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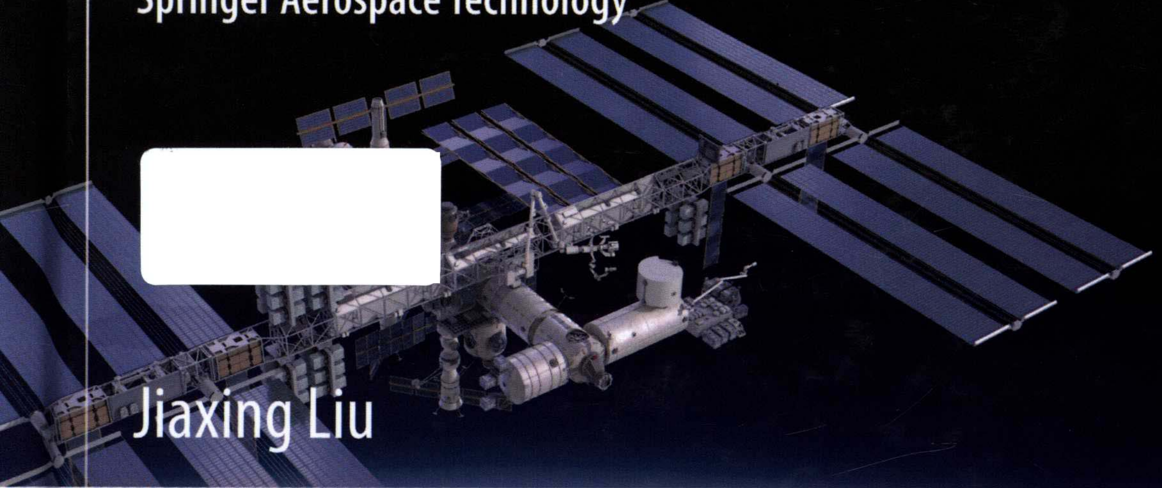

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Spacecraft TT&C and Information Transmission Theory and Technologies

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Foreword

"TT&C" is the abbreviation of tracking, telemetry and command. "Spacecraft information transmission" refers to the mutual transmission of information acquired from or generated by spacecraft and ground station. With the development of technologies, TT&C and information transmission have been organically linked, in that they are complementary in functions, unified in signal design and integrated in equipment. In addition, telemetry and telecommand are essentially a kind of information transmission. From the view of development, information warfare and integrated electronic information system require that TT&C and information transmission be designed on a unified basis and integrated into a single device. Therefore, this book highlights the characteristics of the combination of TT&C and information transmission with the latter being particularly emphasized. Based on the practices of the author in developing various TT&C equipment over many years and trying to combine theory with the practices, the book focuses on the basic technologies commonly applied for C&T system of various vehicles, with the intention to help the readers to obtain deeper understanding about TT&C systems and provide them with a theoretical basis for resolving practical engineering problems.

The book falls into two major parts of TT&C and Information Transmission, and is composed of five chapters. Chapter 1 introduces the past, present and future of TT&C and information transmission technologies. Chapter 2 introduces tracking and orbit measuring theories and technologies, with focus on CW radar's velocity-measuring, ranging, angle measuring technologies and locating technology. Chapter 3 (Information Transmission Technology) introduces analog transmission technology and digital transmission technology. In addition to the basic theories in combination with features of C&T, the telemetry, telecommand and remote sensing technologies are also provided. Chapter 4 (Spread Spectrum TT&C) introduces the application of spread spectrum technologies in C&T field. Chapter 5 introduces the development of TT&C frequency band in combination with special problems occurring in radio transmission channel, such as impacts of rain attenuation, atmospheric attenuation and radio wave propagation upon accuracy of orbit determination during transmission, impact of multi-path transmission, and polarization diversity synthesis.

With its main purpose being the introduction on basic theoretical knowledge and technology, the main feature of this book is the idea of combining TT&C with information transmission, and combining theory with the practical experiences in equipment development.

With the wider application of C&T system, particularly with its increasing significance in military application field, C&T system becomes the only information line between the spacecraft and ground, so there are more and more people engaged in the development, production, application and teaching of such engineering system. However, there are only a few books involving the technology. For this reason, the author, by incorporating the experiences from the practices of engaging in different engineering equipment research for many years, studies and summarizes his published papers and training materials to complete the writing of this book, hoping to provide support to the science-technological workers and university teachers and students who are involved in the development, design, production and application of the C&T system.

This book is compiled under great support from China Southwest Institute of Electronics Technology – the employer of the author – and National Defense Industry Press. Many contents in this book reflect the achievements made by China Southwest Institute of Electronics Technology from developing C&T systems for many years and so it is the fruit of all the participants' efforts. In addition, in the course of compiling this book, academician Yang Shizhong reviewed the manuscript, researchers Lei Li and Zhang Hansan put forward many valuable comments, Yang Hongjun provided a lot of materials, and Liu Yu and Liu Yanmeng completed numerous text processing works. The author hereby expresses his sincere gratitude to all of them for their great support.

Chengdu, China Jiaxing Liu
August, 2013

Contents

Chapter 1
Introduction

1.1 General

This book attempts to present the tracking, telemetry, and command (TT&C) of flight vehicles such as air vehicles (less than 20 km in altitude), near-space vehicles (20–100 km in altitude), and spacecrafts (greater than 100 km in altitude). Those flying at an altitude of more than 2×10^6 km are also known as deep-space vehicles. Specifically, the flight vehicles include missiles, satellites, spaceships, space stations, deep-space probes, near-space vehicles, UAVs, airships, or balloons, all of which are subject to TT&C. For TT&C and communication (C&T) systems, there are radio, optical, infrared, and other types. Among them, the radio continuous-wave C&T system is the most widely used one, which is mainly described in this book.

"Information transmission" for flight vehicles means transmission of information, acquired from or produced by vehicles or ground stations, between them through either point-to-point connection or network. An information transmission system is used to transmit information from a sending terminal to a receiving terminal at another space-time point. It can handle information resulted from telemetry, telecommand, remote sensing, reconnaissance, detection, guidance, scientific experiments and space environment observation, and traditional voice and images as well. The aforesaid information concept has broader implications than the traditional communications concept, for the former contains the telecommand and telemetry information necessary for normal operation of a vehicle platform (generally known as engineering TT&C), the application information acquired or forwarded by the payload (P/L) on the platform, and the information for P/L's telecommand and telemetry (generally known as service TT&C).

With the rapid development of aerospace technology, today presents a greater challenge for C&T. The traditional concept "C&T" is giving way to "communications and navigation," where "navigation" contains traditional tracking, orbit determination, orbit control, and orbit calculation, while "communication" means

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transmission of various types of information, and it has some new extensions such as information resulted from command and telemetry, voice, low-speed data, and the newly extended high-speed data.

1.2 TT&C and Information Transmission

Claude Elwood Shannon, the founder of information theory, defined "information" as "something used to eliminate the uncertainty," that is, a description of uncertainty of the motion state or existence of a thing. It is the unknown elements contained in messages, while signals are the carrier of messages. What we transmit actually are signals. In this sense, information transmission means transmission of unknown elements in messages carried by signals (namely, information).

Information exists in various forms, such as symbol, voice, and image. This book merely focuses on electronic information. An electronic information system is generally an electronic system that allows for generation, acquisition, transmission, processing, application, and countermeasure of information for operation, control, or utilization purposes, taking advantage of such major techniques as ET and IT. A space electronic information system refers to a system that allows for acquisition, transmission, processing, application, and countermeasure of information, using spacecraft platforms. A transmission subsystem is a significant component of an information system. In general, the part of a transmission subsystem that is mounted in a spacecraft is called a "payload" and that on ground is known as a "ground application system."

A TT&C information system acquires vehicle's orbit information (through tracking devices) and telemetry information (through sensors), generates command information through telecommand devices, and then converts and modulates such information to a signal carrier for long-distance transmission, which is eventually received, demodulated, and processed by a receiving terminal before being put into use. As a means of transportation, the information transmission system can be used to transmit TT&C information and others.

Technological progress has led to a close connection between TT&C and information transmission, which is mainly manifested in the following six aspects: (1) Functions. Information transmission depends on TT&C systems to enable air platforms and payloads to work normally and maintain a long service life and also relies on ground TT&C stations to align ground antenna with air platforms by tracking vehicle's orbits, providing a two-way information transmission path between vehicles and ground stations. (2) Signal design. TT&C signals and the signals carrying information have been unified under a common signal system. Unified carrier signals with multi-subcarrier frequency division and spread-spectrum signals with unified data stream are just the case. (3) Devices. TT&C systems and information transmission systems have been integrated together, and multifunctional integrated channel terminals and multifunctional integrated baseband devices have become available. (4) Techniques. Telemetry and telecommand are no more than long-distance transmission of information to realize "remote" measurement and control. With the advancement of software and radio technologies, telemetry and telecommand are performed with a common platform and software. (5) Application. As space technology was put into use after its successful R&D and test, the application of information transmission has been an increasing concern. For example, remote sensing stations, reconnaissance data-receiving stations, tracking and data relay satellite systems, and UAV TT&C systems mainly involve data transmission other than TT&C for payloads. (6) Future development. Information warfare, precision strike, and the development of integrated electronic information systems require the integration of TT&C and information transmission functions into an integrated system. The phrase "information transmission" is employed to describe such system so that it makes a stronger sense when it comes to information warfare and integrated information systems. Also, this coincides with the development trend of informationization.

Look at the "integrating" process of C&T techniques by history [1]. Prior to the 1960s, tracking, telemetry, and command functions were performed by separate devices. In mid-1960s, the S-band system (USB) came into being, having integrated TT&C, voice, and television into one system, using unified frequency-division carrier signals. In the 1980s, the tracking and data relay satellite system appeared, having incorporated TT&C and high-/medium-/low-speed data transmission functions into a single system, using spread-spectrum unified carrier signals with a time-division unified data stream, and now such functions can be performed by one software-supported radio device. Since spacecrafts were put into use, they have been chiefly used for information transmission. In China, C&T techniques evolved in a similar way. Before manned space flight projects were introduced, the TT&C system comprised many separate devices. After that, since voice and image transmission functions were incorporated, it was renamed "C&T system."

1.3 Tasks, Functions, and Classification of TT&C and Information Transmission

Major tasks include [2]:

(1) To perform a flight vehicle's tracking, orbit measuring, attitude measuring, and telecommand of its orbit and attitude to ensure that the vehicle takes off, operates, and returns in normal attitude and predetermined orbit
(2) To perform telemetry and telecommand of a vehicle and its payloads so that it is able to complete operations and perform functions as required
(3) To fulfill various information transmission tasks to provide relevant data for ground application systems
(4) To be used for weapon test range TT&C to provide test data for identifying and evaluating the technical performances of missiles and flight vehicles and to provide a basis for design improvement and finalization as well

(5) To perform safety control tasks in the circumstance that any vehicle or missile launching goes wrong, that is, to transmit commands to blow it up so as to ensure the safety of the launching region or flight course

A C&T system mainly consists of four subsystems for orbit measuring (range, velocity, and angle measuring), telemetry, telecommand, and information transmission. These subsystems are integrated in a single system with information transmission, feedback, and control functions to fulfill C&T tasks. For example, for a satellite C&T system, information acquisition and feedback transmission are done by its tracking and orbit-measuring and telemetry subsystems, transmission of command information and control of the vehicles by its telecommand subsystem, and weapon test and finalization by its TT&C system which performs measurement, control, and evaluation. Without the C&T system, its remote sensing satellite ground application system is sure to fail with regard to reception of high-speed data, telemetry and command of payloads, and satellite orbit determination based on its angle-measurement data. As soon as a spacecraft enters its orbit, it must be subjected to service TT&C and control by the C&T system. Small military satellites usually incorporate TT&C and service functions. As weapons, some spacecrafts and aircrafts must, when used in actual military operations, be equipped with military-purpose TT&C systems to conduct precise TT&C and evaluate strike effects. When the TT&C system is used for weapon guidance, navigation, and control, the three axial parameters of attitude, velocity, and position measured by the guidance/navigation/control subsystem should also be transmitted through the telemetry system to the facilities on ground for analysis, research, and computation before being converted into commands for attitude adjustment, pointing positions, and velocity increments, which are then sent back through the telecommand subsystem and executed on the flight vehicle. It can be seen that the C&T system is of significance in both civil and military fields.

C&T systems can be classified by TT&C object, orbit altitude, TT&C scheme, TT&C station carrier, etc. Shown in Fig. 1.1 are C&T systems classified by TT&C object.

Shown in Fig. 1.2 are C&T systems classified by orbit altitude.

Any spacecraft that flies 300 km – 2×10^6 km above the Earth is called an Earth-orbit spacecraft; that with its orbit being more than 2×10^6 km above the Earth is known as a deep-space probe. Any lunar probe is about 36.3×10^4 km above the Earth.

A TT&C scheme involves what signal form to be employed and how to transmit signals. The composition and performance for a C&T system are closely related to its employed scheme. As TT&C and information transmission systems evolved according to different signal forms and multifunctional integrated transmission schemes, several TT&C schemes have come into being, as shown in Fig. 1.3.

Shown in Fig. 1.4 are C&T systems classified by the carrier for a C&T station:

A C&T system consists of a control center, an onboard C&T subsystem, and a ground C&T subsystem, which form an organic network through the communication systems and timing systems between ground stations. (1) The control center

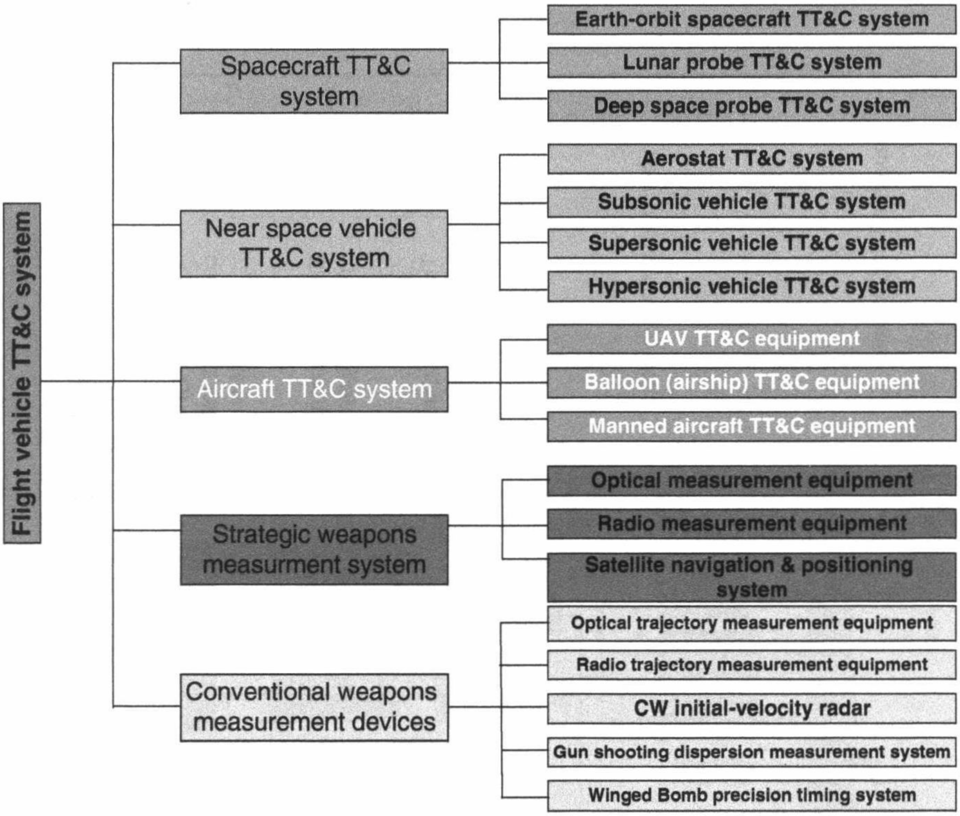

Fig. 1.1 C&T systems classified by TT&C object

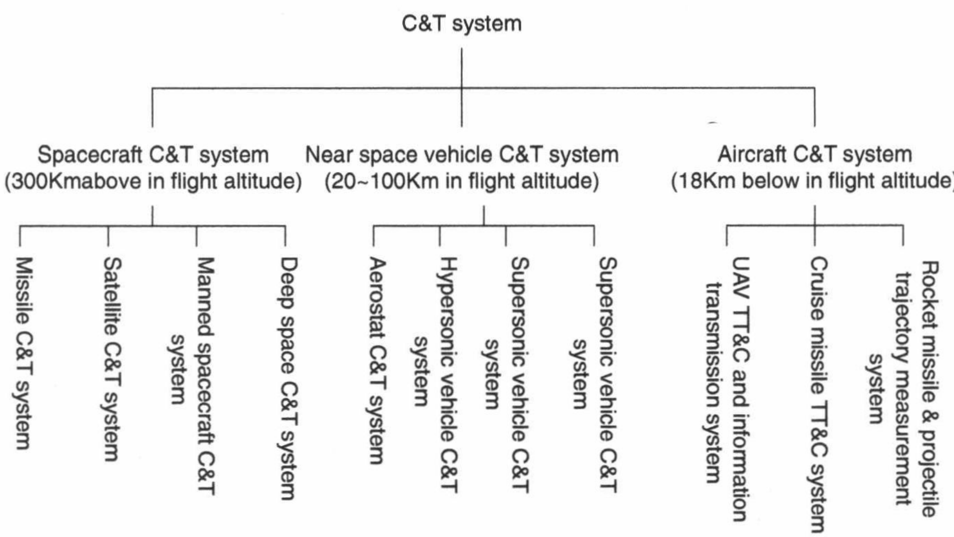

Fig. 1.2 C&T systems classified by flight altitude of a TT&C object