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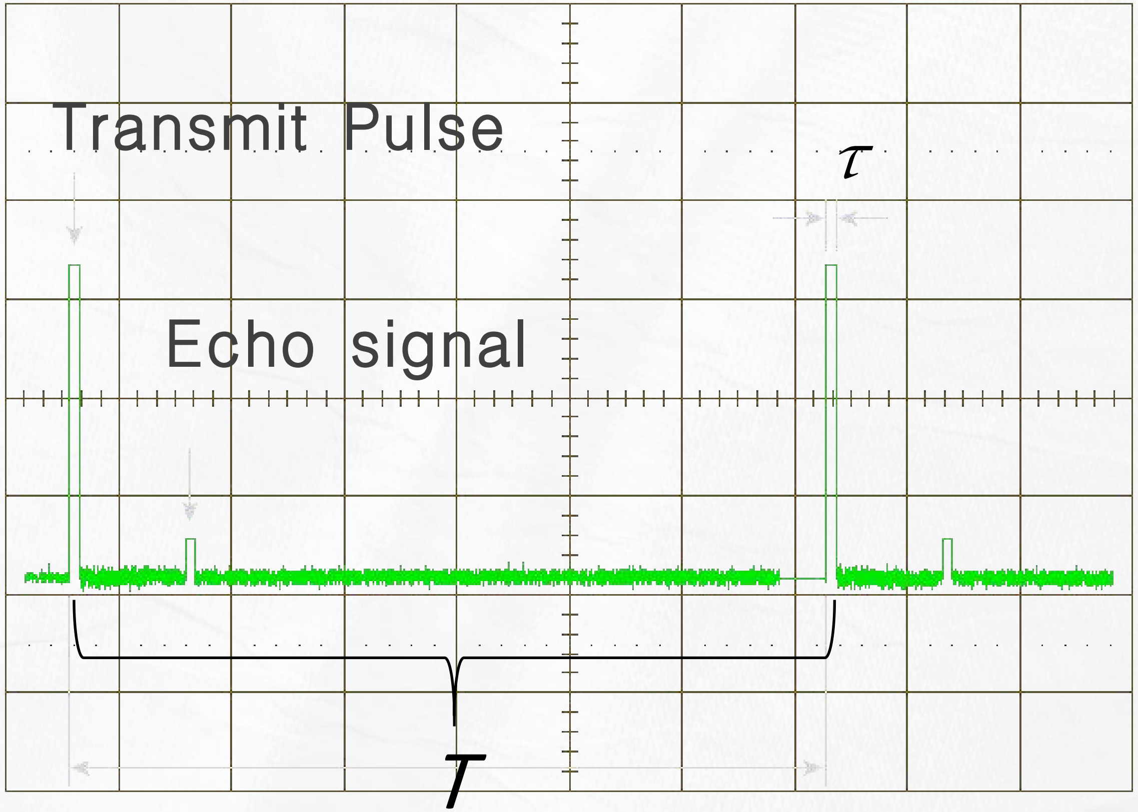
简介

Introduction

脉冲体制雷达

- 峰值功率高 信噪比低
- 分辨率由脉宽决定



$$R_{max} = [\frac{(P_t \cdot \tau) \cdot G^2 \lambda^2 \sigma}{(4\pi)^3 k T_0 F_n (\frac{S}{N})_{o\,\min}}]^{\frac{1}{4}}$$

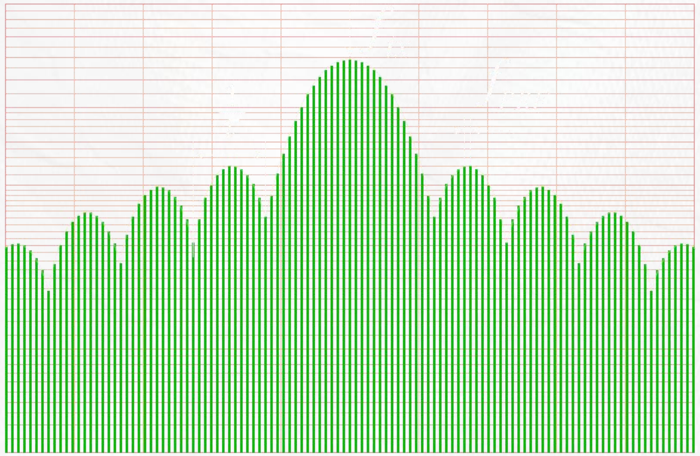
$$\Delta R = \frac{1}{2} c\tau$$

一般性脉冲波形

$$s(t) = rect(\frac{t}{T_p}) \cdot e^{j2\pi f}$$

FT $\longrightarrow$

sinc函数



调频脉冲波形

$$s(t) = rect(\frac{t}{T_p}) \cdot e^{[j2\pi f(t) \cdot t + \phi(t)]}$$

- LFM
- NLFM
- Phase-coded FM

雷达波形与脉冲压缩

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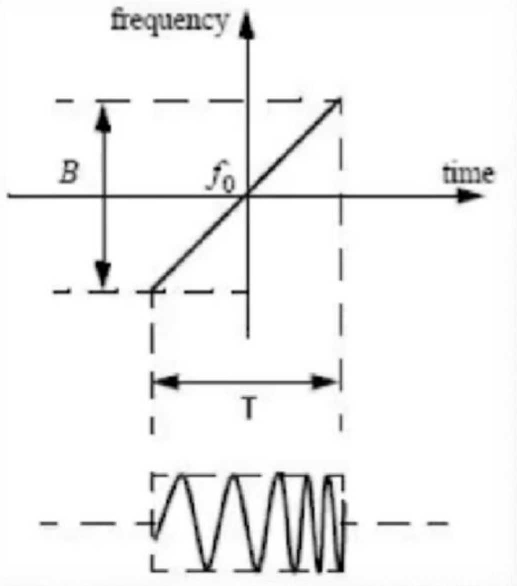
	Linear FM		Nonlinear FM		Phase-coded	
	Active	Passive	Active	Passive	Active	Passive
Range coverage	Limited range coverage per active correlation processor.	Provides full range coverage.	Limited range coverage per active correlation processor.	Provides full range coverage.	Limited range coverage per active correlation processor.	Provides full range coverage.
Doppler coverage	Covers any doppler up to $\pm B/10$, but a range error is introduced. *SNR* and time-sidelobe performance poor for larger doppler.		Multiple doppler channels required, spaced by $(1/T)$ Hz.			
Range sidelobe level	Requires weighting to reduce the range sidelobes below $(\sin x)/x$ falloff.		Good range sidelobes possible with no weighting. Sidelobes determined by waveform design.		Good range sidelobes. $N^{-1/2}$ for an N-element code.	
Waveform flexibility	Bandwidth and pulse width can be varied.	Limited to one bandwidth and pulse width per compression network.	Bandwidth and pulse width can be varied.	Limited to one bandwidth and pulse width per compression network.	Bandwidth, pulse width, and code can be varied.	
Interference rejection	Poor clutter rejection.		Fair clutter rejection.		Fair clutter rejection.	
SNR	Reduced by weighting and by ripple loss versus range.	Reduced by weighting.	Reduced by ripple loss versus range.	No *SNR* loss.	Reduced by ripple loss versus range.	No *SNR* loss.
Comments	1. Very popular with the advent of high-speed digital devices. 2. Extremely wide	1. Widely used in past. 2. Well-developed technology.	1. Limited use. 2. Waveform generation by digital means most popular.	1. Limited use. 2. Extremely limited development.	1. Widely used. 2. Waveform very easy to generate.	1. Limited use. 2. Waveform moderately difficult to generate.

雷达波形与脉冲压缩

Introduction

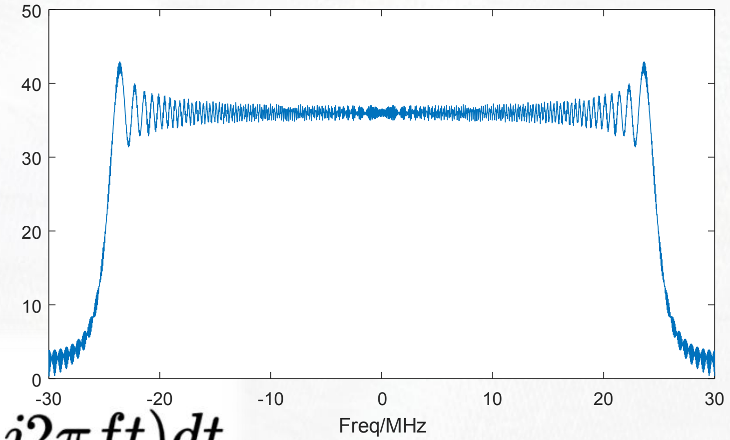
Linear Frequency Modulation Signal
LFM线性调频信号 （Chirp）



- 时域表达式：$$s(t) = rect(\frac{t}{T_p}) \cdot e^{(j2\pi f_0 t + \pi K t^2)}$$
- 相位 $$\phi(t) = \pi K t^2$$
- 瞬时频率 $$f = \frac{1}{2\pi}\frac{d\phi(t)}{dt} = Kt$$
- 带宽 $$BW = |K|T$$
- 时间带宽积TBP $$TBP = |K|T^2$$

雷达波形与脉冲压缩

Introduction



线性调频信号的频谱

利用菲涅尔积分可得到详细的表达式：

$$S(f)=\int_{-\infty}^{+\infty}s(t)\exp(-j2\pi ft)dt=\int_{-\frac{T_p}{2}}^{\frac{T_p}{2}}\exp(j\pi Kt^2)\exp(-j2\pi ft)dt$$

$$=\exp(-j\frac{\pi f^2}{K})\int_{-\frac{T_p}{2}}^{\frac{T_p}{2}}\exp[j(\sqrt{\pi}Kt-\frac{\pi f}{\sqrt{\pi K}})^2]dt$$

做变量代换：

$$dx=\sqrt{2K}dt$$

得到

$$S(f)=\frac{1}{\sqrt{2K}}\exp(-j\frac{\pi f^2}{K})\int_{-X_1}^{X_2}\exp(j\frac{\pi x^2}{2})dx$$

其中
$$\begin{cases}X_1=\sqrt{2K}\frac{T_p}{2}+\frac{2f}{\sqrt{2K}}=\frac{\pi KT_p+2\pi f}{\pi\sqrt{2K}}\\ X_2=\sqrt{2K}\frac{T_p}{2}-\frac{2f}{\sqrt{2K}}=\frac{\pi KT_p-2\pi f}{\pi\sqrt{2K}}\end{cases}$$

由菲涅尔积分：

$$S(f)=\frac{1}{\sqrt{2K}}\exp(-j\frac{\pi f}{K})[C(X_1)+jS(X_1)+C(X_2)+jS(X_2)]$$

线性调频信号的频谱

驻定相位原理（POSP）

$$S(f)=\int_{-\infty}^{\infty}s(t)\exp(-j2\pi ft)\,dt=\int_{-\infty}^{\infty}\mathrm{rect}\left(\frac{t}{T_r}\right)\exp[j\theta(t)]\,dt$$

其中$\theta(t)=\pi K_r t^2-2\pi ft$，求$\theta(t)$关于时间 t 的导数，并令其为 0：

$$\frac{\mathrm{d}}{\mathrm{dt}}\theta(t)=2\pi K_r t-2\pi f=0$$

得到驻留点：

$$t_s=\frac{f}{K_r}\in\left[-\frac{T_r}{2},\frac{T_r}{2}\right]$$

驻定点与TBP有关

在驻留点处对其作Taylor展开

$$S(f)\approx\frac{1}{\sqrt{|K_r|}}rect\left(\frac{f}{K_rT_r}\right)\exp\left\{-j\pi\frac{f^2}{K_r}\right\}\exp\left(\pm j\frac{\pi}{4}\right)$$

匹配滤波器

$$\begin{cases} H(\omega) = KF^*(\omega)\exp(-j\omega t_0) \\ h(t) = Kf^*(t_0 - t) \end{cases}$$

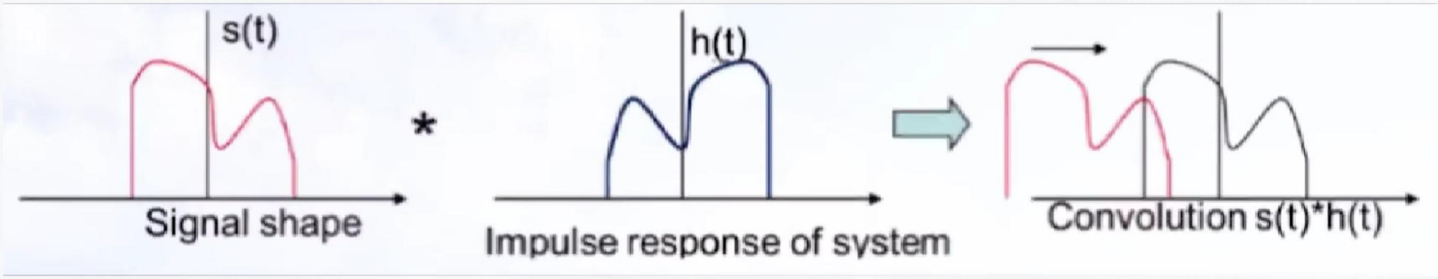
分析思路1：根据Cauchy−Schwarz不等式：

$$\left|\int_{-\infty}^{+\infty} A(\omega)B(\omega)d\omega\right|^2 \le \int_{-\infty}^{+\infty} |A(\omega)|^2 d\omega \cdot \int_{-\infty}^{+\infty} |B(\omega)|^2 d\omega$$

当 $A(\omega) = cB^*(\omega)$ 时等式成立

分析思路2：看成自相关器：

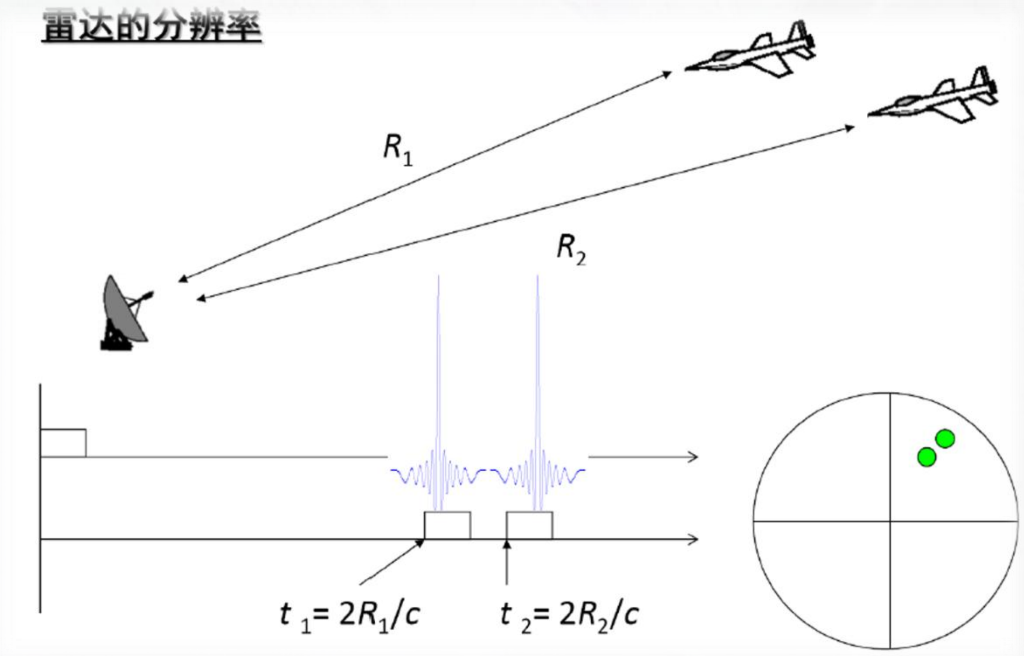
$$\begin{aligned} s_o(t) &= s(t) \otimes h(t) \\ &= \int_{-\infty}^{\infty} s(\tau)h(t-\tau)d\tau \\ &= \int_{-\infty}^{\infty} s(\tau)s^*[\tau-(t-t_m)]d\tau \\ &= R_{ss}(t-t_m) \end{aligned}$$

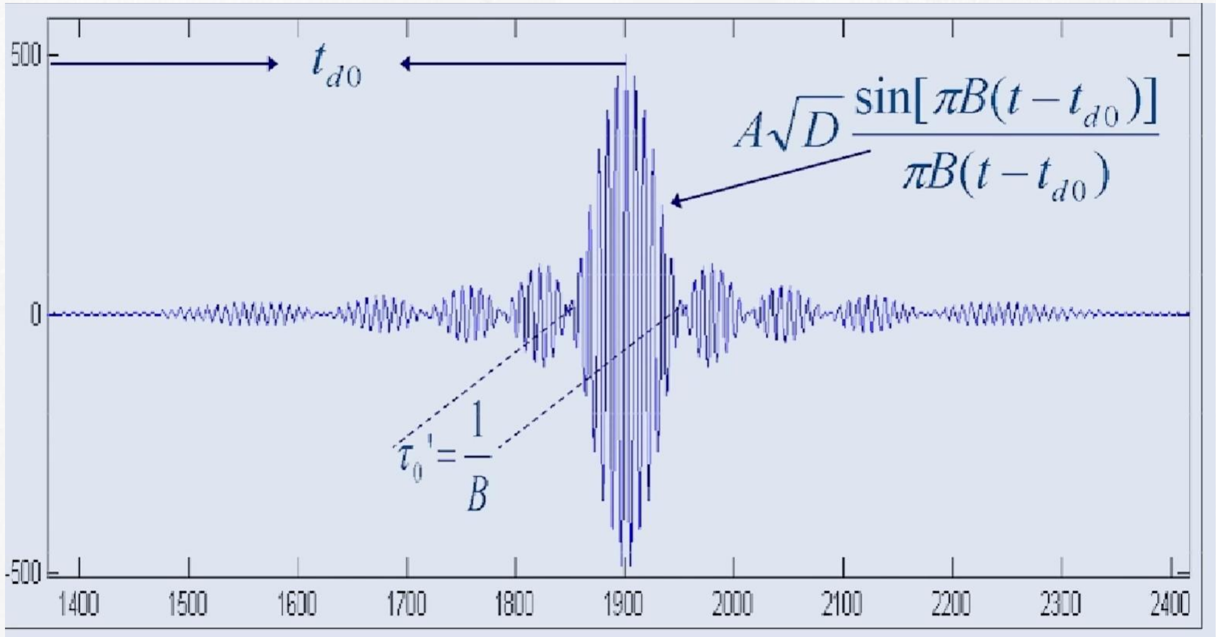


脉冲压缩——匹配滤波器的应用

$$R_{max} = \left[\frac{(P_t \cdot \tau) \cdot G^2 \lambda^2 \sigma}{(4\pi)^3 k T_0 F_n (\frac{S}{N})_{o\,\min}}\right]^{\frac{1}{4}}$$

$$\Delta R = \frac{1}{2} c\tau$$





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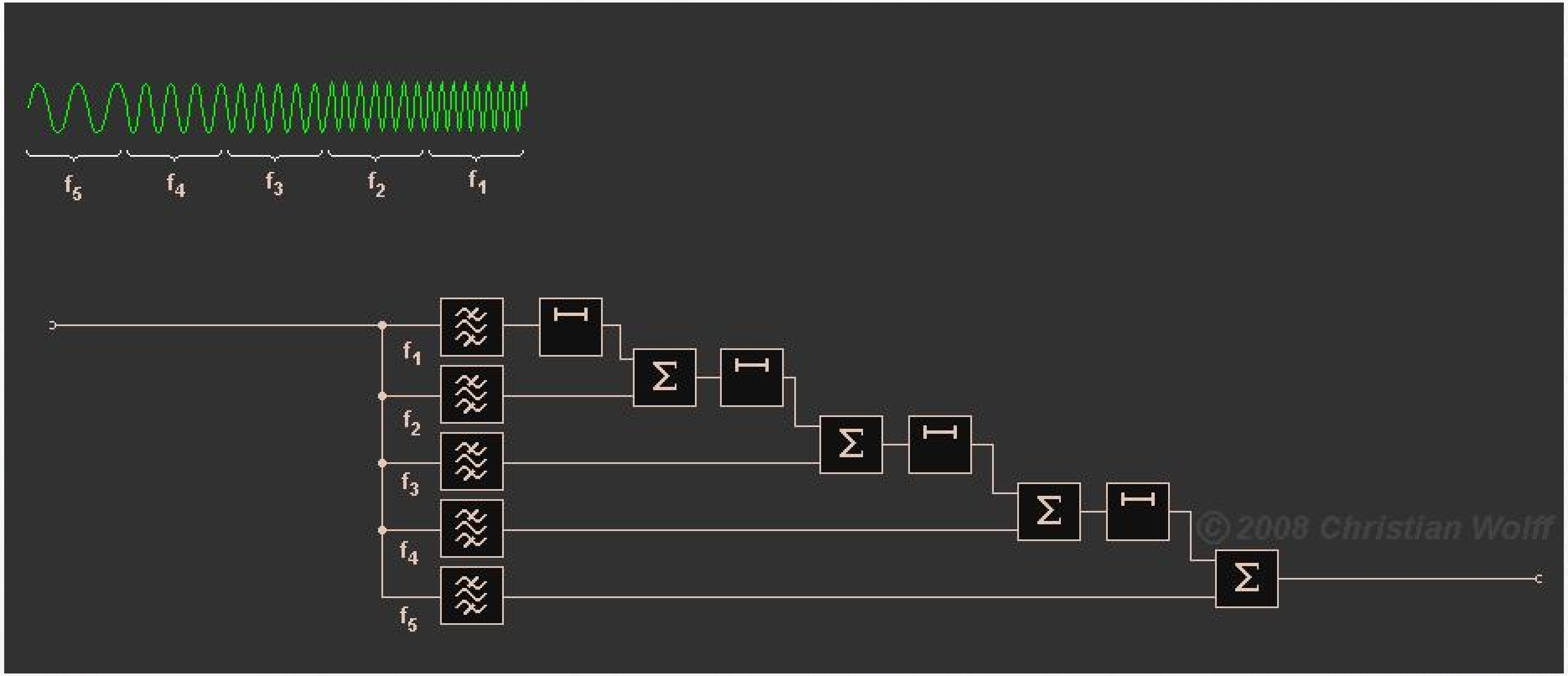
脉冲压缩



LFM信号脉冲压缩仿真

Introduction

1. LFM信号分析

（1）仿真LFM信号；（2）观察不同过采样率下的DFT结果；（3）观察不同TBP的LFM信号的频谱。

2. 脉冲压缩仿真：针对“基带LFM信号”

（1）实现无误差的脉冲压缩，计算指标（IRW、PSLR、ISLR）；

（2）观察频域加窗的影响，计算指标（IRW、PSLR、ISLR）

3.LFM回波仿真：

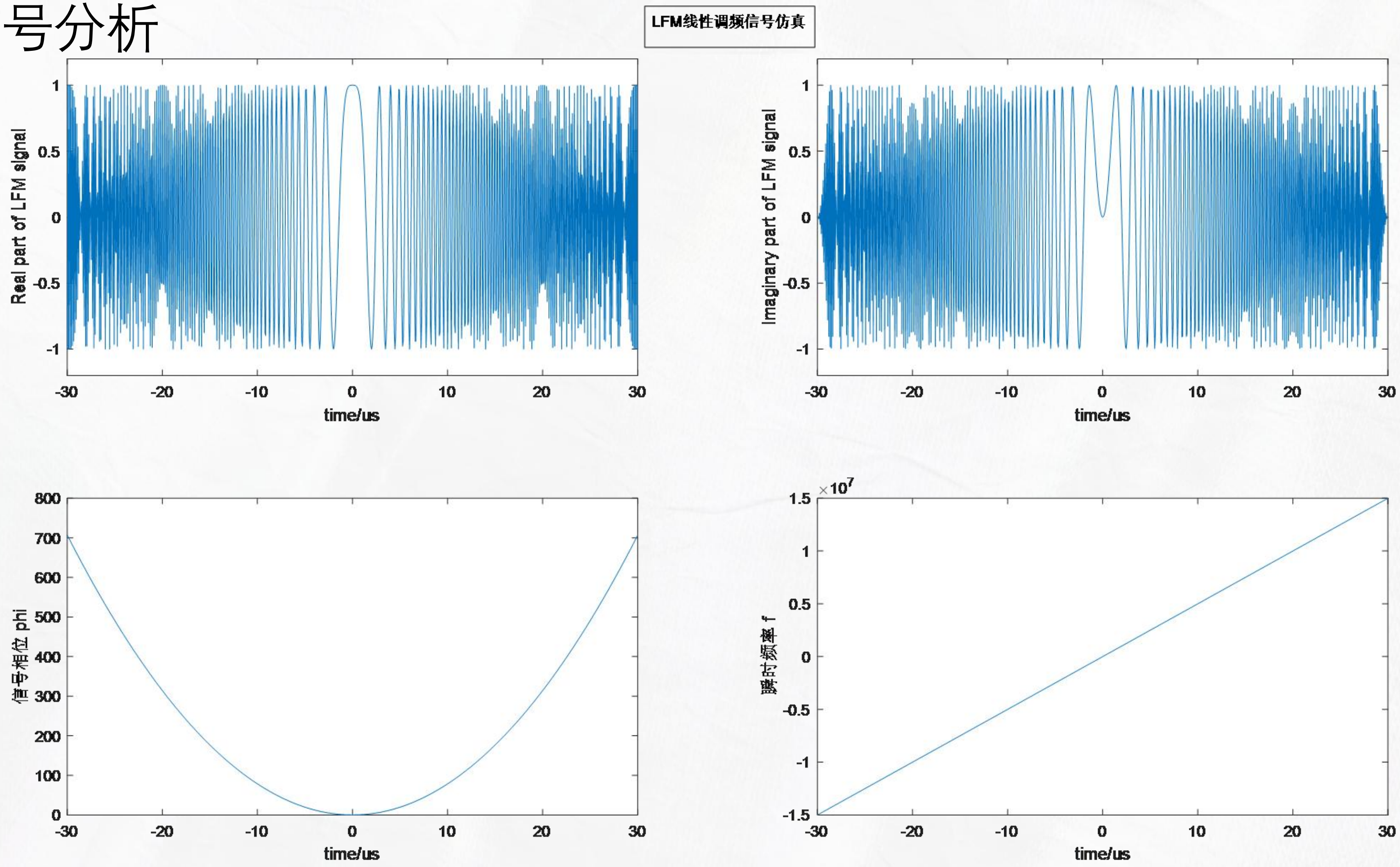
（1）输入参数：目标参数：RCS等于1，分别位于15Km，16Km。LFM信号参数：中心频率5.0GHz，脉冲宽度30us，带宽30MHz。接收机参数：发射信号后0.1ms启动接收机开始接收信号，持续时间0.04ms，按1.2倍过采样因子采样。

（2）输出：完成脉冲压缩。

LFM信号脉冲压缩仿真

Introduction

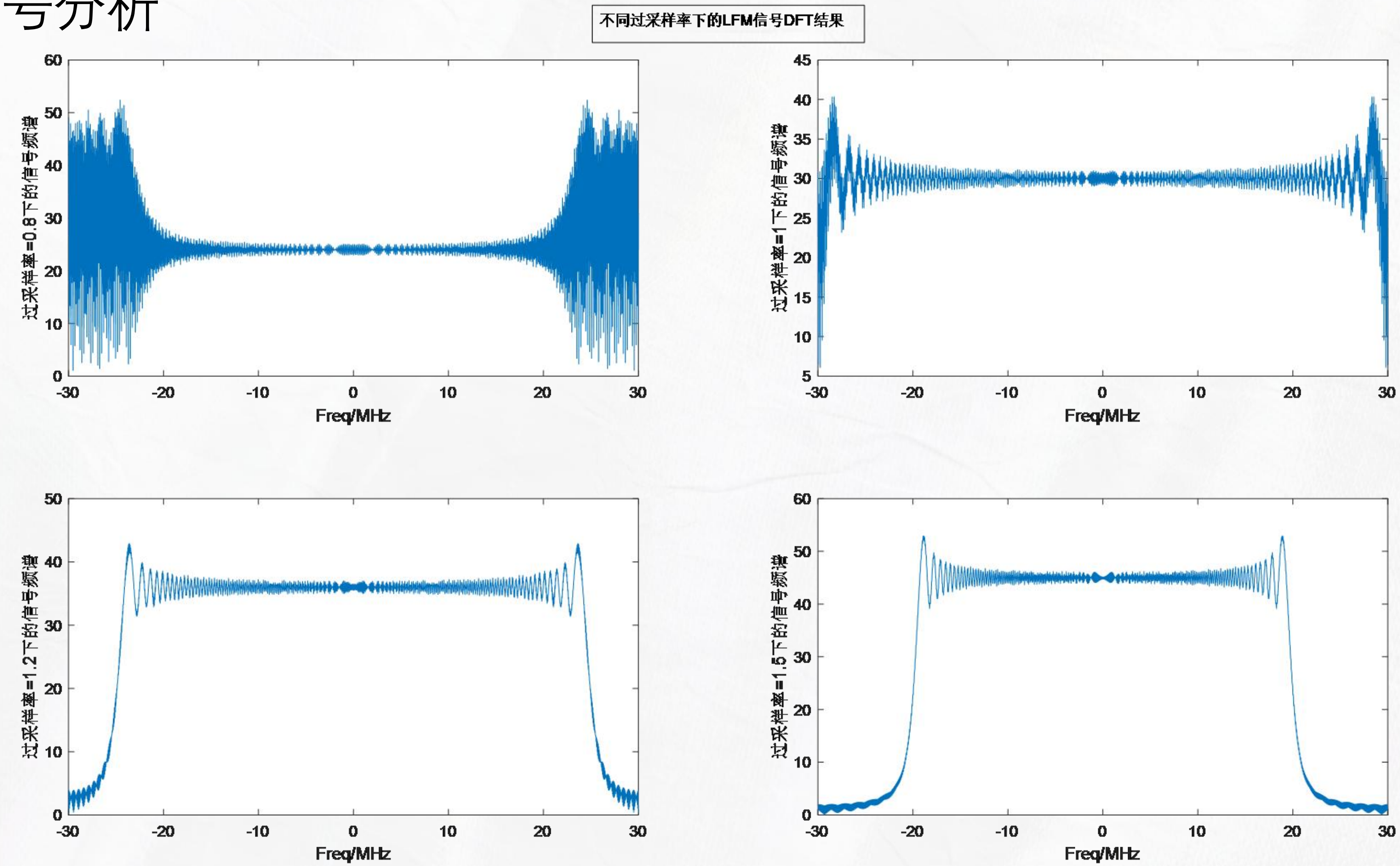
1．LFM信号分析



LFM信号脉冲压缩仿真

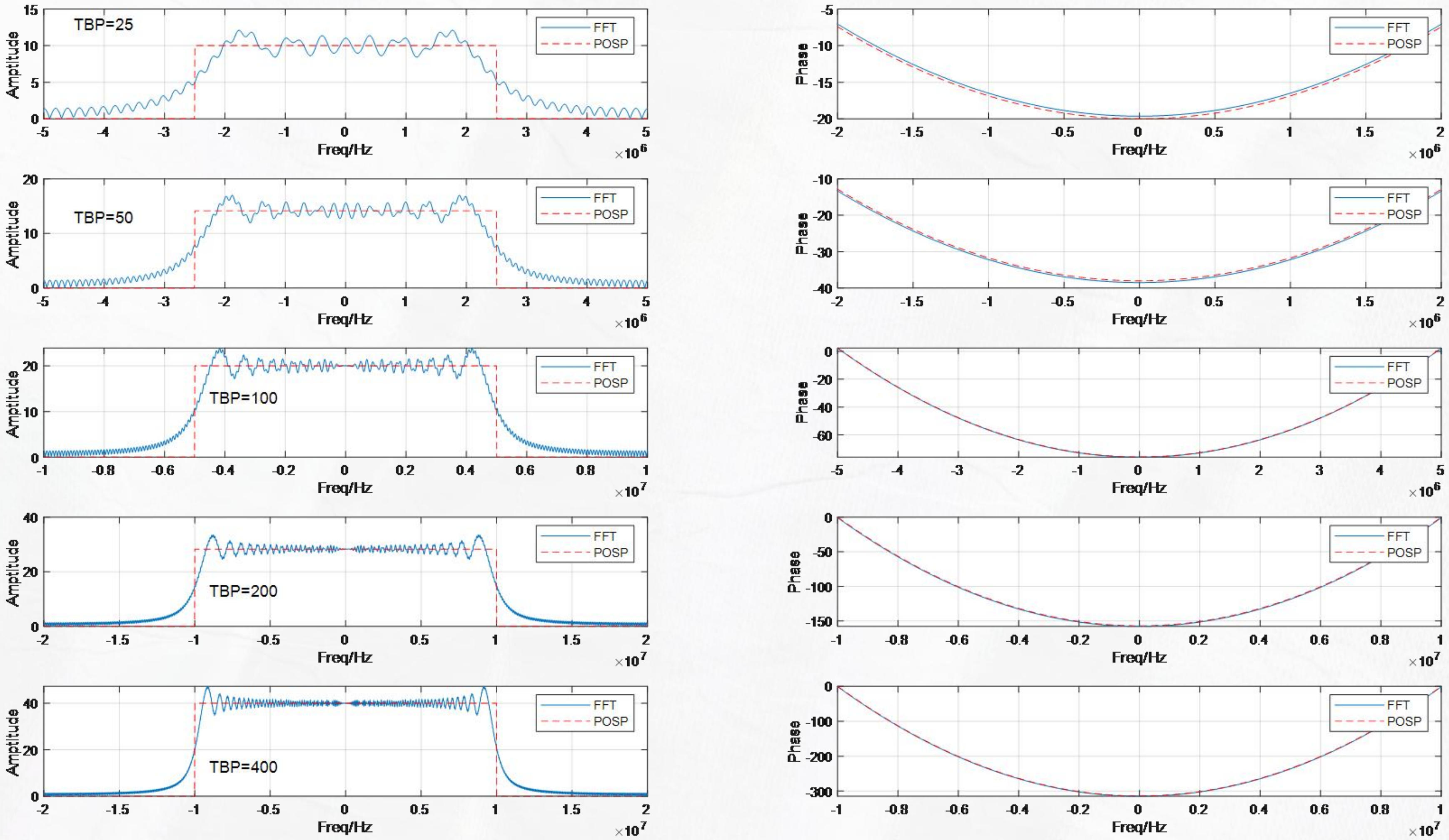
Introduction

1. LFM信号分析



1．LFM信号分析

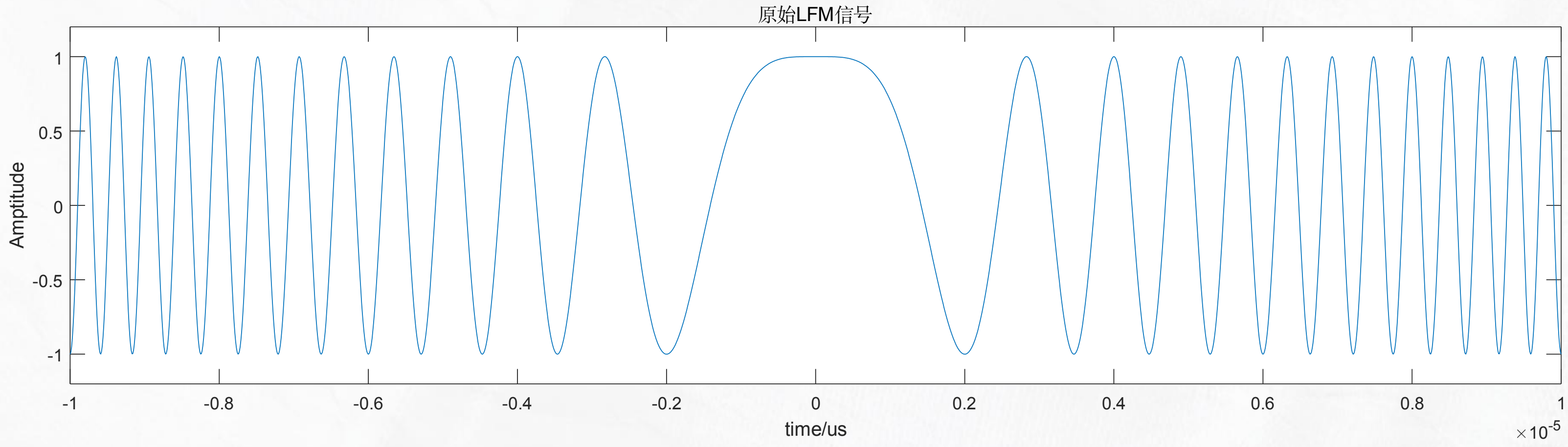
不同TBP下POSP方法近似频谱对比

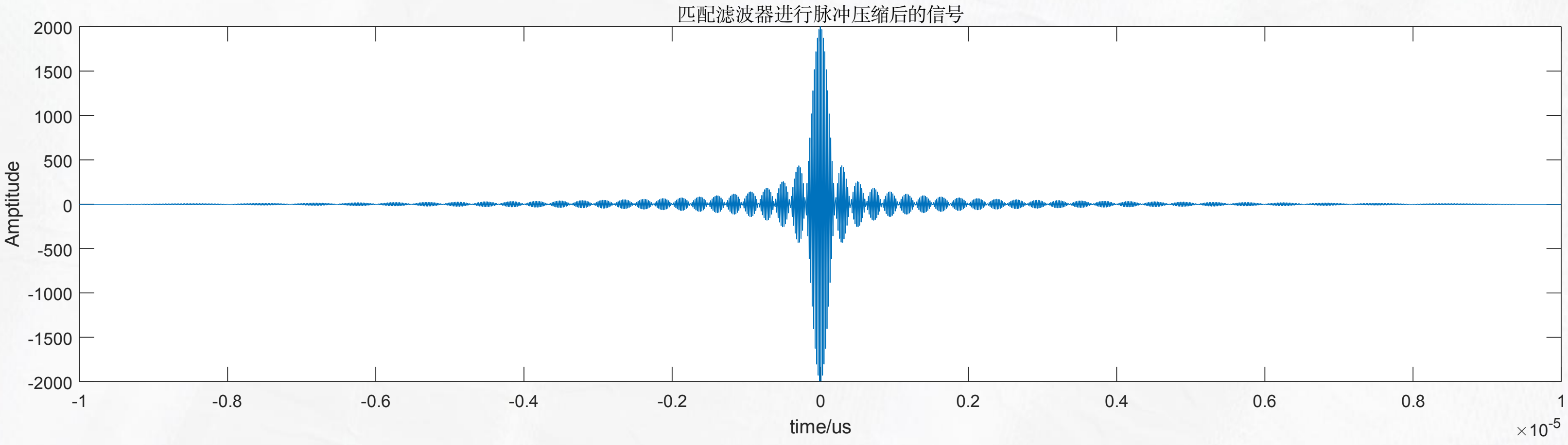


LFM信号脉冲压缩仿真

Introduction

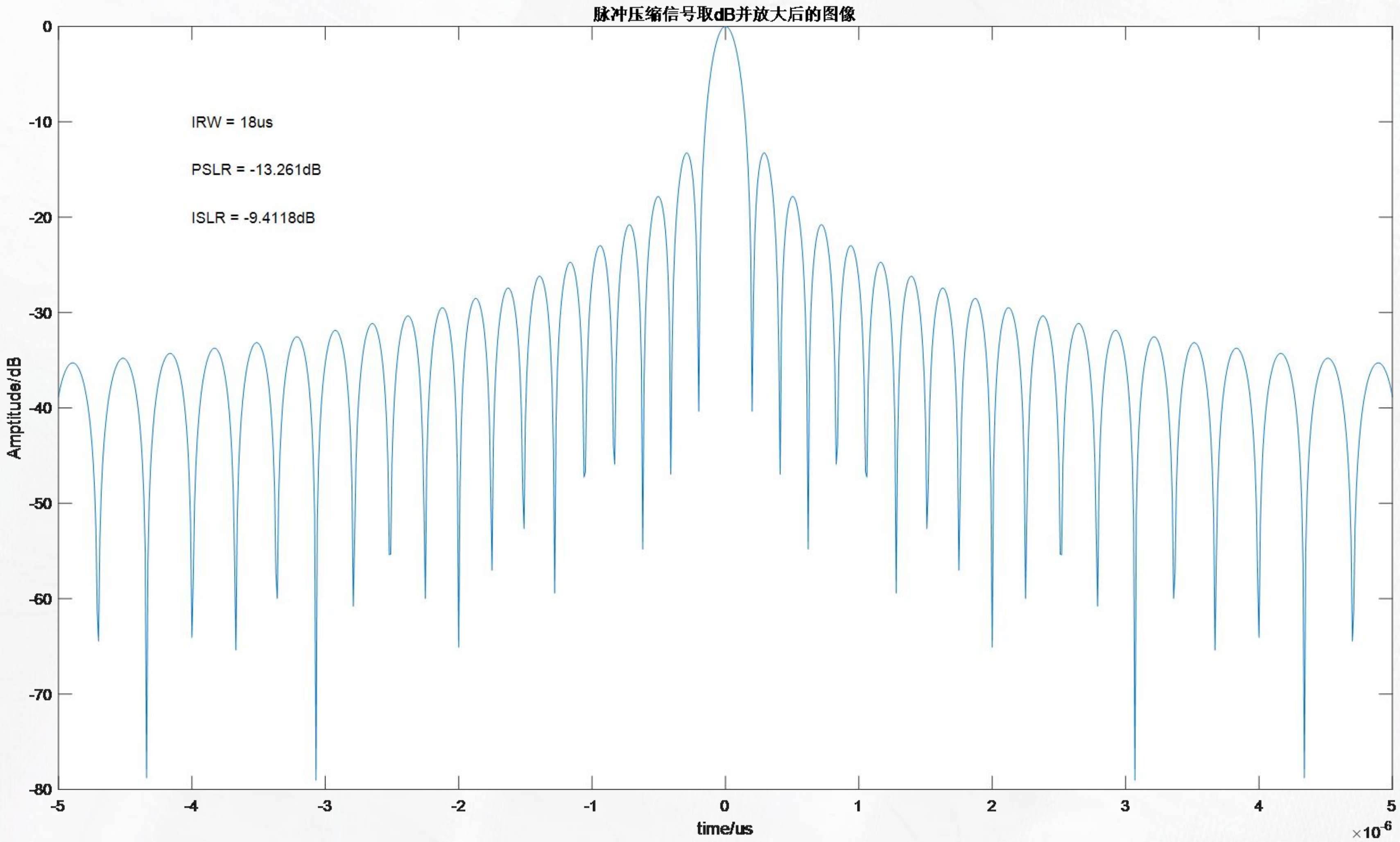
2．LFM脉冲压缩仿真





LFM信号脉冲压缩仿真

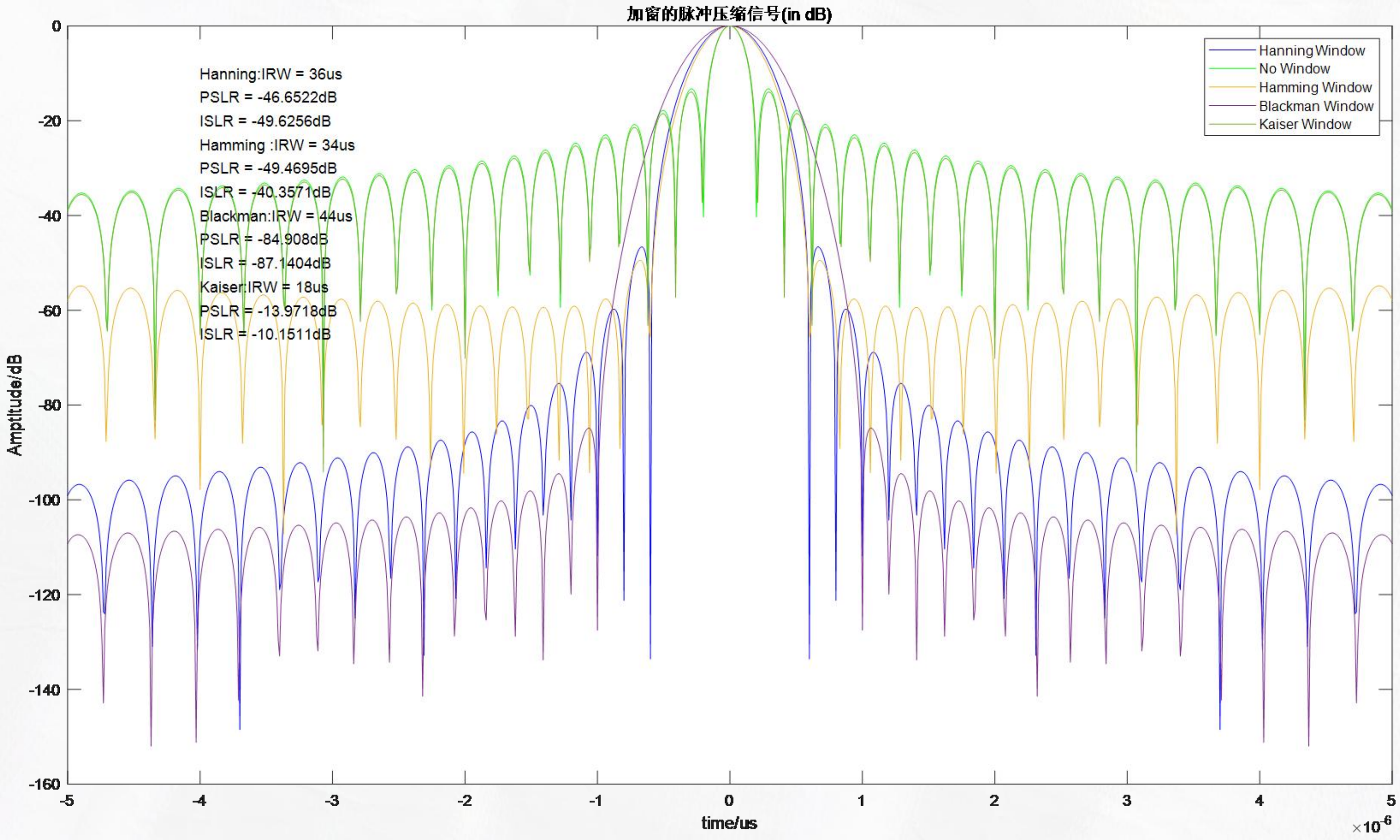
2．LFM脉冲压缩仿真



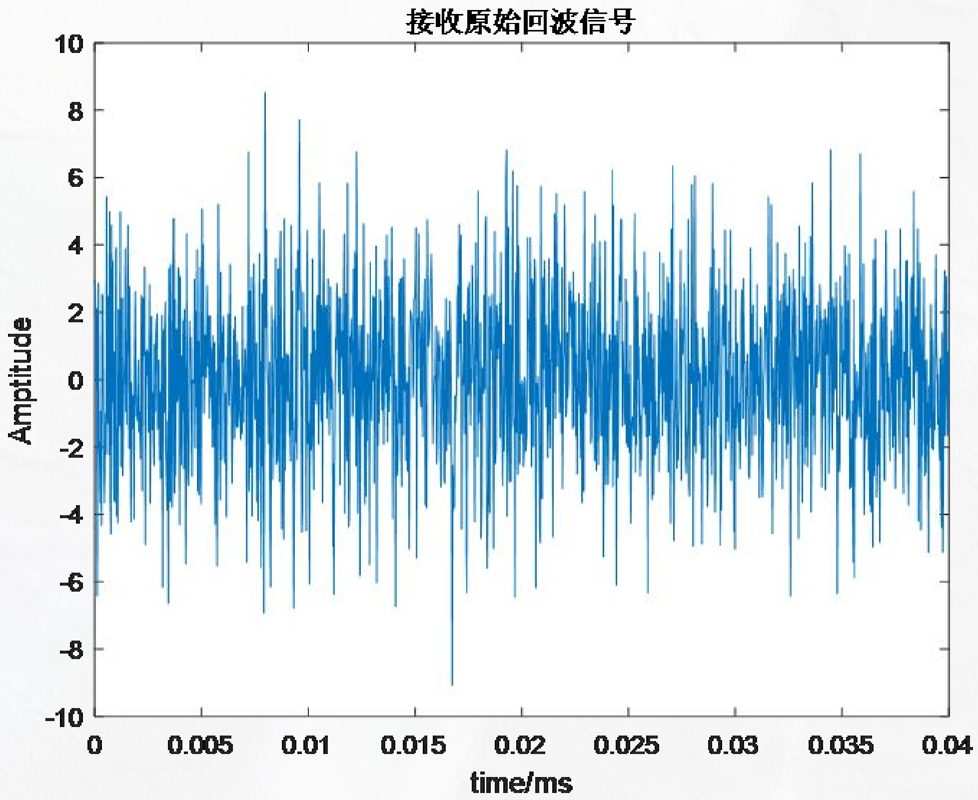
LFM信号脉冲压缩仿真

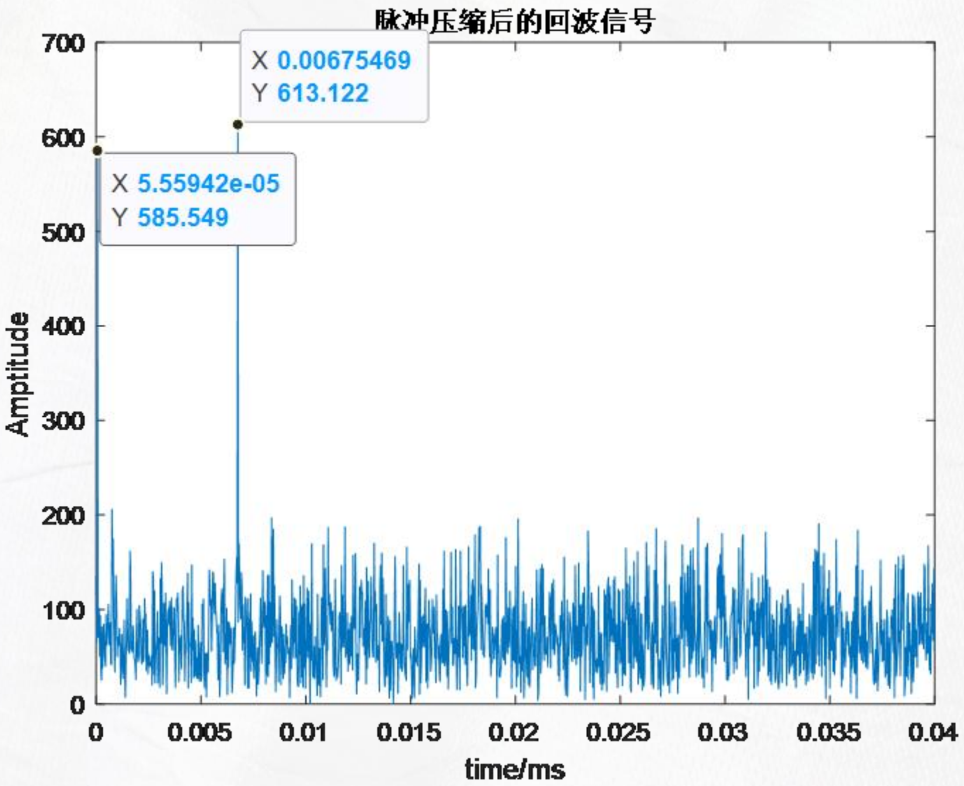
Introduction

2．LFM脉冲压缩仿真



3．回波信号的脉冲压缩仿真





总结和展望

Introduction

Progressive Pulse Compression: A Novel Technique for Blind Range Recovery for Solid-State Radars

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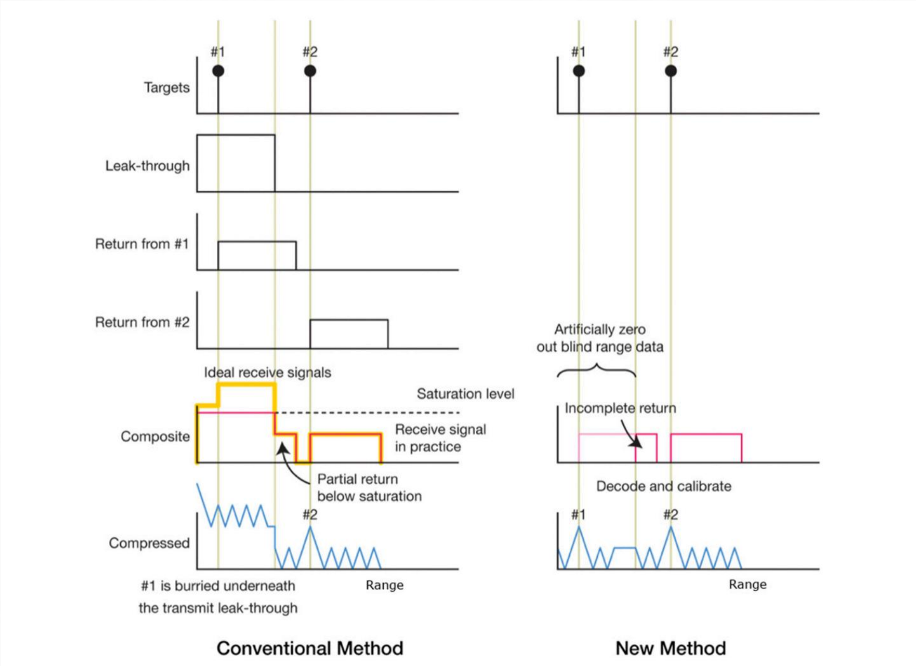

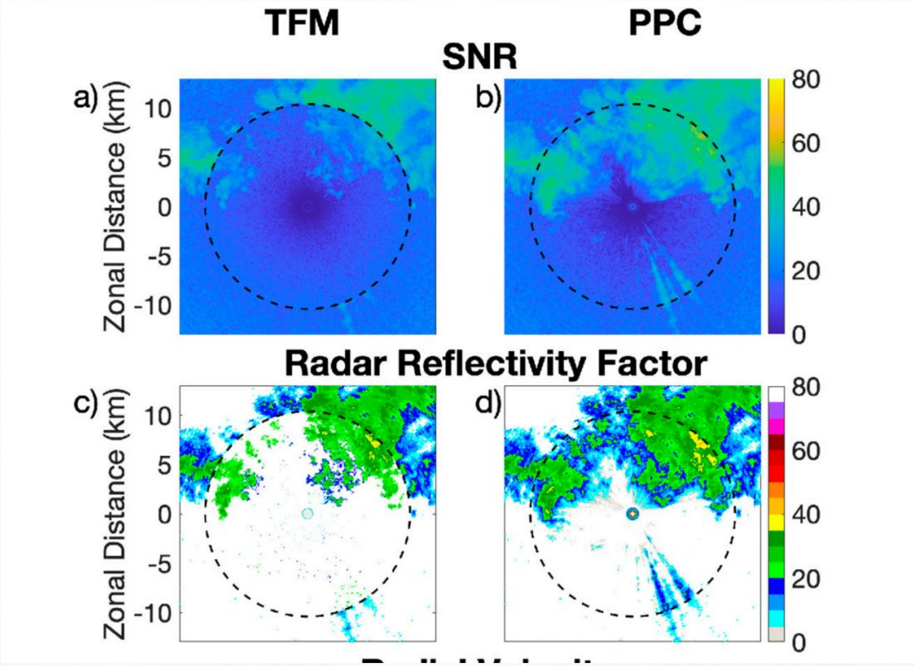

感谢垂听

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