Space Modulation Techniques Hardware Implementations

GJU EWIoT Lab

http://ewiot.gju.edu.jo/

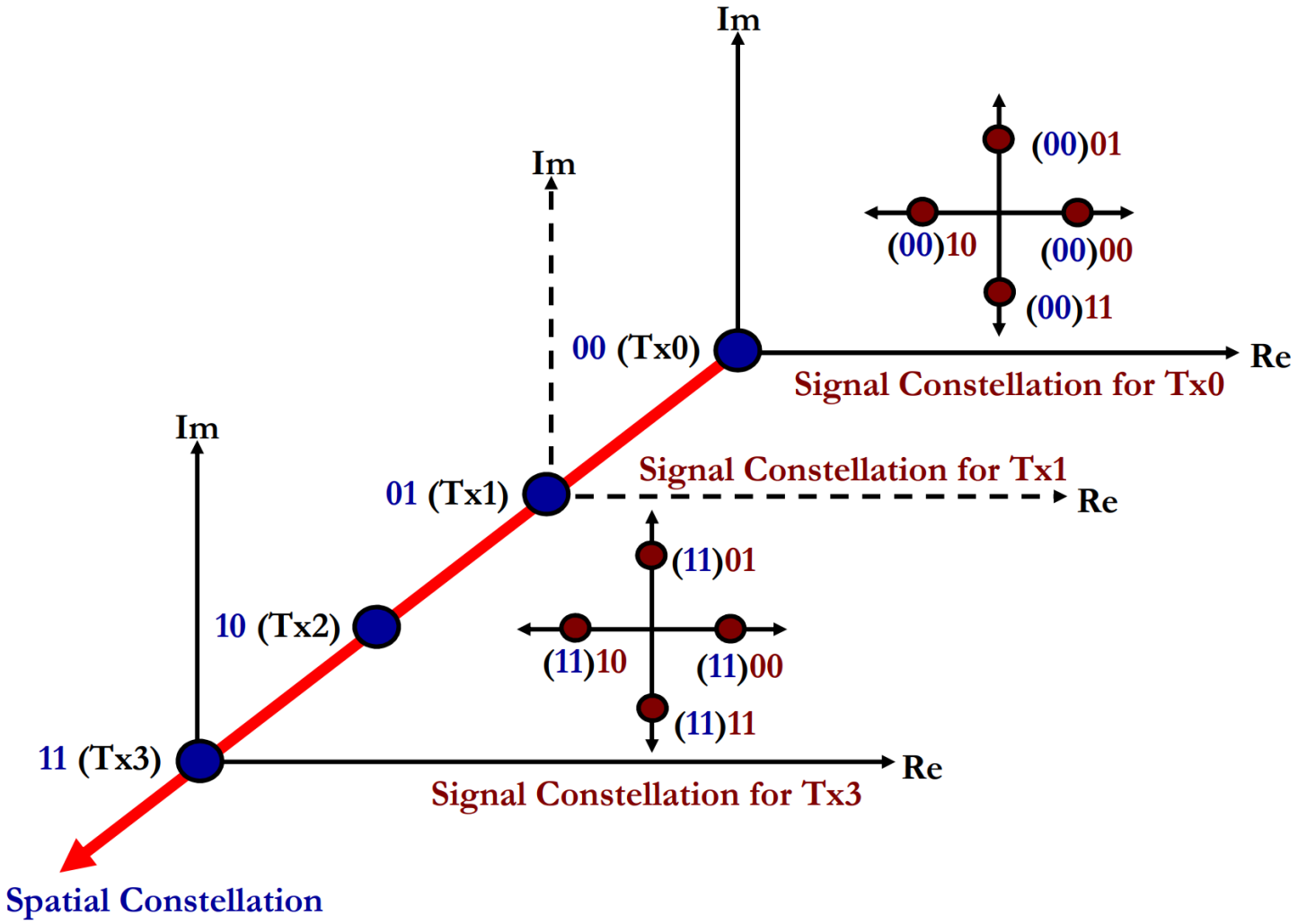
2019 Research Status

Raed Mesleh & Omar Hiari

Space Modulation History

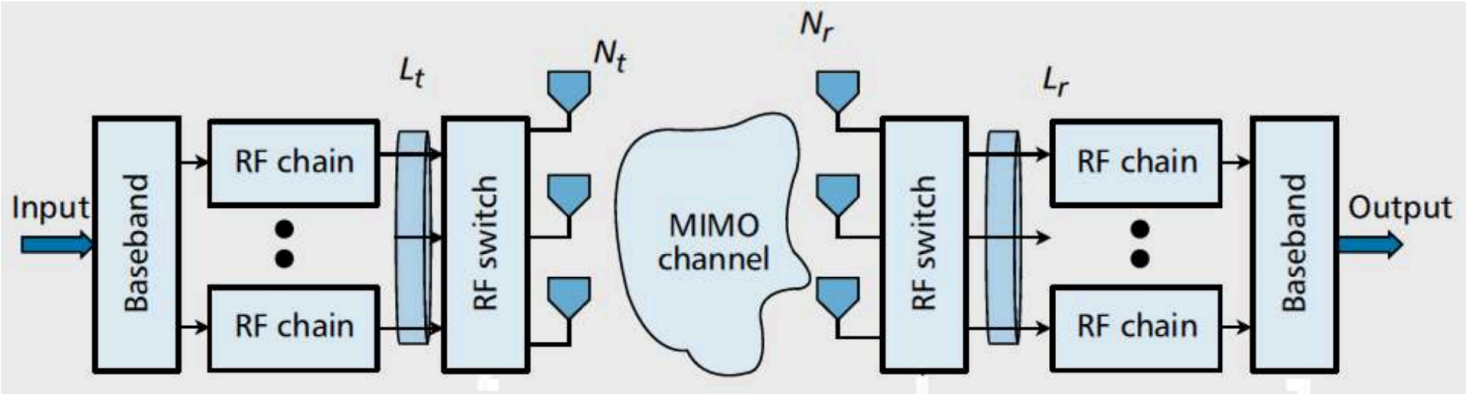
- Theory first popular in 2008
  - **Mesleh, Raed Y., et al. "Spatial modulation."** *IEEE Transactions on vehicular technology* 57.4 (2008): 2228-2241.
- First formal definition of Space Modulation Techniques (SMT) hardware models published in 2017 and patented in 2018
  - **Mesleh, Raed, et al. "Transmitter design and hardware considerations for different space modulation techniques."** *IEEE Transactions on Wireless Communications* 16.11 (2017): 7512-7522.
  - **Raed Mesleh, and Omar Hiari. "Single RF chain transmitter implementing space modulation."** U.S. Patent No. 9,954,586. 24 Apr. 2018.
- Additional definitions followed for transmit and receive techniques as well.

What is Space Modulation?

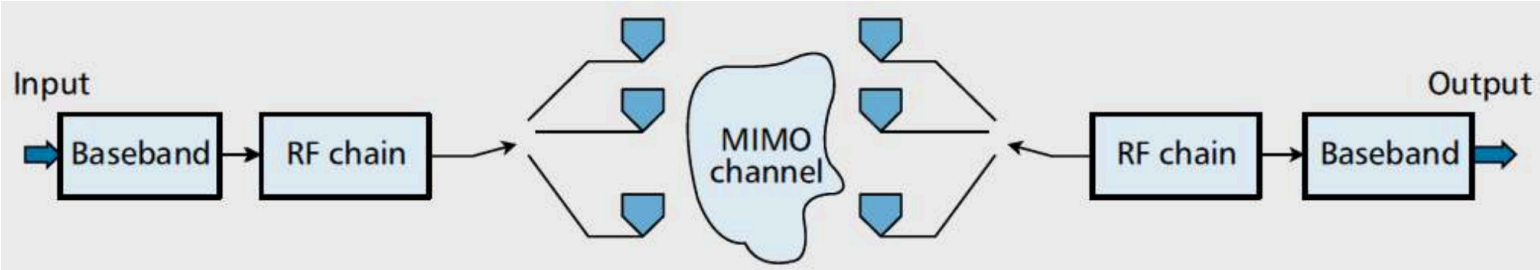


One RF Chain!

Conventional MIMO

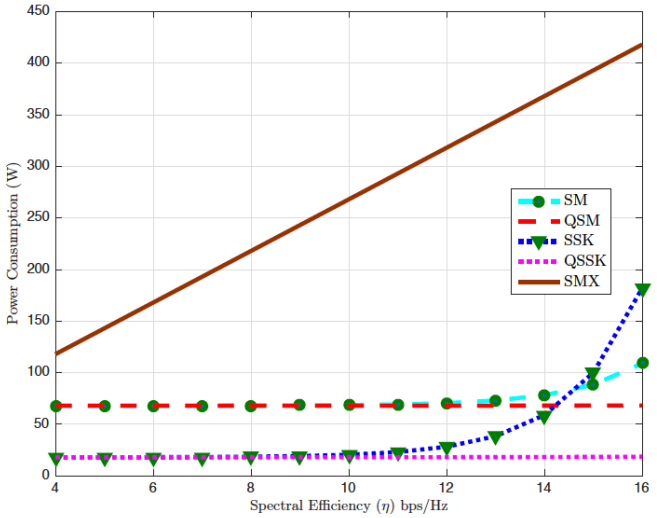


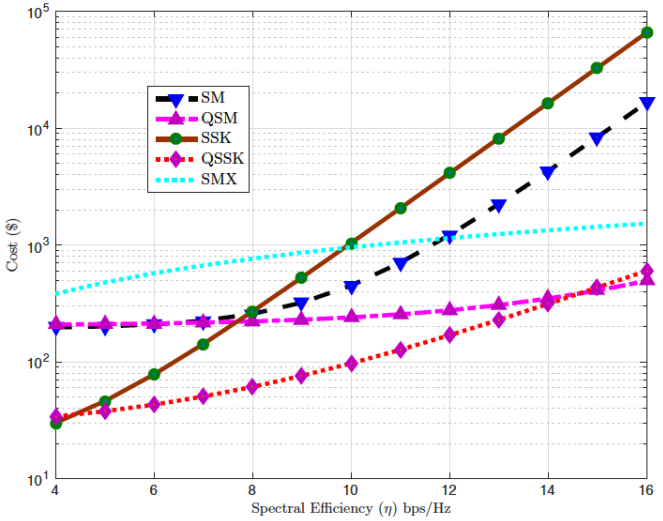
Single-RF MIMO

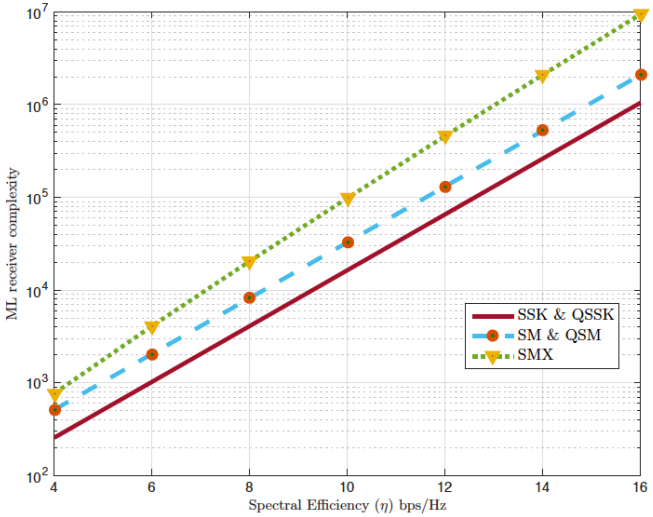


Source: **A. Mohammadi and F. M. Ghannouchi**, "**Single RF Front-End MIMO Transceivers**", IEEE Commun. Mag., Vol. 49, No. 12, pp. 104-109, Dec. 2011.

Low Power, Low Cost, Low Complexity



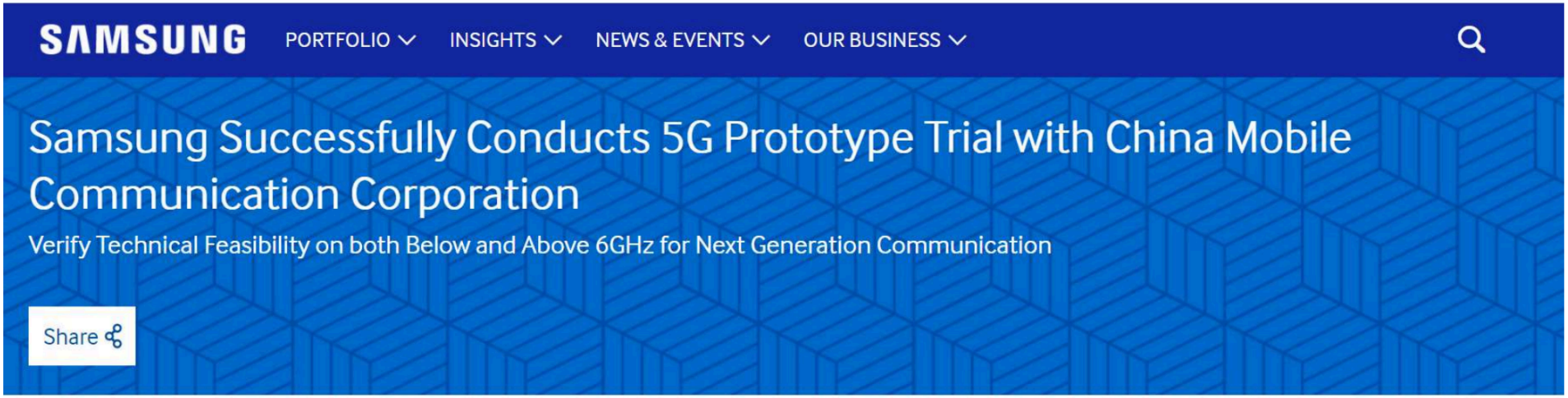




Source: **Mesleh, Raed, Omar Hiari, Abdelhamid Younis, and Sahel Alouneh. "Transmitter design and hardware considerations for different space modulation techniques."** *IEEE Transactions on Wireless Communications* 16, no. 11 (2017): 7512-7522.

Samsung 5G Trials – Nov. 2016

GJU
الجامعة الألمانية الأردنية
German Jordanian University



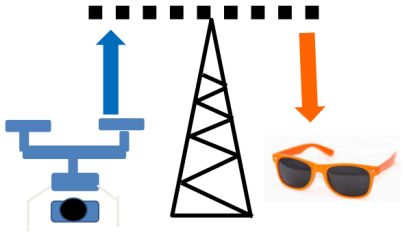
Beijing China – November 09, 2016 - Samsung Electronics announced today it has successfully conducted 5G prototype trial in conjunction with China Mobile Research Institute (CMRI), which was a cooperation milestone between the two companies since Samsung became a member of China Mobile 5G Innovation Center in June 2016.

During the 5G trial test in Beijing, the key technologies like spatial modulation and FBMC (Filter Bank Multicarrier) are validated for the low-frequency (3.5GHz), the performance of throughput, outband emission are tested. With Samsung's ultra-high frequency 5G prototype system and devices powered by advanced beam forming technology, Samsung and China Mobile Research Institute sought to verify mmWave technology's performance and frequency characteristics jointly, including mobility, peak throughput, and multi-user scheduling capacity, as well as mmWave transmission at indoor, penetration loss, etc.

The Spatial Modulation Project – Consortium Lead by Orange

GJU
الجامعة الألمانية الأردنية
German Jordanian University

Objective: To deliver high data rate in connected objects



Base Station: Massive MIMO + ***Advanced*** signal processing

5G links

Object: Miniature antenna(s) + ***Simple*** signal processing

Visual demonstration of Transmit Spatial Modulation

Object transmits with the rate of 2 antennas but has the cost and consumption of 1 antenna

Source: **SpatialModulation Project (2016-2019): https://spatmodulation.cms.orange-labs.fr/**

Intel Patent – Filed Oct 2017

US 20170288933A1

(19) **United States**

(12) **Patent Application Publication**

Mohamed et al.

(10) **Pub. No.: US 2017/0288933 A1**

(43) **Pub. Date: Oct. 5, 2017**

(54) **WIRELESS SIGNAL RECEIVER**

(71) Applicant: **Intel IP Corporation**, Santa Clara, CA (US)

(72) Inventors: **Ahmed Gamal Helmy Mohamed**, Santa Clara, CA (US); **Thomas J. Kenney**, Portland, OR (US); **Shahrnaz Azizi**, Cupertino, CA (US)

(21) Appl. No.: **15/085,299**

(22) Filed: **Mar. 30, 2016**

Publication Classification

(51) **Int. Cl.**

H04L 27/26 (2006.01)

H04B 7/08 (2006.01)

(52) **U.S. Cl.**

CPC ***H04L 27/2697*** (2013.01); ***H04L 27/2653*** (2013.01); ***H04B 7/0891*** (2013.01)

(57) **ABSTRACT**

A satisfactory list detection (LD) receiver based on spatial modulation (SM) orthogonal frequency division multiplexing (OFDM) waveform is provided. In some embodiments, the LD receiver can implement a suboptimal LD detection process that relies on a reduced search space an optimal joint ML detection-based process for the SM-OFDM transmission mode. In some aspects, the overall search space for the optimal joint ML is determined by the total spectral efficiency, which can be divided into two information categories with two different search spaces defined by the number of bits of each category. As such, in some aspects, the LD receiver can permit detecting, with reduced complexity, antenna bits and data bits based on a determination of respective log-likelihood ratios.

Source: **Mohamed, Ahmed Gamal Helmy, Thomas J. Kenney, and Shahrnaz Azizi**. **"Wireless signal receiver."** U.S. Patent Application 15/085,299, filed October 5, 2017.

Publicly Published Hardware Simulation Models

GJU
الجامعة الألمانية الأردنية
German Jordanian University

Simulink Models for the Hardware Implementation of a Family of Space Modulation Techniques

Published: 13 Feb 2019 | **Version 1** | **DOI:** 10.17632/s69yr8kp7f.1

Contributor(s): Omar Hiari, Abdullah Al-Khatib, Raed Mesleh

Description of this data

The data is a collection of Simulink models that form a baseband modeling framework for a family of eight Space Modulation Techniques (SMTs) transmitter hardware models. The techniques include Space Shift Keying (SSK), Spatial Modulation (SM), Quadrature Space Shift Keying (QSSK), Quadrature Spatial Modulation (QSM), Generalized Space Shift Keying (GSSK), Generalized Spatial Modulation (GSM), Generalized Quadrature Space Shift Keying (GQSSK), and

Latest version

Version 1 2019-02-13

Published: 2019-02-13

DOI: 10.17632/s69yr8kp7f.1

Cite this dataset

Hiari, Omar; Al-Khatib, Abdullah; Mesleh, Raed (2019), "Simulink Models for the Hardware Implementation of a Family of Space Modulation Techniques ", Mendeley Data, v1

http://dx.doi.org/10.17632/s69yr8kp7f.1

Statistics

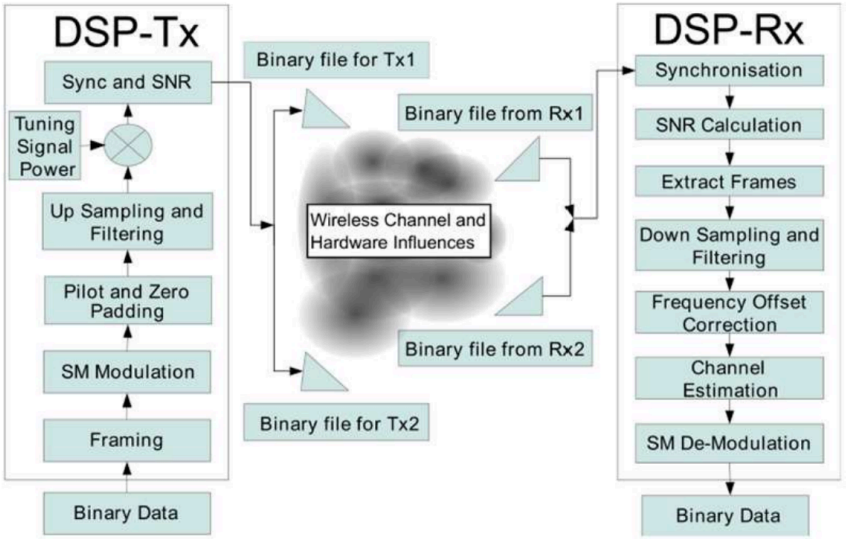
Views: **964** Downloads: **937**

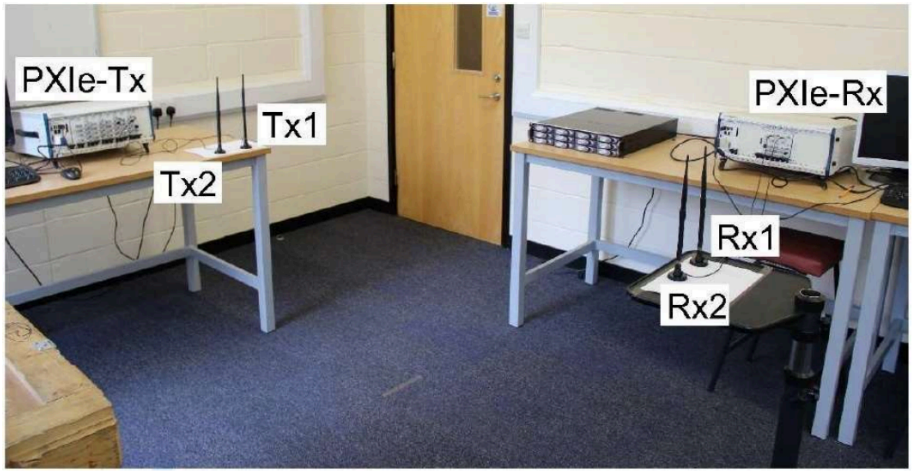
937 Downloads since 2019-02-13

Source: https://data.mendeley.com/datasets/s69yr8kp7f/1

Paper: **Hiari, Omar, Raed Mesleh, and Abdullah Al-Khatib. "A System Simulation Framework for Modeling Space Modulation Techniques."** *IEEE Systems Journal* (2019).

First Hardware Measurements (2013)

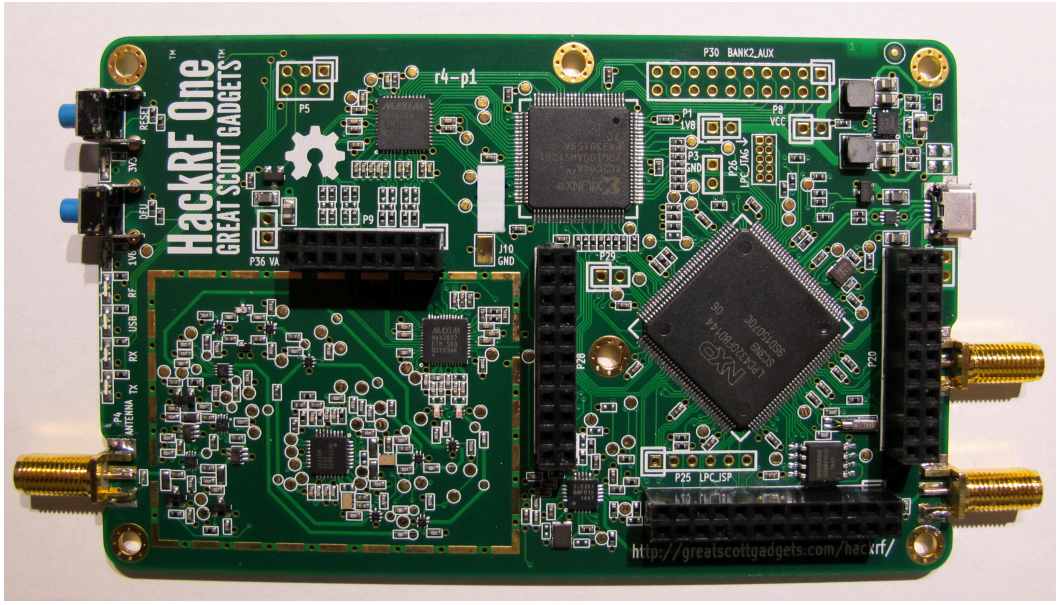




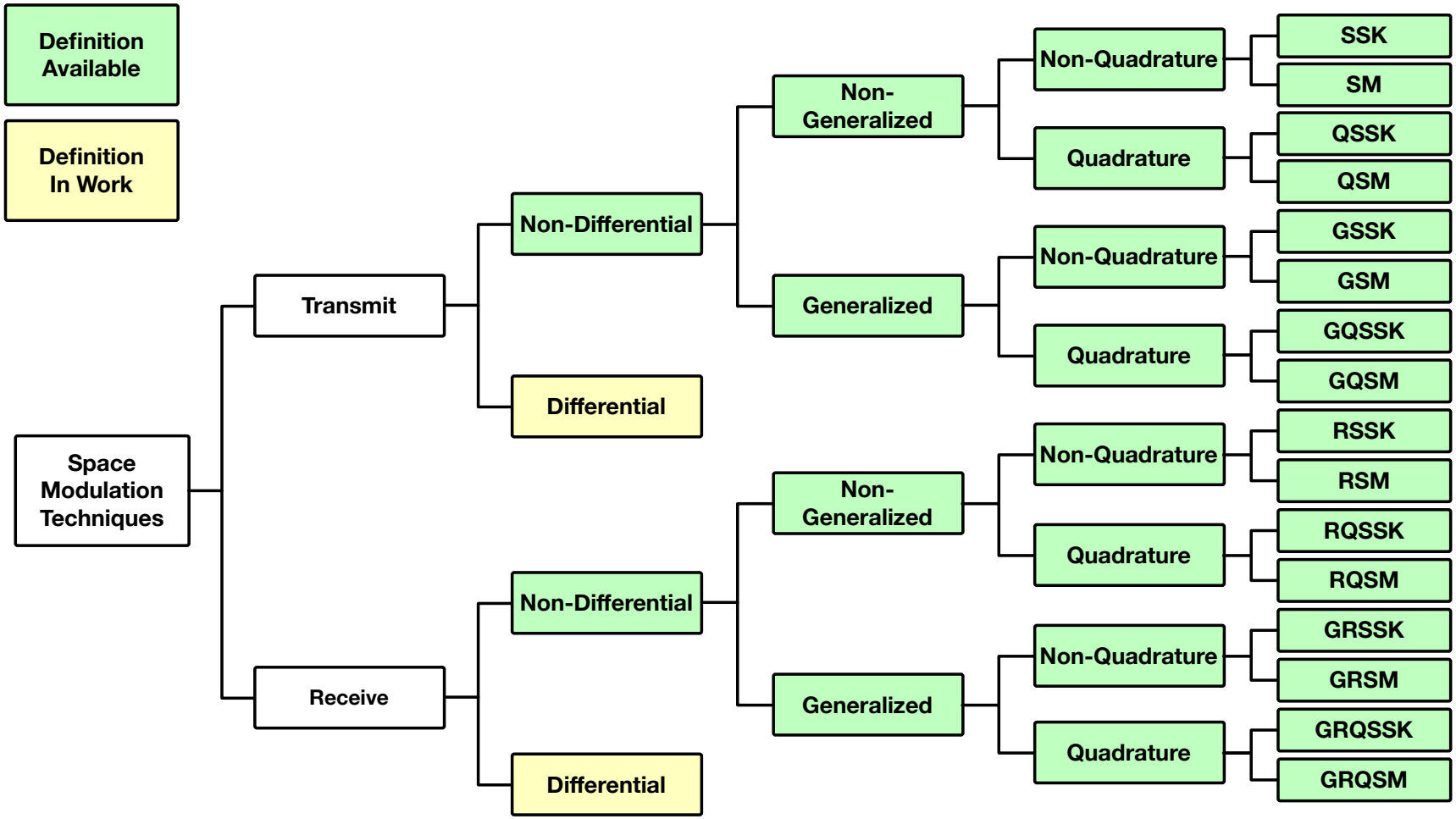
Source: **Serafimovski, Nikola, Abdelhamid Younis, Raed Mesleh, Pat Chambers, Marco Di Renzo, Cheng-Xiang Wang, Peter M. Grant, Mark A. Beach, and Harald Haas. "Practical Implementation of Spatial Modulation."** *IEEE Transactions on Vehicular Technology* 62, no. 9 (2013): 4511-4523.

Our Focus

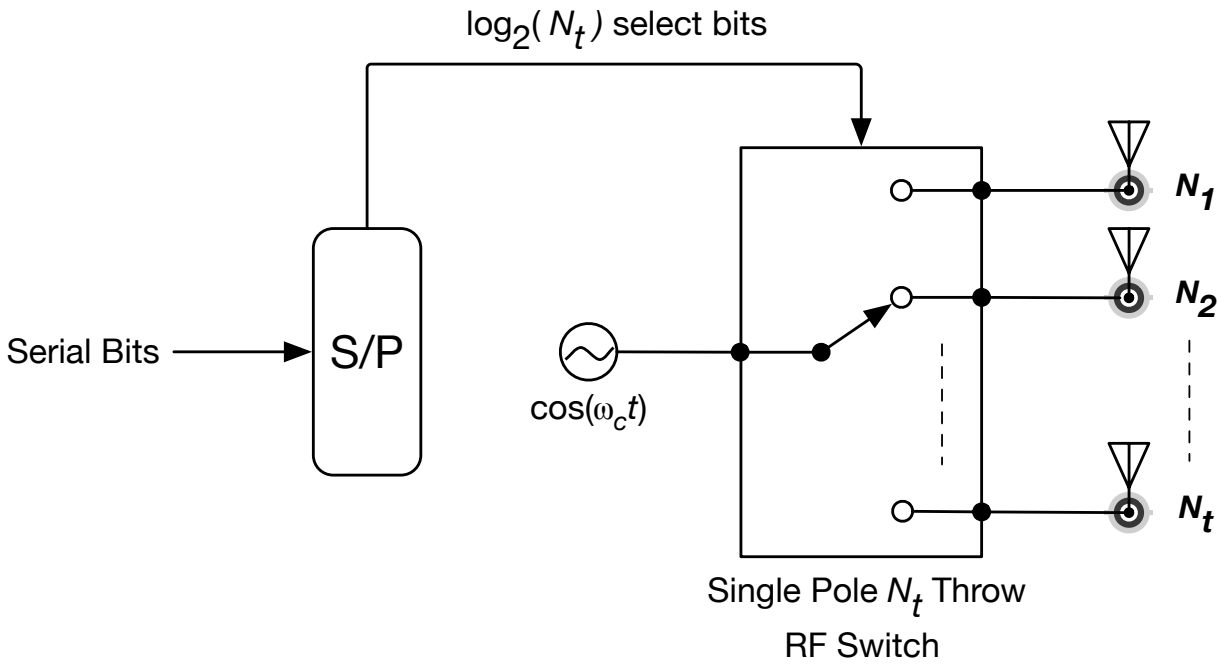
- Defining hardware model implementation possibilities for Space Modulation
  - Dubbed Space Modulation Techniques (SMTs)
- Realizing the actual models as prototypes



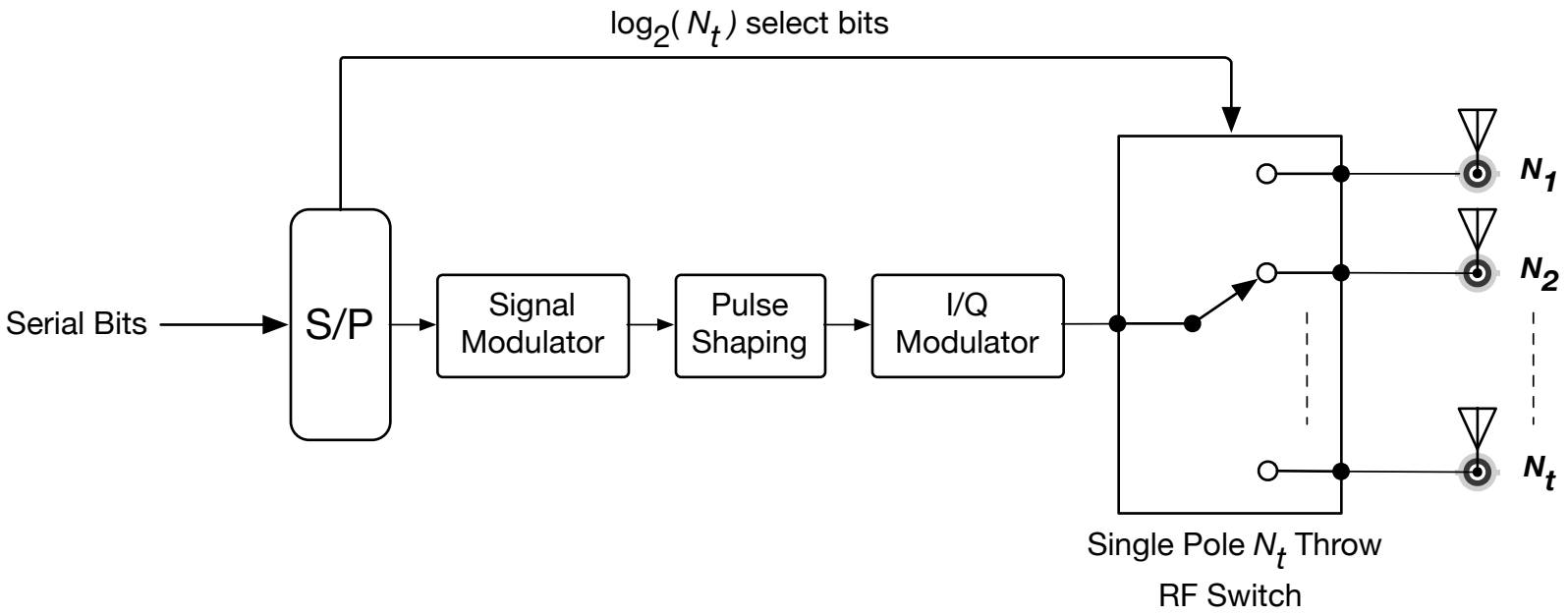
Taxonomy of SMTs



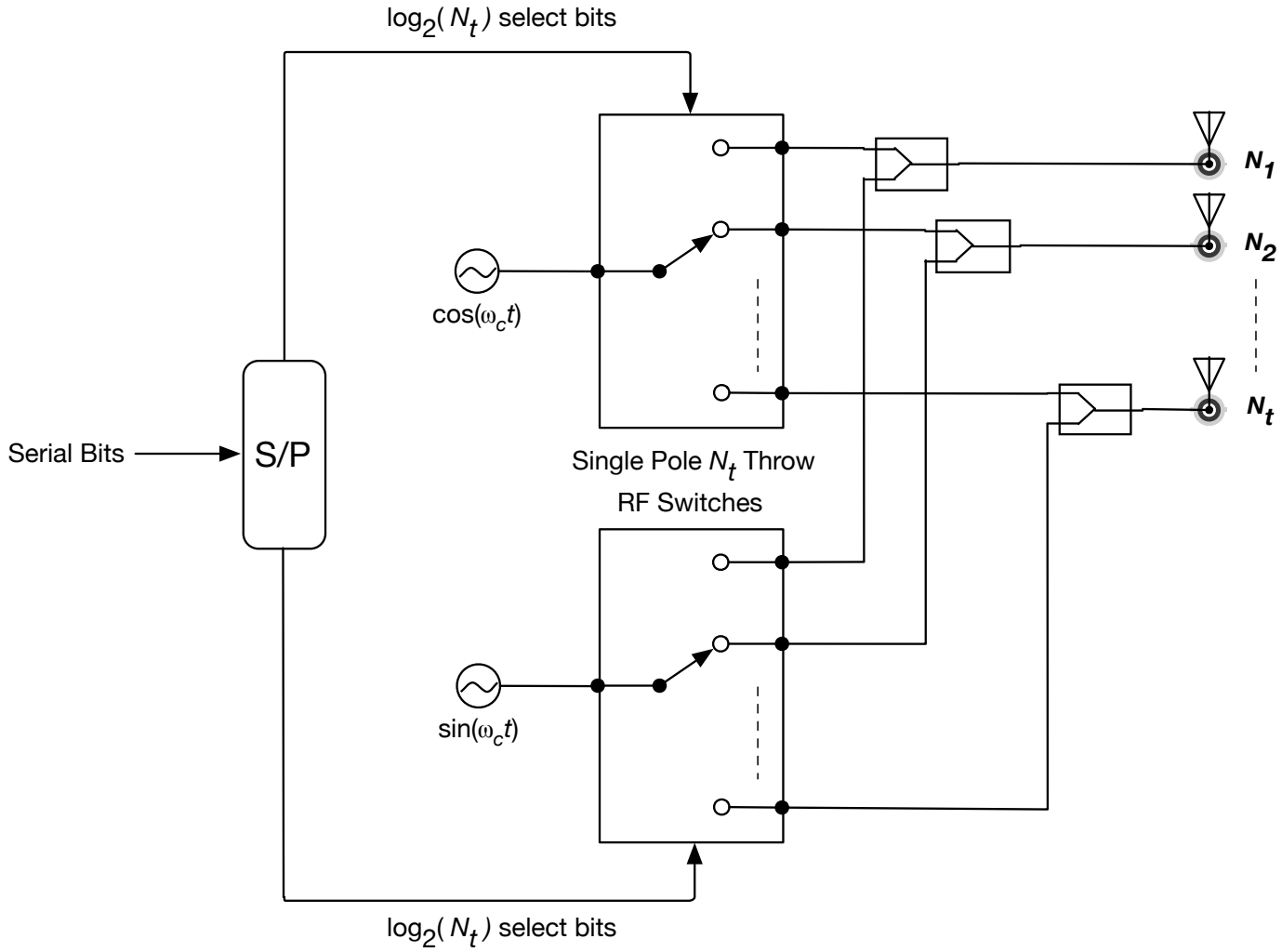
Example of Basic Model (SSK)



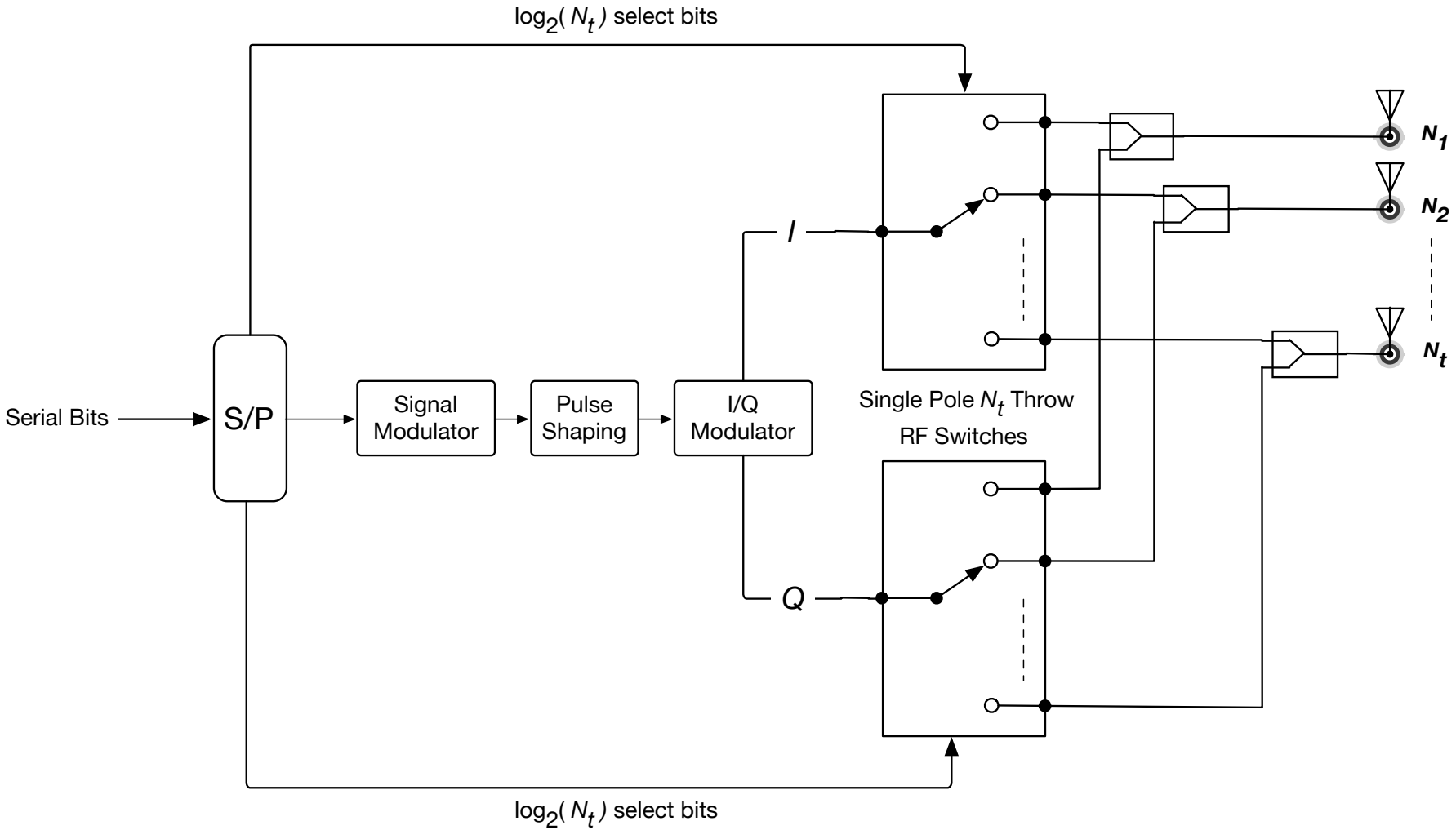
Example of Basic Model (SM)



Example of Basic Model (QSSK)

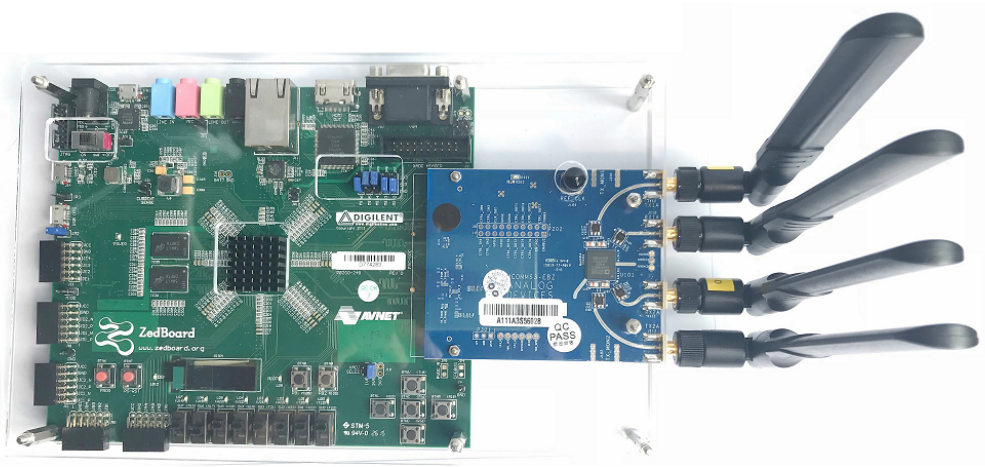


Example of Basic Model (QSM)



First SMT SDR-Based Prototype

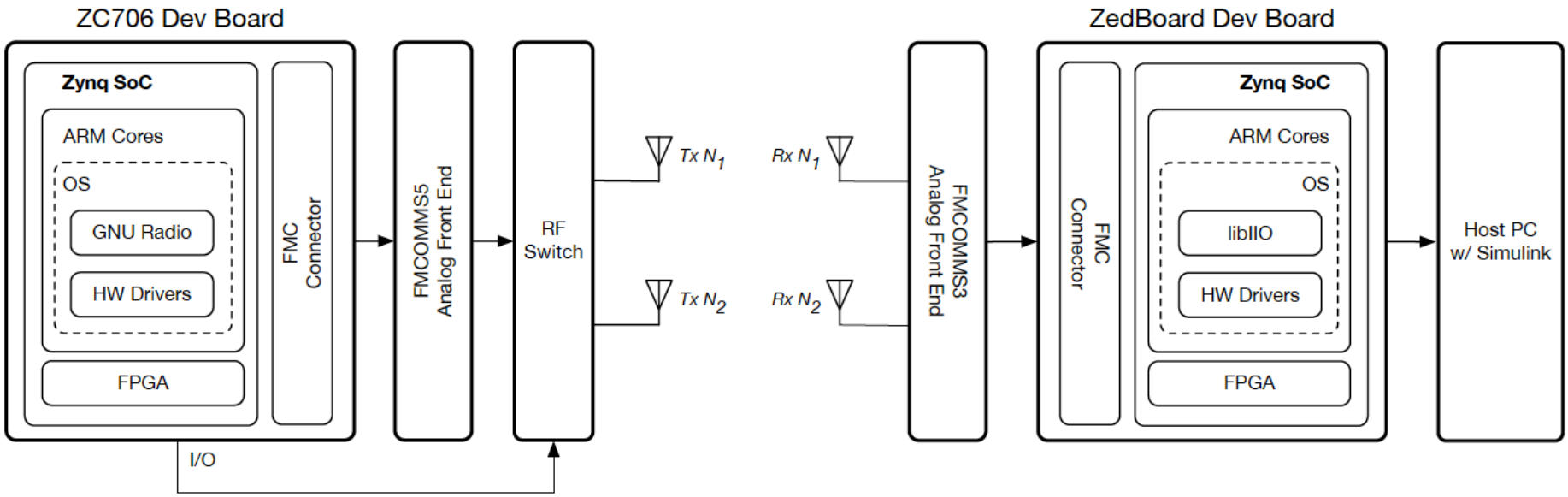
- Based on Xilinx Zynq development boards' (FPGA-based SoC) and AD9361 Analog Devices front end
- Developed prototype implements SSK 2x2 and 4x2 configurations



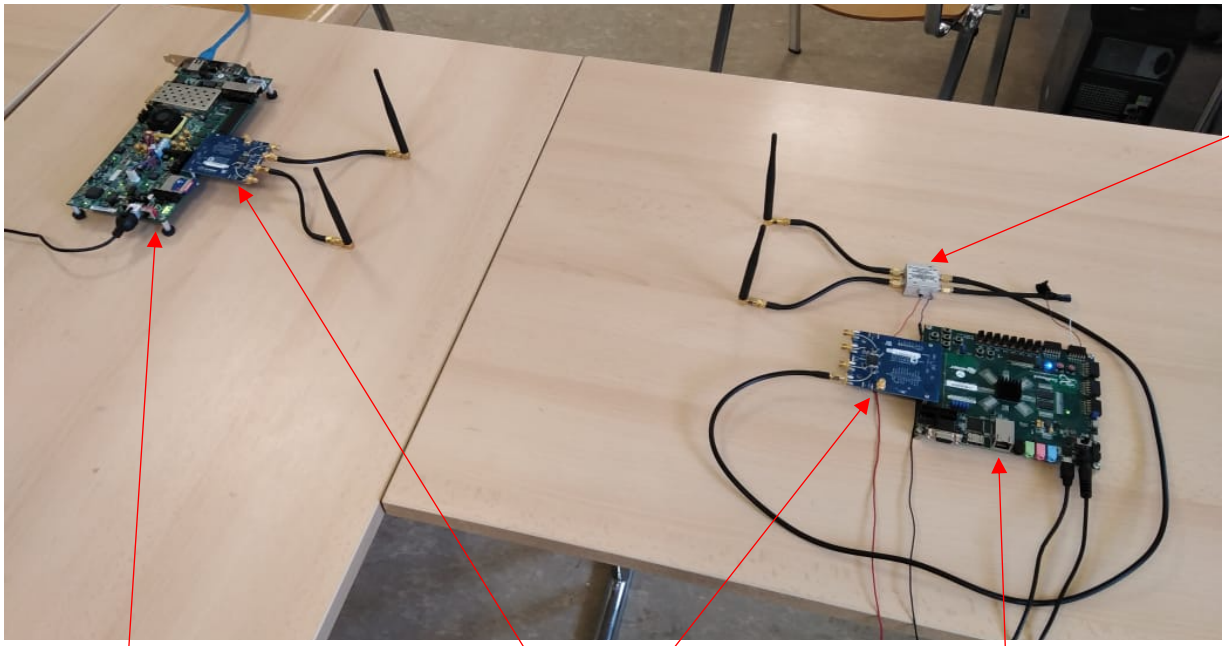
XILINX®

ANALOG DEVICES

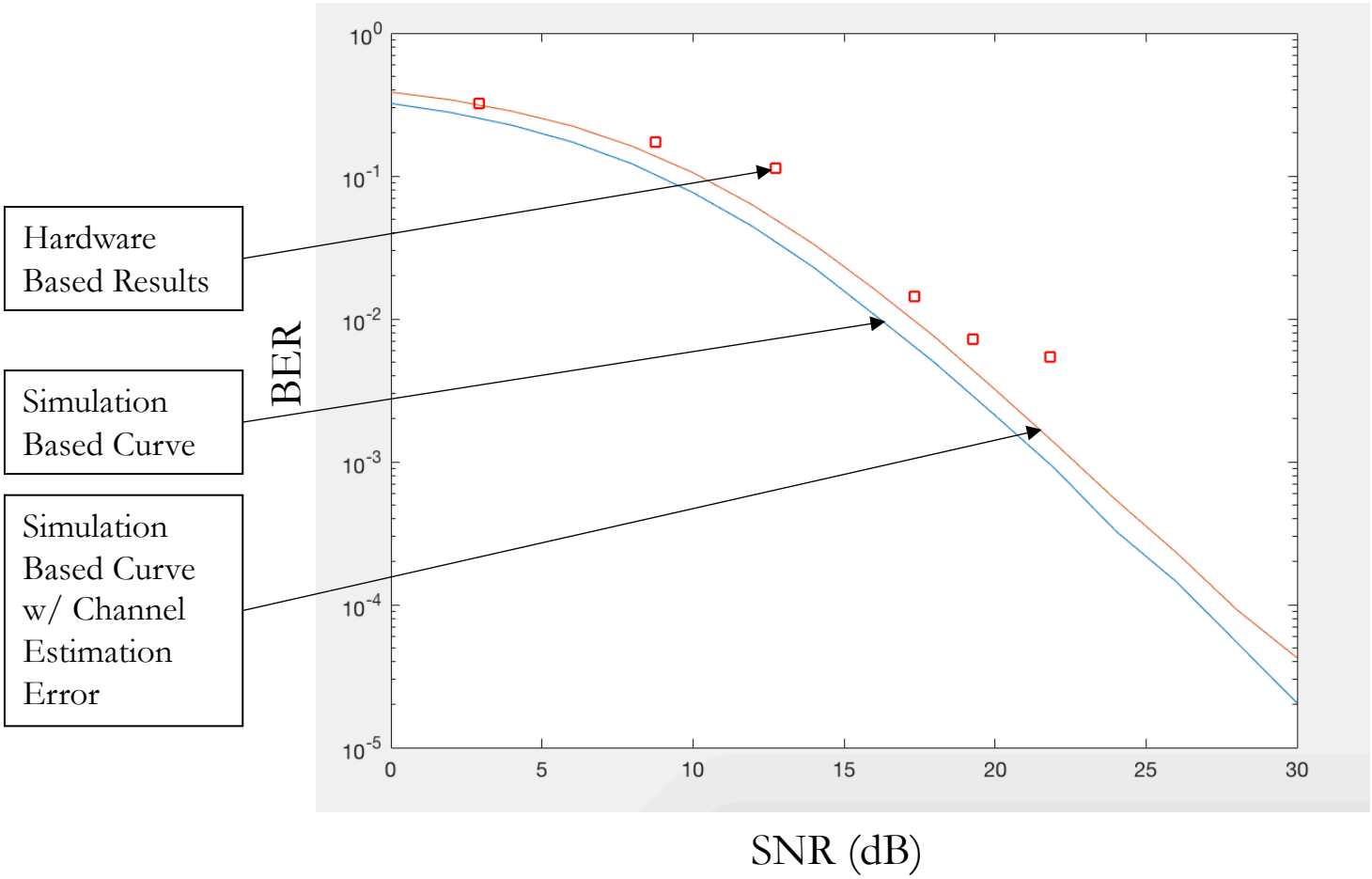
Hardware System Architecture



Picture of Lab Setup



Obtained Performance Results for SSK

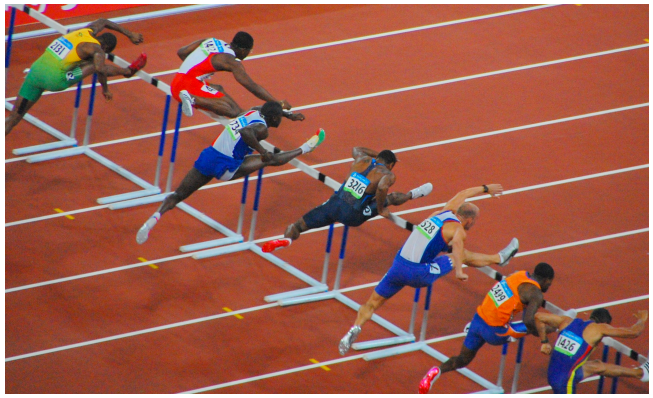


Accomplishments Thus Far

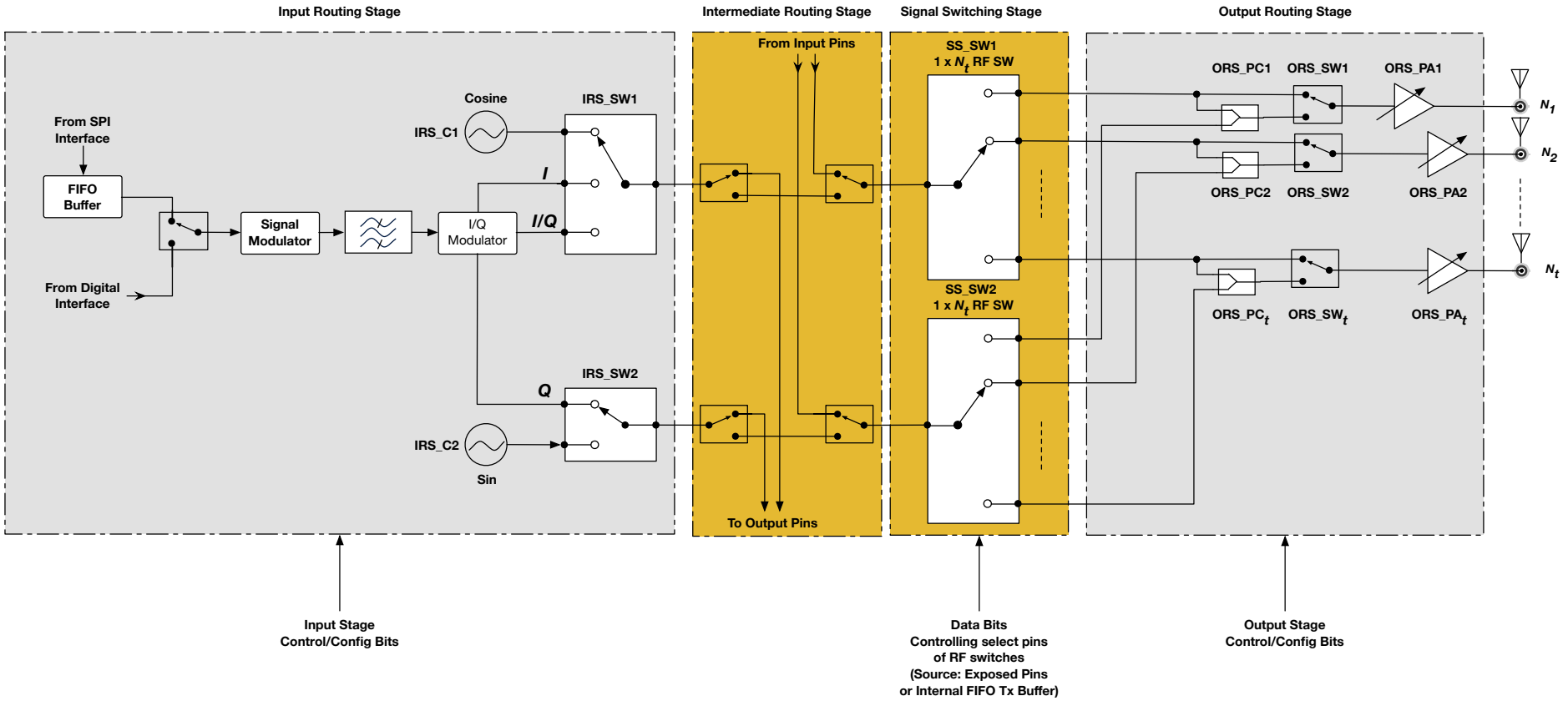
- Hardware definitions
  - All SMTs except differential
  - SMT hardware models patented under US Patent No. 9,954,586
  - 13 Papers published and others under review or being prepared
  - Published SMTs Simulink models in Feb 2019 - available publicly
    - https://data.mendeley.com/datasets/s69yr8kp7f/1
- Hardware Prototypes (SDR-based)
  - 2x2 and 4x2 SSK transmitter and receiver

Ongoing Activities

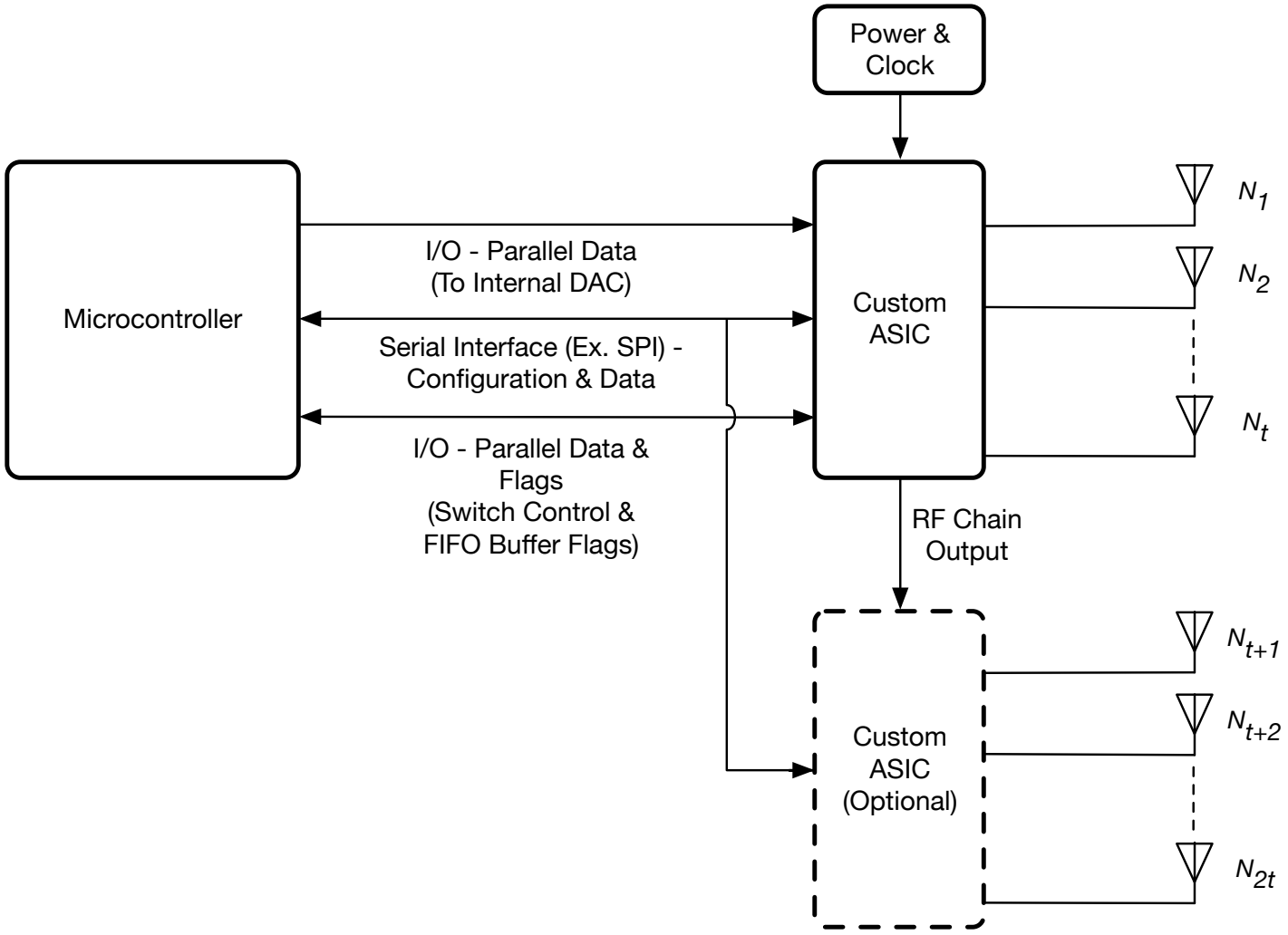
- Definition of differential techniques
- Real-time receiver implementation
- Hardware prototypes for additional SMTs
- Reliability assessment of SMT hardware
- VLSI Implementations for non-differential transmit SMTs
  - Initial low level simulations indicate that up to 0.5 Gbps data rate can be achieved on a 2x2 SSK configuration → 1 Gbps for 2x2 QSSK configuration



One Chip, Many Possibilities



Easy System Expansion w/ Single Chain



Areas for Support

- Patenting the definition of the remainder of hardware techniques
- Funding of VLSI implementations for commercial purposes
- Expanding testing to larger scale Ex. Base stations or Massive MIMO

Some Selected Publications

GJU
الجامعة الألمانية الأردنية
German Jordanian University

- **Hiari, O., Mesleh, R., & Al-Khatib, A.** (2019). "**A System Simulation Framework for Modeling Space Modulation Techniques**". *IEEE Systems Journal*.
- **Hiari, O., & Mesleh, R.** (2018). "**Hardware designs and analysis for variant receive space modulation techniques**". *Transactions on Emerging Telecommunications Technologies*, *29*(12), e3545.
- **Raed Mesleh, and Omar Hiari** . "**Single RF chain transmitter implementing space modulation**." U.S. Patent 9,954,586, issued April 24, 2018.
- **Mesleh, R., Hiari, O., & Younis, A.** (2018). "**Generalized space modulation techniques: Hardware design and considerations**". *Physical Communication*, *26*, 87-95.
- **Mesleh, R., Hiari, O., Younis, A., & Alouneh, S.** (2017). "**Transmitter design and hardware considerations for different space modulation techniques**". *IEEE Transactions on Wireless Communications*, *16*(11), 7512-7522.

Thank You for Your Attention

Lab Website

http://ewiot.gju.edu.jo/

Omar Hiari

omar.hiari@gju.edu.jo

Raed Mesleh

raed.mesleh@gju.edu.jo

This work is part of a project funded by the GJU Deanship of Scientific Research and Higher Education

Project # SIC 41/2016