Wireless Monitoring of S-Parameters Measurement using a Nano-VNA for Biomedical Applications

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ELECTRICAL ENGINEERING
COLORADO SCHOOL OF MINES

ARC
Antenna, RFID, and Computational EM Group

Metabolite Sensing - Contentious Monitoring

Background:

- Researchers developed microneedle patches for continuous, real-time lactate monitoring using skin application without the need for specialized equipment.
- Discomfort from venous or arterial puncture when taken blood sampling
- Other approaches include electrochemical and optical biosensors

Challenges:

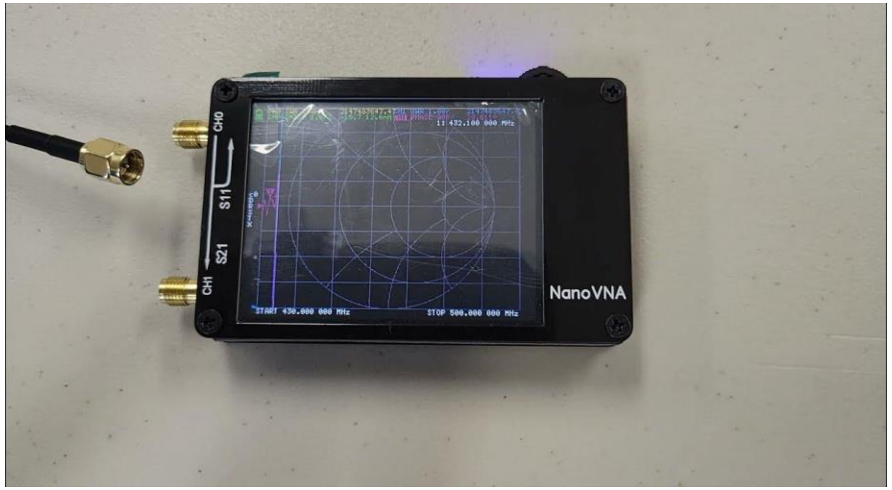
- Venesection problematic for neonates and children
- Arterial catheter use confined to critical care
- Capillary lactate measurements often inconsistent with whole blood levels
- Noninvasive glucose and lactate sensing using on-body resonator circuits that detect concentration changes are not available

D. K. Ming *et al.*, "Real-time continuous measurement of lactate through a minimally invasive microneedle patch: a phase I clinical study," *BMJ Innovations*, vol. 8, no. 2, Apr. 2022, doi: 10.1136/bmjinnov-2021-000864.

Research Objective

- Developed an approach that uses “nano” VNAs, non-invasive sensors, and wireless communication circuits to create practical on-body measurement systems.

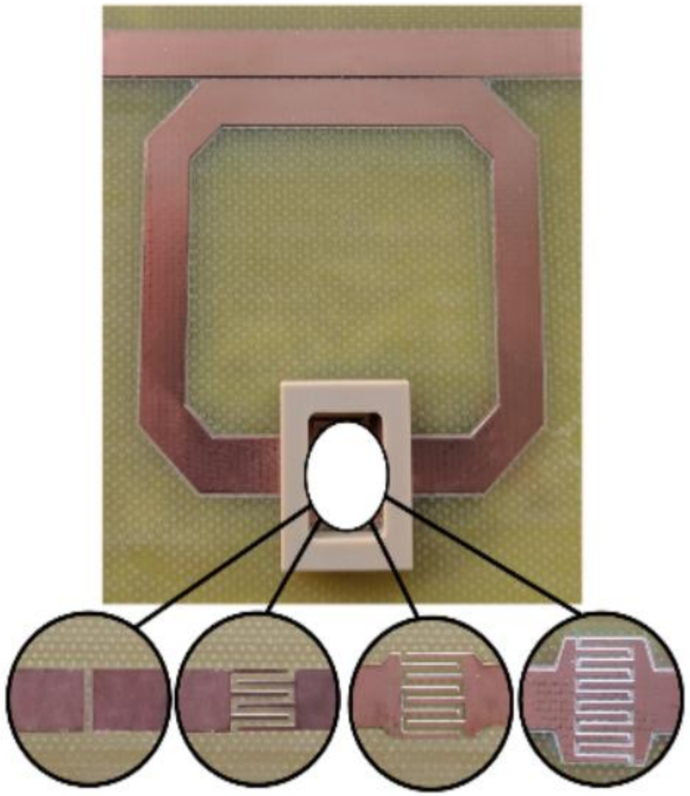
- These systems are capable of transmitting S-parameter for remote analysis, allowing users to move freely while measurements are being taken.



Current Work

- Most current work uses laboratory VNAs attached to a person, which limits the mobility of measurement systems.

- Sensors are designed using patch antennas or coupled split-ring resonators and look for shift in measured S_{11} or S_{21} parameters.



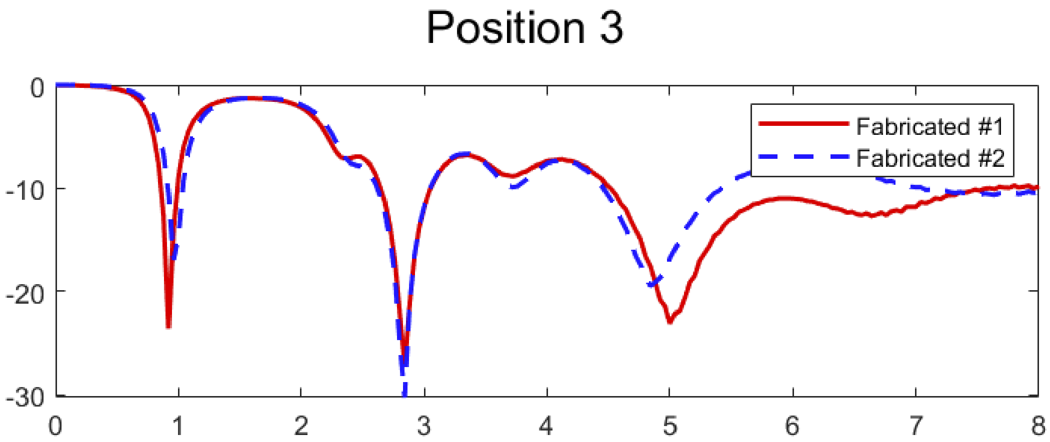
A. Mason, O. Korostynska, M. Ortoneda-Pedrola, A. Shaw, and A. Al-Shamma'a, "A resonant co-planar sensor at microwave frequencies for biomedical applications," Sensors and Actuators A: Physical, vol. 202, pp. 170–175, Nov. 2013, doi: 10.1016/j.sna.2013.04.015.

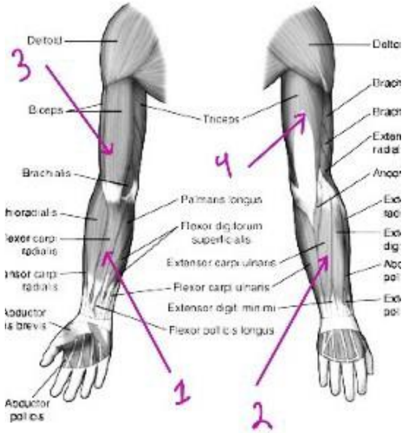
T. Reinecke, J.-G. Walter, T. Kobelt, A. Ahrens, T. Scheper, and S. Zimmermann, "Design and evaluation of split-ring resonators for aptamer-based biosensors," *Journal of Sensors and Sensor Systems*, vol. 7, no. 1, pp. 101–111, Feb. 2018, doi: 10.5194/jsss-7-101-2018.

A. Mason *et al.*, "Noninvasive In-Situ Measurement of Blood Lactate Using Microwave Sensors," *IEEE Transactions on Biomedical Engineering*, vol. 65, no. 3, pp. 698–705, Mar. 2018, doi: 10.1109/TBME.2017.2715071.

Biomedical Sensor/Antenna Designs

A biomedical patch antennas/sensors for remote metabolite measurement developed by the ARC Group At Mines and is used as a test device for sending S-parameters versus glucose variations.





Portability Advancement

- Wireless capability can extend the NanoVNA's use in the field or in testing environments where physical cables are impractical or hazardous.
- Wireless connectivity facilitates real-time data transfer to laptops or smartphones without the limitations of cables.
- Can unscrew the NanoVNA screen and make the device more compact.
- Athletes and patients can move freely during measurements, reflecting true physiological states and behaviors.

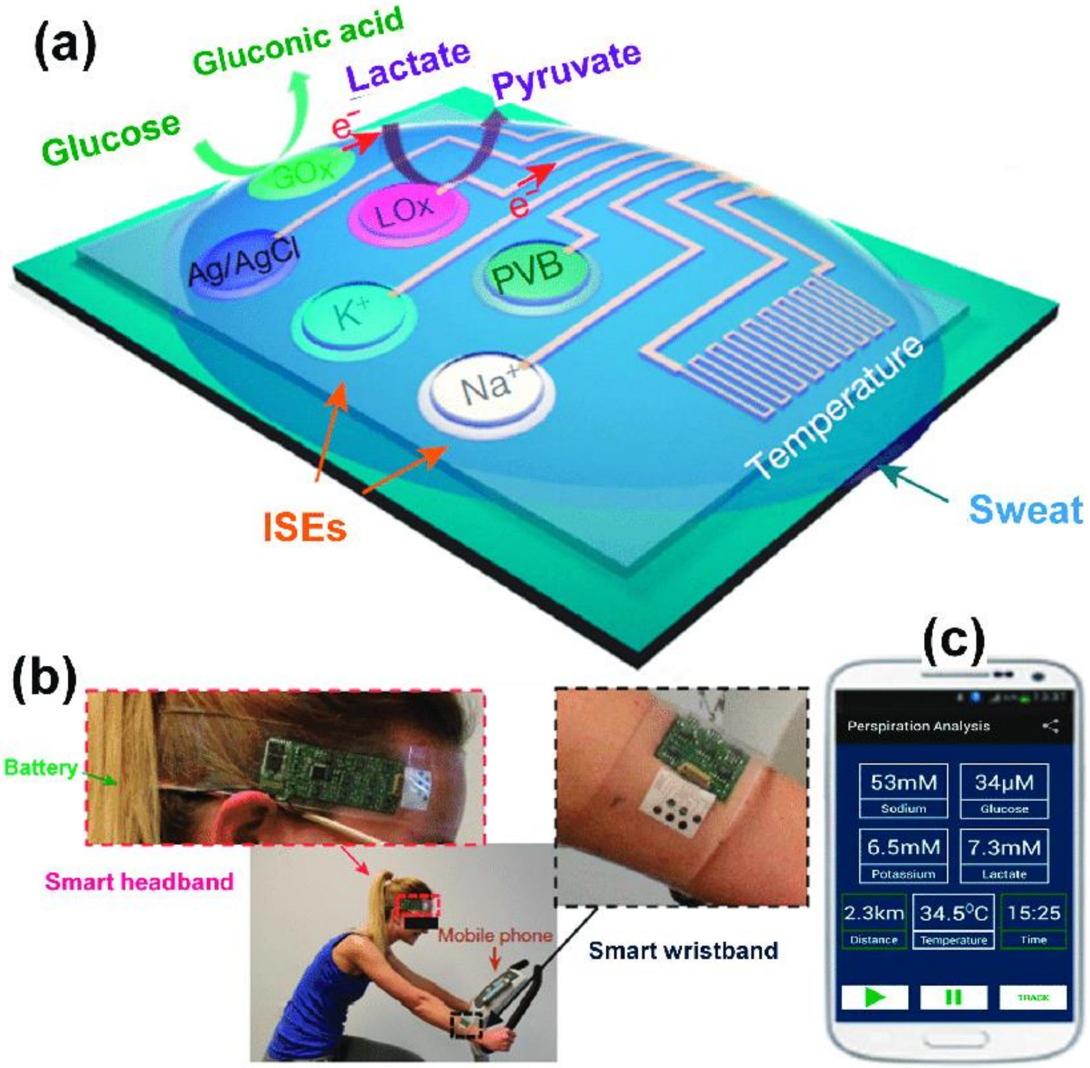
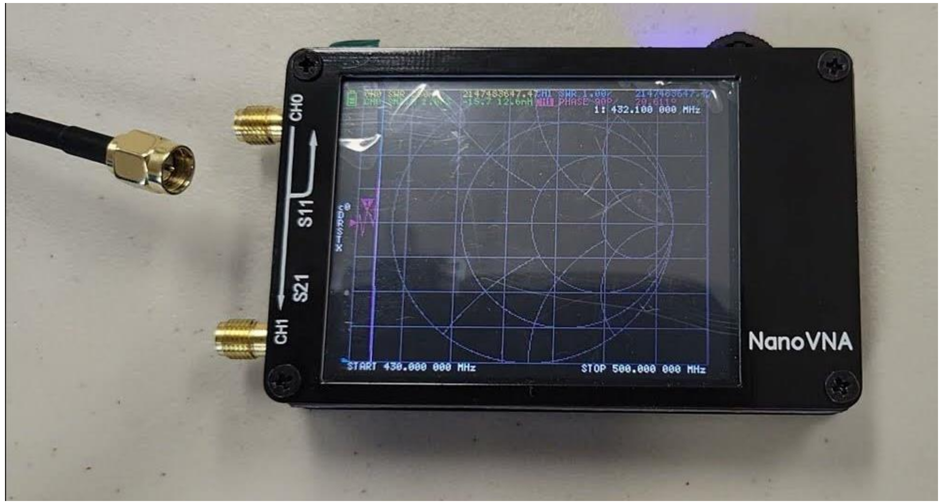


Image from Y. Holade, S. Tingry, K. Servat, T. Napporn, D. Cornu, and K. Kokoh, "Nanostructured Inorganic Materials at Work in Electrochemical Sensing and Biofuel Cells," *Catalysts*, vol. 7, p. 31, Jan. 2017, doi: 10.3390/catal7010031.

NanoVNA-H Characterisitcs

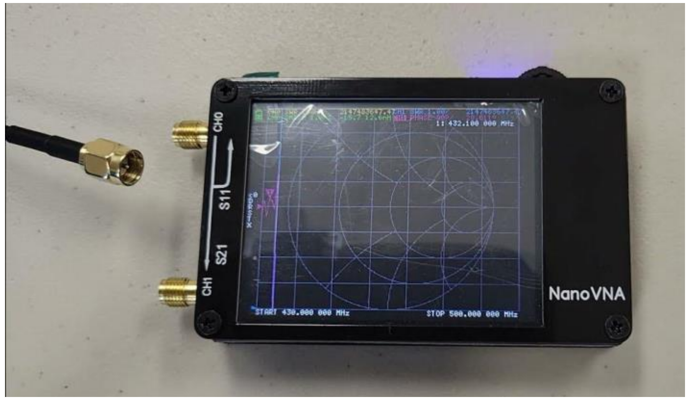
- Originally designed by edy555.
- Includes two ports and is equipped with a simple user interface, consisting of a touchscreen display.
- Display can be detached to render the device more compact and enhancing its portability.
- It is a low cost yet high performance (at its price point) vector network analyzer.



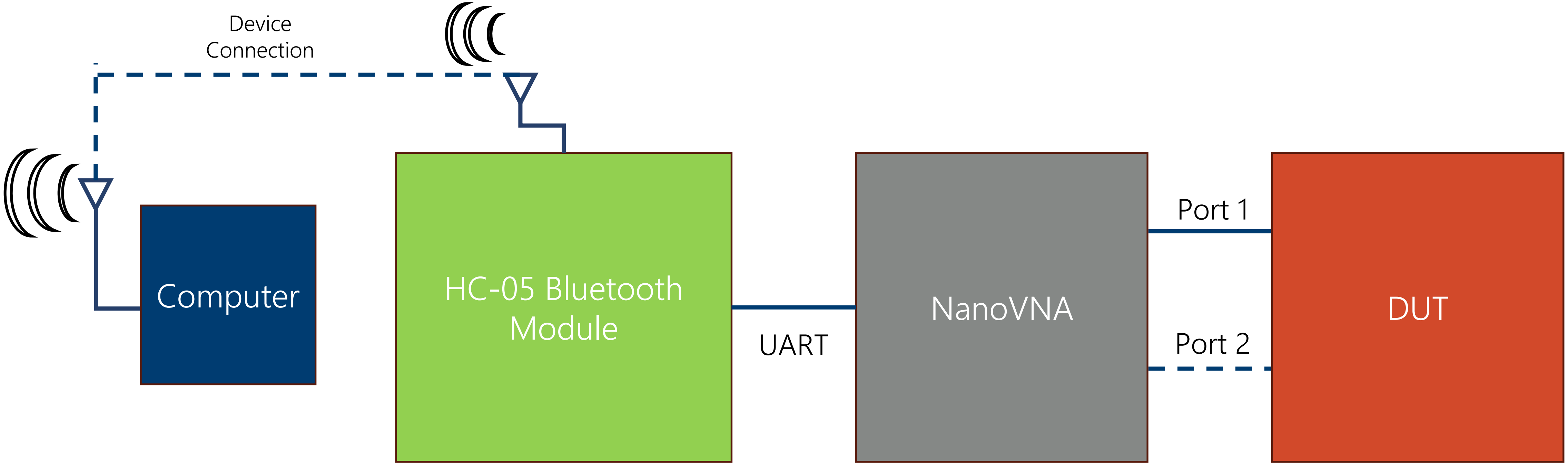
NanoVNA_Console_Commands_Dec-9-19-1.pdf. (n.d.). Retrieved October 19, 2023, from https://4ham.ru/wp-content/uploads/2020/05/NanoVNA_Console_Commands_Dec-9-19-1.pdf
"About NanoVNA | NanoVNA." Accessed: Nov. 01, 2023. [Online]. Available: https://nanovna.com/?page_id=21

NanoVNA-H Specifications and Operating Parameters

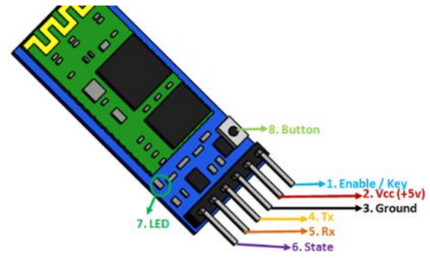
	Value
Frequency Range	50 kHz-900 MHz
Frequency Resolution	100 Hz
Noise Floor	-40 dB
Max Sweep Points	1024
Interface	Micro-USB, hardware UART



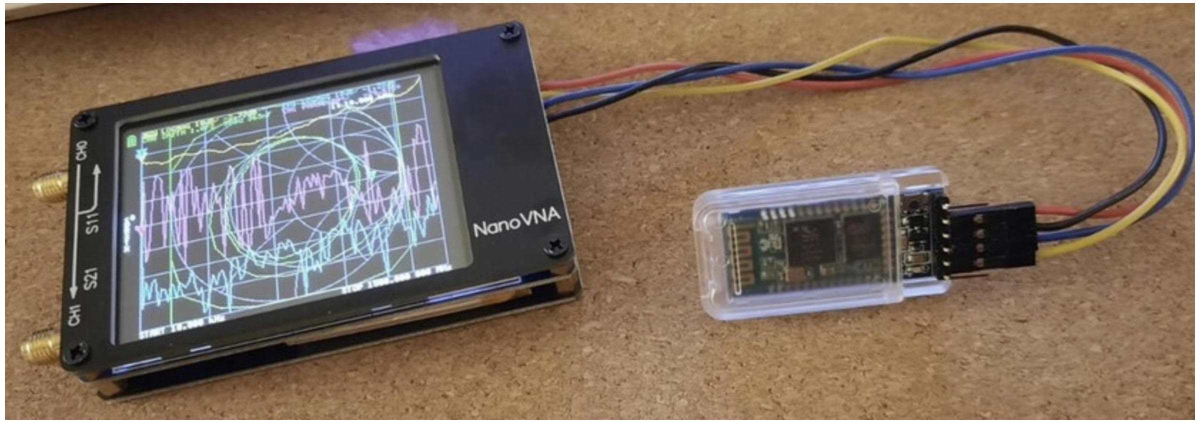
Developed Hardware Configuration

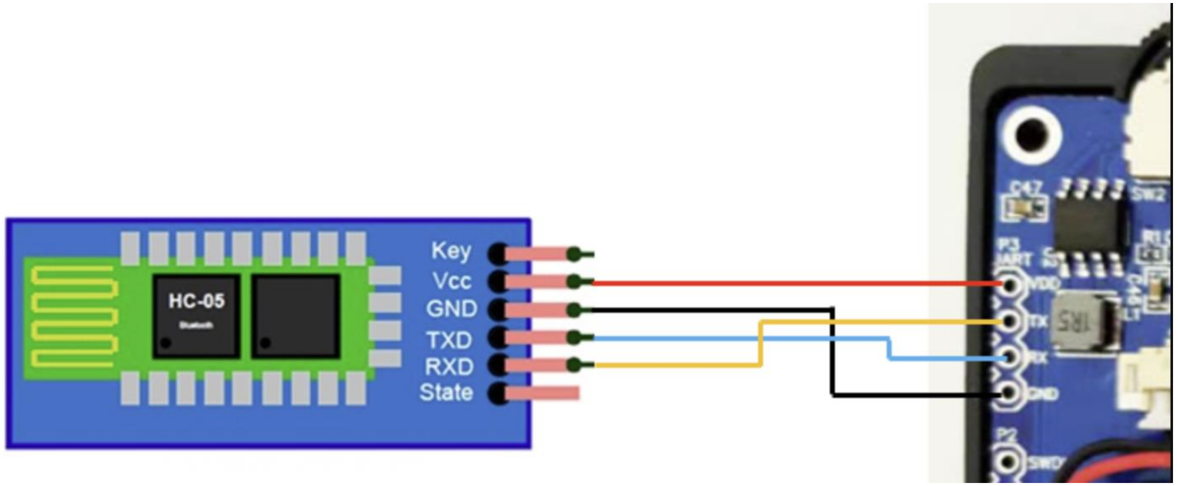


Developed Hardware Set-up



HC-05 Bluetooth Module Pinout



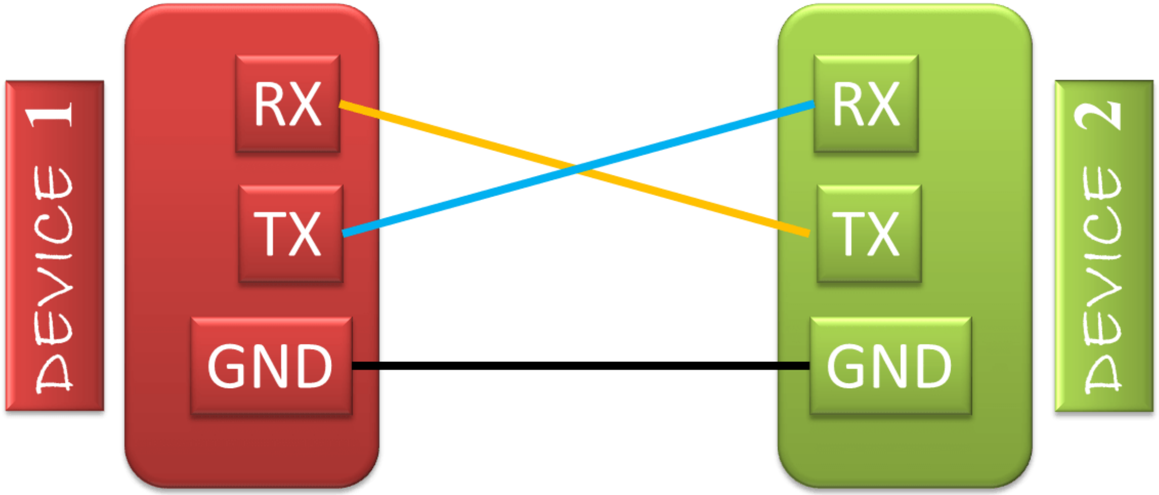


- Jumper Wires are used to connect the VCC, Tx and Rx registers, and GND.
- The registers, Rx (Receive) and Tx (Transmit), act as two-way communication between devices

[1]

Images from "nanovna-users@groups.io | Wireless remote control of nanoVNA-H." Accessed: Mar. 24, 2024. [Online]. Available: https://groups.io/g/nanovna-users/topic/wireless_remote_control_of/76758411

- UART is a serial communication protocol used in embedded systems.
- If USB is active at power-on/reset, the shell starts on the USB virtual serial port.
- If USB is not active, the shell starts on UART1, allowing for serial communication over Bluetooth with HC-05.



UART: A Hardware Communication Protocol Understanding Universal Asynchronous Receiver/Transmitter | Analog Devices. (n.d.). Www.analog.com. https://www.analog.com/en/analog-dialogue/articles/uart-a-hardware-communication-protocol.html
Images from "Serial Communication Methods – Synchronous & Asynchronous," PIJA Education. Accessed: Mar. 11, 2024. [Online]. Available: https://pijaeducation.com/communication/serial-communication-methods-synchronous-asynchronous/

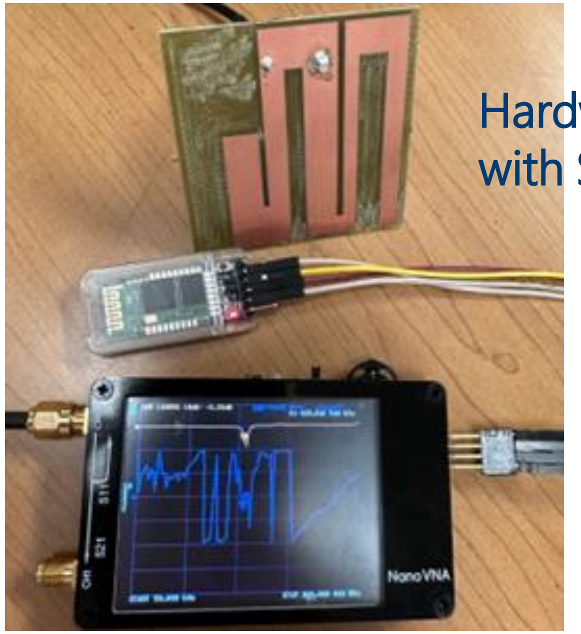
Software Configuration (Remote Sensing)

- Firmware was downloaded to the NanoVNA-H for Bluetooth capabilities.
- A Python library was created to interface with the NanoVNA-H and save measurements for remote communication.
- Uses code adapted from NanoVNA-H GitHub repository.

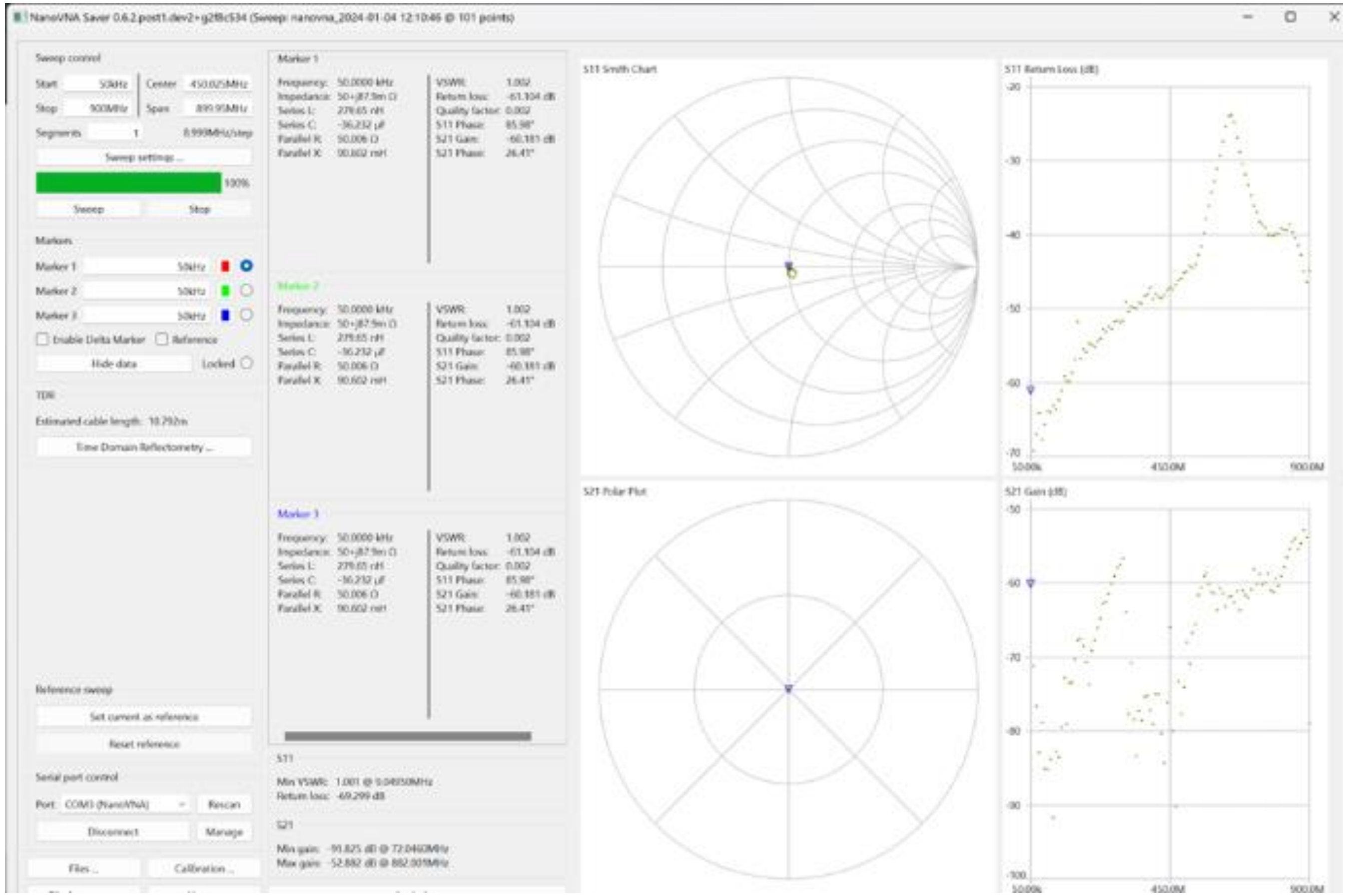
- Installation of the necessary cross tools and firmware update tool:
  - $ brew tap px4/px4
  - $ brew install gcc-arm-none-eabi-80
  - $ brew install dfu-util
- Fetch code and build firmware:
  - $ git clone https://github.com/ttrftech/NanoVNA.git
  - $ cd NanoVNA
  - $ git submodule update --init –recursive

"Firmware with UART support for NanoVNA-H." [Online]. Available: https://github.com/DaveLapp/NanoVNA-H/releases/tag/shell-on-UART-HugenJan2020
L. Elmiladi, "NanoVNA Python Interface." [Online]. Available: https://github.com/lelmiladi/NanoVNA-Python-Interface/tree/main

Software Configuration (VNA Viewer)



Hardware Configuration
with Sensor Antenna



- Utilizes NanoVNA Saver application.
- The displayed image shows the Bluetooth module connected via a COM port, featuring a 50-Ohm calibration load.

Measurement Saving and Data Transfer

1. Connect all hardware according to hardware setup guidelines.
2. Set up Bluetooth connection, and confirm COM port.
3. Modify python code to set sweep parameters.
4. Run Python code, using the Bluetooth COM port, and it will generate the appropriate touchstone files from the measurements.
5. Use scp, sftp, or similar programs to retrieve touchstone files for later analysis.

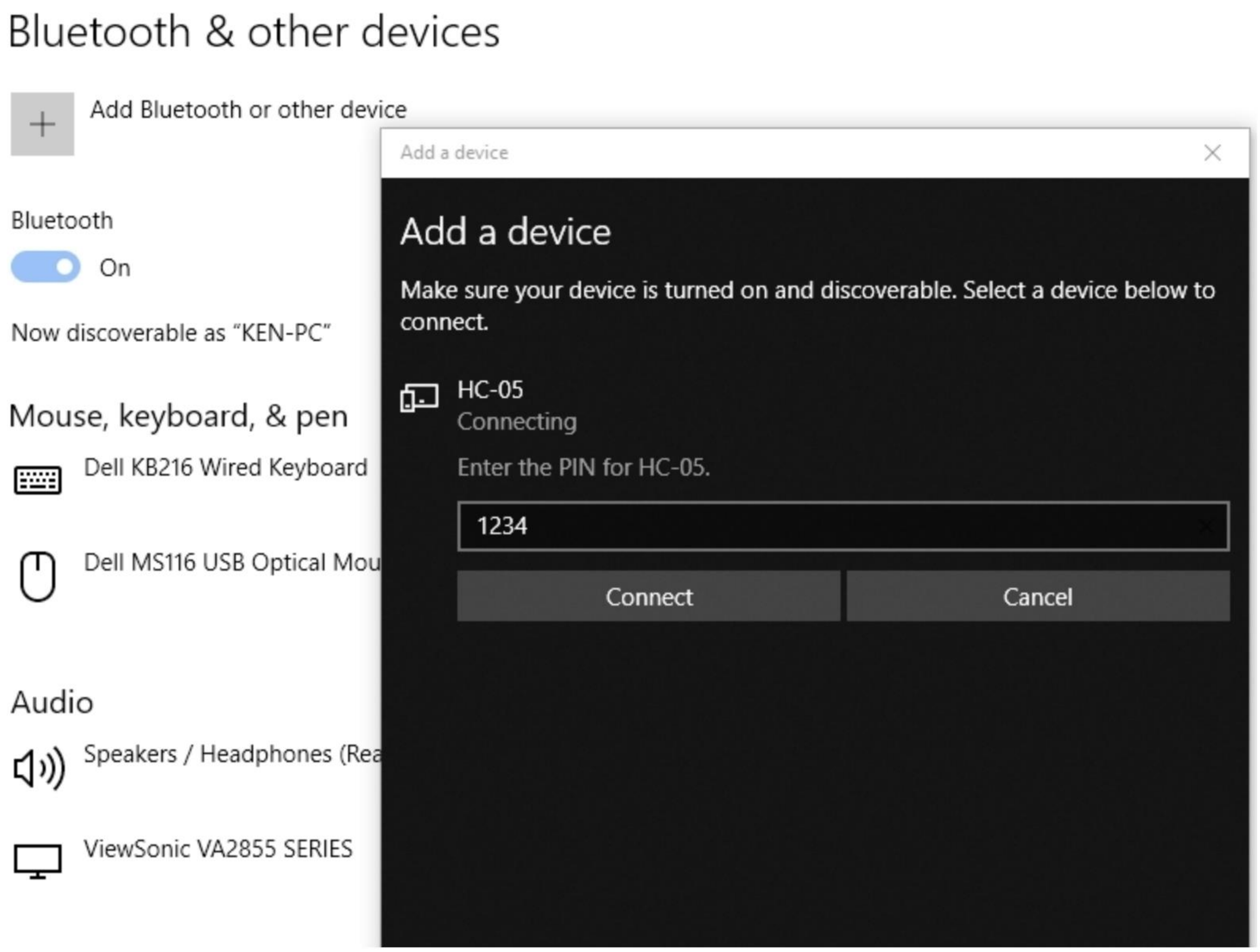
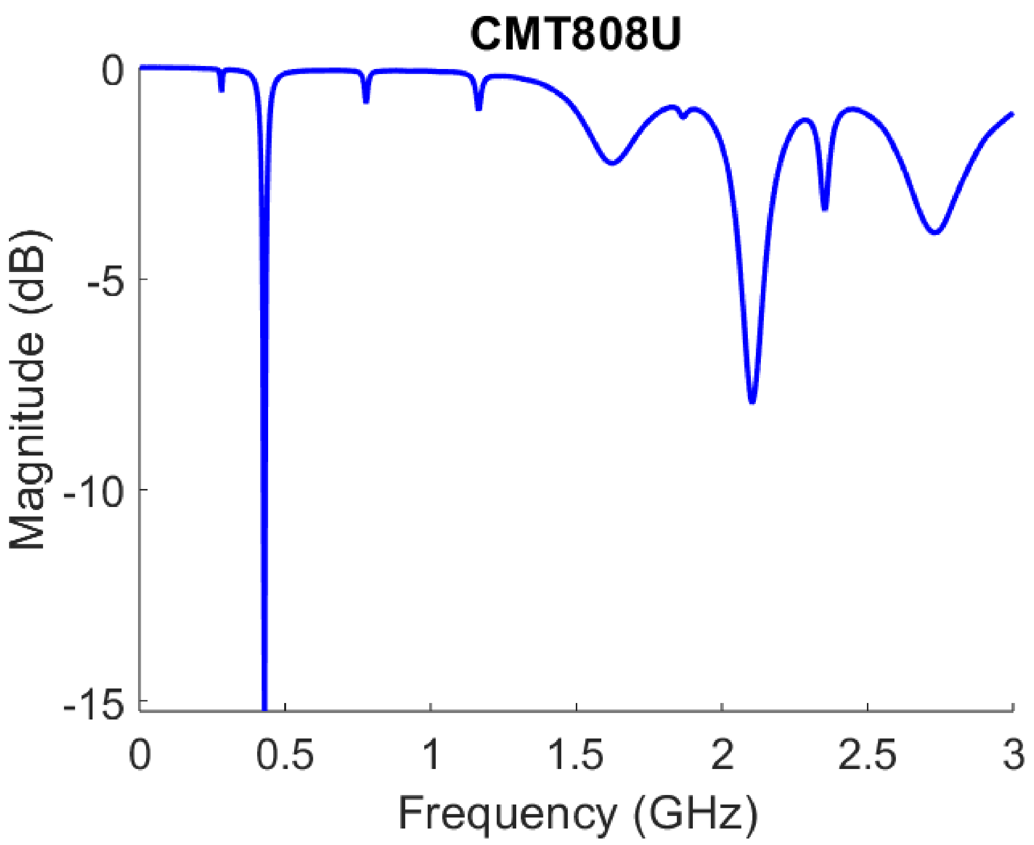


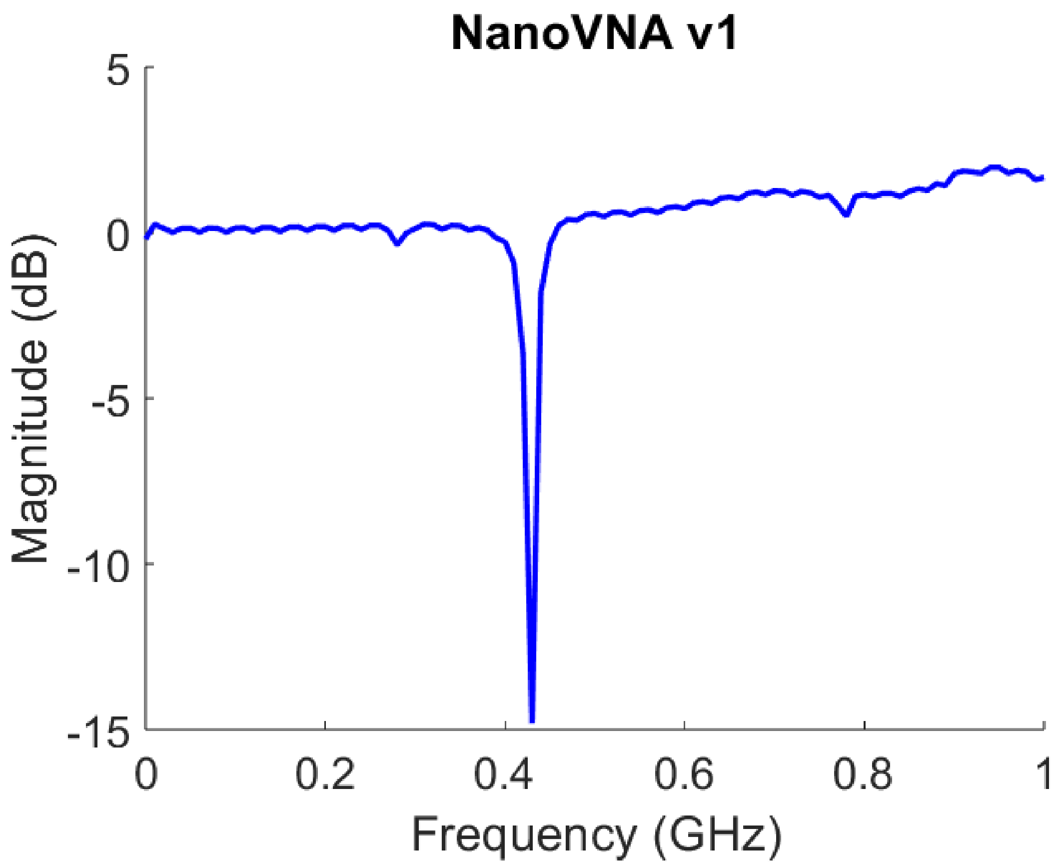
Image from "HC-05 (ZS-040) Bluetooth Module," ProtoSupplies. Accessed: Mar. 11, 2024. [Online]. Available: https://protosupplies.com/product/hc-05-zs-040-bluetooth-module/

NanoVNA v2 and CMT-808U Comparison

- S_{11} plot of antenna measured in free space on Copper Mountain CMT808U



- S_{11} plot of antenna measured in free space on NanoVNA v1



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Next Steps

- Create unified Python library that interfaces with both NanoVNA-H and NanoVNA v2 using the same API.

- Add calibration step to Python library, as the NanoVNA-H and NanoVNA v2 only send raw data values when interfacing with them

Conclusion

- Developed and integrated software and hardware for wireless communication of S-parameters using WiFi/Bluetooth for remote sensing applications.
- Enabled on-body S-parameter measurements while in motion.
- Demonstrated feasibility of remote metabolite sensing with significant implications for healthcare and athletic performance monitoring.
- Development of user-friendly software in MATLAB and Python for data analysis.
- Highlights the potential for a cost-effective, portable solution for real-time lactate/glucose monitoring.
- Opens new possibilities for non-invasive, real-time health monitoring and optimizing athletic performance.

Acknowledgements

- The authors would like to thank Collin Kringlen for lending us a sample antenna for remote metabolite measurement as a test device.

Comments and Questions are Welcome