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DECISION NUMBER SIXTEEN
TO THE TREATY ON OPEN SKIES

CALIBRATION OF GROUND PROCESSING EQUIPMENT, USED FOR THE DETERMINATION OF H_{MIN} FROM VIDEO CAMERAS OR INFRARED LINE-SCANNING DEVICES AND FOR CALIBRATING GROUND-BASED TAPE REPRODUCERS USED TO REPLAY DATA FROM SAR SENSORS

The Open Skies Consultative Commission pursuant to the provisions of Decision 14 and Decision 15 to the Treaty on Open Skies (hereinafter referred to as Decision 14 and Decision 15 has decided as follows:

This calibration procedure shall be followed to calibrate the ground equipment used to process and analyze data collected as a part of certification or demonstration flights. The calibration shall be done prior to these analyses.

Annex A of this Decision provides a description of the Test Patterns to be used in calibration. Annex B of this Decision provides a description of the tests to be performed when an analogue framing video camera is to be certified using a ground video reproducer that is a different model from the airborne video recorder. Annex C of this Decision provides a description of computer-assisted techniques which may be used pursuant to Decisions 14 and 15. These Annexes constitute an integral part of this Decision.

SECTION I. DEFINITION OF TERMS

The following definitions shall apply to terms used in this Decision.

The term "line imaging device" means a device containing one line of detector elements for each wavelength band to be recorded.

The term "frame imaging device" means a device containing either an electronic imaging tube or an array of detector elements for each wavelength band recorded which simultaneously form multiple lines of the image to be recorded.

The term "video camera" means a passive black and white or color, line or frame imaging device, including the conversion of the image into electrical signals operating at optical wavelengths between 0.3 and 1.1 micrometers.

The term "image element" means the digitized signal representing the detected energy of a scene element within each wavelength band to which a video camera is sensitive which is stored in a frame store.

The term "scene element" means, in the case of a black and white video camera, the area on the ground that is projected on to a single detector element, and in the case of a color video camera, means the area on the ground projected on to the detector elements used to provide the different wavelength band data associated with that area on the ground.

The term "image" means an array of image elements corresponding to an equally numbered array of scene elements which cover a contiguous area on the ground.

The term "grey level" means the numerical value of an image element on an eight bit scale between zero and 255.

The term "video densitometer" means a device or technique which is able to extract the numerical value of the grey level of individual image elements from a frame store.

The term "video display" means a monitor used for analysis of data pursuant to this Decision, including any associated image processing electronics, that is capable of displaying an image.

The term "image processing system" means all ground-based equipment and software used to perform the visual or computer-assisted analysis of the images and determination of ground resolution and H_{min}.

The term "frame store" means a digital memory that is capable of storing at least a complete image of a calibration target where each individual image element is stored at a separate memory cell.

The term "scan converter" means a device which has the capability to selectively extract a frame or sub-frame of imagery from data produced by an infrared line scan device or a line-imaging device.

The term “scan line” means a row of image or scene elements that are displayed or imaged sequentially.

The term "line scan formatter" means a device which has the capability to transfer a two-dimensional digital matrix that is stored in the computer into a series of scan lines that corresponds to the output of an infrared line scan device or a line imaging device or synthetic aperture radar, for the purpose of recording such data in line scan format.

The term "frame grabber" means a device which has the capability to convert the output of an analogue video frame imaging device or analogue scan converter into an eight bit digital image for transfer into the computer and image processing system memory.

The term "frame formatter" means a device which has the capability to output data contained in a frame store to an analogue video recorder, in a format that simulates the output of a frame imaging device.

The term "video recorder" means a data recording device capable of storing data collected by a video camera on magnetic tape without the use of encoding techniques. For digital recorders, data must be recorded at eight bits per wavelength band to which a video camera is sensitive.

The term "video tape reproducer" means a device that plays back the information recorded on a video tape.

The term “grey level difference function” means a software-based procedure that computes, summarizes and displays the differences in grey level that occur for each corresponding pair of image elements in two identically-sized images.

The term “linearity of amplitude characteristics” means the measure of the ability of a video tape reproducer to reproduce grey scale values in Test Patterns.

The term “overshoot/undershoot characteristics” means the measure of the errors produced by a video tape reproducer while reproducing signals with large changes in grey scale values between adjacent image elements in Test Patterns.

The term “bar” means, in the case of a digital Test Pattern, a rectangular array of image elements, all of the same grey scale value.

The term “bar width” or “width” means, in the case of a digital Test Pattern, the number of image elements across the bar in the horizontal direction (number of columns in the bar).

The term “bar height” or “height” means, in the case of a digital Test Pattern, the number of image elements along the bar in the vertical direction (number of rows in the bar).

The term “bar pair” means an adjoining pair of bars of the same width and height, but with different grey scale values.

The term “light bar” means the bar in a bar pair with the larger grey scale value.

The term “dark bar” means the bar in a bar pair with the smaller grey scale value.

The term “bar group” means a sequence of adjoining bars of the same width and height whose grey scale values alternate between a single light value and a single dark value. A bar group may begin with either a light bar or a dark bar.

The term "spatial frequency", designated by f, means a frequency measure of a group of bars of bar width ? and is calculated by:

$$f = 1/(2?)$$

The term "bar group amplitude" means a measure of the grey level difference between the light and dark bars of a bar group.

The term "image amplitude function", designated A(f), means the relationship of the bar group amplitude to the spatial frequency corresponding to those bars.

The term "phase correction" means a technique to reduce scan line misalignments in the image caused by correctable time base errors in the video recorder, correctable motion compensation errors, or other errors which are camera induced.

SECTION II. CALIBRATION PROCEDURE FOR VALIDATING THE SOFTWARE AND COMPUTER SYSTEM

The following procedure shall be performed in order to verify that the software and basic image processing computer system are acceptable for performing the tasks required in Section III and for use in analyzing data from certification and demonstration flights.

1. Tests of Image Processing System and Image Quality Acceptability Functions

(A) Frame Store and Cursor Function/Video Densitometer Capability

The six Test Patterns described in Annex A of this Decision and illustrated in Figure 1 of Annex A shall be transferred into the ground processing computer system and presented for viewing. The video display and associated frame store shall be capable of displaying all Test Patterns simultaneously in a single image.

(1) A visual analysis of the displayed Test Patterns shall be performed to ensure conformance with the visual characteristics shown in Figure 1 of Annex A of this Decision. The video display shall be viewed to determine that no readily apparent distortion appears in the image and that all patterns can be simultaneously observed.

(2) The cursor shall be positioned over the four corners of the video display containing the Test Patterns and the image co-ordinates and grey scale value at each location shall be recorded. The cursor locations and grey scale values of the four corners, relative to a co-ordinate system which defines the upper left corner of Test Pattern 1 as (0,0), shall be (0,0) and 20 for the upper left corner; (511,0) and

230 for the upper right corner; (0,479) and 127 for the lower left corner; and (511,479) and 127 for the lower right corner. The cursor shall also be positioned at (25,0). The grey scale value shall be 20. The zoom function of the image processing system may be employed to assist in this task, but shall not change the image co-ordinates or grey level values.

(B) Protractor Function

The image processing software shall be capable of correctly calculating the angle between the rotated rectangle in Test Pattern 5 and any scan line in the image. The angle calculated shall be 5 degrees +/- 1.0 degree.

(C) Aspect Ratio

The aspect ratio shall be determined for the rotated rectangle in Test Pattern 5 by measuring its longer dimension and its shorter dimension in units of pixels. The result of dividing the longer dimension by the shorter dimension shall be 17.7 +/- 10%.

2. Tests of Software Used to Determine the Suitability of Digital Tape Reproducers

The ability of the image processing software to correctly determine the differences between two separate images shall be verified by first loading the entire Test Pattern image into the image processing software and then storing this image into a separate image file outside of the frame store used by the image processing system. This new image file shall then be loaded back into the image processing system and, using the software's grey level difference function, compared to the originally loaded image. Both a video display of the difference and the ability to quantify the magnitude of any grey level changes shall be provided. A grey level difference of zero for each image element shall be verified.

3. Tests of Computer-Assisted Processing Techniques

Any computer-assisted techniques used pursuant to Decisions 14 and 15 shall be described in appendices attached to Annex C to this Decision. These appendices shall be provided by the State Party which sponsors the computer-assisted technique and shall include detailed procedures for validating, in accordance with the procedures of this paragraph, the computer-assisted calculations. Annex C describes the computer-assisted techniques which may be used and is included as part of this Decision.

(A) Validation of Image Amplitude Functions calculations

Test Pattern 4 shall be used to confirm the ability of the software to calculate the Image Amplitude Function A(f). The A(f) shall be calculated by determining the amplitude of each of the bar groups in Test Pattern 4, as follows:

(1) The amplitude a(i) shall be calculated for each of the i = 1, ..., 36 bar pairs of Test Pattern 4 according to the formula:

$$a(i) = 0.5\,(Amax_4(i) - Amin_4(i))$$ where

$Amax_4(i)$ is the maximum calculated grey scale value and $Amin_4(i)$ is the minimum calculated grey scale value of the ith bar pair of Test Pattern 4.

(2) The image amplitude function $A(f_j)$ shall be defined for each of the j = 1, ..., 12 bar groups of Test Pattern 4 as the average of the amplitudes of the three bar pairs belonging to the jth bar group.

(3) The calculated values of these functions shall lie within 1% of the correct values, provided in Table 2 of Annex A, for every bar group.

(B) Last Resolved Bar Group Validation

The ability of the algorithm and software to correctly identify the last resolved bar group shall be validated.

(C) H_{min} Calculation Validation

The ability of the software to correctly apply the formulas for H_{min} for video cameras and infrared line-scanning devices, as specified in the Decisions 14 and 15, shall be validated.

(D) Phase Correction Validation

The ability of the phase correction algorithm and software to correct the known phase error in Test Pattern 6 of Annex A to this Decision shall be verified. This shall be done by first applying this algorithm on Test Pattern 6. The corrected pattern shall then be analyzed by generating an Image Amplitude Function A(f) plot of the corrected pattern, as described in Section II, paragraph 3 (A) of this Decision. The A(f) plot values at bar group numbers 3 and 13shall be within 10% of the amplitude values stated in Annex A of this Decision for Test Pattern 6 for the pattern before the phase errors were introduced.

SECTION III. CALIBRATION PROCEDURES FOR SYSTEMS WHICH EMPLOY GROUND-BASED VIDEO TAPE REPRODUCERS

The specific procedure to be used shall depend on the type of output from the airborne video or infrared sensor system. Figures 1 through 3 of this Decision provide the functional test diagrams for the four generic types of sensor systems: digital framing, digital line-imaging/scanning, analogue framing, and analogue line-imaging/scanning converted to digital. Paragraphs 1 through 3 of this section provide the details for calibrating the ground-based equipment associated with transferring the data from these four types of systems. Procedures for testing tape reproducers used to replay SAR data are also covered in the section on digital line-imaging. Only the tests directly related to validating the performance of the tape reproducer need to be performed for the SAR. These three paragraphs cover the testing of the tape reproducers and associated input/output equipment used to transfer the image from the tape reproducer into the image processing system used for determining the last resolved bar group and calculating H_{min}. Paragraphs 1 and 2 detail the procedures for digital framing and digital line-imaging/scanning systems respectively, while paragraph 3 deals with analogue framing systems. Data from analogue line-imaging/scanning devices shall be converted to digital and, therefore, the procedures of paragraph 2 shall apply. For sensors that produce output in more than one spectral band (such as a color imaging device), the appropriate procedure shall be separately applied to the output of each spectral band of the sensor. Any cables or special interface equipment to be used during certification or demonstration flights shall be the same as those used during this calibration procedure. In all of the tests of this section, the data shall be recorded on to magnetic tape of the same type to be used in the certification or demonstration flight, and at the maximum packing density to be used in an observation flight. If multiple tape types are to be used, each shall be tested separately. Prior to proceeding with the tests described in paragraphs

1 through 3 of this section, the State Party responsible for performing the tests shall, by pre-testing, equipment selection, and/or care in maintaining configuration control be responsible for ensuring that:

(A) The output of the computer shall be capable of simulating the sensor output that is input to the airborne video recorder, to the degree necessary to ensure that all functions used to analyze data from a certification or demonstration flight are present in the equipment and software to be calibrated. This may be done either directly or indirectly, via a device or technique such as a frame grabber, line scan formatter or frame formatter. The output of the computer need not simulate the maximum output data rate of the sensor.

(B) In the case where an analogue ground-based video tape reproducer is to be used to replay information collected and recorded on an analogue airborne video recorder, the ground-based video tape reproducer shall not introduce appreciable degradation of the data recorded by the airborne video recorder. This shall be done by ensuring that the manufacturer's specifications for the quality of replay of such data are consistent with the airborne video recorder's recording capabilities. Further, they shall ensure that the ground-based video tape reproducer is properly adjusted such that the manufacturer's specifications for replay quality are achieved.

1. Calibration Procedure for Systems which use Digital Video Tape Reproducers for Playback from Digital Framing Type Sensors - See Figure 1.

(A) The Test Patterns described in Annex A of this Decision shall be loaded into the computer system, transferred into the ground digital video recorder/reproducer and recorded on the video tape. If the ground-based digital video tape reproducer does not have a record capability, this procedure shall be performed on a video recorder of the same type used on the observation aircraft.

(B) The image of the Test Patterns as generated on the tape in Step A of this paragraph shall then be replayed from the ground-based digital video tape reproducer back into the computer. The grey level difference function shall be used to compare this image to the original. The video recorder/reproducer and associated input/output equipment shall be deemed acceptable if no more than three non-zero differences/errors occur between the two images.

2. Calibration Procedure for Systems which use Digital Tape Reproducers for Playback from Digital Line-Imaging/Scanning or Analogue Line-Imaging/Scanning Converted to Digital Type Sensors - See Figure 2. These types include video line imaging devices, Infrared Line Scanning Devices and Synthetic Aperture Radar Sensors.

(A) The same procedure as described in Section III, paragraph 1 (A) of this Decision shall be used to transfer the Test Patterns to the ground digital video tape reproducer. The line scan formatter shall be capable of positioning the Test Pattern lines (480 lines of 512 image elements each) at any location within the total number of lines and image elements per line of the format used by the line-imaging, line-scanning or SAR sensor. This shall be verified by using the line-scan formatter to position the Test Patterns at three different locations and then

demonstrating the ability to extract the complete Test Patterns for display in the image processing system by means of the system's scan converter.

(B) Using one of the images of the Test Patterns extracted via the scan converter as described in Section III, paragraph 2 (A) of this Decision, the same procedure as described in Section III, Paragraph 1 (B) of this Decision shall be performed. It shall be verified that no more than three non-zero differences occur between the two images. In the case that obvious equipment malfunctions prevent meeting this criterion, the State Party owning the equipment shall be allowed to repeat this test after adjustment of the equipment and until the criterion is satisfied.

3. Calibration procedure for systems which use analogue video tape reproducers for playback from analogue framing type sensors - See Figure 3.

(A) Image Acquisition

(1) Transfer the Calibration Test Patterns shown in Figure 1, Annex A of this Decision via the frame formatter into the airborne video recorder and record on to the magnetic media for at least 10 seconds.

(2) Playback the recorded image of the Calibration Test Patterns from the airborne video recorder used in step (1) of this subparagraph.

(3) With the frame grabber, acquire images of the recorded Calibration Test Patterns from the airborne video recorder, and save them in files for later processing.

(a) If the ground video tape reproducer is of the same model as the airborne video recorder, one image shall be acquired.

(b) If the ground video tape reproducer is of a different model from the airborne video recorder, two images shall be acquired.

(4) If the ground video tape reproducer is of a different model from the airborne video recorder:

(a) Replace the airborne video recorder with the ground video tape reproducer, keeping all other components the same.

(b) Move the magnetic media created in step (1) of this subparagraph from the airborne video recorder to the ground video tape reproducer and play back the recorded image of the Calibration Test Patterns using the ground video tape reproducer.

(c) With the same frame grabber used in step (3) of this subparagraph, acquire two images of the recorded Calibration Test Patterns from the ground video tape reproducer, and save them in files for later processing.

(B) Sampling Tests:

Using any one of the images acquired in subparagraph (A) of this paragraph, the sampling capability of the frame grabber shall be checked to ensure that sampling of the played-back Test Pattern image occurs at an acceptable rate. The sampling rate for the played-back image of the test pattern

shall be deemed to be acceptable provided that there are at least as many image elements across the displayed sensor frame as there are in each row of the Test Pattern. If sampling produces more image elements per row than exist in each row of the Test Pattern then, prior to performing tests in subparagraph (C) of this paragraph, if required, the images obtained in subparagraphs (A) (3) or (A) (4) of this paragraph shall be resampled to result in new stored images of the Test Pattern with each line having exactly one image element per Test Pattern column (512 total per line).

(C) Ground Video Tape Reproducer Tests:

If the ground video tape reproducer to be used is of a different model from the airborne video recorder, the ground video tape reproducer shall pass all tests specified in Annex B to this Decision before it may be used in the certification or demonstration flight data analysis. The original tape containing the imagery collected from these tests shall, upon request, be made available to other States Parties for further testing and verification following the certification or demonstration flight. This shall not delay the signing of the certification report or delay an observation flight.

This Decision shall enter into force simultaneously with the Treaty on Open Skies and shall have the same duration as the Treaty. Decided in Vienna, in the Open Skies Consultative Commission, on 12 October 1994, in each of the six languages specified in Article XIX of the Treaty on Open Skies, all texts being equally authentic.

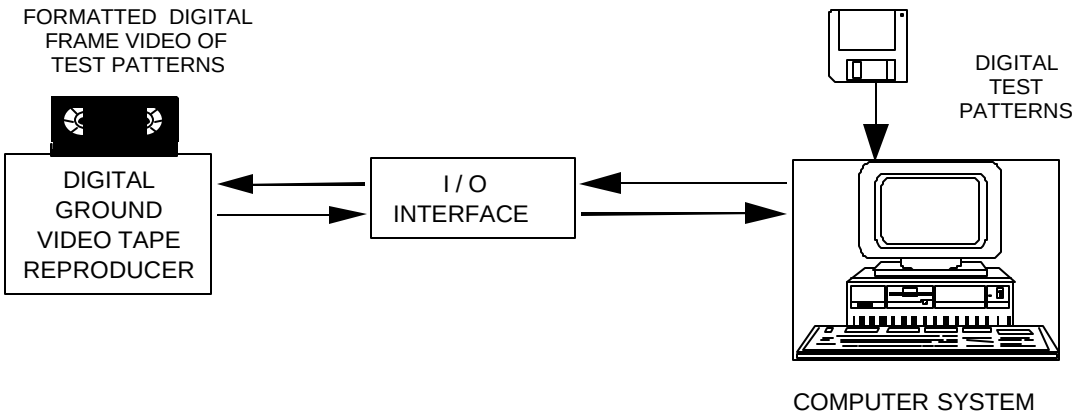

FIGURE 1-- DIGITAL FRAMING TYPE SENSORS

CALIBRATION BLOCK DIAGRAM FOR GROUND PROCESSING EQUIPMENT
USED WITH DIGITAL FRAME IMAGING DEVICES

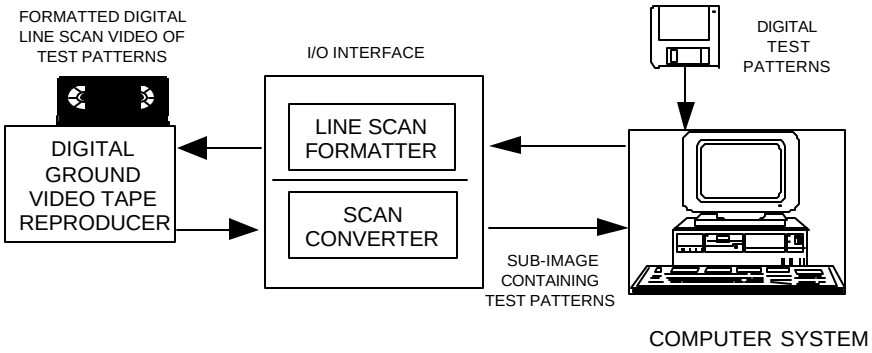

FIGURE 2
DIGITAL LINE-IMAGING/SCANNING
OR ANALOGUE LINE-IMAGING/SCANNING CONVERTED TO DIGITAL TYPE SENSORS

CALIBRATION BLOCK DIAGRAM FOR GROUND PROCESSING EQUIPMENT
USED WITH LINE IMAGING DEVICES,
INFRARED LINE SCANNING DEVICES, OR SYNTHETIC APERTURE RADARS

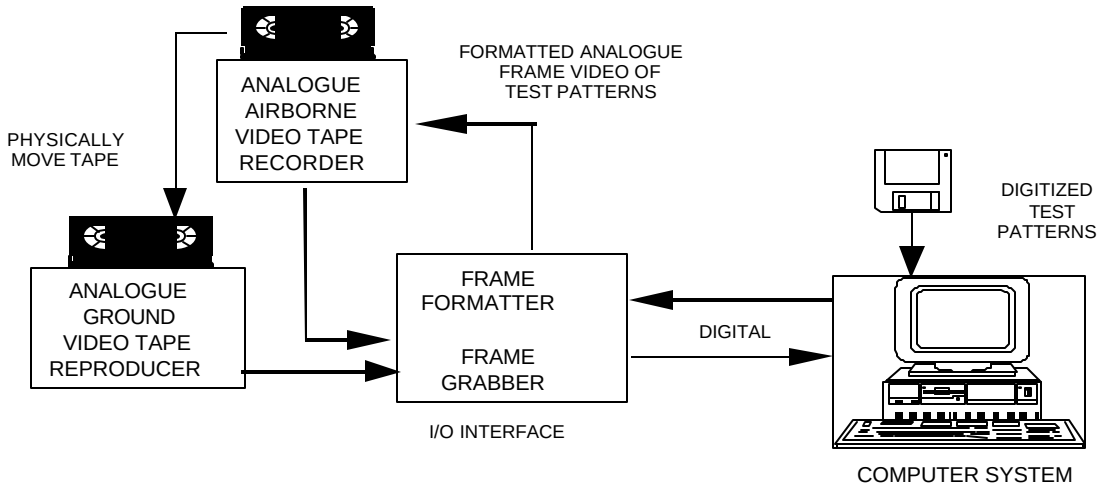

FIGURE 3-- ANALOGUE FRAMING TYPE SENSORS

CALIBRATION BLOCK DIAGRAM FOR GROUND PROCESSING EQUIPMENT
USED WITH ANALOGUE FRAME IMAGING DEVICES