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The Essential Digital Signal Processing In HF Radar Target Detection

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Abstract

The moving target detection with HF radar must consist of four steps of signal processing, which are: pre-processing, range processing, azimuth processing and subsequent processing. Pre-processing is done by the low-pass filtering and signal sampling. Range processing is used to produce the initial distance information, mainly consist of the low-pass filter processing and fast Fourier transform (FFT).
Azimuth processing is by using the adaptive beamforming, which is the compliance with the linearly constrained minimum variance benchmark, to do the weighted processing; then by doing different FFT, to get the formula with a function of delta and a Sine function, this formula contains the moving target distance, direction and frequency informations. Subsequent processing should use some of the high-resolution processing or CFAR technique. These steps of signal processing were verified by measured data. By understanding these steps, we can optimize certain aspects according to real needs, to realize the purpose of high frequency radar monitoring large area

Introduction

High-frequency radar (HF radar) usually must meet ahigher average transmit power to achieve its long-rangedetection capability and effective target discrimination [1];in addition to the transmitting and receiving antenna arraywith special requirements, the radar generally uses the linearfrequency modulation continuous wave signal [2, 3], byusing these emission signals, HF radar digital signal processingin the course of target detection will be discussed;it will also be tested and verified with the measured databy HF sky wave radar.

2. Essential basic signal processing for HFradar target detection

The signal processing flow of HF radar as shown in Figure1, it can be divided into four processes, namely (a)pre-processing; (b) distance processing; (c) azimuth processing;(d) subsequent processing**.**

2.1. Digital signal pre-processing for HF radar system

In the flow chart of Figure 1, any a signal received by an antenna, after mixing with the local oscillator signal, thensuccessively through digital receiver, analog to digital converterand low-pass filter, transforms into a secondary intermediatefrequency signal about a few MHz; then by doingsignal sampling with 25 kHz sampling rate, got a discretesignal. Setting that radar linear frequency modulationsignal S0 can be expressed as the following function:

S0 = Aexp(j2πf0(t))

M−1

m=0

u(t − mT)

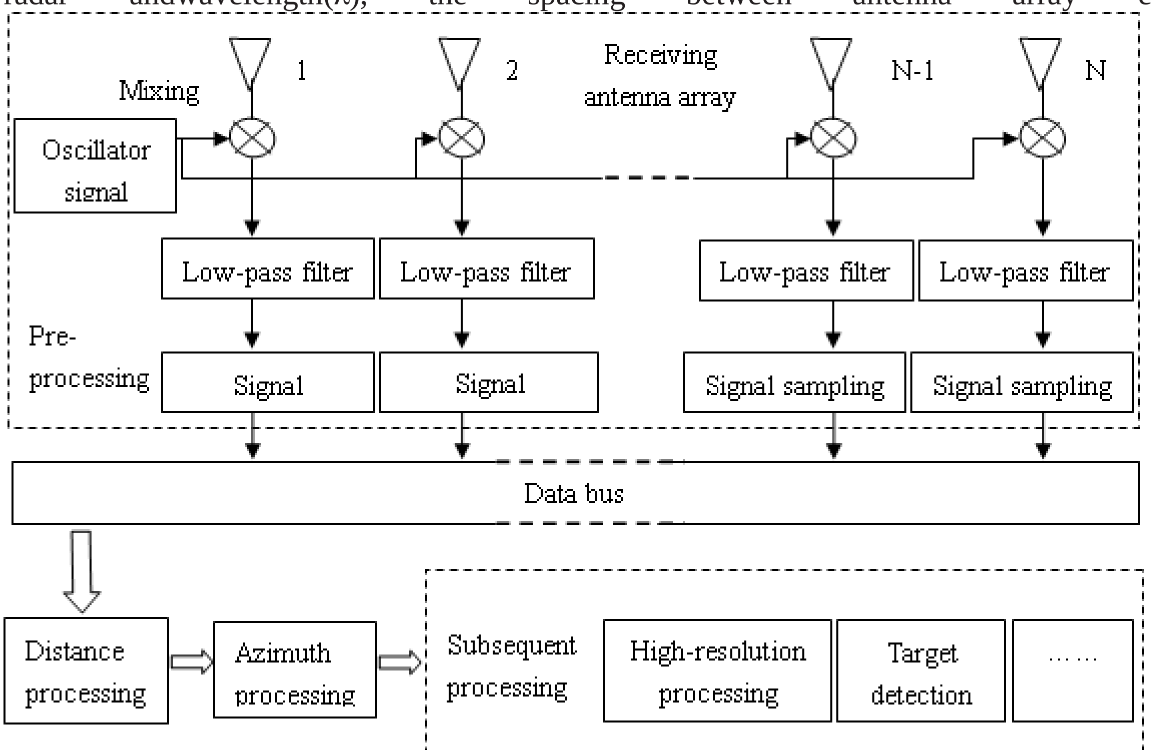
where u(t) =

exp(jπβt2), 0 ≤ t ≤ T

0, else

Here A is the signal amplitude, f0 radar working frequency,T its pulse cycle, M the number of continuouslyemitted pulse, β frequency modulation slope, βt is the frequencychanging linearly with time.

2 Supposing a moving target's initial position has therelative distance R away from a launch radar, an azimuthangle α diverging from the normal direction of the receiving antenna array, and the moving targets radial velocity isvR, its Doppler frequency fT ; assuming the working of radar andwavelength(λ), the spacing between antenna array elements



d. By formula (1), while the n − th antenna unit receivesthe (m+1)−th pulse echo signal Sn,m(t) from the movingtarget, Sn,m(t) as:Sn,m(t) = Aexp

j2π

(n − 1)d sin α

λ

)

· exp(j2πf0(t − τ))u(t − mT − τ), (2)

Where τ is the delay of the radar received signal from it

emitted one.

τ =

2(R + vR · t)

c

=

2R

c

+ fT · t

f0

(3)
In Figure 1, the local oscillator signal S0(t) only has a time
delay τ0 compared with the radar emitted signal, written as
[4]
S0(t) = Aexp[j2πf0(t − τ0)]u(t − mT − τ0). (4)
Where τ0 = 2R0/2c. After the signal mixing with the
radar echo signal in formula (2), the following formula is
got
Sn,m(t) · S0
∗(t) = A2 exp

---

j2π
(n − 1)d sin α
λ

exp

---

j4πf0
R0 − R
c
· exp(−j2πfT · t) (5)
·u(t − mT − τ) · u
∗(t − mT − τ0)

2.2. Digital signal processing in the distance processing

Using tmto replace t−mT, tm to do mT in formula (5),
as for u(t−mT−τ)·u∗(t−mT−τ0), its instant frequency
f(t) is as the following on the basis of formula (1),
f(t) =

−β(τ − τ0), · · · ,
−β(τ − τ0) + βT, · · · ,
· · ·

---

tm ∈ [max(τ0, τ), T + min(τ0, τ))
tm ∈ [min(τ0, τ), T + max(τ0, τ)) (6)
Since the frequency |−β(τ −τ0)+βT| less than |−β(τ −
τ0)|, after a low-pass filter, only the former keeps. Using
formula (1) to deduce the u(t−mT−τ)·u∗(t−mT−τ0) of
formula (5), after passing through the low-pass filter, got
Sn,mmixing(afterlow−pass) = A2 exp

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j2π
(n − 1)d sin α
λ

· exp(jϕ) · exp

− j2πβ

---

fT
f0

t2
m

rect(t)
· exp

− j2πβ

2(R − R0)
c
+ ft · tm
f0
+ fT
β
− 2R
cf0
fT
−

---

fT
f0

2

tm

tm

· exp

− j2π

1 − 2βR
cf0

fT · tm

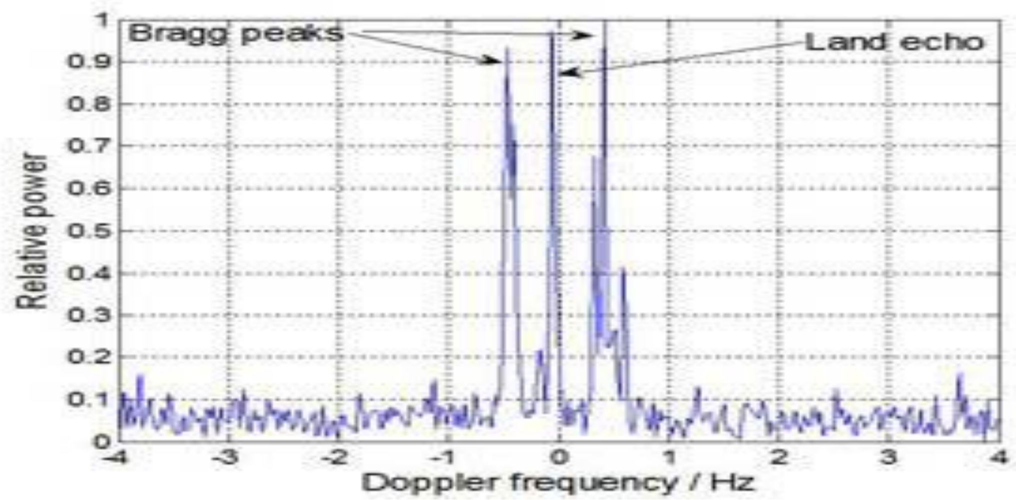
ϕR is the phase corresponding to the distance fR of a movingtarget. At the narrow pulse position of the ’Sinc’ functioncontains the distance information, but when fT isn’tknown, it is still not a certain distance.

2.3. Digital signal processing in the azimuth processing

Adaptive beamforming, which complying to the guidelinesof linearly constrained minimum variance, is used todo azimuth processing. The adaptive beamforming is todo weighted summation for the signals received by eachantenna , and when the constraint is constant to asignal gain at a certain direction, to make the antenna arrayhas a minimum output power. Assuming that an antennareceived signal sequence X(t) is N ×M dimensional matrix,Weighted by W, the output Y of the adaptive beamformingis got by using Y (t) = WH · X(t) [6].
With the optimal weight coefficient W, then back to formula(8), range, azimuth processing can be continued.Within the m-pulse, the echoes received by antenna elements,from the same range gate, are weighted

3. Measured data validation by HF sky wave
Radar

By using a sampling frequency of 5.6MHz, then 512 echounitsextracted from each resident beam as a distance gate,finally weighting function of Chebyshev window to suppressside-lobe pulse pressure, after finishing the distanceand azimuth processing, the data of every distance gatewere saved in the dat files. Selecting 850 distance gate asan example, getting the data from the dat file, doing FFTfor it, the power spectra of this distance gate was got, asshowing in Fig. 2. In the frequency spectrogram of the 850distance gate, two left and right Bragg peaks were at -0.44Hz and 0.43 Hz respectively, midpoint of 2 peaks positionswas at -0.005Hz, which was the point of genuine
zero frequency due to the existence of the radar systemfrequency offset. The sea echo Bragg peak Doppler frequency(fB) and the radar operating frequency (f0) satisfyf0 = ±0.102
f0(MHz)(Hz) [14]. By calculating, thetheretical values of the Bragg peaks is of ±0.436Hz. Wecan see the theretical value was basically consistent withthat of the measured. Fig. 3 was a case, which averaging8 adjacent distance gates spectra of the 850 as the thresholdlevel, the spectra of 850 distance gate minus the level,taking into account the radar system frequency offset, the
prominent signal was at the actual zero Doppler frequency,this is generally caused by the differences of land-echopeaks between the 850 distance gate and its neighboring,so it isnt a target [13].



In the signal processes for target detection, earlier usinglow-pass filter to remove some of the clutter, keeping movingtarget information, reducing the dynamic range of subsequentprocessing, then the beat signal of a moving targetis done FFT. After this, the frequencies contains the atmospheric noise, sea clutter and target informations. Atmosphericnoise isotropic, its frequency spectrum is in theGaussian distribution. For the echoes of the sea clutter,its first-order and second-order Bragg spectral distributionis also the Gaussian. Due to fast speed, aircraft has highDoppler frequency, big difference from background, relativelyeasy to detect; but as sea moving target speed islimited, the Doppler frequency of the background sea cluttershould not be overlooked, so the follow-up processingof ship detection will be a huge challenge

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