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| SPS internal use | |  |  | |
| Progress Report Received |  |  | SPS Reference: | ████ |

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|  | **Emerging Security Challenges Division**  **Science for Peace and Security Programme**  **Multi-Year Project Final Report**  insert project title  ***Long-Range Stand-Off Microwave Radar for Personnel Protection***  submit completed report in **Microsoft Word format** to [sps.admin@hq.nato.int](mailto:sps.admin@hq.nato.int) |

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| Project Start Date | Project Duration | Date of this Report |
| July 1, 2015 | Extended until 1 April 2019 | March 4, 2019 |

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|  | Project Co-Directors | | | |
|  | Title and Name | Institution | Country | email |
| NPD | Prof. Natalia K. Nikolova | McMaster University | Canada | nikolova@ieee.org |
| PPD | Prof. Victor I. Naydenko | NTUU KPI | Ukraine | victor\_naydenko@ukr.net |
|  | ████ | ████ | ████ | ████ |
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| Abstract & Current Status | provide an abstract of the project and its accomplishments (no more than one-half page) |

The objective of this project is to develop a compact portable (possibly wearable) warning system for the stand-off detection of on-body concealed weapons such as knives, handguns, grenades, and especially explosive vests. The envisioned system will be controlled by an on-board computer where the radar signals will be processed by cognitive algorithms based on three modules: (i) feature extraction in both time and frequency domains, (ii) libraries of “threat” and “non-threat” targets, and (iii) target classifiers based on neural networks. The project is focused on protecting military or law-enforcement personnel from acts of terrorists and militants who often adopt a civilian disguise to inflict as much destruction and death as possible. The system could also be useful in civilian protection; for example, private security personnel could use it.

All tasks pertaining to hardware module development have been completed and all effort is currently on hardware integration, system integration and validation. Preparation is underway to visit the team in Kyiv in late spring for measurements and validation in an operational environment.

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| Project Goals | summarize the major goals and objectives of the project; highlight any changes from the project plan or previous reports (this is unusual) |

We aim at designing an effective warning system that can achieve stand-off distances of at least 10 m (with true-positive detection rate above 90%) and preferably as long as 20 m (with true-positive detection rate above 80%).

The proposed solution to the above challenging engineering task involves several tasks. First, the transmitted power needs to be increased and yet it must remain sufficiently low to ensure compliance with the radiation safety regulations currently in place. Second, the sensitivity and the dynamic range of the radar receiver must be increased. Third, the signal-processing module of the system can be significantly improved by: (i) adding more features to the portfolio of the processed radar signal, (ii) improving the feature extraction methods, (iii) improving the background-clutter removal techniques, and (iv) optimizing the cognitive algorithms for faster and more accurate recognition of a signal feature.

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| Summary of Accomplishments | summarize accomplishments under these goals |

Transmitters have been designed, built and tested by both the Canadian and Ukrainian teams. The Canadian team has successfully built a transmitter that fully complies with the requirements of a 5.5 GHz bandwidth and 11 Vp-p voltage. The Ukrainian team has also been able to build a transmitter with a slightly narrower frequency bandwidth and lower voltage; but it too complies with the requirements.

Antennas have been designed, built and tested by both teams that comply with the requirements. The Ukrainian team produced an antenna that is linearly polarised and impedance matched over the full-required bandwidth of 0.5 GHz to 5GHz. The Canadian team also produced linearly polarised antennas of bandwidth from 0.3 GHz to 5 GHz. Both antenna sets are now in use.

A receiver that utilises equivalent time sampling to yield an effective sampling rate of 10 GS/s has been designed and built. This receiver offers an affordable and compact solution to capture signals ranging from 0.5 GHz up to 5GHz.

The signal-processing module is nearing completion with the pre-processing chain complete and validated. Feature extraction has also been completed and is being validated.

System integration is near completion and the Canadian team is preparing for a visit to Kyiv in late spring for real life scenario tests that is enabled through collaboration with industrial partners in Ukraine.

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| Accomplishments | detail accomplishments and progress achieved by this project |

**Details on the antenna, transmitter and receiver designs as well as modules of the signal-processing unit are given in the documents listed below:**

E.A. Eveleigh, A.S. Beaverstone, and N.K. Nikolova, “Printed cactus monopole antenna with enhanced impedance bandwidth,” *IEEE AP-S/URSI Int. Symp. on Antennas and Propagation*, July 2019, Atlanta, GA.

V.I. Naydenko, D.I. Dovhal, M.A. Kozachuk, N.K. Nikolova, and D.S. Shumakov, “Radiating element based on the two-wire line with horns,” *Int. J. of Engineering and Science Invention (IJESI)*, vol. 8, no. 2, pp. 63–69, Feb. 2019.

A. A. Qureshi, “Concealed weapon detection data preprocessing: LTR region extraction and background clutter removal”, EMVi-R-92 Tech. Report, McMaster University, January 2019.

A. D. Pitcher, “A compact and affordable ultra-wideband equivalent sampling receiver: receiver design part IV: FPGA design and control”, EMVi-R-90 Tech. Report, McMaster University, January 2019.

A. D. Pitcher, “A compact and affordable ultra-wideband equivalent sampling receiver: receiver design part III: revision 2.0 design and preliminary testing”, EMVi-R-89 Tech. Report, McMaster University, January 2019.

A. D. Pitcher, “A compact and affordable ultra-wideband equivalent sampling receiver: receiver design part II: revision 1.0 discoveries”, EMVi-R-88 Tech. Report, McMaster University, January 2019.

A. A. Qureshi, “Late time response (LTR) region extraction from the signal: CWD data preprocessing”, EMVi-R-87 Tech. Report, McMaster University, October 2018.

C. W. Baard, “Antipodal antenna design”, EMVi-R-86 Tech. Report, McMaster University, September 2018.

E. A. Eveleigh, “Compact transmitter for pulsed-radar detection of on-body concealed weapons: transmitter design part III: component and layout investigation”, EMVi-R-84 Tech. Report, McMaster University, August 2018.

A. D. Pitcher, J. J. McCombe, E. A. Eveleigh, N. K. Nikolova, “Compact transmitter for pulsed-radar detection of on-body concealed weapons”, *IEEE MTT-S Int. Microwave Symp.,* June 2018, Philadelphia, PA.

V. I. Naydenko, M. A. Kozachuk, and V. R. Bendak “Звіт по гранту G4992 про виконану роботу протягом п’ятого півріччя”, April 2018 (in Ukrainian).

A. D. Pitcher, “Compact transmitter for pulsed-radar detection of on-body concealed weapons: transmitter design part II: jitter and noise analysis”, EMVi-R-80 Tech. Report, McMaster University, March 2018.

V. I. Naydenko, M. A. Kozachuk, and M. V. Balakirev “Звіт по гранту G4992 про виконану роботу протягом третього півріччя”, April 2017 (in Ukrainian).

V. I. Naydenko “Річний звіт по Гранту G4992,” October, 2016 (in Ukrainian).

J. J. McCombe and N. Nikolova, “Transmitter specifications for the stand-off detection of on-body concealed weapons,” CEM-R-72 Tech. Report, McMaster University, July, 2015.

**Detailed elaborations on the receiver design can be found here:**

J. J. McCombe and A. S. Beaverstone, “Design of the receiver for the concealed weapon detection system – part I,” CEM-R-75 Tech. Report, McMaster University, March, 2016.

**Correspondence between Canadian and Ukrainian teams on Ukrainian transmitter design can be found here:**

N. K. Nikolova and A. D. Pitcher, “Tx Pulse Waveform Spectrum,” February, 2017.

V. I. Naydenko, “Трансмітер нового покоління 31.12.2016 для Канади”, December, 2016.

**Correspondence between the Canadian and Ukrainian teams on the Ukrainian transmitter and Canadian receiver interfacing options:**

C. W. Baard, “Email to Dr. Naydenko: transmitter feedback”, September 2018.

A. D. Pitcher, “Email to Dr. Naydenko – August 2017,” August 2017.

Maxim Integrated, “High-Frequency Waveform Generator,” MAX038 Datasheet – Rev 7, August 2007.

V. I. Naydenko, “Відповідь на питання (виправлена),” August 2017.

**Correspondence regarding the erratum to the translation of the Handbook in Ukrainian can be found here:**

N. K. Nikolova, “NATO Handbook Translation Erratum,” August 2017.

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| Collaboration | detail the collaboration and consultation among co-directors and their groups |

The project-related matters are discussed between Prof. Nikolova (NPD) and Prof. Naydenko (PPD) regularly via emails. The communication flow has been facilitated by the presence of a Ukrainian native speaker in the Canadian team (Dr. Denys Shumakov) for the most part of the project duration. Dr. Shumakov has left the McMaster team following the completion of his degree; however, he still aides the team remotely with correspondence and translation. Apart from email communication, the following meetings have also taken place:

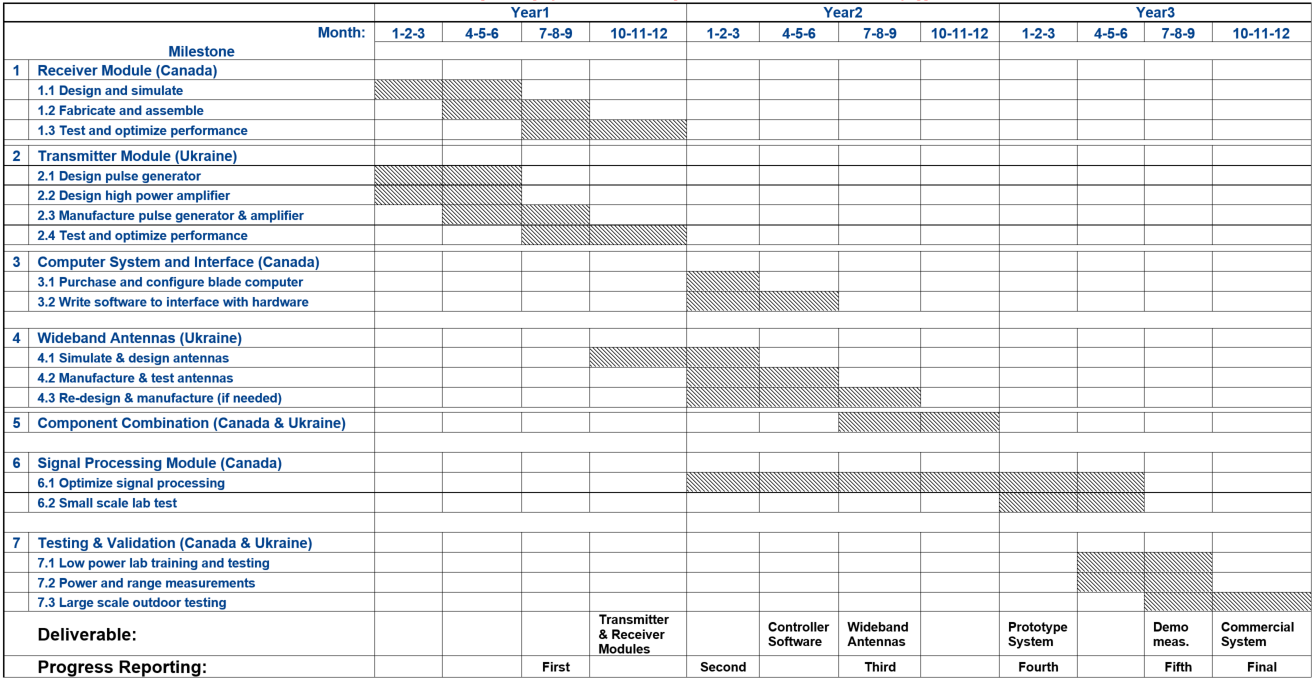
Denys Shumakov went to Kyiv at the end of December 2015 to meet with the Ukrainian team. The trip’s agenda included discussing technical progress, financial evaluation for the up-to-date period of the NATO G4992 Project and planning the collaborative work for the next 6-months period.

A live meeting between the two teams took place during the EuCAP conference in Paris (March 2017). The meeting’s agenda was to discuss the technical progress, specifications of the transmitter and the challenges in integrating the Ukrainian transmitter with the Canadian receiver. The teams also evaluated the finances for the up-to-date period of the NATO G4992 Project. Planning was done for the future collaborative work at that time.

The Canadian and Ukrainian teams met in person at the SPS 60th Anniversary Celebration (November 2018) to discuss project progress as well as the integration between the Ukrainian transmitter module and the Canadian receiver module.

The Canadian team is planning a trip to Kyiv, Ukraine, in the late spring or early summer of 2019. The goal of the trip is to integrate the sub-components and to test the system hardware and the signal-processing methods for concealed-weapon detection.

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| Milestones & Deliverables | list project milestones and deliverables their current status; if they are not complete, explain and detail the impact on the project outcomes |



The team is now at the end of the project (see Schedule above).

The receiver module is now operational and is in the final stage of measuring its jitter and noise characteristics (milestone 1.3). After noise and jitter characteristics have been measured, milestone 1 will be considered completed.

The fabrication and testing of the transmitter modules are now complete and milestone 2 is completed.

Computer communication control to interface with the hardware is currently being improved to facilitate higher data transfer rates between the receiver FPGA and the host computer (milestone 3.2).

The wideband antennas have been fabricated and tested (milestone 4). This milestone is now considered done.

Final component combination/integration (milestone 5) between the Canadian and Ukrainian team’s components will take place late spring during the Canadian team’s trip to Kyiv. The Canadian team now has all the components in place to work on subsequent milestones of system testing and validation.

The signal-processing module (milestone 6) is nearing completion with only feature extraction remaining to be validated (milestone 6.1).

Testing and validation (milestone 7) are to be completed at Kyiv during the Canadian teams visit in late spring.

The remaining tasks are to be completed before or at the end of the visit to Kyiv in the late spring. These remaining tasks are as follows:

1. Characterize receiver (milestone 1).
2. Finalize the communication control between the FPGA and host computer (milestone 3).
3. Integration of the Ukrainian and Canadian system components and evaluating the systems performance (milestone 5). Integration strategies have already been discussed between the two teams via our meetings.
4. Finalize the signal processing modules (milestone 6).
5. Perform testing and validation of the system (milestone 7).

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| Training & Professional Development | detail training and professional development activities |

**Denys Shumakov attended two conferences in 2015:**

IEEE AP-S/URSI International Symposium on Antennas and Propagation, Vancouver, Canada, July 19-24, 2015.

IEEE International Conference on Numerical Electromagnetic and Multiphysics Modelling and Optimization (NEMO), Ottawa, Canada, August 12-14, 2015.

**Denys Shumakov attended one conference in 2016:**

10th European Conference on Antennas and Propagation EuCAP 2016, Davos, Switzerland, April 10-15, 2016.

**Aaron Pitcher and Denys Shumakov attended the following conference in March, 2017:**

11th European Conference on Antennas and Propagation EuCAP 2017, Paris, France, March 19-24, 2017.

**Natalia Nikolova and Denys Shumakov attended the following conference in June 2017:**

2017 International Microwave Symposium (IMS), Honolulu, Hawaii, June 4-9, 2017.

**Natalia Nikolova and Denys Shumakov attended the following conference in July 2017:**

2017 IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, San Diego, California, USA, July 9-14, 2017

**Natalia Nikolova, Denys Shumakov and Aaron Pitcher attended the following conference in August 2017:**

XXXIInd International Union of Radio Science General Assembly & Science Symposium (URSI), Montréal, Québec, Canada, August 19-26, 2017.

**Natalia Nikolova attended the following conference in April 2018:**

12th European Conference on Antennas and Propagation, London, UK, April 9-13, 2018

**Natalia Nikolova attended the following conferences in 2018:**

IEEE AP-S/URSI Int. Symp. on Antennas and Propagation, July 2018, Boston, MA.

IEEE MTT-S Int. Microwave Symp., June 2018, Philadelphia, PA.

**Aaron Pitcher attended the following events in 2018:**

ESoA Course: “Radar 2020 – Future Radar Systems”, May 7 – 11, 2018, Karlsruhe, Germany. (organized by the European School of Antennas in cooperation with the Karlsruhe Institute of Technology)

IEEE MTT-S Int. Microwave Symp., June 2018, Philadelphia, PA.

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| Impact | describe the impact of the project on the scientific community and the public |

**The following conference paper has been presented:**

A. D. Pitcher, J. J. McCombe, E. A. Eveleigh, N. K. Nikolova, “Compact transmitter for pulsed-radar detection of on-body concealed weapons”, *IEEE MTT-S Int. Microwave Symp.,* June 2018, Philadelphia, PA.

**The following papers were published:**

E.A. Eveleigh, A.S. Beaverstone, and N.K. Nikolova, “Printed cactus monopole antenna with enhanced impedance bandwidth,” *IEEE AP-S/URSI Int. Symp. on Antennas and Propagation*, July 2019, Atlanta, GA.

V.I. Naydenko, D.I. Dovhal, M.A. Kozachuk, N.K. Nikolova, and D.S. Shumakov, “Radiating element based on the two-wire line with horns,” *Int. J. of Engineering and Science Invention (IJESI)*, vol. 8, no. 2, pp. 63–69, Feb. 2019.

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| Implementation | detail how the results of this project have been, are being, and will be implemented |

The McMaster team is currently working in conjunction with an industrial partner to further develop the concealed weapon detection technology developed under the SPS program. The envisioned goal is to push a product to the security market that can be deployed in a multitude of settings to protect civilians, security and military personnel from concealed threats.

An in depth evaluation of hardware and signal processing algorithms developed under this program is currently underway to understand the viability of using these components in public settings. It is envisioned that industrialisation of the various components will take place after this investigation.

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| Project Participants and Roles | list the participants in the project and the rough fraction of their time spent on it; describe briefly how each contributed to the project; add or subtract rows as needed |

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| Name | Affiliation | Position/Title | % Time | Role |
| Aaron Pitcher | McMaster University | Master Student | 100% | FPGA programming and Application Software Development. |
| Denys Shumakov | McMaster University | PhD Student, now graduated | 0% | Liaise with Ukraine, component integration, monthly project updates. |
| Eric Eveleigh | McMaster University | Master Student | 100% | Canadian transmitter module optimization, fabrication and manufacturing. Alternative antenna design. |
| Arooj Qureshi | McMaster University | Research Assistant | 100% | Signal Processing Module. |
| Maksym Kozachuk | Taras Shevchenko National University of Kyiv | Graduate Student | 50% | Design, simulation and fabrication of a transmitter module. |
| Volodymyr Bendak | NTUU “KPI” | Undergraduate Student | 30% | Design and simulation of antennas |
| Charl Baard | McMaster University | Research Engineer | 50% | Assist is tasks pertaining to the receiver, signal processing and antenna design. |
| Dmytro Dovhal | NTUU KPI | Undergraduate student | 30% | Design and simulation of antenna |
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| Criteria for Success | list the Criteria for Success established in the Project Plan and your evaluation of their completion |

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| Criterion | Relative Weight | Complete | Comments |
| Development of a highly sensitive direct sampling receiver (5.5 GHz bandwith) | 25% | 99% | ████ |
| Development of a high-power (10-20 W) transmitter module | 25% | 100% | ████ |
| Development of wideband antennas | 25% | 100% | ████ |
| Development of Signal Processing | 25% | 90% | ████ |
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| Products & Dissemination | please list all products and outcomes of the project |

Journal articles, conference papers, book chapters, and other publications (please do not attach copies)

E.A. Eveleigh, A.S. Beaverstone, and N.K. Nikolova, “Printed cactus monopole antenna with enhanced impedance bandwidth,” *IEEE AP-S/URSI Int. Symp. on Antennas and Propagation*, July 2019, Atlanta, GA.

V.I. Naydenko, D.I. Dovhal, M.A. Kozachuk, N.K. Nikolova, and D.S. Shumakov, “Radiating element based on the two-wire line with horns,” *Int. J. of Engineering and Science Invention (IJESI)*, vol. 8, no. 2, pp. 63–69, Feb. 2019.

A. A. Qureshi, “Concealed weapon detection data preprocessing: LTR region extraction and background clutter removal”, EMVi-R-92 Tech. Report, McMaster University, January 2019.

A. D. Pitcher, “A compact and affordable ultra-wideband equivalent sampling receiver: receiver design part IV: FPGA design and control”, EMVi-R-90 Tech. Report, McMaster University, January 2019.

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A. D. Pitcher, “A compact and affordable ultra-wideband equivalent sampling receiver: receiver design part II: revision 1.0 discoveries”, EMVi-R-88 Tech. Report, McMaster University, January 2019.

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C. W. Baard, “Antipodal antenna design” EMVi-R-86 Tech. Report, McMaster University, September 2018.

E. A. Eveleigh, “Compact transmitter for pulsed-radar detection of on-body concealed weapons: transmitter design part III: component and layout investigation”, EMVi-R-84 Tech. Report, McMaster University, August 2018.

A. D. Pitcher, J. J. McCombe, E. A. Eveleigh, and N. K. Nikolova, “Compact transmitter for pulsed-radar detection of on-body concealed weapons”, *IEEE MTT-S Int. Microwave Symp*., June 2018, Philadelphia, PA.

A. D. Pitcher, “Compact transmitter for pulsed-radar detection of on-body concealed weapons: transmitter design part II: jitter and noise analysis,” EMVi-R-80 Tech. Report, McMaster University, March 2018.

J. J. McCombe, and A. S. Beaverstone, “Design of the receiver for the concealed weapon detection system – part I,” CEM-R-75 Tech. Report, McMaster University, March 2016.

J. J. McCombe, and N. K. Nikolova, “Transmitter specifications for the stand-off detection of on-body concealed weapons,” CEM-R-72 Tech. Report, McMaster University, July 2015.

J. J. McCombe “Cognitive microwave radar for the stand-off detection of on-body concealed weapons,” CEM-R-70, Tech. Report, McMaster University, March 2015.

Conference presentations and public lectures

N.K. Nikolova (NPD), C. Baard, A. Beaverstone, E. Eveleigh, J. McCombe, A. Pitcher, A. Qureshi, D. Shumakov, Dr. V. Naydenko (PPD), M. Balakirev, V. Bendak, D. Dovhal, D. Gnatiuk, M. Kozachuk, and N. Salamatina, “Long-range stand-off microwave radar for personnel protection: NATO Science for Peace Project: SPS-G4992”, *NATO SPS 60th Anniversary Gala*, Brussels, Belgium, Nov. 29, 2018.

N.K. Nikolova, ““Smart” radar for security surveillance in the making at Mac,” *Innovation Nation* *2019*, Hamilton, Canada, Jan. 20, 2019. (aired on Cable 14 Hamilton, Hamilton's community cable station)

E.A. Eveleigh, A.S. Beaverstone, and N.K. Nikolova, “Printed cactus monopole antenna with enhanced impedance bandwidth,” *IEEE AP-S/URSI Int. Symp. on Antennas and Propagation*, July 2019, Atlanta, GA.

V.I. Naydenko, D.I. Dovhal, M.A. Kozachuk, N.K. Nikolova, and D.S. Shumakov, “Radiating element based on the two-wire line with horns,” *Int. J. of Engineering and Science Invention (IJESI)*, vol. 8, no. 2, pp. 63–69, Feb. 2019.

A. D. Pitcher, J. J. McCombe, E. A. Eveleigh, and N. K. Nikolova, “Compact transmitter for pulsed-radar detection of on-body concealed weapons”, *IEEE MTT-S Int. Microwave Symp*., June 2018, Philadelphia, PA.

N. K. Nikolova, J. J. McCombe, D. S. Shumakov, and A. S. Beaverstone, ““Smart” radar for stand-off security screening in the making at Mac,” CAFÉ E-Xpress Morning Lecture Series, McMaster University, Dec. 2015.

J. J. McCombe, N. K. Nikolova, and D. S. Shumakov, “Long-range stand-off microwave radar for personnel protection,” NATO Project Meeting, McMaster University, Dec. 2015.

Inventions, Patents, & Licenses

Patents:

On-body Concealed Weapon Detection System, United States Patent No. 10229328, issued 12 March, 2019. inventors: Natalia K. Nikolova and Justin J. McCombe

Other products such as web sites, databases, etc. released to the scientific community or the public

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Project publicity (please attach copies of articles or reports about the project)

Article in “Київський Політехнік”, №12 (3151), April 7th 2016, ст. 2:

“Грант НАТО”

Article in “McMaster Daily News”:

http://dailynews.mcmaster.ca/article/mcmaster-engineer-uses-microwave-technology-to-detect-concealed-weapons/

Article in McMaster Daily News:

http://dailynews.mcmaster.ca/article/mcmaster-engineer-uses-microwave-technology-to-detect-concealed-weapons/

Article on McMaster Engineering website:

http://www.eng.mcmaster.ca/news/2015/microwave\_technology.html