

BISTATIC FORWARD SCATTERING ISAR SIGNAL MODEL WITH DIGITAL AUDIO BROADCAST TRANSMITTER

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Abstract: *This work presents Bi-static Inverse Synthetic Aperture Radar (BISAR) signal model with a Digital Audio Broadcast (DAB) waveform. A BISAR topology with geometry that consists of stationary transmitter and receiver, and moving target is described. The object position in the space is determined by kinematic vector equations. Mathematical model of DAB signal reflected from a complex object is described. Two dimensional (2-D) image reconstruction is implemented by applying correlation with an emitted waveform or Fourier transform on a range direction, and Fourier transform on an azimuth direction.*

Key words: *Digital audio broadcast waveform, Bi-static Inverse Synthetic Aperture Radar*

1. INTRODUCTION

BISAR technology for imaging of a target of interest uses bi-static radar topology with spatial distributed transmitter of opportunity, receiver, a moving target, and application of the principle of synthetic aperture radar for image reconstruction. A variety of waveform models such as DVB-T, DVB-S, CDMA, fifth generation (5G) mobile communications - NR and OFDM can be used to illuminate the target. Because of the common application of DAB in Europe, Asia and Australia and a good coverage it is a viable option for radar imaging. DAB signal is suggested in [1, 2]. The application DAB in passive radar detection is discussed in [3].

A passive radar approach using DAB signal, and its detection capability based on passive radar in terms of bi-static range resolution, techniques for direct signal interference reduction and clutter cancelation is presented in [4, 5]. Sensing and positioning based on DAB waveform and network passive radar is discussed in [6, 7].

The DAB waveforms have moderate bandwidth and advanced modulation technique, offering good potential for remote imaging and sensing. This work proposes an analysis of the DAB signal for the purposes of BISAR application. A thorough description of the DAB waveform to evaluate the imaging capability in BISAR application is suggested. This method is often used in traffic obstacles detection.

The scope of this work is to describe analytically the BISAR geometry with a DAB transmitter and derive a mathematical model of DAB signal and derive image reconstruction procedure. The rest of the paper is organized as follows. Section 2 describes BISAR geometry and equation, section 3 discusses DAB waveform and BISAR signal model. In Section 4, a BISAR image reconstruction algorithm is posed. Conclusion remarks are given.

2. BISAR GEOMETRY AND EQUATIONS

A. BISAR Geometry

The BISAR topology is presented in Fig. 1. Considering a DAB stationary transmitter and receiver that can be situated in air, on land or on sea surface. The target is considered as point scatterers, and it is not further specified by type. The BISAR geometry and its

comprising components, DAB transmitter, target and receiver are situated in a Cartesian coordinate system

Oxyz. The target presented as an assembly of scattering points defined by vector coordinates \mathbf{G} is depicted in independent coordinate system OXYZ. \mathbf{R}^s , and \mathbf{R}^r are the position vectors of the transmitter and receiver, respectively in a coordinate system of observation Oxyz.

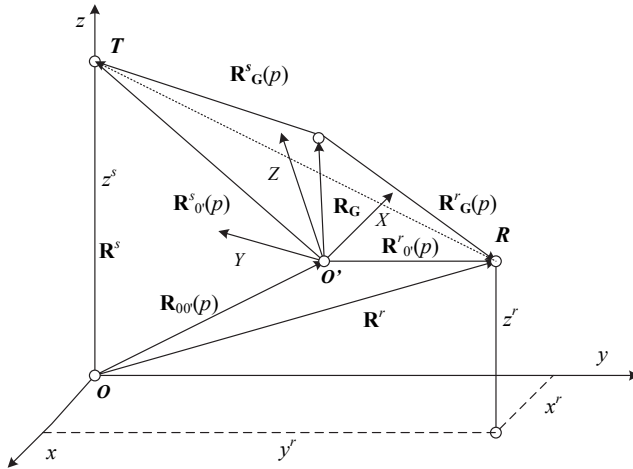


Figure 1. BISAR Geometry

B. BISAR Vector Equations

\mathbf{R}_G is the vector position of G-th scattering point in the coordinate system OXYZ and $\mathbf{R}_{00'}(p)$ is the current position vector of the target mass centre at the moment p. Based on the geometry in Fig.1 the following kinematical vector equations hold:

Range distance vector from the transmitter to the mass centre of the target

$$\mathbf{R}^s(p) = \mathbf{R}^s - \mathbf{R}_{00'}(p) = \mathbf{R}^s - \mathbf{R}_{00'}(0) - \mathbf{V} \left(\frac{N}{2} - p \right) T_p \tag{1}$$

where \mathbf{V} is the velocity vector of the target, T_p is azimuth samples period, $p = \overline{0, N-1}$ is the azimuth index, N is the full number azimuth samples.

Range distance vector from the mass centre of the target to the receiver

$$\mathbf{R}^r(p) = \mathbf{R}^r - \mathbf{R}_{00'}(p) = \mathbf{R}^r - \mathbf{R}_{00'}(0) - \mathbf{V} \left(\frac{N}{2} - p \right) T_p . \tag{2}$$

Range distance vector from the transmitter to the G-th scattering point of the target

$$\begin{aligned} \mathbf{R}^s_{\mathbf{G}}(p) &= \mathbf{R}^s(p) + \mathbf{A}\mathbf{R}_{\mathbf{G}} \\ &= \mathbf{R}^s - \mathbf{R}_{00}(0) - \mathbf{V}\left(\frac{N}{2} - p\right)T_p + \mathbf{A}\mathbf{R}_{\mathbf{G}} \end{aligned} \tag{3}$$

where \mathbf{A} is Euler transformation matrix.

Range distance vector from the \mathbf{G} -th scattering point of the target to the receiver

$$\begin{aligned} \mathbf{R}^r_{\mathbf{G}}(p) &= \mathbf{R}^r(p) - \mathbf{A}\mathbf{R}_{\mathbf{G}} \\ &= \mathbf{R}^r - \mathbf{R}_{00}(0) - \mathbf{V}\left(\frac{N}{2} - p\right)T_p - \mathbf{A}\mathbf{R}_{\mathbf{G}} \end{aligned} \tag{4}$$

The round trip range distance transmitter- \mathbf{G} -th scattering point of target-receiver is defined as

$$R_{\mathbf{G}}(p) = \left| \mathbf{R}^s_{\mathbf{G}}(p) \right| + \left| \mathbf{R}^r_{\mathbf{G}}(p) \right|. \tag{5}$$

Expressions (1-5) are applied to model a BISAR signal.

3. DAB WAVEFORM AND BISAR SIGNAL MODEL

DAB waveform

The waveform of the DAB signal is represented a transmission frame structure corresponding to the juxtaposition in time. Each frame is divided of a sequence of consecutive OFDM symbols. Each symbol consisting of a number of carriers.

The DAB transmission signal is defined as the sum of two signals - the main signal $s(t)$ and an optional signal. The initial OFDM symbol of transmission frame is the „Null symbol” with duration NULL. The rest of the transmission frame is a juxtaposition of OFDM symbols of duration T_S .

Each of these OFDM symbols shall consist of a set of equally-spaced carriers, with a carrier spacing equal to $1/T_u$. The waveform $s(t)$ is defined by the following expression:

$$s(t) = \text{Re} \left\{ e^{2j\pi f_c t} \sum_{m=-\infty}^{+\infty} \sum_{l=0}^L \sum_{k=-K/2}^{K/2} z_{m,l,k} \cdot g_{k,l}(t - mT_F - T_{NULL} - (l-1)T_S) \right\} \tag{6}$$

$$g_{k,l}(t) = \begin{cases} 0 & \text{for } l = 0 \\ e^{2j\pi k(t-\Delta)/T_U} \cdot \text{Rect}(t/T_S) & \text{for } l = 1, 2, \dots, L \end{cases} \tag{7}$$

Where

L is the number of OFDM symbols per frame without the Null symbol ,

K is the number of transmitted carriers,

T_F is the transmission frame duration,

T_{NULL} is the Null symbol duration,

$T_s = T_U + \Delta$. is the duration of OFDM symbols of indices $l = 1, 2, 3, \dots, L$,

T_U is the inverse of the carrier spacing,

Δ is the duration of the time interval called guard interval,

$z_{m,l,k}$ is the complex D-QPSK symbol associated to carrier k of OFDM symbol l during transmission frame m . The values are defined as follows For $k = 0$, $z_{m,l,k} = 0$, in order for the central carrier not to be transmitted;

f_c is the central frequency of the signal.

DAB waveform can vary in four transmission modes, defined by varying numbers of sub-carriers and symbol durations in order to utilize different frequency bands (VHF Band III, L-Band)

For example for transmission mode 1 is defined by the following parameters – $L = 76$, $K = 1536$, $T_F = 196\ 608\ \text{T}$ (96 ms), $T_{\text{NULL}} = 2\ 656\ \text{T}$ (~1,297 ms), $T_s = 2\ 552\ \text{T}$ (~1,246 m), $T_u = 2\ 048\ \text{T}$ (1 ms) $\Delta = 504\ \text{T}$ (~246 μs)

BISAR Signal Model

The BISAR signal model is a delayed copy of the OFDM DAB waveform, and in a discrete form can be expressed as

$$S(k, p) = \sum_G \sum_{k=-\lfloor \frac{K}{2} \rfloor}^{\lfloor \frac{K}{2} \rfloor - 1} z_{m,l,k} \exp [j 2\pi k f (t - K \frac{(t-d)}{T_U} - t_{ijk}(p))] \quad (8)$$

where G is the object vector coordinates. $t_{ijk}(p) = \frac{R_{ijk}^s(p) + R_{ijk}^r(p)}{c}$ is the time delay of the signal reflected by the G -th scattering point

4. BISAR IMAGE RECONSTRUCTION ALGORITHM

The image reconstruction procedure includes two steps – range compression and azimuth compression. The range compression is a cross correlation between a received BISAR signal and the emitted waveform, i.e.

$$I(\hat{k}, p) = \sum_k S(k, p) \cdot S_l^{qm}(k - \hat{k}), \quad (9)$$

where \hat{k} is the range coordinate of the scattering point in the BISAR image.

The azimuth compression or the complex image extraction is performed by fast Fourier transform, i.e.

$$I(\hat{k}, p) = \frac{1}{N} \sum_p I(\hat{k}, \hat{p}) \exp\left(-j \frac{2\pi \cdot p \cdot \hat{p}}{N}\right) \quad (10)$$

where \hat{p} is the azimuth coordinate of the scattering point in the BISAR image, N is the full number of azimuth samples.

CONCLUSION

A BISAR signal model based on a DAB waveform is developed. A 2-D image is extracted by 2-D FFT for range and azimuth compressions of the received BISAR signal.

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