Vital Sign Sensing in GNURadio

Isabella Lenz and Jacob Holtom

School of Electrical, Computer, and Energy Engineering

Arizona State University

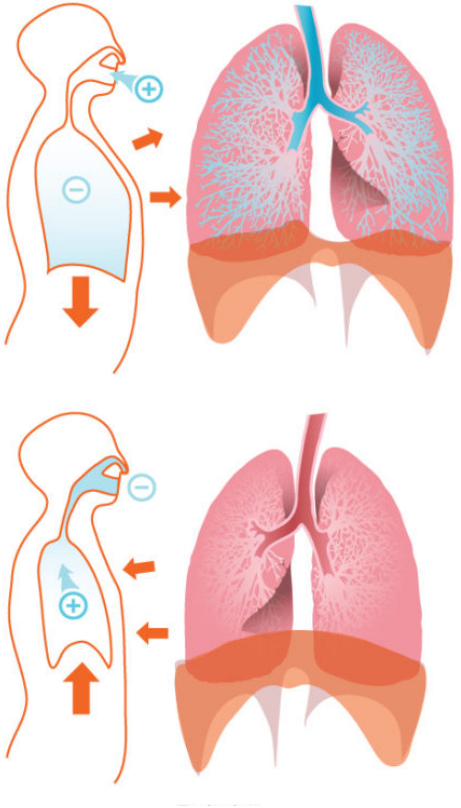
Wireless Information Systems and Computational Architectures

Topics

- Heart and Respiration Physiology
- Traditional Monitoring Approaches
- Radar Based Monitoring
- Vital Sign Signal Model
- Existing Radar Approaches
- Motivation for Software Defined Radio
- Experimental Setup
- Signal Processing
- Demo

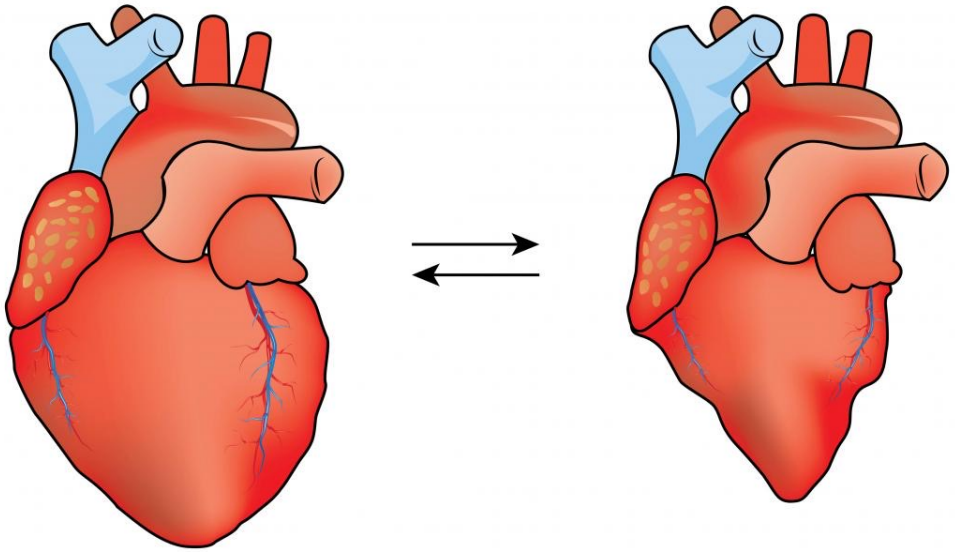
Respiration Physiology

- **Inspiration**
  - Diaphragm and external intercostal muscle contract
  - Lungs expand
  - Oxygen rich air enters lungs
- **Expiration**
  - Diaphragm and external intercostal muscle relax
  - Lungs recoil
  - CO2 rich air forced out of lungs
- **12-20 breaths per minute in healthy adults**
  - Higher or lower rates can signify health conditions



Heart Physiology

- **Heart muscles constrict and relax to drive circulation of blood through the body**
  - Oxygen rich blood to tissues
  - Oxygen poor blood to lungs
- **Normal resting 60-100 beats per minute**
  - Varies person to person and over time based on physical needs
- **Abnormal heart rate can indicate disease**



Traditional Monitoring

Respiratory Rate

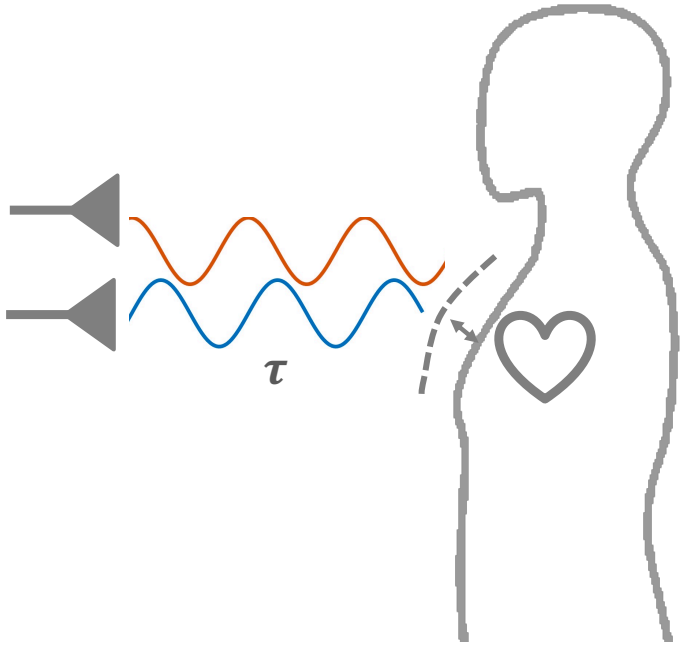
- **Counting Breaths**
  - Intermittent
  - Subject to human error

Heart Rate

- **Electrocardiogram (ECG)**
  - Measures electrical activity of heart
  - Electrodes attached to skin
    - Uncomfortable, clinical environment
- **Photoplethysmography (PPG)**
  - Optical measurement
  - Detects changes in blood volume during circulation
  - Smart watch approach

Radar Based Monitoring

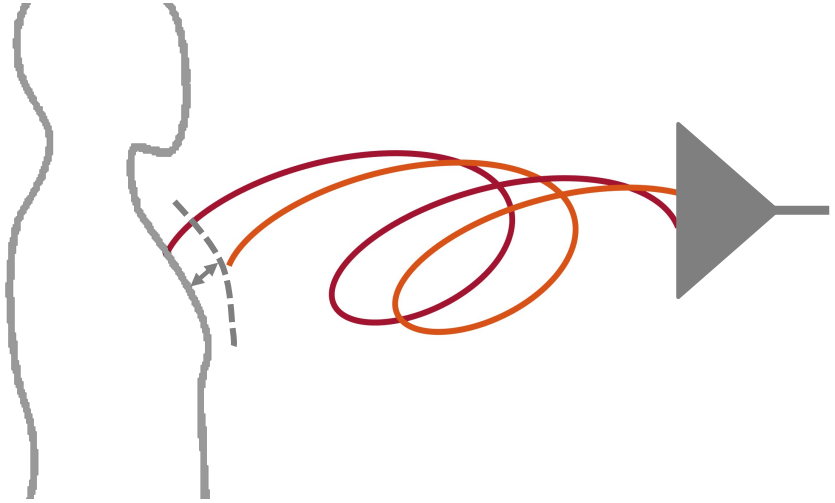
- A radio signal is transmitted towards a subject
- Chest wall displacement modulates transmitted signal
- Modulated signal contains heart and respiratory rate information

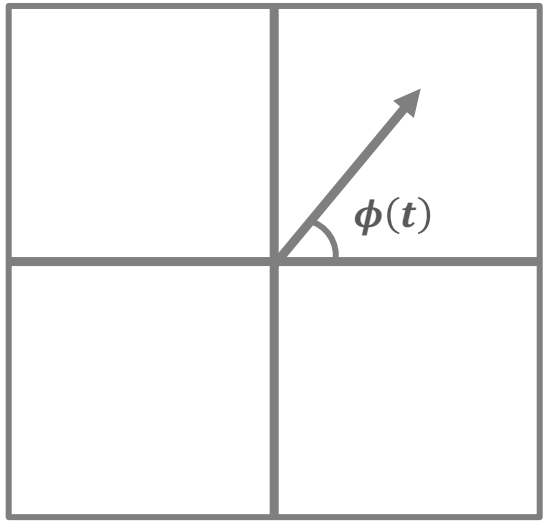


Vital Sign Signal Model

- **Doppler Theory:**
  - a tone reflected off an oscillating target (chest) returns with time varying phase proportional to displacement

$$\phi(t) = \frac{4\pi}{\lambda} d(t)$$

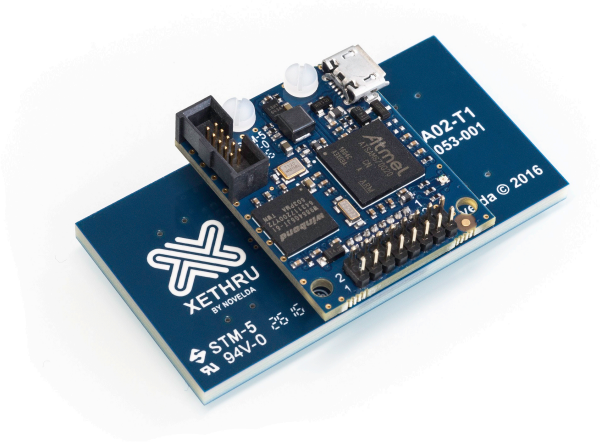


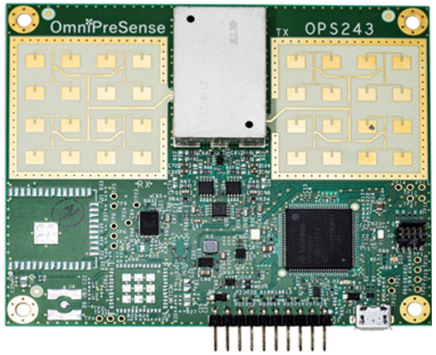


Receiver

Existing Research

- **Advancement is needed before consumer or clinical use**
- **Many Approaches**
  - Radar Styles
    - Unmodulated CW (velocity)
    - Frequency Modulated CW (velocity, range)
    - Ultra-Wideband Impulse (velocity, range)
    - Phased Array/ MIMO
  - Post processing techniques
    - Time-frequency analysis
    - Numerical analysis
    - Ranging and localization
    - Beamforming
    - Motion cancellation



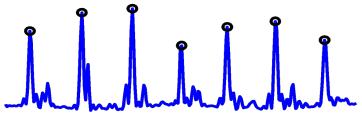


Previous WISCA Radar Vital Signs Research

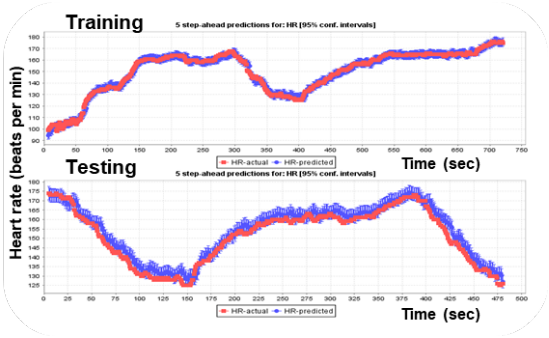
- **Various Cardiac Signals**
  - Heartbeat
  - R-R Interval
  - Heart acoustic
- **Multiple Subjects**
  - Separation
  - Localization (MIMO)
- **Exercise Monitoring**
- **Through Wall Monitoring**

Radar-Estimated Heart Sound Signal

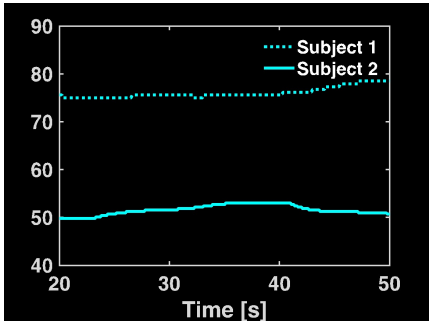
RR Interval Analysis



HR while Running on Treadmill

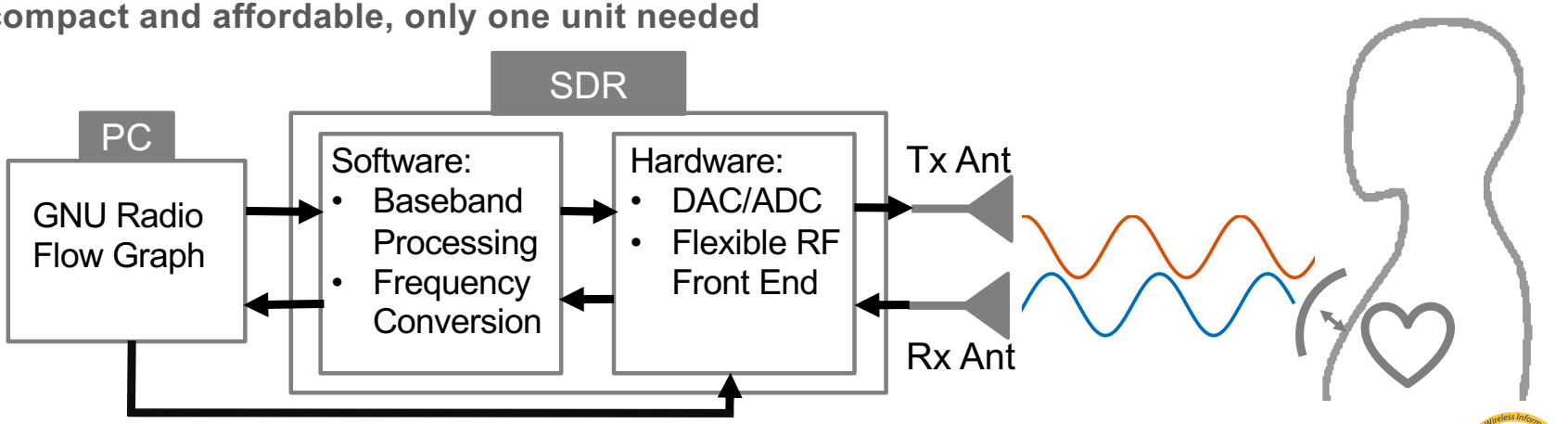


Multi-Subject Heart Rates



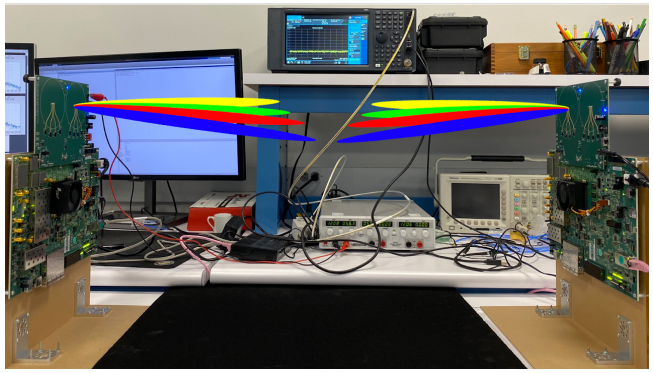
SDR Motivation

- **Most research has been done using custom hardware/hardcoded radar sensors**
- **Changing waveforms and other parameters requires significant effort or new sensor**
- **SDRs allow the user to easily define and switch between various radars architectures**
  - **directly compare types of radar**
  - **compact and affordable, only one unit needed**



Future Direction

- **Exciting problem with high potential impact**
  - More people working on it means faster innovation
  - SDR with GNURadio make for an accessible testbed
- **Extensions:**
  - Waveforms:
    - FMCW, SFCW, Pulsed...
  - Shorter wavelengths
  - Phased Arrays/MIMO Systems
  - New and improved signal processing approaches

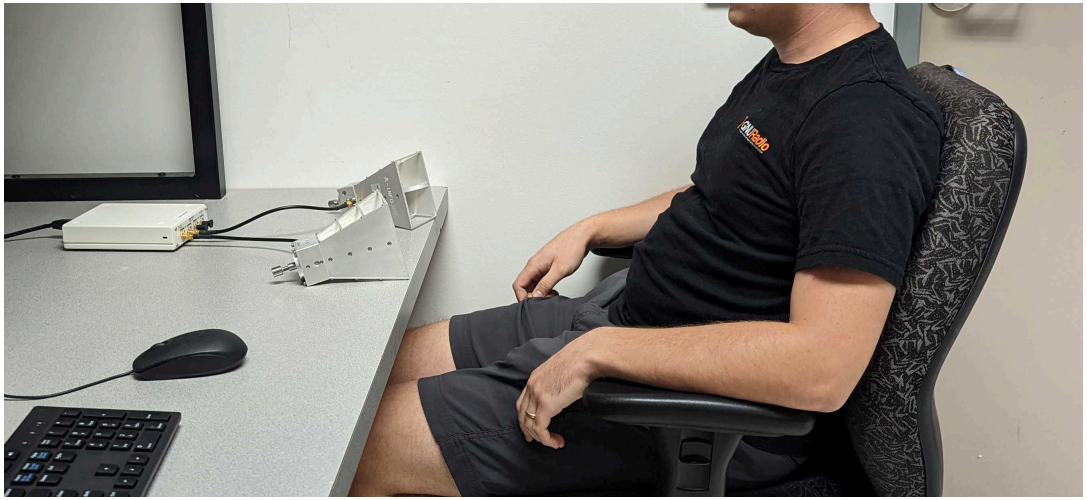


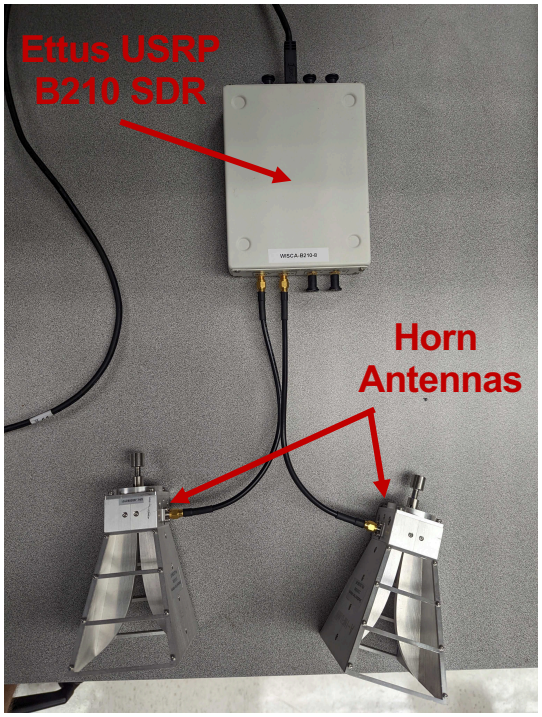
Pi-Radio mmWave SDR MIMO Set-Up

Sivers EVK

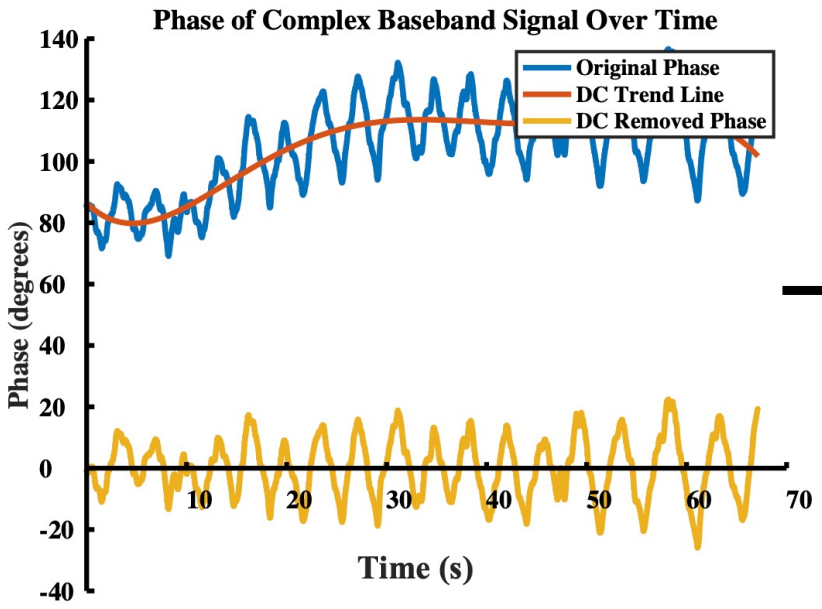
Experimental Setup

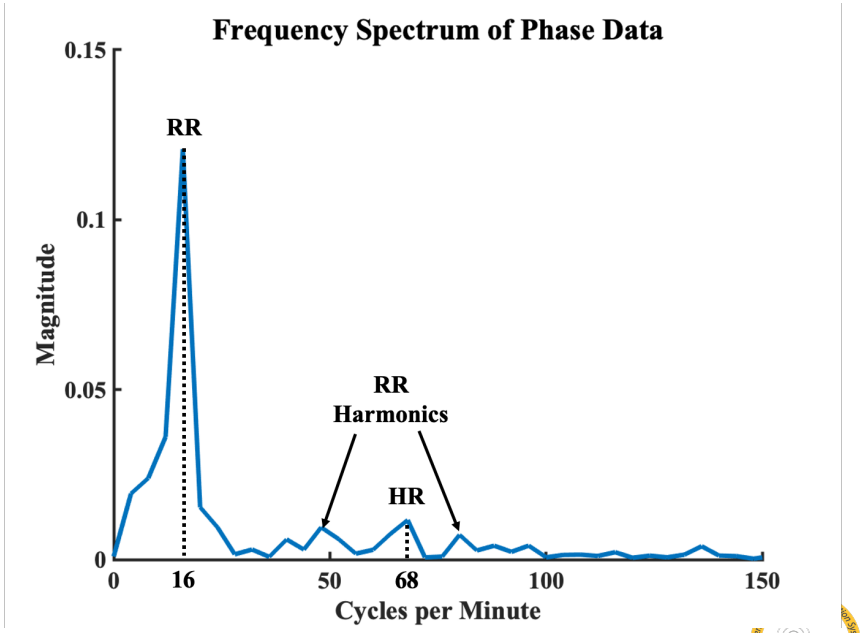
- Subject sits still and breathes normally
- ~50 cm from bistatic SDR radar system
- Chest height inline with antennas



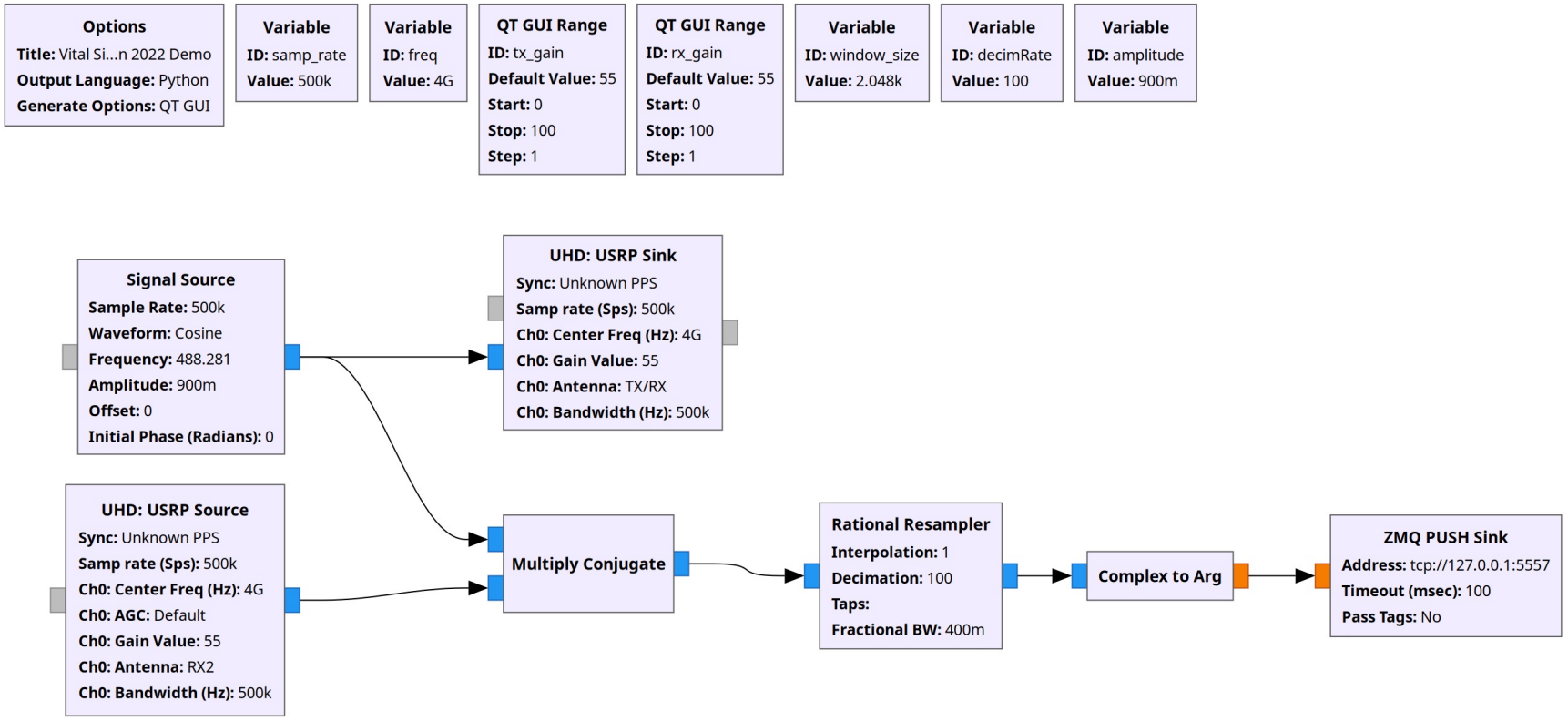


Signal Processing



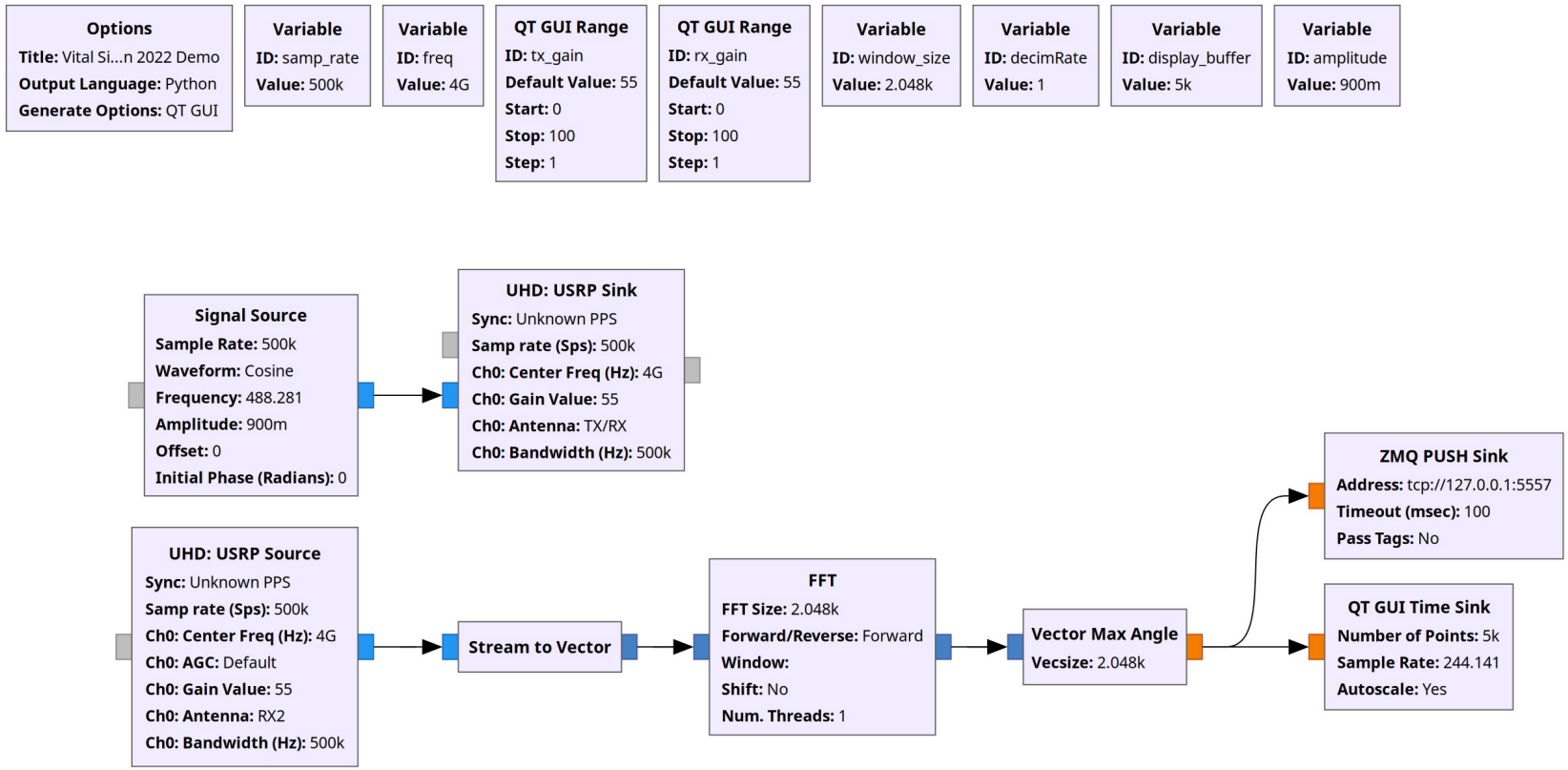


GNURadio Flowgraph



GNURadio Flow Graph

Many ways to do the same thing



Real-Time Demonstration