Radar-Communication Integration: An Overview 概述

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Abstract. ~~Radar-communication integration combines radar system and communication system together~~. These two systems have similar structures, and communication system can take advantage of radar's excellent hardware features if integrated. This technique is still under study and may take decades to achieve practical application. The motivation of such integration is presented in the beginning of this paper. Main approaches including time-sharing, sub-beams and signal-sharing are shown, and the most promising signal-sharing approach is detailed discussed with its three typical realizations. Characteristics, including advantages and disadvantages of these approaches are also analyzed. Three typical integration application scenarios are described in the end of this paper.

三种典型的应用场景

1. Introduction

Radar system and communication system are all vital systems in military equipment playing unique important roles in modern warfare. Yet for a long time, the development of these two systems are independent, occupying plenty of space in equipment, increasing equipment's radar cross-section(RCS), and worsening the electromagnetic environment on equipment. The equipment itself and these two systems are all affected.

The concept of radar-communication integration is proposed in recent few decades, where radar and communication are accomplished at the same time in the same system. Such a concept develops basing on active phased array radar (APAR), whose various advantages make the concept possible. In this paper, main technical approaches of radar-communication integration are discussed, along with different approaches' advantages and disadvantages. Radar-communication integration is the trend of battlefield equipment, and the development of relating techniques will dramatically change the form of combat.

2. Motivation of Integration

After decades of technological development, the difference between radar and communication systems is becoming smaller. The frequency bands these two systems are using respectively are completely different from decades ago. Radar system is starting to use VHF band, which is originally used by communication system, and communication system is also working on bands used to belong to radar system [1]. These two systems also have similar structures, all including antenna, transmitter, receiver, signal processer and signal generator. As the development of processing device, the processing capability and versatility of signal processing device is also get higher, further reducing the hardware differences between these two systems.

Radar system and communication system are all of great importance at actual wartime use. Information is obtained from radar system, and delivered through communication system. Since these two systems are already of high similarity on hardware, they can be combined somehow sharing

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hardware from antenna to the receiver, and only some merging work is needed in software of signal processer and generator.

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Let's take battlefield reconnaissance mission for example. If radar system and communication system work separately, then reconnaissance process requires three steps: ① obtaining battlefield information, ② manual handling, and ③ transmitting battlefield information. Two systems and manual intervention is involved here. If radar system and communication system are integrated, then the process is simplified into two steps: ① obtaining and ② transmitting battlefield information. Only one system and no manual intervention is involved, which means higher reliability. Streamlining the whole system reduces the RCS of reconnaissance aircraft and improves electromagnetic compatibility. All these improvements are highly valuable in wartime. For another example of aircrafts performing measuring tasks, it's impossible to transfer the massive amounts of data produced in action to the ground relying on current data link. Such data exchange work has to be done after the aircraft landed. If a broadband data link is demanded for transmitting data, simply adding a high-power or high-gain antenna is unrealistic. If the hardware of existing airborne radar can be used for data transfer, problem is solved while the cost saved. All in all, the advantages of radar-communication integration list as follows [2]:

1. System utilization is improved, and the equipment costs are reduced. Mobility improvement in wartime is of great practical significance.
2. The advantages of radar are sufficiently used, such as high power and strong directivity. This improves communication quality and increase the effective communication distance.
3. The system automation level is improved, thus raising data transfer speed and solving problems such as poor communication security and high bit error rate (BER).

3. Main approaches 主要方法

There are several approaches for radar-communication integration at current time. The key difference between these approaches is how radar signal and communication data is combined. Depending on what domain where radar part and communication part can be separated, approaches are divided into the following categories.

3.1. Time-sharing 时分

Time-sharing is the simplest approach in all solutions for radar-communication integration. In this approach, we simply reuse antenna, transmitter and receiver by adding a strobe switch [3], as is shown in Fig. 1. When communication is in need, it switches to use communication modem, while radar functions are completely disabled. On finishing communication, it switches back to radar signal processer and generator, and radar functions are restored. It's obvious that the overall communication time proportion cannot be too high in order not to affect radar detection performance. Also, communication state cannot last too long for a single time, or possible object lost may lead to disadvantage in battlefield. Then time-sharing approach just fits in situations where only *short burst* communication is needed, which means it's difficult for this integration approach to replace current communication system completely. However, the advantage of this approach is that this simple design requires no major changes to both hardware and software, and there's no need to re-design radar waveform and communication waveform. The low demanding means this approach can be chosen as transitional technique or a supplement to current communication system.

In order to minimize the impact on radar detection performance, the handshake process establishing link and closing process removing link need to be designed carefully. According to [3,4], the performance of such communication link is relatively poor, and can only be called as radar systems joined with communication function. To further achieve the requirement for reliable communication, a selective retransmission protocol is needed, which makes communication process more complicated and performance decline further.

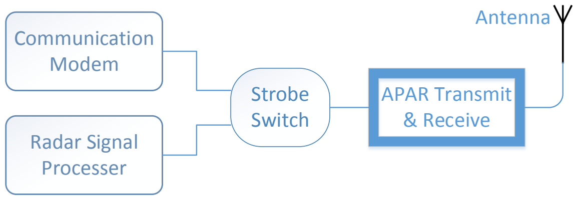

Fig. 1 A schematic diagram of time-sharing approach

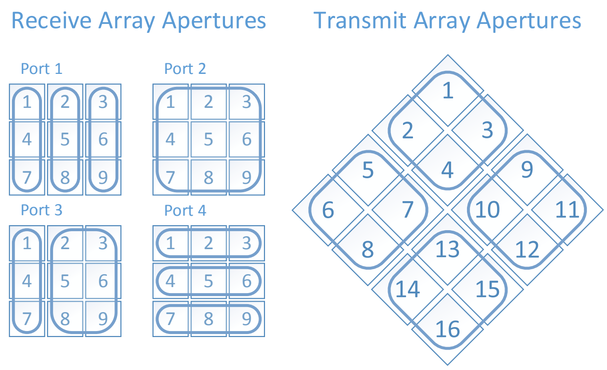

Fig. 2 An example of receive & transmit array apertures in sub-beams approach

缝隙，孔径

3.2. Sub-beams

相控阵雷达 PAR

Sub-beams approach is used in phased array radar, whose array undergoes a regional breakdown of areas used for different purposes, including radar, communications, calibration, electronic warfare (EW) and so on. Reference [5] describes AMRFC project in detail, in which phased array radar is used for multiple purposes. The software and hardware architecture, test bench setting up, and some zoning configurations under given cases are detailed described. American commercial companies have tested sub-beams approach on F-22 and BAC1-11, and the data transfer rate is up to 274Mbit/s [1].

Phased array radar has the advantage that no mechanical motor parts are needed to control beam pointing, which is achieved through a 2-D active radiating elements array. In sub-beams approach, the 2-D array is divided into a number of sub-arrays. Take project in [5] as example, the receive array is divided into 3×3 namely 9 sub-arrays, and the transmit array is divided into 4×4 namely 16 sub-arrays. Each sub-array has its independent working strategy. The flexibility to assign different purposes is achieved through developing different sub-array combining configurations, or called as apertures. An aperture example of the project in [5] is shown in Fig. 2. When combined, transmit sub-array cannot be reused, while receive sub-array can be reused, which is beneficial for multi-usage signal processing.

Because the total power of phased array radar is certain, if some part of the beam is used for communication, EW or other purposes, the signal power left for radar declines inevitably, which means a certain impact on radar performance.

3.3. Signal-sharing 信号共享

The main idea of signal-sharing is to mix communication signal with radar signal, using a same signal waveform, which allows the radar system to add communication function while maintaining its original function. Different from the former two approaches, there is no significant separation between radar part and communication part in time domain or spatial domain. Communication data is superimposed on or modulated into radar signal, achieving radar-communication integration, and combination of radar and communication occurs in the frequency domain.

3.3.1. Orthogonal Frequency-division Multiplexing (OFDM). The speed and range accuracy of OFDM radar signal are good, and communication data can be loaded on OFDM signal. So OFDM signal can be used as the signal for radar-communication integration. The expression of OFDM signal shows as follows

$$x(t)=\sum_{\mu=0}^{N_{sym}-1}\sum_{n=0}^{N_c-1} d(\mu N_c+n)\exp(j2\pi f_n t)\,rect\left(\frac{t-\mu T_{OFDM}}{T_{OFDM}}\right) \tag{1}$$

N_c：载波个数；N_{sym}：单载波上符号个数

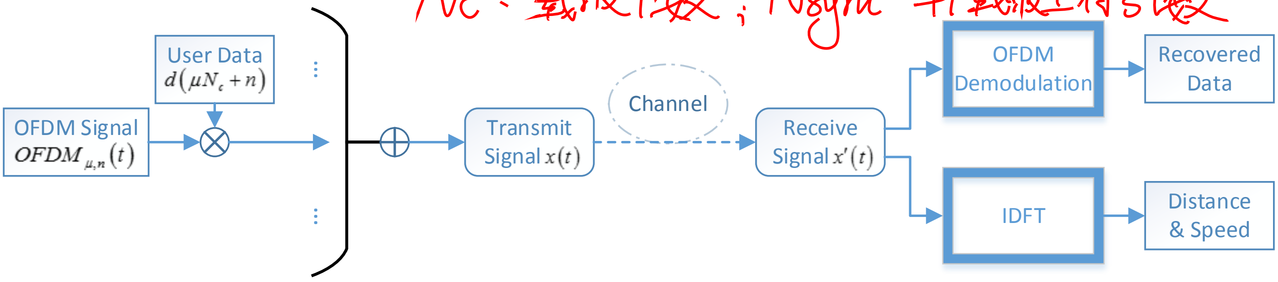

Fig. 3 The system block diagram of OFDM approach

The user data $d(\mu N_c+n)$ is loaded on every subcarrier. Received data can be obtained by performing OFDM demodulation to echo signals, and the distance and speed of target can be obtained by performing inverse discrete Fourier transform (IDFT) [6,7]. The whole process of OFDM approach is shown in Fig. 3.

In [6], some field tests are conducted for some simple target scene, and simple multipath problem is handled. But notes that OFDM signal is not a constant envelope waveform, and thus does not fit radar amplifier well. OFDM is more suitable for close-range scenes [1]. 近距离

3.3.2. Frequency- division Multi-carrier. We use Chirp multi-carrier signal as example here. One single Chirp signal can only supply a low data transmission rate, therefore a group of Chirp multi-carrier signal $\{s_k(t)|0\le k\le N-1\}$ at different carrier frequency is used in order to make full use of radar channel. $s_k(t)$ expresses as follows [8]

$$s_k(t)=rect\left(\frac{t}{T}\right)\exp\left(j2\pi f_k t+j\pi\mu t^2\right), k=0,\ldots,N-1 \tag{2}$$

where carrier frequency $f_k=f_0+k\Delta f$, and the window function $rect\left(\frac{t}{T}\right)=\begin{cases}1 & ,0\le t<T\\ 0 & ,else\end{cases}$.

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These Chirp signals have quasi-orthogonality between each other, which can improve channel utilization and data transfer rates. When the bandwidth overlap rate is less than 25%, the effect on signal detection can be ignored [7]. Select some signals from the whole quasi-orthogonal signal group to load user data. In the demodulation step, signals loaded with user data are used for data restoring, and the rest of signals are used for threshold determination as a part of radar signal processing.

门槛，下限

3.3.3. Spread Spectrum (SS). The theoretical basis of SS is Shannon–Hartley theorem from information theory. Pseudo-random sequences whose frequency is far higher than useful signal are used to modulate useful signal, which is the original communication data in this case. Then the frequency spectrum of useful signal is expanded to a much higher frequency band, thereby increasing the channel capacity. So such approach can maintain a certain transmission capacity even if the channel signal to noise ratio (S/N) is relatively low [9]. Common applications of SS include GPS system and CDMA mobile communication system.

跳频

There are mainly two types of SS: Direct-sequence spread spectrum (DSSS) and frequency-hopping spread spectrum (FHSS) [9]. For DSSS, one certain period of pseudo-random sequence represents one certain symbol, and the whole pseudo-random sequence namely the communication data is used for SS. For FHSS, one certain frequency hopping pattern represents one certain symbol, and the whole hopping sequence is used for SS.

In the variety of SS codes, polyphase code such as Frank code, P code, Oppermann code, etc., has a good pseudo-randomness and non-cyclic autocorrelation [10], which meets the requirements of radar-communication integration. SS codes are also more difficult to be cracked, in other words, safer. However, PN code is Doppler-sensitive and thus not fit in high-speed mobile platform, and Oppermann code is too complex to put into practical use [1]. Thus the type of SS code and the way symbols are represented have to be chosen carefully in order to improve communication performance while ensuring radar detection performance.

4. Application Scenarios 应用场景

Radar application scenarios can be broadly divided into three types: airborne radar, ground-based radar and shipborne radar [11]. Because radar-communication integration is assumed to be developed basing on currently existing radar, here comes a rough application prospect on the three scenarios in the direction of radar-communication integration.

机载的，航空的，空运的

4.1. Airborne Radar-communication Integration

机载雷达

Airborne radar has unbreakable limits in size, weight and power. Fighters, especially UAVs, are commonly used in reconnoitering (侦察) targets, thus the radar tasks include SAR imaging and ground moving target indication (GMTI). Reconnoitered information including SAR images and ground targets will be transferred back to the ground or ship using communication system. Such missions can be completed through a unified system with the benefit of radar-communication integration. Equipment streamlining (流线型) for aircrafts, especially for UAVs, has a major significance, enhancing endurance and maneuver capability.机动能力

4.2. Ground-based Radar-communication Integration

Ground-based radar doesn't have so many restrictions like airborne radar. The space for radar is often enough, and power supplied is as high as possible to make radar's range as far as possible. The main purpose of ground-based radar is alert and target tracking, so it requires 360° coverage. Therefore there need three or more phased array faces or one rotating phased array face. Then the system has good communication performance in each direction. Ground station needs to communicate with navy and aircrafts, and the hardware of ground-based radar will be used for communication if radar-communication integration is applied. This fully uses surveillance radar's advantages, such as high power and far working distance.

高功率和远距离工作　　监视雷达

4.3. Shipborne Radar-communication Integration

舰载　　严格

The demand for applying radar-communication integration on board is not so stringent. There is plenty of space for any equipment in need, and radar antennas and communication antennas can also be placed separately in order to avoid electromagnetic interference. But navy (海军) needs reconnaissance 侦察 aircrafts as an extension of detection range, and the need for communication between ship and aircraft is urgent. Thus radar-communication integration is still needed to complete the entire system. Like ground-based scenario, shipborne radar requires 360° coverage, bringing good communication performance in any direction. Four phased array faces or one rotating phased array face can achieve full coverage considering the structural design of navy ships.

5. Summary

In this paper, we introduced radar-communication integration concept, in which radar system and communication system are integrated as one single system. Such integration is possible due to the declining differences between hardware of these two systems, and some advantages of radar system are also applicable to communication system if integrated. We discussed main approaches of radar-communication integration, including ① time-sharing approach, ② sub-beams approach, and ③ signal-sharing approach. We also looked into three common application scenarios.

As the development of electronic equipment, the integrating tendency of originally unrelated devices is get stronger [7]. Radar-communication integration is the future direction of both radar and communication system. Current studies on radar-communication integration are still theoretic and simulative, and a *real* such system is still too far from reality. The level of both hardware and theories still needs to improve to achieve a *real* radar-communication integration system.

目标：

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