

A Ku-Band Altimeter for Improved Estimation of Electromagnetic Bias in Radar Altimetry

Don E. Crockett
Brigham Young University, MERS Laboratory
459 CB, Provo, UT 84602
801-378-4884, FAX: 801-378-6586
don.crockett@byu.edu

Abstract— A Ku-band altimeter has been designed and is currently being constructed. Tower and airplane measurements will be taken from the system. The data from this instrument will be used for improvement in electromagnetic(EM) bias estimation. This paper presents a description of the hardware for the altimeter and the experiment to be performed. This instrument will be used in an experiment in support of the upcoming NASA/CNES JASON-1 mission.

INTRODUCTION

Satellite EM bias estimation studies and direct EM bias measurements made from aircraft and towers have shown that modeling the EM bias in terms of wave height and wind speed alone is insufficient. A Ku-band altimeter has been designed to collect data for improvement in EM bias estimation. The experiment which is proposed is unique in that the same instrument will be used for both the tower and the airplane experiments. By performing the experiment in the tower and airplane using the same instrument, the EM bias can be better characterized.

A design for a new Ku-Band altimeter to collect sea surface height measurements is shown in Figure 1. The altimetry data from this instrument will be used to de-

velop algorithms to better estimate the EM bias. Design criteria for this altimeter include low cost, low power, and a system which can be mounted on a tower and flown in a lightweight four passenger airplane.

Operation of this Ku-band altimeter is very similar to the JASON1 altimeter[4]. The 14 GHz altimeter transmits a linear frequency modulated(LFM) chirp which is generated from a linearized voltage controlled oscillator. Two cross fanbeam slotted waveguide antennas will be used to achieve a 1.2 degree beamwidth and a resulting antenna spotsize of six meters. The receiver uses a matched correlation filter, digitizes this signal, and performs the FFT. The data is then corrected for aircraft motion with an inertial navigation unit/GPS. This paper presents a description of the operation of the altimeter, the design and testing of the LFM chirp generator, and a description of the experiment to be performed.

DESCRIPTION OF THE SYSTEM

The block diagram of the altimeter is outlined in Figure 1. A signal with frequency of 13 GHz is mixed with a 0.5-1 GHz LFM chirp. A custom built filter then removes the lower sideband. The signal then goes into a 3 dB power divider which equally splits the signal to the transmitter and receiver. The transmit signal is then amplified and transmitted. The return signal passes through a low noise amplifier(LNA) and is mixed down to baseband. The receive signal is then digitized and an FFT is computed.

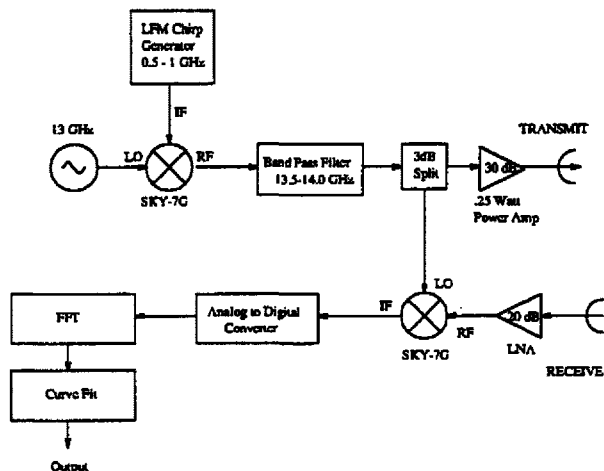


Figure 1: The block diagram of the 14 GHz altimeter.

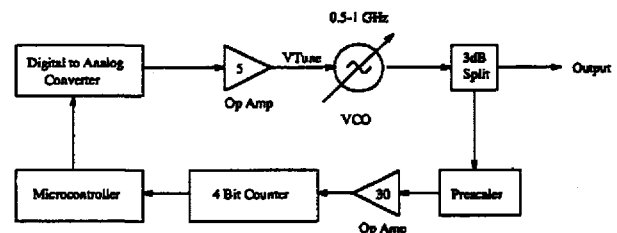


Figure 2: The block diagram for the Linear Frequency Modulated(LFM) Chirp Generator.

One of the fundamental components of the system is the custom built LFM chirp generator (see Figure 2). A microcontroller generates a digital linear voltage. This digital value then goes into a ten bit digital to analog converter(DAC). An operational amplifier amplifies the DAC voltage which is used to tune a voltage controlled oscillator(VCO). A 3 dB split divides the signal for the LFM chirp output and for a feedback loop. The microcontroller uses the feedback to determine how the VCO varies from linearity and adjusts the digital output accordingly. Significant software coding was required to program the microcontroller to perform the linearization of the VCO.

The linearity of the LFM chirp is one of the key variables to determine the resolution of the system. The best resolution which can be achieved is approximately one over the bandwidth. After computing the autocorrelation of a chirp produced from the VCO, the resolution without linearization of the VCO is 1.804 meters(see Figure 3); the best resolution which could be achieved for an ideal chirp is one meter resolution. Figure 4 shows a plot of voltage versus frequency for the VCO in the range of 10-260 MHz.

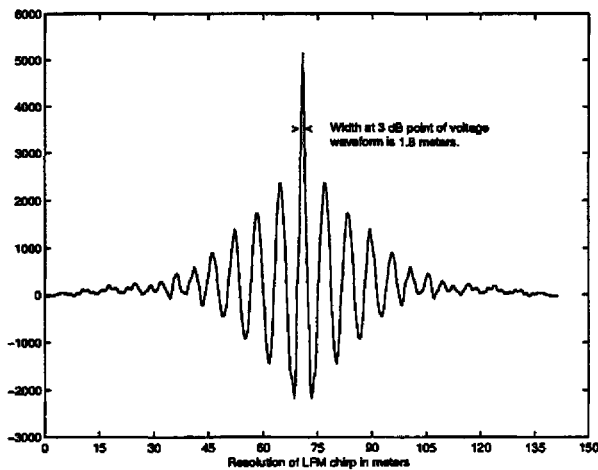


Figure 3: A plot of the autocorrelation of a 300 MHz bandwidth LFM chirp with a 0.1 μ second period from the VCO multiplied by the speed of light.

The carrier is generated from a 2.3-3.0 GHz VCO, then multiplied and filtered to achieve a 13 GHz signal. Once the LFM chirp is generated, the 0.5-1 GHz signal is mixed with a 13 GHz carrier. A filter removes the lower sideband from the mixed signal. The signal is divided in two; one signal is transmitted and the other is used for mixing down. A power amplifier amplifies the signal to a power of 0.25 Watts. The resulting transmitted chirp is a frequency from 13.7-14 GHz.

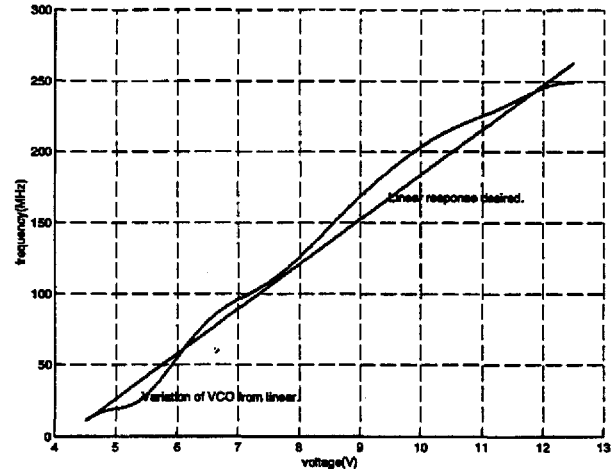


Figure 4: A voltage(Volts) versus frequency(MHz) plot for the linearity of the VCO.

Two cross fanbeam slotted waveguide antenna will be used to achieve a 1.2 degree beamwidth and a spotsize of three to six meters. The antenna properties restrict the LFM chirp bandwidth to 300 MHz. After the LNA on the receiver front end, the received signal is mixed with a copy of the transmitted signal.

An in-system computer will take care of all system control, data collection, and signal processing. At base-band, the signal is digitized, the FFT is performed, the data is curve-fitted, and averaged. In aircraft experiments the data is corrected for aircraft motion with an existing motion measurement system.

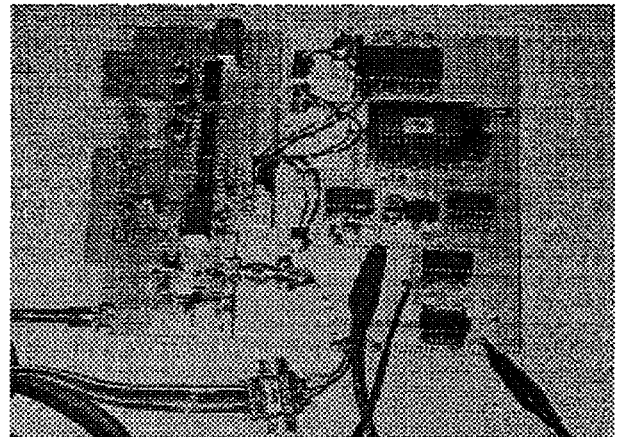


Figure 5: A picture of the LFM Chirp Generator. The board shown in the picture does not include the filter, power divider, and power amplifier.

LFM CHIRP GENERATOR

The LFM chirp generator, shown in Figure 5, is the fundamental component of the entire system. In order to test the linearity of the system, a prototype receiver was built. The signal from the LFM chirp generator was split, with one signal going to a mixer and the other going through a delay line. The delay was introduced into the system via a 33 foot length of cable. A mixer then mixed the two signals. Equation 1 was used to approximate the frequency of the signal which resulted from the delay line,

$$\text{frequency}_{\text{return}} = \frac{l \text{ BW PRF}}{V}, \quad (1)$$

where l is the length of the cable, BW is the frequency bandwidth of the chirp, V is the velocity in the cable, and PRF is the pulse repetition frequency. The velocity in the cable was approximately 2.2×10^8 meters per second, the frequency bandwidth was 450 MHz, and the PRF was 100 Hz.

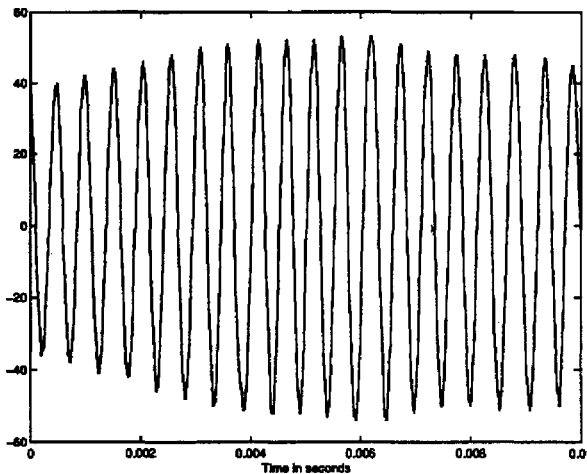


Figure 6: The resulting waveform from the delay line on the mixer output.

The waveform measured on the output of the mixer is shown in Figure 6. An FFT was performed on this signal and compared to the value of 2.2 kHz which was obtained from Equation 1. In Figure 7, the plot of the magnitude of the FFT of the return signal shows a peak at 2 kHz. The difference in value can be attributed to not accurately knowing V , the velocity of the wave in the cable. The results show the performance of the LFM chirp generator will meet the required specification for linearity.

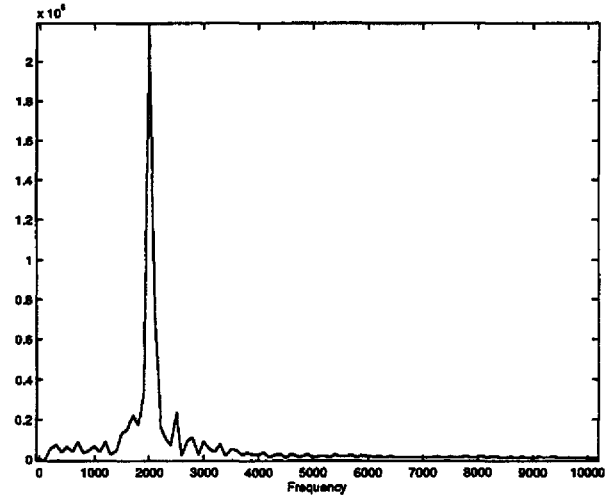


Figure 7: The FFT of the output from the mixdown. The width of the signal at the one half power point is 80 Hz.

FUTURE WORK

The receiver, antennas, and computer control for the altimeter are currently under construction. The LFM chirp generator is the fundamental piece of the altimeter, and it also was the one component which would require the most time for design and construction. Other components will require less time to build.

The prototype used for testing the LFM chirp generator will be the same design used for the actual receiver. The prototype can be seen in Figure 8. In the figure, starting from right to left can be seen a four-way power di-

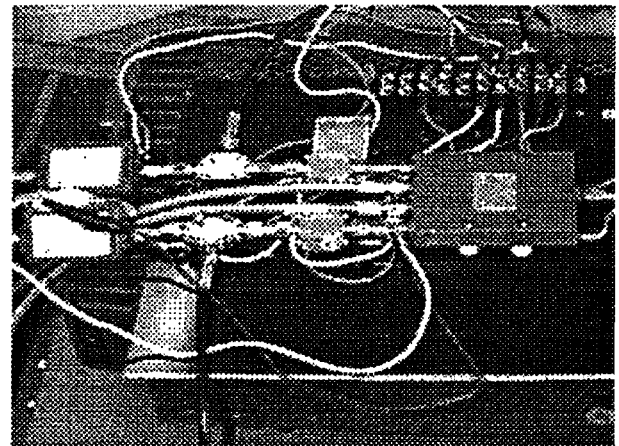


Figure 8: A picture of the receiver prototype. In this picture, the input signal from the LFM chirp generator comes from the right and the received signal comes from the left.

vider, two amplifiers, two mixers, and two more amplifiers. The power divider splits the LFM chirp into a transmit signal and two receive signals (the fourth signal is not used). Phase information was obtained by having two receive channels. The amplifiers shown in the picture amplify the signals going in to the mixer. From the right amplifier is a copy of the transmitted signal and from the left comes the delayed signal. In this setup, the mixer outputs the signal resulting from the delay line.

The last thing which will need to be done is integration of the entire system. A computer will control the operation of the system as well as process the collected data. All components of the system will also need to be mounted in a case which will allow operation from a small four passenger airplane.

EXPERIMENT TO BE PERFORMED

Experiments from this system will be performed off the coast of California in 2000-2001. The altimeter is scheduled to operate on two different platforms: a tower and an airplane. The experiment which will be performed using this Ku-band altimeter is unique in that the same instrument will be used for the tower and for the airplane experiments. The importance of taking both measurements comes from the fact that the EM bias has been measured to be different from the two platforms [1],[3]. Recently the work of Smith and Arnold [5] has shown the tower measurements are similar to satellite measurements [2]. This experiment will allow more accurate tower measurements which can improve satellite EM bias estimation.

ACKNOWLEDGMENTS

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REFERENCES

- [1] D.V. Arnold, W.K. Melville, R.H. Stewart, J.A. Kong, W.C. Keller, and E. Lamarre "Measurements of Electromagnetic Bias at Ku and C Bands," *Journal of Geophysical Research*, vol. 100, No. C1, pp. 969-980, 1995.
- [2] P. Gaspar, J.P. Florens, "Estimation of the Sea State Bias in Radar Altimeter Measurements of Sea Level: Results From a New Nonparametric Method," *Journal of Geophysical Research*, vol. 103, No. C8, pp. 15,803-15,814, 1998.
- [3] L.G. Hevizi, E.J. Walsh, R.E. Macintosh, D. Vandemark, D.E. Hines, R.N. Swift, J.F. Scott, "Electromagnetic Bias in Sea Surface Range Measurements at Frequencies of the TOPEX/POSEIDON Satellite," *IEEE Trans. on Geoscience and Remote Sensing*, vol. 31, No. 2, pp. 376-388, 1993.
- [4] J. Richard, L. Rey, A. Fauré, "JASON Altimeter - Technologies and Performance," *IEEE Geoscience and Remote Sensing Symposium*, vol. 4, pp. 2017-2019, 1998.
- [5] J.D. Smith, D.V. Arnold, "Non-Parametric Representation of the Electromagnetic Bias in Radar Altimetry," *IEEE Geoscience and Remote Sensing Symposium*, 1999.