

# **Target Simulation for Internal Layers of Greenland Ice Sheet**

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## **Abstract**

Radar Systems and Remote Sensing Laboratory (RSL) at the University of Kansas developed a wideband radar that operates over the frequency range, 600 MHz to 900 MHz used to map the near surface internal layers in glacial ice. As many commercial wireless devices use this frequency range, it is not possible to test the radar system in the continental United States. We solved this problem by developing a radar target simulator for testing and calibrating the radar in laboratory without the need for expensive field trips to polar regions. It uses optical and microwave delay lines for evaluating and optimizing the performance of the wideband radar. The target simulator replicates reflections from the air-firm interface and the internal layers of the ice sheet, which are spaced about 50 cm apart, and the feed-through signal between the transmit and receive antenna. We simulated the internal layers by incorporating a feedback loop with a short delay line. This paper presents the scientific requirements for mapping the near-surface internal layers and details of the design, construction, and evaluation of the wideband radar target simulator.

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## 1.0 Introduction

The melting of mountain glaciers, contributions from polar ice sheets, and the thermal expansion of oceans have led to the increase in sea level of about 2mm/yr over the last century [1]. The Intergovernmental Panel on Climate Change predicts that sea level may rise between 20 and 100 cm by the end of this century, which has serious consequences to people living in coastal areas [2]. In the recent IEEE Spectrum magazine Perry reported that Tuvalu, a Pacific Island Nation, was evacuated because of the fear that the rising sea level will submerge it [3].

The polar ice sheets contribution to the sea level rise has been a topic of much debate and speculation. To assess the contribution of the polar ice sheets to the rising sea level, we need accurate information on the mass balance of the ice sheets. We can determine the mass balance using the flux or volumetric approach. With the flux approach, we must compare the net long-term average input — net accumulation — and output — ice flow — fluxes. We have to measure changes in surface elevation to determine the mass balance using the volumetric method [4]. We need an estimate of the accumulation rate to compute the ice flux as well as to interpret any changes in surface elevation particularly to identify any effects associated with short-term regional climate fluctuations.

Over the past few years the Radar Systems and Remote Sensing Laboratory (RSL) at the University of Kansas has been exploring the application of wideband radars for mapping the dated internal layers — isochrones — of the Greenland ice sheet to estimate the accumulation rate. Such research led to the development of a frequency

modulated continuous wave (FM-CW) radar for this application [5]. The isochrones embedded within the ice sheets form under pressure due to annual accumulation of snow melt events, and volcanic ash events. Traditionally, experts determine the accumulation rate by analyzing ice cores and stratigraphy in snow pits. Because of extreme conditions in polar regions it is not feasible to collect a sufficient number of cores or to dig many pits to reduce the errors induced by the spatial and temporal variations in accumulation. Wideband radar mapping, coupled with core and pit data, will help reduce the uncertainty associated with interpolating the ice core data and helps cut costs while providing a larger area of coverage.

Testing of radar systems in the UHF band is difficult, due to interference from and to television broadcast signal and wireless devices such as cell phones. Therefore, it is critical to develop a means of testing the radar system before deployment in the remote polar regions. Thus we need a target simulator to replicate the conditions in the field for mapping the internal layers. The target simulator is designed to simulate the primary reflections seen in radar echograms. Reflections include the antenna feed-through, reflections from the air-firn interface and from the internal layers. The target simulator will not only help in optimizing the system performance, but also will enable calibration of the radar while in the field.

We designed and developed a target simulator using optical and microwave delay lines. With our design, we performed computerized simulations using the Advanced Design System 1.5 (ADS). ADS, commonly referred to as EESof<sup>®</sup>, is a product of Agilent Technologies. We constructed the rapid prototype from the optimized schematic. Once we constructed the prototype we used the network analyzer to characterize the

components used in the radar and target simulator. Through the characterization process, we obtained the scattering matrices. We used these scattering matrices to create a realistic system model for the EESof<sup>®</sup> simulation for generating target simulator response that can be compared to the measured data.

## 2.0 Background

The University of Kansas conducted surface-based experiments in 1998 and 1999, using the FM-CW radar, which operated in the frequency range, 170 to 2000 MHz [6]. Kanagaratnam et al. [6] analyzed the data obtained from this ultra-wideband radar to determine the optimum frequency range within the constraints of operating onboard an aircraft. They chose the frequency range of 600-900 MHz to maximize sensitivity of the radar in mapping the near surface internal layers, while minimizing the interference to aircraft navigation and communication systems. They also developed a prototype system operating in the aforementioned frequency range. Kanagaratnam et al [6] used this system to collect data during the 2001 field season over Greenland, and demonstrated that near-surface internal layers can be mapped with better than 1 m resolution. However, the system performance was less than ideal. Problems associated with it were identified during these experiments such as inadequate isolation between transmitter and receiver sections of the radar and insufficient receiver dynamic range. To assist with the development and testing of an improved radar, we developed a radar target simulator. The target simulator duplicates the field conditions in polar regions, allowing researchers to optimize the radar without repeated trips to the field [6].

The use of microwave and optical fiber delay lines is a well-established practice for producing target simulators for radar systems [7]. Microwave delay lines are

nominally used for short time delays or close range simulation while the optical fiber is used for long time delays or simulation of long ranges. There are several commercial target simulators that have been implemented with either of the aforementioned delay lines but none of commercial simulators are useful to us because we require one unit that utilizes both. The use of both optical and microwave delay lines allows us to simulate the antenna feed-through, reflections from the air-firm interface, and the reflections from the internal ice layers in one unit while remaining within the size and weight constraints.

### 3.0 Methodology

To fully optimize the performance of the radar in a laboratory-controlled environment, we developed a target simulator. In the early stages of developing the target simulator, we utilized the ideal components in the simulation process, as shown in Figure 1.

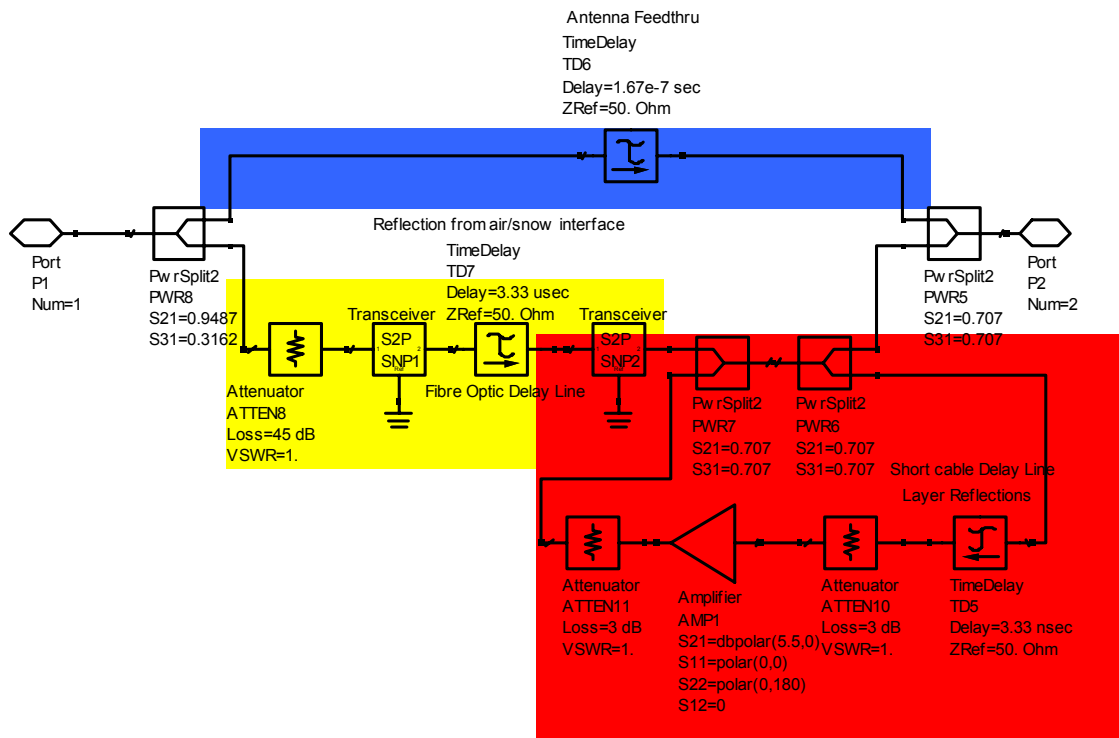


Figure 1 Schematic of the target simulator using ideal components.

To realistically model the response of the system, we measured the scattering parameters ( $S_{11}$ ,  $S_{12}$ ,  $S_{21}$ , and  $S_{22}$ ) of the components using a Hewlett Packard 8753D Network Analyzer. Using a General Purpose Interface Bus (GPIB) card, we interfaced the Network Analyzer to EESof<sup>®</sup> to capture the data. Figure 2 shows the setup we used for the characterization process.

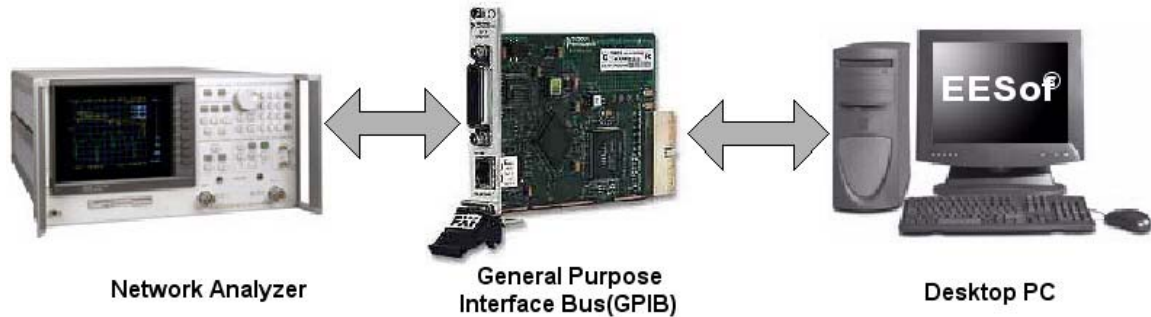


Figure 2 Experimental setup used for the characterization process.

We characterized the individual components over the 600 – 900 MHz frequency range. Once we completed characterization of all the components, we used the resulting data sets of these components in our EESof<sup>®</sup> circuit simulation shown in Figure 3.

The target simulator shown in Figure 1 consists of three main sub-sections for simulating the antenna feed-through signal shown in blue, the air-firm interface return shown in yellow, and the returns from internal layers shown in red. The transmitted signal is fed to the input port of a 90/10 power splitter (PWR8). This splitter then sends 90% of the signal energy through a 50m copper coil delay line (TD6) of 167 nsec to simulate the antenna feed-through.

The antenna feed-through signal is the energy that is directly coupled from the transmitting antenna to the receiving antenna. The remaining 10% passes through a 45-dB attenuator (ATTN8), which reduces the power level to within the capabilities of the

RF-to-optical transceiver. The signal is then fed to the input port of an RF-to-optical transceiver (SNP1), which allows the use of optical fiber to simulate the large time delay

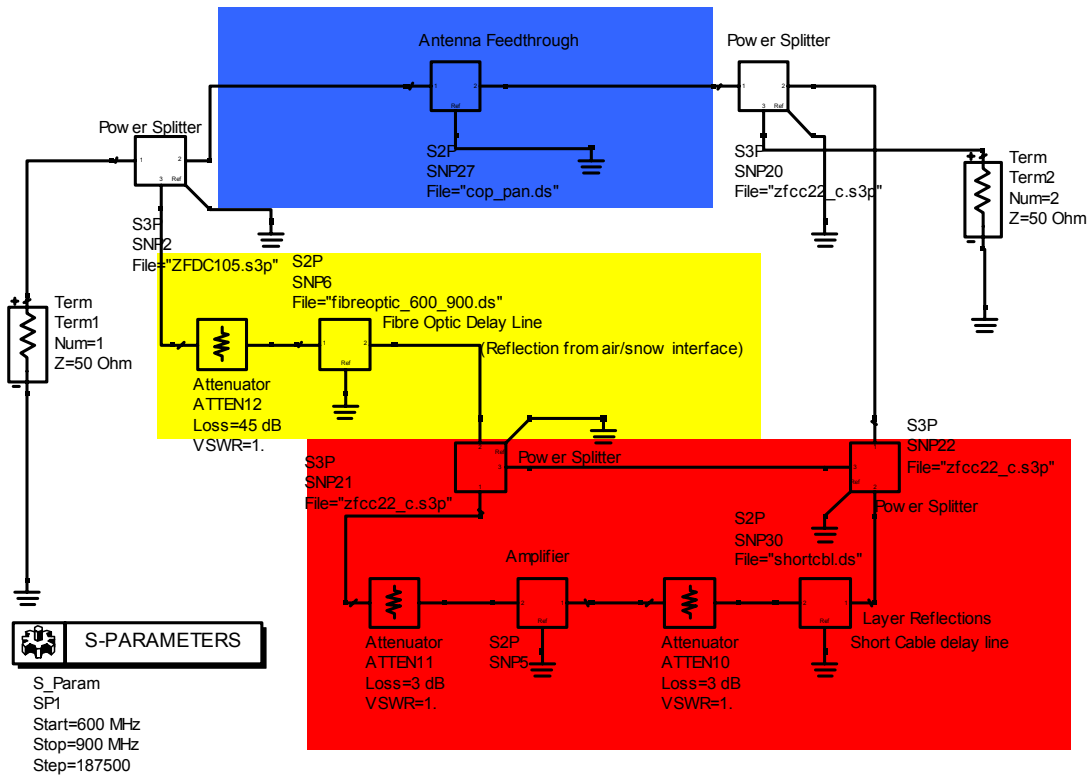


Figure 3 Schematic of the target simulator using the measured S-parameters of the actual components.

(TD7) of 3.33  $\mu$ sec. This simulates the distance between the aircraft and the surface of ice. TD7 is made of approximately 580 m of SMF-28 optical fiber. The optical signal passes through the optical fiber. The output signal from the optical fiber is fed to optical-to-RF transceiver (SNP2), where it is converted from the optical frequency region to the RF region.

Since the target simulator will also be used aboard the aircraft for in-flight testing, weight and size were important considerations. This led to the use of optical fiber. Furthermore, the optical fiber has a lower attenuation-to-length ratio, thus simulating free-space travel. The transceiver RF output signal then passes through a 50/50-power

combiner (PWR7) and a 50/50 power divider (PWR8). This provides two paths: one in which the signal passes directly to a 50/50 power combiner (PWR5) and the other in which the signal passes to the output. A portion of this signal is transmitted through a shorter delay line (TD5) approximately 1 m, simulating the internal layers of ice. The thickness of each layer of ice is modeled to be approximately 50 cm. The output of the delay line is then fed to a 3-dB attenuator (ATTEN10), an amplifier (AMP1), and to another 3-dB attenuator (ATTEN11), after which it returns to the power combiner (PWR7). The signal continues this process, simulating multiple reflections, which result from many internal ice layers. We add the attenuators, ATTEN10 and ATTEN11 to reduce the reflections due to impedance mismatch at the amplifier interface. The output port of power combiner (PWR5) is then connected to the receiver. We performed component-wise S-parameter simulation, from 600 to 900 MHz, to obtain the scattering parameters. We also performed S-parameter simulation of the assembled target simulator. This measurement is similar to a step-frequency radar measurement using a network analyzer whereby the inverse Fourier transform of the  $S_{21}$  measurement yields the reflection profile.

## 4.0 Discussion of Results

In this section, we compare the data obtained from the EESof<sup>®</sup> simulations with those obtained from the actual target simulator. Figure 4 shows the comparison between the network analyzer measurement, plotted in red, and the simulation results—plotted in blue—over the entire beat frequency range. We see that the agreement between the measured and EESof<sup>®</sup> simulated data are excellent. The 20 dB mismatch in the noise level is due to the quantization noise of the 16-bit A/D converter in the network analyzer,

which was not accounted for in the simulations. The network analyzer we used has a dynamic range of only about 100 dB, which caused the noise level to be about 20 dB higher than the noise level for the simulation.

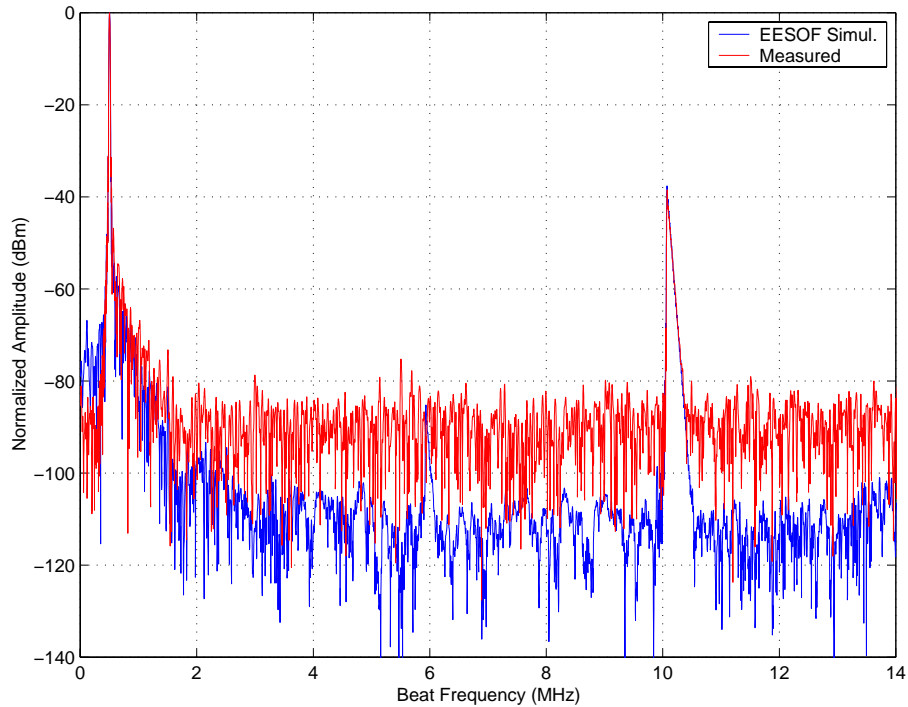


Figure 4 A comparison of the network analyzer measurements and EESof<sup>®</sup> simulation over the entire beat frequency range.

Figure 5 shows the comparison between the EESof<sup>®</sup> simulated results and the measured data over the desired surface and internal layer returns. Figure 6 shows the assembled target simulator along with the SMA adapters. These SMA adapters — which were also used to connect the target simulator to the network analyzer — caused a slight insertion loss and delay, and were not accounted for in the simulations.

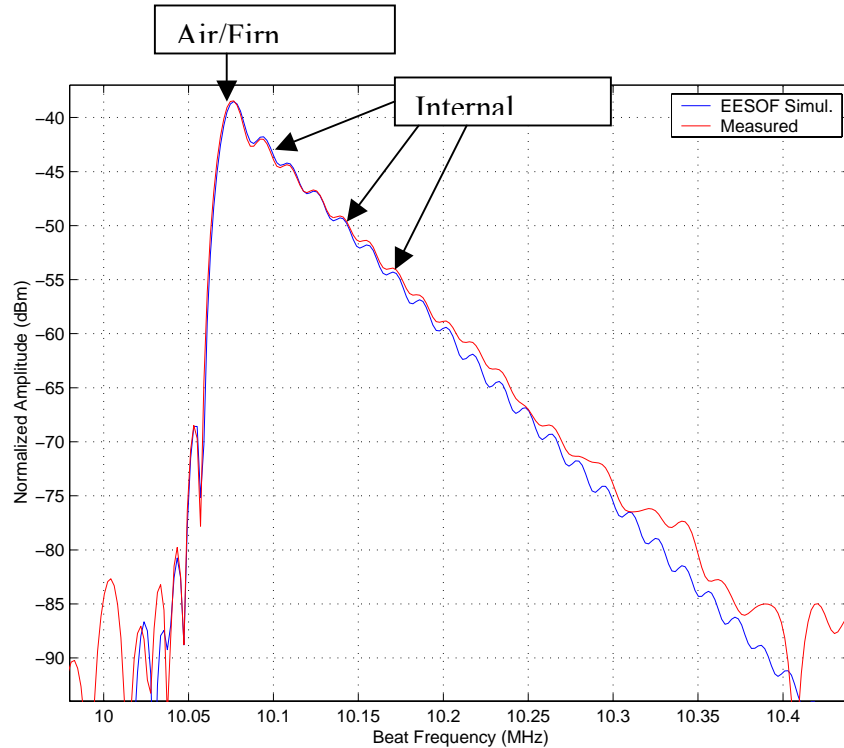


Figure 5 Comparison between network analyzer measurement and EESof<sup>®</sup> simulation over the desired beat frequency range.

We characterized these adapters separately and corrected the data to compensate for the losses. We see from the Figure 5 that there is good match between the simulated and the measured data when the Signal to Noise Ratio (SNR) is high. However, the mismatch between measured and simulated data increases as the SNR decreases. There is a near perfect match between both the measured and simulated data until 10.2 MHz — where the SNR is above 20 dB. This frequency of 10.2 MHz corresponds to about 4 m into the ice. As the SNR falls below 20 dB, we see the mismatch begins to appear. At 20 dB SNR there is a mismatch of about 1 dB and the mismatch increases gradually, and at 0 dB SNR there is mismatch of about 3 dB.

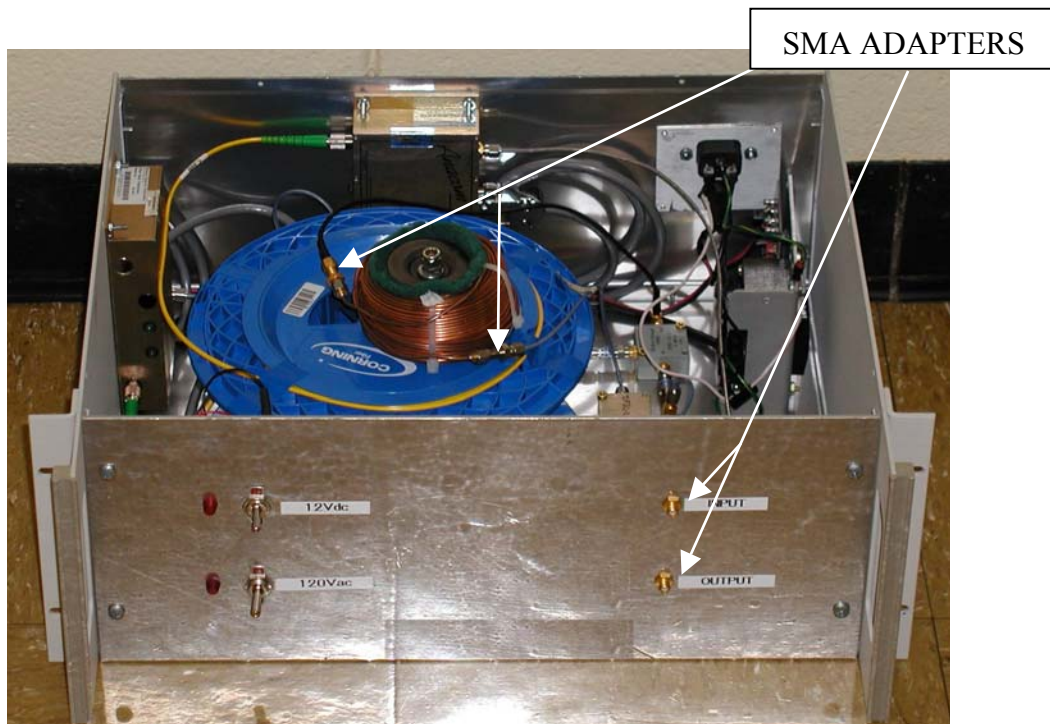


Figure 6 The assembled target simulator

The uncertainty in the signal level when the SNR is less than 20 dB can be explained from Figure 7, where the actual signal is normalized as one and the resultant received signal is plotted as a function of SNR. The two received signals are basically noise added and subtracted to the original signal. We can see from Figure 7 that as the SNR increases the two received signals converge to the actual signal. From Figure 7 we can infer that when the SNR is equal to 0 dB there is indeed a mismatch of close to 3 dB and as the SNR approaches 40 dB the mismatch reduces to 0 dB. This explains the discrepancy between measured and simulated responses. Figure 8 shows the excellent match between the simulated and the measured response of the antenna feed-through. The multiple reflections result in a slight mismatch around 0.57 MHz, as a result of impedance mismatches in the component connections.

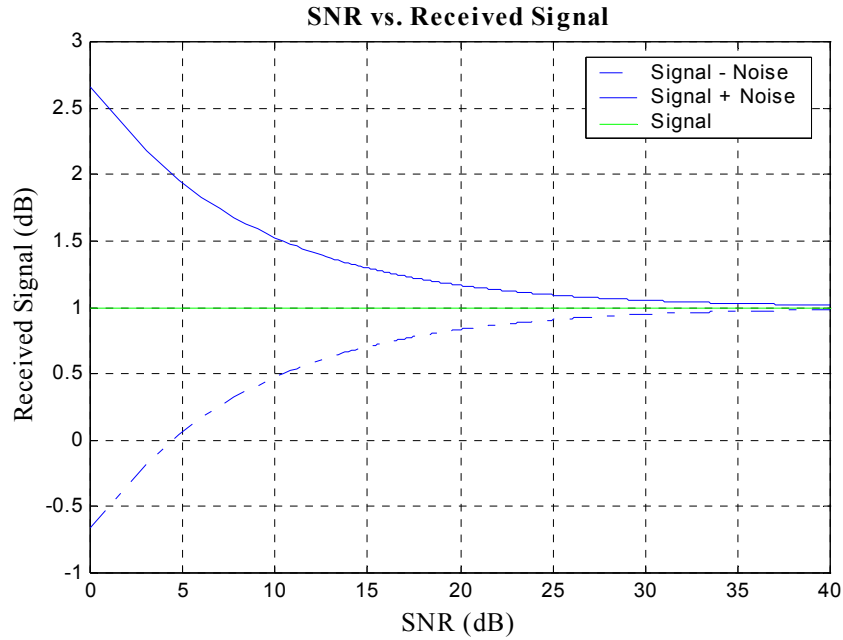


Figure 7 Plot of the uncertainty in signal level as a function of SNR

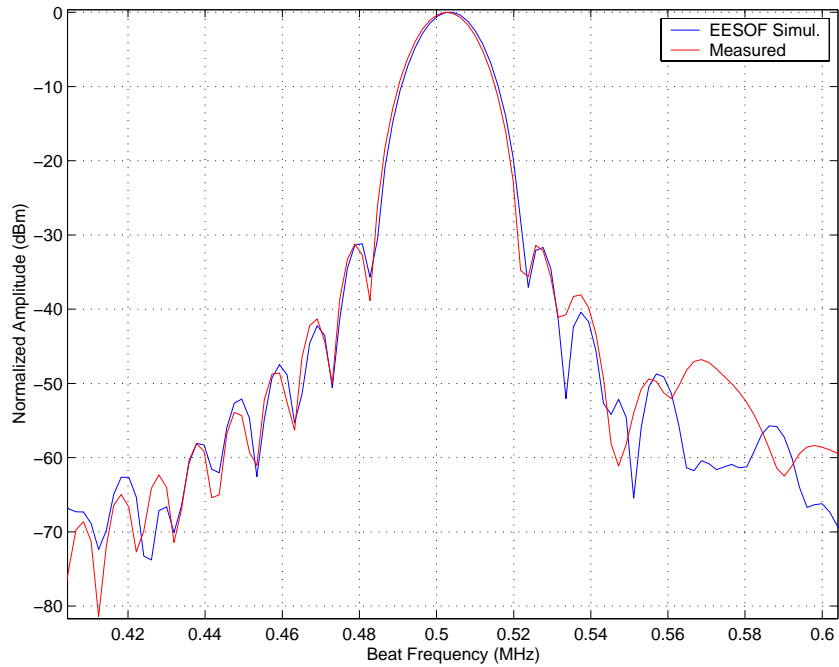


Figure 8 Comparison between network-analyzer measurements and EESof<sup>®</sup> simulation of the antenna feed-through

## 5.0 Conclusions

It is clear from the results obtained that using a fiber-optic cable to simulate the large path length between the aircraft and the ice surface, and a short cable, as a time delay to mimic the internal layers of ice is an effective solution. The unique contribution of this project is the inclusion of a *feedback* mechanism using a short cable to simulate the internal layers of ice sheet. Researchers can use the simulator to optimize the wideband radar performance in the laboratory, without having to go to the field.

We observed excellent agreement between the simulated and the measured responses when the SNR is large. However, with a low SNR we observed a small mismatch between the measured and the simulated response. This mismatch is because of noise-related uncertainty in the measured data. The simulator we developed can also be utilized to calibrate the wideband radar in the field for developing an accurate system model for the radar. Such a model can then be used in deconvolution algorithms to improve the quality of data. For future improvement, we suggest that a temperature stabilization device be incorporated to make the system immune to temperature fluctuations.

## **6.0 Acknowledgements**

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## 7.0 References

- [1] IPCC Second Assessment Report: Climate Change, A Report of the inter-governmental Panel on Climate Change, 1995.
- [2] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2001: Impacts, Adaptation, and Vulnerability (Summary for Policy Makers), Geneva, Switzerland, February 13-16, 2001.
- [3] Perry, T. S., Capturing Climate Change, *IEEE Spectrum*, vol. 39, no.1, pp.58-65, 2002
- [4] Paterson, W.S.B., *The Physics of Glaciers*, Pergamon, England, 1998.
- [5] Pannirselvam Kanagaratnam, Airborne Radar for High Resolution Mapping of Internal layers in Glacial Ice to Estimate Accumulation Rate, Ph.D. Dissertation, The University of Kansas.
- [6] Kanagaratnam, P., S. Gogineni, N. Gundestrup and L. Larsen, High-resolution radar mapping of internal layers at the North Greenland Ice Core Project, *Journal of Geophysical Research*, vol. 106, no. D24, pp. 33,799-33,812, 2001.
- [7] Anderson, C., and M. Zari. "Variable Delay Lines Offer Continuously Variable Range Selection for Radar Target Simulators." *Microwave Journal*. Vol. 37 pp. 246-251. April 1994a.

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