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Produced by the NASA Center for Aerospace Information (CASI)
PROTOTYPE COLOR FIELD SEQUENTIAL
TELEVISION LENS ASSEMBLY

(Radio Corp. of America) 139 p HC $5.75

FINAL REPORT
OCTOBER, 1974

PREPARED FOR
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
JOHNSON SPACE CENTER
Houston, Texas 77058

UNDER CONTRACT NO. NAS 9-13688

ASTRO-ELECTRONICS DIVISION
RCA CORPORATION
PRINCETON, NEW JERSEY 08540
PREFACE

This is the final report on the project "Prototype Color Field Sequential Television Lens Assembly", performed for the Johnson Space Center of the National Aeronautics and Space Administration under Contract NAS 9-13688. It covers work performed from November 1973 through October 1974, and responds to the documentation requirements set forth in the Data Requirements List, Item 4 of the contract.
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SECTION I
INTRODUCTION AND SUMMARY

The Astro-Electronics Division (AED) of RCA submits to NASA this final report covering the design and development of a prototype Color Field Sequential Television Lens Assembly under Contract No. NAS 9-13688.

The primary purpose of this contract is to design, build, and evaluate a prototype modular lens assembly with a self-contained field sequential color wheel. The effort includes the design of a color wheel of maximum efficiency, the selection of spectral filters, and the design of a quiet, efficient wheel drive system.

This report discusses the design tradeoffs considered for each aspect of the modular assembly. Emphasis has been placed on achieving a design which can be attached directly to an unmodified camera, thus permitting use of the assembly in evaluating various candidate camera and sensor designs. A technique is described which permits maintaining high optical efficiency with such an unmodified camera. The recommended implementation of the color wheel assembly uses an edge-driven color wheel and a direct drive (no gearhead) cartridge motor.

A motor synchronization system has been developed which requires only the vertical synchronization signal as a reference frequency input. Equations and tradeoff curves have been developed to permit optimizing the filter wheel aperture shapes for a variety of different design conditions.
The completed hardware, delivered to JSC in October, 1974 consists of a color filter wheel module, an attached remote controllable zoom lens, and a control box which includes the electronics required to operate the color wheel and lens function motors.

The finished hardware demonstrates the viability of providing field sequential color operation in the form of a "kit" attachment for future space missions.
SECTION II
TECHNICAL DISCUSSION

A. PROGRAM OBJECTIVES

The major objectives of the program effort are as follows:

- Develop modular field sequential lens assembly which adapts B&W camera to color.
- Minimize mechanical and electrical interfaces to camera.
- Adapt to standard commercial ("C") mount if feasible.
- Study/optimize filter segment shapes.
- Study/trade-off motor and lens types.
- Fabricate, assemble, test, deliver with associated B&W camera.
- Provide engineering drawings and specifications to permit duplication.

The satisfactory completion of these objectives has provided a modular assembly which can be interfaced with minimal effort to a black and white camera. This in turn allows standardization of camera design for a spacecraft application (e.g., the Space Shuttle) while permitting the conversion to color if and when required by the simple attachment of a module to the existing hardware.
While the final cameras could anticipate such a module and be configured to optimize the interface, we have attempted to solve the more general case. That is, the development of a module which can be attached to any existing standard interface camera. Thus the completed unit could be used for laboratory evaluation of the relative performance characteristics of different cameras and sensor types. This restriction limits the theoretical optical efficiency which can be achieved. The mechanical design was developed to permit easy adaptation to an optimized interface camera with an attendant increase in optical throughput.

To demonstrate the finished performance, the program provides for a standard black and white camera to be supplied and tested with the color wheel module. A 1" (25.4 mm) vidicon format is anticipated as the maximum requirement for the Shuttle or similar space system. Similarly, a silicon target vidicon represents the lowest sensitivity sensor anticipated for use, and also possesses the low lag characteristics needed for field-sequential operation. Accordingly, we selected an MTI Model 55 camera for purchase and use. This camera includes a 1" format silicon vidicon, standard "C" mount lens interface, and remote sync provisions, and is considered to be typical of "standard" available cameras.

B. FILTER WHEEL DESIGN

An important consideration in the design of the Field Sequential Television Lens Assembly is the optimization of the mechanical shape and location of the color filter segments. The ideal goal is to provide maximum efficiency of exposure for a given set of constraints, while maintaining uniform exposure and zero crosstalk from one spectral filter to the other.
The sole function of the filter wheel is to provide color separation; that is, to arrange for light of only one spectral characteristic to strike any point on the faceplate between any two successive scans of the point by the scanning beam. Ideally, then, if the filters could be coplanar with the image plane, the filter mechanism would consist of an endless succession of rectangular filters, moving across the image plane at the same velocity as the scanning lines, with the motion so controlled that successive filter boundaries coincide with successive scan lines. As the filter plane is moved away from the image plane, it becomes necessary, in order to maintain color separation, to provide an opaque bar between adjacent filters of sufficient width to prevent any light from reaching the image plane at the instantaneous location of the scanning line. The resulting limitations can be appreciated with reference to Figure 1.

In Figure 1, scan line separation is shown by showing extrapolated locations of scan lines above and below the raster during retrace time. The required width (B) of each opaque bar is then determined, as shown, by the size of the exit pupil and its distance from the image plane, and by the distance of the filter plane from the image plane. The size of the filter opening (A) is determined by the same geometry, and filter efficiency is given by \( \frac{A}{A+B} \). It is also clear from the geometry of Figure 1 that there is a maximum separation of filter plane and image plane at which color separation can be achieved.

Equations required to design maximum transmission efficiency filter wheels were initially developed in Appendix A of RCA Proposal No. 102004-A. The equations given in the proposal were modified to take into account the finite distance of lens exit pupil from the image plane.
Figure 1. Theoretical Maximum Efficiency Geometry

\[ \text{EFFICIENCY} = \frac{A}{A+B} \]
These equations were written into a computer program, which was then designed to perform the iterative trial and error process required to achieve maximum transmission efficiency. In summary, the computer program does the following calculation:

**Given:**

(a) Raster size (width and height).
(b) Retrace time (as a percent of total scan interval).
(c) Distance of lens exit pupil from image plane.
(d) Distance of filter wheel from image plane.
(e) Number of sets of three (3) filters installed on filter wheel.
(f) Maximum lens opening (f-number).
(g) Maximum diameter of filter wheel apertures.

Using this information, the computer program will determine the significant design parameters for a filter wheel which will have maximum transmission efficiency while still insuring that the active scan line is always masked from direct illumination by the scene. The significant outputs of the program are:

(a) Separation of filter wheel rotation axis from optical axis.
(b) Orientation of raster with respect to line joining filter wheel axis and optical axis.
(c) Transmission efficiency.
(d) Minimum diameter of filter wheel apertures.
While developing the computer program, a previously unobserved limitation on design parameters was discovered; namely:

\[ R \sin P > \frac{Y (1-U/S) + U/Q}{2} \]

where
- \( R \) is separation of filter wheel axis from optical axis,
- \( P \) is angle between line joining these two axes and scan line direction,
- \( Y \) is raster height,
- \( U \) is separation between filter wheel and image plane,
- \( S \) is distance from lens exit pupil to image plane, and
- \( Q \) is lens f-number at maximum lens opening.

This relationship effectively establishes a lower limit on the maximum diameter of the filter wheel aperture; but this limit cannot be expressed explicitly because of the trial-and-error nature of the computation.

Optimum filter wheel designs were obtained for a number of trial conditions. In all cases, the following were assumed:

- Raster size is 0.375" by 0.500";
- Retrace time is 10%;
- Lens exit pupil distance from the image plane is 5"; and
- Maximum lens opening is f/2.
In all cases except the last three, the number of filter sets was assumed to be two. Output values are shown in Table 1 for a number of values of $U$ (separation between filter wheel and image plane) and $OD$ (maximum diameter of filter wheel aperture). Tabulated outputs are $R$ and $P$ as previously defined, minimum filter aperture diameter ($ID$), and transmission efficiency ($E$). The three designs marked with asterisks in Table 1 are shown drawn to scale in Figures 2, 3 and 4.

Additional parametric curves were then prepared, showing the tradeoffs as individual design parameters are varied.

**TABLE 1. TRIAL WHEEL DESIGNS**

<table>
<thead>
<tr>
<th>OD</th>
<th>MINIMUM</th>
<th>1.8&quot;</th>
<th>1.87&quot;</th>
<th>2.0&quot;</th>
<th>2.2&quot;</th>
<th>MINIMUM</th>
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<tbody>
<tr>
<td>.15</td>
<td>$R$</td>
<td>.486&quot;</td>
<td>.561&quot;</td>
<td>.669&quot;</td>
<td>.777&quot;</td>
<td>.662&quot;</td>
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<tr>
<td></td>
<td>$P$</td>
<td>.27.7°</td>
<td>.44.9°</td>
<td>.54.3°</td>
<td>.60.0°</td>
<td>.21.1°</td>
</tr>
<tr>
<td></td>
<td>$ID$</td>
<td>.311&quot;</td>
<td>.454&quot;</td>
<td>.706&quot;</td>
<td>.950&quot;</td>
<td>.688&quot;</td>
</tr>
<tr>
<td></td>
<td>$E$</td>
<td>54%</td>
<td>61%</td>
<td>66%</td>
<td>69%</td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>$OD$</td>
<td>(1.649&quot;)</td>
<td>(1.685&quot;)</td>
<td>(1.685&quot;)</td>
<td>(1.685&quot;)</td>
<td>(1.719&quot;)</td>
</tr>
<tr>
<td>.20</td>
<td>$R$</td>
<td>*.494&quot;</td>
<td>.551&quot;</td>
<td>.589&quot;</td>
<td>.659&quot;</td>
<td>.767&quot;</td>
</tr>
<tr>
<td></td>
<td>$P$</td>
<td>28.6°</td>
<td>43.1°</td>
<td>47.9°</td>
<td>53.7°</td>
<td>59.7°</td>
</tr>
<tr>
<td></td>
<td>$ID$</td>
<td>.304&quot;</td>
<td>.410&quot;</td>
<td>.500&quot;</td>
<td>.664&quot;</td>
<td>.908&quot;</td>
</tr>
<tr>
<td></td>
<td>$E$</td>
<td>49%</td>
<td>54%</td>
<td>56%</td>
<td>63%</td>
<td>55%</td>
</tr>
<tr>
<td></td>
<td>$OD$</td>
<td>(1.685&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
</tr>
<tr>
<td>.25</td>
<td>$R$</td>
<td>.502&quot;</td>
<td>.541&quot;</td>
<td>.649&quot;</td>
<td>*.757&quot;</td>
<td>.673&quot;</td>
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<tr>
<td></td>
<td>$P$</td>
<td>28.9°</td>
<td>40.4°</td>
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<td>59.4°</td>
<td>22.0°</td>
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<td></td>
<td>$ID$</td>
<td>.299&quot;</td>
<td>.366&quot;</td>
<td>.621&quot;</td>
<td>.867&quot;</td>
<td>.662&quot;</td>
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<td>$E$</td>
<td>45%</td>
<td>48%</td>
<td>53%</td>
<td>56%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>$OD$</td>
<td>(1.719&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
<td>(2.05&quot;)</td>
</tr>
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</table>
Figure 2. Trial Wheel Design No. 1

**Figure 2.** Trial Wheel Design No. 1
Figure 3. Trial Wheel Design No. 2

ID = 0.87"
OD = 2.20"
EFF = 56%
WHEEL AXIS TO OPTICAL AXIS = 0.757
CLEARANCE = 0.25"

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Figure 4. Trial Wheel Design No. 3
Based on the geometry of Figure 1, with a raster height of 0.375 inch, a duty cycle of 0.9 (10% retrace time) and an exit pupil to image plane distance of 5.728 inches (the value given for the 6 x 13T21 lens), maximum exposure efficiency is plotted in the upper half of Figure 5 as a function of separation between filter wheel and image plane for several values of f-number (f-number is approximately equal to exit pupil distance from image plane divided by exit pupil diameter). This graph clearly shows that for each f-number there is an upper limit on filter wheel distance at which complete color separation can be obtained.

Since overall integrated image plane illumination is proportional to filter efficiency and inversely proportional to the square of f-number, the values plotted in the upper half of Figure 5 have been divided by the square of f-number and replotted in the bottom half of Figure 5. The envelope of the solid lines is shown as a dashed line in this plot, and this represents a measure of the upper limit, as a function of filter distance from the image plane, of the integrated exposure which can be obtained in the image plane with complete color separation.

As has been noted, the graphs plotted in Figure 5 represent upper limits of light efficiency. The geometry upon which they are based (as shown in Figure 1) is appropriate only for a filter wheel of infinite diameter, however. The dependence of filter wheel efficiency on wheel diameter can be seen from the graphs of Figure 6. These have been plotted for the other system parameters as shown in the figure. The maximum efficiencies of 60.8% and 35.4% are shown as the circled points in Figure 5.

It is clear from Figure 6 that filter wheel efficiencies obtainable with reasonable (≈2 inches) wheel diameters are significantly, but not prohibitively, lower than theoretical maxima. In the upper half of Figure 5, brackets have been used to show this
Figure 5. Limiting Efficiency as Function of F-Number and Wheel Distance
Figure 6. Efficiency vs. Wheel Diameter
loss for a number of filter distances and f-numbers. In each case, the top of the bracket indicates filter wheel efficiency with an infinite diameter wheel, and the bottom of the bracket gives efficiency with a wheel having a 2-inch maximum diameter of the filter opening.

Several additional trade-off studies have been performed. The parameters involved in these studies are shown in Figure 7. The location of the scanned raster relative to the filter wheel is shown. The distances from the wheel axis to the center of the raster/optical axis is \( R_1 \) and the angle between the line joining these axes and the horizontal raster direction is \( \delta \). OD is the largest diameter of the filter openings, and ID is their smallest diameter. Exposure efficiency is found by swinging an arc through the filter openings with center at the wheel axis; efficiency is then given by arc length within an opening divided by arc length between two successive corresponding edges of filter openings.

The first trade-off studies involved filter diameter (OD) and number of filters per wheel (which may be any multiple of 3). In Table 2, the trade-off is tabulated at f/4 for a filter distance of 0.9 inch. OD varies from 1.6 to 2.2 inches, and the number of filters from 3 to 9. Exposure efficiency is expressed here as decimal; the value in parentheses is in each case the decimal efficiency divided by the square of f-number, and represents a measure of overall efficiency. In Table 3, corresponding data are plotted for a lens opening of f/2 and a filter distance of 0.2 inch. Examination of these figures shows that efficiency improves with increasing wheel diameter (as shown previously in Figure 6), but over the range of OD covered by the data, the variation is not dramatic. At the 0.9 inch filter distance, efficiency does not change significantly with number of filters, while at the 0.2 inch distance some improvement with decreasing number of filters is seen. Data for six
EFFICIENCY = \frac{A}{A+B}

Figure 7. Filter Wheel Geometry
(6) filters at OD = 1.6 inches and for nine (9) filters at OD = 1.6, 1.8 and 2.0 inches are absent because these configurations are subject to different optimization criteria and are less efficient than direct extrapolation would predict. From Tables 2 and 3 we can conclude that if OD = 2 inches is a reasonable value in terms of space limitations, it is worthwhile considering larger wheels only if substantial (1 or 2 inches) increases in diameter can be tolerated. We can further conclude, with the help of Figure 8 which shows a typical 3-filter design, that efficiency advantages of 3- over 6-filter designs do not outweigh the mechanical disadvantages of complicated filter shape.

**TABLE 2. FILTER DISTANCE 0.9"; F/4**

<table>
<thead>
<tr>
<th>OD</th>
<th>No. of Filters</th>
<th>Eff.</th>
<th>ID</th>
<th>R</th>
<th>P</th>
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</thead>
<tbody>
<tr>
<td>1.6</td>
<td>3</td>
<td>.218 (.014)</td>
<td>.247</td>
<td>.441</td>
<td>63.4°</td>
</tr>
<tr>
<td>1.8</td>
<td>3</td>
<td>.235 (.015)</td>
<td>.512</td>
<td>.555</td>
<td>71.3°</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>.242 (.015)</td>
<td>.293</td>
<td>.523</td>
<td>37.9°</td>
</tr>
<tr>
<td>2.0</td>
<td>3</td>
<td>.252 (.016)</td>
<td>.745</td>
<td>.665</td>
<td>75.1°</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>.257 (.016)</td>
<td>.547</td>
<td>.631</td>
<td>53.7°</td>
</tr>
<tr>
<td>2.2</td>
<td>3</td>
<td>.267 (.017)</td>
<td>.964</td>
<td>.771</td>
<td>77.2°</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>.267 (.017)</td>
<td>.798</td>
<td>.741</td>
<td>61.2°</td>
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<tr>
<td></td>
<td>9</td>
<td>.271 (.071)</td>
<td>.694</td>
<td>.723</td>
<td>38.7°</td>
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Figure 8. 3-Filter Wheel
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<td>0.372</td>
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<tr>
<td>1.8</td>
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<td>0.580 (.145)</td>
<td>0.625</td>
<td>0.579</td>
<td>69.7°</td>
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<td></td>
<td>6</td>
<td>0.529 (.132)</td>
<td>0.394</td>
<td>0.548</td>
<td>41.9°</td>
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<tr>
<td>2.0</td>
<td>3</td>
<td>0.613 (.153)</td>
<td>0.858</td>
<td>0.689</td>
<td>73.3°</td>
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<tr>
<td></td>
<td>6</td>
<td>0.585 (.146)</td>
<td>0.648</td>
<td>0.655</td>
<td>53.2°</td>
</tr>
<tr>
<td>2.2</td>
<td>3</td>
<td>0.634 (.159)</td>
<td>1.082</td>
<td>0.796</td>
<td>75.7°</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>0.618 (.155)</td>
<td>0.893</td>
<td>0.763</td>
<td>59.3°</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>0.593 (.148)</td>
<td>0.788</td>
<td>0.747</td>
<td>38.9°</td>
</tr>
</tbody>
</table>

Tradeoffs were also performed involving filter distance from the image plane and lens f-number, as shown in Table 4. It is clear from this data that the filter wheel should be placed as close as possible to the image plane (as is indicated also by Figure 5). It also appears that there is not a clear choice between f/4 and f/5 at the 0.9 inch filter distance, but design for f/2 at the shorter distances, despite the lower filter efficiencies, is significantly better in terms of overall efficiency.

The compatibility of designs for the same OD and number of filters, but for different filter distances and f-numbers, was also examined. In Figure 9, it is shown that a single control shape in the wheel can be used to accept masks designed for f/4 at 0.9 inch, f/2 at 0.3 inch and f/2 at 0.2 inch. These are three of the designs for which data is given in Table 4.
Figure 9. Mask Shapes
and are those which would probably be used at the designated distances.

TABLE 4. SIX FILTERS; OD = 2"

<table>
<thead>
<tr>
<th>Filter Distance</th>
<th>f/no.</th>
<th>Eff.</th>
<th>ID</th>
<th>R</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>.9</td>
<td>4</td>
<td>.257 (.016)</td>
<td>.547</td>
<td>.631</td>
<td>53.7°</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>.366 (.015)</td>
<td>.667</td>
<td>.659</td>
<td>58.0°</td>
</tr>
<tr>
<td>.3</td>
<td>2</td>
<td>.448 (.112)</td>
<td>.551</td>
<td>.633</td>
<td>51.1°</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.592 (.066)</td>
<td>.681</td>
<td>.663</td>
<td>54.5°</td>
</tr>
<tr>
<td>.2</td>
<td>2</td>
<td>.585 (.146)</td>
<td>.648</td>
<td>.655</td>
<td>53.2°</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>.682 (.076)</td>
<td>.731</td>
<td>.675</td>
<td>54.9°</td>
</tr>
</tbody>
</table>

The effect of arbitrarily increasing the lens opening without changing the filter design was examined for the case of the f/4 opening with filter distance of 0.9 inch. The immediate result is of course that color separation is no longer complete, but the study is complicated by the fact that different points in the image plane are affected differently. Data are plotted in Figure 10 for five image plane locations: the center and the four corners of the raster. Each curve is a plot of instantaneous relative illumination at the image point as a function of filter wheel angular position. For each image point there are three curves: the solid curve for an f/4 illumination cone, the dashed curve for an f/3 illumination cone, and the dot-and-dash curve for an f/2.26 illumination cone. The phase of the filter wheel angular position coordinate.
was established for each point to compensate for the fact that the active scan line passes the different points at different times; the result is that the beginning and end of each curve correspond to the times that the scan line passes the point under consideration. When two curves occur near the beginning or end of the time plotted, it means that the point is illuminated simultaneously through two different filter segments.

Associated with each of the fifteen curves in Figure 10 is a set of three numbers separated by slashes. These three numbers represent, respectively, the integrated exposure of the point under consideration to energy transmitted through the preceding filter, the desired filter, and the following filter. The first and last numbers are therefore a measure of crosstalk, while the middle number is a measure of exposure to desired energy. The numbers used here are on the same scale, and therefore directly comparable, with the numbers for overall efficiency given in parentheses in Tables 2, 3, and 4.

As would be expected, the first and third numbers are always zero for operation at f/4, since the configuration was designed for complete color separation at this lens opening. However, even at f/3, the first and third numbers are significantly non-zero at only one of the five image points, this being the raster corner nearest the filter wheel axis. This means that image plane illumination can be almost doubled (0.028 vs. 0.016) at the cost of only a slight—probably negligible—amount of color crosstalk in one corner of the picture. The effects of further increasing the aperture to f/2.26 are clearly more severe in terms of color crosstalk, but until a definite upper limit on crosstalk is established, it is not certain that even this amount of crosstalk will degrade the color performance significantly.
It should be noted that crosstalk may be reduced by use of smaller mask openings in the two channels which provide excessive radiant input. In that case, the results presented would be representative of red crosstalk into blue and green channels, but would be pessimistic for crosstalk from blue and green channels into the others.

The effects of misplacement of the filter wheel axis relative to the raster (errors in angle \( \Phi \) of Figure 7) were also investigated. For the wheel designed to operate with an f/4 lens opening at a distance of 0.9 inch from the image plane, errors in this angular setting of 10 degrees in either direction produce shading (due to misalignment with the apertures) no greater than 4%, and crosstalk does not exceed 4%. For the filter wheel designed to operate with an f/2 lens opening at a distance of 0.2 inch from the image plane, 10 degree misalignments may produce shading errors as large as 15% and crosstalk as large as 10%; but for 5 degree errors in either direction neither of these errors will exceed 5%.

C. FINAL DESIGN

As will be shown in the lens selection/interface section, the effective "C" mount separation can be reduced to 0.6". The closest anticipated separation will be established by the sensor faceplate thickness with added mechanical clearance. For a silicon sensor, the effective optical distance from faceplate to focal plane is 0.113". A design value of 0.15" was chosen to provide mechanical clearance.

The filter wheel aperture dimensions were designed to accommodate the closest anticipated wheel/sensor spacing; mask overlays will provide the required shaping for increased spacing and/or transmission trimming.
Masking aperture shapes and geometry were calculated for the two limiting cases. Figure 11 shows the required shape for condition one (0.15" spacing). The calculated offset angle between the wheel axis and the optical axis is 59.1°, and the offset dimension is 0.750". The angular separation between the upper and lower boundaries is 41.85°; therefore, the optical efficiency can be calculated by comparison to the maximum aperture (60°):

\[
\frac{41.85}{60.00} \times 100 = 69.75\% 
\]

The corresponding shape for condition two (0.6" spacing) is shown in Figure 12. The offset dimension (0.750") is unchanged; however, the required offset angle is now 64.9°. The angular efficiency for this case is:

\[
\frac{22.66}{60.00} \times 100 = 37.8\% 
\]

Since the offset angle is different for the two cases (and for any other case between these two limits) an adjustment method must be provided. The housing design has been made circular to permit rotational adjustment after seating the "C" mount thread. This same adjustment can be used to accommodate the required offset difference angle by aligning the front housing to a different reference mark. For the optimized interface situation, it is assumed that the front housing will be fitted with a quick-disconnect bayonet mount, the separation distance will be fixed, and therefore no angular offset adjustment is required.

An additional consideration is the relative phasing of the filter wheel and the mask shape. The filter wheel opening, shown in Figure 13, was calculated to encompass the mask shape for the two limiting cases. The horizontal line at the top
Figure 12. Mask Aperture, 0.6" Spacing

Dashed curve is obtained from corresponding solid curve by 22.66° rotation.

Rotate 8.26° clockwise to fit wheel drawing.

Raster angle is 64.9°
Distance is .750".
Figure 13. Filter Wheel Aperture
of each mask is designed to be parallel to the scan line at the top of the raster. To insert the 0.15" mask in the wheel aperture, while maintaining nominally symmetric clearance between the mask aperture and the wheel aperture, its reference axes are rotated 2.46° clockwise. This establishes a reference location for the wheel phase detector. If the housing (which contains the phase detector) is now rotated, to adjust the angular offset corresponding to a different aperture/sensor spacing, then the relative phase with respect to the horizontal mask line is similarly rotated.

In turn, this rotation could be corrected for by requiring a different nominal position of the wheel phase detector. Since the phase detector position is adjustable to compensate for system tolerances, additional adjustment range could be provided. An alternate method is to provide the compensating adjustment in the initial insertion of the aperture mask. This eliminates the requirement for readjusting the nominal phase detector position. Following this procedure, the 0.6" mask axes are thus rotated by $2.46^\circ + (64.9^\circ - 59.1^\circ)$, or $8.26^\circ$ clockwise. Figures 14 and 15 show the two filter masks inserted in the filter wheel openings at their respective angles.

In addition to the nominal mask shapes shown, additional masks are provided, for which the upper and lower boundaries are brought closer together while maintaining the same relative shape. This permits fine trimming of the relative sensitivity of each of the three spectral bands. Coarse balance is provided by using neutral optical density filter segments located in the rear face of the filter wheel.

**D. LENS AND "C" MOUNT CONSIDERATIONS**

The basic specification for a "C" mount lens interface is defined in USA STD PH22.76-1960. The parameter of importance
Figure 14. 0.15" Mask, Inset in Wheel Aperture
Figure 15. 0.6" Mask, Inset in Wheel Aperture
For this application is the focal distance from the mounting flange to the focal plane which is specified as 0.690° (17.5 mm). Therefore, any camera designed to accept a standard "C" mount lens will have its front flange seating surface set at this exact dimension from the sensor focal plane.

When we attach a color wheel module to such a camera, it must lie forward of the 0.69" dimension. Since many existing cameras do not include provisions for axial adjustment of the sensor focal plane we conclude that the lens used with such a system must be such as to provide a mechanical back focal length of 0.69" plus the thickness of the module. This represents a significant constraint in the choice of a suitable available lens. Further, as discussed in depth in the filter wheel design section of this report, increasing the filter aperture to sensor focal plane spacing imposes a decreasing limit on achievable optical throughput efficiency.

The program objectives to be considered in the lens selection are as follows:

<table>
<thead>
<tr>
<th></th>
<th>IRIS</th>
<th>F/2 to F/22</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Focal Length</td>
<td>12 MM to 75 MM (9° - 56° FOV)</td>
</tr>
<tr>
<td>b</td>
<td>Focus</td>
<td>1 Ft to Infinity</td>
</tr>
<tr>
<td>c</td>
<td>Format</td>
<td>0.625&quot; Diagonal</td>
</tr>
<tr>
<td>d</td>
<td>Back Focal Distance</td>
<td>&gt; 1.5&quot;</td>
</tr>
<tr>
<td>e</td>
<td>Controls</td>
<td>Adaptable for Remote Drives</td>
</tr>
<tr>
<td>f</td>
<td>Construction</td>
<td>Space Qualifiable Design</td>
</tr>
<tr>
<td>g</td>
<td>Interchangeability</td>
<td>Lens/Wheel Assembly With Other Commercial Lenses</td>
</tr>
</tbody>
</table>
A survey of existing lens designs was performed to permit selection of an optimum match between the objectives and available designs. The assembled lens data is shown in Table 5. The Angenieux 13-78 mm lens initially appeared to be an optimum selection in terms of parameter compatibility. Further investigation showed, however, that this design is not yet in full production. An engineering model and two prototypes have been delivered for evaluation. Within the next year tooling will be completed and production models made available. This was not compatible with the present program delivery requirements; however, this lens should be considered for future applications. The best alternate selection appears to be the Angenieux 15-90 mm lens which is similar in design to the 12.5-75 mm version which was space qualified on the GCTA program.

In adapting the finished design of the field sequential lens assembly to future space cameras, it can reasonably be anticipated that they can be designed with the sensor mounted flush with the front camera flange. This allows maintaining close sensor to filter aperture spacing (with attendant increase in throughput efficiency), and relaxes the lens back focal length requirement. Since we desire to use the assembly initially with unmodified "C" mount designs, we have explored means to minimize the effects of the 0.69" flange to focal plane distance. Consider Figure 16 which shows the geometry involved. Rays "A" and "B" represent the limiting rays from the exit pupil of the lens as illustrated in Figure 1 (for simplicity of illustration, ray "A" is shown here horizontal; this does not affect the results). If we insert in the optical path a parallel face glass plate (Item 1) with the index of refraction \( n' \), incident rays will be deviated according to their angle of incidence. Ray "B" shown dashed represents the undeviated path without the glass plate. Ray "C" shows the path for a similar ray brought to focus at point \( P \), with the glass plate inserted.
<table>
<thead>
<tr>
<th>Focal Range</th>
<th>Lens Manufacturer</th>
<th>Magnification Ratio</th>
<th>Field Angle</th>
<th>Near Focus</th>
<th>Weight</th>
<th>Dia x Length</th>
<th>PV4 Angle</th>
<th>Diameter</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 - 60</td>
<td>Angenieux</td>
<td>1.0</td>
<td>41° - 11°</td>
<td>48</td>
<td>1 lb 1 oz</td>
<td>2.5 - 22</td>
<td>56° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
<tr>
<td>25 - 125</td>
<td>Canon</td>
<td>1.6</td>
<td>58° - 9°</td>
<td>60</td>
<td>2 lb 5 oz</td>
<td>2.8 - 22</td>
<td>53° - 6°</td>
<td>1.6 - 22</td>
<td>3 oz</td>
</tr>
</tbody>
</table>
### TABLE 5. LENS SELECTION (Continued)

<table>
<thead>
<tr>
<th>Format</th>
<th>Focal Range</th>
<th>£.s.</th>
<th>Mfr.</th>
<th>Field Angle</th>
<th>Near Focus Inches</th>
<th>Weight</th>
<th>Dia x Length Inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>VID</td>
<td>30 - 150</td>
<td>2.7 - 22</td>
<td>Wollensak</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VID</td>
<td>16 - 80</td>
<td>2.0 - 27</td>
<td>Schnieder</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VID</td>
<td>20 - 100</td>
<td>2.4 - 100</td>
<td>Schnieder</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VID</td>
<td>25 - 150</td>
<td>3.5 - 22</td>
<td>Elgeer</td>
<td></td>
<td></td>
<td>3½</td>
<td>12 oz</td>
</tr>
<tr>
<td>VID</td>
<td>20 - 80</td>
<td>1.9 - 22</td>
<td>Elgeer</td>
<td></td>
<td></td>
<td>2½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>16 - 160</td>
<td>1.6 - 22</td>
<td>TTH</td>
<td></td>
<td></td>
<td>17½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>16 - 160</td>
<td>3.2 - 22</td>
<td>TTH</td>
<td></td>
<td></td>
<td>5½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Varitol 20</td>
<td>2.2 - 22</td>
<td>TTH</td>
<td></td>
<td></td>
<td>Large</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>20 - 80</td>
<td>2.5 - 22</td>
<td>Angenieux</td>
<td>43 - 12</td>
<td>48</td>
<td>14 oz</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>15 - 90</td>
<td>2.5 - 22</td>
<td>Angenieux</td>
<td>55 - 10</td>
<td>48</td>
<td>1½</td>
<td>7 oz</td>
</tr>
<tr>
<td>V</td>
<td>12 - 120</td>
<td>2.6 - 22</td>
<td>Angenieux</td>
<td>67 - 7° 30</td>
<td>30</td>
<td>3½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>15 - 150</td>
<td>1.9 - 22</td>
<td>Angenieux</td>
<td>55°-6°</td>
<td>60</td>
<td>2½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>25 - 250</td>
<td>3.2 - 22</td>
<td>Angenieux</td>
<td>35 - 3° 30</td>
<td>60</td>
<td>6½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>15 - 300</td>
<td>4.5 - 22</td>
<td>Angenieux</td>
<td>55 - 3°</td>
<td>60</td>
<td>4½</td>
<td>7 oz</td>
</tr>
<tr>
<td>V</td>
<td>13 - 78</td>
<td>2.2 - 22</td>
<td>Anvenieux</td>
<td>68°- 13°</td>
<td>24</td>
<td>3½</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>18 - 130</td>
<td>2.2 - 22</td>
<td>Zoomar</td>
<td></td>
<td>48</td>
<td>4½</td>
<td></td>
</tr>
</tbody>
</table>
Figure 16. Geometry With Included Glass Plate
We calculate the effective length \( L' \) as follows:

\[
H = L \tan \phi \quad (1)
\]

\[
H = L' \tan \phi \quad (2)
\]

so \( L' = \frac{L \tan \phi}{\tan \phi} \quad (3) \)

\[
L' = \frac{L \sin \phi}{\sin \phi} \frac{\cos \phi}{\cos \phi} \quad (4)
\]

Using Snell's Law \( n \sin \phi = n' \sin \phi' \),

\[
L' = L \frac{n}{n'} \frac{\cos \phi}{\cos \phi'} \quad (5)
\]

For small angles of \( \phi \) (< 20°), \( \frac{\cos \phi}{\cos \phi'} \) is greater than 0.97 and can be approximated by 1.0. Then Equation (6) can be simplified to:

\[
L' = L \frac{n}{n'} \quad (7)
\]

Typical optical glass index of refraction \( n' \) is 1.5. Thus, the effective length \( L' \) with the plate installed is \( L/1.5 \) or \( 2/3 \) of the length \( L \) without the plate. The insertion of the plate has two beneficial results for this application. First, the filter aperture position for a given mechanical distance \( D \) is effectively reduced by \( L/3 \). This permits designing a smaller masking width, thus increasing the through-put efficiency. Second, the effective mechanical focal distance \( F \) is increased by \( L/3 \), thus providing increased clearance for the mechanical components of the color filter wheel assembly.
This technique was employed in the final configuration of the module assembly. A compensating glass plate, 0.650" thick, with index of refraction of 1.523 was used to provide an effective separation (filter aperture to focal plane) of 0.6".

E. MECHANICAL DESIGN

Two basic mechanical concepts were studied during this program; namely, an edge driven color wheel using a "cartridge" type motor, and an integral rotor-wheel using "pancake" motor. Investigations have been pursued to establish the tradeoffs in selecting an optimum approach. Initially, the pancake motor system appeared to have the greatest number of advantages. Subsequent continuation of the investigations led to the recommendation of the edge driven system as representing the more optimum implementation. Layout drawings for both systems were generated. The pancake motor concept layout is shown in Figure 17, while the cartridge motor concept is shown in Figure 18. A sample of an existing design pancake motor was obtained from the vendor (Schaeffer Magnetics) for evaluation of magnetic interference and interface effects.

The relative comparison of significant elements between the two systems is as follows:

1. Pancake Motor System
   a. Advantages
      • Minimum number of bearings (2)
      • No gear passes
   b. Disadvantages
      • Significant magnetic interference with sensor (can be shielded)
Figure 17. Pancake Motor Concept Layout
Figure 18. Cartridge Motor Concept Layout
Possible magnetic interference if magnetic wheel position pickup used.

- Inflexible wheel diameter (constrained to available motor diameters).
- Large diameter of stator predicts greater weight.
- High motor vendor start up and repeat order unit cost.

2. Cartridge Motor System
   a. Advantages
      - No magnetic interference
      - Flexible wheel diameter (easily changed by new gear blank).
      - Lower weight
      - Motor start-up and repeat order unit cost significantly lower.
   b. Disadvantages
      - Two additional bearings
      - One gear pass

In addition to the above items, the fixed stator length of the available pancake motor is somewhat greater than the anticipated path length of the cartridge system. In turn, this tends to restrict the lens selection in terms of back focal length, although acceptable lenses have been identified. Operating power measurements on a sample pancake motor have also been somewhat greater than the equivalent cartridge.
motor, although this is not thought to be fundamental to the motor design. Experimental application of magnetic shielding to the pancake motor has reduced the interference effects to indiscernible levels; however, the cost is increased weight in the assembly.

Based on the above consideration the cartridge motor system was chosen as the prime candidate, and detailed design is based on this approach. The cartridge motor concept layouts show that the basic approach is feasible. If future applications were to justify the design expenditure required to overcome the shortcomings noted, it would be a viable approach.

Key items of the pancake assembly shown in Figure 17 are as follows:

1. Main Housing
2. "C" Mount Adapter
3. Filter Wheel
4. Hysteresis Ring Rotor
5. Motor Stator
6. Lens Mounting Flange

Items 1, 2, and 3 are similarly identified for the cartridge layout in Figure 18.

The angular position of the starting thread of the "C" mount is not controlled by specification, therefore, both layouts show a means for rotating the color wheel axis about the optical axis after seating the mating "C" mount thread. If the basic design is extended for future applications to a bayonet or other fixed position mounting attachment, the adjustment feature can be readily deleted without a major design change.
F. MOTOR SYNCHRONIZATION AND PHASING

The lens assembly is required to interface with standard cameras. It can be expected that such cameras can furnish "V" or "H" rate signals for motor sync reference but will not include provisions for adjusting the relative phase of the motor drive and a vertical field. Before proceeding with a final motor selection in terms of operating frequency and number of poles, we examined techniques for motor drive phasing to determine if any bounds need be placed on the selection.

Motor phasing techniques already developed, such as were used in the GCTA cameras (Contract NAS 9-11260) utilize a digital phase shift system to compare and adjust the relative phase of the color wheel and vertical blanking. When the motor sync system is included with the camera sync generator, the implementation was found to be straightforward for a particular value of motor frequency and number of poles (420 Hz and 8, respectively). For the present program the motor phasing system must be considered part of the lens assembly, operable from only the "V" or "H" reference.

The specific pancake motor under consideration was used as a test case; however, general conclusions are drawn from the results. The motor characteristics are:

- 36 Poles
- 180 Hz Input
- 600 RPM

1 pole pair = \frac{360^\circ}{18} = 20^\circ \text{ shaft rotation}

1 pole pair = 360^\circ \text{ electrical drive shift}
Using the original GCTA phasing technique, 90° electrical shift would provide:

\[
\frac{20}{\frac{360}{90}} = 5° \text{ position correction}
\]

Assuming a six-segment wheel with phase references 180° apart, correction speed for a maximum initial error condition of 180° would be:

\[
\frac{180°}{2 \times 5° \times 10 \text{ RPS}} = 1.8 \text{ seconds}
\]

The original GCTA design utilized an 8 pole, 6300 RPM, 420 Hz motor with a 10.5/1 gear reduction. This design required 4.2 seconds for phase correction; however, the granularity of each correction step was 2.1° for a 90° shift of the voltage drive. The correction granularity represents a limit on the allowable unused area between wheel segments, and can be reduced by decreasing the amount of electrical shift for each correction step.

The shift is reduced from 90° to 45° by correction at double the original frequency. The tradeoff is in phase correction accuracy versus correction speed, which are in inverse ratio.

In selecting the sync rate to be used in the motor phase comparison, we must consider that the required motor drive frequency, while coherent with both "V" and "H" rates, is not necessarily an integral sub-multiple of the "H" rate. Therefore, a locked oscillator must be used to provide the reference frequency. Since the "V" rate is required for use in the wheel phase comparator it can also be used for the locked oscillator reference. Thus, only a single sync signal need be routed from the camera to the lens assembly.
A block diagram of the selected motor phasing system is shown in Figure 19. Required input signals are the camera "V" rate reference and the wheel position phase reference. The frequency dividers shown are for a 120 Hz motor. Other combinations can be accommodated by changing the division ratio. As shown, the pulse snatching for phase correction is performed at twice the minimum frequency, to provide 2.5P steps for each correction increment.

Using a cartridge motor and a 3/1 gear reduction at the rim drive, a motor speed of 1800 RPM is required. If the motor is designed with 8 poles, the input frequency is 120 Hz, and the block diagram is identical to Figure 19. If a 12 pole design is used, the input frequency required is 180 Hz. This can be achieved simply by changing divider "A" in the block diagram from a \( \div 3 \) to a \( \div 2 \). Similarly, other combinations can readily be accommodated by this system.

The detailed logic diagram for the color wheel motor control system is shown in Figure 20 and the related timing diagram is shown in Figure 21. Implementation of the logic functions was accomplished using CMOS logic elements to minimize power consumption.

With regard to the wheel position sensor, a number of different techniques were considered, as follows:

- **Optical**
  - IR emitter and photodetector.

- **Magnetic**
  - Hall effect packaged with amplifier.

- **Magnetic**
  - Hall effect sensor and amplifier.

- **Magnetic**
  - Permanent magnet - with induction coil - available with digital signal conditioning (di-Mag).
Figure 19. Color Wheel Logic Block Diagram
Figure 20. Color Wheel Motor Detailed Logic
Figure 2L. Color Wheel Motor Timing Diagram
The optical technique has previously been used to perform this function on the GCTA design. The most direct application is to place the source and sensor on opposing faces of the wheel. Since in the present design we are attempting to minimize the sensor/wheel spacing (to maximize throughput efficiency), it is undesirable to locate any portion of the phasing detector behind the wheel. It might be possible to overcome this problem by using a reflective optical technique; however, this is expected to be difficult to implement.

Hall effect devices have been applied as magnetic position indicators in brushless dc motor applications where the magnetic pole piece is inherent in the motor rotor. This technique could be applied here by installing a magnet near the perimeter of the wheel. Recently developed monolithic integrated circuits (e.g., Sprague ULN 3000M) contain a silicon Hall generator and integral amplifier in one small package. However, the Hall sensitivity of silicon is very low (33 mV/kilogauss) and an operating magnet strength of about 500 gauss is required. In addition to the problem of achieving this field strength in a small magnet, it raises the possibility of generating interference in the camera sensor. A GaAs Hall generator is approximately 100 times as sensitive as the silicon device; it could therefore be used with a proportionally smaller magnet. Such a device is not available in a single package; a separate amplifier would be required.

The final method considered is also magnetic, but requires only a ferrous metal perturbation (such as a soft iron slug) to generate an output. It utilizes a small permanent magnet with a concentric induction coil. Passage of the ferrous metal past the pole piece creates an output by induction. Such a device, utilized in the final design, is available in a compact package with included digital interface conditioning under the trade name "Di-Mag", and appears to provide the greatest design freedom.
G. COLOR FILTER SELECTION

1. Introduction

The prototype lens assembly will be demonstrated with the MTI-55 TV camera employing a silicon vidicon. It is anticipated that the bulk of the demonstration as well as evaluation testing will be conducted in an indoor laboratory area where artificial lighting will be employed. This may well correspond to real world Shuttle usage where dark side of the earth operations will employ artificial lighting to permit some measure of direct observation as well as TV coverage.

When a combination usage is planned, a single, properly shaped, trim filter can correct a natural to artificial (or vice versa) condition. Since the case of artificial illumination is expected to require greatest overall system sensitivity, we used that case to compute the spectral filter characteristics, using a silicon target sensor. Provision is included for adding a separate color trim filter, in a holder attached to the front of the lens, to correct the relative R-B-G spectral sensitivities when natural illumination is used. The range of achievable individual filter passbands is large; however, the gamut of existing multi-layer film designs is considerably more restricted. The design is examined within the practical limits of existing interference filters.

Experimental determination of the optimum color wheel filter sequence was established early in the development phase of field sequential television in terms of the affect of image sensor lag. The optimum sequence was found to be R-B-G; that sequence was used for the present modular color wheel assembly development.

Complete details of the spectral filter tradeoffs are contained in the second Engineering Design Report previously submitted under this contract. Salient details are summarized here.
2. Reference Computation

In the process described in the following paragraphs, tungsten illumination at 3000°K is assumed. The colorimetry calculations then consist of cascading the spectral characteristics of tungsten, the sensor spectral responsivity, and all filters employed for spectral separation and ir rejection in each channel. Factors not considered but certainly contributory to color performance in a field sequential system are: incomplete erasure of sensor data in a single (1/60 second) scan due to scan line separation, and inherent retentivity of the target after scanning by the electron beam, i.e., lag. These factors, depending on the effective cross section of the electron beam and the inherent characteristics of the silicon target, may be significant but are more simply treated experimentally.

A colorimetry reference was established by computing the spectral sensitivity of a high quality RCA broadcast camera. This camera employs three Plumbicons and is set-up for indoor operation with tungsten illumination, about 3000°K color temperature.

Spectral separation in this broadcast camera is accomplished with a dichroic prism. The overall spectral response for the three channels of this type camera is shown in Figure 22, where the peak response is normalized.

The numbers appearing under the curves of Figure 22 are normalizing factors required to provide equal peak response. Of course as adjusted in the camera for equal video amplitude on a neutral scene, normalization will require equal areas under the curves. Note that the green channel will have maximum and the blue channel minimum sensitivity.
Figure 22. Overall Spectral Characteristics of Broadcast Camera
3. Color Filters for the Silicon Sensor

The RCA 4532 silicon vidicon has a spectral responsivity that is substantial over the entire visible spectrum and extending into the near IR. When cascaded with the 3000°K tungsten lighting the spectral response shows a continued rising characteristic towards the near IR region.

As a starting point the GCTA color wheel filters, cascaded with the 650 nanometer trim filter and IR rejection filter used on GCTA (RCA assembly drawing 2269728), were cascaded with the silicon at 3000°K response. As a direct result of the rising IR characteristics, the colorimetry of this type filter wheel, as used with silicon and artificial illumination, is considered unsatisfactory for several reasons. The blue channel response is too narrow causing a severe loss in sensitivity as well as poor blue color reproduction. The red response is too wide with excessive green channel overlap again leading to poor colorimetry.

As the next step at arriving at satisfactory colorimetry the red and blue filter characteristics were modified and a different IR rejection filter was assumed. The modified red channel was computed for a 590 nanometer short wavelength Schott glass, and a Fish-Schurman (F-S) 650 trim filter and Schott 1 millimeter HA-11 IR absorbing glass for long wavelength shaping. The characteristic of the IR absorption filter is particularly important when a silicon sensor is employed because of the extended long wave response of this type vidicon. The HA-11 response is less than 3 percent in the 800 to 900 nanometer range.

The computed blue channel response consisted of a F-S 495-C in cascade with a F-S ML-3025S for trimming. The HA-11 was not included in this computation since its effect on the blue
channel is not significant. The 1 MM HA-11 was used for the green computation since it provides some band shaping in the long wavelength portion of the green spectrum.

The composite curves obtained were considered to be quite satisfactory from the colorimetry standpoint. Red-green crossover is comparable to that achieved with the high quality broadcast camera. The blue channel is somewhat narrow but is in the acceptable range. Normalizing factors (for equal peak response) are modest compared to that obtained with the original GCTA filter. Values of 1.0, 1.09, and 2.30 for the red, green, and blue channels respectively are indicative of the relative channel gain required, although adjustment will be made for equal areas rather than equal peak response.

As a final step in the filter specification process, an attempt was made to reduce the number of individual elements required. For this reason the 650 trim assumed for use in the red channel was replaced with the ML 3025-S used with the blue filter. Since this has the effect of extending the red response into the long wavelength end of the spectrum, the 1 MM HA-11 was replaced with the somewhat narrower 2 MM HA-11. The original GCTA green filter (RCA 2262639) was maintained. The overall spectral response of the camera is then as shown in Figure 23.

Note that the overall response is quite similar to that shown in Figure 12 although some slight narrowing of the blue channel has resulted and the red channel is somewhat more asymmetrical. The peak response numbers are slightly closer together than before with the green showing the highest sensitivity. When the area normalization process is taken into account the red channel is most sensitive, with the green requiring 1.11 times and the blue requiring 1.97 times the gain of the red.
Figure 23. Final Version of Silicon Sensor Response With Revised Spectral Filters and 30°0°K Illumination
The final filter specification then consists of a filter wheel with a red channel of Schott 570 glass, a green channel as specified for GCTA (RCA 2262639), and a blue channel of F-S 495-C. The specification control drawings for these filters (SK-2277732, 33, and 34) are included in the drawing section. The lens path will employ the F-S 3025-S trim filter and the 2 MM HA-11 ir rejection filter, (SK-2277746) also included in the drawing section. In addition, the red and green filter-wheel segments will incorporate .2 neutral density filters to aid in sensitivity normalization.

Further adjustment of relative gain is obtained by trimming the individual filter-wheel openings. (The trimming process is described in Section B of this report). If all filters are nominal the trimming adjustment will require a reduction by a factor of .81 for the red channel and .90 for the green channel.

H. WEIGHT ESTIMATE

The major component pieces of the color wheel module assembly are listed in Table 6. The associated dimensional drawings were used to calculate the predicted weight of each part by dividing them into geometric shapes. The calculated values are shown in Table 6, and are compared to measurements after fabrication. The front and rear housings will be fabricated of aluminum for the engineering model based on finish and handling considerations. The flight equivalent parts can be fabricated of magnesium with an attendant weight reduction of 35 percent.

I. PERFORMANCE DATA

After completion of fabrication and assembly of the color wheel module, a detailed test program was conducted to provide verification of performance parameters and/or comparison to the program objectives. Certain parameters, e.g., color crosstalk,
# TABLE 6.  WEIGHT BREAKDOWN

<table>
<thead>
<tr>
<th>P/N</th>
<th>ITEM</th>
<th>LABS (UNIT)</th>
<th>LABS SUB-TOT</th>
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<tr>
<td>2277726-1</td>
<td>Lens Retainer</td>
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<td>.0858</td>
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<td>Al</td>
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<td>2277718-1</td>
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<td>.0441</td>
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Color Wheel Assembly Total  1.2629
Lens (6 x 15B)  1.167 lbs
Remote Function (100 grams each)  .661 lbs
are associated solely with the field sequential system. These were measured with the color wheel module installed. Other parameters, such as resolution, are common to the black and white system. These were measured with and without the color wheel module installed, and comparative data obtained. A test procedure (RCA TP-2279979) was generated to specify test methods and record data. The measured performance shows that the desired objectives have been satisfactorily achieved.

The more important data items are summarized below:

a) Resolution

Data was measured with the zoom lens attached directly to the camera, and then with the filter wheel module inserted and operating. The results are shown in Table 7.

<table>
<thead>
<tr>
<th>RES LINE NO.</th>
<th>B&amp;W</th>
<th>R-1</th>
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The deviations are negligible and within measurement accuracy, verifying that no resolution degradation is introduced by the filter wheel module.

b) Shading

Data was similarly obtained, with and without the filter wheel module. The results are shown in Table 8.
TABLE 8. SHADING DATA

<table>
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<th>POINT OF MEASUREMENT</th>
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<tr>
<td>20% From Top</td>
<td>32</td>
<td>32.9</td>
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<tr>
<td>50% From Top</td>
<td>25.7</td>
<td>25.2</td>
</tr>
<tr>
<td>80% From Top</td>
<td>37</td>
<td>35.9</td>
</tr>
<tr>
<td>Vertical</td>
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Again, negligible change in shading performance is noted.

c) Video Field Balance

To verify the adjustment (trim) balance between the individual spectral filters, the data shown in Table 9 was obtained. The measurements confirm the ability of the filter aperture trim masks to be used in setting individual field signal amplitudes.

TABLE 9. VIDEO BALANCE

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<th>FIELD</th>
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<tr>
<td>R 1</td>
<td>0.98</td>
<td>2</td>
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<tr>
<td>B 1</td>
<td>0.97</td>
<td>3</td>
</tr>
<tr>
<td>G 1</td>
<td>1.01</td>
<td>1</td>
</tr>
<tr>
<td>R 2</td>
<td>0.99</td>
<td>1</td>
</tr>
<tr>
<td>B 2</td>
<td>0.97</td>
<td>3</td>
</tr>
<tr>
<td>G 2</td>
<td>1.02</td>
<td>2</td>
</tr>
</tbody>
</table>
d) Jitter

The jitter caused by the rotation of the filter wheel is a measure of the parallelism achieved in assembling the individual filter segments to the filter wheel. An objective specification of 0.25 µs was established. Measurements showed no detectable jitter for five of the six segments. The sixth one measured 0.02 µs which is well within specification.

e) Filter Wheel Efficiency

The filter wheel efficiency was measured by recording the video signal for a particular color segment, with and without the wheel rotating. The previously calculated value for the 0.6" spacing case was 38 percent. The measured value was found to be 44 percent, slightly better than predicted. This difference may be attributable to tolerances in the mask fabrication, although the exact cause could not be determined.
SECTION III

ENGINEERING DRAWINGS

The following pages contain copies of the applicable engineering drawings for the various components and assemblies which constitute the color lens assembly and its associated control box.
NOTES

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REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

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TOLERANCES ON FINISHED DIMENSIONS UNLESS OTHERWISE SPECIFIED

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ANGULAR DIMENSIONS ±1/2°

SEE RCA PURCH SPEC FOR STOCK TOL

FIRST MADE FOR

NEXT ASSY USED ON

22636 41-501 COLOR CAM.
| CONTR. NO. | RADIO CORPORATION OF AMERICA  
|           | CAMDEN, N.J.  
|           | ASTRO ELECTRONIC DIV, PRINCETON, N.J. |
| MATERIAL  | BUSHING, THRUST |
| QTY REQ'd | 501 |
| QTY RECD  | 501 |
| ITEM NO.  | 5604 |
| CODE IDENT NO. | 49671 |
| SIZE      | B 1974052 |
| QTY      | 1 |

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- **CL.303 Cond. A 2010521-50**
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- .200 Dia.

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- **160070**

**Drawn Date:**

- **12-69**

**Checked Date:**

- **07-69**

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**Weight:**

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* WITHOUT FLANGE

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2. BEARINGS SHALL BE WET VACKOTE LUBRICATED PER BALL BROS RESEARCH CORP PROCESS BPS15-1 USING LUBRICANT 36236. BEARINGS SHALL BE STORED IN SEALED CONTAINERS UNTIL USE.
3. MARK PART NO. RCA 1974400 & APPROPRIATE DASH NO. ON CONTAINERS.
4. LUBRICATE USING G300. SILICON GREASE. GREASE SHALL UNIFORMLY FILL MIN 20% MAX 30% OF THE VOID VOLUME WITHIN THE BEARING. BEARINGS SHALL BE STORED IN SEALED CONTAINERS UNTIL USED.

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**Reproducibility of the Original Page is Poor**

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**First Made For**

NEXT ASS'Y USED ON COLOR CAMERA

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**Contract N**

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**Commodity**

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**Drawn By**

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**Checked By**

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**Design Act**

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**DRAWN**

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**CHECKED**

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**CODE IDENT NO.**

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**Bearing, Lubricated**

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**SHEET 1 OF 1**
NOTES:
1. MATERIAL: OPTICAL CROWN GLASS (C-1)
   RETICLE GRADE, NOMINAL INDEX OF 1.523.
2. SURFACES QUALITY SHALL BE 60-40
   OR BETTER, FACES SHALL BE FLAT
   TO GRINGS, FACES SHALL BE
   PARALLEL TO 3 MIN/ARC,
3. APPLY ANTI-REFLECTION COATING
   TO SURFACES A&B.

FOLDOUT FRAME } PRINTING PAGE BLANK NOT FILMED

REVISION STATUS WHERE MORE THAN ONE SHEET

SH REV SH REV

THD DATA TO BE INTERPRETED USING
NBS HDBK H28 AND MIL-STD-9

INTERPRET DIMENSIONS AND
TOLERANCES PER ANSI Y14.5-66

UNLESS OTHERWISE SPECIFIED
THE SURFACE FINISH OF
MACHINED PARTS SHALL NOT
EXCEED A MAXIMUM READING
125/PER ANSI STD B46.1 — 1962

SHUTTLE T.V.

RCA COMMODITY CODE:

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FIRST APPLICATION

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**MATERIALS AND SPECIFICATIONS**

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING.

**DESIGN ACTIVITY**
- M.C. TO: June 5, 1962
- M.C. FROM: Electronics Division, Princeton, N.J. Plant

**DRAWING**
- CONTRACT NO.: NAS-1368

**SPECIFICATIONS**

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**TOLERANCES ON DRAWN DATE**
- ABOVE 24: ±.05
- 2 TO 24: ±.03
- 0 TO 2: ±.02

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RCA COMMODITY CODE:

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<th>REV</th>
</tr>
</thead>
</table>

THD DATA TO BE INTERPRETED USING NBS HDBK H28 AND MIL-STD-9
INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5-66

UNLESS OTHERWISE SPECIFIED THE SURFACE FINISH OF MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING \( \pm 0.005 \) PER ANSI STD B46.1 — 1962

\( \sqrt{.015} \)

SECTION A-A

SK2279979 SHUTTLE T.V.

NEXT ASSY USED ON FIRST APPLICATION

ANGULAR DEGREES

MATERIAL
<table>
<thead>
<tr>
<th>CODE IDENT</th>
<th>IDENTIFYING NO.</th>
<th>DESCRIPTION</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR</td>
<td>1980032-1</td>
<td>PASSIVATED DIP</td>
<td></td>
</tr>
<tr>
<td>AR</td>
<td>2010521-80</td>
<td>ST. STL ROD .656 DIA.</td>
<td>QQ-S-764a</td>
</tr>
</tbody>
</table>

MATERIALS AND SPECIFICATIONS

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING

DIMENSIONS

<table>
<thead>
<tr>
<th>UNITS</th>
<th>TOLERANCES</th>
<th>2 PLACE DECIMALS</th>
<th>3 PLACE DECIMALS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UP TO 6</td>
<td>± .02</td>
<td>± .010</td>
<td></td>
</tr>
<tr>
<td>ABOVE 6 to 24</td>
<td>± .03</td>
<td>± .015</td>
<td></td>
</tr>
<tr>
<td>ABOVE 24</td>
<td>± .06</td>
<td>± .020</td>
<td></td>
</tr>
</tbody>
</table>

ANGULAR DIMENSIONS ± 1/2°

MATERIAL: SEE TABLE

CONTRACT NO. NA59-13688

REL

RCA CORPORATION - NEW YORK, NY

ASTRO-ELECTRONICS DIVISION, PRINCETON, N.J. PLANT

BUSHING, THRUST

B 49671 SK2273306

SCALE 4:1 WEIGHT 2.6 GR. SHEET 1 OF 1
NOTES:
1. ALL CAPACITORS ARE IN MICROFARADS
2. ALL RESISTORS ARE IN OHMS

THD DATA TO BE INTERPRETED USING NBS HDBK H28 AND MIL-STD-9

INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5-66

UNLESS OTHERWISE SPECIFIED THE SURFACE FINISH OF MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING 125 PER ANSI STD B46.1 — 1962

RCA COMMODITY CODE:

NEXT ASSY

USED ON

FIRST APPLICATION
NOTES:
1. ALL RESISTORS VALUES ARE IN OHMS, ±1%
2. ALL CAPACITORS ARE IN MICROFARADS
   ADJUST R7 FOR 10.0 VOLTS AT E3

REPRODUCIBILITY OF THE ORIgINAL PAGE IS POOR

REVISION STATUS
WHERE MORE THAN ONE SHEET

THD DATA TO BE INTERPRETED USING NBS HDBK H28 AND MIL-STD-9
INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5-66

RCA COMMODITY CODE:

UNLESS OTHERWISE SPECIFIED THE SURFACE FINISH OF
MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING
\[ \frac{125}{1000} \] PER ANSI STD B46.1 -- 1962

QTY REQD PER DASH NO.

CODE

IDENT

NEXT ASSY
USED ON
FIRST APPLICATION

MATERIAL: SEE

7059

1417-3 (4-71)
<table>
<thead>
<tr>
<th>MATERIALS AND SPECIFICATIONS</th>
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</thead>
<tbody>
<tr>
<td>CONTRACT NO.</td>
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<tr>
<td>CODE IDENT NO.</td>
</tr>
<tr>
<td>SIZE</td>
</tr>
<tr>
<td>SCALE</td>
</tr>
<tr>
<td>WEIGHT</td>
</tr>
</tbody>
</table>

**MATERIALS**:

- Steel
- Aluminum

**SPECIFICATIONS**:

- Length: 12.5" ± 0.010
- Width: 8.0" ± 0.015
- Height: 2.0" ± 0.020

**NOTES**:

- DESIGN ACTIVITY APPROVED: DATE
- DRAWN BY: DATE
- CHECKED BY: DATE

**REVISIONS**

- LTR
- DESCRIPTION
- DATE
- APPROVED
NOTES:
1. MATERIAL - CRES (TYPE 303) BAR, 2.81 DIA
   QQ-S-264 A (2010521-30).
2. PRESS FIT ITEM 2 INTO ITEM 1.
3. WORKMANSHIP SHALL BE IN ACCORDANCE
   WITH PARTS LIST, ITEM 3.
4. TAG OR BAG PART NO. 49671-9277717501
   PER MIL-STD-130.
5. ALTER ITEM 1 AS SHOWN.

SECTION A-A

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR
SEE NOTE 5

SEE NOTES 1 & 2.

SECTION A-A

FOR PARTS LIST SEE PL SK2277717

GEAR

MATERIALS AND SPECIFICATIONS

<table>
<thead>
<tr>
<th>QTY REQD PER DASH NO.</th>
<th>CODE IDENT</th>
<th>IDENTIFYING NO.</th>
<th>DESCRIPTION</th>
<th>SPECIFICATION</th>
<th>SEE NOTE NO.</th>
</tr>
</thead>
</table>

UNLESS OTHERWISE SPECIFIED
THE SURFACE FINISH OF
MACHINED PARTS SHALL NOT
EXCEED A MAXIMUM READING
.010" PER ANSI STD B46.1 — 1962

INTERPRET DIMENSIONS AND
TOLERANCES PER ANSI Y14.5-65

THD DATA TO BE INTERPRETED
USING NAS 649 R2B AND
MIL-STD-9

ANGULAR DIMENSIONS ±1/8"
**LIST TITLE:** PREPARE

**DATE:** 1959

**SHEETS:** 966

**DESIGN ACTIVITY:** CONTRACT NO. NAS9-13688

---

**REVISIONS**

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<th>LTR</th>
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<th>LTR</th>
<th>DESCRIPTION</th>
<th>DATE</th>
<th>APPROVED</th>
</tr>
</thead>
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**INTERPRET SYMBOLS USED AS FOLLOWS:**

<table>
<thead>
<tr>
<th>UNITS OF MEASURE (UM)</th>
<th>QUANTITIES</th>
<th>SYMBOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>A — Inches</td>
<td>X — Applicable document</td>
<td>U — Govt or customer furnished</td>
</tr>
<tr>
<td>B — Feet</td>
<td></td>
<td>R — Vendor item, See specification or source control drawing.</td>
</tr>
<tr>
<td>C — Yards</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D — Ounces</td>
<td>O — For ref only</td>
<td>K — Govt or customer furnished and installed</td>
</tr>
<tr>
<td>E — Pints</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F — Quarts</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G — Gallons</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H — Barrels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J — Pounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L — Pair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M — Suit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N — Kit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P — Roll</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R — Box, Case</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ITEM</td>
<td>QUANTITY REQUIRED</td>
<td>CODE IDENT</td>
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<tr>
<td>1</td>
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<td>00141 A824-56</td>
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<tr>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>X</td>
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</table>
NOTES:
I. TAG OR BAG PART NO. 49671-5K2277718-1 PER MIL-STD-130.
### Materials and Specifications

<table>
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<tr>
<th>QTY REQD PER DASH NO.</th>
<th>CODE IDENT</th>
<th>IDENTIFYING NO.</th>
<th>DESCRIPTION</th>
<th>SPECIFICATION</th>
<th>NOTE</th>
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</thead>
<tbody>
<tr>
<td>-1</td>
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<td></td>
<td>X 8020022</td>
<td>SPEC WORKMANSHIP</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AR 1980032-1</td>
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<td>PASSIVATE DIP</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>AR 2010521-42</td>
<td></td>
<td>CRES(TYPE 303) BAR .375 DIA</td>
<td>3Q-5-764A</td>
<td></td>
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</table>

**Note:**
- Unless otherwise specified, the surface finish of machined parts shall not exceed a maximum reading of .02 per ANSI Std B46.1 — 1962.
- Tolerances on basic dimensions are in inches and include thickness of plating.
- Tolerances on basic dimensions are in inches and include thickness of plating.
- Tolerances on angular dimensions are ± 1/2°.
- Design activity approved.

**RCA Commodities Code:**
- **SHAFT, COLOR WHEEL**

**Contract No.:** N-59-13688

**Scale:** 4/1

**Weight:**
- RCA CORP.

**Drawing Date:** Apr 22, 1968

**Checked by:** Apr 22, 1968

**Date:** May 24, 1968

**Designed by:**

**Application:**
- **First Application**

**Next Assy Used On:**
- **Shuttle P.V.**

**Next Assy:**
- **SK22777FA**

**Size:**
- **49671**

**Code Ident No.:** SK2 27 77 18
NOTES:
1. TAG OR BAG PART NO. 49671-5K2277722-1
   PER MIL-STD-130.

DI 412(4)-40 UNC-2B

.15 G DIA

C'BORE

.250 DIA X .015 DEEP

UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES AND
MACHINED PARTS SHALL NOT INCLUDE THICKNESS OF PLATING
EXCEED A MAXIMUM READING OF .015 IN. PER ANSI STD B46.1-
1962.

THE SURFACE FINISH OF DIMENSIONS AND TOLERANCES
ARE TO BE INTERPRETED UP TO 6 .010.

ANGLE DIMENSIONS ± 14°

FIRST APPLICATION

RCA COMMODITY CODE:
SK227979 SHUTTLE TV

NEXT ASY USED ON

QTY REQ'D PER DASH NO.

CODE  ID NT

UNLESS OTHERWISE SPECIFIED,
DIMENSIONS ARE IN INCHES AND
MACHINED PARTS SHALL NOT INCLUDE THICKNESS OF PLATING
EXCEED A MAXIMUM READING OF .015 IN. PER ANSI STD B46.1-
1962.

THE SURFACE FINISH OF DIMENSIONS AND TOLERANCES
ARE TO BE INTERPRETED UP TO 6 .010.

ANGLE DIMENSIONS ± 14°

FIRST APPLICATION

RCA COMMODITY CODE:
SK227979 SHUTTLE TV

NEXT ASY USED ON

QTY REQ'D PER DASH NO.

CODE  ID NT
REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
A ADDED .250 DIA. C' BCREX 9/24/76 D. V. L.

A 0.015 DEEP

SEE NOTE 1

NOTE

1.03 X 45° TYP

0.03 X 45° TYP

MATERIALS AND SPECIFICATIONS

UNLESS OTHERWISE SPECIFIED, THE SURFACE FINISH OF MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING

PER ANSI STD B46.1 — 1962

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING

TOLERANCES ON:

BASIC DIMENSIONS

UP TO 6  \pm 0.02  \pm 0.01

6 TO 34  \pm 0.03  \pm 0.015

ABOVE 34  \pm 0.06  \pm 0.02

INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5-1982

TGD DATA TO BE INTERPRETED USING NBK H2B AND MIL-STD-4

ANGULAR DIMENSIONS \pm 1/4°

CLAMP

C 49671  SK2277722

SCALE 4/1  WEIGHT
NOTES:
1. TAG OR BAG, PART NO. 49671-SK2277726-1 PER MIL-STD-130.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.
.136 Dia
6 holes
Eq. spaced
On 1.938 Dia B.C.

**NOTES:**
1. TAG OR BAG PART NO. 49671-SK2277728-1
   PER MIL-STD-130.

**DIAGRAM:**
- .136 Dia
- 6 holes
- Eq. spaced
- On 1.938 Dia B.C.

**TOLERANCES:**
- UNLESS OTHERWISE SPECIFIED,
  THE SURFACE FINISH OF
  MACHINED PARTS SHALL NOT
  EXCEED A MAXIMUM READING
  1/2 PER ANSI STD B46.1 — 1952

**DIMENSIONS:**
- UNLESS OTHERWISE SPECIFIED,
  DIMENSIONS ARE IN INCHES
  AND INCLUDE THICKNESS OF PLATING

**INTERPRET DIMENSIONS AND**
**TOLERANCES PER ANSI Y14.5-1982**

**TYPICAL DATA TO BE INTERPRETED**
**USING NBS HDBK H2B AND**
**NBS-STD-9 ABOVE 24 ± .06 ± .025 ANGULAR DIMENSIONS**

**RCA COMMODITY CODE:**
SK 227979

**NEXT ASSY USED ON:**
FIRST APPLICATION
## Materials and Specifications

**Part Description:** Spec. Workmanship

**Specification:** QQ-A-561

**Contract No.:** NAS9-13488

**Drawn By:** [Signature]

**Drawn Date:** Apr 25, 1967

**Checked By:** [Signature]

**Checked Date:** Oct 1967

**Design Activity Applied By:** [Signature]

**Design Activity Applied Date:** [Date]

**Shim, Lens-Retainer**

**Shuttle TV**

**Next Assy Used On:**

**First Application:**

**RCA Commodity Code:**

**Code Ident No.:** C 49671

**Scale 2/1**

**Sheet 1 of 1**

---

**UNLESS OTHERWISE SPECIFIED:**

- THE SURFACE FINISH OF MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING 15/2 PER ANSI STD B46.1 — (.312)

- DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING

- TOLERANCES ON:
  - BASIC DIMENSIONS: ± .02
  - 2 PLACE DECIMALS: ± .010
  - 3 PLACE DECIMALS: ± .006

- ANGULAR DIMENSIONS: ± 1/2°

---

**Raw Text:**

- 2.16 dia.
- .032 (REF.)
- FOLDOUT SEAM

---

**Image Details:**

- Engineering drawing with dimensions and identifying marks.
NOTE

1. MATERIAL: OPTICAL GLASS RETICLE GRADE.
SURFACES QUALITY SHALL BE GO - 40 OR
BETTER, FACES SHALL BE FLAT TO 6
RINGS, FACES SHALL BE PARALLEL TO
3 MIN/ARC.

2. INCONEL NEUTRAL DENSITY COATINGS SHALL
BE APPLIED TO SURFACE A, PROVIDING FILTER
DENSITIES AS TABULATED.

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR
**TABLE 1: OPTICAL DENSITY VALUE**

<table>
<thead>
<tr>
<th>DASH No.</th>
<th>OPTICAL DENSITY VALUE</th>
<th>NOMINAL % T</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>1 ± 0.025</td>
<td>79</td>
</tr>
<tr>
<td>3</td>
<td>2 ± 0.025</td>
<td>63</td>
</tr>
<tr>
<td>4</td>
<td>3 ± 0.025</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>4 ± 0.025</td>
<td>40</td>
</tr>
<tr>
<td>6</td>
<td>5 ± 0.025</td>
<td>32</td>
</tr>
</tbody>
</table>

**MATERIALS AND SPECIFICATIONS**

**FILTER SEGMENT, NEUTRAL DENSITY**

**CONTRACT NO.** N-59-13623

**DRAWN BY:** [Signature]

**CHECKED BY:** [Signature]

**SPECIFICATION:** SK2277731

**SKU:** 49671

**PAGE:** 1/1
NOTE

1. MATERIAL: OPTICAL GLASS RETICLE GRADE.
SURFACES QUALITY SHALL BE GO - 40 OR BETTER. FACES SHALL BE FLAT TO 6 RINGS, FACES SHALL BE PARALLEL TO 3 MIN/ARC.
GLASS SHALL BE SIMILAR TO SCHOTT OG590 HAVING SPECTRAL CHARACTERISTICS AS SHOWN ON GRAPH, WAVELENGTH FOR 50% TRANSMISSION POINT SHALL BE 590 ± 10 NM.
### Materials and Specifications

<table>
<thead>
<tr>
<th>QTY REQ'D PER DASH NO.</th>
<th>IDENTIFYING NO.</th>
<th>DESCRIPTION</th>
<th>SPECIFICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>8030022</td>
<td>SPEC. WORKMANSHIP</td>
<td>SEE NOTE 1</td>
</tr>
</tbody>
</table>

#### Materials and Specifications

**Product:** FILTER SEGMENT, RED

**RCA:** RCA CORPORATION

**Contract No.:** N-59-13688

**Drawing:** D-1001001

**Date:** 5-10-80

**MILS:** MILS TD-9

**Angular Dimensions:** ±1/2

**Shuttle:** Used on RCA Commodity Code.

**Next Assy:** Used on...

**First Application:**...

---

**Note:**

- The surface finish of dimensions are in inches and include thickness of plating.
- Machined parts shall not exceed a maximum reading of ±0.0156.
- Check dimensions and tolerances per ANSI Y14.5M-1973.
- Dimensions are basic.
- Tolerances on:
  - 2 Place Decimals: ±0.02
  - 3 Place Decimals: ±0.010

---

**Graph:**

- % Transmittance vs. λ (Wavelength) in nm.

---

**Diagram:**

- Diagram of the filter segment with dimensions ±0.1 mm and 2 mm.
NOTE

1. MATERIAL: OPTICAL GLASS RETICLE GRADE. SURFACES QUALITY SHALL BE 60 - 40 OR BETTER. FACES SHALL BE FLAT TO 6 RINGS, FACES SHALL BE PARALLEL TO 3 MIN/ARC.

2. SURFACE A shall have an interference coating similar to FISH-SCHURMAN ML495C, HAVING SPECTRAL CHARACTERISTICS AS SHOWN. MAX. AND MIN. WAVELENGTHS FOR 50% TRANSMISSION POINTS SHALL BE:
   400 NM ± 10 NM
   480 NM ± 10 NM

SURFACE A

ANGLES AND TOLERANCES PER ANSI Y14.5-60.

THD DATA TO BE INTERPRETED USING NBS HDBK 1189 AND MIL-STD-9.

ANGULAR DIMENSIONS ± 1/8.

FILTER SEGMENT, BLUE

CONTRACT NO. NAS9-13688

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING.

TOLERANCES ON BASIC DIMENSIONS:

| UP TO 6 | ± 0.02 | ± 0.010 |
| 6 TO 24 | ± 0.03 | ± 0.015 |
| ABOVE 24 | ± 0.06 | ± 0.020 |

THD TO BE INTERPRETED USING NBS HDBK 1189 AND MIL-STD-9.

ANGULAR DIMENSIONS ± 1/8.

DESIGN ACTIVITY APPROVED: A季后田, May 9, 1974.

SCALE: LONG, WEIGHT

REFERENCE: RCA COMMODITY CODE.

FILTER SEGMENT, BLUE

CONTRACT NO. NAS9-13688

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING.

TOLERANCES ON BASIC DIMENSIONS:

| UP TO 6 | ± 0.02 | ± 0.010 |
| 6 TO 24 | ± 0.03 | ± 0.015 |
| ABOVE 24 | ± 0.06 | ± 0.020 |

THD TO BE INTERPRETED USING NBS HDBK 1189 AND MIL-STD-9.

ANGULAR DIMENSIONS ± 1/8.

DESIGN ACTIVITY APPROVED: A季后田, May 9, 1974.

SCALE: LONG, WEIGHT

REFERENCE: RCA COMMODITY CODE.

FILTER SEGMENT, BLUE

CONTRACT NO. NAS9-13688

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING.

TOLERANCES ON BASIC DIMENSIONS:

| UP TO 6 | ± 0.02 | ± 0.010 |
| 6 TO 24 | ± 0.03 | ± 0.015 |
| ABOVE 24 | ± 0.06 | ± 0.020 |

THD TO BE INTERPRETED USING NBS HDBK 1189 AND MIL-STD-9.

ANGULAR DIMENSIONS ± 1/8.

DESIGN ACTIVITY APPROVED: A季后田, May 9, 1974.

SCALE: LONG, WEIGHT

REFERENCE: RCA COMMODITY CODE.

FILTER SEGMENT, BLUE

CONTRACT NO. NAS9-13688

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES AND INCLUDE THICKNESS OF PLATING.

TOLERANCES ON BASIC DIMENSIONS:

| UP TO 6 | ± 0.02 | ± 0.010 |
| 6 TO 24 | ± 0.03 | ± 0.015 |
| ABOVE 24 | ± 0.06 | ± 0.020 |

THD TO BE INTERPRETED USING NBS HDBK 1189 AND MIL-STD-9.

ANGULAR DIMENSIONS ± 1/8.

DESIGN ACTIVITY APPROVED: A季后田, May 9, 1974.

SCALE: LONG, WEIGHT

REFERENCE: RCA COMMODITY CODE.
NOTE

1. MATERIAL: OPTICAL GLASS RETICLE GRADE. SURFACES QUALITY SHALL BE GO - 40 OR BETTER. FACES SHALL BE FLAT TO 6 RINGS. FACES SHALL BE PARALLEL TO 3 MIN/ARC. GLASS SHALL BE SIMILAR TO SCHOTT OG515 HAVING SPECTRAL CHARACTERISTICS AS SHOWN ON GRAPH. SURFACE 'A' SHALL HAVE AN INTERFERENCE COATING SIMILAR TO FISH-SCHURMAN ML 580 NM, HAVING SPECTRAL CHARACTERISTICS AS SHOWN. MAX. AND MIN. WAVELENGTHS FOR 50% TRANSMISSION POINTS SHALL BE:

515 NM ± 10 NM
580 NM ± 10 NM.
NOTES:

1. MATERIAL: SCHOTT HAII FILTER GLASS

2. SURFACES QUALITY SHALL BE 60-40 OR BETTER, FACES SHALL BE FLAT TO GRINDS, FACES SHALL BE PARALLEL TO 3 MIN/ARC.

3. SURFACE "A" SHALL HAVE AN INTERFERENCE COATING SIMILAR TO FISH-SCHURMAN ML3025S (8/18/71).

4. RESULTANT FILTER SHALL HAVE NOMINAL TRANSMISSION FROM 415 TO 550 NM OF 85% ± 4% THE 50% TRANSMISSION POINTS SHALL BE:

\[
380 \text{ NM} ± 10 \text{NM} \\
645 \text{ NM} ± 10 \text{NM}
\]
UNLESS OTHERWISE SPECIFIED THE SURFACE FINISH OF UNLSS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES AND TOLERANCES ON DEGREES ARE IN MINUTES.
MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING IN
THAT PARTS TO BE INTENDED FOR INSIDE USES TO 66
HEIGHT OF PLATING MGM

BOEING ACTIVITY APP.

REVISIONS

SCALE 4:1 WEIGHT

DATE

REVISIONS

DATE

APPROVED

AREA

0.79 (2 MM)

BANDPASS FILTER

SK2277742

49671

24.7

SEE NOTE 1

8030022

SPEC WORKMANSHIP

DESCRIPTION

INTERPRET DIMENSIONS AND TOLERANCES PER ANSI Y14.5M-1986

UP TO 6

± .02

± .010

SEE NOTE 1

NOTE 1

SPECIFICATION

SOURCE 24

± .020

± .015

409670

6 70v24 W

7 .03

.015

MIL STD-9 ANGULAR DIMENSIONS ; DESIGN ACTIVITY APPS.

FIRST APPLICATION SCALE

SECOND APPLICATION SIZE

WEIGHT

SHEET 1 OF 1
NOTES:

1. TAG OR BAG PART NO. 49671-SK2277761-1
   PER MIL-STD-130.
NOTES:

1. U1 & U8 ARE TYPE CD4011AE
2. U2, U4, U5, U6, U11 ARE TYPE CD4027AE
3. U3 IS TYPE CD4023AE
4. U7 & U9 ARE TYPE CD4018AE
5. U10 IS TYPE CD4046AE
6. U12 IS TYPE CD4050AE
7. ALL CAPACITORS ARE IN MICROFARADS UNLESS OTHERWISE STATED
8. ALL RESISTORS ARE IN OHMS UNLESS OTHERWISE STATED
A. MOVED LEAD BETWEEN U7-6 & U1-8 TO U7-11 & U1-8; ADDED R12; MOVED R1; FROM U3-10 TO U11-1

B. ADDED BUFFER BETWEEN 10-11-74 & 12-10-74.

GOH2 STEPPER CLOCK OUT

Q1 COLLECTOR, REVERSED

PINS 16 & 17

FILTER WHEEL DRIVE AND PHASING LOGIC - 2A1

RCA COMMODITY CODE:

SCALE : WEIGHT

SHEET 1 OF 1
### NOTES:

10. **Stepper Motor Logic & Driver**

   - Used for lens zoom, focus, & iris drives

11. **I.C. Power & Ground Connections**

### MATERIALS AND SPECIFICATIONS

<table>
<thead>
<tr>
<th>QTY REQ'D PER DASH NO.</th>
<th>CODE IDENT</th>
<th>IDENTIFYING NO.</th>
<th>DESCRIPTION</th>
<th>SPECIFICATION</th>
<th>SEE NOTE NO.</th>
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</thead>
</table>

**UNLESS OTHERWISE SPECIFIED**

- The surface finish of machined parts shall not exceed a maximum reading of 12.5 μm (0.0005 inch) as measured per ANSI Y14.9-1974.
- Interpolate dimensions and tolerances per ANSI Y14.9-68 unless otherwise specified.
- The dimensional tolerance on basic dimensions is ±.001 inch unless otherwise specified.

**TOLERANCES ON**: 2 PLACE DECIMALS, 3 PLACE DECIMALS, CHECKED DATE

<table>
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<th>CONTRACT NO.</th>
<th>NASI-13688</th>
<th>REL.</th>
<th>DRAWN</th>
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**SCHEMATIC**

STEPPER MOTOR LOGIC & DRIVER BD. 2A3, 2A4, 2A5

**RCA CORPORATION** NEW YORK, NY

**ASTRA ELECTRONICS DIV. PRINCETON, N.J.**

**PLANT**

**SCALE**

- WEIGHT
- SHEET 1 OF 1
REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

1. MAKE ITEM 2 FROM ITEM 1.
2. FINISH - PASSIVATING DIP, P80005-1.
3. MATERIAL - DRILL 200, CARBON STEEL (TYPE IV) J1500M 60011-601003-55.
4. PRESS FIT, ITEM 3 A TO ITEM 2.
5. SURFACES A & B SHALL BE PERPENDICULAR TO STEP BORE WITHIN 0.002 T.I.R.
   SURFACES A&B IN INDIVIDUAL CAVITIES SHALL BE FLAT TO WITHIN 0.001 T.I.R.
6. WORKMANSHIP SHALL BE IN ACCORDANCE WITH PARTS LIST, ITEM 4.
7. Tag or Bag Part No. 49571 - SK227998B - 001 PER MIL-STD-130.

SECTION A-A

SECTION C-C

SECTION B-B

REPLACEMENT SCALE 6/1
## Parts List

**Prepared by:** X. Siler  **Date:** May 17, 1974

**Contract No.:** NAS-9-13688

### Revisions

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### Interpret Symbols Used As Follows:

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<td>A — Inches</td>
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<tr>
<td>P — Roll</td>
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<tr>
<td>R — Box, Case</td>
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*RCA 2400-3 (8-68)*
# Parts List

## Gear Housing, Front

### List Title: Gear Housing, Front

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<td>C — Yards</td>
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<td>G — Gallons</td>
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**UNITS OF MEASURE (UM):**

- A — Inches
- D — Feet
- C — Yards
- D — Ounces
- E — Pints
- F — Quarts
- G — Gallons

**QUANTITIES:**

- X — Applicable document
- O — For ref only
- U — Govt or customer
- K — Govt or customer

**SYMBOLS:**

- X — Govt or customer
- O — For ref only
- U — Govt or customer
- K — Govt or customer

**Contract No.:**

NAS9-13688

**Prepared By:**

E. Rogers

**Date:**

May 6, 1974

**Checked By:**

E. Rogers

**May 30, 1974**
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* DENOTES VENDOR ITEMS. SEE SOURCE CONTROL OR SPECIFICATION CONTROL DRAWING BEFORE ORDERING.

U M - IN COLUMN HEADING DENOTES UNITS OF MEASURE (USE STANDARD ABBREVIATION)

EXPLANATION OF SYMBOLS IN TYPE COLUMN
1 - DENOTES TOOL DRAWING
2 - DENOTES CONTROLLED ITEM (CLASSIFIED)
3 - FOR QUANTITY AND EFFECTIVITY REFER TO EFFECTIVITY BLOCK
SEE NOTE 7

DRILL CSK., TAP INSTALL ITEMS PER ITEMS 6 HOLES 256 S PACE ON 1.9356 A. B.

SEE NOTES 245

NOTES:
2. DRILL .021 X .0499X HOLE FOR ITEMS 2.
3. PRESS FIT ITEMS INTO ITEM 1, SEAT FLUSH WITH ITEM 2, LOCK (SURFACE).
4. FINISH BLEND AND SEE 1500 FOR 1.
5. ALL COATINGS SHALL BE IN ACCORDANCE WITH PARTS LIST, ITEMS 5.
6. FILL IN ADJUSTABLE HOLES PER 14-1STD-1975.
7. ENGRAVE: WELD WIDE L.I. AND ARROWHEAD APPARENTLY IS SHOWN, IT SPECIFIED.

FINISH, FILL W/WHITE AFTER APPLYING FINISH.
FOR PARTS LIST SEE PLK2279977

GEAR HOUSING
(FRONT)
NOTES:
1. SECURE GEAR, ITEM 6, IN POSITION USING SET SCREW, ITEM 23. DRILL .038-.036 A HOLE USING PART DRILLED HOLE IN ITEM 6 AS A PILOT. PIN ITEM 6 TO MOTOR SHAFT USING ITEM 24. REMOVE SET SCREW, ITEM 23 AND DISCARD.
2. ROTATE MOTOR TO ADJUST GEAR CENTER DISTANCE. ADJUST FOR MIN .002 TO MAX .004 BACKLASH BETWEEN ITEMS 3 AND 4.
3. BOND ITEMS 9 AND 10 USING ITEMS 25, 26 AND 27 PER ITEM 25.
4. ITEMS TO BE FLUSH WITH SURFACE A.
REAR VIEW SHOWN WITH ITEMS REMOVED

SEE NOTES 344

SURFACE A

FILTER MODEL -

SPECS

REPRODUCIBILITY OF THE TYPICAL PAGE IS POOR.
# Parts List

**List Title:** FILTER WHEEL MODULE ASSEMBLY

**Prepared by:** [Name] MAY 1974

**Checked by:** [Name] MAY 1974

**Contract No.:** NAS9-13688

**Design Activity Approval Date:** [Date]

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## Quantities

- **X**: - Applicable document
- **U**: Govt or customer furnished
- **V**: Vendor item, See specification or source control drawing.
- **O**: For ref only
- **K**: Govt or customer furnished and installed
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* DENOTES VENDOR ITEMS - SEE SOURCE CONTROL OR SPECIFICATION CONTROL: DRAWING BEFORE ORDERING.
UM - IN COLUMN HEADING DENOTES UNITS OF MEASURE (USE STANDARD ABBREVIATION)
EXPLANATION OF SYMBOLS IN TYPE COLUMN:
1 - DENOTES CONTROLLED ITEM (CLASSIFIED)
2 - DENOTES TOOL DRAWING
3 - FOR QUANTITY AND EFFECTIVITY REFER TO EFFECTIVITY BLOCK

CLASSIFICATION:
FOLDOUT FRAME

I. UNLESS OTHERWISE SPECIFIED
   ALL RESISTOR VALUES ARE IN OHMS
   ALL DIODES ARE IN "H" SERIES
   ALL TRANSISTORS ARE 2N2222A
   ALL CAPACITOR VALUES ARE IN MFD

NOTES:
NOTES:
1. TAG OR BAG PART NO. 49671-SK22834-471 PER MIL-STD-130.
2. PRIOR TO BLACK ANODIZE FINISH 1980043-1, MASK SURFACES B & C.
3. CHEMICAL TREATMENT FOR ALUM. PER 1980135-1.
NOTES:

FOR ALL DASH NUMBERS

1. MATERIAL - PHOSPHOR BRONZE SHEET, 0.006 THK,
   QQ-B-750 (2), 49671-2010016-156.

2. ETCH TO PATTERN INDICATED (AREAS IN BLACK
   DESIGNATE MATERIAL).

3. FINISH - CHEMICAL BLACK FOR BRASS 1980176-1.

4. TAG OR BAG PART NO. 49671-SK2283465-E5
   PER MIL-STD-130.

REPRODUCIBILITY OF THE
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REDUCE TO 1,000±.005

DASH-3
REDUCE TO 1.000±.005

DASH-4

FOLDOUT FRAME
NOTES:

1. Bond items 9 thru 15 to item 1, using items 16, 17 and 18 per item 20. Vent cavities between filters by leaving a void in the potting at the toe of the segments.

2. Bond items 14 and 15 to outer face of items 12 and 13. Buildup from wheel face .005 max.

3. Item 14 selected to balance channel outputs prior to bonding per notes 1 & 2.

4. Adjust shim (item 5) to provide 1.5 lb.+0.5 preload on bearings (item 2).

5. Adjust individual filter position during bonding, so that after bonding, the maximum transmitted image shift between any two filter segments shall not exceed 0.01 mm.

Reproducibility of the original page is poor.
OF THE S POOR

SECTION A\AA

FOR PARTS LIST SEE PL2K283469

MATERIALS AND SPECIFICATIONS

UNLESS OTHERWISE SPECIFIED
THE SURFACE FINISH OF MACHINED PARTS SHALL NOT EXCEED A MAXIMUM READING
V 0.8 PER AND STD 846.1 -- 1968

TOLERANCES

WIDTH TOLERANCES

STANDARD TOLERANCES PER M4 AS

data to be interpreted

SK228346 MAGNETIC

FILTER WHEEL ASSEMBLY

D 49671 SK2283469

SCALE 4/1 NOTATION

PAGE 1 OF 1
NOTES:

1. LENS LIMIT SWITCHES NOT USED
2. S1 THROUGH S7 ARE MOUNTED ON FRONT PANEL
3. T.P.-1 THROUGH T.P.-15 ARE MOUNTED ON FRONT PANEL