Name:	Fadhel Ghannouchi	Administrative Use Only:			
Institution:	University of Calgary	SHEET #:	55	VOXCO ID:	165
Program:	Strategic Chair				
Grant Title:	AI Strategic Chair in Intelligent RF Radio Technology				
Reporting Period:	2018/2019	**Submission Date:**	2019-05-10		

ALBERTA INNOVATES

Annual Progress Report Submission

OVERVIEW & GUIDELINES

This report will be used to assess and measure the annual progress achieved by Alberta Innovates funded SRP research projects and Chair programs. The report should be concise, and will be reviewed for progress toward the milestones and deliverables outlined in the research proposal. Certain information shared through this report will be summarized and aggregated to allow for reporting on the outcomes of Alberta Innovates funding.

This annual report must provide information pertaining to the previous fiscal year, for the period: April 1 to March 31.

Notes:

- **In accordance with university policy, progress reports should be submitted to Alberta Innovates by the researcher only after it has been reviewed by the university.**

- **Financial Reporting (Statement of Revenues and Expenses) is also required and comes from the University Research Services Office; however, researchers must sign off on the report before it can be submitted to Alberta Innovates. Please ensure financial reporting sign-off occurs in a timely fashion.**

The deadline for submission of this annual report is:

For SRP Grants: the 1st of May.
For Chair Grants: the 15th of May.

Questions regarding report submission can be directed to:

Adam Brown, SRP and Chairs Program Coordinator at

adam.brown@albertainnovates.ca

(780)-450-5560

1. EXECUTIVE SUMMARY

Please provide an overview of the SRP project or Chair program, including a summary of the year's achievements and outcomes. Please use language that is quite readable for government and industry alike, and suitable for public release. Recommended length is 500 words or less.

The Alberta Innovate strategic Chair in Intelligent RF Radio Technology led to the recognition and positioning of the University of Calgary as an emerging world-class research institution in the area of RF (radio frequency) radio systems through the research activities that have been conducted over the last decade in the Intelligent Radio Laboratory (iRadio Lab). The research program centered on the development of enabling technologies related to microwave and millimeter-wave (mm-wave) technologies relevant to5G (5th generation) wireless, satellite and space communications, and Internet of Things (IoT). The thrust of research program encompasses devices, circuits and systems, adaptive digital signal processing, modeling of devices and systems, linearization and equalization concepts, MIMO and Multi-Antenna (MA) transceivers, software-hardware implementation and integration, design and realization of circuits and systems using hybrid and integrated technologies.

The iRadio Lab is staffed with more than twenty graduate students and researchers. The main space dedicated to iRadio Lab is at the University of Calgary's ICT building (ICT 305 and ICT 318) and used as offices for graduate students and research staff, as well as the research program's main instrumentation, simulation, and design areas. Additional spaces in A Block of the Engineering Building (ENA 5 and ENA 108) utilized for printed circuit board fabrication and prototyping and the mm-wave facility is composed of state-of-the-art signal generation and analysis equipment and offers the capabilities of ultra-wideband on-wafer measurement capabilities at mm-wave frequencies (up to 67 GHz).

During the last year, efforts were deployed to meet the research objectives planned within the Alberta Innovate Strategic Chair and the strategic grant obtained from the Natural Science and Engineering of Canada (NSERC) to develop linear and efficient transmitters for RF front-ends for 5G and satellite communications. Moreover, an additional team of researchers and graduate students have been dedicated to develop fully integrated C and X band amplifiers fabricated in space qualified Gallium Nitrate (GaN) process for the fourth-generation of Radarsat constellation. This project is sponsored by the Space Technology Development Program (STDP) of the Canadian Space Agency.

The innovative and application-oriented R&D activities being carried out at iRadio Lab in this past year led to the award of 2 US patents, 1 Chinese patent, 1 Swedish patent and the filing of 3 patent applications; the publication of 29 refereed journal papers (published and accepted) and 10 refereed conference papers (published and accepted). Also,iRadio Lab researchers gave 7 invited talks and contributions to workshops in international conferences and universities along with other outreach activities.

During the last year, iRadio Lab was successful in securing funding amounting to $312 K, $200 K, $490 K, $400 K, $ 70K and $175 K from NSERC, Canada Research Chairs (CRC) program, Canadian Space Agency, Canadian Foundation of Innovation, industrial partners and the University of Calgary, respectively. Also, in-kind contributions and equipment donation in the amounts of about $150 K from CMC, and $230 K of in-kind contributions from the University of Calgary were obtained during the reporting period. In addition, the lab's equipment and infrastructure was leveraged to generate $78k of revenue. Furthermore, many students and postdoctoral fellows have were awarded scholarships and fellowships over the last year, totaling an annual of $220 K.

2. ACHIEVEMENTS AND OVERVIEW

This is the core of the report and should address how the research project / program is progressing towards the goals of the initial research proposal. It should include a description of : (i) research activities undertaken, (ii) results achieved, (iii) challenges identified, and (iv) mitigation strategies.

Recommended length is 1,000-2,000 words. Please include at the beginning of your response a short precis or bullet-point list of the most significant achievements and challenges during the reporting period. It is important to describe progress in not too technical terms and for potential public release.

For this reporting year, the iRadio Lab focused on the nine research areas outlined in last year's objectives, and our efforts have results in strong progress across all fronts. In this section, the main achievements and outcomes of each of the nine research projects are outlined.

Some of the highlights of the iRadio Lab's research achievements over the past year include:
- Design of a high-performance GaN MMIC amplifier with up to 47 dBm power output.
- Successful design and fabrication of mmWave amplifiers.
- Design of energy harvesting receivers and rectifiers.
- Development of beamforming and impairment-correcting MIMO DPDs and multi-band DPDs.
- Development of hybrid radio-over-fiber systems working in the mmWave band

Project 1: Development of a nonlinear transistor model for GaN NRC fabrication process

Currently, a novel reliable small signal model parameter extraction of asymmetric GaN-based Heterojunction Field Effect Transistors (HFETs) has been proposed and implemented. An efficient systematic searching procedure based on pinch-off and cold weak-forward S-parameters has been developed to consider the asymmetric structure of GaN HFETs and find the optimal values of the gate and drain pad capacitances Cpg and Cpd. Considering that the depletion region extension is varied with the gate bias voltage Vgs slightly even below pinch-off voltage, the obtained initial values of the extracted parameters are optimized by artificial bee colony (ABC) algorithm to improve the reliability of parameter's extraction. The developed parameter extraction method shows excellent accuracy and reliability. The proposed procedure can be extended to asymmetric GaN devices with various process technologies. The developed approach has been validated by an asymmetric 0.15 μm GaN HFET over a wide range of bias conditions and frequencies.

Project 2: Design and prototyping of C and X-band GaN MMIC amplifiers for space applications.

The objectives of this project were to design C- and X-band amplifiers based on Gallium Nitride (GaN) monolithic microwave integrated circuit (MMIC) technologies for space application. Previously, two version driver amplifiers for each band were designed and prototyped. The measured results showed a good agreement with the simulation. High power amplifier (HPA) for each band was designed and prototyped during the past year. The simulation meets all the de-rating requirements for the space application. The on-wafer pulsed small signal test results showed an excellent agreement with the simulation. The on-wafer and on-breadboard pulsed large signal test results showed that the C-band GaN MMIC HPA can output up to 47 dBm power with a power added efficiency (PAE) of 46% within 300 MHz bandwidth while the X-band GaN MMIC HPA can output up to 47 dBm power with a PAE of 42% within 600 MHz bandwidth. Besides that, three versions of C-band low noise amplifier (LNA) were designed and prototyped. The measured results showed that frequency response of one version had a flatness of 0.02 dB. The noise figure can achieve 0.8 - 1 dB.

Project 3: Design and prototyping of K- and Ka-band GaN MMIC amplifiers for mm-wave 5G applications.

Among the mmW frequencies, K-band and Ka-band constitute significant contenders for 5G wireless systems. In such systems, the high peak to average power ratio (PAPR) of the modulated signals causes a critical challenge in power amplifier design. A Doherty power amplifier is one of the most well-known techniques that improve efficiency at back-off power level. As a result, we targeted the design of a compact wideband MMIC Doherty power amplifier (DPA) based on a 0.15-μm GaN HEMT process to be used for 5G wireless systems.

The initial prototype exhibits a simulated output power of 28.2 dBm, drain efficiency equal to 26% at peak power and 20% at 6 dB output power back-off. In parallel, a high-efficiency K-band harmonic tuned power amplifier (PA) operating from 18.5-25.5 GHz was also designed. The efficiency and output power of the MMIC PA achieved over the band higher than 35% and 29 dBm, respectively.

Project 4: Development of a power efficient DSM based transmitter architecture.

Our focus was directed to the discrete-time delay impact which appears when implementing the DSM transmitters on an FPGA using blocks running at the same clock rate. To investigate the effect of these delays, we modeled the sources of discrete delays using a generic model using the first order DSM transfer function.

By deriving the transfer function for the first order DSM, we identified the effect of the unwanted delays and canceled their effects by adding a post-compensation block based on the fundamental first-order DSM. This block uses the first-order DSM for its transfer function to determine the effect of undesired delays, and we were able to develop a proprietary mitigation method followed by and compensation technique. The proposed solution validation was implemented on FPGA using different signals and oversampling ratios, and this work has resulted in a refereed journal publication.

Project 5: Development of digital predistortion techniques for the multiband transmitters.

Over the past year, the iRadio Lab has continued its push towards developing high-performance linearization and digital pre-distortion solutions for multi-band RF transmitters on multiple fronts. One approach developed is based on the formulation of a novel two-dimensional curtailed harmonic memory polynomial (2D-CHMP) model to capture harmonic interferences, cross-modulation and intermodulation distortion. By taking into account the various sources of distortion and re-working the multi-band predistortion model formulation, the proposed 2D-CHMP DPD provides similar linearization performances as compared to the most intensive multi-band DPD models while requiring a lower number of coefficients, and significantly reduced. As a study, it is shown that the proposed model can be further adapted to a low-precision (low-bit) environment by utilizing principal component analysis.

Modeling and predistortion technologies such as the above are developed to complement the lab’s work on cutting-edge, efficient multi-band transmitter and receiver hardware and techniques to improve the efficiency and performance of next-generation multi-band systems.

Project 6: Development of a broadband rectifier for energy harvesting purposes.

The iRadio Lab has developed a linear, low-power and blocker tolerant quadrature phase shift frequency selective (QPS-FS) receiver. The receiver has the capability of harvesting the energy of unwanted in-band and out-of-band blockers and interferers to self-power the receiver. The QPS-FS receiver separates the undesired blockers and interferers from the desired band RF signal, which are collected for energy harvesting purposes. This method utilizes existing modulated signals and thus can be directly applied to communication systems, while also maintaining an error vector magnitude (EVM) under 2%. The QPS-FS receiver has been tested to tolerate more than 0 dBm of continuous wave (CW) blocker power at a frequency offset of 40 MHz or higher away from the RF signal carrier frequency.

To harvest the maximum amount of energy, a broadband energy harvesting circuit was designed and fabricated using diodes and broadband matching network. With over a decade of bandwidth and energy efficiency higher than 50%, this harvester was able to provide the required energy for operating the receiver for 24 hours per day at frequencies lower than 400 MHz and more than 8 hours per day for higher frequencies between 400 MHz and 1 GHz.

Project 7: Development of distortion and hardware impairments mitigation techniques for massive MIMO
Massive MIMO systems are projected to play a key role in 5G wireless communication networks, and the iRadio Lab has continued to aggressively pursue this avenue of research. Through the past year, the Lab has produced cutting-edge MIMO linearization and modeling techniques that cover the various aspects of MIMO RF transmitter design.

In one approach, the sub-optimal and time-varying load matching presented by antennas has been taken into account by identifying the reflection at the PA-antenna interface to be non-ideal and non-static to unify the problem of mismatch and mutual coupling. This lead to the development of a reflection-aware PA modeling and linearization method to compensate the adverse effect of mismatch and mutual coupling, with consistent, reliable performance.

Another key practical consideration for Massive MIMO RF transmitters is beamforming. A beam-oriented digital predistortion (BO-DPD) technique was proposed. In massive MIMO hybrid beamforming transmitters, the conventional DPD to linearize each PA is impractical to implement because the number of digital chains is less than the number of PAs. However, the BO-DPD can resolve this issue by constructing and linearizing the “virtual” main beam signal rather than each single PA by combining the various PA outputs to approximate and estimate the feedback signal need for DPD synthesis. This method has been found to succeed in linearizing a MIMO system utilizing beamforming while also maintaining robustness to rapid changes in the array angles.

On another front, the iRadio lab has built on its prior experience developing MIMO DPDs by developing a neural network-based DPD model which takes all the various inherent MIMO impairments into account to provide a one-step single-model digital mitigation solution to MIMO transmitter compensation.

Project 8: Development of mixers-less receivers for wireless communications

Development of mixers-less receivers for wireless communications project aims at the development of low-power and broadband radio receiver design for Internet of Things (IoT) applications. To address the various challenges related to IoT implementation, a mixer-less broadband, frequency selective, and frequency tunable radio receiver architecture was proposed. The proposed architecture was theoretically analyzed and practically implemented to validate the proposed concept. The implemented receiver system with a wideband receiver calibration approach provided less than 2% of error vector magnitudes (EVM) between the transmitted and received constellation points for various modulated signals having bandwidths up to 4 MHz. Also, in an actual implemented system, the test receiver could sustain up to 5 dBm of blocker power without any significant degradation in the receiver performance in terms of EVMs between transmitted and received constellation points for 4/16-QAM and LTE signals having 1 MHz and 1.4 MHz bandwidths, respectively. This new invention is the subject of an US patent application.

Project 9: Development of Radio-over-Fiber (RoF) transmitter for wireless communications networks

The Radio over Fiber (RoF) and mm-wave project aims at the development of RoF transmitter for front-haul downlink communication link suitable for the next generation (5G) wireless communication. The proposed architecture links one central baseband unit (BBU) to a remote radio head (RRH) unit located about 12 Km away.

We have demonstrated experimentally for the first time a distributed digital predistortion (D-DPD) model for RoF downlink suitable for broadband 5G signals. The model reduces the analog to digital converter (ADC) sampling frequency up to 1/3 by comparison to the required ADC speed of conventional DPD technology while maintaining the same signal quality in term of Error Vector Magnitude (EVM). We also proposed a proof-of-principle for digital sub-band (SB) filtering layout for RoF downlink transmitter. A demonstration of 4 and 8 SB processing for a 256 QAM 100 MHz-bandwidth long-term evolution advanced (LTE-A) signal is presented. This technology reduces the required processing speed of DPD signal block generation.

3. MILESTONES PROGRESS

Please provide information below on the progress of the milestones for the project titled:

"AI Strategic Chair in Intelligent RF Radio Technology"

(the list is based on the milestones outlined in the proposal):

MILESTONE	STATUS
Milestone 1: Development of a nonlinear transistor model for GaN NRC fabrication process	As Scheduled
Milestone 2: Design and prototyping of C and X-band GaN MMIC amplifiers for space applications.	As Scheduled
Milestone 3: Design and prototyping of K and Ka band GaN MMIC amplifiers for mm-wave 5G applications.	As Scheduled
Milestone 4: Development of a power efficient DSM based transmitter architecture.	As Scheduled
Milestone 5: Development of digital predistortion techniques for the multiband transmitters.	As Scheduled
Milestone 6: Development of a broadband rectifier for energy harvesting purposes.	As Scheduled
Milestone 7: Development of distortion and hardware impairments mitigation techniques for massive MIMO radios	As Scheduled
Milestone 8: Development of mixers-less receivers for wireless communications	As Scheduled
Milestone 9: Development of Radio-over-fiber (RoF) transmitter for wireless communications networks	As Scheduled

****Provide the following additional information is required for milestones that were delayed, modified or cancelled only.****

• For each milestone that was delayed, modified, or cancelled please briefly explain the reasons why (bullet points acceptable).

• For delayed milestones, please also list the progress made within this reporting period, and plan to address the setbacks (bullet points).

4. PLANS, OBJECTIVES AND MAJOR CHANGES FOR NEXT YEAR

In this section please describe your plans, project / program evolution and proposed work for the next year.

Be sure to include any major changes proposed to the direction of the project or program as it was laid out in the research proposal. Examples include the following: a greater than 20% variation above or below budgeted line items, a significant change in research direction, or a change in expected completion date.

This section has a direct bearing on the report approval process, therefore please be as clear as possible about the general areas of proposed work. Technical details are not required and recommended length is no more than 1,000 words.

Project 1: Development of a nonlinear transistor model for GaN NRC fabrication process

Many researchers have been focused on designing application circuits using the emerging GaN technology. Because GaN enjoys high electron mobility,

high carrier density, high saturation velocity, and high breakdown field in the channel, and also high thermal conductivity, the outstanding high-power and high-frequency capabilities of GaN HFETs, qualify it to be an optimal device for designing high-power power amplifiers (PAs) in high-frequency application. There will be an urgent need for a transistor model, which can efficiently simulate the device behavior and its inherent parasitic effects over a wide range of bias voltages, powers, and frequencies. The developed parameter extraction method can be used for asymmetric GaN HFETs small signal modeling. The developed method can also be used for asymmetric GaN HFETs large signal model in the future.

Project 2: Design and prototyping of C and X-band GaN MMIC amplifiers for space applications. GaN MMIC technologies enable the amplifiers to operate at high frequency with high power density and high efficiency, which would reduce the size significantly. Our goal going forward is to design integrated radio frequency front-end module which is composed of HPA, LNA and switch with the GaN MMIC technology.

Project 3: Design and prototyping of K and Ka-band GaN MMIC amplifiers for mm-wave 5G applications.

Wideband and high-efficiency PAs are highly desirable for reliable operation of RF system. Both the input and output nonlinearity of the device are used in this project to improve PA performance. To overcome the limitations of existing architectures, the parasitic effects at these high frequencies will be considered to develop compensation methods to prevent any performance degradation. A wideband PA will be designed as a proof of concept to the new PA design methodology.

Project 4: Development of a power efficient DSM based transmitter architecture.The implementation of all digital delta-sigma modulators requires a high-speed processing platform. For high-efficiency applications where the bandwidth is relatively narrow such as internet of things sensors, the use of DSM-based transmitters is a promising solution to achieve high power efficiency. Going forward, the iRadio Lab’s goal is to expand on the development of DSM-based transmitters that incorporate real-time linearization capabilities.

Project 5: Development of digital predistortion techniques for multiband transmitters. In the coming year, we plan to build on the iRadio Lab’s well-established leadership in the multi-band DPD space by focusing on wider- and higher-order multiband scenarios to accommodate 5G wireless applications.

Project 6: Development of a broadband rectifier for energy harvesting purposes.

The objective for the next period is to develop more efficient energy harvesting circuits by using active nonlinear semiconductor components (transistors). This will be carried out in two stages. First, a transistor model suitable for use in energy harvesting design will be developed. Then, this model will be used to design a highly efficient harvesting circuit using harmonic tuning and waveform shaping techniques.

Project 7: Development of distortion and hardware impairments mitigation techniques for massive MIMO Radios

We plan to continue the iRadio Lab's work in this area by extending the work done in the past year for beamforming MIMO RF transmitters and building on the use of complexity-reduction and adaptive and non-standard modeling and compensation approaches such as neural networks and others. Additionally, the effect of reflection and impedance mismatch is a target for potential exploration.

Project 8: Development of mixers-less receivers for wireless communications

Energy harvesting enabled self-powered self-sustainable radio systems will be essential components in future generations of networks and devices for Internet of Things (IoT) applications as they will provide maintenance-free operation with minimal human invention. Designing energy harvesting systems and radio transceiver systems with energy harvesting capabilities will enable design and development of autonomous, low-power and self-sustainable radio units meeting green energy requirements. The current implementation of mixer-less receiver system has been done in printed circuit board (PCB) technology using discrete circuit components that limits the performance of the overall system. The plan includes the design and implementation of an integrated architecture that is expected to have lower power consumption, smaller circuit size and improved system performance in terms of energy harvesting efficiency and radio system operation.

Project 9: Development of Radio-over-fiber (RoF) transmitter for wireless communications networks Radio-over-Fiber (RoF) technologies will play a key role in 5G networks; as they form the backbone of the network between the pico-cells and the centralized processing units, making the transmission of high data rates (~10 Gbps) possible in 5G mmWave systems. In addition to RoF, the Free-Space Optics ((FSO) is considered in our plans in the field of satellite communications or deep space discovery due to the high-speed data needed to connect the plant.To alleviate the high processing speed required for next-generation signals, perfect reconstruction quadrature mirror filters (QMFs) are used. Currently, we are conducting several experiments towards the application of RoF in the satellite communications by involving free space optics (FSO) in a bi-directional link. These architectures will shed the light on FSO possible impairments and methods of treatment.

5. COLLABORATIONS

Joint work with other universities, research institutes and industry are all valued by Alberta Innovates.

Points to note:

- Include active Bi-lateral or multi-lateral partnerships that have resulted from or are directly linked to this grant

- Include agreement between a member of the research team/group to participate in a network consortium multi-centre study or other initiative

- Under 'Potential Collaborations' include collaboration or partnerships at an early stage of discussion where there has been no tangible output

DO NOT report here:

- Collaborations or partnerships restricted by contractual confidentiality

- Funding gained through successful collaborative funding applications should be reported in answer to question 11, "Other funding" of this report

Alberta Government	0
Other Provincial/Municipal Government	0
Federal Government	2
Academic (Canadian)	2
Academic (International)	13
Industry (Canadian)	3
Industry (International)	3
Not-for-Profit Organization	0
Consortium	0
Potential Partnership	0

Please provide specific details below:

Type of Entity	Name of Entity	Nature of Collaboration	Description
1. Academic (Canadian)	Mitacs	Other	Research support of Dr. Anis Ben Arfi
2. Federal Government	NSERC	Applied Research	GaN Trnsistor Modeling
3. Federal Government	Canada Space Agency	Applied Research	GaN High Power Amp Development
4. Academic (Canadian)	Dr. A. Kouki	Academic Collaboration	LINC Based Amplifiers
5. Academic (International)	Dr. N. Boulejfene	Academic Collaboration	Augmented Hammerstein model

6. Academic (International)	Dr. Wenhua Chen	Academic Collaboration	Multiband transmitters
7. Academic (International)	Dr. Biao Hu	Academic Collaboration	High power microwave radiation
8. Academic (International)	Dr. Xin Hu	Academic Collaboration	Adaptive digital predistortion technology
9. Academic (International)	Dr. Md A Maktoomi	Applied Research	Energy harvesting
10. Academic (Canadian)	Dr. K. Wu	Applied Research	Poly-Grames Research
11. Academic (International)	Dr. Donglin Wang	Academic Collaboration	Indoor Wireless Location
12. Academic (International)	Dr. Mohamad Hashmi	Academic Collaboration	Waveform Engineering
13. Academic (International)	Dr. A. Gharsallah	Academic Collaboration	Implementation of DPD
14. Industry (International)	NXP Semiconductors	Applied Research	High Efficiency Amplifiers
15. Industry (Canadian)	Nanowave Technologies	Applied Research	Amplifiers for Avionics
16. Academic (International)	Dr. Meenakshi Rawat	Academic Collaboration	Distortion & Impairment
17. Academic (International)	Dr. Oualid Hammi	Academic Collaboration	Linearization of Wireless
18. Academic (International)	Dr. Anwar Jarndal	Academic Collaboration	Modeling of GaN Transistors
19. Academic (International)	Prof. T. Liu	Academic Collaboration	Modeling and Compensation

20. Industry (Canadian)	Analog Devices	Applied Research	Digital Predistortion for 5G
21. Industry (International)	United Monolithic Semiconductors	Applied Research	GaN devices
22. Industry (Canadian)	Norsat Corporation	Applied Research	Satellite Communications
23. Industry (International)	Win Semicondoctors	Applied Research	GaN Device's Fabrication

6. RESEARCH TEAM MEMBERS

Within the research team, please provide the number of people in each of the categories below:

Team Leader	1
Faculty Team Member	5
Research Staff	7
PhD Candidate	10
MSc Candidate	2
Visitor	3
Undergraduate	0
Support Staff	2

*Research Staff includes: Post-Doctoral Fellows, Research Engineers, Research Associates, etc.

Please indicate the total number of full-time equivalent (FTE) positions across all of the above categories that were directly supported using Program Funds in this reporting period
(ex. if MSc candidate student 25% supported by Program Funds, that is 0.25 FTE Position):

11.5

Since your program involves a variety of partners, it is important to identify their roles in the program. In the table below, please provide the role, full name, e-mail and any awards or special information that should be noted.

Role	Name	Email	Awards/Special Info
1. Team Leader	Fadhel Ghannouchi	fadhel.ghannouchi@ucalgary.ca	Chair and Lab Director
2. Faculty Team Member	Mohamed Helaoui	mhelaoui@ucalgary.ca	Associate Professor
3. Faculty Team Member	Abu Sesay	sesay@ucalgary.ca	Professor, Collaborating Researcher
4. Faculty Team Member	Abraham Fapojuwo	fapojuwo@ucalgary.ca	Professor, Collaborating Researcher
5. Faculty Team Member	Leonid Belostotski	lbelosto@ucalgary.ca	Professor, Collaborating Researcher
6. Faculty Team Member	Laleh Behjat	laleh@ucalgary.ca	Professor, Collaborating Researcher
7. Support Staff	Caron Currie	caron.currie@ucalgary.ca	Project Administrator
8. Support Staff	Abubaker Abdelhafiz	ahbabdel@ucalgary.ca	Research Associate, Lab Manager
9. Research Staff*	Md Ayatullah Maktoomi	mohammad.maktoomi@scranton.edu	Postdoctoral Fellow
10. Research Staff*	Hwiseob Lee	hwiseob.lee@ucalgary.ca	Postdoctoral Fellow

11. Research Staff*	Mehrdad Gholami	No longer available	Postdoctoral Fellow
12. Research Staff*	Imen Mrissa	No longer available	Postdoctoral Fellow
13. Research Staff*	Moshin Aziz	No longer available	Research Associate
14. Visitor	Oualid Hammi	ohammi@ucalgary.ca	Visiting Researcher, KUFPM
15. Visitor	Xin Hu	xin.hu1@ucalgary.ca	Visiting Researcher, China Scholarship Council
16. PhD Candidate	Anis Ben Arfi	abenarfi@ucalgary.ca	Successfully defended January 11, 2019
17. Research Staff*	Anis Ben Arfi	abenarfi@ucalgary.ca	Postdoctoral Fellow
18. PhD Candidate	Moshin Aziz	No longer available	Successfully defended June 26, 2018
19. PhD Candidate	Abul Hasan	No longer available	Successfully defended May 17, 2018
20. PhD Candidate	Abubaker Abdelhafiz	ahbabdel@ucalgary.ca	Successfully defended June 21, 2018
21. PhD Candidate	Ahmed Abournemra	ahmed.abounemra@ucalgary.ca	PhD Candidate
22. PhD Candidate	Tushar Sharma	tsharm@ucalgary.ca	Successfully defended April 24, 2018; PDF at Princeton
23. PhD Candidate	Yulong Zhao	yulong.zhao@ucalgary.ca	PhD Candidate
24. PhD Candidate	Mahmood Noweir	mahmood.noweir@ucalgary.ca	PhD Candidate
25. PhD Candidate	Sagar Dhar	sagar.dhar@ucalgary.ca	PhD Candidate
26. MSc Candidate	Sichong Li	sichong.li@ucalgary.ca	MSc Candidate (co-supervisor)
27. MSc Candidate	Abdul.Rafay	No longer available	Successfully defended April 18, 2018
28. PhD Candidate	Dawood Shekari Beyragh	dawood.shekaribeyrag@ucalgary.ca	PhD Candidate
29. Visitor	Deepayan Banerjee	deepayan.banerjee@ucalgary.ca	Visiting PhD Student
30. Research Staff*	Xiang Li	lxiang@ucalgary.ca	Postdoctoral Fellow

7. GRADUATES & COMPLETED POST-DOCS

Alberta Innovates is committed to increasing the number of graduates in areas of strategic importance to Alberta. Please provide information on last year's graduates using the tables below:

Post-Doctoral Fellow	5
PhD Graduate	4
MSc Graduate	1

Please indicate the total number of full-time equivalent (FTE) positions across all of the above categories that were directly supported using Program Funds in this reporting period
(ex. if MSc candidate student 25% supported by Program Funds, that is 0.25 FTE Position):

2.58

Please provide specific information on graduates below:

Role	Name	Email	Awards/Special Info
1. PhD Graduate	Abul Hasan	ahasan@ucalgary.ca	Reseracher at National Energy Technology
2. Post-Doctoral Fellow	Ben Arfi, Anis	abenarfi@ucalgary.ca	Mitacs Award, Analog Devices
3. Post-Doctoral Fellow	Md Ayatullah Maktoomi	mohammad.maktoomi@scranton.edu	Faculty at Scranton University, USA
4. Post-Doctoral Fellow	Hwiseob Lee	hwiseob.lee@ucalgary.ca	Mitacs Award, Norsat Corporation
5. Post-Doctoral Fellow	Mehrdad Gholami	No longer available	PDF at Waterloo University
6. Post-Doctoral Fellow	Imen Mrissa	No longer available	Engineer at Ericsson, Ottawa
7. PhD Graduate	Abdelhafiz, Abubaker	ahbabdel@ucalgary.ca	NSERC PDF, University of Calgary
8. PhD Graduate	Aziz, Moshin	No longer available	Engineer with Analog Devices, Ottawa
9. PhD Graduate	Sharma, Tushar	tsharm@ucalgary.ca	PDF at Princeton University, USA
10. MSc Graduate	Rafay, Abdul	No longer available	Engineer at Xilinx, Ottawa

8. INTELLECTUAL PROPERTY

Using the tables below, please provide information pertaining to intellectual property.

In the table immediately below, use the second column (# Granted in the Year) for reporting spin-off companies:

	# Applied in the Year	# Granted in the Year
Patents	1	3
Licenses	0	1
Spin-Offs	0	1
Other	0	0

*For Spin-Offs, please list Corporate Name / # in Title Column.

Date: 18/12/2018 **Status:** Granted
IP Type: Patents **#:** 10,158,382 **Jurisdiction:** US

Title: Signal amplification and transmission based on complex delta sigma modulator

Description: Apparatuses and methods for power amplification and signal transmission using complex delta-sigma modulation are disclosed. In one embodiment, a complex delta sigma modulator unit comprising a complex polar quantizer within an integrator loop is disclosed. The complex polar quantizer quantizes the envelope of a complex integrated signal and produces a complex quantized

Date: 06/11/2018 **Status:** Granted
IP Type: Patents **#:** 10,122,334 **Jurisdiction:** US

Title: High efficiency ultra-wideband amplifier

Description: An amplifier comprising an active device having an output terminal for driving a load impedance in response to a signal applied to an input terminal and a current source connected to the active device to provide a bias to the active device wherein when the active device is operated an output power of the active device increases with increasing load impedance.

Date: 03/18/2019 **Status:** Granted
IP Type: Patents **#:** 1550180A1 **Jurisdiction:** SE

Title: Extended bandwidth digital Doherty Transmitter

Description: An extended bandwidth digital Doherty transmitter includes a baseband signal processing block including a digital predistortion unit. It also includes a digital signal distribution unit and a digital phase alignment unit, a signal up-conversion block, an RF power amplification block including the carrier amplifier and one or two peaking amplifiers; and an RF Doherty combining network. In

Date: 03/04/2018 **Status:** Applied
IP Type: Patents **#:** WO 2018/176163 **Jurisdiction:** WO

Title: SYSTEM AND METHOD FOR A FREQUENCY SELECTIVE RECEIVER

Description: A receiver comprising a signal phase shifting block generating concurrent phase shifted copies of an input signal, and an impedance translation function block configured to receive the phase shifted

copies of the input signal and generate a down converted signal wherein the impedance translation function block is driven by a single clock signal of frequency determined by a desired carrier

IP Type: Spin-Offs* **Jurisdiction:** Canada

Title: Agile MMIC inc.

9. PUBLICATIONS

Please provide information on the following:

Refereed journal publications	29
Conference proceedings	6
Books and Chapters	0
Special/Invited presentations	7
Awards	0
Theses	5

Please list details of all publications below.

Sample Formats:

Article in a collection

A.J. Albrecht, "Measuring Application-Development Productivity," *Programmer Productivity Issues for the Eighties* , 2nd ed., C. Jones, ed., IEEE CS Press, 1981, pp. 34-43.

Article in a conference proceeding

M. Weiser, "Program Slicing," *Proc. 14th Int'l Conf. Data Eng* . (ICDE 98), IEEE CS Press, 1998, pp. 439-449.

Article in a journal or magazine

I.E. Sutherland, R.F. Sproull, and *R.A. Schumaker, "A Characterization of 10 Hidden-Surface Algorithms," *ACM Computing Surveys* , Mar. 1974, pp. 1-55.

Book

W.M. Newman and R.F. Sproull, *Principles of Interactive Computer Graphics* , 1979, p. 402.

Digital Publication

R. Bartle, “Early MUD History,” Nov. 1990; http://www.ludd.luth.se/aber/mud-history.html.

NOTE: Please place an asterisk (*) before the name of graduate students and post-docs who are co-authors on the publications listed.

Conference Publications

1. A. Saxena*, D. Banerjee*, M. Hashmi* and F. Ghannouchi, "Design of Compact Dual-Band Matching Network with Single Unequal Susceptance Cancellation Stub," in IEEE Asia-Pacific Microwave Conference (APMC), Kyoto, Japan, pp. 300-302, 6-9 November 2018.

2. A. Hasan*, M. Helaoui* and F. M. Ghannouchi, "Performance of quadrature phase shift frequency selective receiver in presence of blockers," in IEEE Topical Conference on Wireless Sensors and Sensor Networks (WiSNet), Anaheim, CA, USA, pp. 15-18, 12 March 2018.

3. X. Du*, C. J. You, X. Li*, M. Helaoui*, J. Cai and F. M. Ghannouchi, "Evaluation of knee voltage effect and soft turn-on characteristic on the load modulated continuous class-B/J power amplifier," in IEEE MTT-S International Wireless Symposium (IWS), Chengdu, China, pp. 1-3, 02 July 2018.

4. S. K. Dhar*, M. Helaoui* and F. M. Ghannouchi, "Temperature Dependent Robust Behavioral Modeling of Non-Linear Power Amplifier," in Asia-Pacific Microwave Conference (APMC), Kyoto, Japan, pp. 378-380, 6-9

November 2018.

5. N. Chagtmi*, A. Harguem, N. Boulejfene* and F. M. Ghannouchi, "Six-Port Based High Performance Concurrent Dual-Band Receiver," in Asia-Pacific Microwave Conference (APMC), Kyoto, Japan, pp. 875-877, 6-9 November 2018.

6. D. Bannerjee*, A. Saxena*, M. S. Hashmi* and F. M. Ghannouchi, "A Compact Dual-Band Impedance Matching Network Based on All-Pass Coupled Lines," in IEEE 61st International Midwest Symposium on Circuits and Systems (MWSCAS), Windsor, ON, Canada, 5-8 August 2018.

Journal Papers 1. M. Noweir*, M. Helaoui*, W. Tittel and F. M. Ghannouchi, "Carrier Aggregated Radio-Over-Fiber Downlink for Achieving 2Gbps for 5G Applications," IEEE Access, Vol. 7, pp. 3136-3142, 2019.

2. N. Chagtmi*, N. Boulejfen*, W. Zhang*, A. Hassan*, C. Fager and F. M. Ghannouchi, "Augmented Hammerstein model for the calibration of six-port based dual band wireless receivers," International Journal of RF and Microwave Computer-Aided Engineering, Vol. 29: Issue 2, 2019.

3. M. Aziz*, M. V. Amiri*, M. Helaoui* and F. M. Ghannouchi, "Statistics-Based Approach for Blind Post-Compensation of Modulator's Imperfections and Power Amplifier Nonlinearity," IEEE Transactions on Circuits and Systems I: Regular Papers, pp. 1-13, 2019.

4. A. B. Arfi*, M. Jouzdani*, M. Helaoui* and F. M. Ghannouchi, "A Novel High-Pass Delta-Sigma Modulator Based Digital-IF Transmitter with Enhanced Performance for SDR Applications," IEEE Transactions on Circuits and Systems II: Express Briefs, pp. 1-1, 2019.

5. Y.-L. Zhao*, F. M. Ghannouchi, M. Helaoui*, X. Li*, X. Du*, W. Zhang* and T. Apperley, "Doherty Transmitter Based on Monopole Array Antenna Active Load Modulation," IEEE Microwave and Wireless Components Letters, pp. 1-3, 2018.

6. W. Zhang*, A. Hasan*, F. M. Ghannouchi, M. Helaoui*, Y. Wu, C. Yu and Y. Liu, "Concurrent Dual-Band Low Intermediate Frequency Receiver Based on the Multiport Correlator and Single Local Oscillator," IEEE Microwave and Wireless Components Letters, Vol. 28: Issue 4, pp. 353-355, 2018.

7. W. Zhang*, A. Hasan*, F. M. Ghannouchi, M. Helaoui*, Y. Wu, L. Jiao and Y. Liu, "Homodyne Digitally Assisted and Spurious-Free Mixerless Direct Carrier Modulator With High Carrier Leakage Suppression," IEEE Transactions on Microwave Theory and Techniques, Vol. 66: Issue 3, pp. 1475-1488, 2018.

8. W. Zhang*, A. Hasan*, F. M. Ghannouchi, M. Helaoui*, X. Li*, Y. Wu, L. Meng and Y. Liu, "Concurrent Dual-Band Receiver Based on the Multi-Port Correlator for Wireless Applications," IEEE Transactions on Circuits and Systems II: Express Briefs, Vol. 65: Issue 6, pp. 759-763, 2018.

9. D. Wang*, M. Fattouche, F. M. Ghannouchi and X. Zhan, "Quasi-Optimal Subcarrier Selection Dedicated for Localization With Multicarrier-Based Signals," IEEE Systems Journal, pp. 1-12, 2018.

10. D. Wang*, M. Aziz*, M. Helaoui* and F. M. Ghannouchi, "Augmented Real-Valued Time-Delay Neural Network for Compensation of Distortions and Impairments in Wireless Transmitters," IEEE Trans. Neural Netw. Learn. Syst., Jun 12 2018.

11. X. Hu, T. Liu, Z. Liu, W. Wang and F. M. Ghannouchi, "A Novel Single feedback Architecture With Time Interleaved Sampling for Multi-band DPD," IEEE Communications Letters, 2019.

12. A. Ben Arfi, M. Helaoui and F. M. Ghannouchi, "Delay-compensation block for first-order low-pass delta-sigma modulators," Microwave and Optical Technology Letters, Vol. 61: Issue 3, pp. 583-586, 2019.

13. M. Aziz, M. V. Amiri, M. Helaoui and F. M. Ghannouchi, "Statistics-Based Approach for Blind Post-Compensation of Modulator's Imperfections and Power Amplifier Nonlinearity," IEEE Transactions on Circuits and Systems I: Regular Papers, pp. 1-13, 2019.

14. T. Sharma, E. R. Srinidhi, R. Darraji, D. G. Holmes, J. Staudinger, J. K. Jones and F. M. Ghannouchi, "High-Efficiency Input and Output Harmonically Engineered Power Amplifiers," IEEE Transactions on Microwave Theory and Techniques, Vol. 66: Issue 2, pp. 1002-1014, Feb 2018

15. T. Sharma, J. Roberts, D. G. Holmes, R. Darraji, J. K. Jones and F. M. Ghannouchi, "On the Double-Inflection Characteristic of the Continuous-Wave AM/AM in Class-F $^{-1}$ Power Amplifiers," IEEE Microwave and Wireless Components Letters, Vol. Early Access, pp. 1-3, 2018.

16. T. Sharma, D. G. Holmes, R. Darraji, E. R. Srinidhi, J. Staudinger, J. K. Jones and F. M. Ghannouchi, "On the Second-Harmonic Null in Design Space of Power Amplifiers," IEEE Microwave and Wireless Components Letters, Vol. 28: Issue 7, pp. 600-602, 2018.

17. T. Sharma, P. Aflaki, M. Helaoui and F. M. Ghannouchi, "Broadband GaN Class-E Power Amplifier for Load Modulated Delta Sigma and 5G Transmitter Applications," IEEE Access, Vol. 6, pp. 4709-4719, 2018.

18. M. Noweir, Q. Zhou, A. Kwan, R. Valivarthi, M. Helaoui, W. Tittel and F. M. Ghannouchi, "Digitally Linearized Radio-Over Fiber Transmitter Architecture for Cloud Radio Access Network's Downlink," IEEE Transactions on Microwave Theory and Techniques, pp. 1-11, 2018.

19. X. Liu, Q. Zhang, W. Chen, H. Feng, L. Chen, F. M. Ghannouchi and Z. Feng, "Beam-Oriented Digital Predistortion for 5G Massive MIMO Hybrid Beamforming Transmitters," IEEE Transactions on Microwave Theory and Techniques, Vol. 66: Issue 7, pp. 3419-3432, 2018.

20. P. Jaraut, M. Rawat and F. M. Ghannouchi, "Harmonically Related Concurrent Tri-Band Behavioral Modeling and Digital Predistortion," IEEE Transactions on Circuits and Systems II: Express Briefs , Vol. Early Access, pp. 1 - 1, 2018.

21. P. Jaraut, M. Rawat and F. M. Ghannouchi, "Composite Neural Network Digital Predistortion Model for Joint Mitigation of Crosstalk, I/Q Imbalance, Nonlinearity in MIMO Transmitters," IEEE Transactions on Microwave Theory and Techniques, pp. 1-10, 2018.

22. P. Jaraut, M. Rawat and F. Ghannouchi, "2-D Curtailed Harmonic Memory Polynomial for reduced complexity in Concurrent Dual-Band Modeling and Digital Predistortion with the second band at Harmonic Frequency," IET Communications, 2018.

23. R. Essaadali, A. Jarndal, A. B. Kouki and F. M. Ghannouchi, "Conversion Rules Between X-Parameters and Linearized Two-Port Network Parameters for Large-Signal Operating Conditions," IEEE Transactions on Microwave Theory and Techniques, pp. 1-12, 2018.

24.

R. Essaadali, A. Jarndal, A. B. Kouki and F. M. Ghannouchi, "On the Accurate Voltage and Current Analytical Relationship to X-Parameters of a Nonlinear Two-Port Network," IEEE Transactions on Microwave Theory and Techniques, Vol. 66: Issue 10, pp. 4439-4451, 2018.

25. X. Du, C. J. You, Y. Zhao, X. Li, M. Helaoui, J. Cai and F. M. Ghannouchi, "Wideband high-efficiency linearized PA design with reduction in memory effects and IMD3," International Journal of Microwave and Wireless Technologies, Vol. 10: Issue 04, pp. 391-400, 2018.

26. X. Du, C. J. You, M. Helaoui, J. Cai and F. M. Ghannouchi, "Investigation of load modulated inverse Class-F

power amplifier with extended conduction angle," International Journal of RF and Microwave Computer-Aided Engineering, Vol. 28: Issue 8, 2018.

27. X. Du, C. J. You, J. Cai, M. Helaoui, F. M. Ghannouchi, Y. Zhao and X. Li, "Novel Design Space of Load Modulated Continuous Class-B/J Power Amplifier," IEEE Microwave and Wireless Components Letters, Vol. 28: Issue 2, pp. 156-158, 2018.

28. S. K. Dhar, M. S. Sharawi and F. M. Ghannouchi, "Microwave Connector De-Embedding and Antenna Characterization [Education Corner]," IEEE Antennas and Propagation Magazine, Vol. 60: Issue 3, pp. 110-117, 2018.

29. S. K. Dhar, A. Abdelhafiz, M. Aziz, M. Helaoui and F. M. Ghannouchi, "A Reflection-Aware Unified Modeling and Linearization Approach for Power Amplifier Under Mismatch and Mutual Coupling," IEEE Transactions on Microwave Theory and Techniques, Vol. 66: Issue 9, pp. 4147-4157, 2018.

Invited Talks 1. “5G Research at the iRadio Lab”, Tsinghua University, China, July 2018.

2. “Enabling RF technologies for 5G communications and Internet of Things”, South China University of Technology China, September 2018

3. “Intermodulation Mitigation in Concurrent Multi-band PAs using Multi-band Predistortion Techniques”, International Microwave Symposium, June 2018, Philadelphia, USA,

Mohamed Helaoui

4. “Humanitarian Applications of Amateur Radio Technology”, Anis Ben Arfi, IEEE Northwest Leadership Summit, Vancouver, August 2018.

5. “Humanitarian Applications of Amateur Radio Technology”, Anis Ben Arfi, 3rd IEEE PES Student Congress, Brasil, August 2018.

6. “Humanitarian Applications of Amateur Radio Technology”, Anis Ben Arfi, IEEE Tunisian Students & Young Professionals Congress, December 2018.

7. " Toward 5G Networks: RF challenges and Trends", The Chinese University of Hong Kong, September, 2018

Theses

1. Mohsin Aziz, PhD Thesis " Blind Compensation of Impairments in Wireless Transceivers", defended June 26, 2018.

2. Abul Hasan, PhD Thesis "Frequency Agile and Low Power Homodyne Radio Receivers", defended May 17, 2018.

3. Abdul Rafay, MSc Thesis "Novel, 2.4 and 5.8GHz Dual-band, 2-Stage RF-DC Charge-pump with Load-tuned Transmission Lines for DC Output Boost", defended April 18, 2018.

4. Abubaker Abdelhafiz, PhD Thesis "Efficient Digital Predistortion for Next-Generation Wireless Systems Using Optimization and Signal Processing Techniques", defended June 21, 2018.

5. Anis Ben Arfi, PhD Thesis " Signal Processing Techniques for Broadband Radio Applications", defended June 27, 2018.

10. OUTREACH

Please describe community outreach activities such as meetings with trade missions/VIPs, community events, public presentations, involvement with schools, and significant media exposure. Please provide hyperlinks to media coverage, or upload photos/associated articles where possible.

10. OUTREACH

The iRadio Lab always has been and remains actively engaged in outreach activities. The lab is staffed by many highly motivated, high-caliber students who are active leaders in the technical community and Canadian society at large; mainly through the Institute of Electrical and Electronic Engineers (IEEE) and its numerous student branches. IEEE organizes and sponsors a variety of technical and socially-minded initiatives that aim to foster positive relationships between academia, industry and the larger communities.

As was the case in prior years, iRadio Lab members continue to hold leadership positions in IEEE, including being the heads of local sections, committee chairs, organizing committee chairs and prominent volunteers.The iRadio Lab and its members have been particularly active in advocating for the humanitarian application of wireless and radio frequency research, with an emphasis on amateur and HAM radio benefiting under-served and under-privileged communities such as Reserves, with some examples of invited talks and keynote presentations given below:

1. IEEE NW Leadership Summit, 2018 IEEE Young Professionals Pacific Northwest Leadership Summit, Vancouver 2018.

2. Talk at IEEE PES Student Congress, Sao Paolo Brazil, August 2018

3. Tunisian Students and Young Professionals, (Collaboration/Partnership event between students and professionals in the field) December 2018

4. IEEE Rising Stars Conference, Las Vegas NV, January 2-4 2019

11. OTHER FUNDING RECEIVED

Using the following table, please provide information on additional funding you've received from various sources in the previous fiscal year for the period:

April 1 to March 31 (this reporting period).

This information is used to calculate the leverage ratio pertaining to the funding from AI.

Points to note:

1. Include only the total amount of funding received in the previous fiscal year, for the period April 1 to March 31 (this reporting period). Include any funding for which you or a Team Member are a Principal Investigator (PI) or co-PI.
2. Select the Funding Type from the drop-down provided.
3. 'Proof' is to indicate whether you have access to a proof that you are associated with the funding (e.g. your name on a contract or a letter of confirmation of funding).
4. Use the Notes area to provide any comments on the funding.

Applicant Name: Fadhel Ghannouchi
Funding Source: Canada Research Chair **Amount:** 200,000.00
Proof of Funding: Yes
Funding Description: Chair

Applicant Name: Mohamed Helaoui **Co-recpient:** Fadhel Ghannouchi
Funding Source: NSERC **Amount:** 224,000.00
Proof of Funding: Yes
Funding Description: Strategic

Applicant Name: Fadhel Ghannouchi
Funding Source: Other Federal Government **Amount:** 490,000.00
Proof of Funding: Yes
Funding Description: Contract

Applicant Name: Fadhel Ghannouchi **Co-recpient:** Mohamed Helaoui
Funding Source: University (cash) **Amount:** 78,089.00
Proof of Funding: Yes
Funding Description: iRadio Lab Revenues

Applicant Name: Fadhel Ghannouchi
Funding Source: University (cash) **Amount:** 175,000.00
Proof of Funding: Yes
Funding Description: Salaries

Applicant Name: Fadhel Ghannouchi
Funding Source: University (in-kind) **Amount:** 230,000.00

Proof of Funding: No
Funding Description: Lab Space

Applicant Name: Fadhel Ghannouchi
Co-recpient: Mohamed Helaoui
Funding Source: Canada Foundation for Innovation
Amount: 400,000.00
Proof of Funding: Yes
Funding Description: CFI #33513

Applicant Name: Fadhel Ghannouchi
Funding Source: NSERC
Amount: 58,000.00
Proof of Funding: Yes
Funding Description: Discovery

Applicant Name: Mohamed Helaoui
Funding Source: NSERC
Amount: 30,000.00

Funding Description: Discovery

Applicant Name: Fadhel Ghannouchi
Co-recpient: Mohamed Helaoui
Funding Source: Consortium
Amount: 150,000.00
Proof of Funding: No
Funding Description: CMC

Applicant Name: Fadhel Ghannouchi
Co-recpient: Mohamed Helaoui
Funding Source: Industry (cash)
Amount: 70,000.00
Proof of Funding: Yes
Funding Description: contributions several grants/awards

Funding Source: Other
Amount: 220,000.00
Proof of Funding: No
Funding Description: Scholarships & fellowships

12. FINANCIAL REPORTS

A Statement of Revenues and Expenses for each research project and program is sent to researchers by the finance department of the University Research Services Office (RSO).

Researchers should be getting a statement on a semi-annual and annual basis. Please make sure that you have returned a signed copy to the finance department so that it may be forwarded to Alberta Innovates as your official financial report.

Thank you for submitting your annual progress report.

List Of Attachments: