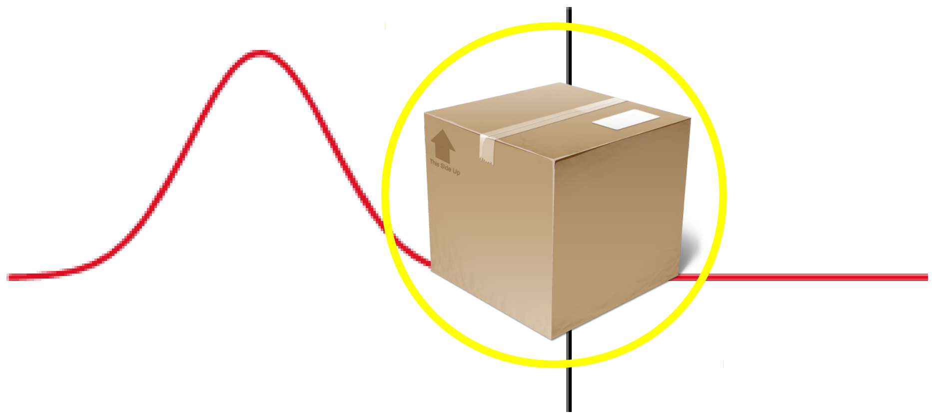
Toward RF-Based Material Detection



Alejandro Perez

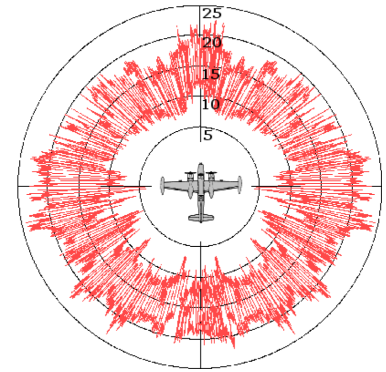
Toward RF-Based Material Detection

Related Work

$$P_r = \frac{P_t G_t}{4\pi r^2}\sigma\frac{1}{4\pi r^2}A_{eff}$$

Radar Cross-Section:

[1] Paul Saville. Review of radar absorbing materials. Technical report, DTIC Document, 2005.

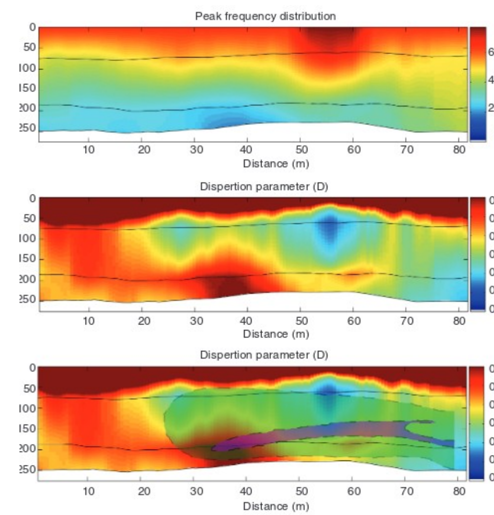


Building Materials (Penetration Loss, Reflection coefficients, Attenuation):

[2] W. C. Stone, NIST Construction Automation Program: Electromagnetic Signal Attenuation in Construction Materials. U.S. Dept. of Commerce, Technology Administration, NIST Gaithersburg, Md, 1997.

Ground Penetrating Radar:

[3] John H. Bradford. Frequency-dependent attenuation analysis of ground-penetrating radar data. Geophysics, Vol. 72, No. 3, pages J7–J16, 2007.



Backscatter:

[4] Dinesh Bharadia, Kiran Raj Joshi, and Sachin Katti. Full duplex backscatter. In Proceedings of the Twelfth ACM Workshop on Hot Topics in Networks, pages 4:1–4:7, NY, NY, USA, 2013. ACM.

TTWR RCS/FDTD:

[5] Travis D. Bufler, Ram M. Narayanan, Traian Dogaru. Radar Signatures of indoor clutter for through-the-wall radar. SPIE 9077, Radar Sensor Technology XVIII, 90770E, 2014.

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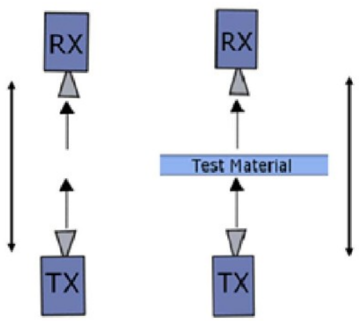
Toward RF-Based Material Detection



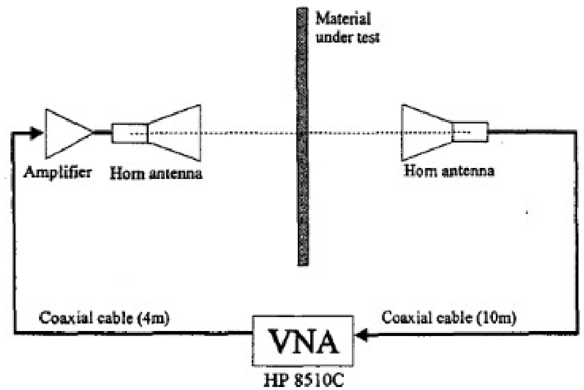
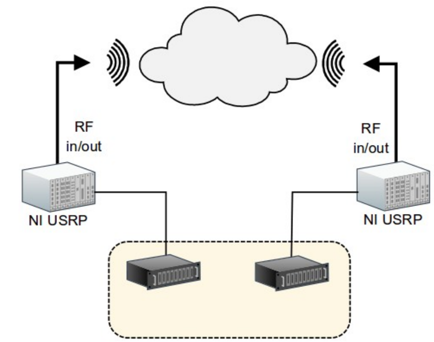


Figure 1: Measurement system set-up



45MHz-50GHz

[6] I. Cuinas and M.G. Sanchez. Measurement of transmission coefficients of radiowaves through building materials in the 5.8 ghz frequency band. In Antennas and Propagation Society International Symposium, 1999. IEEE, volume 3, pages 1474–1477 vol.3, July 1999.

869.5 MHz

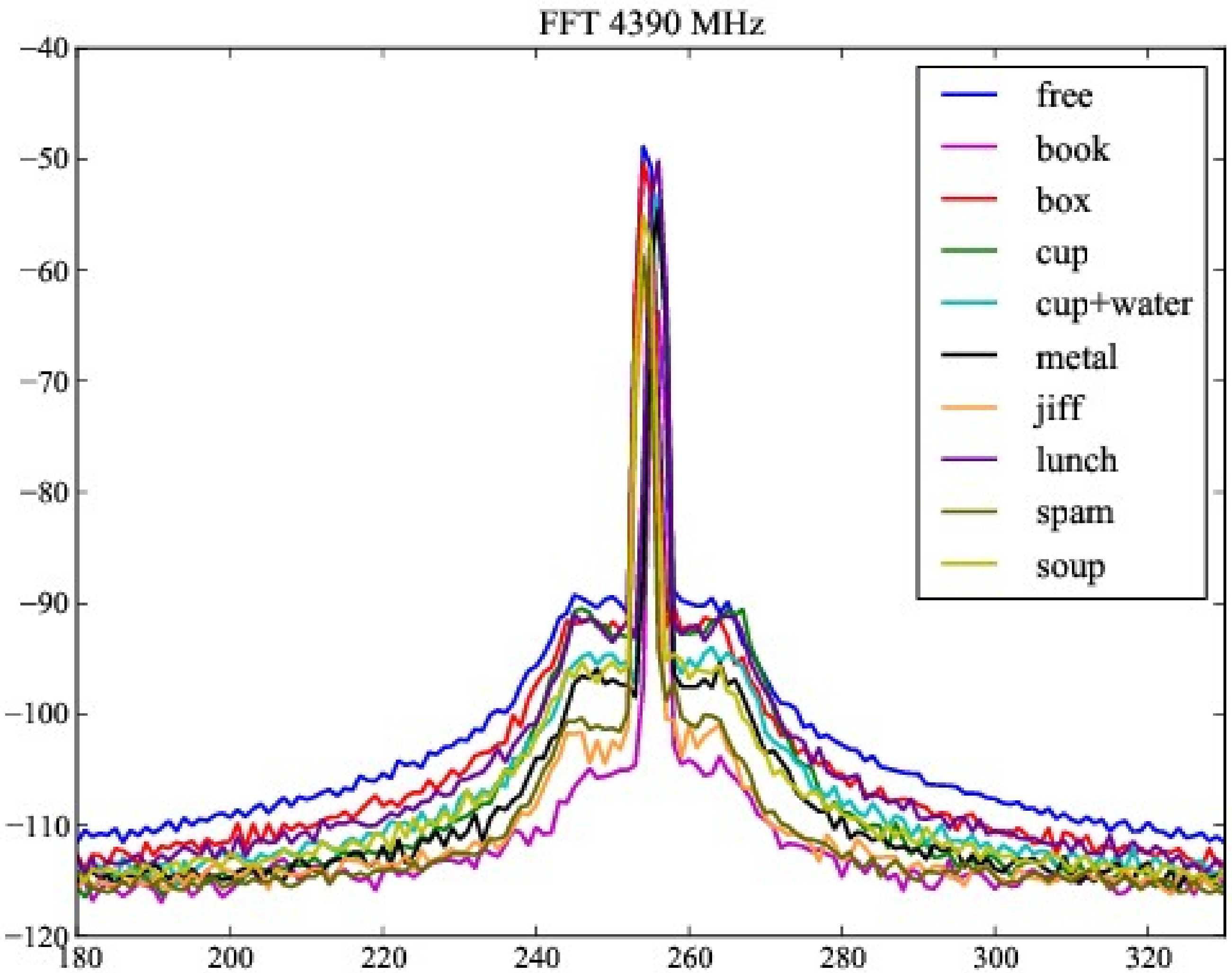
[7] Martin Tomis, Libor Michalek, and Marek Dvorsky. Design of measurement system for determining the radioclimatology effect on the radio signal propagation using universal software radio. Advances in Electrical and Electronic Engineering, 11(6), 2013.

28 GHz

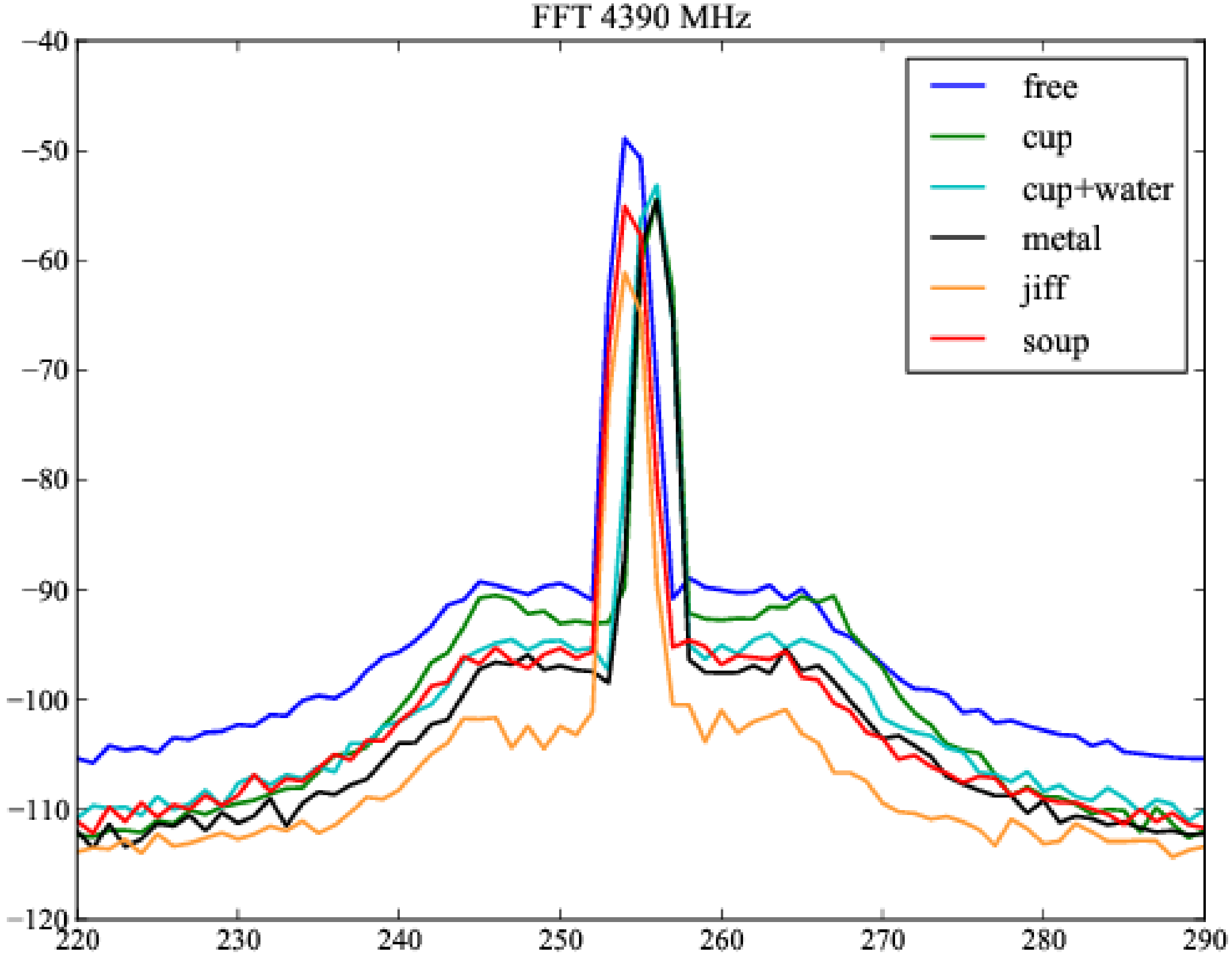
[8] H. Zhao, et al. 28 ghz millimeter wave cellular communication measurements for reflection and penetration loss in and around buildings in new york city. In ICC, pages 5163–5167. IEEE, 2013.

Transmission Loss

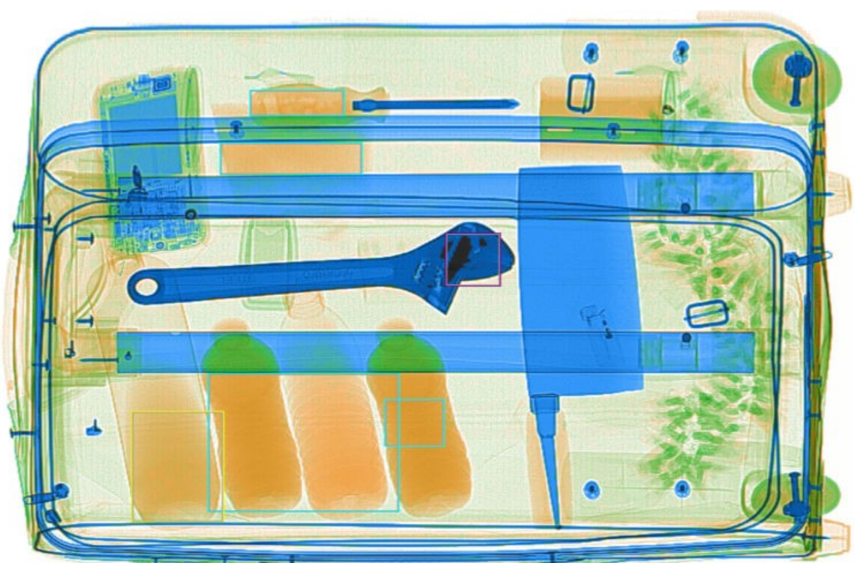
Transmission Loss



Transmission Loss



Scanning



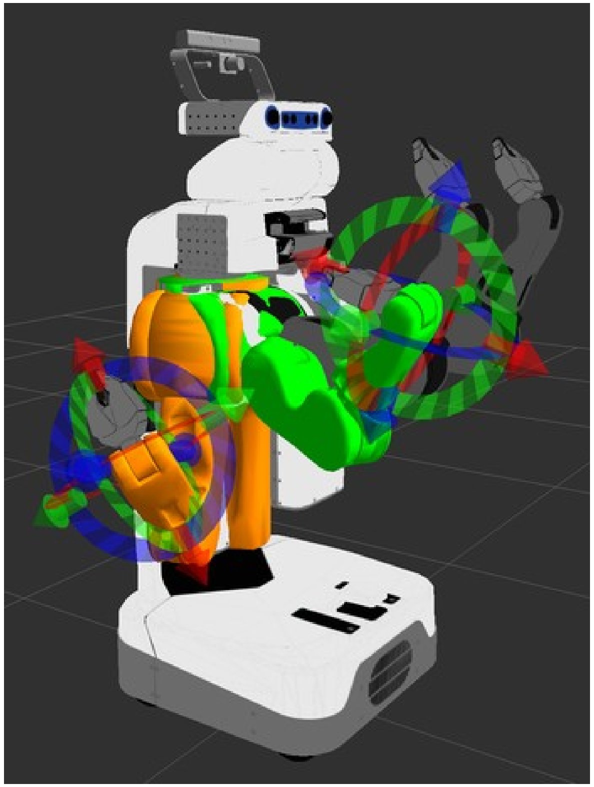
Scanning: Material-induced Loss

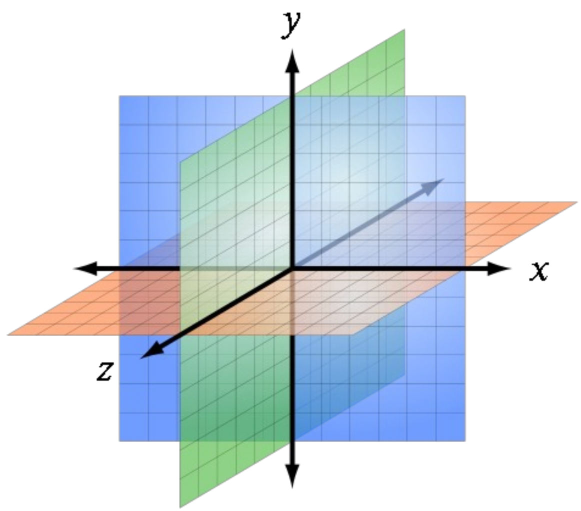
$$\frac{P^{\mathrm{Rx}}}{P^{\mathrm{Tx}}} = G^{\mathrm{Tx}} G^{\mathrm{Rx}} \left(\frac{\lambda}{4\pi d} \right)^2$$

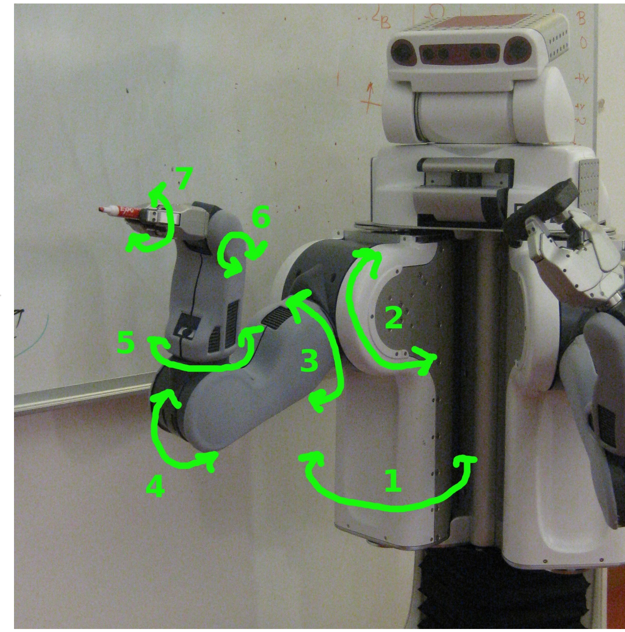
$$P^{\mathrm{Rx}}(d) = P^{\mathrm{Tx}} G^{\mathrm{Tx}} + G^{\mathrm{Rx}} - 20 \log 10 \left(\frac{4\pi d}{\lambda} \right)$$

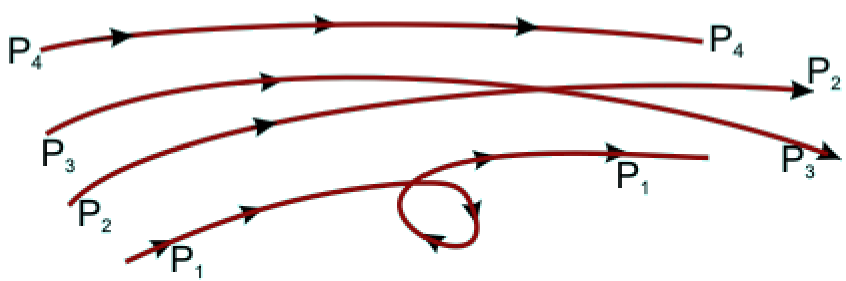
$$\mathbb{L} = \bar{P}^{\mathrm{Rx}}(d) - \tilde{P}^{\mathrm{Rx}}(d).$$

Scanning: Straight-line Trajectories









Scanning: Straight-line Trajectories

$$j^{\mathrm{n}} = (\theta_1, \theta_2, \theta_3, \cdots, \theta_7) \in \mathbb{R}^7,$$
$$q^{\mathrm{n}} = (p, R)$$
$$p^{\mathrm{n}} = (x, y, z)$$
$$R^{\mathrm{n}} = (q_0, q_1, q_2, q_3)$$
$$q = f(j)$$

$$j^{\mathrm{Rx}}, j^{\mathrm{Tx}} : [0, T] \in \mathbb{R}^7$$
$$j^{\mathrm{Rx}}(0), j^{\mathrm{Tx}}(0) = (q_i^{\mathrm{Rx}}, q_f^{\mathrm{Rx}}),$$
$$j^{\mathrm{Rx}}(T), j^{\mathrm{Tx}}(T) = (q_i^{\mathrm{Tx}}, q_f^{\mathrm{Tx}})$$
$$f(j^{\mathrm{Rx}}(0), j^{\mathrm{Tx}}(0)) = q_i^{\mathrm{Rx}}, q_i^{\mathrm{Tx}},$$
$$f(j^{\mathrm{Rx}}(T), j^{\mathrm{Tx}}(T)) = q_f^{\mathrm{Rx}}, q_f^{\mathrm{Tx}}$$
$$\forall f(j^{\mathrm{Rx}}(t), j^{\mathrm{Tx}}(t)) \in [0, T]$$

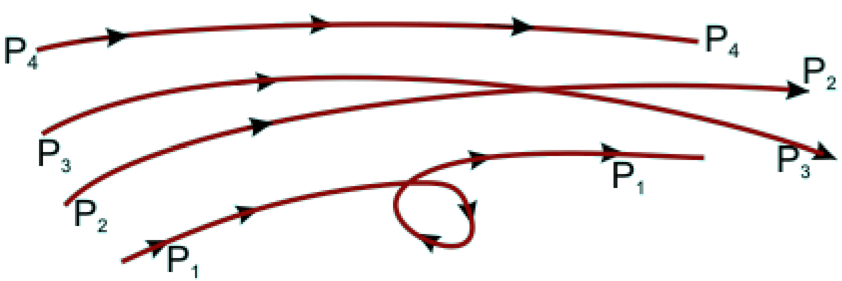
$$\left(p_x^{\mathrm{Rx}} = p_x^{\mathrm{Tx}}\right) \wedge \left(p_z^{\mathrm{Rx}} = p_z^{\mathrm{Tx}}\right)$$

$$p_y^{\mathrm{Rx}} = -p_y^{\mathrm{Tx}}$$

$$|p_y^{\mathrm{Rx}} - p_y^{\mathrm{Tx}}| = d$$

and,

$$\int_0^T \Delta R^{\mathrm{Rx}} + \Delta p_1^{\mathrm{Rx}} + \Delta p_2^{\mathrm{Rx}} = \int_0^T \Delta R^{\mathrm{Tx}} + \Delta p_1^{\mathrm{Tx}} + \Delta p_2^{\mathrm{Tx}} = 0$$



Scanning: Localized Attenuation

$$\Sigma : [0, T], \sigma(t) = (q(t), \mathrm{DFT}(t))$$
$$S = (s_i, \cdots, s_k),\ d_\Delta = \left(\frac{d_\sigma}{k}\right) \text{ s.t. } q_i \in s_i \text{ and } q_f \in s_k$$
$$s_i := \{\sigma \in \Sigma : s_i^{p3} < q_{p3} < s_i^{p3} + d_\Delta\}$$

$$\bar{S} = (P'_{\bar{s}_i}, \cdots, P'_{\bar{s}_k})$$

$$\tilde{S} = (P'_{\tilde{s}_i}, \cdots, P'_{\tilde{s}_k})$$

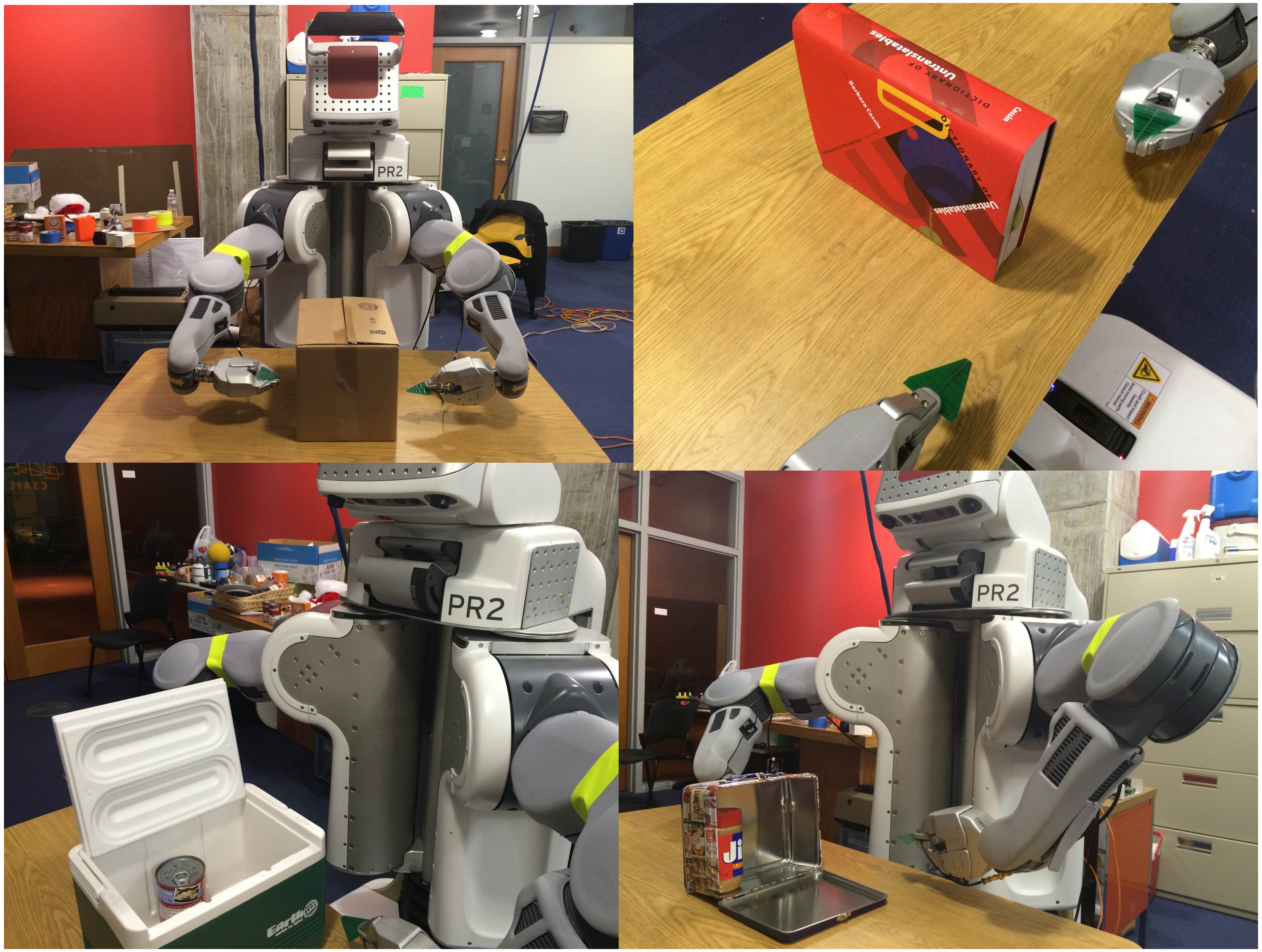
$$S_{\mathbb{L}} = (\mathbb{L}_i = P'_{\bar{s}_i} - P'_{\tilde{s}_i}, \cdots, \mathbb{L}_k = P'_{\bar{s}_k} - P'_{\tilde{s}_k})$$

Scanning

Scanning

CSAIL

Scanning



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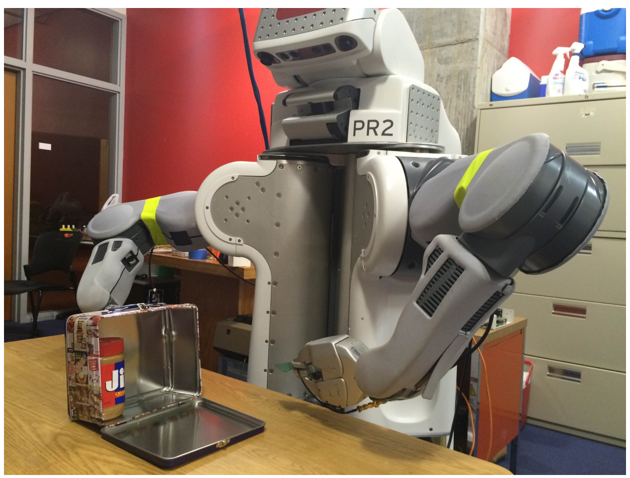
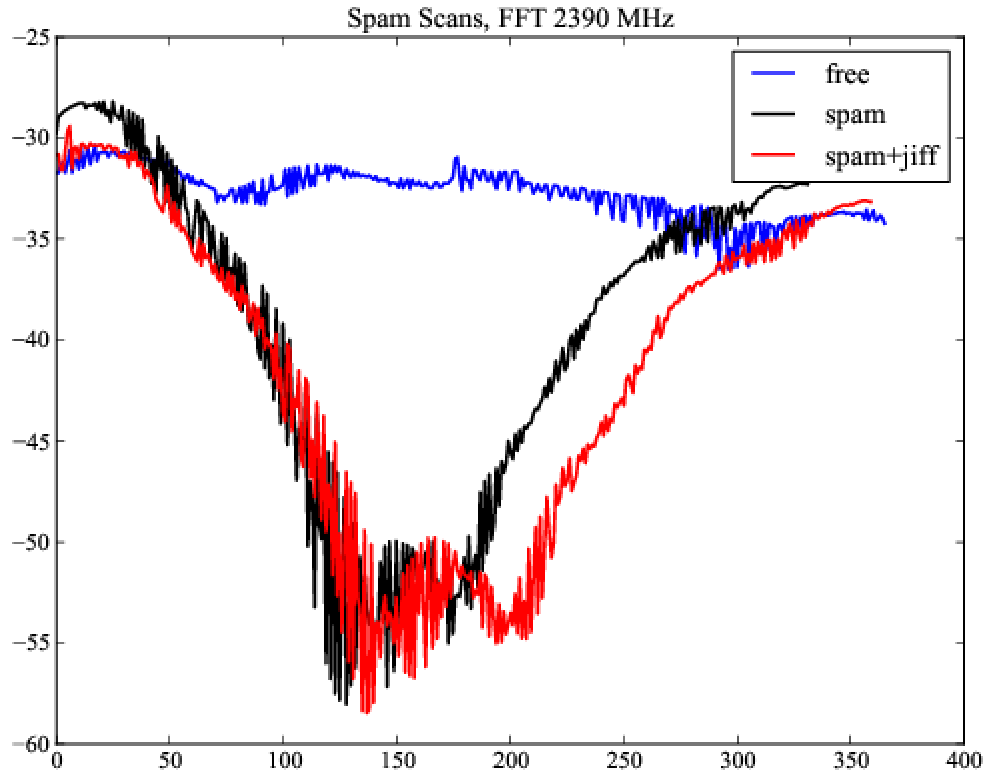
Scanning: Metallic Lunch Box (2390 MHz)





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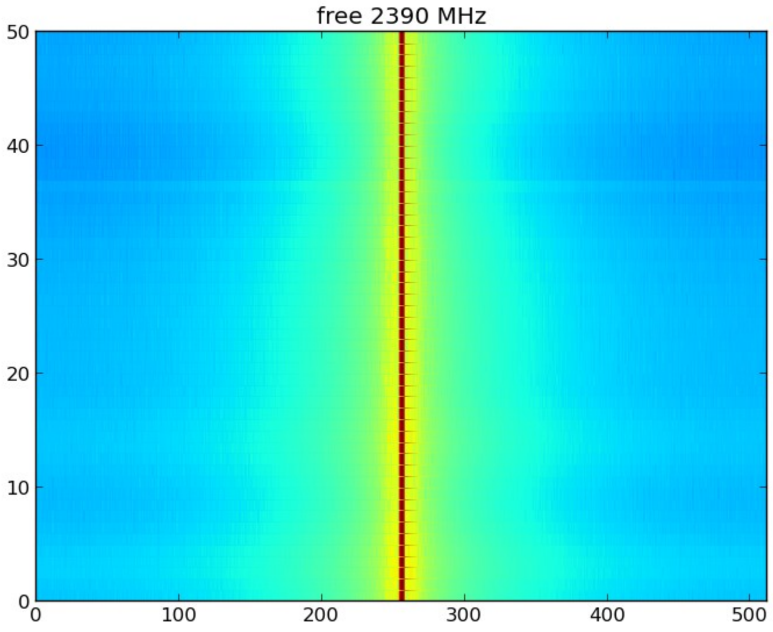
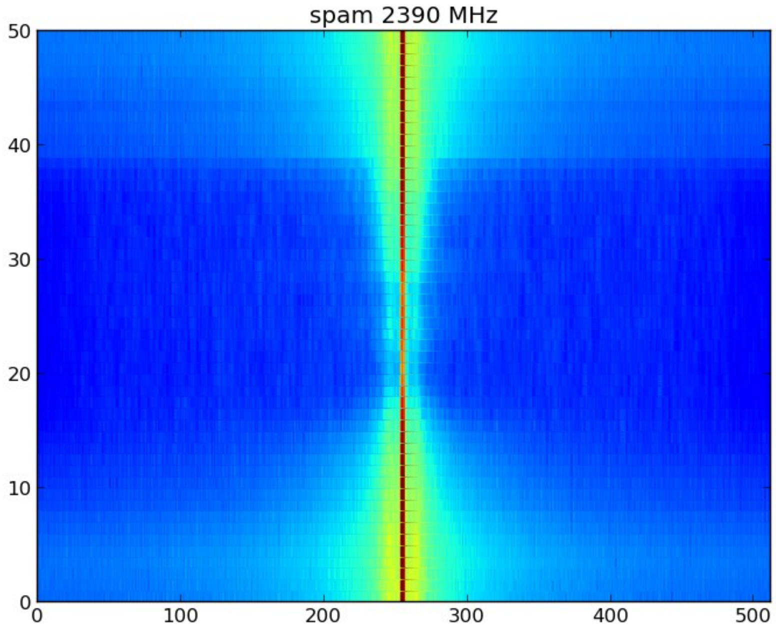
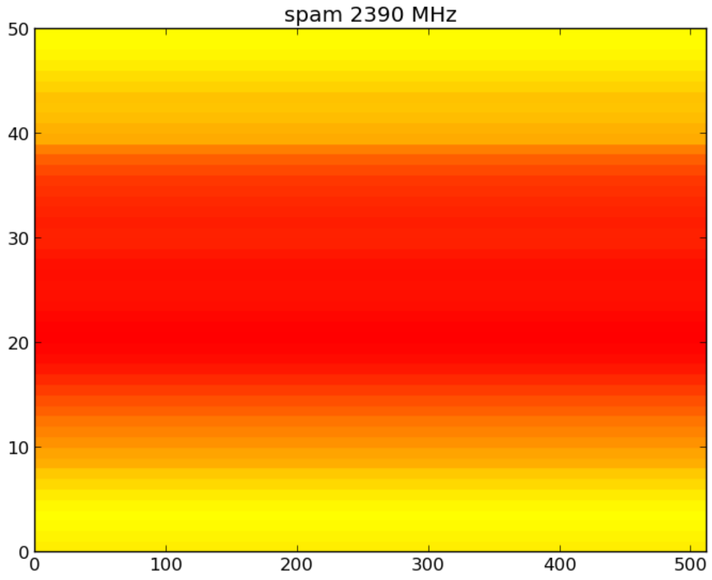
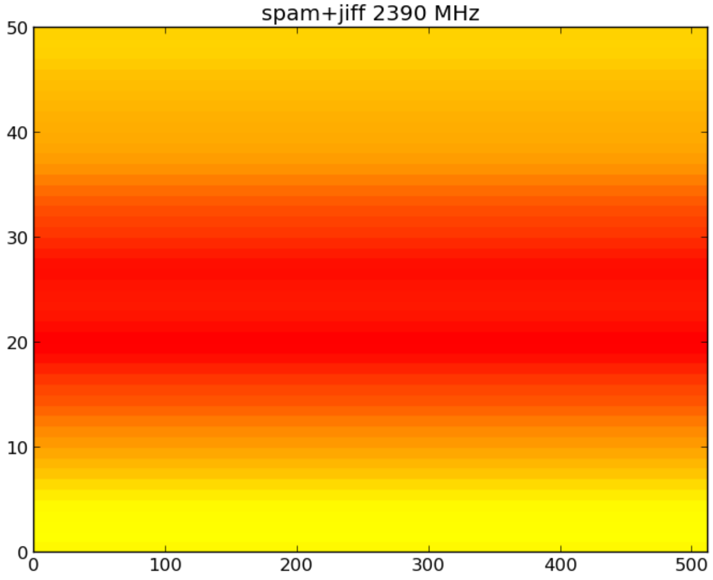
Scanning: Metallic Lunch Box (2390 MHz)

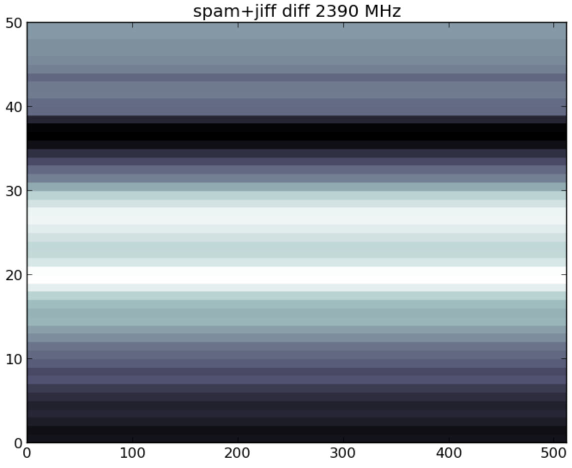




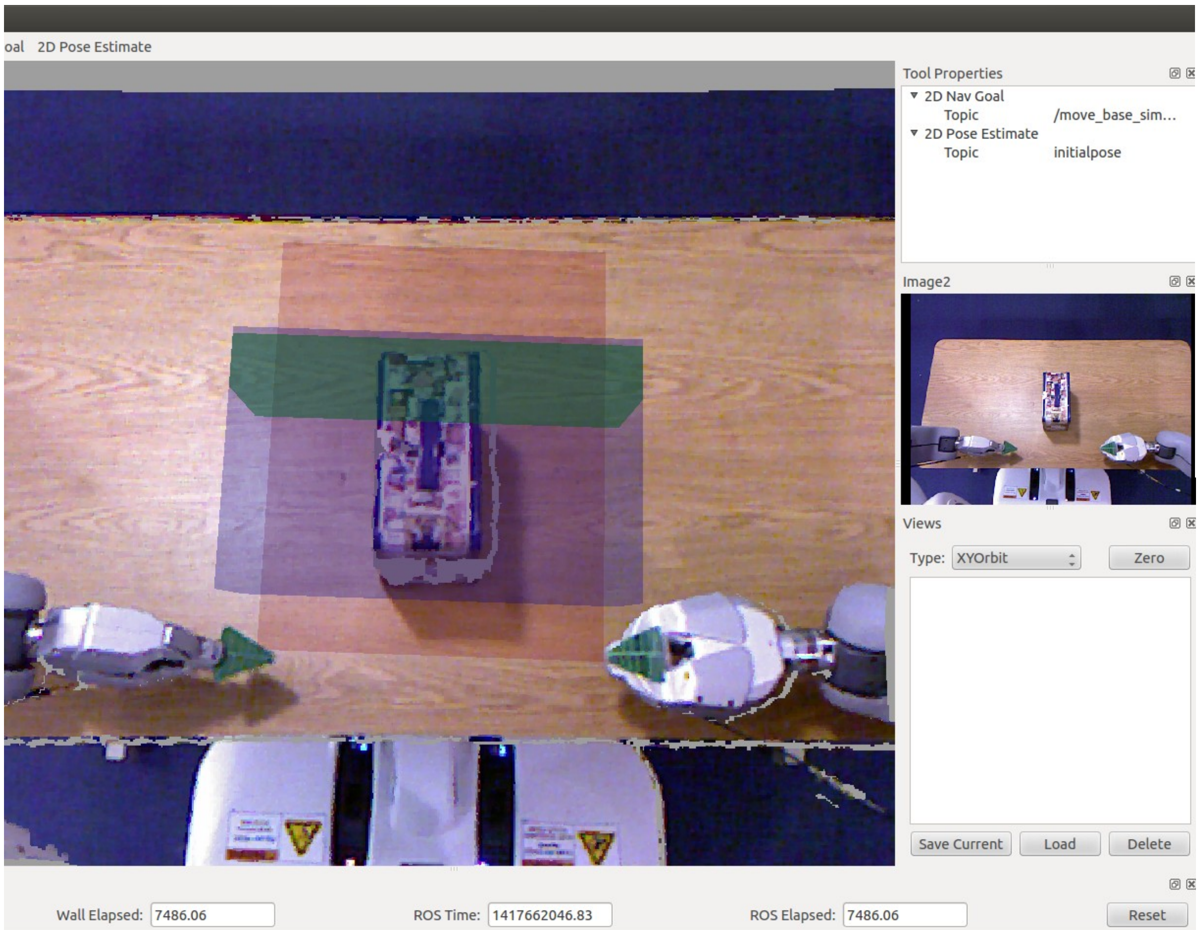
Scanning: Metallic Lunch Box (2390 MHz)

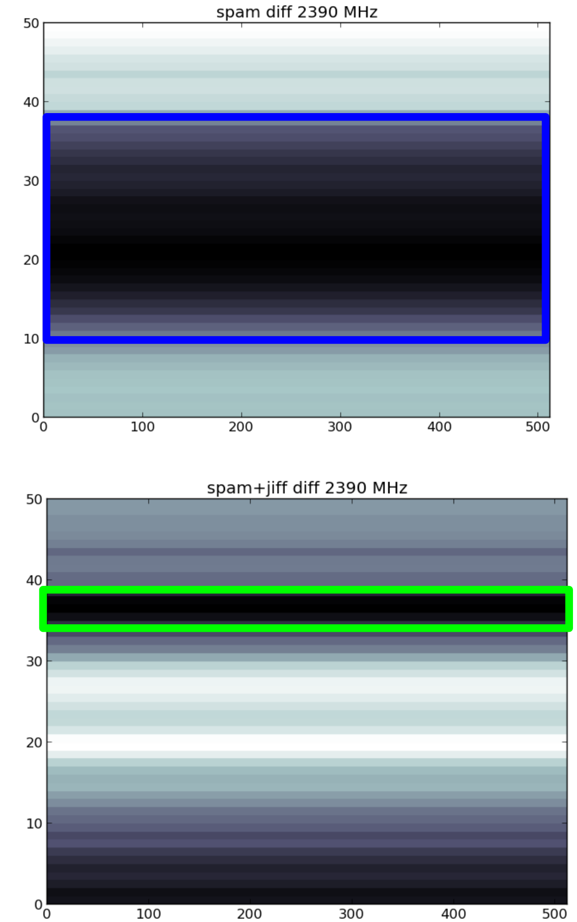




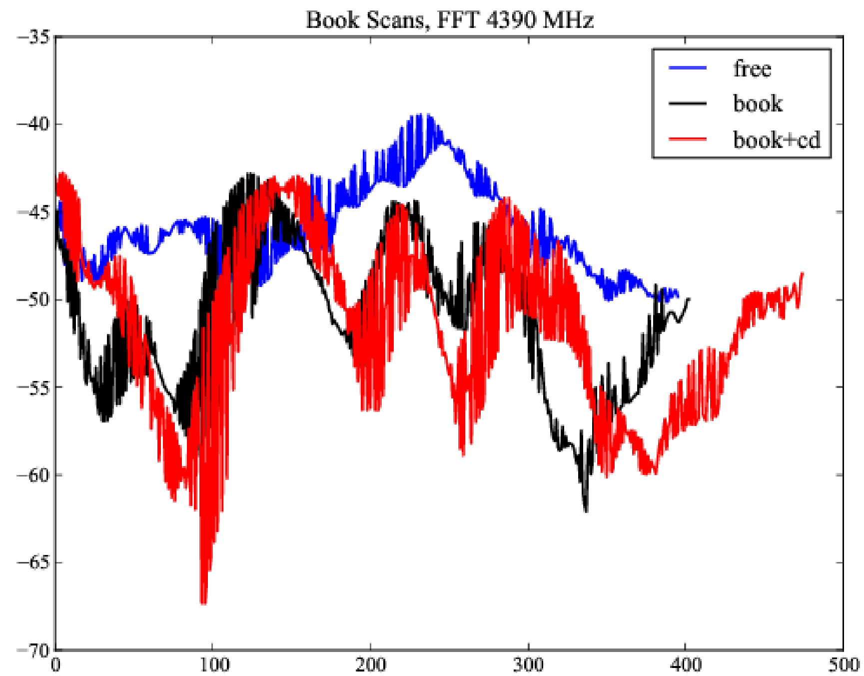


Scanning: Metallic Lunch Box (2390 MHz)

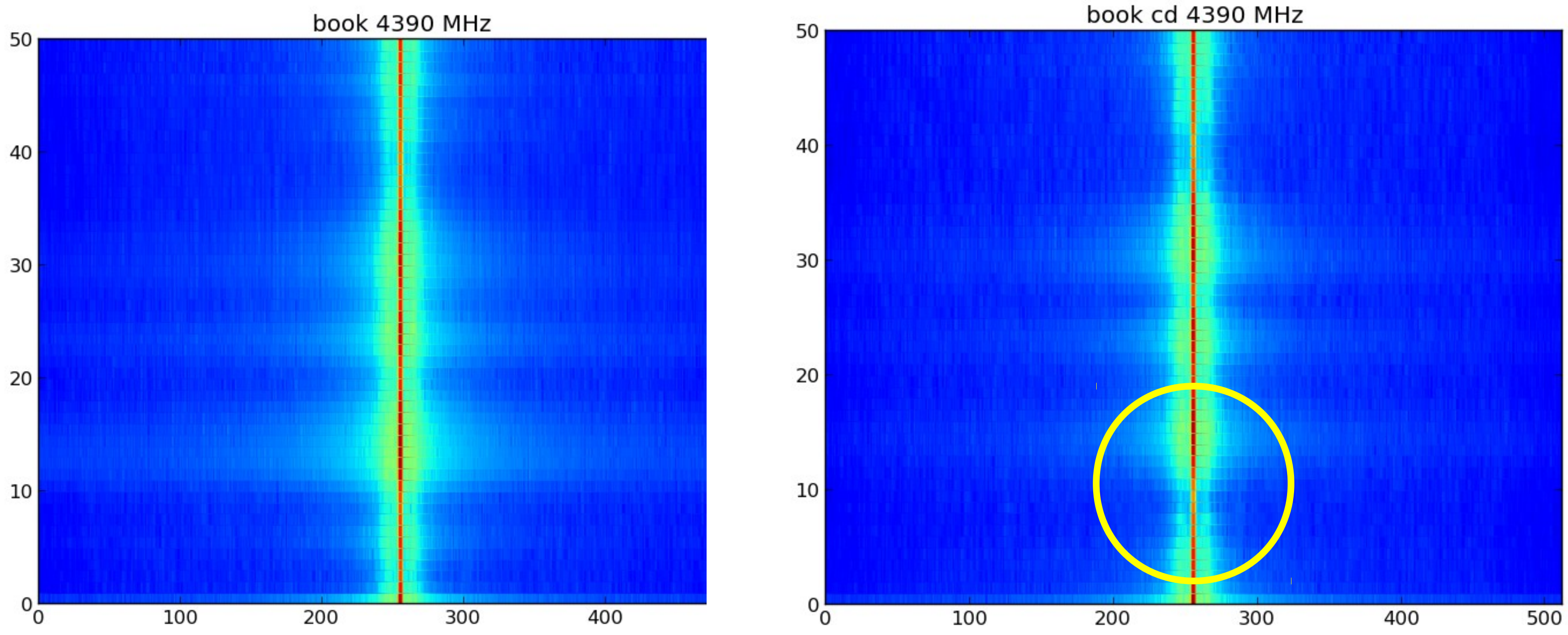




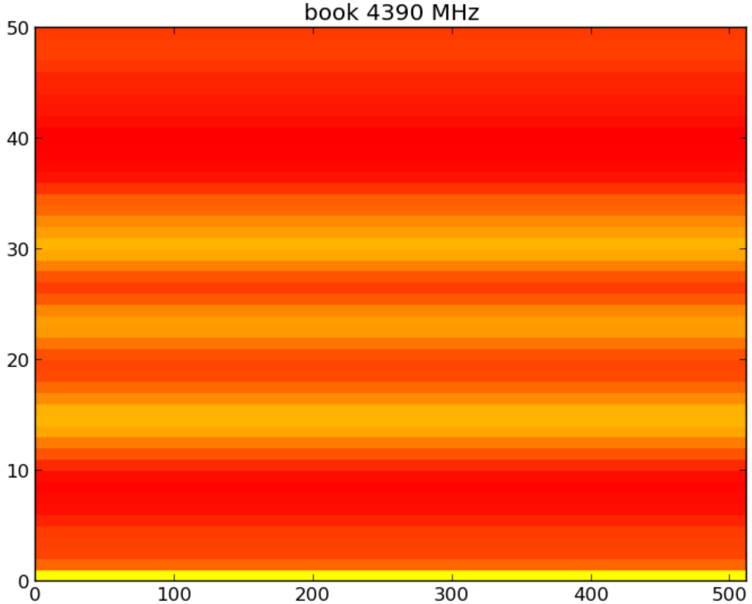
Scanning: Book + CD (4390 MHz)

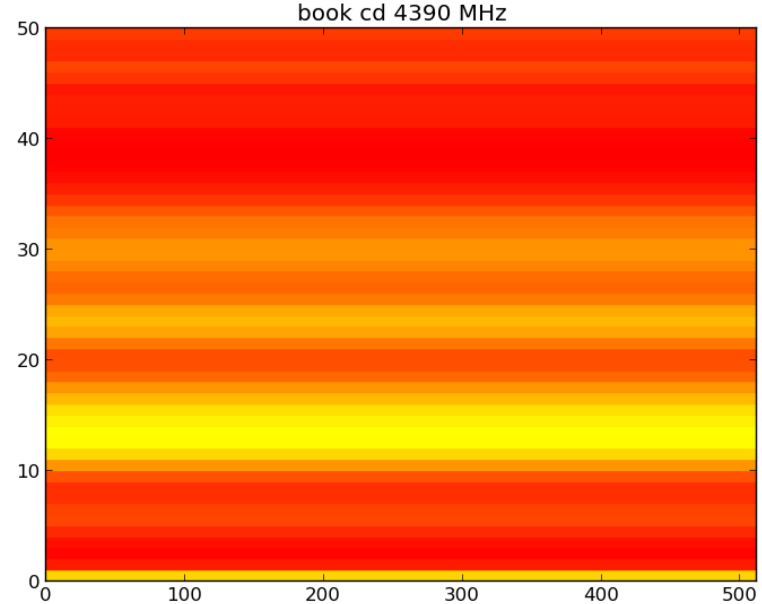


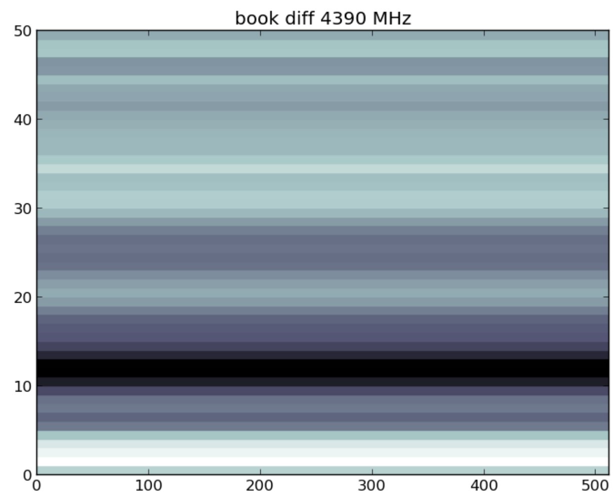
Scanning: Book + CD (4390 MHz)



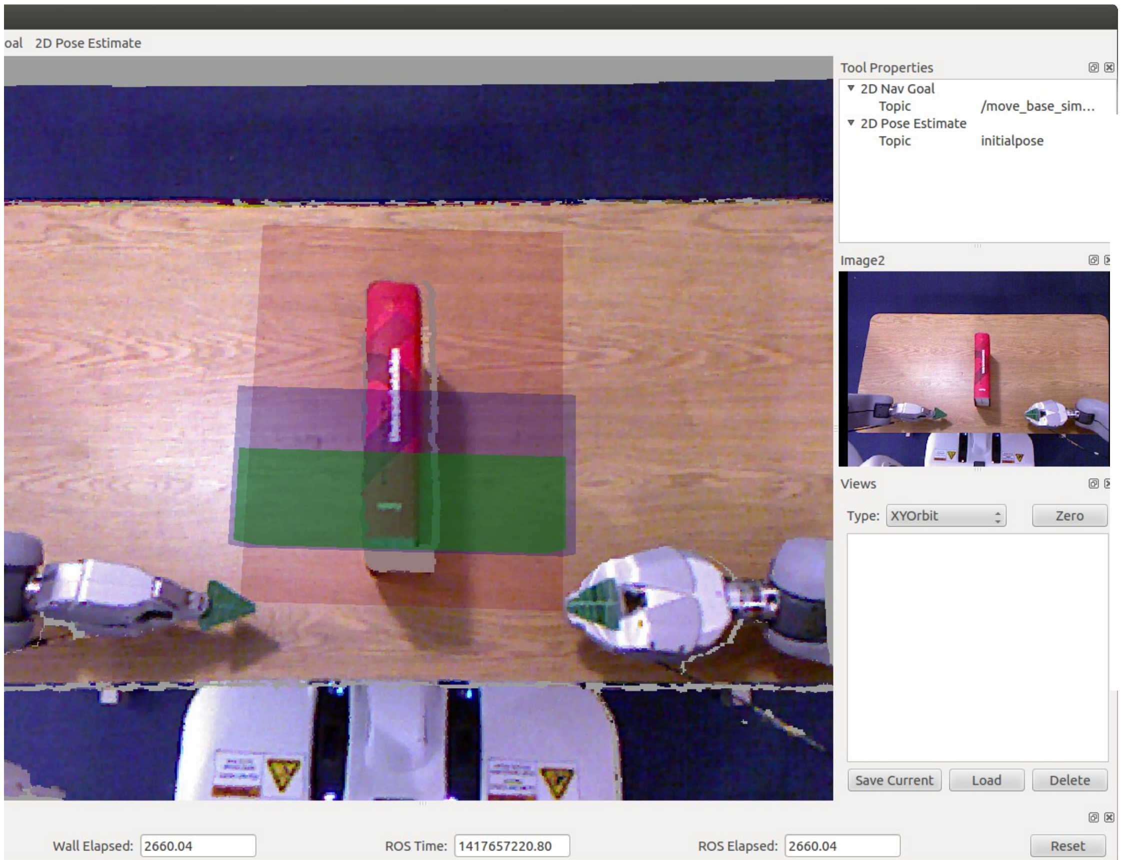
Scanning: Book + CD (4390 MHz)

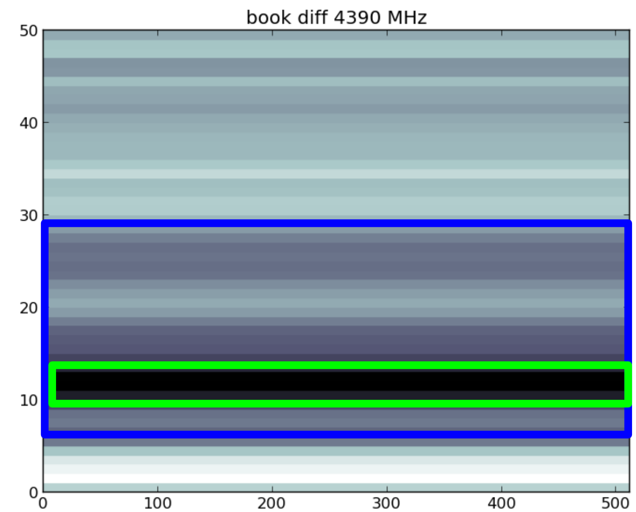






Scanning: Book + CD (4390 MHz)





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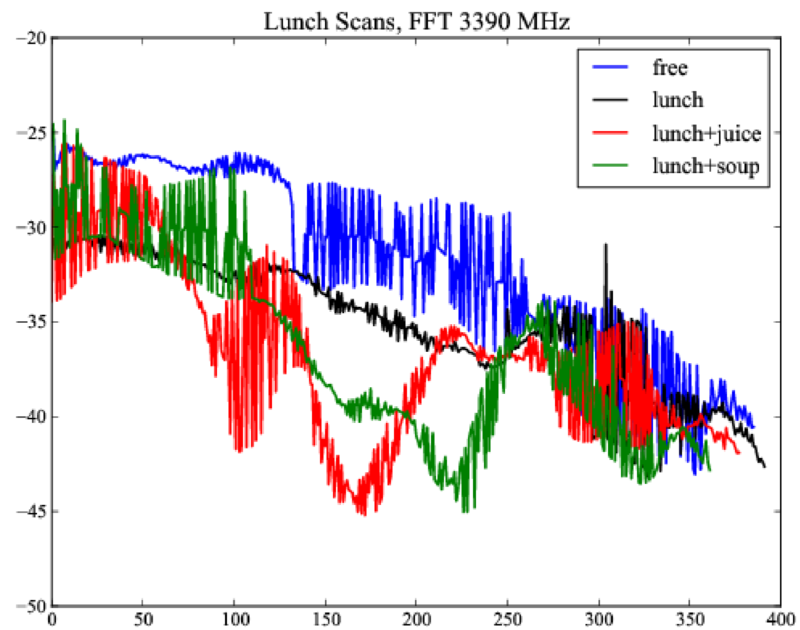
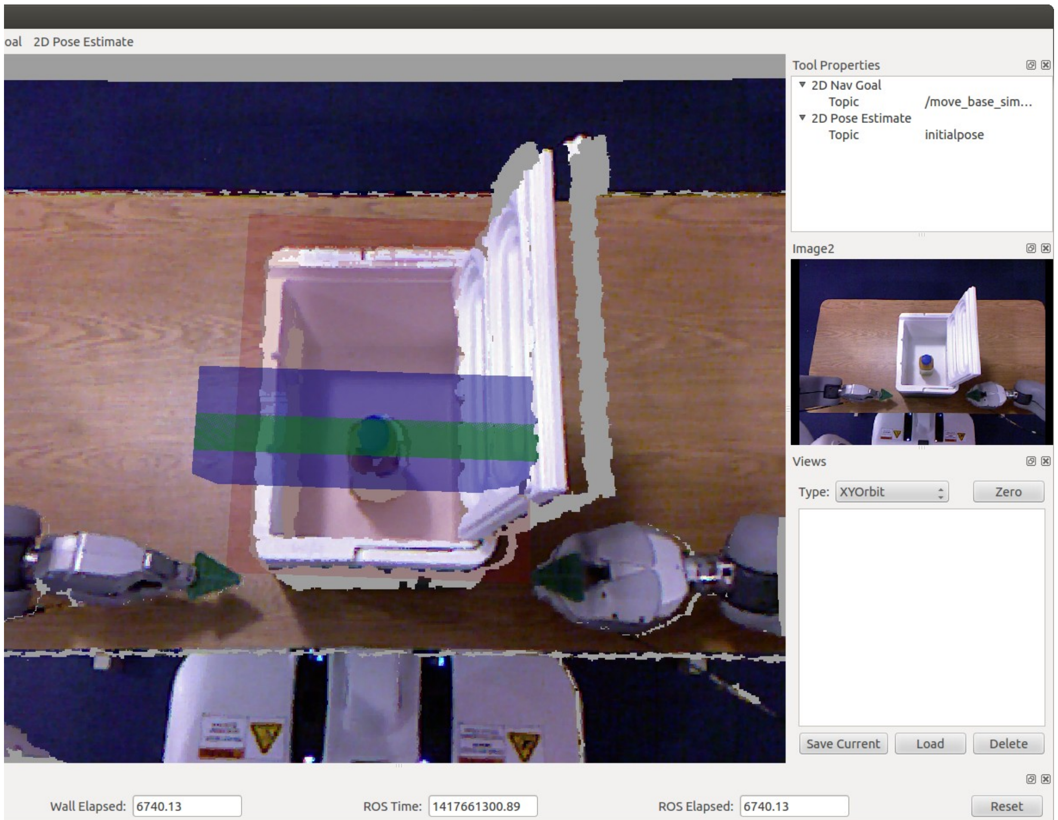
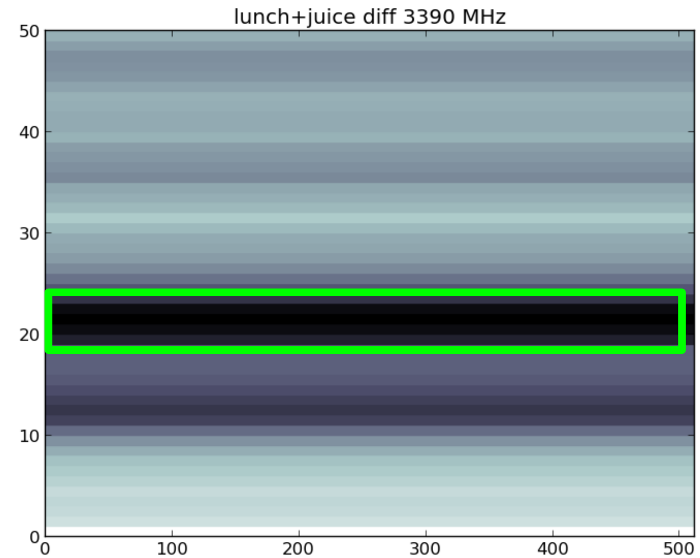
Scanning: Plastic Lunch Box (3390 MHz)



Scanning: Plastic Lunch Box (3390 MHz)





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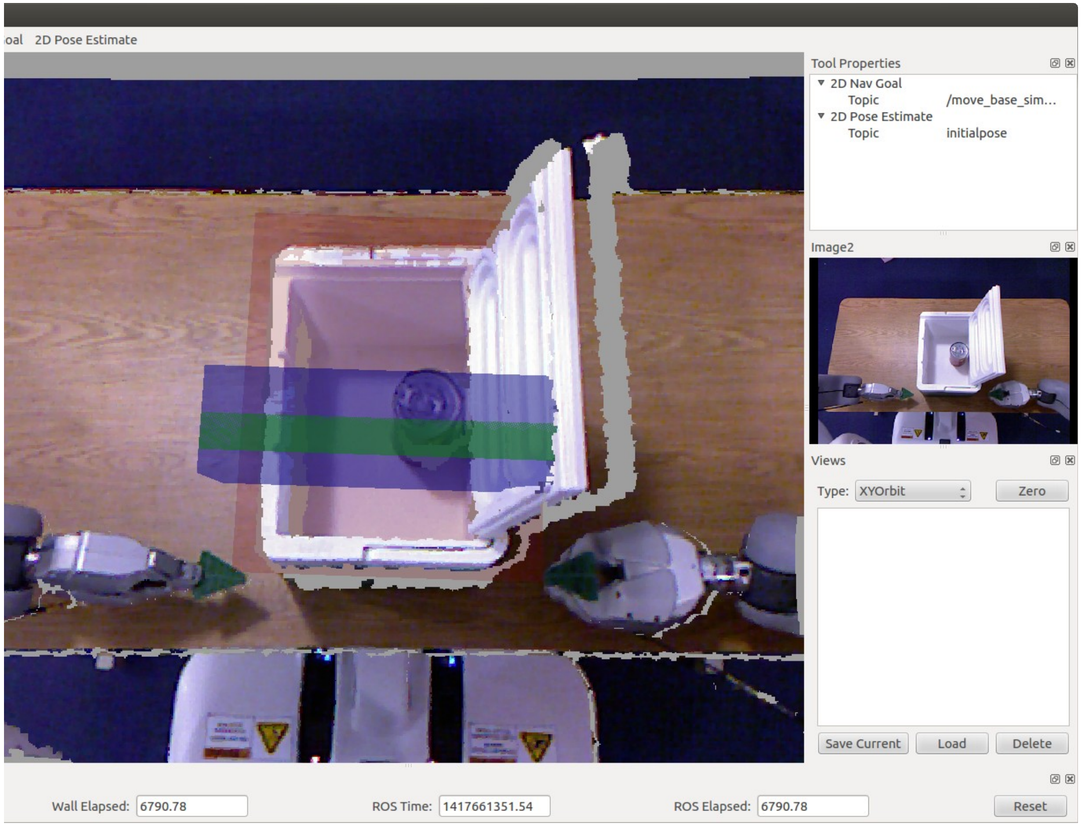
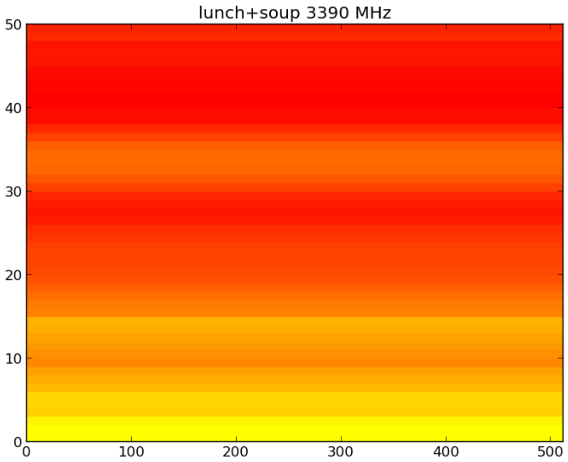
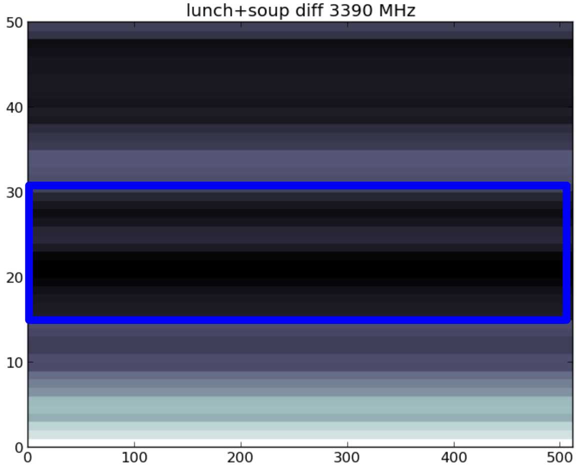
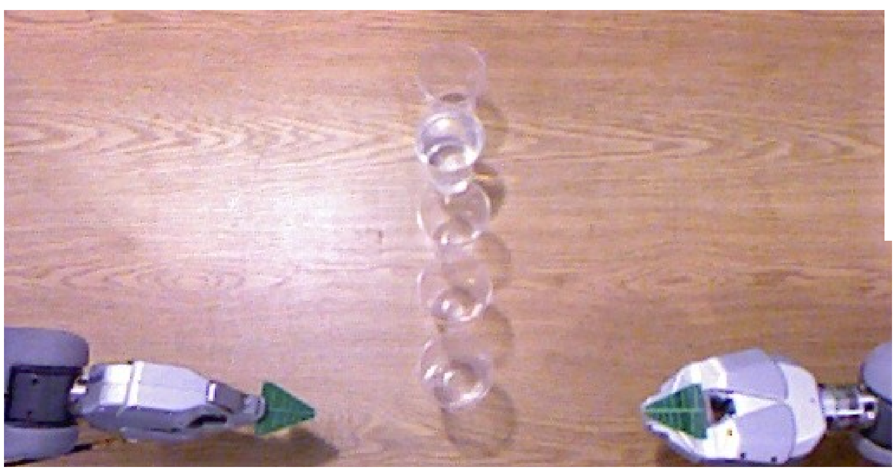
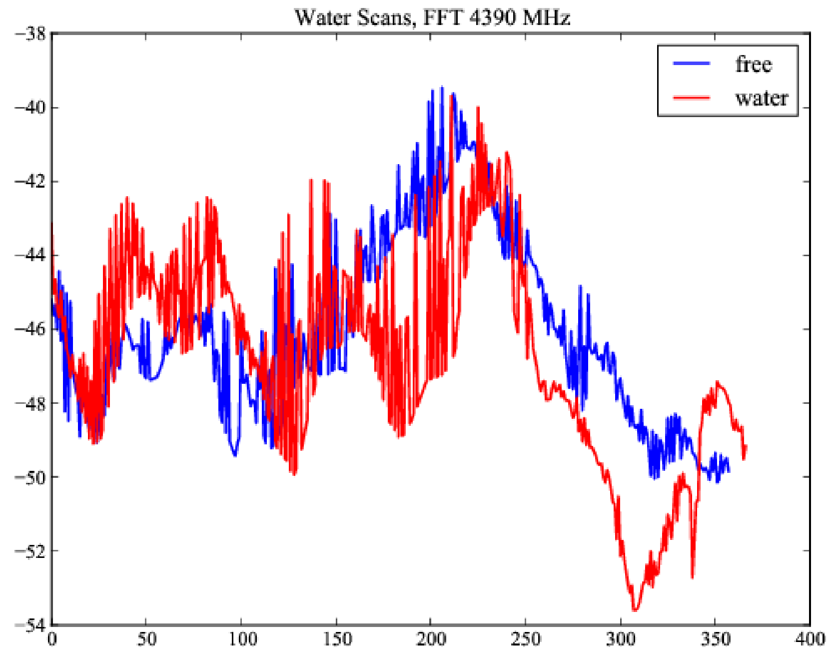




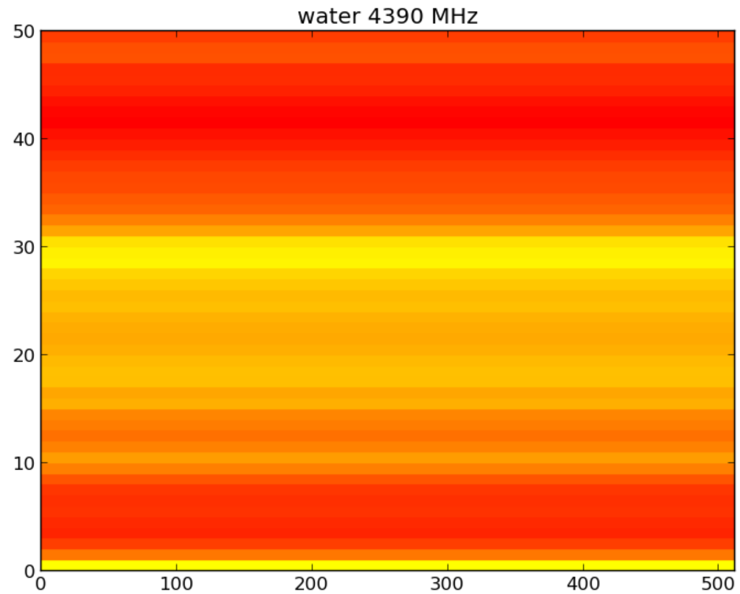


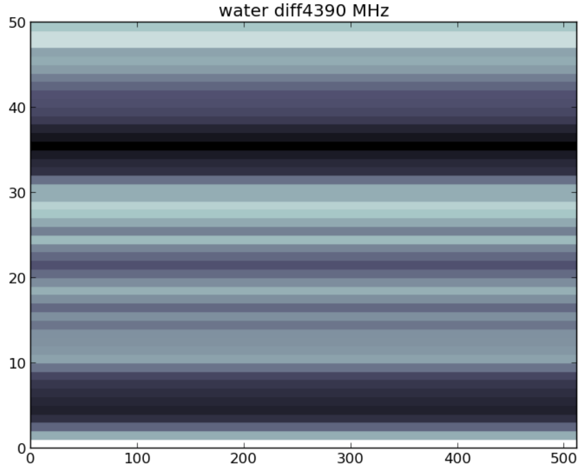
Scanning: Water (4390 MHz)





Scanning: Water (4390 MHz)





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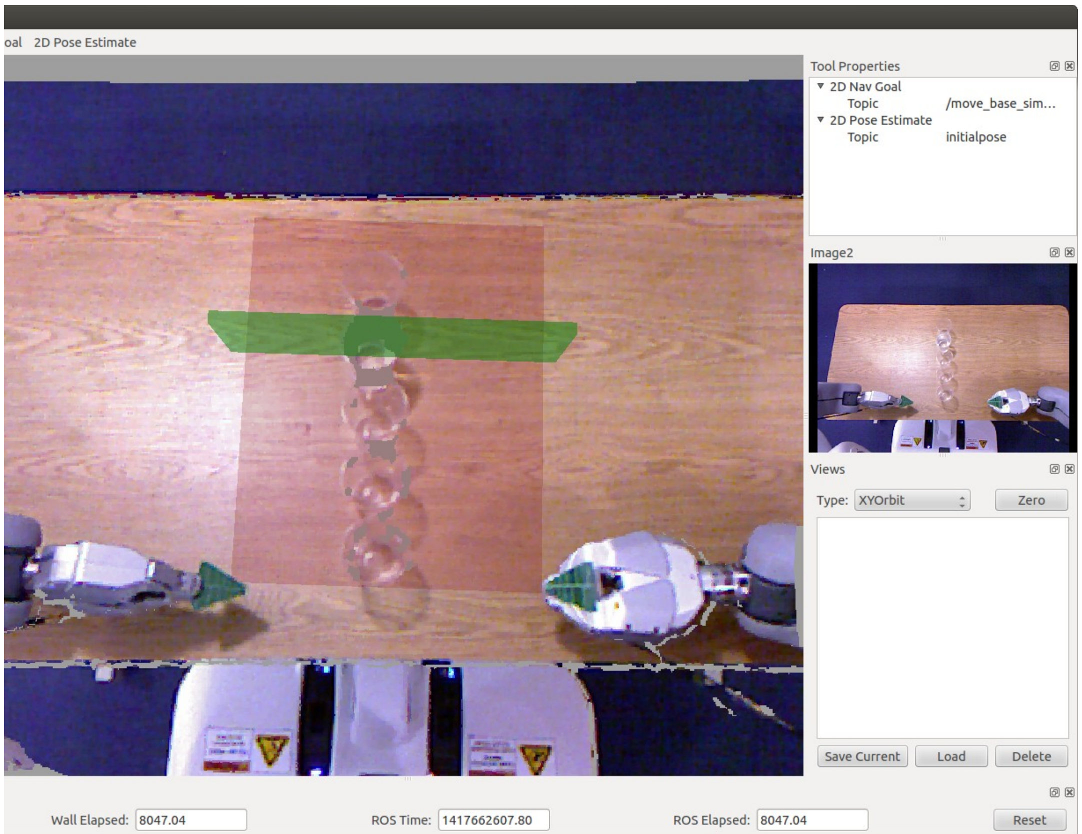
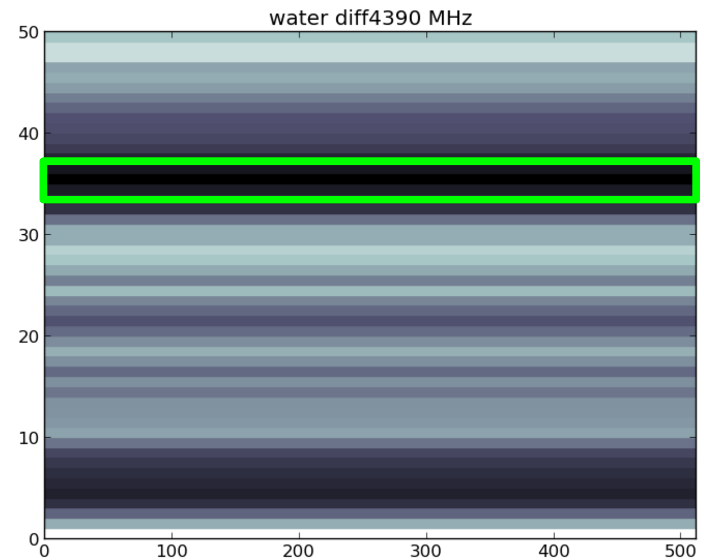
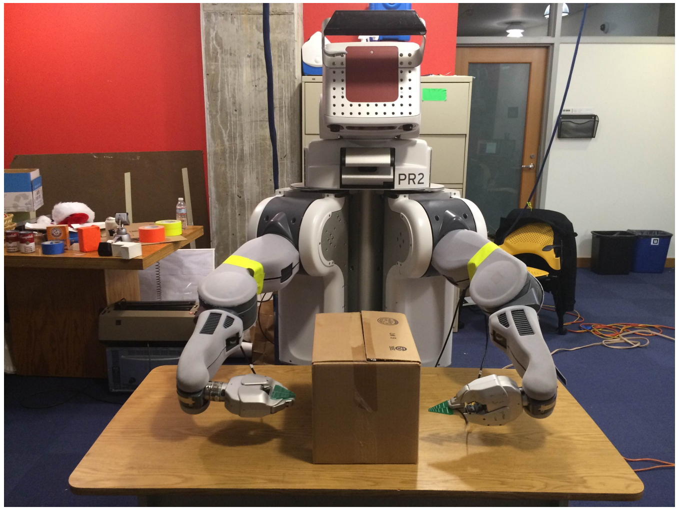
Scanning: Water (4390 MHz)

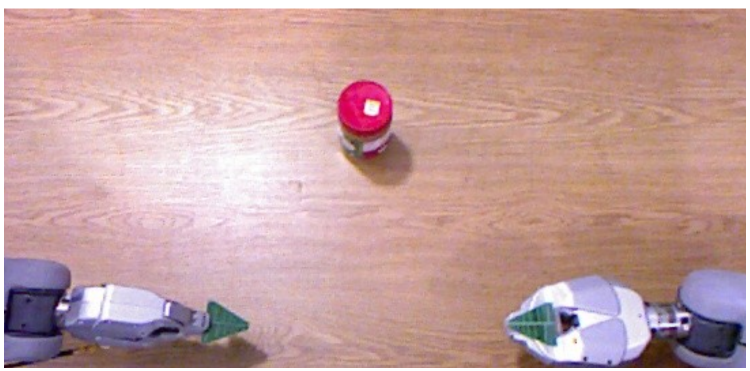


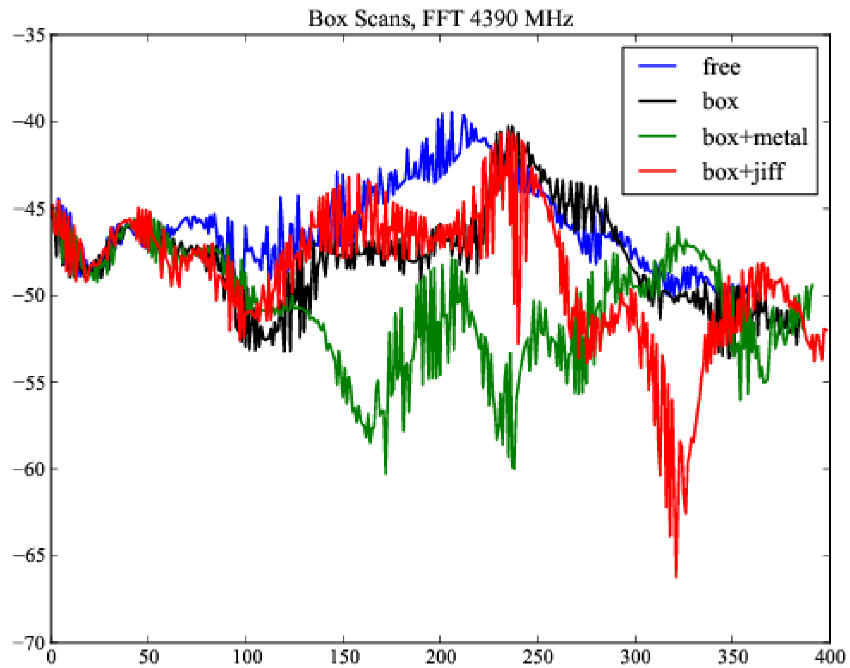


CSAIL

Scanning: Cardboard Box (4390 MHz)







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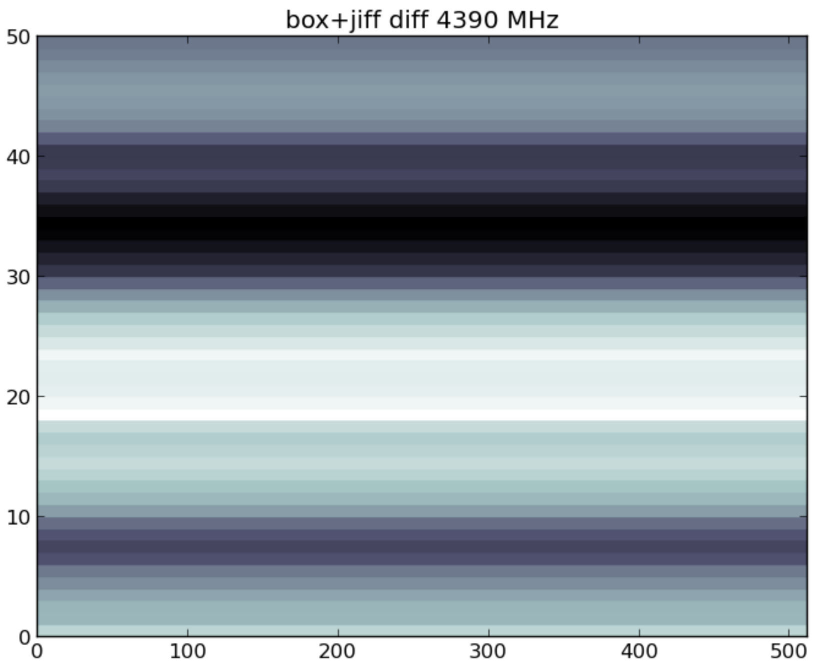

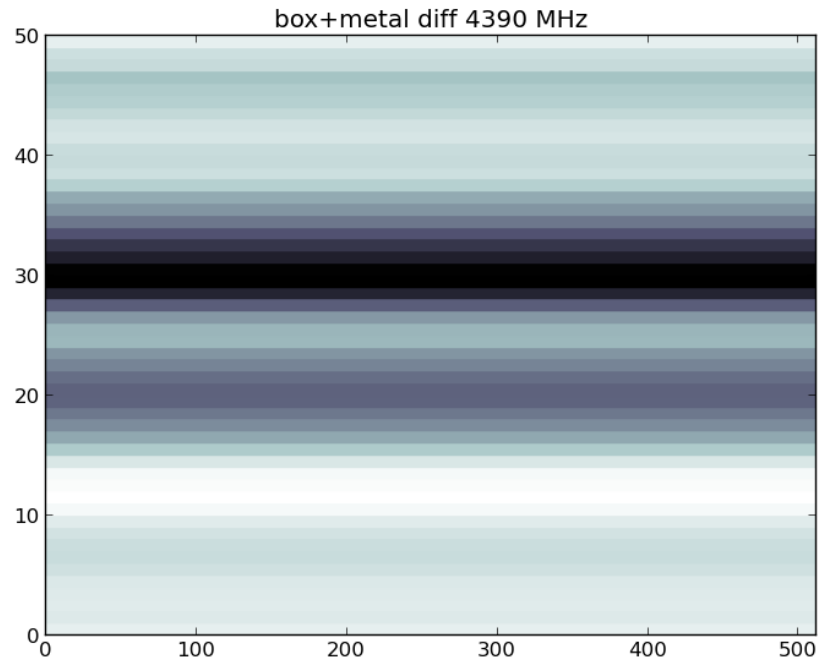

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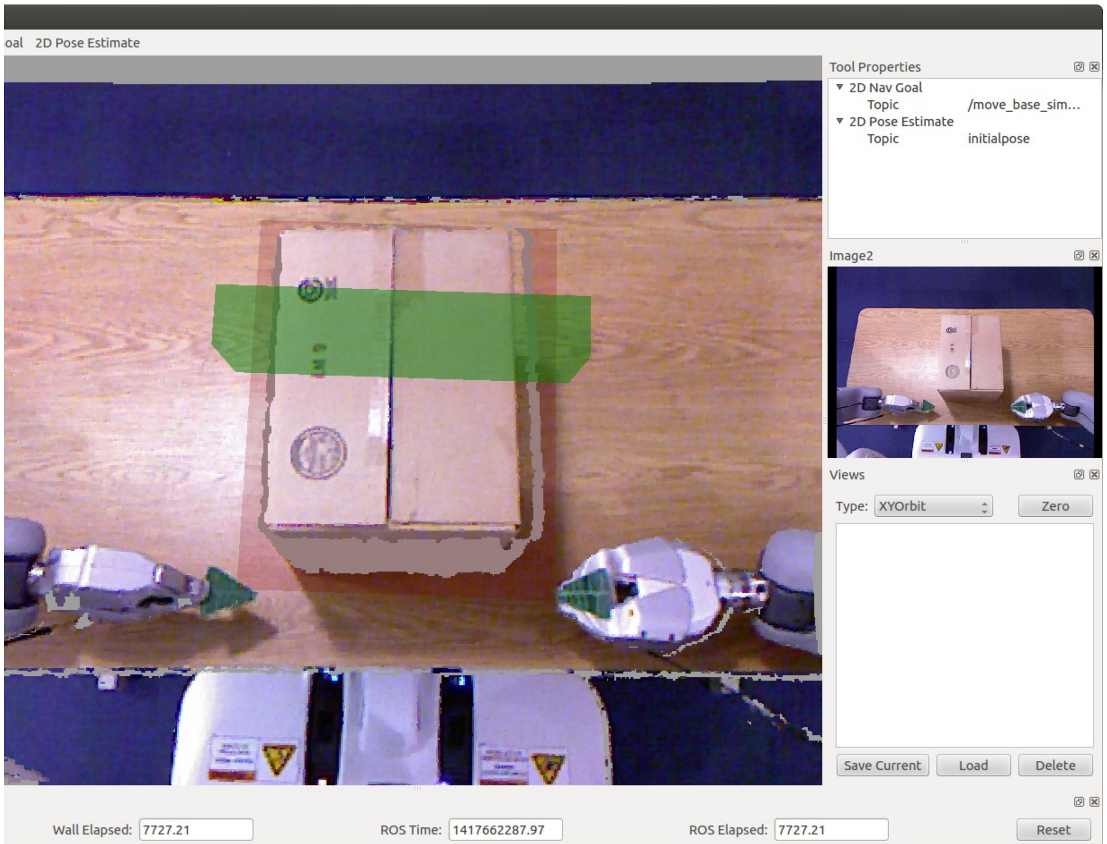

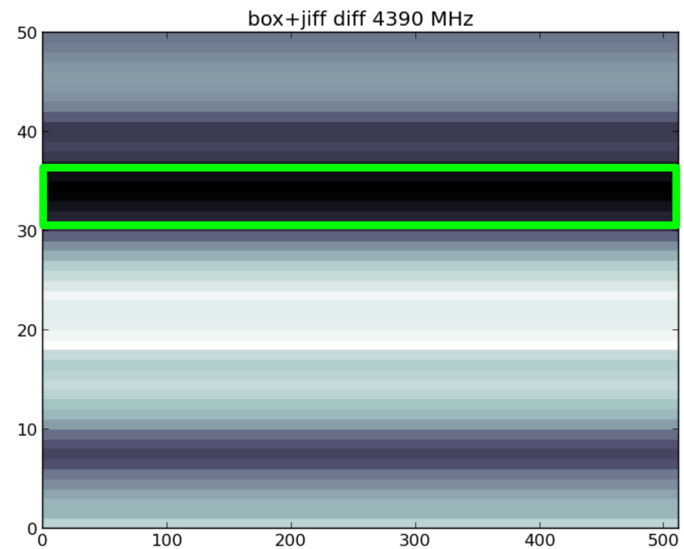

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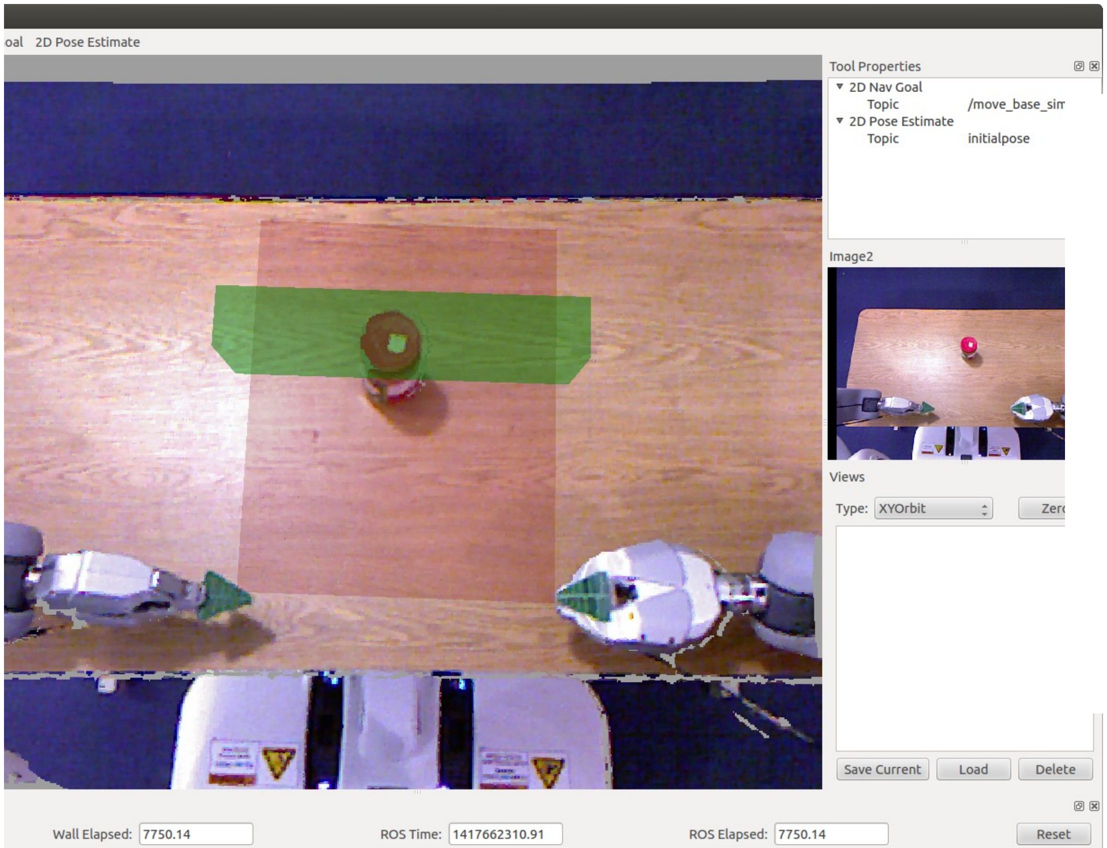
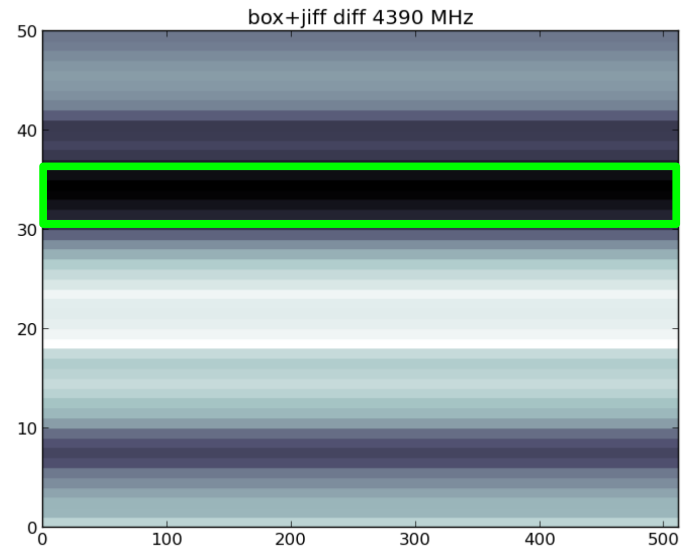
Scanning: Cardboard Box (4390 MHz)





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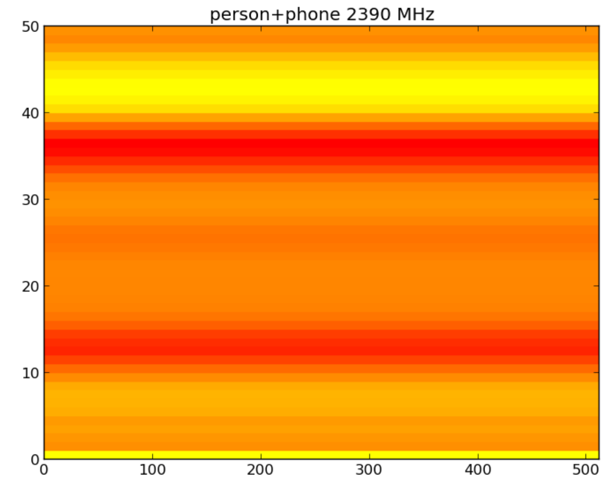
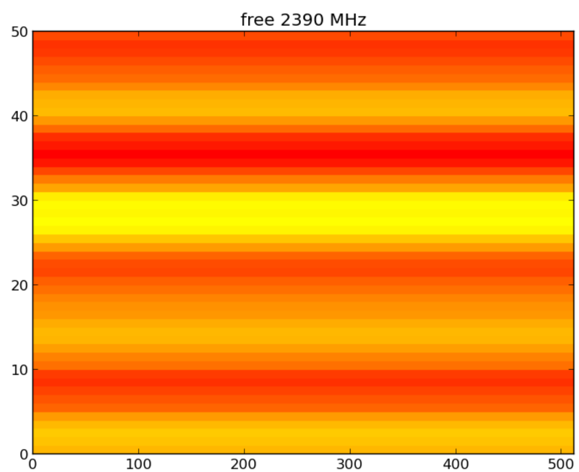
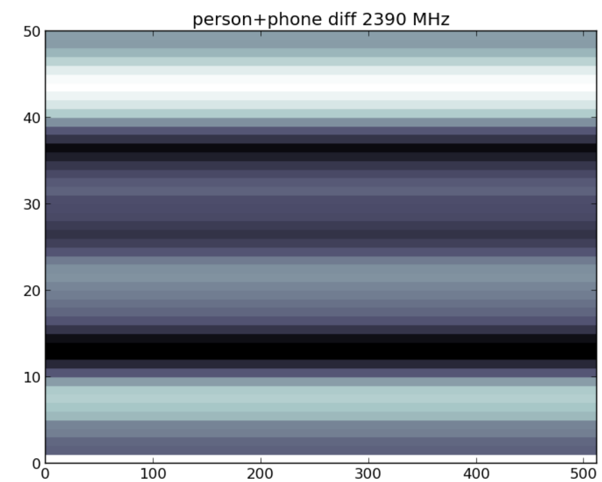
Scanning: Person (2390 MHz)

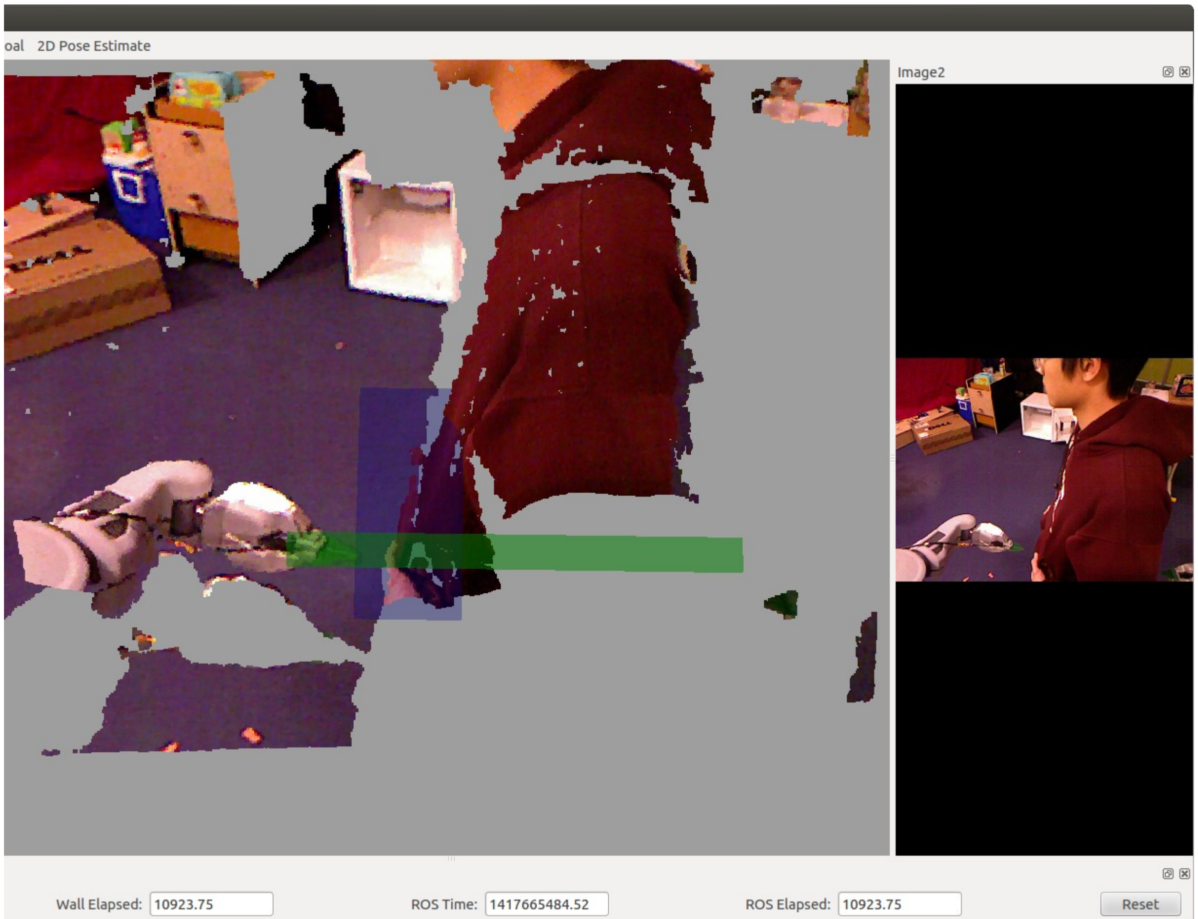
Scanning: Person (2390 MHz)

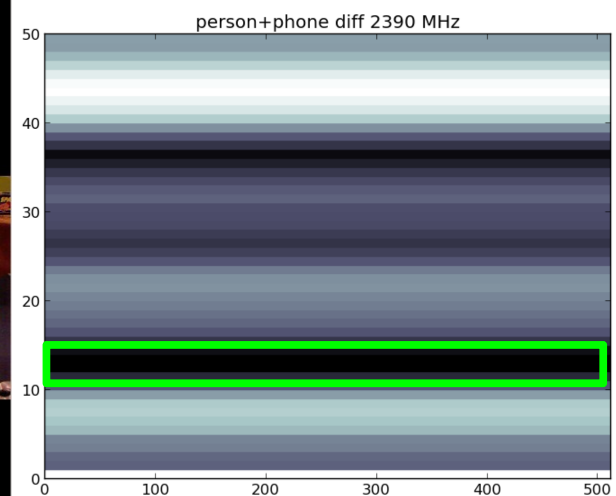






Scanning: Person (2390 MHz)





Current Work

- Varying Frequency
- Reflection, circular trajectories
- Geometry-based attenuation estimates
- Real-time emphasis on areas of interest
- Account for differences in gripper pose, vibration

$$\frac{P_r}{P_t} = G_t(\theta_t, \phi_t) G_r(\theta_r, \phi_r) \left(\frac{\lambda}{4\pi R}\right)^2 (1 - |\Gamma_t|^2)(1 - |\Gamma_r|^2) |\mathbf{a}_t \cdot \mathbf{a}_r^*|^2 e^{-\alpha R}$$

where

- $G_t(\theta_t, \phi_t)$ is the gain of the transmit antenna in the direction (θ_t, ϕ_t) in which it "sees" the receive antenna.
- $G_r(\theta_r, \phi_r)$ is the gain of the receive antenna in the direction (θ_r, ϕ_r) in which it "sees" the transmit antenna.