array (LOFAR) is a radio telescope currently being designed and planned. Its targeted observational frequency window lies in the range 10–250 MHz. The initial test station (ITS) is a full scale prototype of a LOFAR station, and it became operational in December 2003. It consists of 60 sky noise limited dipoles, configured in a five-armed spiral, which are connected to a digital receiver backend. ITS operates in the frequency band 10–40 MHz, and the observed signals are directly digitized without the use of mixers. The data can be stored either as time series or as covariance matrices.

To enhance the sensitivity of LOFAR, time-continuous man-made radio signals can be suppressed by applying spatial filtering techniques. In order not to deteriorate the LOFAR calibration processes, it is required that the station beamshapes vary only very slowly. In practice this means that spatial filters are limited to semi-fixed filters ("fixed nulls").

In this paper we demonstrate spatial filtering capabilities at the LOFAR ITS test station, and relate it to the LOFAR RFI mitigation strategy. We show the effect of spatial filters by applying them to antenna covariance matrices, and by applying different beamforming scenarios. We show that in frequency ranges which are occupied with man-made radio signals, the strongest observed astronomical sky sources can be recovered by spatial filtering. We further focus on the subspace structure of the observed covariance matrices, and relate it to system properies such as crosstalk, and to the radio environment such as multipath effects.

Design Constraints for RFI Nulling at the ATA

G. R. Harp
Allen Telescope Array, SETI Institute

The Allen Telescope Array is a new 350-element radio telescope currently under construction in Northern California. Single-tap beamformers combine signals from all these elements to provide 16 simultaneous dual-polarization beams on the sky. We intend to leverage the large-N aspect of this array to perform RFI nulling in the beamforming process, and have developed new techniques that operate in a single-tap beamformer. We point out that for moving RFI sources, beamformer coefficients must be controlled on a surprisingly fast time scale and have a complex temporal structure. Because the SKA is larger and may observe at shorter wavelengths, beamformer constraints there will be even tighter.

POSTCORRELATION TECHNIQUES

Reference Antenna Techniques for Cancelling Interference from Moving Sources

Daniel A. Mitchell
The University of Sydney

Interference mitigation techniques which modify signals from auxiliary reference antennae to model and cancel interference from an astronomical observation can be applied in the time domain, where the RFI voltage is modelled and subtracted from the astronomy signal path (adaptive noise cancelling), or they can be applied to the auto and cross-correlated voltage spectra in the frequency domain (post-correlation cancelling). For ideal receivers and a single, statistically stationary interfering signal, both pre and post-correlation filters can result in complete cancellation of the interference from the observation. The post-correlation method has the advantage of being applied on 10s or 100s of millisecond time scales rather than 10s or 100s of nanosecond time scales. However since the cancellers use cross-correlated power measurements to gauge the interference power in the astronomy signal path from that in the reference signal paths, if the transmitter location changes during the time integration the varying phase differences cause decorrelation of the cross-correlations which can limit the effectiveness of the algorithms. If the decorrelation is not too severe it can be corrected for, at the expense of a noise increase. The time domain adaptive cancellers are allowed to slightly vary their internal coefficients and adapt to the changing phases, which means that they avoid the decorrelation problem, however the freedom to move also results in a noise increase. In this paper the performance of both types of cancellers in the presence of interference from a moving source is compared.

Correlations of spectral intensity fluctuations: application to RFI mitigation

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This paper describes a technique involving correlations between fluctuations in spectral intensities. When applied to intensity data available as a function of time and frequency, the result can be viewed in form of a correlation map, wherein the temporal correlation between fluctuations in every possible pair of spectral channels is represented. Such a correlation map, in addition to serving as a useful diagnostic tool for the measuring system itself, offers a wealth of information on spectral channels affected by RFI and inter-modulation, if any. Although such estimations are inherently less sensitive as compared to those from voltage-correlations, the technique promises much broader applicability given that the necessary intensity data are more commonly available.

The strengths and weaknesses of this technique relevant to RFI mitigation are discussed, and are illustrated with real-life examples. An extension of such an analysis to polarization data is explored, and the results are discussed.

Post-correlation ripple removal and RFI rejection for Parkes Telescope survey data

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The University of Melbourne

F. H. Briggs
Australian National University

M. R. Calabretta
Australia Telescope National Facility

The Multibeam receiver on the Parkes telescope has been used for many neutral hydrogen (H I) imaging projects, for example the H I Parkes All Sky Survey (HIPASS) and the Southern Galactic Plane Survey. In nearly all experiments to date, basic radio frequency inteference (RFI) rejection has been accomplished on a per-feed basis, using the median statistic throughout the processing, which eliminates outliers in a non-parametric fashion at the ex-

pense of increased statistical noise. The classic 21-cm baseline ripple problem, rife in Parkes 21-cm survey data, has been largely ignored, except for the subtraction of a coarse template which is independent of feed, time, telescope elevation, and receiver rotation. The ripple is especially strong during daytime, when the Sun acts as a broadband RFI noise source.

Here we report on new techniques that we are developing—for application to raw, post-correlation Multibeam data—which handle RFI rejection and ripple suppression in more sophisticated ways. RFI can be identified by the presence of coincident outliers on multiple feeds, by sharp increases or decreases in flux time series that are inconsistent with a beam-smeared sky, and by the presence of highly polarised flux. We present our progress with this approach and highlight some remaining difficulties. We also present a novel technique for modelling the variation during telescope scans of 21-cm baseline ripple caused by stray continuum radiation undergoing multiple reflections in the telescope cavity, and demonstrate its application to HIPASS data; this may increase the usefulness of daytime spectral line observing. Finally, we describe our on-going efforts to measure the response of the Parkes telescope and Multibeam system to on-axis continuum radiation sources.

Post-Correlation RFI Excision with the VLA and the EVLA

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National Radio Astronomy Observatory

To a synthesis interferometer, a source of RFI differs from a distant unresolved astronomical source primarily in its rapid differential phase rate. Providing that the correlator sampling is sufficiently rapid, and that the RFI emissions do not drive the signal transmission or processing components to non-linear behavior, the well-established methods of self-calibration and source subtraction which are commonly employed to remove the responses from unwanted astronomical sources should be applicable to sources of RFI. We will discuss the applicability of this approach to RFI excisions,and give examples of its effectiveness on data taken with the VLA.

CHARACTERIZATION AND ALGORITHMS

RFI Identification and Mitigation Using Simultaneous Dual Station Observations

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Cornell

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NRL

RFI mitigation is a critically important issue in the development of next-generation radio telescopes including the SKA. Most designs for the SKA involve multiple stations with spacings up to a few thousands of kilometers and thus will need to deal with RFI environments drastically different from that of conventional single-station telescopes. As demonstrator observations and analysis for the SKA-like instruments, and to develop RFI mitigation schemes that may help in the designs of the SKA, we recently conducted simultaneous observations with Arecibo and the GBT. The observations were aimed at diagnosing RFI and using the uncorrelated RFI between the two sites to excise RFI from several generic kinds of measurements such as giant pulses from Crab-like pulsars and weak HI emission from galaxies in bands heavily contaminated by RFI. This paper will present observations, analysis, and RFI identification and excision procedures that are effective for both time series and spectroscopy applications using multi-station data.

Cyclostationary Detectors for RFI Mitigation in Radio Astronomy

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LESI/Polytech'Orleans

Rodolphe Weber
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This paper presents a scheme for removing efficiently cyclostationary radio frequency interferences (RFI) from astronomical data. Various methods have been experimented to eliminate those RFI depending on the type of interferences and the type of instruments. The present study focuses on time-frequency blanking on data coming from a single dish. Time-frequency blanking consists in removing polluted data blocks in the time-frequency plane before integration in order to clean up the spec-

trum. The time-frequency plane is obtained in real time by a digital filter bank based on FFT or polyphase filter. The blanking decision depends on the kind of detectors implemented.

The detection criteria are generally based on a statistical contrast between the signal of interest (SOI) and the RFI. For example, the most used criterion is the power estimation. Indeed, its low complexity makes it possible real time implementation. But, its effectiveness depends on the RFI level which must be obviously high. Moreover, the probability of false alarm may increase rapidly if the reference level is not stationary or if the SOI becomes so bright that the system may blank both the RFI and the SOI.

This paper presents two detectors based on the temporal properties of a particular class of RFI, called the cyclostationary signals. These detectors are power independent. Besides they can work with real time constraints and detect RFI with a low Interference Signal Ratio (ISR).

The first section will present the hypothesis and the properties of the signals used in this paper. The second one will define the cyclostationarity and will compare the two detectors. In the third section, an example of time-frequency blanking is described and discussed.

Another algorithm for Phased Array Null formation

L. Kogan
National Radio Astronomy Observatory

The phased array beam pattern null towards the RI source can mitigate effect of the RFI. Several algorithms for creating null at the phased array beam pattern have been designed. See for example ATA memos of Geoffrey Bower [1] and G.R. Harp [2]. Another algorithm for creating null at the phased array beam pattern is described here. This algorithm is based on modification of algorithm of array configuration optimization minimizing side lobes of an array [3]. We tested this algorithm for possible SKA antenna station as a phased array of 19 antennas. The results are very similar to the simulation described by G. Bower and G.R Harp. The null can be created at one direction and at the square around the given direction. The narrow null ($\sim 0.1\frac{\lambda}{D}$) at the level $>$ 100db can be easily created at the cost of loosing signal to noise ratio at the main direction at the level of 3%. Widening the null to $0.5\frac{\lambda}{D}$ leads to null level $\sim 40db$ and loosing 13% of signal to noise ratio. The phase and amplitude correction to create the null have to be given with the very high accuracy which may be not practical. Rounding phase correction to 1 degree and weight to 0.1 aggravates the null from $> 100db$ to $\sim 50db$.

[1] Bower, Geoffrey C., Simulations of Narrow-Band Phased-Array Null Formation for the ATA, ATA memo #37, 2001

[2] Harp, G. R. Customized Beam Forming at the Allen Telescope Array, ATA memo #51, 2002

[3] L. Kogan, Mathematic basis of an array configuration optimization minimizing side lobes, EVLA memo #71, 2004

The Effect of Amplifier Gain Compression on Correlation Coefficient

Rick Perley
National Radio Astronomy Observtory

Robert Hayward
National Radio Astronomy Observatory

Modern wideband interferometers will be required to operate in an environment with very strong artificial emissions – some of which when entering through isotropic sidelobes, will raise the total system power by 20 dB or more above the levels expected from observations of cold sky. In such an environment, high linearity of the total signal processing path is a key requirement for a useful astronomical telescope. In this contribution, we report the results of an experiment where two tones, with powers sufficient to place the VLA's X-band amplifiers into 1 dB and 6 dB compression were added to four of the VLA's antennas. Observations of a strong astronomical source, with and without this injected tone, allowed us to carefully measure the induced error in the correlation coefficient, and hence allow an estimate of the resulting image degradation.

M I T I G A T I N G R F I A T R F

Interference Mitigation Using an Array Feed

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J. Richard Fisher, Richard Bradley
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Spatial filtering techniques for RFI mitigation require multiple, spatially separated looks at the interfering signal. For a large reflector, this can be accomplished with an array feed. We show using simulations that an array of electrically small elements in conjunction with a spatial filtering algorithm can provide high antenna sensitivity even in the presence of RFI.

We first consider 7 and 19 element dipole arrays and a 25-meter Very Large Array (VLA) type paraboloidal reflector with no interference, to determine the achievable aperture and spillover efficiencies. For a receiver temperature of 15 K and 300 K background, the sensitivity in Jy^{-1}

obtained for the 7 element array was approximately 35% higher for the array feed than that of a circular waveguide feed with diameter optimized for maximum sensitivity at 1612 MHz. The sensitivity of the 19 element array feed was 50% greater than the 7 element array.

In the presence of an interferer, we define an effective sensitivity,

$$S_{\mathit{eff}} = \frac{G}{T_{sys} + T_{int}}$$

where G is antenna gain in K/Jy, T_{sys} is the combined receiver and antenna spillover temperature, and T_{int} is the interferer power at the output of a beamformer which combines inputs from the array feed elements using the max-SNR algorithm. For the 7 element array and a single interferer, the effective sensitivity is close to the sensitivity with no interferer except for a few interferer arrival angles at which the effective sensitivity drops by several dB. At these angles, the array feed response to the interferer is nearest to the response to a signal at boresight in an inner product sense. The optimal solution found by the spatial filtering algorithm admits more spillover noise than at other interferer arrival angles, so that T_{sys} increases. With a larger array (19 elements), variations in effective sensitivity with interferer arrival angle still occur, but are less severe. These results indicate that array feeds offer a promising solution for RFI mitigation, and may provide superior performance to standard feeds in the absense of RFI as well.

RFI mitigation at a 2 GHz band by using a wide-band high-temperature superconductor filter

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Severe radio frequency interferences (RFIs) at S-band (2 GHz) due to third-generation mobile phone system (IMT-2000) have started since 2002 at a 34-m antenna located at the Kashima Space Research Center, National Institute of Information and Communications Technology (NICT, formerly Communications Research Laboratory) in Japan. It was difficult to continue observations at the S-band due to the saturation of the downconverter by RFI signals.

To mitigate RFIs, a new High-Temperature Superconductor (HTS) band-pass filter was developed in cooperation with
DENSO CORPORATION Research Laboratories. The HTS filter has superior characteristics as follows; sharp frequency cut-off, wide bandwidth, and low losses. Since an LNA of the S-band receiver was not saturated, we installed the filter to the LNA output to avoid the unnecessary increase of system temperature.

Consequently we could mitigate RFIs and observations at the S-band becomes possible again. Even though RFIs become stronger than the present situation and the saturation of LNA occurs, we can install the HTS filter in front of the LNA because of its low losses.

Suppression of Self-Generated RFI Emissions for the EVLA

Steve Durand, Robert Ridgeway, Jim Jackson, Rick Perley
National Radio Astronomy Observatory

The EVLA will be a fully digital radio telescope, with high speed sampling (4 GSamp/sec) done at each antenna, a digital Fiber Optic transmission system to convey the signals from the antenna to the correlator, and a very large digital correlator located at the VLA central site. To ensure that emissions from this digital circuitry not overwhelm the astronomical emissions that the telescope is designed to detect, a very high level of suppression for each potential radiating component must be implemented. In this report we describe our efforts in chracterizing the emissions from each module, and the design and testing of RFI shielding for the EVLA's racks, bins, and modules. Based on extensive testing, we believe that the EVLA will be able to operate free of self-generated interference.

Determination, control and improvement of an SKA radio environment in South Africa

Neel Smuts Pr Eng
Neel Smuts Consultancy cc

South Africa, in its bid to host the SKA, has adopted a dual approach to determine, assess and improve the radio environment and RFI that would be experienced by the SKA. The one approach was to determine all the transmissions that would provide signals which exceed the various threshold levels, including the saturation level, by means of computerised signal level calculations and the establishment of a database which could be used for assessment and analysis. The other was to carry out RFI measurements at the sites according to the RFI Measurement Protocol. This paper aims to provide a review of the data collection and the computerised signal calculation process. At the same time it was realised that the regulatory position would be a key issue and required attention.

The method used to create the database for transmissions in the frequency band from 150 MHz to 25 GHz which would affect the SKA will be described as well as its limitations and the process used to carry out calculations to predict signal levels. The telecommunications and broadcasting signal distribution network operators were involved in this process. The saturation level and the radio astronomy threshold levels are included in the database. Possible improvements to the radio environment are receiving attention.

As the telecommunications and broadcasting regulatory framework will play a key role in the control and improvement of the radio environment, an analysis of the existing regulatory framework in the context of the SKA was done considering the SKA science requirements, ITU Recommendations and Resolutions and South African legal provisions. An overview of this process will be provided.

A summary will be provided of the results obtained, the analyses carried out and the conclusions made. Analyses made include factors such as signal level graphs, number of signals involved and spectrum occupancy.

P O S T E R S

Signal Analysis and Blanking Experiments on DME Interference

J.R. Fisher
NRAO

No abstract available at time of printing.

RFI shielding and mitigation techniques for a sensitive search for the 327 MHz line of Deuterium

Alan E. E. Rogers, Joseph C. Carter, Preethi Pratap
Haystack

Marcos A. Diaz
Boston U.

An array of 25 stations each with 24 crossed-dipoles is being built at the Haystack Observatory in Westford MA. This array has been designed to make a sensitive search for the 327 MHz spectral line of Deuterium. Since the deuterium line is expected to be about 50 dB weaker than the the 1420 MHz hydrogen line the amelioration of RFI is the major challenge for the "Deuterium array". Locally generated RFI both from the array and from nearby sites has been reduced by extensive shielding and in some cases the removal of consumer electronics, like certain digital answering machines, which emit strong signals in the 327.3 to 327.5 MHz band of prime importance for the search. Since almost all the RFI comes from the horizon the station array have parasitic directors added to the dipoles to reduce the response at the horizon. A RFI monitor with 12 active yagi antennas pointed every 30 degrees in azimuth provides a means of determining the direction of the RFI and information of frequencies and time spans with need to be excised from the array data. We present details of the array design, the RFI excision algorithms, levels of spectral and continuum RFI measured at the observatory and the performance of the array from initial long integrations from a subset of the full array.

Using Multiple Beams to Distinguish RFI From ETI Signals

G. R. Harp
Allen Telescope Array, SETI Institute

The Allen Telescope Array is a multi-user instrument and will perform simultaneous radio astronomy and SETI observations. It is a multi-beam instrument, with 16 independently steerable dual-pol beams at 4 different tunings. Given 4 beams at one tuning, it is possible to discriminate RFI from true ETI Signals by pointing the beams in different directions. Any signal that appears in more than one beam can be identified as RFI and ignored during SETI observations. We discuss the effectiveness of this approach for RFI discrimination using realistic simulations of the ATA-350. We find, for example, that there is only 1% probability that RFI present in one beam will appear at 10x smaller levels in the other 3 beams.

Measurements of L- and C-Band RFI from Earth-Observing Remote Sensing Instruments

Steve Ellingson
Virginia Tech

Joel Johnson
Ohio State

L-band (1.4 GHz) and C-Band (6.8 GHz) are important for remote sensing of geophysical parameters by total power radiometry from air- and spaceborne systems. As part of a NASA-funded project to develop an interference-robust radiometer for L-band remote sensing, we conducted preliminary observations during flights over the Continental U.S., Pacific Ocean, and Japan. Our instrumentation allowed us to capture RFI waveforms by coherent sampling of 14 MHz bandwidth, tuned from about 1300 MHz to about 1700 MHz. We summarize these observations, and extrapolate these measurements to determine the implications for ground based radio astronomy.

Recently, we have extended our efforts to C-Band, and plan similar observations around 6.8 GHz this summer. However, useful data is already available from WINDSAT (a C-band remote sensing satellite), which provides sensitive dual-polarized measurements of brightness temperture. RFI is clearly visible in this data, as already

demonstrated by Njoku et al. (IEEE T. GRSS, 2003). Although waveform information is difficult to obtain from these measurements, we are able to make some conclusions about the RFI including likely impact on ground-based radio astronomy.

R E S T A U R A N T S

The following table lists some local restaurants, grouped by street:

- **Lakeshore Dr.** runs east-west along the shore of Okanagan Lake.
- **Main St.** (one way, north bound) intersects Lakeshore at the Penticton Lakeside Resort.
- **Martin St.** (one way, south bound) is 1 block west of Main.
- **Front St.** runs east from Main, 1 block south from Lakeshore.
- **Westminster Ave** runs west from Main, 1 block south from Lakeshore.
- **Burnaby Ave** intersects Westminster 9 blocks west of Main.
- **Eckhardt Ave** runs east-west, 6 blocks south of Lakeshore.

In the following, B=breakfast, L=lunch, D=dinner, and the cost ratings are: $ = under $10; $$ = $10–$12; $$$ = $10–$20; $$$$ = $15–$25. A star indicates particularly good value. Note that some restaurants do not open on Sunday and/or Monday.

Restaurant	**Style**	**Meals**	**Rating**	**Address**	**Phone**
The Barking Parrot	Pub	LD	$	21 Lakeshore Dr. W	493 9753
Magnum's On The Lake	Regional	BLD	$$$$	21 Lakeshore Dr. W	493 9768
Jillo's Upstairs Bistro	North American	BLD	$$$	274 Lakeshore Dr. W	492 3663
Vallarta Grill	Mexican	LD	$$$	988 Lakeshore Dr. W	492 5610
Salty's Beach House	Carribean	LD	$$$	1000 Lakeshore Dr. W	493 5001
Hog's Breath Coffee Co.	Coffee shop	BL	$	202 Main St.	493 7800
Green Beanz Café	Coffee shop	BL	$	218 Martin St.	493 8085
Johnny Donair	Meditteranean	LD	$$ *	219 Main St.	770 1913
Time Out Café	Coffee shop	BL	$	261 Main St.	493 6632
Chef K's Jazz Cafe	Southern California	D	$$$$ *	314 Main St.	493 2488
Mykonos Pizza & Spaghetti House	Meditteranean	LD	$$	329 Main St.	493 5322
Elite Restaurant	North American	BLD	$	340 Main St.	492 3051
Pacific Brimm	Coffee shop	BL	$	103-399 Main St.	490 8725
José's Pepper Club Café	US South-West	BLD	$$	205-399 Main St.	487 2150
Navratan Fine Cuisine of India	Indian	LD	$$$ *	413 Main St.	490 4746
Subway	Takeout	LD	$	109-437 Martin St.	490 3490
Isshin Japanese Deli	Japanese	LD	$$ *	101-449 Main St.	770 1141
Roberto's Pasta Bar	Pasta	LD	$$ *	101-483 Main St.	770 1447
Beijing Restaurant	Chinese	LD	$	504 Main St.	492 2144
Melina's Greek-Italian Taverna	Meditteranean	LD	$$	557 Main St.	493 3365
Theo's Restaurant	Greek	LD	$$$ *	687 Main St.	492 4019
La Casa Ouzeria	Greek	LD	$$$ *	1090 Main St.	492 9144
Gypsyheart Dream Café		BLD	$$ *	73 Front Street	490 9012
Chinese Laundry	Chinese	LD	$$	123 Front St.	492 2828
Scampi's Restaurant	Italian	LD	$$$	102-151 Front St.	493 7330
King's Garden Restaurant	Chinese Buffet	LD	$$	101 Westminster Ave W	492 2121
Lee's Overseas Delights	East Asian	LD	$ *	139 Westminster Ave W	492 7172
Tokyo Japanese Restaurant	Japanese	LD	$$$	101-786 Westminster Ave W	492 6610
Villa Rosa Restaurant	Italian	LD	$$$$ *	795 Westminster Ave W	490 9595
Jade Gardens Restaurant	Chinese	LD	$$	902 Westminster Ave W	492 7259
Denny's Restaurant	North American	BLD	$$	939 Burnaby Ave W	490 9390
Bear's Den Restaurant	North American	BL	$	950 Westminster Ave W	492 0225
Granny Bogner's	German	D	$$$$ *	302 Eckhardt Ave W	493 2711
Kettle Valley Station Pub	Pub	LD	$$	1070 Eckhardt Ave W	493 3388
Mon Thong Thai Restaurant	Thai	LD	$$ *	2985 Skaha Lake Road	770 9791

FINANCIAL INSTITUTIONS

Below are listed the financial institutions located in downtown Penticton, within a few blocks of the north end of Main St.

Name	**Address**	**Phone**
Bank of Montreal	195 Main St	492 4240
CIBC	295 Main St	770 3333
HSBC	201 Main St	492 2704
Prospera Credit Union	402 Main St	770 8500
Royal Bank	302 Main St	490 4400
Scotia Bank	401 Main St	770 7450
TD Canada Trust	390 Main St	770 2300
Valley First Credit Union	184 Main St	490 2700