# [EN-A-079] Interference mitigation in linear cell FOD radar by using FMCW signal source with different sweep speed

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**Abstract:** This paper reports a feasibility study on methods for interference mitigation in linear cell FOD radar systems consisting of many millimeter-wave antenna units connected by optical fibers. Linear cell radar can provide low-cost and high-performance solution for FOD detection, however, interference between the antenna units may degrade the performance. We investigated interference of FMCW radar units when frequency sweep speed has slight difference.

**Keywords:** Radar, radio-over-fiber, millimeter-wave, FM-CW, frequency sweep, linear cell

## 1. INTRODUCTION

Detection of foreign-object debris (FOD) in airport runways is very important to ensure safe landing and taking-off. According to an FAA report, loss in the global aviation industry due to FOD is about one billion annually. Total estimated indirect loss, caused by flight delays, would be more than ten billion annually [1]. From the above, automatic detection system of FOD in airports would be required for safe and economical airport operation. For detection of FOD, we proposed a linear cell radar, which can monitor a few kilometer-long airport runways by using many antenna units linearly located along with the area to be observed [2-5]. Wideband frequency chirp signal sources for FMCW radar operation can be shared by the antenna units through centralized configuration with radio-over-fiber (RoF). Interference between antenna units would cause false images, if the antenna units share the same FMCW signal source. Directions of millimeter-wave beams from the antennas can be synchronized to avoid such interference, however, strong millimeter wave from another antenna unit would be detected by an antenna unit through unpredicted reflection on smooth surfaces such as bodies of air planes. In such cases, it is not easy to distinguish false images from images of real objects. In order to solve this issue, we have investigated a linear cell system with FMCW signal sources with different sweep speed. If the difference in sweep speed is large enough, we can suppress such false images. Noise floor would depend on the difference in sweep speed, because a part of interference signals would be converted into IF band in a particular time slot. We performed a simple experiment to investigate feasibility of a linear cell system with different sweep speed.

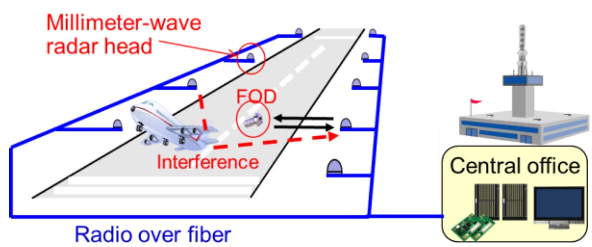


Figure 1 Linear cell radar diagram [2-5]

## 2. BASIC PRINCIPLE

FMCW radar is one of continuous-wave radars, as shown in Fig. 2, measuring distance by beat frequency between transmitted and reflected signals. Distance between the antenna and a target can be written by

$$R = \frac{c\Delta t}{2} = \frac{f_b}{4 f_w} c\Delta t \ \ [\mathrm{m}] \qquad (1)$$

where c, Δt, $f_b$, $f_w$, and ΔT denote the speed of light, time of flight, beat frequency, frequency sweep range and sweep time, respectively. A theoretical expected range resolution of an FM-CW radar, ΔR, can be given by

$$\Delta R = \frac{c}{2 f_w} \ [\mathrm{m}] \quad (2)$$

In this paper, we consider a case where interference waves directly coming from another antenna. Interference signal has different frequency sweep width from transmitted signal, that is, different sweep speed. As shown in Fig. 2, when the interference is occurred, a beat signal by

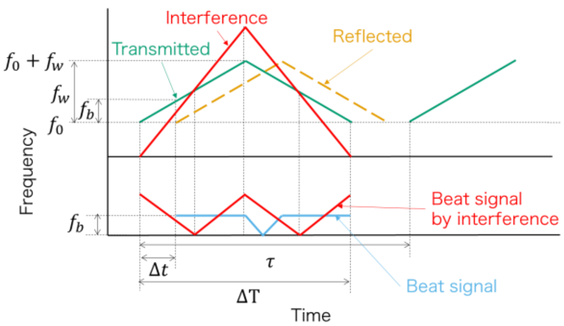


Figure 2 Linear cell radar diagram

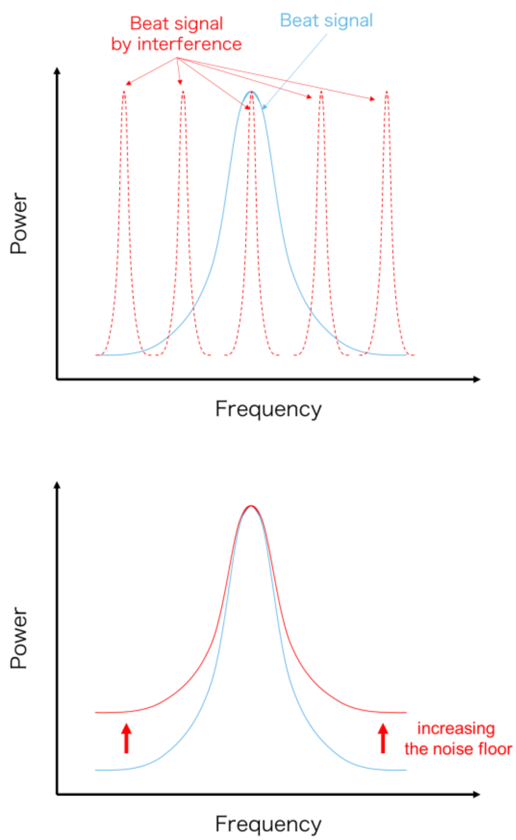


Figure 3 Mechanisms of FMCW radar interference

interference overlaps with the desired beat signal in a spectrogram. As shown in Fig. 3, the interference beat signal frequency would fluctuate in frequency domain and overlap the desired signal in the IF band. Thus, the beat signal by interference increases noise floor of time averaged IF spectra. When the sweep speed difference is larger, the overlap would be smaller and the noise floor degradation can be suppressed.

## 3. EXPERIMENT

### 3.1 Method

A basic FMCW radar configuration is shown in Fig. 4, and our experimental setup for evaluation of the interference effect in the FMCW radar system is shown in Fig. 5. Because the experimental setup uses RoF instead of radio-wave radiation in the air, this enable to remove extrinsic factor except interference. A distance to object in Fig. 4 corresponds to optical fiber path difference in Fig. 5. Transmitted and interference signals are produced by an arbitrary waveform generator (AWG) with two electric outputs. Both signals are synchronized with a sweep time, where frequency sweep width has difference. This is equivalent to varying sweep speed difference between transmitted and interfering signal. Parameters of signals are shown in Table 1. Although the actual linear cell radar demonstrated in an airport uses millimeter-wave, we performed our experiment in 1-3GHz band. We expect that this experiment shows basic features of possible interference in FMCW radar systems. A frequency chirp

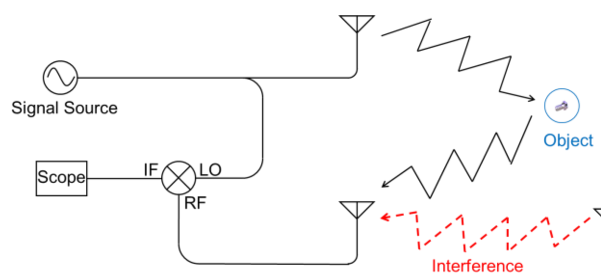


Figure 4 Basic FMCW radar diagram

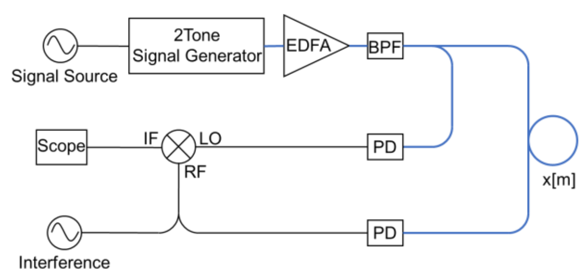


Figure 5 Experimental setup diagram of FMCW radar

Table 1 Parameters of signals

| | Transmitted signal | Interference signal |
|---|---|---|
| Sweep time<br>ΔT | 50μs | |
| Center frequency<br>$f_c$ | 2GHz | 2GHz |
| Sweep width<br>$f_w$ | 1GHz | 1.1~1.5GHz |

signal generated by the AWG was converted into an optical two-tone signal, which was generated by a Mach-Zehnder modulator (MZM), and the signal distributed into 2 paths over fibers. The interfering signal was mixed with the signal in the longer path in Fig. 5. A spectrum analyzer acquired spectrograms and spectra of IF signals consisting of the desired and interfering beat signals.

### 3.2 Result

The IF spectrum is shown in Fig. 6, and the IF spectrogram is shown in Fig. 7. As shown in Fig. 6, a peak intensity in the vicinity of 20MHz is the desired beat signal, whose frequency increases in proportion to optical fiber length difference according to Eq. 1. As shown in Fig. 7, it was confirmed that a beat signal by interference overlapped with the beat signal from the object, and duration of the overlaps and noise floor decreased in proportion to sweep speed difference. We also analyzed relations between SNR and sweep speed. As shown in Fig. 8, SNR increased in proportion to difference of sweep speed. Point to note is that SNR shown in Fig. 7 is linear scale in order to confirm linearity. At 50% of difference, the SNR was deviated from linearity because our spectrum analyzer with narrow resolution band width could not capture interference signal crossing the desired signal rapidly. In the future, we use not only swept-tuned spectrum analyzer but also FFT-based spectrum analyzer in order to investigate the SNR with large speed difference. The SNR degradation was about 10dB, when the difference was 10%.

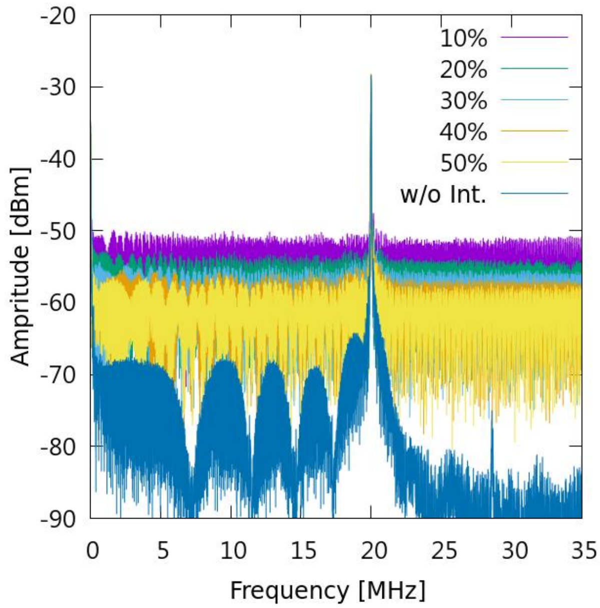


Figure 6 IF spectrum

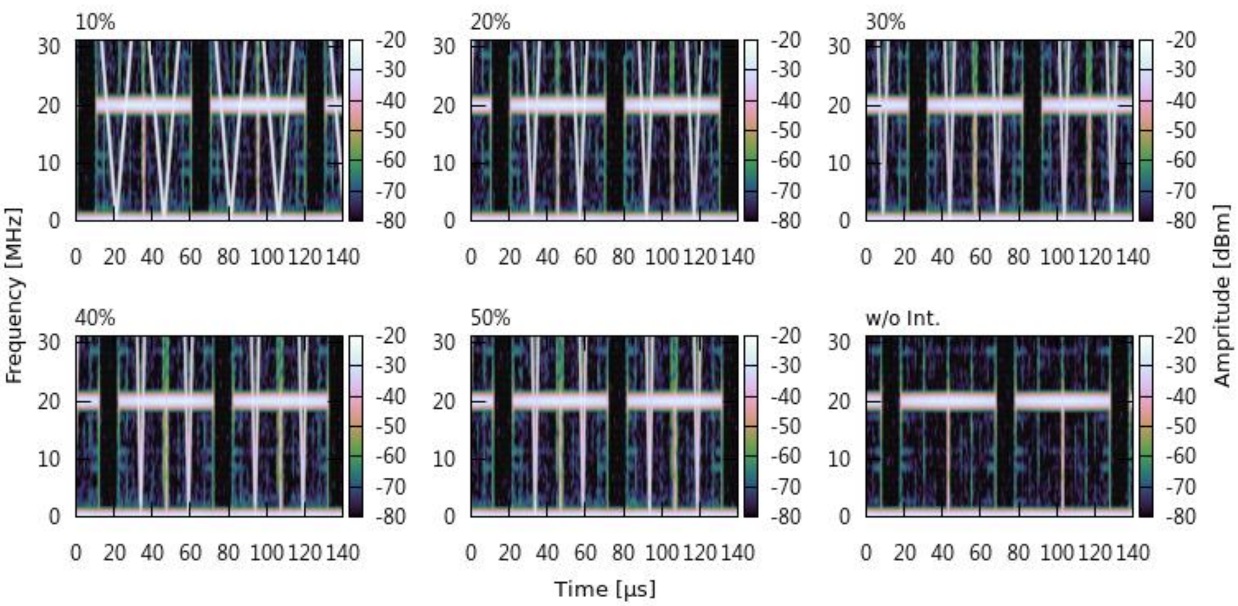


Figure 7 IF spectrogram

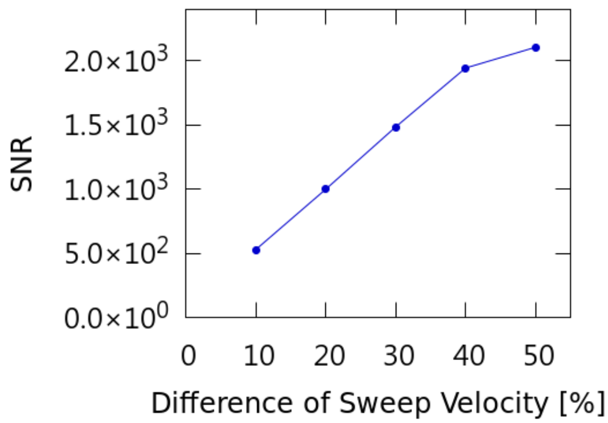


Figure 8 Relations between SNR and sweep speed

Table 2 Parameters of signals

| Difference of sweep speed [%] | SNR [dB] |
|---|---|
| 10% | 27.2 |
| 20% | 30.0 |
| 30% | 31.7 |
| 40% | 32.9 |
| 50% | 33.2 |
| w/o Int. | 37.0 |

## 4. CONCLUSION

In this paper, we discussed the relation between interference and difference of sweep speed in the FMCW linear cell radar. It was confirmed that a beat signal by interference overlapped the desired beat signal, and duration of overlap and noise floor decreased in proportion to sweep speed difference. Also, additional experiment with FFT-based spectrum analyzer is required because deviation from linearity at the point of 50% in Fig. 8 was caused by bandwidth limitation of our experimental setup. Although the signal frequency in this experiment is different from that in the actual linear cell FOD radar, discussion in this paper would be applicable to millimeter-wave radar because FMCW interference theory does not basically depend on signal frequencies.

## ACKNOWLEDGMENTS

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