

## Introduction

Total electron content (TEC) can be measured from the path created between radio beacons mounted in low Earth orbit (LEO) satellites and ground receivers. Universal Software Radio Peripheral (USRP) has been widely used as ground receivers due to its reliability, data quality and the feasibility.

However, for this kind of experiments USRP only uses 20% of its maximum performance (sample rate, number of bits). Therefore, a cheaper SDR receiver is tested in order to compare its quality.

One feature of sophisticated receivers like USRPs is the external PPS input. This characteristic allows to synchronize remote systems. Normally, cheaper receiver doesn't have it included, however using an external transmitter board can have similar results

## Representation

Theoretically an IQ signal can be represented as:

$$z_1 = A_1 e^{j\omega t + j\phi_1}$$

$$z_2 = A_2 e^{j\omega t + j\phi_2}$$

$$\frac{z_1}{z_2} = A_{12} e^{j(\phi_1 - \phi_2)}$$

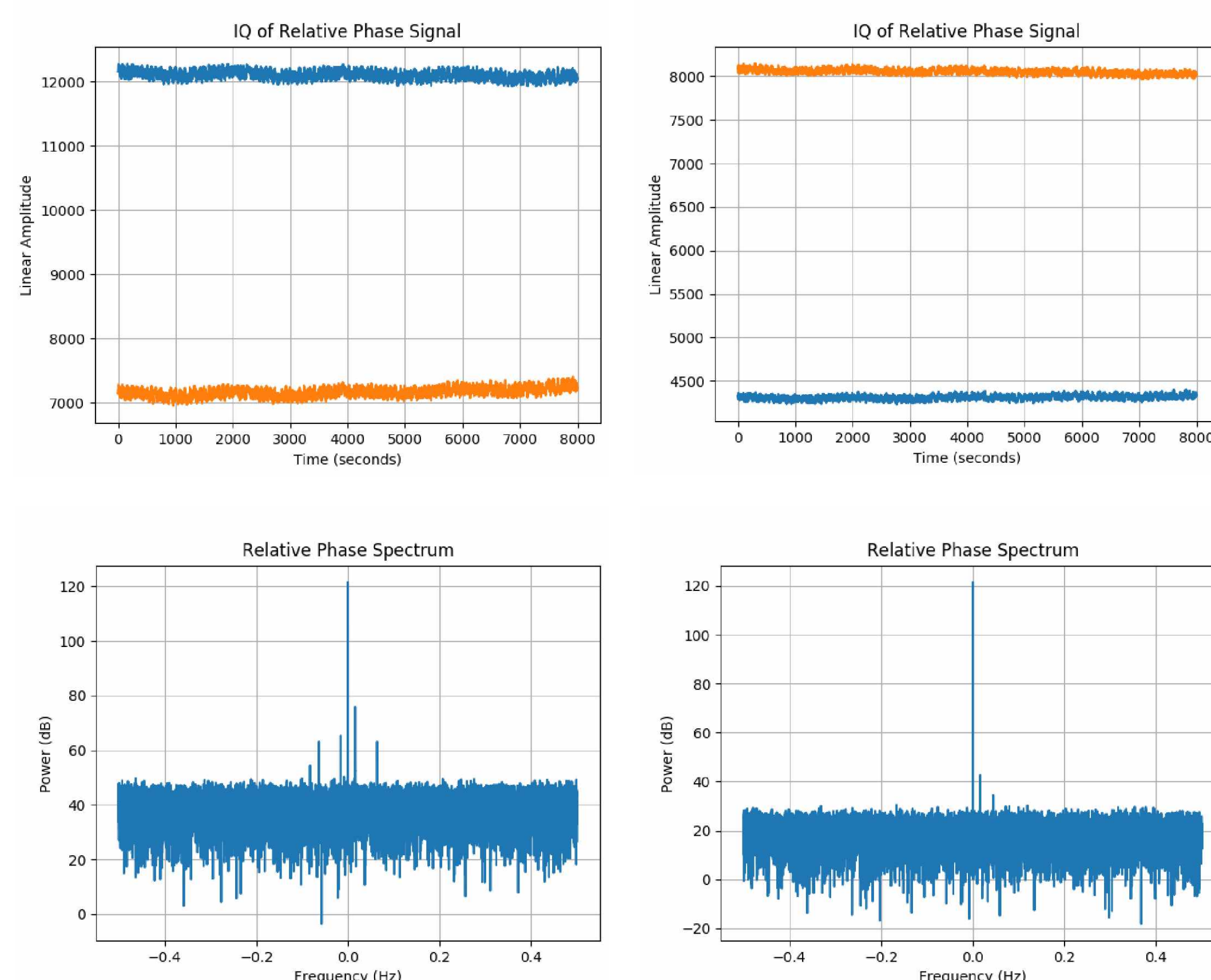
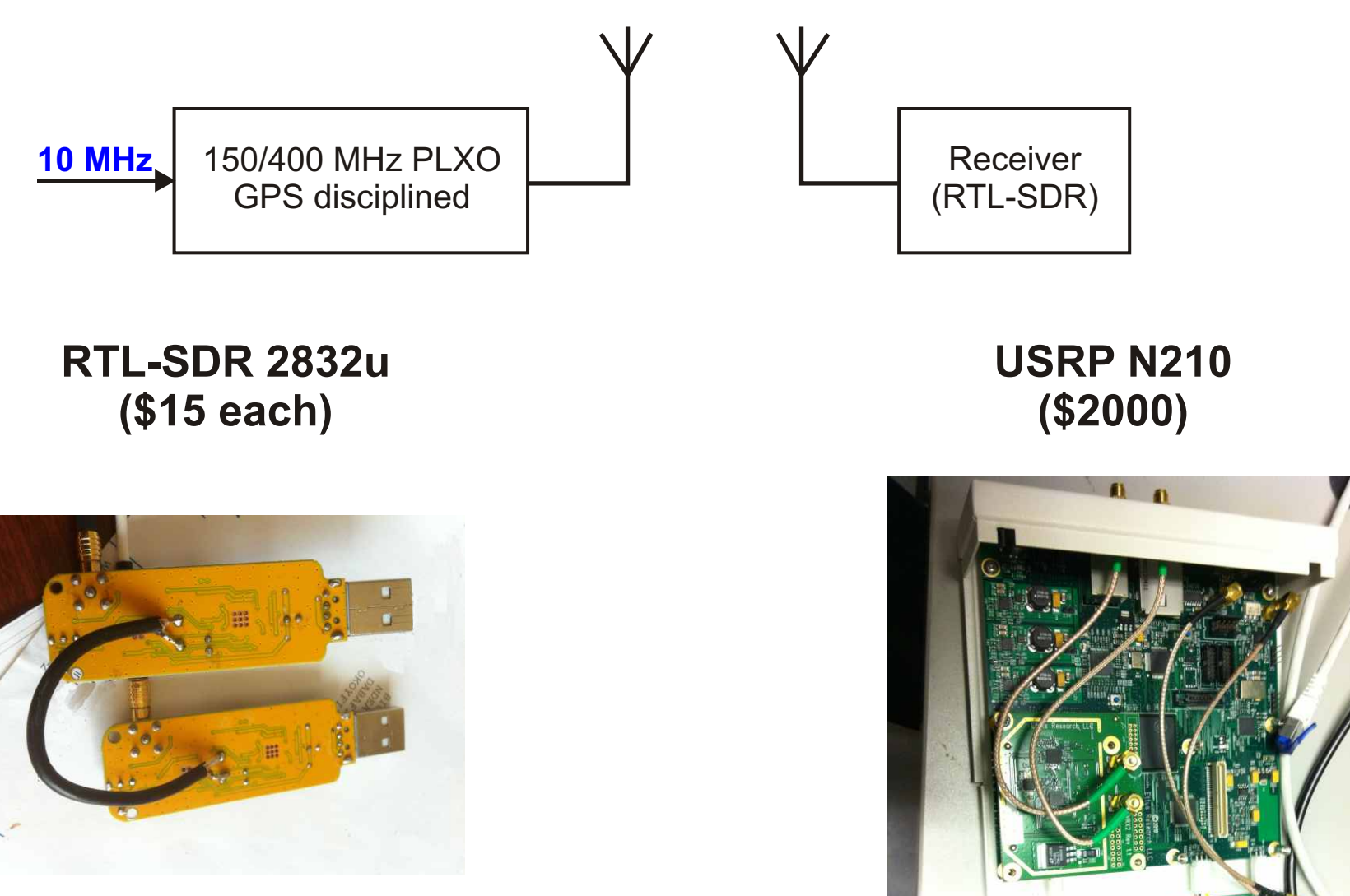
But in a real case the IQ signal contains more factors:

$$z_1 = A_1 e^{j\omega t + j\Delta\omega_1 t + j\phi_1}$$

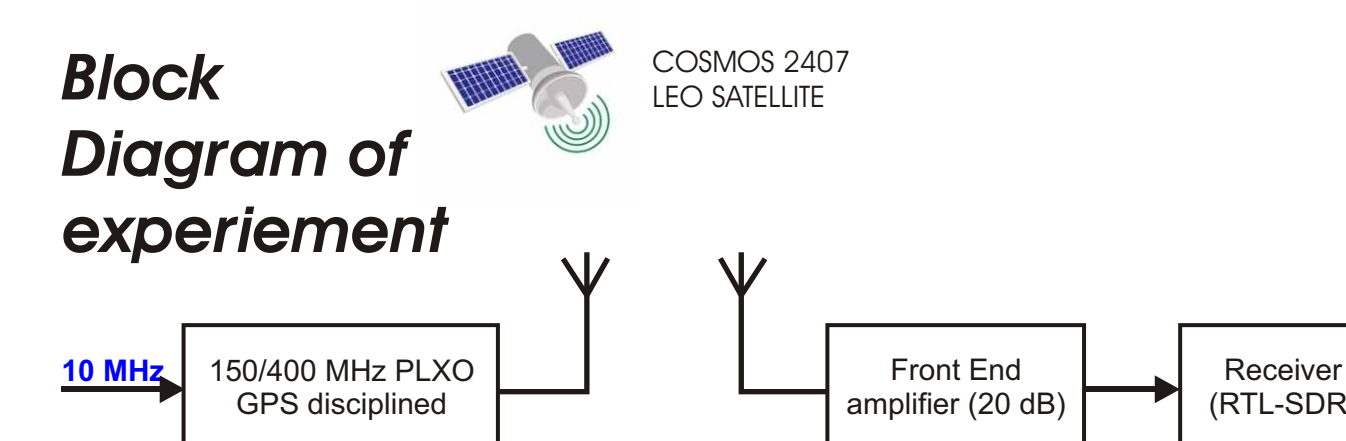
$$z_2 = A_2 e^{j\omega t + j\Delta\omega_2 t + j\phi_2}$$

$$\frac{z_1}{z_2} = A_{12} e^{j(\Delta\omega_1 - \Delta\omega_2)t + j(\phi_1 - \phi_2)}$$

First, a good test to measure is the relative phase noise of two receivers which allows to check if the system has a detectable sample drift (Spectrum and IQ of the  $z_1/z_2$  ratio)



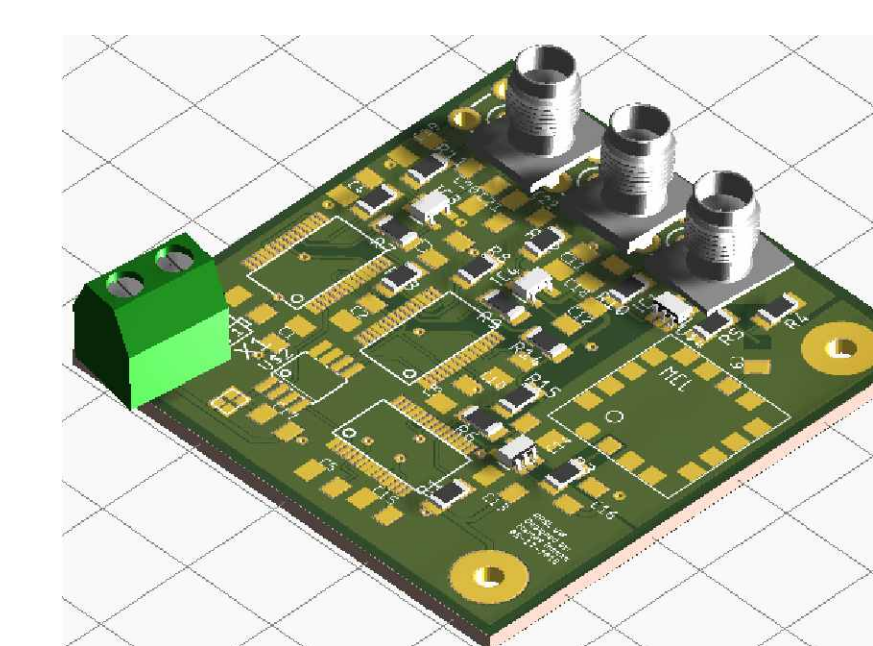
## Results



EM research PLXO multiplier



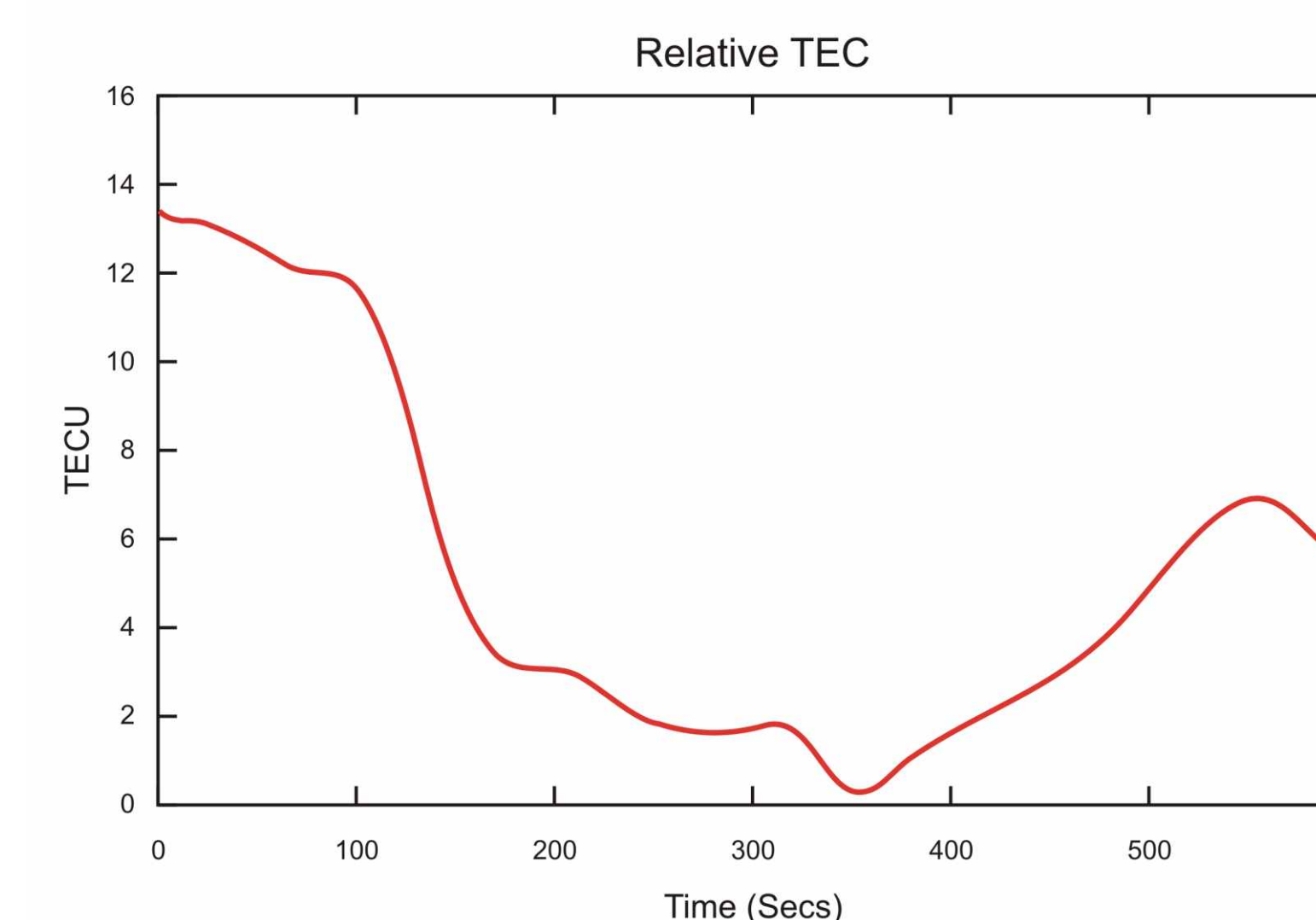
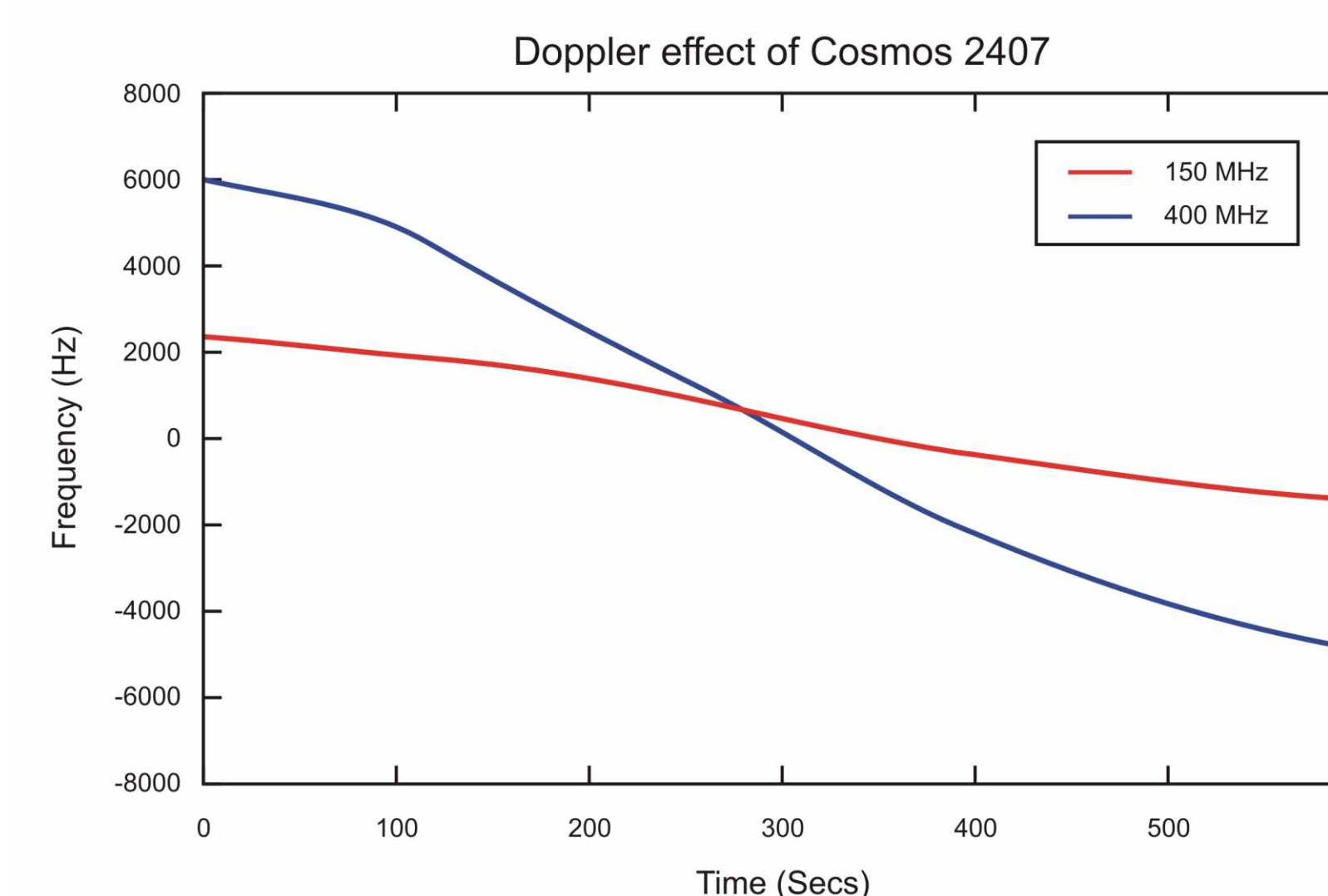
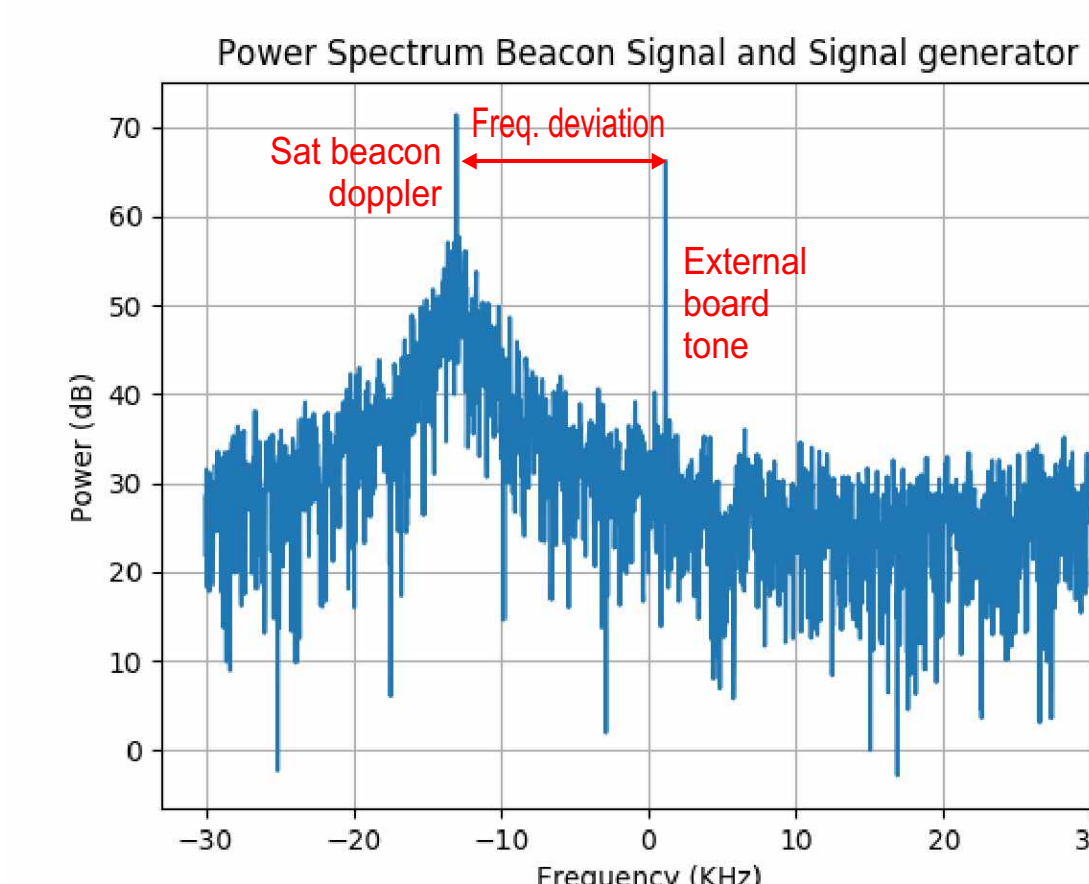
Design of a transmitter board 150 MHz / 400 MHz / 1066 MHz



Preprocessing by using the Yamamoto's technique

$$X[m, \omega] = \sum x[n] h[n - m] e^{-j\omega n}$$

Where  $h[n]$  is the hamming window



## Conclusions

- External transmitter board helps to estimate the drift of the intermediate frequency in the receiver and compensate the lack of external PPS
- TEC receivers don't require a large number of bits, neither high sample rate because phase measurement is accurate with coherent integration. Therefore, cheap receivers as RTL-SDR can give decent results.
- SDR technology is a growing movement so there will be a wide variety of products are in the market. This will lead to more interesting alternatives which will allow to have sophisticated receivers at a inexpensive prices.

## References

- VIERINEN, Juha. Beacon satellite receiver software for ionospheric tomography. 2011.
- YAMAMOTO, Mamoru. Digital beacon receiver for ionospheric TEC measurement developed with GNU Radio. Earth, Planets and Space, 2008, vol. 60, no 11, p. e21-e24.
- BERNHARDT, Paul A.; SIEFRING, Carl L. New satellite-based systems for ionospheric tomography and scintillation region imaging. Radio science, 2006, vol. 41, no 5.