Modeling the Relationship of Frequency, Temperature, and Resistivity of Vanadium Dioxide

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Research Experience for Undergraduates – Summer 2015

Introduction and Broader Impact

Vanadium Dioxide (VO_2):

- Metal-to-Insulator transition
- Temperature sensitive
- Capacitive

Figure 1. CFSA and bowtie [1] antennas using VO_2 developed at SDSM&T.

Antennas:

- Multiple frequencies
- Fewer antennas needed

The objective of this study is to model the relation of temperature, frequency, and resistivity of VO_2 to allow for better simulations of the material for use in frequency dependent applications. Prior research done by our group has demonstrated the potential that VO_2 has for phase-changing antennas. Electromagnetic simulations used for VO_2 so far has only accounted for resistance, which we hypothesize may have resulted in deviations between the obtained simulated and measured antenna performance (i.e. antenna gain).

Procedure

Measurements

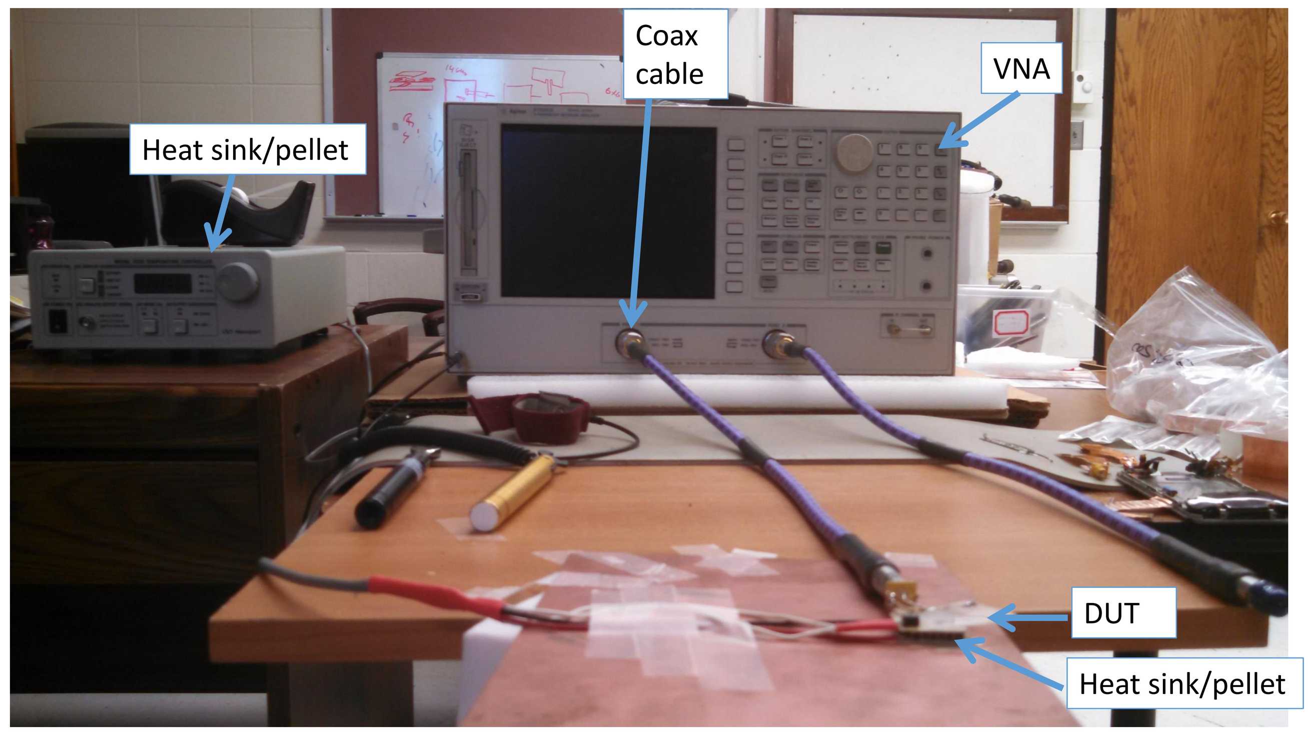

Figure 2. Equipment setup.

The impedance of the VO_2 thin strip integrated on a VO_2 antenna was measured using an Agilent 8753ES S-Parameter Network Analyzer for every 2°C from 30°C to 100°C and from 100°C to 30°C. The frequency range for these measurements was from 30 KHz to 6 GHz. **Figure 2 shows the setup used to take these measurements.**

3D Models

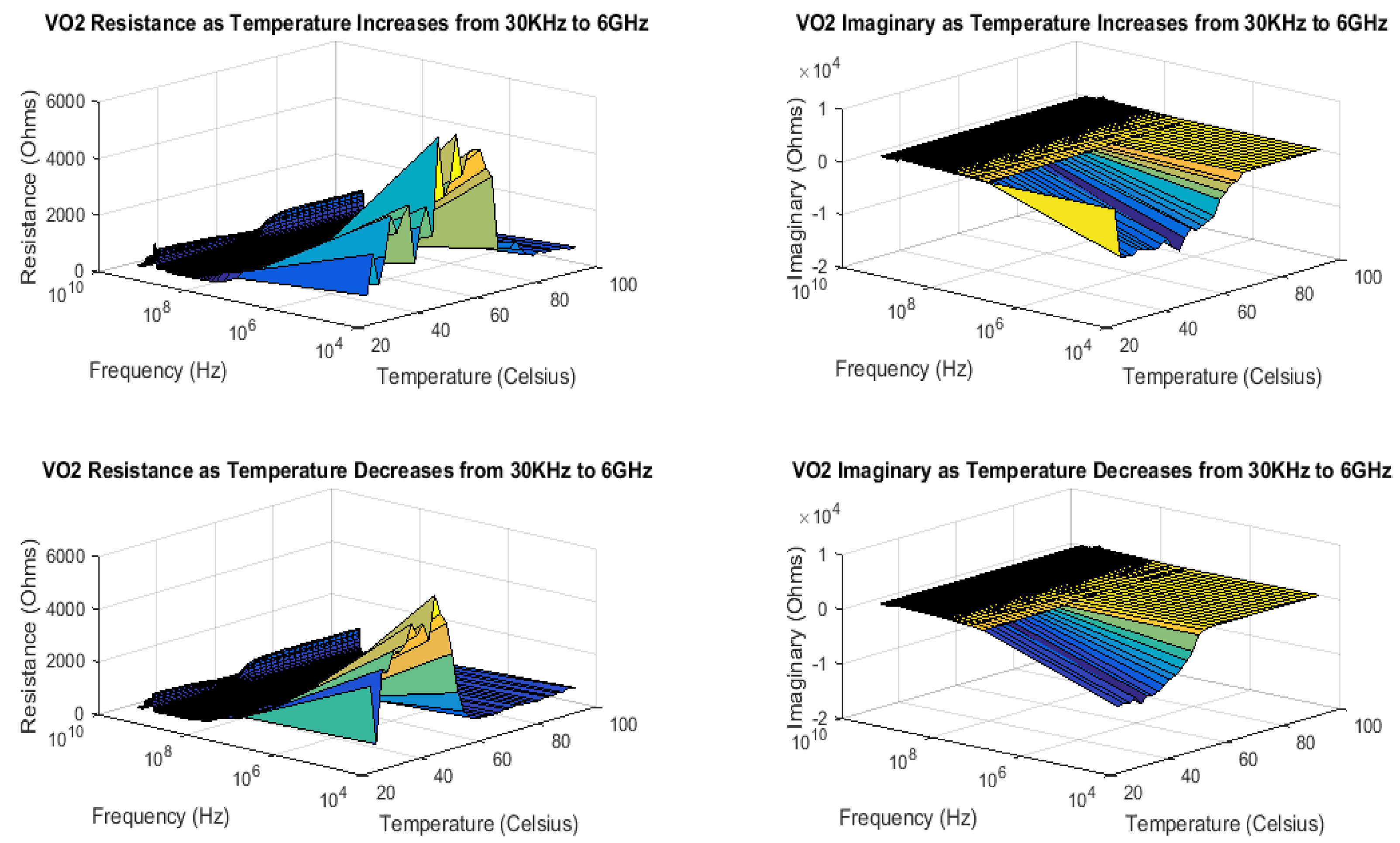

Figure 3. 3D models created in MATLAB for resistance and imaginary in relation to temperature and frequency as the temperature increased and decreased. Results match the expected outcome for an integrated thin strip of VO_2 between thicker metal.

Results

Resistivity

Based on the equation for resistance of thin film resistors, $R=\rho L/A$, 3D models for the resistivity were made.

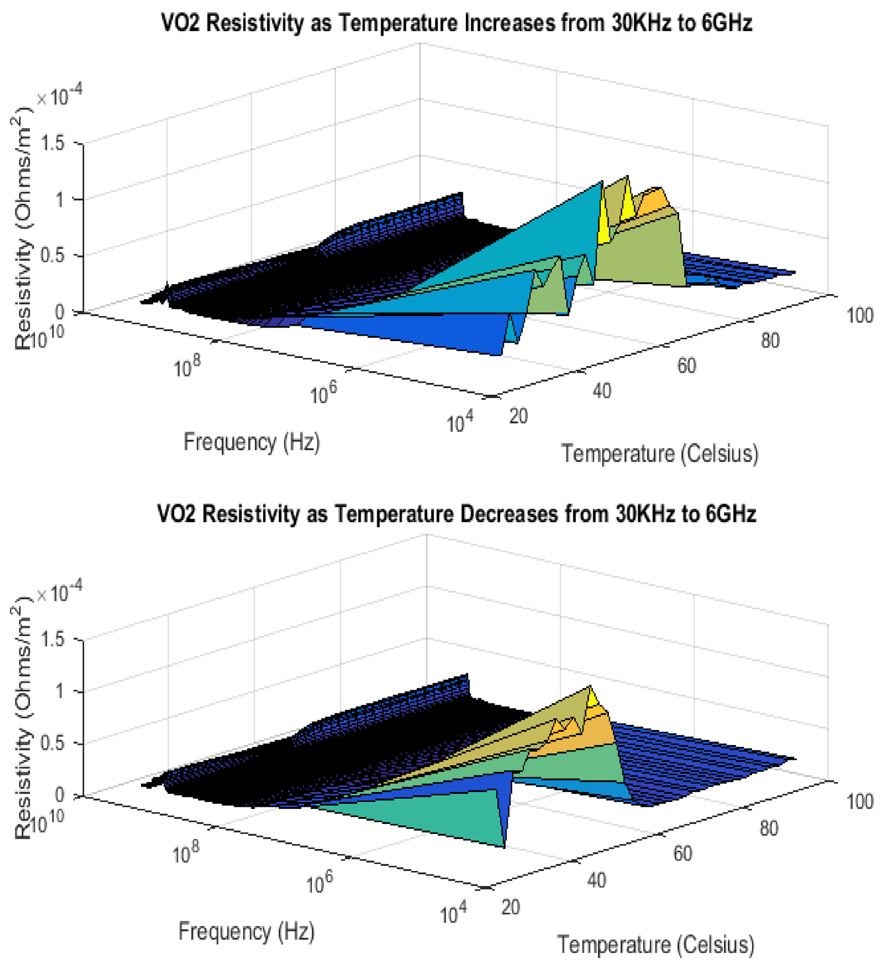

Figure 4. 3D models for resistivity in relation to temperature and frequency.

The resistance decreased as temperature increased which demonstrates the material's insulating property.

A small peak at 2.4 GHz, due to the leads connecting the VO_2 to the SMA connector can be seen.

The resistance also featured a gradual decline as frequency increased. This is explained by the structure's properties that resembles a planar integrated capacitor.

These characteristics can be observed in Figures 3 and 4.

Simulation

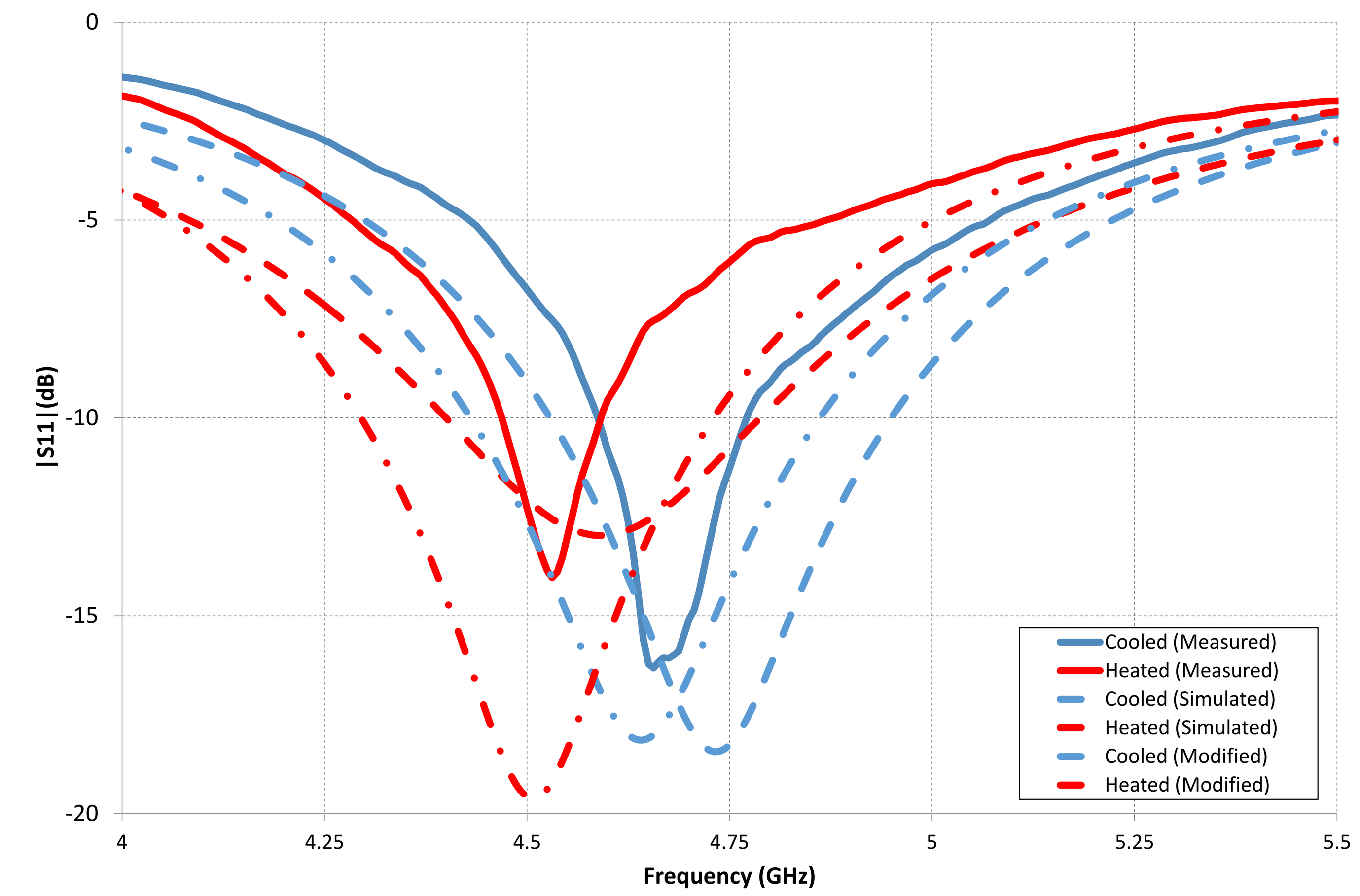

Figure 5. VO_2 bowtie antenna return loss measurement and simulation results from [1], superimposed with the simulated data obtained from the 3D models using the complex impedance values.

The modified simulation using data from the real and imaginary 3D models matched the values for the antenna's measured return loss closer than the simulation that accounted only for the resistance.

However, the modified heated simulation's gain was significantly off compared to the original heated simulation. **The comparison of the simulated (modified and original) and measured return loss can be seen in Figure 5.**

Conclusions and Future Work

The 3D models for the relationship of frequency, temperature, and resistivity produced results that matched the properties of the integrated VO_2 strips on the antenna surface. From this data, more accurate simulations for the frequency response of antennas using VO_2 were created.

Additional measurements will need to be made to account for the VO_2 complex impedance at frequencies under 30 KHz and above 6 GHz. This data explained the reactive behavior (energy storage and slightly reduced gain) of the developed bowtie antenna. Also, this research can be extremely useful in modeling future antennas that employ VO_2 in their design. More data will need to be tested e.g. using a VO_2–only wafer to extract models for larger VO_2 surfaces.

[1] T. S. Teeslink, D. Torres, J. Ebel, N. Sepúlveda, and D. E. Anagnostou, (2015). Reconfigurable bowtie antenna using metal-insulator transition in vanadium dioxide, IEEE Antennas and Wireless Propagation Letters, 1381-1384.

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