混响环境下声源定位算法研究

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上海交通大學
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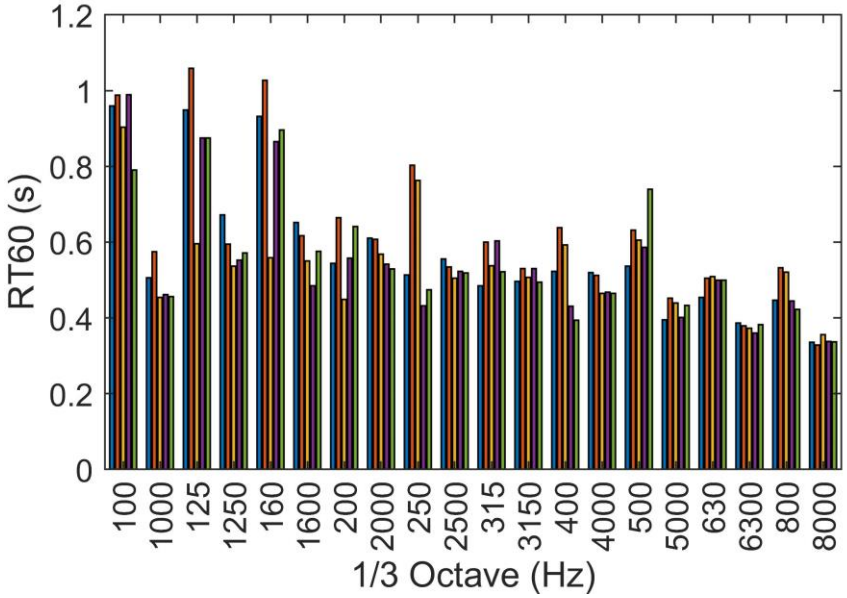
1.混响时间测量



1/3倍频程吸声系数

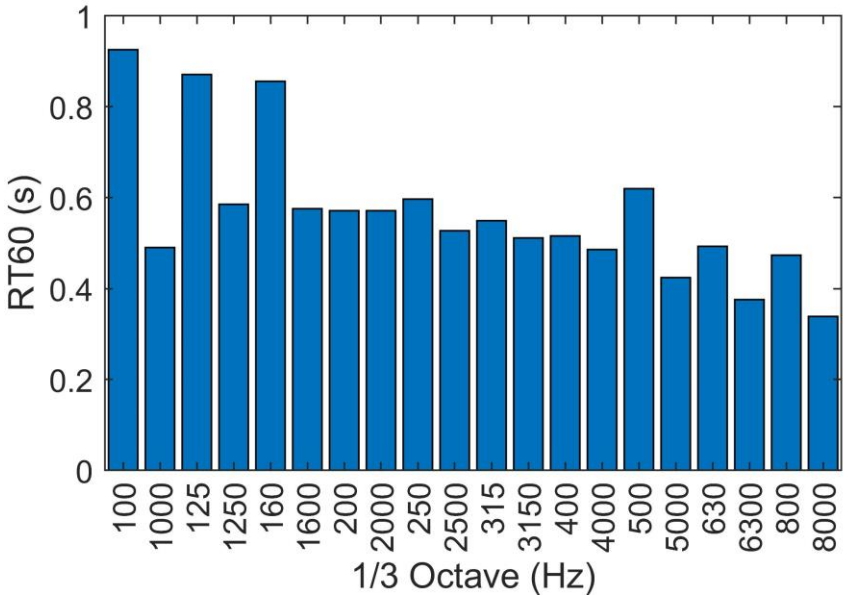
脉冲响应积分法:

- 测量脉冲响应（气球）
- 求解能量衰减曲线
- 根据衰减斜率计算混响时间

能量衰减曲线计算公式:

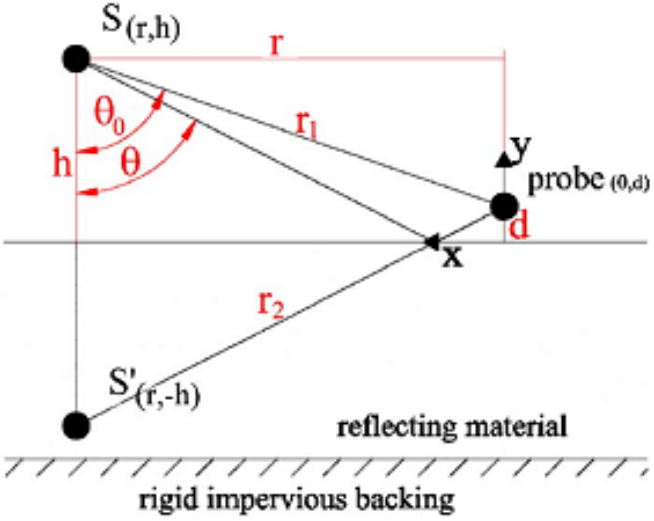
$$\mathrm{E(t)} = \int_{t}^{+\infty} p^2(t)dt$$

1.混响时间测量



1/3倍频程吸声系数平均值

2.吸声系数测量



平面波反射的镜像源模型

基于PU探头的吸声系数测量

$$R(\omega,\theta)=e^{ik(r_1-r_2)}\frac{r_2}{r_1}\frac{Z(d,\omega)\left(\frac{1-ikr_1}{-ikr_1}\right)cos\theta-\rho c}{Z(d,\omega)\left(\frac{1-ikr_2}{-ikr_2}\right)cos\theta_0+\rho c}$$

垂直入射：

$$R(\omega,\theta)=e^{ik(r_1-r_2)}\frac{r_2}{r_1}\frac{Z(d,\omega)\left(\frac{1-ikr_1}{-ikr_1}\right)-\rho c}{Z(d,\omega)\left(\frac{1-ikr_2}{-ikr_2}\right)+\rho c}$$

吸声系数：

$$\alpha=1-|R|^2$$

2.吸声系数测量

PU探头测量

垂直入射：

$$R(\omega,\theta)=e^{ik(r_1-r_2)}\frac{r_2}{r_1}\frac{Z(d,\omega)\left(\frac{1-ikr_1}{-ikr_1}\right)-\rho c}{Z(d,\omega)\left(\frac{1-ikr_2}{-ikr_2}\right)+\rho c}$$

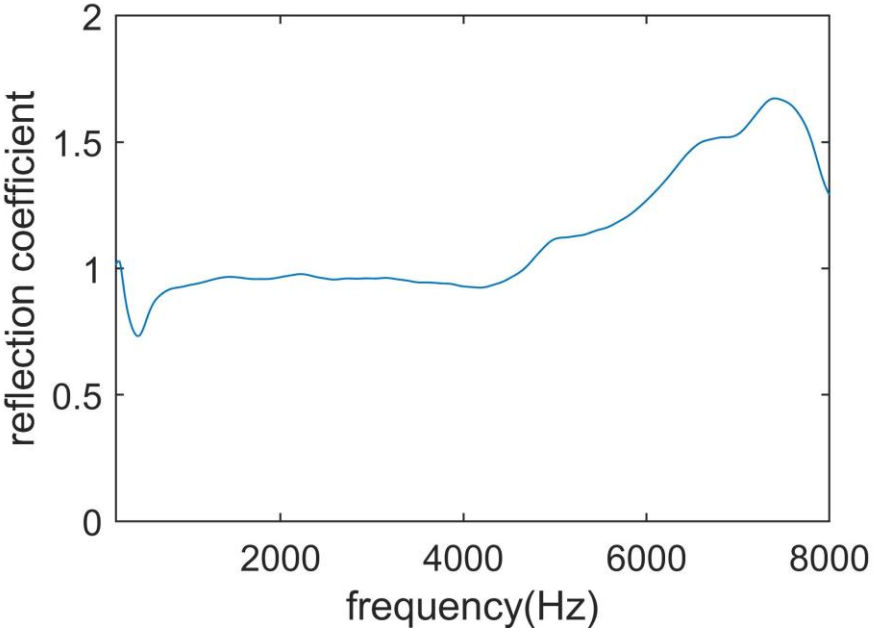
$$d\to 0$$

$$\mathrm{R}(\omega)=\frac{z(\omega)-\rho_0 c_0}{z(\omega)+\rho_0 c_0} \qquad z(\omega)=\frac{1+\mathrm{R}(\omega)}{1-\mathrm{R}(\omega)}\rho_0 c_0$$

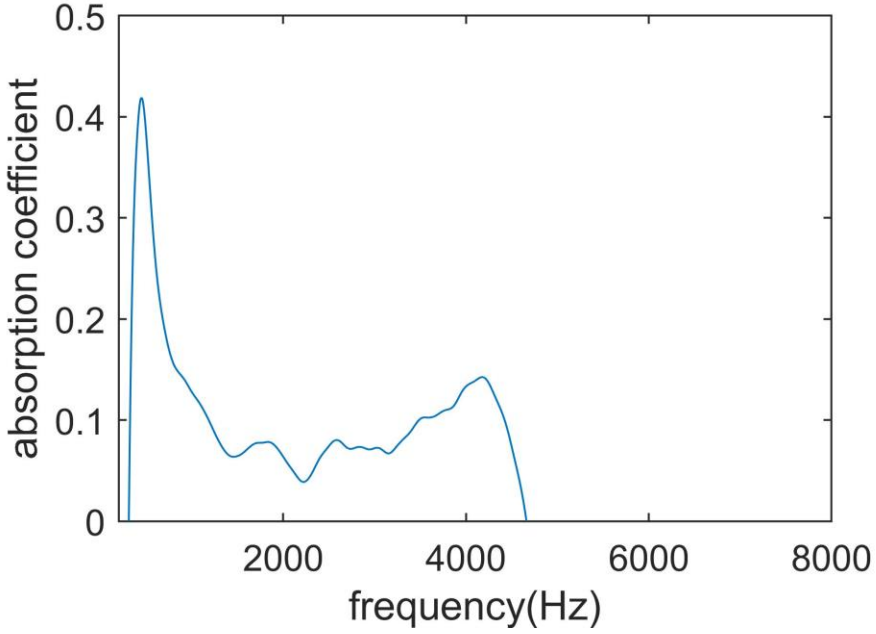
任意入射角度下的反射系数：

$$R(\omega,\theta)=\frac{z(\omega)cos\theta-\rho_0 c_0}{z(\omega)cos\theta+\rho_0 c_0}$$

2.吸声系数测量

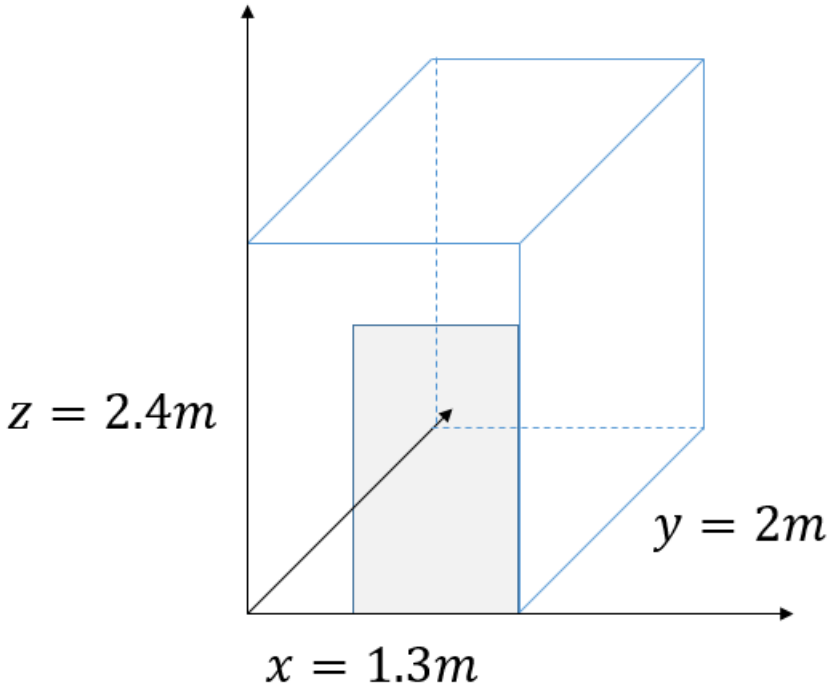


反射系数



吸声系数

3.数值仿真



房间模型

- 房间尺寸：1.3×2×2.4 (m^3)；
- 反射系数系数：根据测量结果；
- 施罗德频率：$f \approx 600$ (Hz)；
- 分析频率：1000~4000Hz
- 声源位置：(0.46,0.5,1.27)m；
- 阵列中心：(0.65,1.5,1.27)m；
- 传声器信号：$y(t) = s(t) * h(t)$

3.数值仿真

房间脉冲响应：

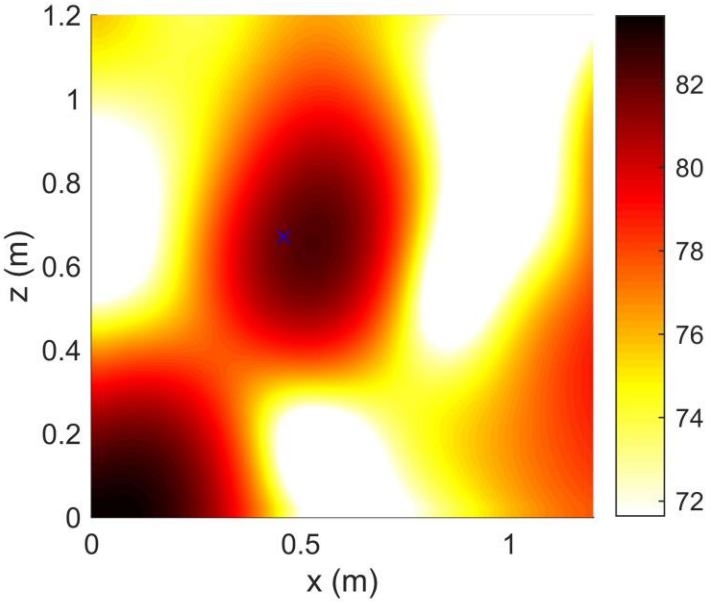
$$h(t,X,X')=\sum_{p=0}^{1}\sum_{r=-\infty}^{\infty}\beta_{x,1}^{|m_x-q|}\beta_{x,2}^{|m_x|}\beta_{y,1}^{|m_y-j|}\beta_{y,2}^{|m_y|}\beta_{z,1}^{|m_z-v|}\beta_{z,2}^{|m_z|}\frac{\delta\left(t-\left|\overrightarrow{\boldsymbol{R}_p}-\overrightarrow{\boldsymbol{R}_r}\right|/c\right)}{4\pi\left|\overrightarrow{\boldsymbol{R}_p}-\overrightarrow{\boldsymbol{R}_r}\right|}$$

房间频率响应：

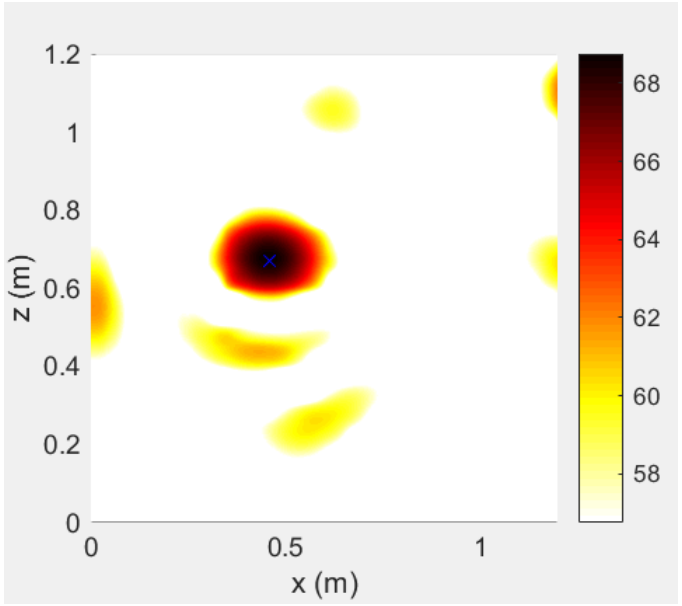
$$h(\omega,X,X')=\sum_{p=0}^{1}\sum_{r=-\infty}^{\infty}\beta_{x,1}^{|m_x-q|}\beta_{x,2}^{|m_x|}\beta_{y,1}^{|m_y-j|}\beta_{y,2}^{|m_y|}\beta_{z,1}^{|m_z-v|}\beta_{z,2}^{|m_z|}\frac{exp\left(i\omega\left|\overrightarrow{\boldsymbol{R}_p}-\overrightarrow{\boldsymbol{R}_r}\right|/c\right)}{4\pi\left|\overrightarrow{\boldsymbol{R}_p}-\overrightarrow{\boldsymbol{R}_r}\right|}$$

3.数值仿真

1000Hz仿真结果



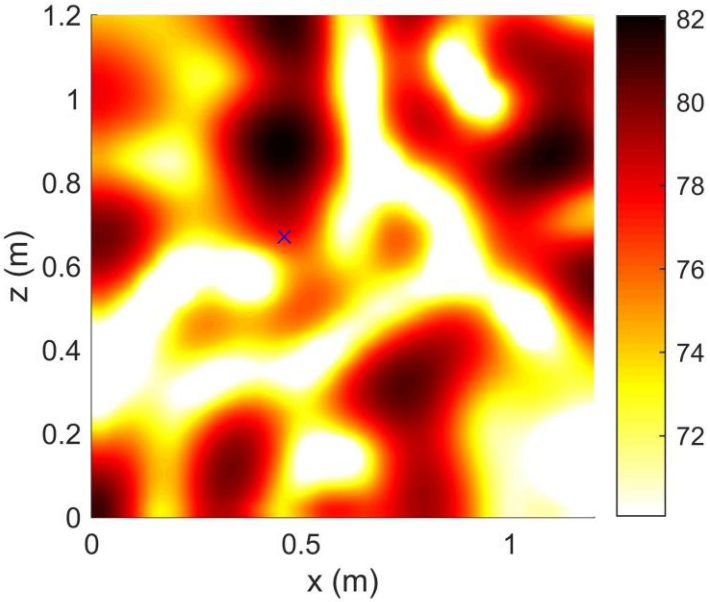
BF



ISM

3.数值仿真

2000Hz仿真结果



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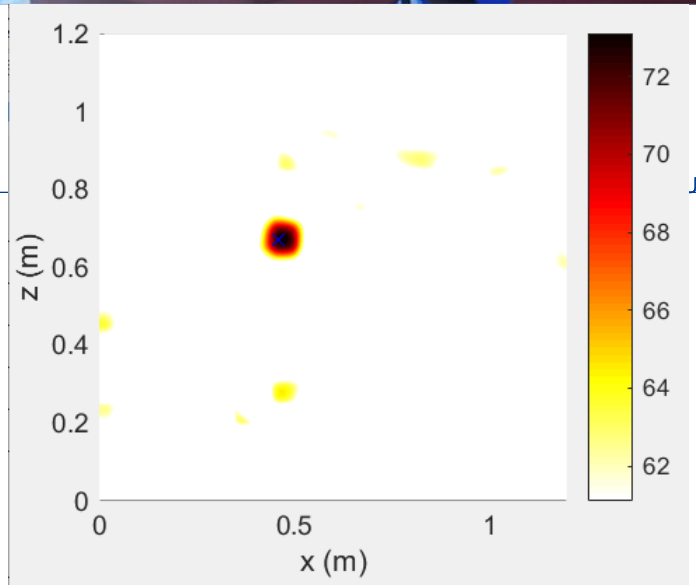
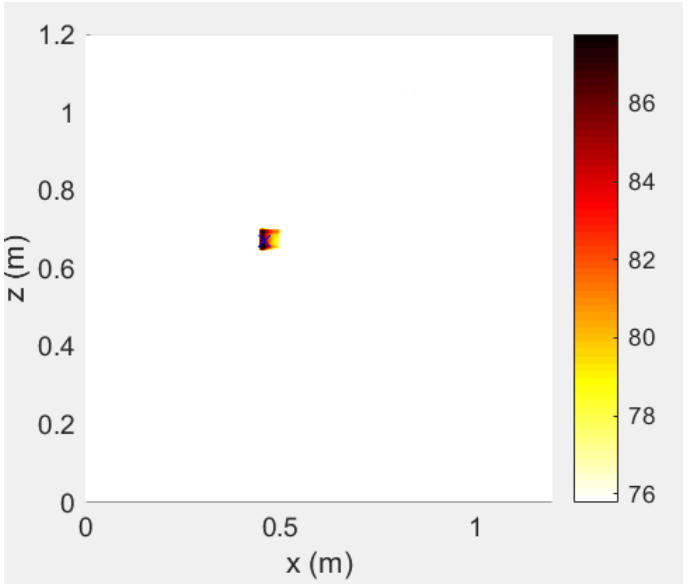
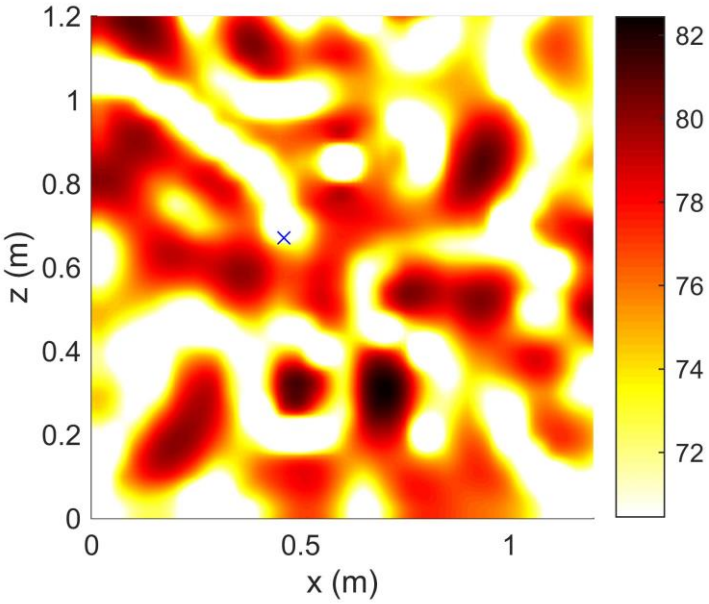




ISM

3.数值仿真

3000Hz仿真结果



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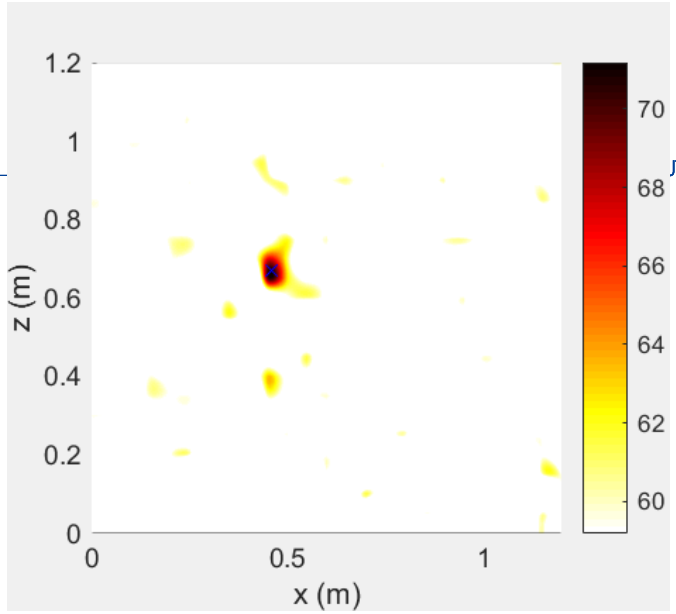
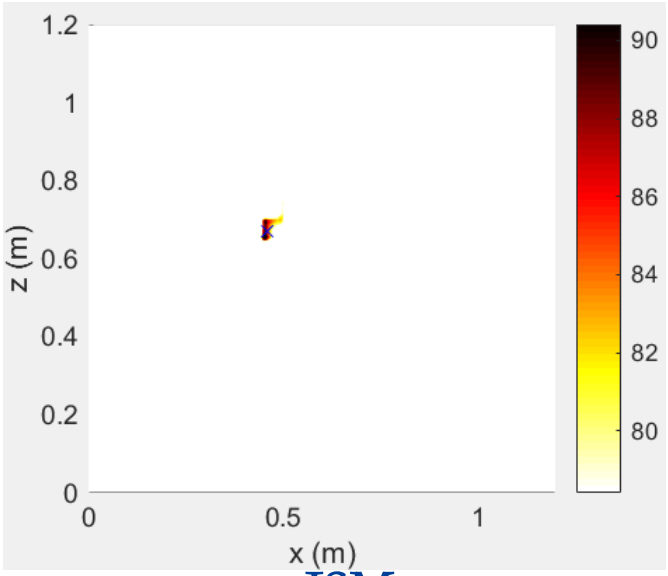
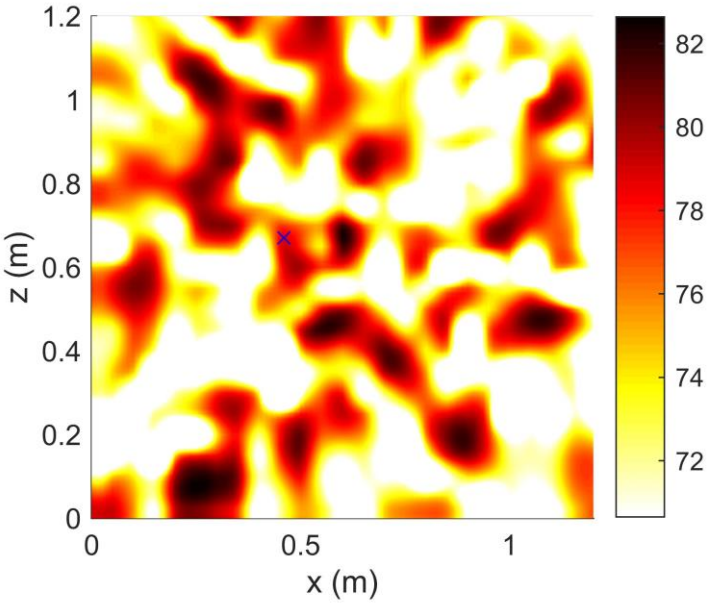




ISM

3.数值仿真

4000Hz仿真结果



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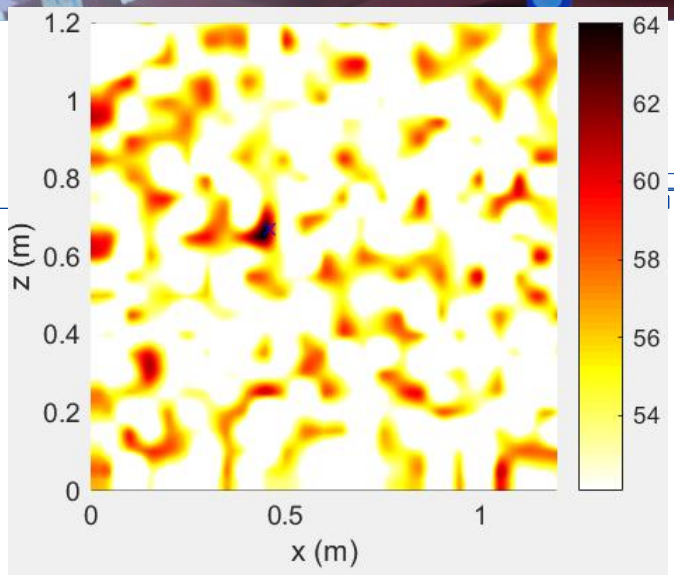

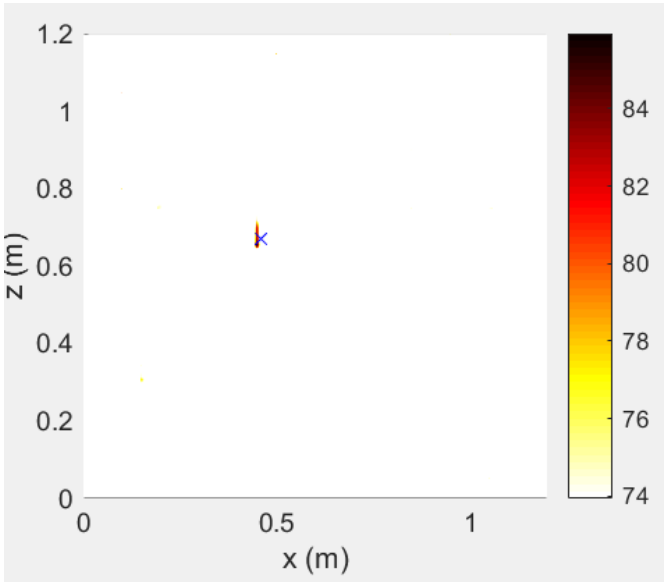

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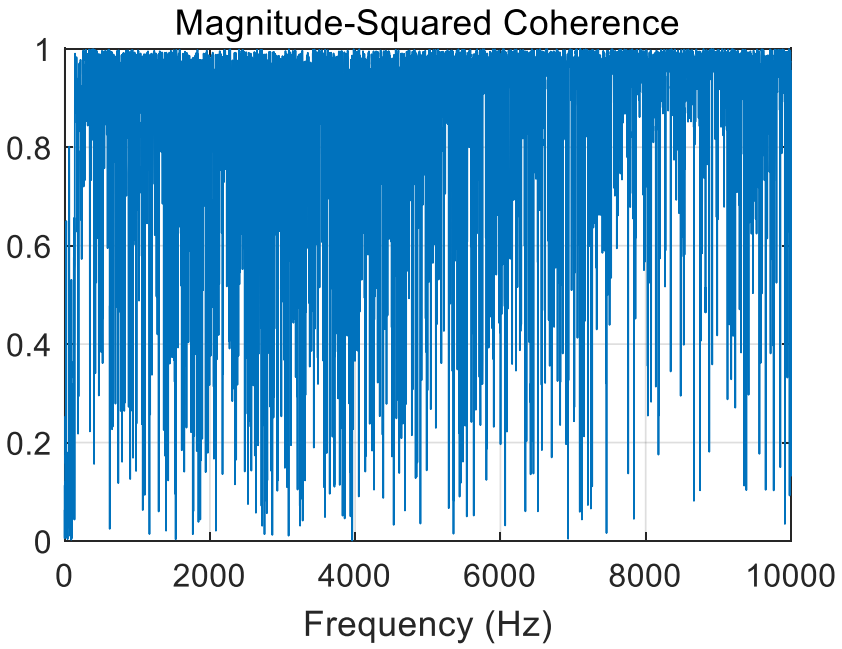
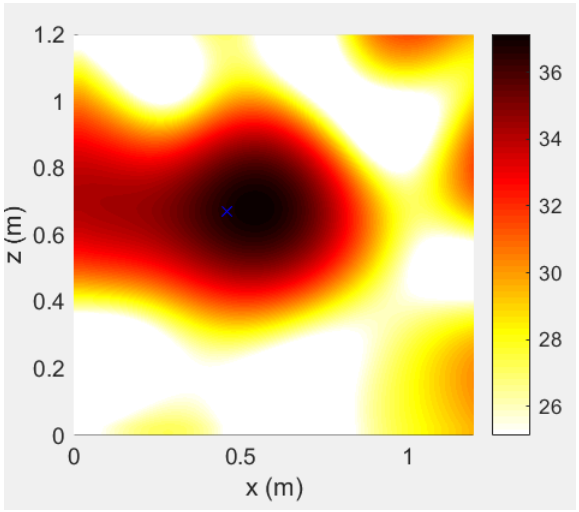
4.实验结果

声源：白噪声

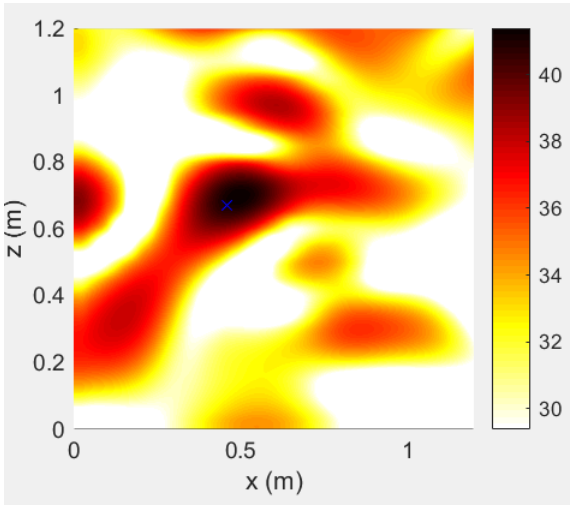


信号相干性分析

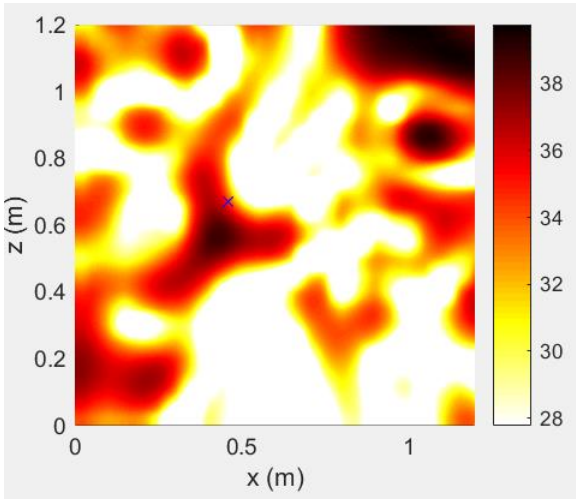
4.实验结果



1000Hz BF

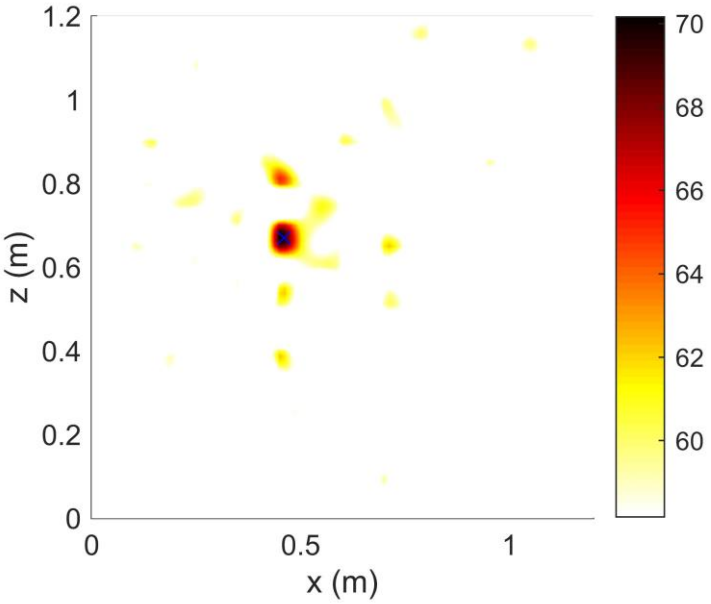


2000Hz BF

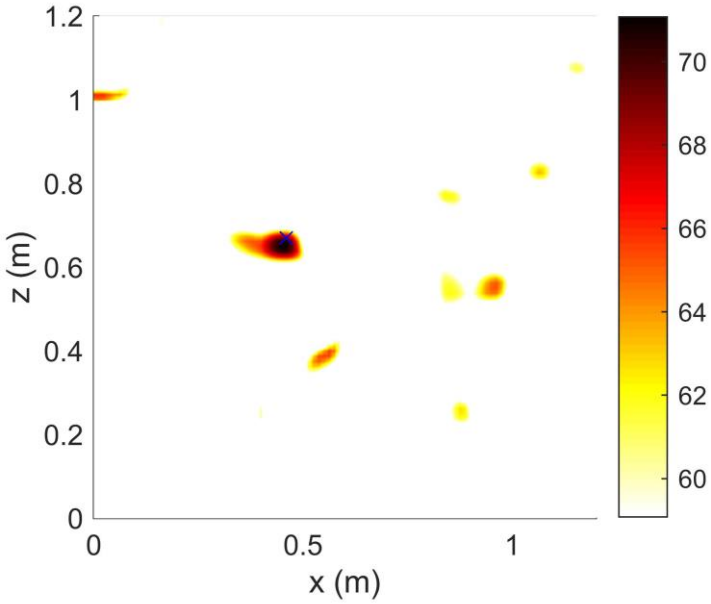


3000Hz BF

4.实验结果



1000Hz ISM



2000Hz ISM