Implementation of a self-tracking antenna system based on monopulse techniques

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Introduction

- Functional prototype of a passive tracking system for a moving target from which an RF signal is received.
- It will be used mounted on a low-orbit satellite antenna system and unmanned vehicles.
- RF operating signal: 1.8 GHz.
- Technique used: Monopulse

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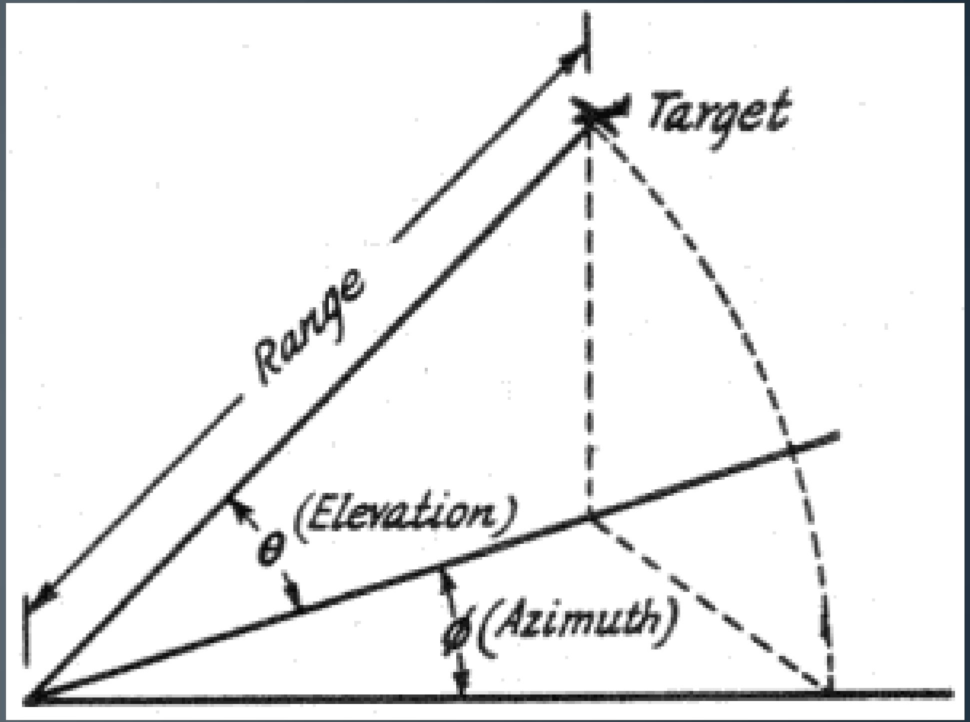
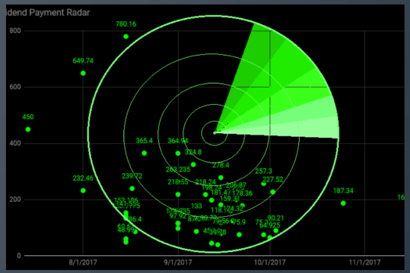
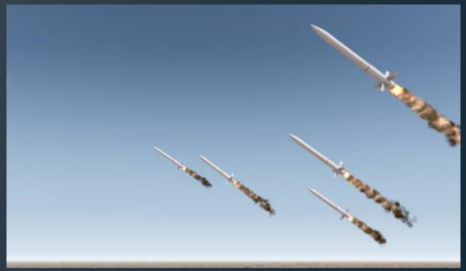
Monopulse

- Tracking radar.
- Signals in this type of radar: Azimuth and elevation.
- Applications:
  - Tactical missile control
  - Tracking of known or unknown targets
  - Analysis of trajectories and echo variations
  - Support applications
  - Satellite tracking, UAV, balloon loads.







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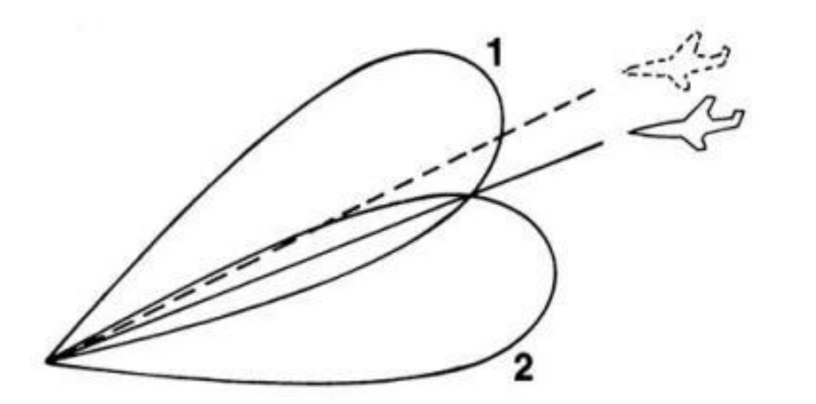
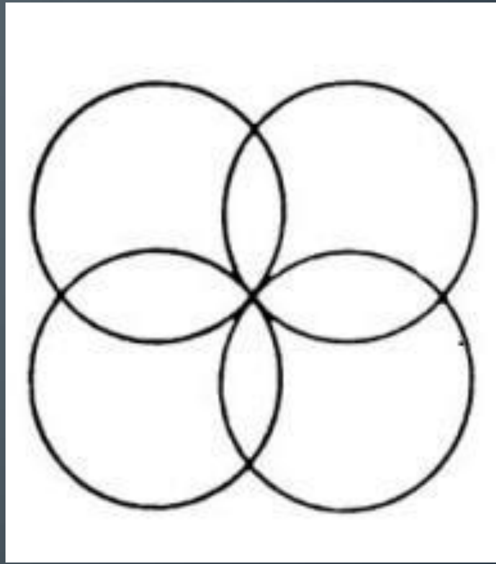
Monopulse Operation

- For an error signal:
  - 2 lobes
  - Perspective plane
  - Error is the difference between perspective and actual position
- For two error signals:
  - 4 lobes/2 perpendicular planes
- Monopulse advantages:
  - Four simultaneous lobes
  - A single measurement pulse
  - Free from mechanical vibrations
  - Efficient
  - Can be passive





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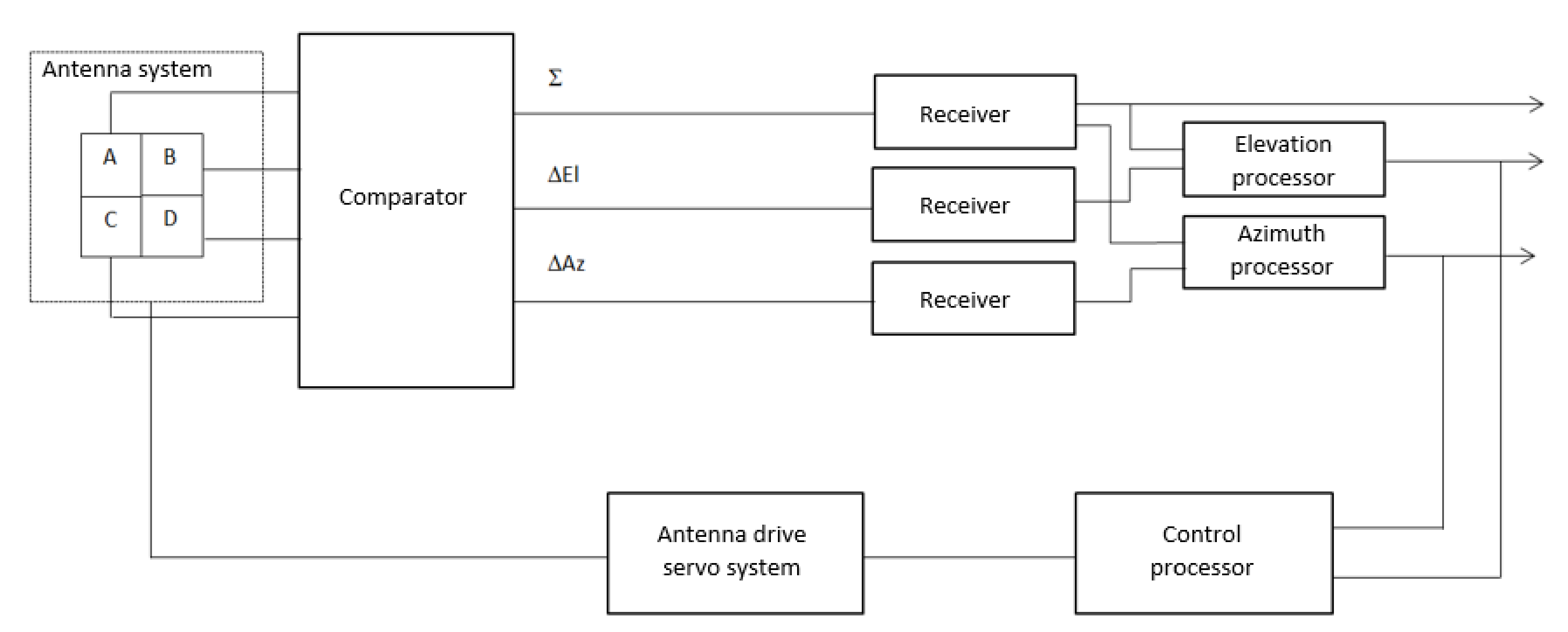
Monopulse types



- By measurement:
  - Amplitude
  - Phase
- By number of channels:
  - A channel
  - Two channels
  - Three channels
- Proposed system:
  - Amplitude measurement system
  - Single channel

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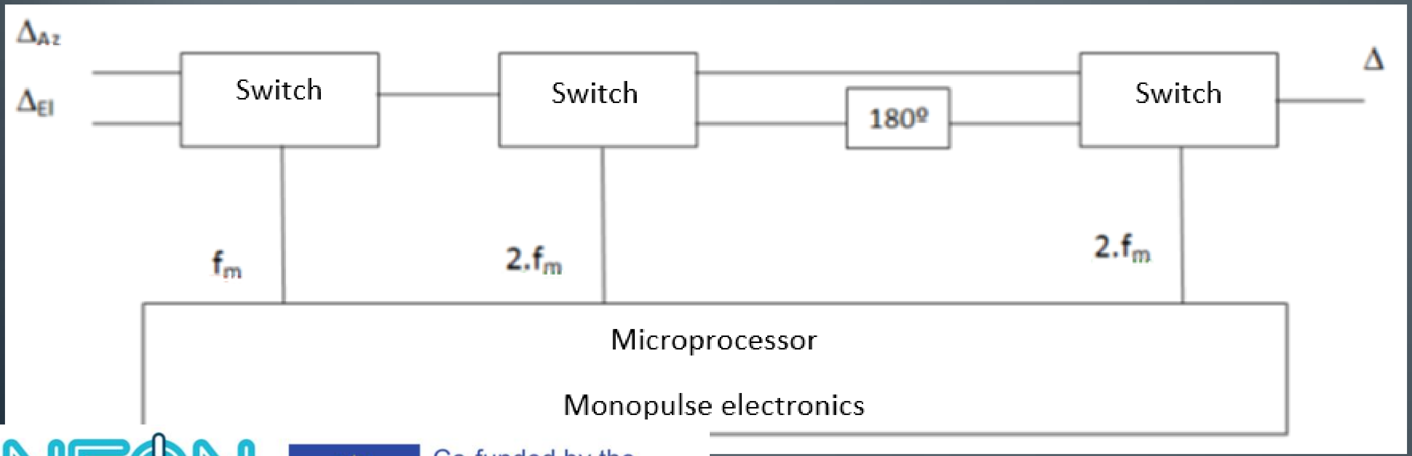
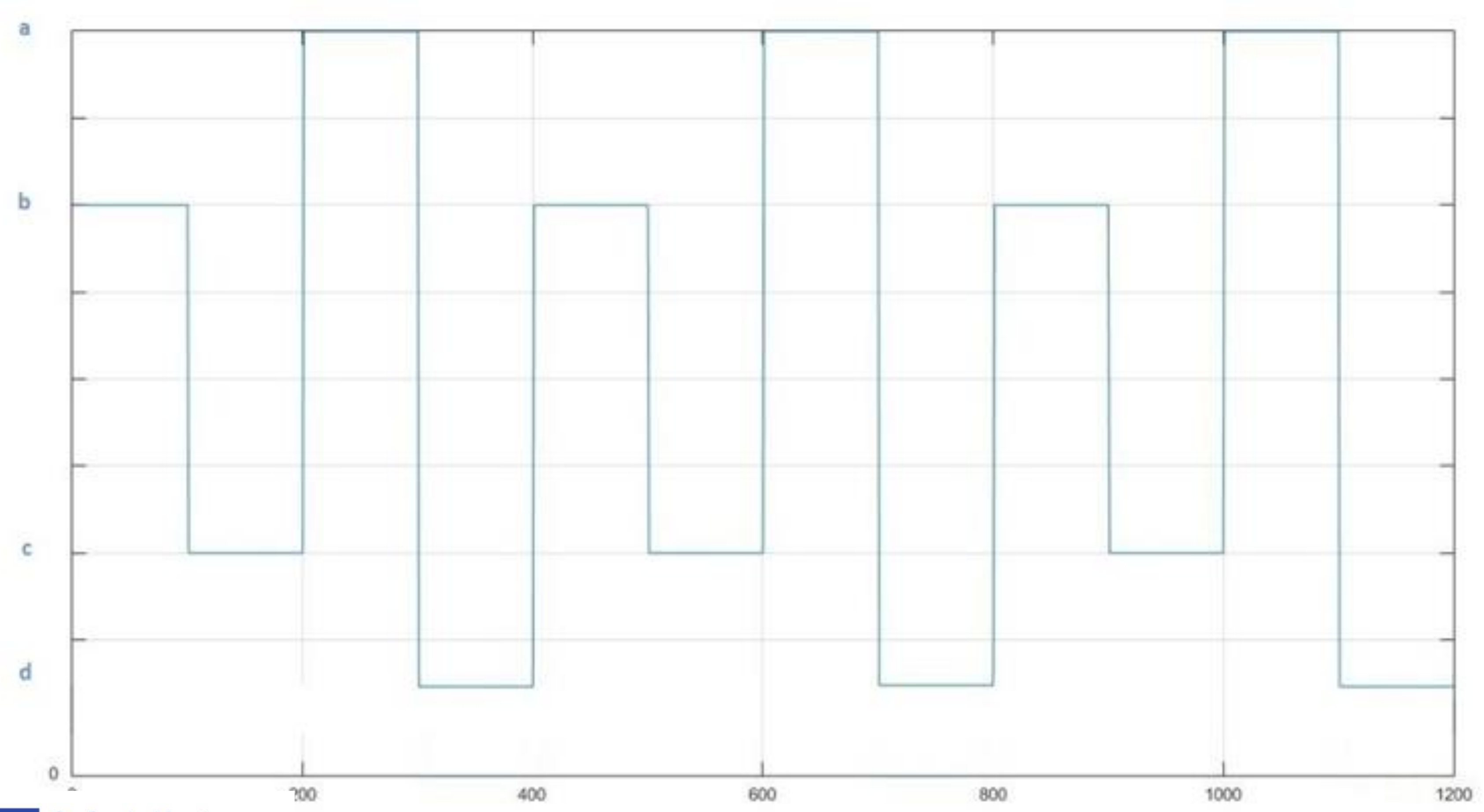
Pseudomonopulse

- Single channel system
  - TDM
  - FDM
  - SCAMP
  - Pseudo monopulse



- Pseudo monopulse:
  - Multiplexes the difference signals into a single
  - System of switches (Monoscan Converter) and Adder (Coupler)
  - Controlled by Monopulse Electronics (microcontroller)
  - Use more than one pulse
    - Advantages:
      - Lower complexity
      - Low signal degradation
      - Low cost
      - Good dynamic range
      - Reliable
      - Good synchronization with antenna
      - Acceptable and correctable tracking error

Signal expected at the exit



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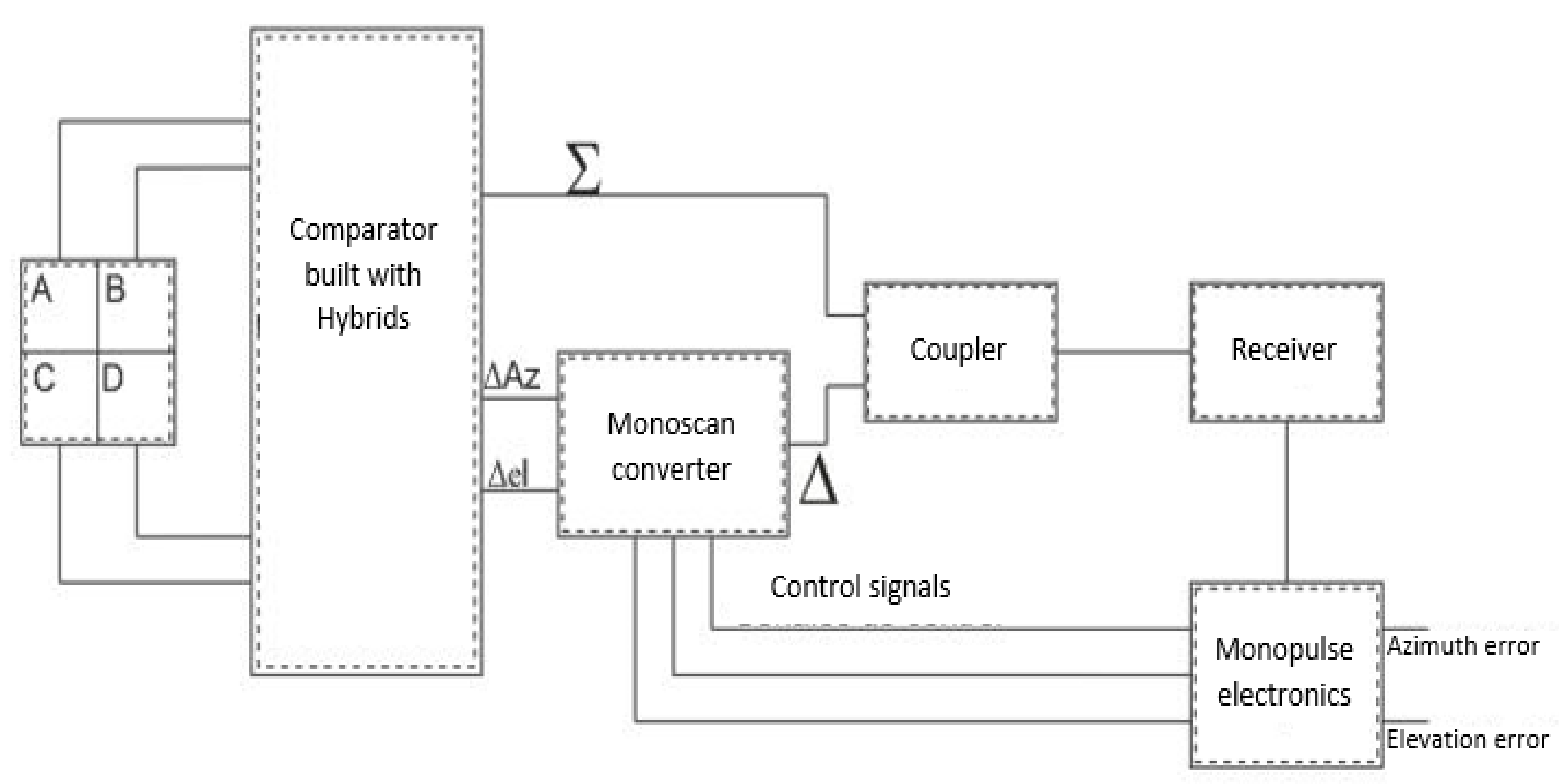
Stages

- Antenna
- Comparator
- Switch system
  (or Monoscan converter)
- Monopulse electronics
- Directional coupler
- Receiver
  - Low noise amplifier (LNA)
  - Mixer
  - Local oscillator
  - Demodulator



- Control system
- Servo and motor system

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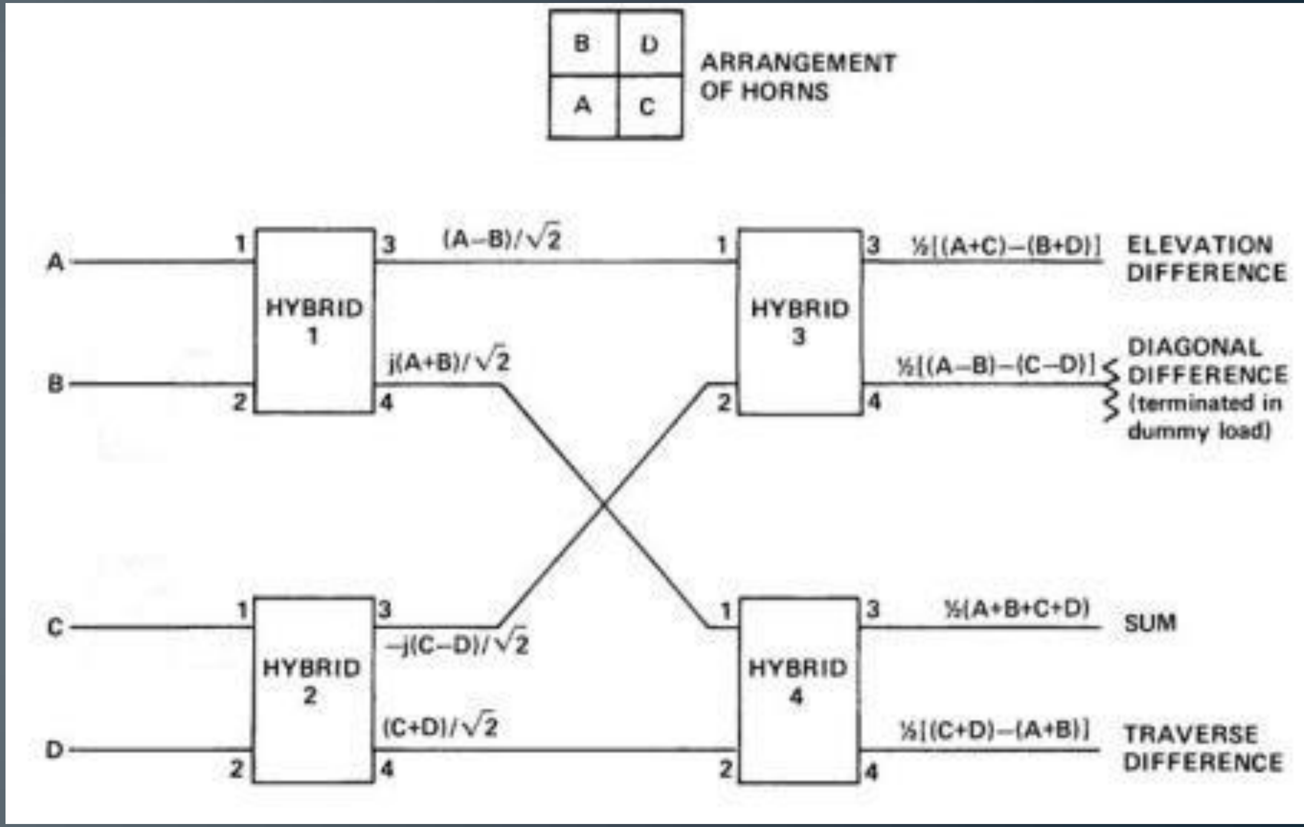
Comparator

- Objective: generate the difference and sum signals.
- Specific configuration, based on the generating equations:
  - (A+B + C+D)/2 → Add
  - [(A+C)-(B+D)]/2 → Elevation
  - [(C+D)-(A+B)]/2 → Azimuth
- Special devices are used, which generate addition and subtraction of electromagnetic signals.



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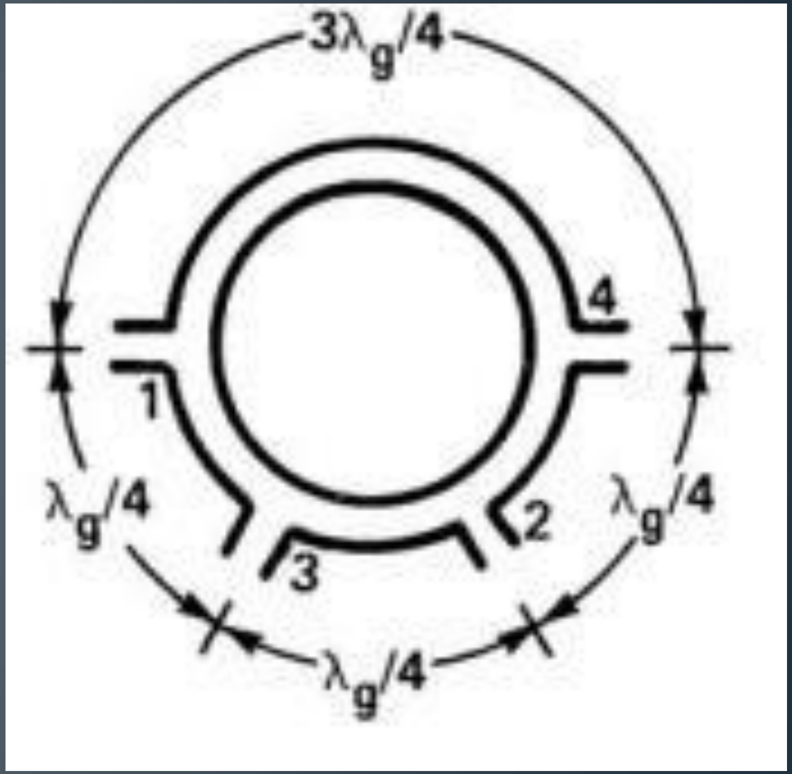
Hybrid coupler

- Four-port passive transmission line type.
- It has two inputs and two outputs.
- It is built with sections with specific lengths, so that:
  - An output adds to the signs.
  - And another subtraction to the signs.
- Use of Microstrip/Stripline technology in RF.
- Parameters:
  - Impedance (Z_0=50 Ω)
  - Frequency (1.8 GHz)
  - Dielectric (FR4)



Main simulation results

Case	Ideal	Microstrip	Stripline
1- 2	-3dB	-3.46 dB	-3.4dB
1- 4	-3dB	-3.67 dB	-4.18dB
2– 3	-3dB	-3.5 dB	-4.02dB
3 - 4	-3dB	-3.46 dB	-3.41dB
1-1 (2-2, 3-3, 4-4)	Inf	-39.9 dB	-22.9 dB
1-3 (2-4)	Inf	-35 dB	-25.8 dB
phase (2,3) – phase (3,4)	0°	-0.4°	-3.8°
phase (1,4) – phase (1,2)	180°	180.4°	175.6°

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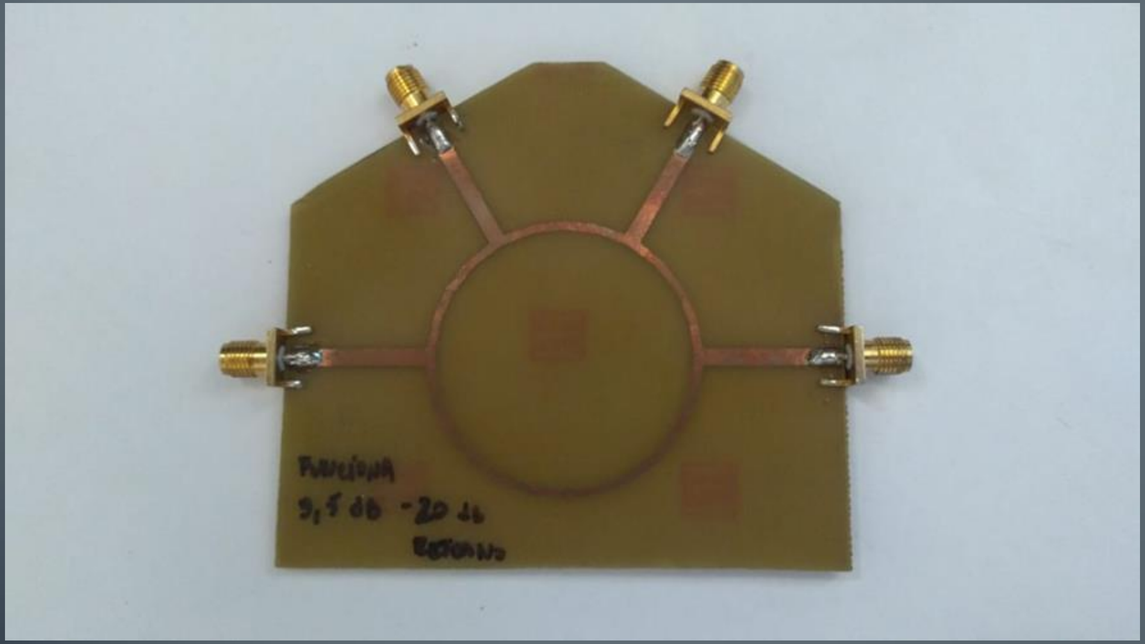
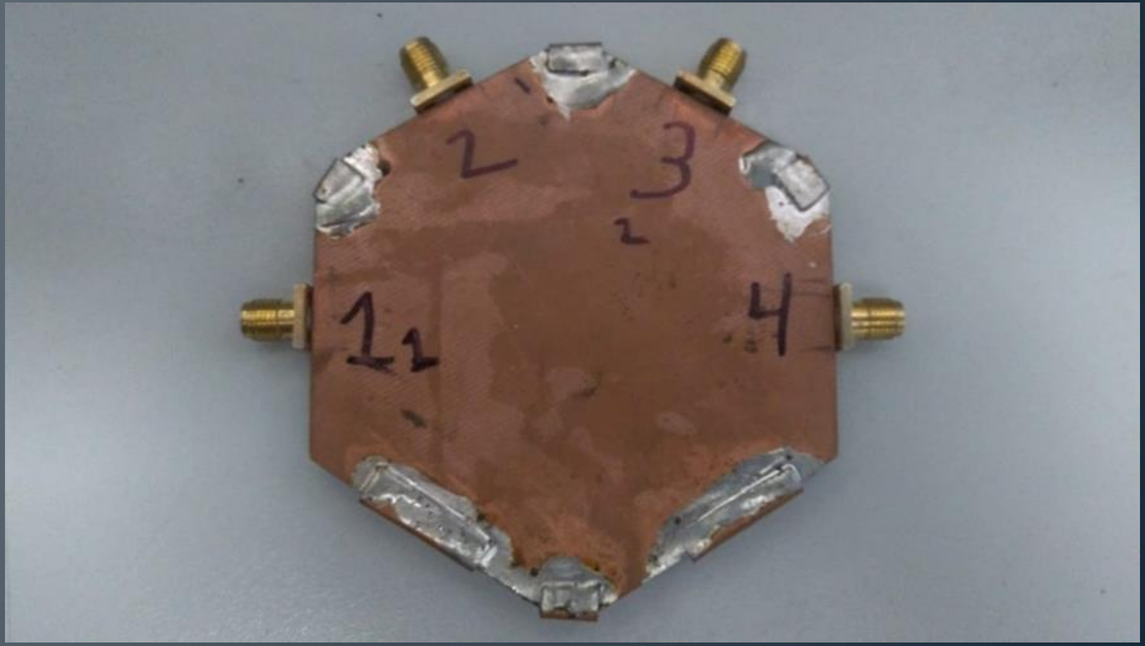
Implementation

- The boards were assembled using an insolator provided by the laboratory.





Microstrip board results

Case	Ideal	Simulation	Implementation
1- 2	-3dB	-3.46dB	-3.54dB
1- 4	-3dB	-3.67dB	-3.67dB
2– 3	-3dB	-3.5dB	-3.59dB
3 – 4	-3dB	-3.46dB	-3.59dB
1-1 (2-2, 3-3, 4-4)	Inf	-39.9 dB	-22.35 dB
1-3 (2-4)	Inf	-35 dB	-37.4 dB
phase (2,3) – phase (3,4)	0°	-0.4°	0°
phase (1,4) – phase (1,2)	180°	180.4°	174.19°

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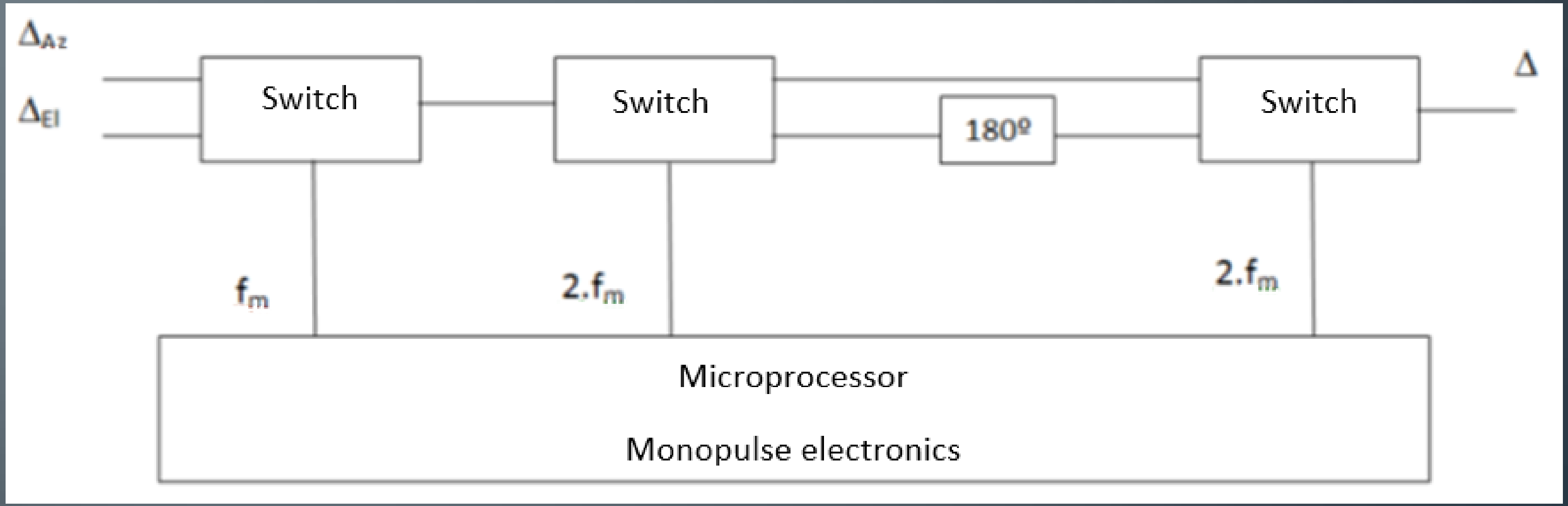
Switch system

- Multiplexes the difference signals, into a single signal, containing both data.
- It consists of three switches, controlled by the Monopulse Electronics.
- A 180° offset is placed, in order to be able to distinguish the sign.



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Design and implementation

- Chosen switch: MASWSS0136
- Two boards were used, interconnected with two lines 180° out of phase..
- Design of the same in Altium, based on design criteria for RF.

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Monopulse electronics

- Functions:
  - Generate switch control signals
  - Demultiplex the signals coming from the receiver
  - Provide the control signals, which in turn, are the output signals of the system
- Use of microprocessors:
  - Arduino UNO
- Square waves as control signals (668 and 1336 Hz, respectively).
- From the demultiplexing, the error signals are sent as PWM outputs.

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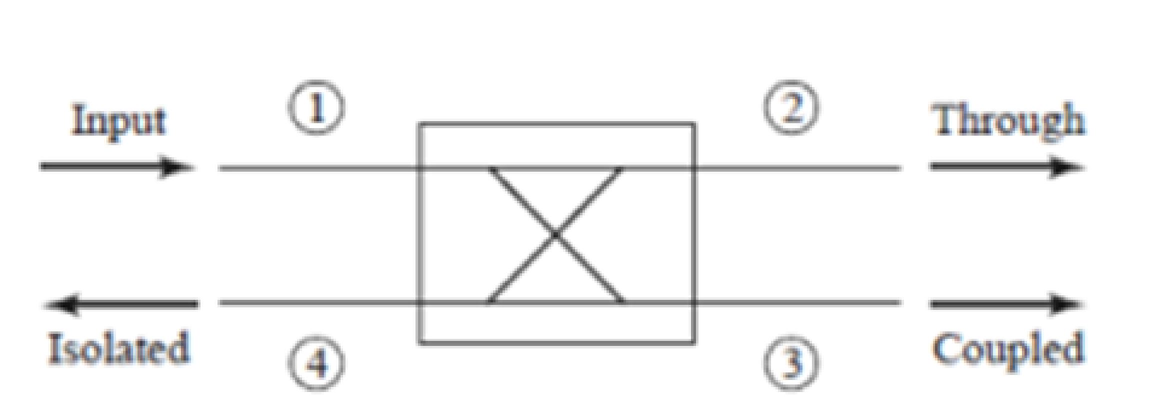
Coupler

- The multiplexed difference signal is combined with the sum signal coming from the comparator.
- AM modulation.
- Coupler was designed with the following parameters:
  - Coupling: 12 dB
  - Frequency: 1.8 GHz
  - Stripline
  - Impedance: 50 Ω



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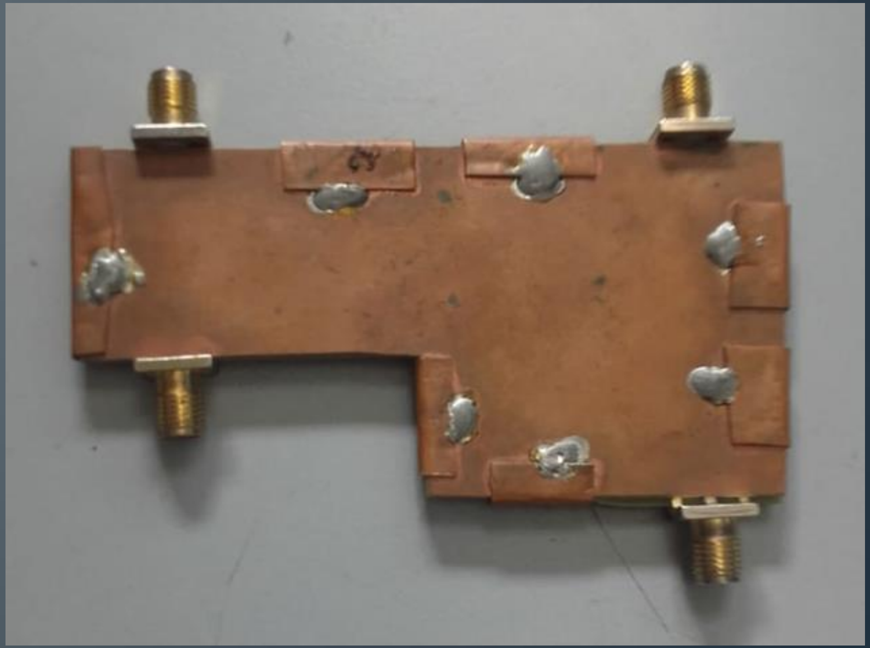
Design, modeling and simulation

- As with the hybrid couplers, the measurements were calculated using Ansoft Designer.
- It was modeled and simulated with HFSS at the frequency of interest.



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Implementation and results

- Proceeded to assemble the board using the same insolator.

Parameter	Simulation (dBm)	Implementation (dBm)
in1-in1	-19.1	-21.27
in1-in2	-26.4	-19.78
in1-out	-0.997	-2.27
in2-in2	-19.9	-25.82
in2-out	-12.4	$\boxed{-8.97}$
out-out	-19.9	-18.97

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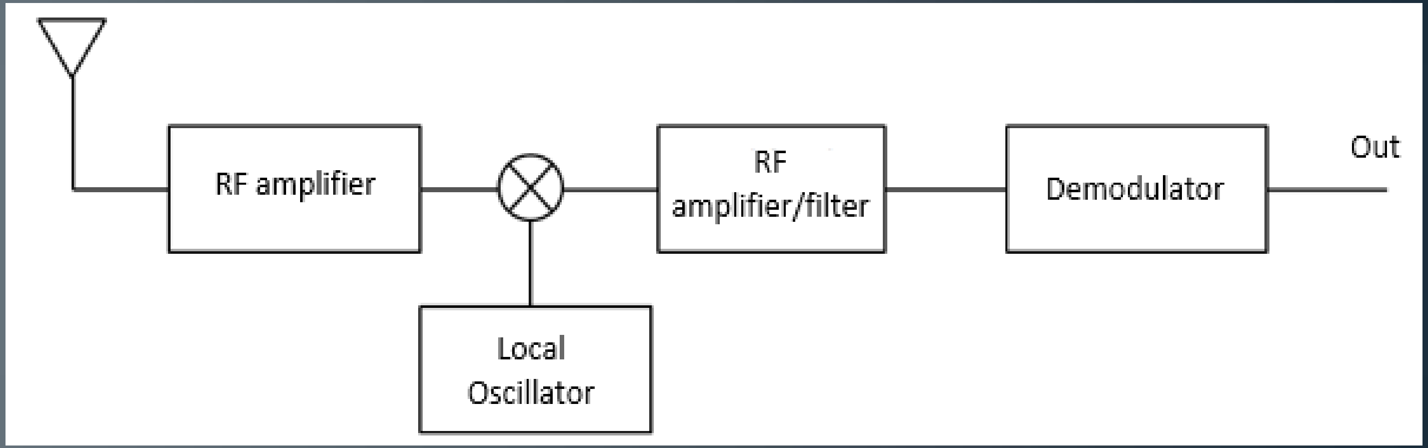
Receiver

- Based on Superheterodyne receiver.
- Stages:
  - Low Noise Amplifier at the input
  - Mixer
  - Local oscillator
  - Demodulator
    - SDR
    - Analogical



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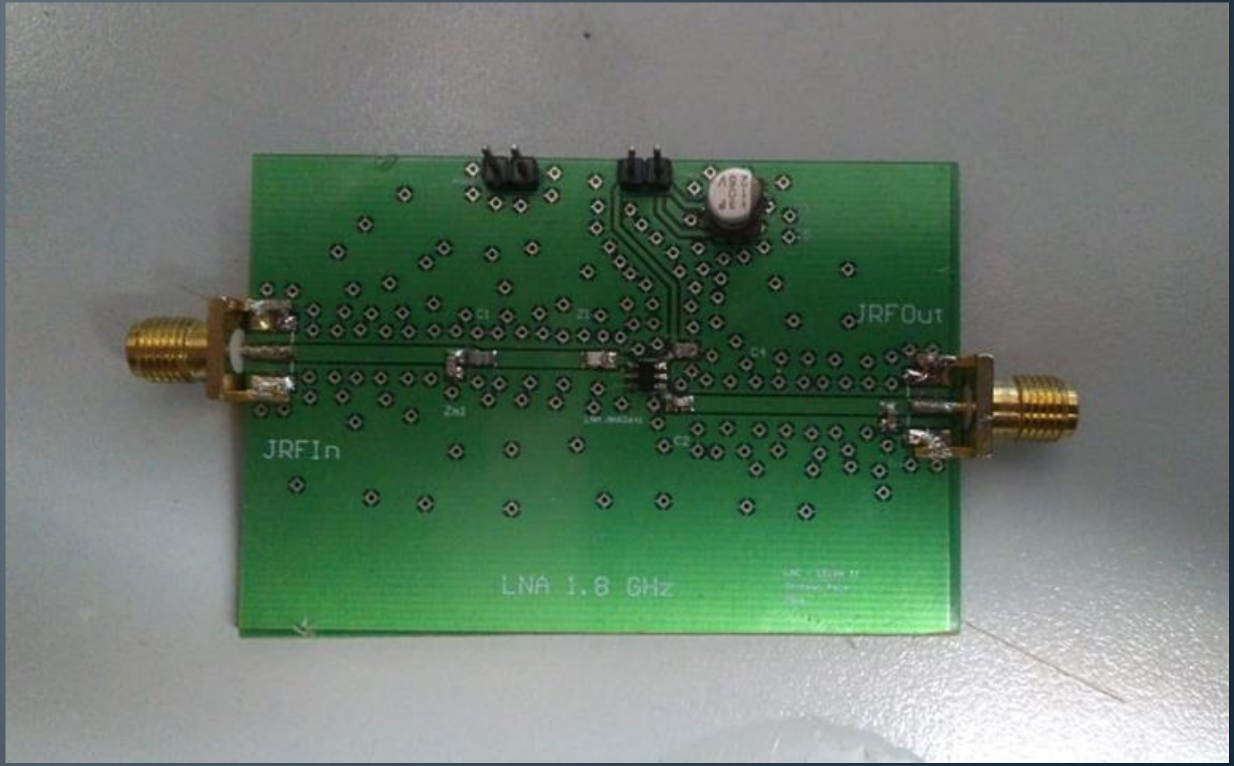
Low noise amplifier (LNA)

- Low level input signal.
- A total gain of 20 dB is desired, at the working frequency.
- Two MAX2640 amplifiers were used, connected in cascade.
- Board design criteria in RF.
- Results:
  - Actual gain: 19.23 dB



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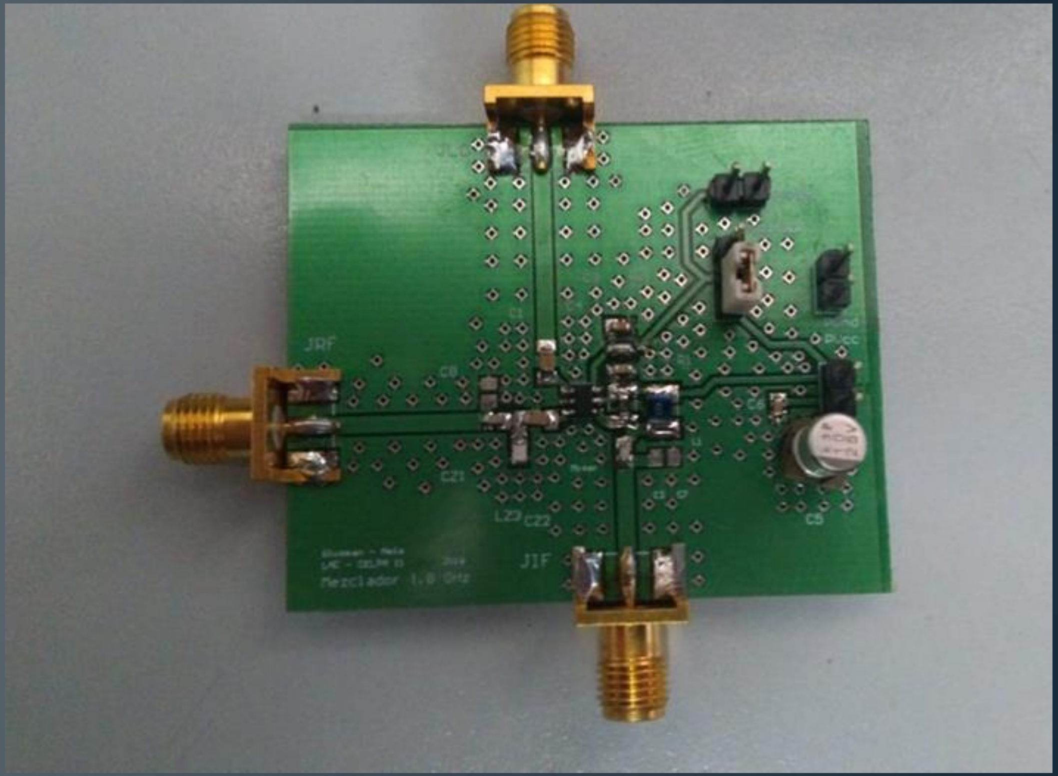
Mixer

- The working signal (1.8 GHz) must be frequency shifted to a frequency at which the demodulator can operate.
- The integrated MAX2680 was used.
- Board design criteria in RF.
- The integrated ADF 4351 (signal synthesizer) was used as local oscillator, controlled by a PIC 4550.
- Results:
  - SDR IF frequency: 50.4 MHz
  - Analog IF frequency: 417 kHz

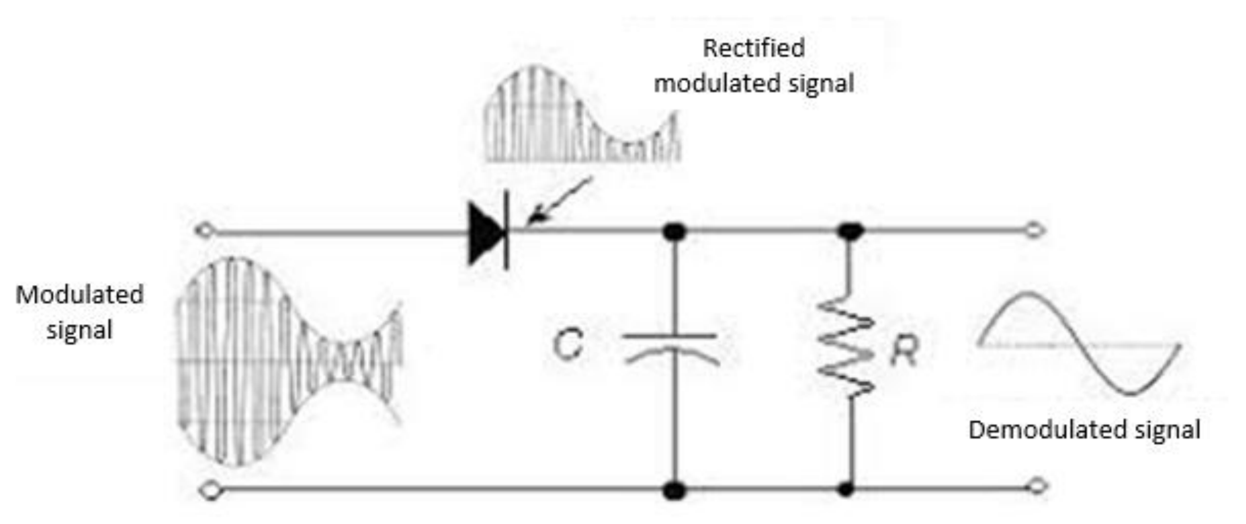


Demodulator

- Demodulation in AM of the signal coming from the coupler

SDR
Testing

Analog demodulator
Definitive system



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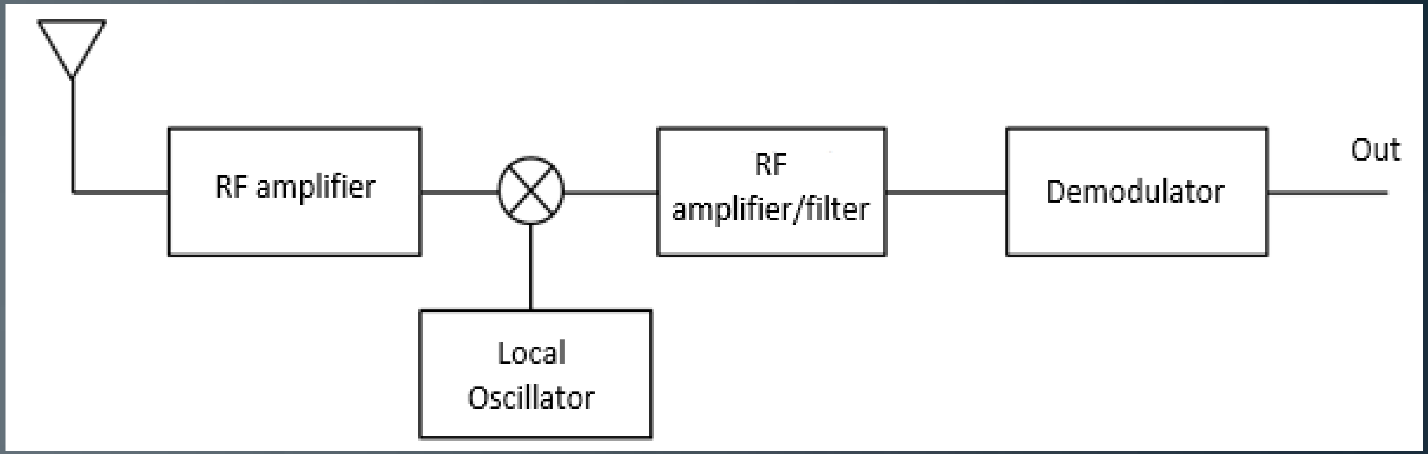
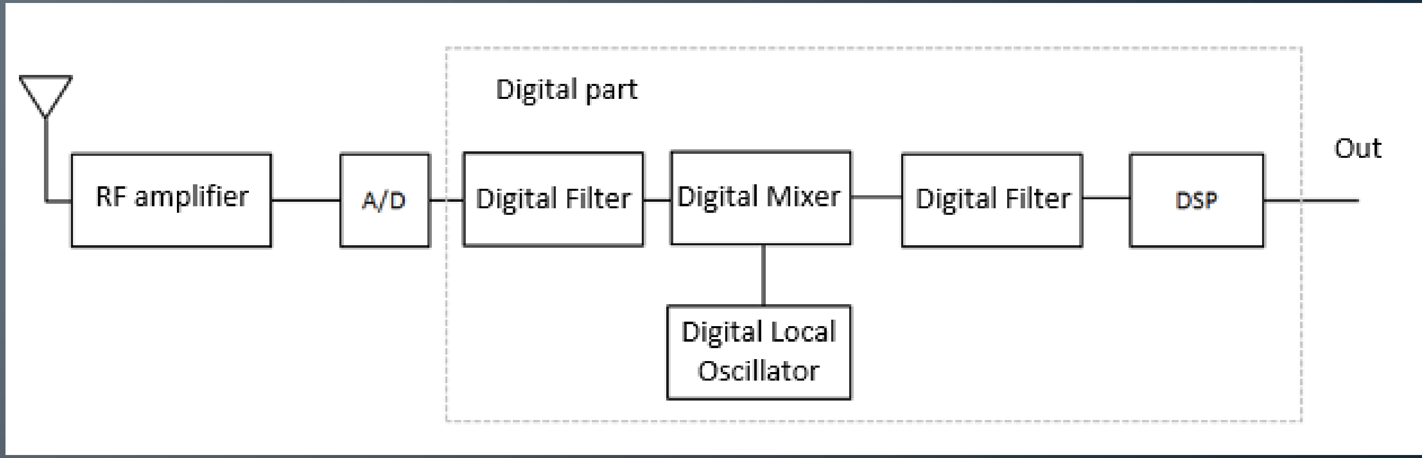
Software defined radio (SDR)

- Single or multi-stage digitization of the receiving device
- Digital processing:
  - DSP
  - FPGA
- Advantages:
  - Versatility
  - Diversity of dedicated software
  - Broad support





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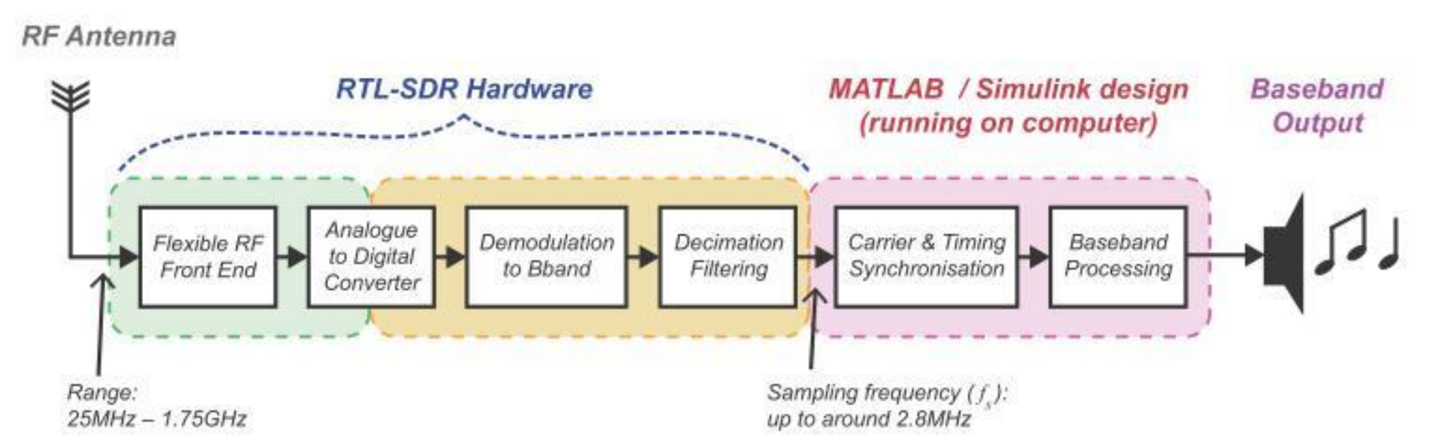
RTL-SDR

- Characteristics:
  - Wide bandwidth
    - 25 MHz to 1,7 GHz
  - USB
    - DSP➔PC
  - Dedicated software
    - Matlab
    - HDSDR
- Objectives:
  - Receiver and equipment operation verification
  - Define analog demodulator design



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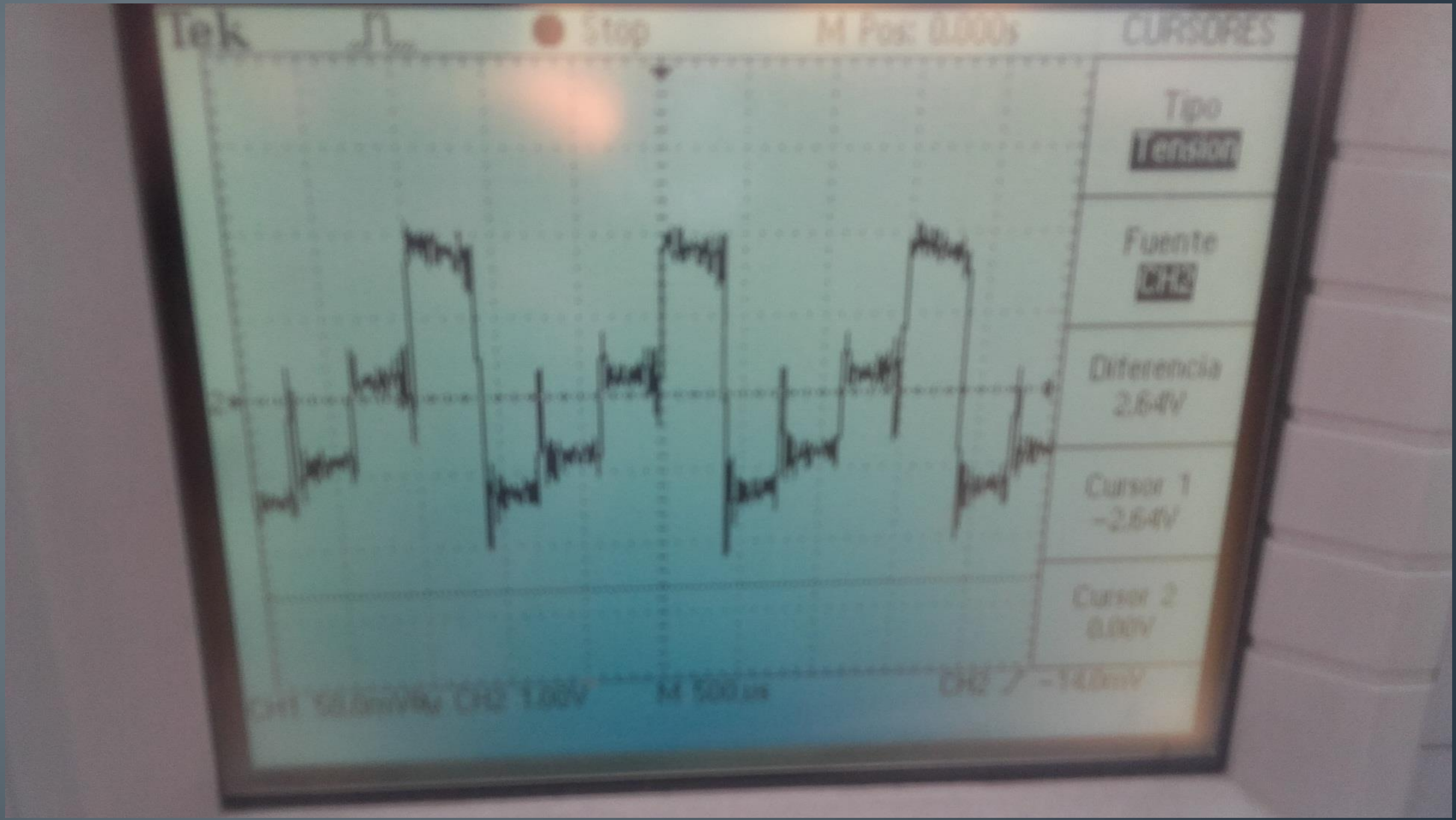
Results with SDR



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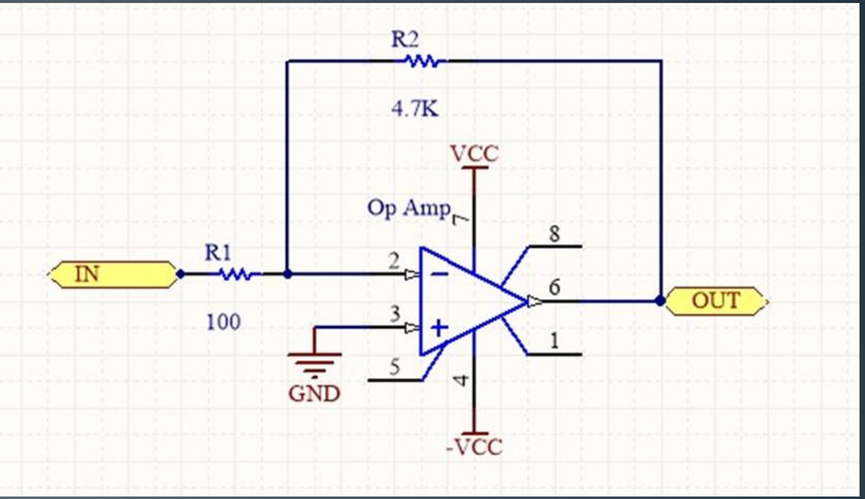
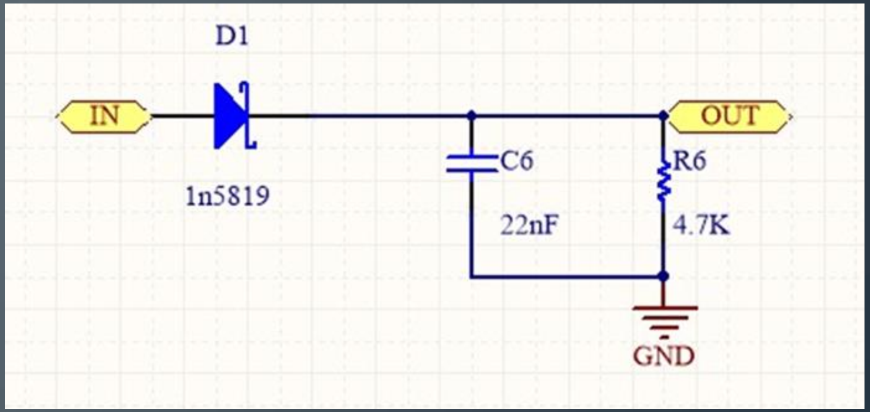
Analog Receiver

- Envelope detector with diode
- Input signal characteristics:
  - Modulated frequency: 668 Hz
  - Carrier frequency: 417 KHz
- Components used:
  - Audio amplifier: AO LM318
  - Diode: 1N5819





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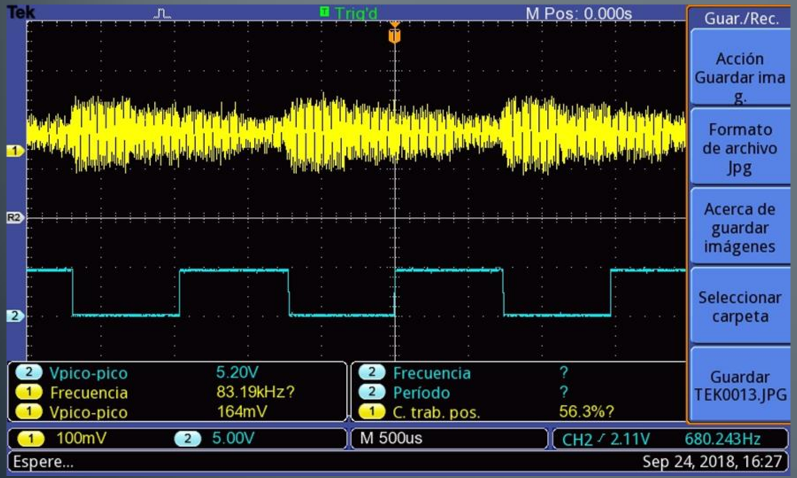
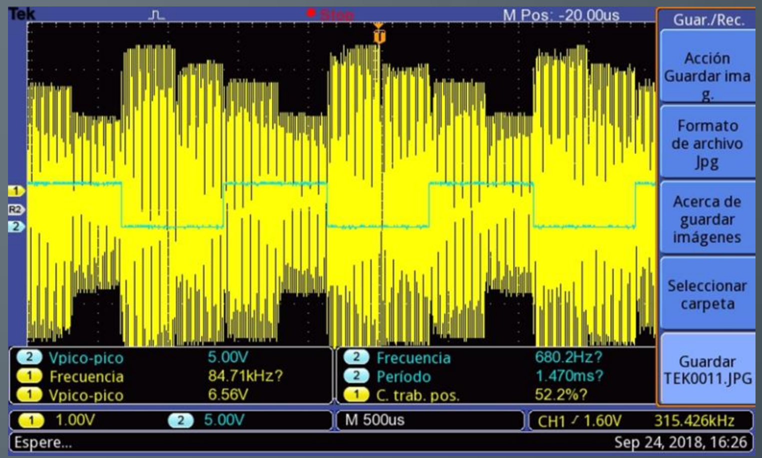
Individual test results

- Results:
  - Amplification: 32 dB
  - Demodulated frequency 668 KHz

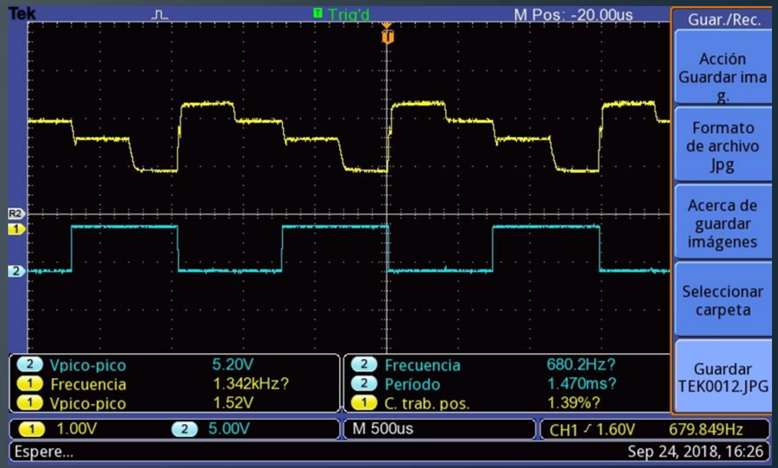
- Input



- Amplifier output



- Demodulator output



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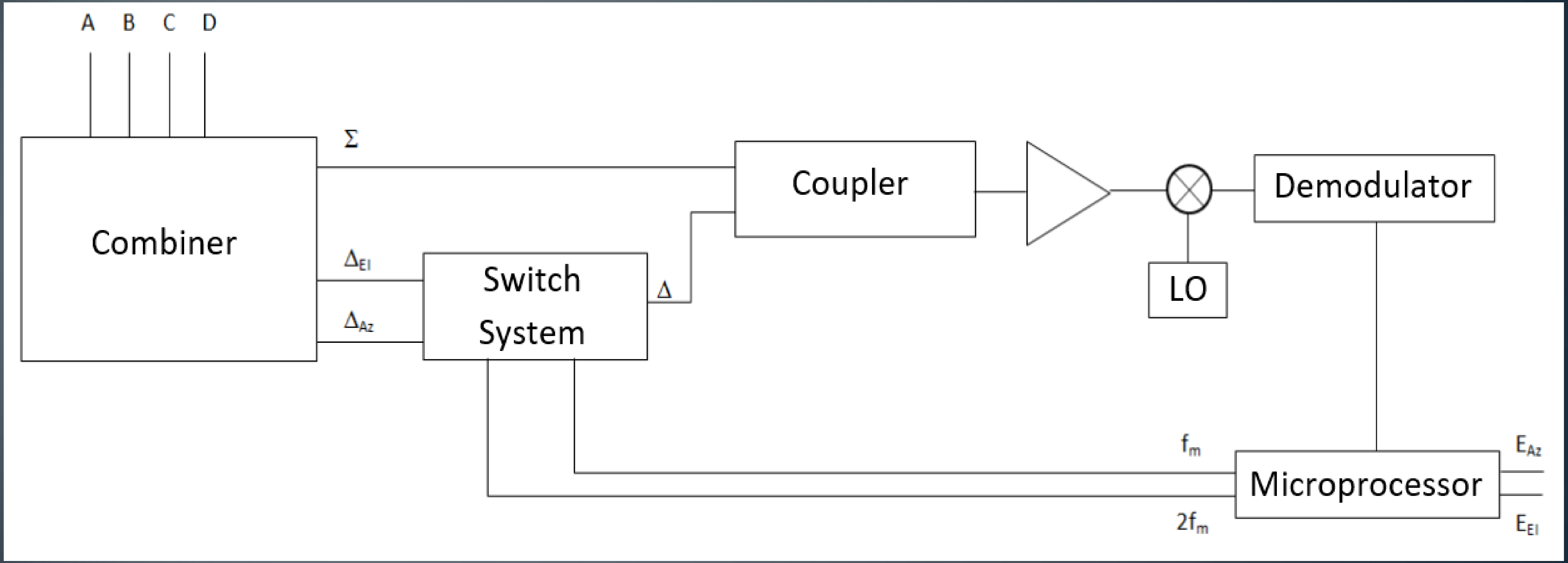
Final device



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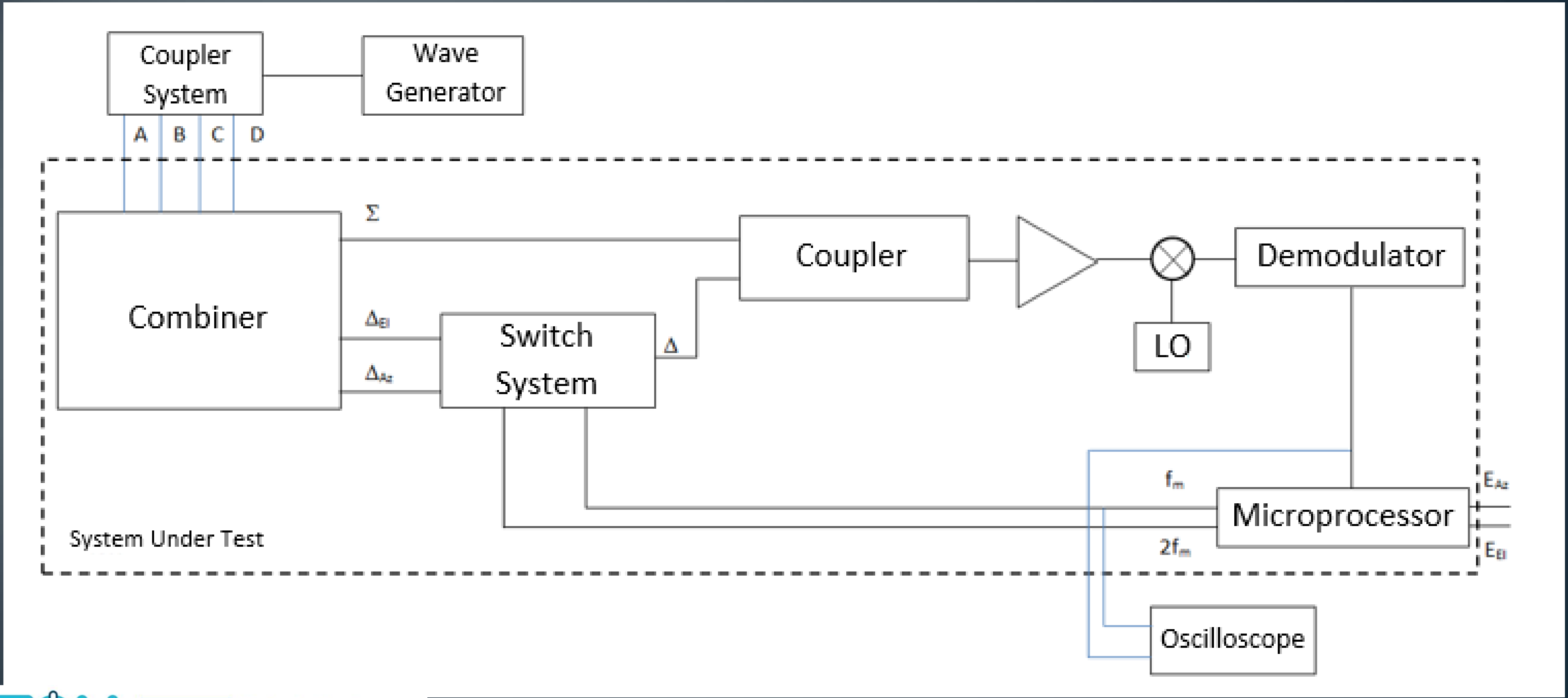
Proposed testing bench



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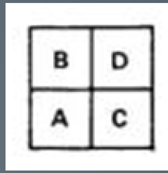
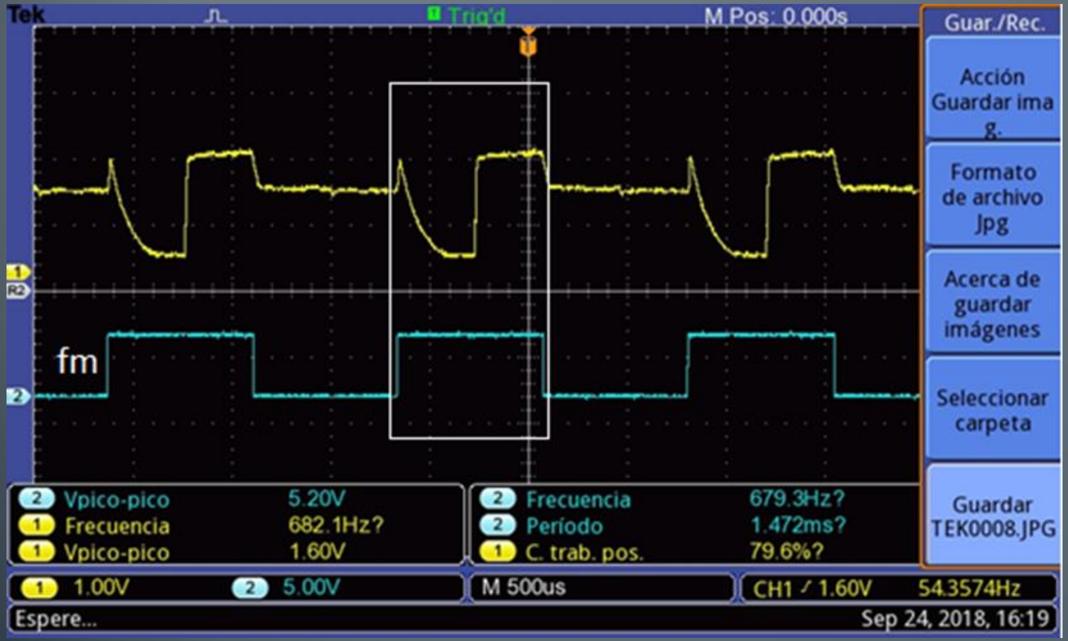
Results

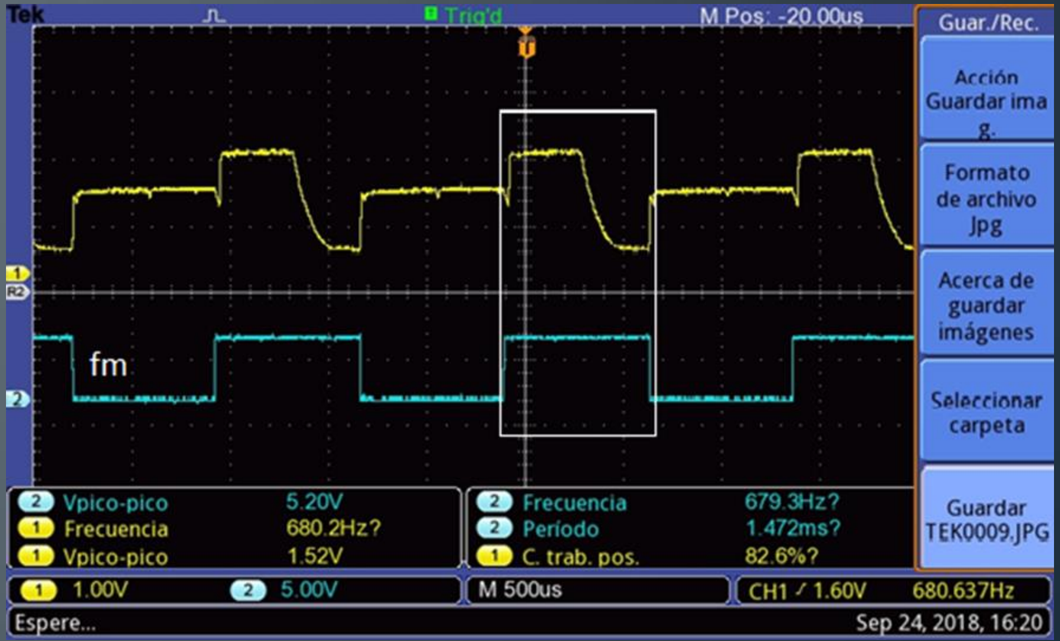
Elevation error → [(C+D)-(A+B)]



- Positive (C+D)



- Negative (A+B)



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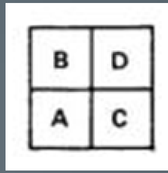
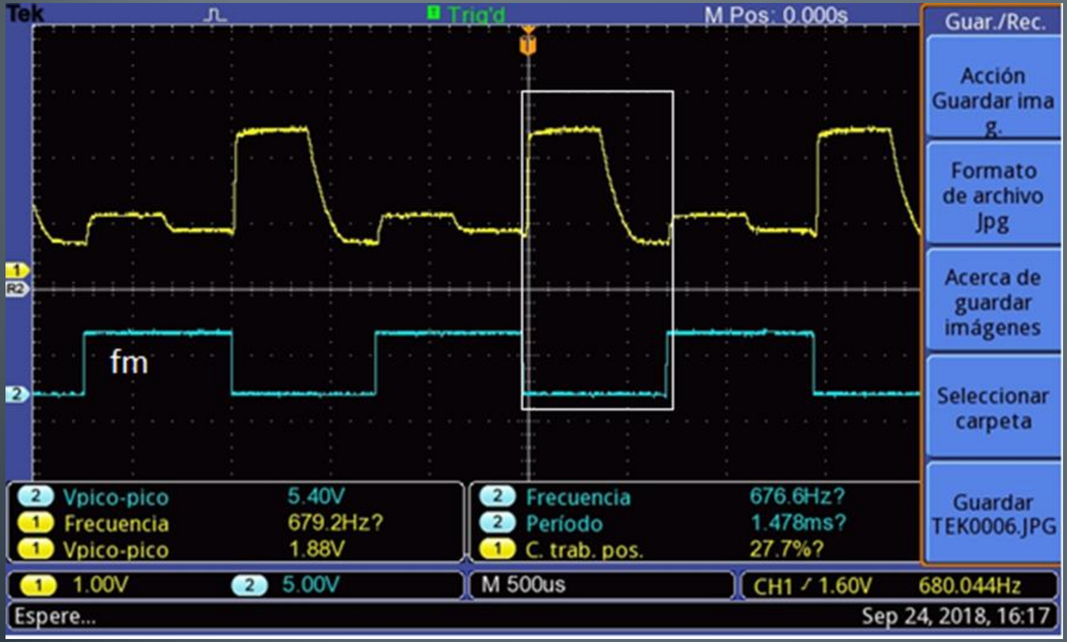
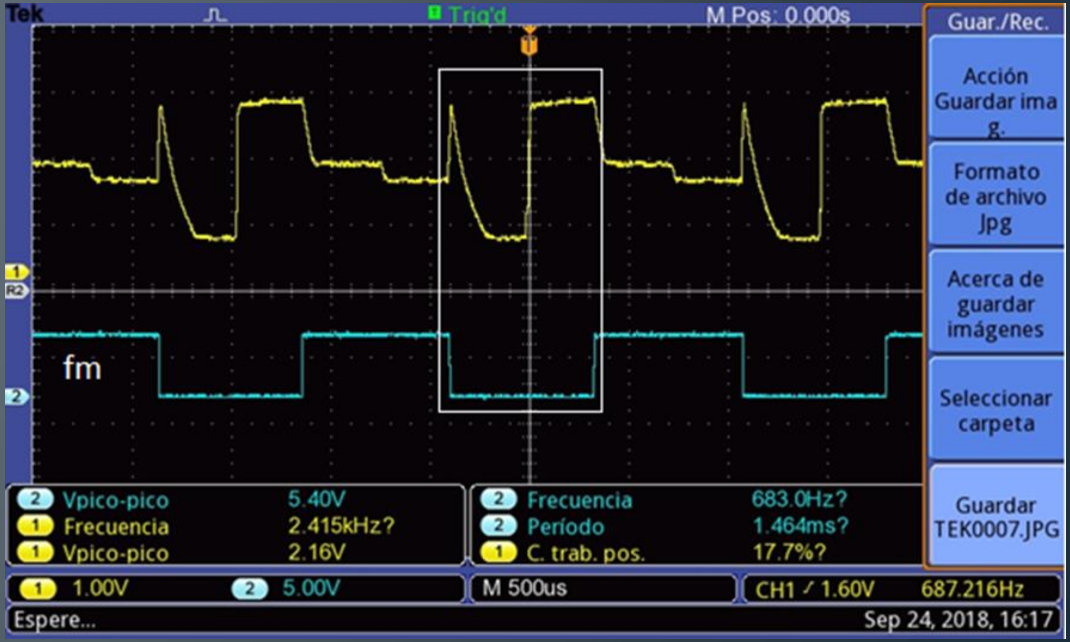
Results

Azimuth error → [(A+C)-(B+D)]



- Positive (A+C)
- Negative (B+D)





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Conclusion

- A prototype was assembled that meets the specifications and parameters initially established.
- Detection of azimuth and elevation error signals, with their corresponding PWM output signals.
- The measurements of the implementations of each stage were within the established tolerable limits.
- Learning and use of specific software.
  - Microstrip, Stripline: Ansoft Designer, HFSS
  - Board Design: Altium
  - Circuit Design and Simulation: LTSpice
  - SDR: Matlab, HDSDR
- Putting into practice knowledge from various areas within the specialty.
- Use of SDR technology

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Improvements and future developments

- Generate single board:
  - RF: Delays, lengths and widths of lines
  - Phase
  - Transfer
- Build an antenna array:
  - Four lobe system
  - Robust, to avoid interference
- SDR applied in real-time OS
- Control system
  - System to control: Incoming signal, servos and antenna

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Thanks!

We will answer your questions and concerns

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