TELEVISION CAMERAS EMPLOYING SOLID-STATE IMAGING SENSORS FOR MANNED SPACECRAFT APPLICATIONS

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ABSTRACT

In past manned spacecraft programs, particularly since the advent of Apollo, on-board television systems have served a key role in the transfer of information concerning in-space activities as they occur. The next generation of manned space programs will expand the television usage from its primarily public information role to a whole host of operational support activities that will require exacting performance capabilities. The Space Shuttle television system will incorporate a versatile complement of TV equipment which will allow the positioning, quantity, and performance capabilities of the multiple TV cameras to vary as dictated by the particular mission. However, current TV camera technology employing glass-enclosed, vacuum processed image sensors results in a bulky device that restricts its location and versatility. This paper addresses these problems and discusses the potential solutions that can be achieved through the employment of solid-state image sensors - for both monochrome and color applications.

I. INTRODUCTION

Television has continually grown in its importance for manned space flight since its early use in the Apollo Program. Beginning with Apollo 7 and continuing throughout the Apollo, Skylab, and ASTP (Apollo Soyuz Test Project) programs, more and more demands have been made resulting in expanded capabilities of the inflight TV systems. Black-and-white television was replaced by color. Television on the lunar surface evolved from a slow-scan (10 frames per second) black-and-white to an EIA-compatible field-sequential color output. Control and use of the camera system transferred from strictly crew-operated manual control to almost independently remote control operation by the mission controllers in Houston. Environmental requirements expanded from the relatively simple in-cabin situation to the very uncompromising environments of outer space and on the lunar surface. The number of cameras employed for a mission grew from one during the early Apollo flights to two for later Apollo missions and Skylab, and to four for ASTP (plus four Russian TV cameras for their system). The uses of the system and its product has also increased in complexity - initially, the TV was used practically solely for purposes of increasing the public's awareness of the space program and information dissemination. Later, support of the experimental aspects of the missions was provided, and finally experiments were conducted that employed television as an integral part of the program.

However, the next generation of manned space programs will greatly broaden the scope of television usage and the attendant demands for more exacting performance. Those activities that comprise the Space Shuttle program can best be grouped into three areas of operation - within the crew compartment, within the payload bay (an area approximately 60 feet long and 15 feet in diameter), and mounted on the remotely-controlled manipulator arms. Included in the scope of tasks that television will play a key role in supporting will be general Shuttle operations and crew activities, the onboard experimental activities, the entire spectrum of remote manipulative functions - payload inspection, deployment and retrieval, servicing, repositioning, etc., and the operations concerning the attached payload (e.g., Spacelab) programs. In a large percentage of these tasks, the success of the operation will greatly depend on the performance of the television system. Such parameters as resolution, extreme ranges of light levels, high linearity with minimum distortion, wide dynamic range, and high blooming resistance are among the key performance demands for which the Shuttle television system must be optimized.

II. PRESENT SYSTEM

The Shuttle Orbiter closed-circuit television (CCTV) system is being designed and implemented to be a versatile and flexible complement of TV equipment. This will allow the positioning, quantity, and performance capabilities of the multiple TV cameras and their associated hardware to vary as dictated by the specific requirements of a particular mission. The CCTV system as is presently baselined for use on the Shuttle program is composed of a total of five TV cameras - one portable, color camera for use in the crew compartment; one black-and-white camera mounted on the forward payload bay bulkhead and another on the aft bulkhead; and one black-and-white camera each mounted on the port and starboard remote manipulator arms. There are additional camera mounting locations being provided throughout the Orbiter for use when needed. The latter four TV cameras have a remotely-controlled pan and tilt capability which allows them practically unlimited viewing range within the restrictions of the mounting location. A variety of lenses, both fixed-focal length and zoom, with remote-control capability will be used as required to support the specific mission requirements. A small, monochrome monitor which connects to the portable, color TV camera is provided to assist the crewman in adjustments and pointing of the camera. Two console-type monochrome monitors will be mounted at the rear of the crew compartment to support the crewman as he performs a task which requires TV viewing. The CCTV system control and distribution functions are performed by two units called the video switching unit and the remote control unit which for simplicity shall be referred to herein as the video control unit (VCU).

The multitude of functions of the video control unit serves well to illustrate the complexity of the Shuttle CCTV system. The VCU generates the master composite sync signals for all of the TV cameras, monitors, etc. It generates a color frame sync for each camera (this is in keeping with the philosophy that each camera will be designed such that conversion from monochrome to color capability, and vice versa, can be made simply thus resulting in a commonality of camera equipment), a camera location identification code, and a full field test signal (or signals) to be used in monitor setup and downlink transmission checkout. The VCU recognizes inputs from both the onboard control panel and ground uplink sources as commands to control camera, lens, pan and tilt, monitor, etc., functions which must be remotely controlled. These control messages are then amplitude-time division multiplexed with the sync signals and sent to the selected locations. Switching of all the various video inputs to the various selected outputs (including the monitors, the downlink signal processors, and payloads operating in the payload bay) is done by the VCU. Also, the VCU supplies a split-screen capability for both of the console-type monitors.

One major area of concern within the currently envisioned CCTV system configuration is the fact that the current state-of-the-art television camera - those previously proven by experience and use in space - incorporates a glass enclosed, vacuum processed image sensor. This type of sensor is highly susceptible to vibration and thermal damage thus requiring bulky protection which results in large devices and high program cost. This bulky size and its correspondingly excessive weight in many instances may prove to be very marginal if not in fact actually unusable for certain potential Shuttle mission situations. Television operations in some portions of the crew compartment will be severely hampered due to the close proximity of the candidate camera positions to the subjects of interest. The size of certain payloads; the necessary close proximity of the payload cameras to some payload extremities; the constraining nature of the volume required for a large size camera to be panned and/or tilted over a wide range; the size, weight, and volume constraints of mounting a TV camera with pan and tilt capability on a manipulator arm (whose own volume for operation and stowage represent highly restrictive problems in themselves); the need for precise, extremely accurate TV viewing of alignment cue markings used in payload manipulations... these all reflect the types of problem areas that must be addressed during the life of a multi-mission, multi-year space program, particularly with the present TV camera image sensor technology.

III. ADVANCED SYSTEMS

A television camera that employs a solid-state imaging device (SSID) as the image sensor if adaptable to the specialized performance and environmental requirements that will be encountered on manned space missions appears to offer the needed versatility. Such a camera should be much smaller than its tube-type equivalent (possibly as much as 90% smaller) since the sensor itself requires only a small fraction of the tube-required space and much of the electronic circuitry can be made an integral part of the sensor chip. A corresponding substantial reduction in camera weight estimated to be as much as 80% less than current tube sensor cameras should be attainable. Power consumption, a third highly important factor in all space flight applications, is estimated to approach an 85% reduction from the current technology.

Prototype development work by JSC with a variety of SSID technologies has produced extremely encouraging results. All indications point to the possibilities of relatively early incorporation of a solid-state TV camera into the Shuttle CCTV program as being both very feasible and quite advantageous. Solid-state TV cameras appear to offer significant improvements in certain performance parameters over those currently attainable. The linearity characteristics of the SSID appear to be significantly better than those attainable with image tubes. Lag (residual imaging) is not present with solid-state imaging devices. Low light level operation as well as designs for a wide dynamic range are progressing satisfactorily. The signal-to-noise and vertical and horizontal resolution capabilities of SSID cameras appear to be capable of achieving at least performance comparable to the commercial industry tube-type cameras. At this time, there do not appear to be any insurmountable problems associated with these SSID cameras being operated in a space environment. However, a more detailed investigation into this aspect of SSID camera development still remains to be conducted.

In terms of a long range, multi-mission program such as the Shuttle, it has been estimated that substantial cost savings can be realized. It is anticipated that the space-type version of the solid-state TV camera will result in a weight reduction of 10 pounds per camera and an approximate 90% size reduction will result in decreased mounting structure weight. Furthermore, the use of a solid-state camera will result in reduced development costs for camera thermal controls and vehicle structure/camera loading requirements. The unit cost of a solid-state camera designed for space environments is expected to be possibly one-third that of a tube-type camera. The number of tube-type cameras that have been estimated to be needed to support the Shuttle program through 1992 has been based on a limited shelf and operating life which dictates a periodic refurbishing and/or discarding of the cameras from flight status. It is estimated that the lifetime of the current image-tubes is such that they will require periodic replacement throughout the program while the SSID may need no replacement. The solid-state camera should be much less susceptible to operating life limitations and should have a greatly increased shelf life. Thus, the quantities of solid-state cameras need be much less for the program duration.

Thus far, practically all of the government and industry efforts related to solid-state TV camera development has disregarded the need for color capability. The present market potential for solid-state cameras has been concentrated in areas where black-and-white cameras are quite adequate. However, the manned space program has identified a significant set of requirements that necessitate color. Some of these prime uses thus far identified include providing additional precision and parts discrimination information for manipulative tasks in space; providing subtle, discrete color changes for use in inspection operations, e.g., to evaluate the effects of environmental exposure of heat shields; and, enhancement of the downlinked spacecraft video pictures so as to increase their acceptance potential as an information transfer medium to the public. Essentially the same program cost reduction considerations as have been mentioned above would apply for the color solid-state TV camera case with a greater percentage unit cost reduction possibly being realized.

Intensification of emphasis for development of a color solid-state TV camera suitable for use on manned space missions is currently being undertaken. Certain major design considerations must be addressed in order to be acceptable as a replacement for the currently employed tube-type color TV camera. The primary problem area concerns the attainment of a balanced spectral response for the three primary colors (red, green and blue) of the visible spectrum. The current SSID technology exhibits a relatively low blue response. Another consideration is achieving operating performance characteristics approaching, if not comparable to, the monochrome camera version. Certain techniques that could be employed to achieve a color capability as well as balancing the spectral response might lead to a color camera but with a severely reduced overall performance capability. Lastly, an evaluation is required to determine whether, for space applications, the full NTSC (National Television System Committee) or a quasi-field-sequential mode (field sequential color is presently employed for manned spacecraft transmission systems) of color generation should be used.

In summary, solid-state television cameras most certainly will figure prominently in future manned space programs. Intensified development work is currently progressing with the goal of incorporating low cost, high performance SSID cameras into the Shuttle program during the early phases to effect substantial program cost reductions.