MILITARY AVIONIC DISPLAYS

GEC AVIONICS

OVERVIEW OF MILITARY AVIONIC DISPLAYS

By C T Bartlett C Eng MIEE

Introduction

Engineers involved in display technology will naturally address display performance in terms of brightness, colour or line width and overlook the primary function which is to communicate.

Vision is the most powerful sense and substantial volumes of data can be rapidly absorbed and processed by the brain. However operation of a military aircraft is becoming even more complex and it is all too easy to overload the pilot with unnecessary data.

In this lecture I shall initially outline some of the applications of displays in the military cockpit and then describe the types of displays currently found there. It is then necessary to review the environment for which we are designing and consider the display technologies available to best fulfill the objectives. The lecture concludes with a brief look at the trends in displays and the future cockpit.

What are displays used for?

The data required by every pilot whether civil or military will include:-

- Flight Information
- Maps and Route
- Engine Airframe Data
- Cockpit Control

The military pilot has an additional bewildering array of real and synthetic data to view and assess concerned with threat avoidance and target identification. The optimum cockpit display is defined both by the display technology and by the display format. Brightness and resolution and colour capability are defined by the former but the form of characters and the use of colour are examples of the latter. The size of a display is also a key parameter in order to distinguish multiple threats adequately. Fine resolution on a small display is not adequate in this respect.

Since the information must be presented from a very restricted area most display surfaces are required to be multi-function. Both Raster and Cursive capabilities may be necessary in this respect.

The actual location of the display is also crucial. Gun aiming data for example must be presented Head Up whilst engine data is perfectly adequate Head Down.

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Summary of Display Types

The nomenclature for aircraft displays in simply determined by the angle of the head when viewing them. Thus there are Head Up and Head Down Displays with Helmet Mounted Displays being a special case of Head Up.

In addition all the traditional 'steam gauges' can be replaced by electronic displays and there may be special reversionary instruments for 'get-you-home' purposes.

Head Up Display (HUD)

The HUD presents a high brightness image into the pilots forward field of view to allow operation, essentially throughout the mission, head up.

The basic concept of the HUD is the use of a semi-reflective combiner glass through which the pilot observes the outside world and on which is projected the flight information. A relay lens system is used to collimate the projected image to infinity such that it is correctly focussed relative to the outside world. The input to this optical system is a high brightness monochrome CRT. Both cursive and raster modes are common with cursive in flyback also used.

High brightness is necessary for daylight operation to view the display against direct sunlight. A CRT luminance typically of 30,000 Cd/m^2 is required but conversely a luminance of less than $0.3Cd/m^2$ is necessary at night. A wide range of stability and luminance are essential.

In daylight the HUD displays symbology generated by a waveform generator computed from data derived from units such as the Air Data Computer, Inertial Navigation System and Stores Management System. At night this symbology is overlaid on a video picture from an infra-red sensor.

The field of view is the prime parameter and this is defined as a Total Field of View, which is a function of the optical design, and an Instantaneous Field of View which is always less than the total and is determined by the viewing position.

A typical refractive HUD has a Total Field of View of 25^0 circular of which the pilot may see upto 18^0 in azimuth by 20^0 in elevation at any instant.

Such a field of view is sufficient for day operation but at night the maximum possible azimuth field is needed for 'looking into turns' and 30^0 is typical. This larger field of view is achieved with holographic optical elements. In essence the collimating lens of the HUD relay is integrated with the combiner element thus permitting it to be much larger.

Holographic coatings can also be used on conventional refractive HUD combiner glasses to improve both the tranmission and display brightness. The use of holographics is not without penalty however and the greatest problem is the introduction of a restricted head motion box within which the image can be seen.

There is also a complex interaction between the characteristics of a hologram and the CRT phosphor in respect of spectral bandwidths.

Head Down Displays (HDD)

These are the oldest type of electronic display having originated with early radar scopes and developed into the workhorse of the cockpit.

Typically a HDD contains a CRT with drive circuits, power regulation and frequently a simple processor. More advanced units may contain a symbol generator and databus interface.

The size of a HDD is typically defined by an ARINC standard of square format with one inch increments - thus 5" x 5", 6" x 6" etc. This is not ideal for the normal 4:3 aspect ratio video and indeed rectangular format displays are found particularly in the civil cockpit.

The high brightness and resolution requirements have determined that the military cockpit is still dominated by monochrome displays. In addition sensors like FLIR and LLTV are monochrome. The civil cockpit which is shaded from direct sunlight to a far greater extent saw the introduction of colour displays.

The limitation on overall luminance of a colour display is made worse by the need for a triple notch type of filter to improve the contrast. Resolution is also limited by shadowmask dot pitch and Beam Index by stripe pitch. Although the frame sequential colour technique of Liquid Crystal Shutter is now practicable this technology has other drawbacks.

A HDD typically has a bezel around it with key switches and a 'tactile' or touch sensitive surface may be fitted. Such a touch screen may be mechanised by infra-red diode matrix or surface accoustic wave techniques.

HDD will operate in raster, cursive and mixed modes but raster only units are acceptable. The raster HDD based on shadowmask technology provides one of the most reliable and simple cockpit displays.

The greatest problem with retrofit of displays is the considerable depth of the CRT and the cost of tailoring to a special size.

Reversionary and Replacement Instruments

Pilots still have a preference for a bank of mechanical instruments as back up in the event of power failure. Since all pilots commence training on aircraft fitted only with such gauges they serve a useful purpose as a familiar display in the event of disorientation problems.

Such instruments can all be replaced by electronic equivalents which can be more reliable and versatile. Where gauges are currently driven by air pressure (from pitot heads) then the replacements will incorporate a transducer and must also be battery powered.

Reversionary Instruments are the same instruments as described above but may be located in an out of the way place or accessible in emergency only.

It is in this area of instrumentation that LCD has made the first inroads.

Helmet Mounted Displays

These devices include:-

Night Vision Goggles
Helmet Mounted Sight
Helmet Mounted Display

Night Vision Goggles incorporate Image Intensifier Tubes that operate over a spectral range of 650nm to 950nm and amplify a scene illuminated by starlight into a visible scene. The device is normally two channel to give a binocular field of view and although this field of view is much restricted compared to the eye the NVG can be used over the whole range of head movement.

Image intensified goggles can provide a valuable aid to night flying particularly in helicopters. In fast jets the major drawback is that they must be removed before ejecting from the aircraft.

The Helmet Mounted Sight is a daylight display and is designed to overcome the problem of a fixed aiming reticle as provided by a HUD. With a HUD it is necessary to turn the aircraft to the target but with a head mounted sight and missiles that can be released off boresight this is no longer necessary. The sight is usually a simple LED reticle projected into the pilots field of view in front of one eye.

The Helmet Mounted Display is essentially a HUD on the head and combines the best features of that device with a field of view limited only by head movement.

HMD developed out of NVG's to provide an integrated and thereby ejection safe system. With adaptation to the optical train it is feasible to inject a sight or CRT's. With the CRT comes the capability of presenting a suite of symbology and/or FLIR imagery. The combination of image intensifiers and FLIR provides a useful overlap of spectral response.

Current HMD are often modular to provide a display which can be adapted to the mission.

Since the HMD is part of the pilots equipment numerous other factors such as cooling, comfort and communications also become part of the design.

A key requirement for helmet mounted equipment is a head tracker which determines the head pointing position with respect to the aircraft datum.

Design Constraints

A military display has a specific function to perform but the design is influenced by the operating environment, by secondary needs of the user and by a host of standards and specifications.

The military environment is characterised by extremes of temperature, high vibration levels, harsh EMC and an overwhelming need for reliability and ease of maintenance. Design of the display device must make allowance for the environment by for example incorporation of special shock resistant mounts, rugged shadowmasks and solar radiation resistant display surfaces.

Human factors naturally affect the visual aspects of the display but the secondary features will include safety aspects. A HUD for example may have to provide bird-strike protection and a HMD is an integral part of the pilot's helmet which must still fully protect the wearers head.

The secondary needs of the user are evident in the necessity for low weight, although in the case of an HMD this is really a priority item. The requirements for high reliability and maintainability stem naturally from a consideration of the possible locations where military equipment is used and the availability of equipment and personnel to effect repairs.

Finally the standards and specifications ensure a defined standard of performance throughout hardware, software and documentation. The design is constrained by example by definition of a MIL-STD-1750 processor architecture whereby the method of implementation may be selected but not the mode of operation.

Display Techology

The design and performance of some display devices have been described earlier but from the point of view of a display designer need further definition.

Ever increasing performance is required of the HUD CRT with line brightness of $\geq$100,000 Cd/m^2 being demanded. A raster luminance of 30,000 Cd/m^2 is also a target. Although in both cursive and raster modes the resolution is demanding, the spot size will be different and optimising a CRT for both modes is rarely feasible. CRT phosphors are P1, P43 and now P53 but whereas the broad spectrum of P1 gave a gentle line broadening the spiked response of P43 and P53 can give rise to colour fringing unless optics are fully chromatically corrected.

Areas of the CRT face may also require special phosphors or clear areas for techniques of brightness monitoring or integrity checking.

Colour CRT's are available as Shadowmask, Beam Index and Penetron.

Shadowmask tubes with invar masks are available with dot pitches of 0.2mm and permit beam currents of up to 1.5mA. The major limitation is the poor efficiency created by the mask.

Potentially the beam index tube overcomes the luminous deficiency of the shadowmask but in fact performance is limited by beam spreading ultimately giving rise to poor colour purity. The greatest drawbacks are the poor performance at very low light levels, constrained by the need for an index return, and the complex drive electronics required.

Penetron tubes are really limited to two phosphors and hence to colours ranging from red through yellow to green. The HV switching is an extra complexity which with overall poor brightness has kept applications of this tube to cabin environments, air traffic control for example.

Liquid Crystal Shutters placed in front of a monochrome CRT retain the high resolution of the CRT. A full RGB display is possible but luminance is limited by the polariser and two colour shutters are more usual. The information must be presented in a frame sequential manner necessitating video frame stores.

Various flat panel display technologies are available the majority being emmissive displays although the most successful to date is Liquid Crystal which is non-emmissive.

A comparison of the various technologies is given.

Where a high luminance display is required only LED and LCD devices are currently in service. LED is used for data displays notably being specified for the Eurofighter cockpit. The supertwist type of LCD is usually used in replacement instruments.

Active Matrix LCD offers good contrast and full colour at reasonable resolution. The prime drawbacks are the high power requirements for backlighting, heating at low temperature and current poor production yields.

The Future

The display manufacturer will always demand higher luminance and higher resolution in a smaller lighter package and the CRT will continue to fulfull this demand for many years.

HUD CRT's may need to provide a full daylight raster and minature 1/2 inch CRTs will be needed for Helmet Displays. Final anode voltages will continue to be stepped up to meet higher luminance at small spot size and gun designs will be refined by computer design.

The future for colour CRT's is more difficult to predict because of the competition from flat panel devices. Development of shadow mask tubes is still possible for example with slotted masks but at very high cost. Beam indexing may well be developed further but the physical size of colour tubes will limit their application.

We are seeing the need for large area displays typically of 10 x 9 inches and these can only be produced in the fast jet cockpit with LCD technology.

Helmet Mounted Displays can more easily provide "wall to wall" displays and ultimately will do so in colour.

The concept of the virtual cockpit where the pilot sees only synthetic pictures or via sensors is feasible now.

The limiting factors in display technology are as always budget constraints and user acceptance.

A MODERN FIGHTER COCKPIT

AVIONICS DISPLAYS

TYPE OF DATA TO BE DISPLAYED

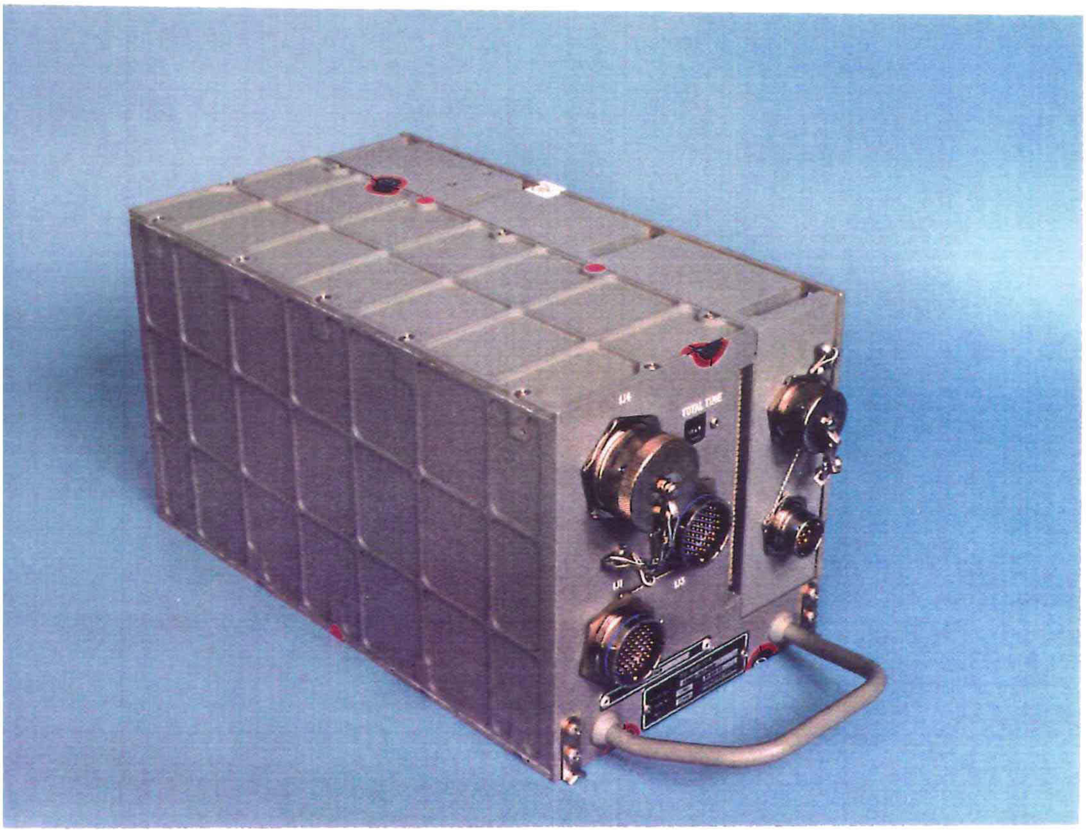
- FLIGHT INFORMATION
  - ❑ SPEED
    - ■ – GROUNDSPEED
    - ■ – AIRSPEED
  - ❑ ALTITUDE
    - ■ – PITCH
    - ■ – BANK
    - ■ – YAW
    - ■ – ANGLE OF ATTACK
- MAPS & ROUTE
  - ❑ WAYPOINTS
  - ❑ BEACONS
  - ❑ MAP
  - ❑ AIRLANES
  - ❑ AIRFIELD DATA
- ENGINE/AIRFRAME DATA
  - ❑ ENGINE
    - ■ – TEMPERATURE
    - ■ – OIL PRESSURE
    - ■ – RPM
  - ❑ ELECTRICAL
  - ❑ FUELS
  - ❑ AIR CONDITIONING/PRESSURISATION
- COCKPIT CONTROL
  - ❑ AIR CONDITIONING
  - ❑ COMMUNICATIONS

AVIONICS DISPLAYS

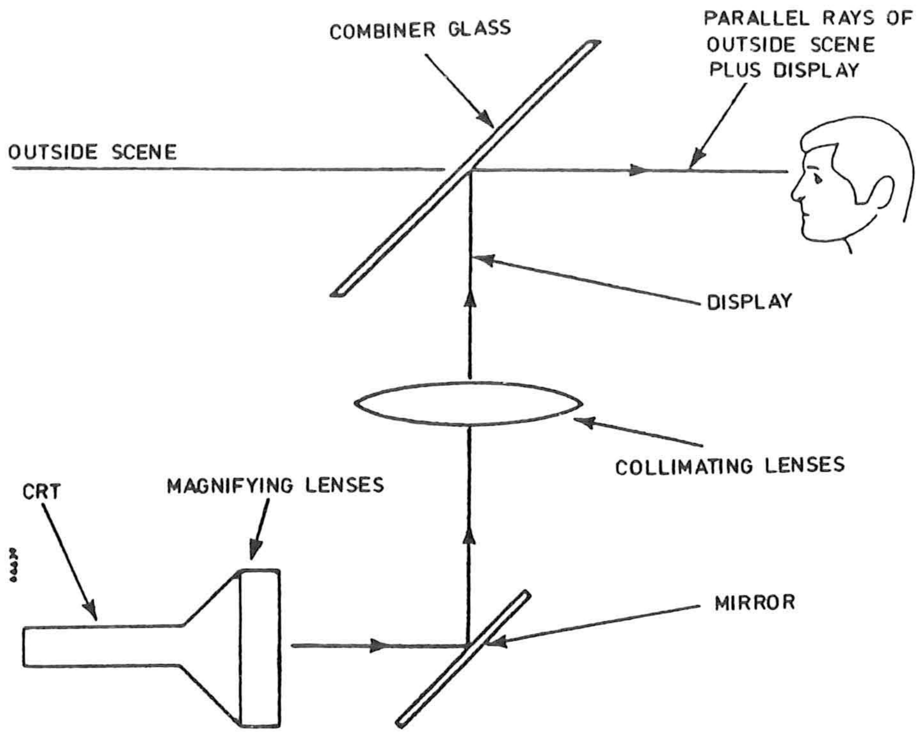
GENERAL FEATURES OF A COCKPIT DISPLAY

- BRIGHTNESS
  - ❑ VISIBLE IN INTENSE SUNLIGHT
  - ❑ DIMS TO LOW INTENSITY FOR NIGHT
- RESOLUTION
  - ❑ CAPABLE OF BOTH RASTER AND CURSIVE
- GREY SHADES
  - ❑ 16 SHADES
- COLOUR
  - ❑ 16 COLOURS
- SIZE
  - ❑ LARGE FIELD OF VIEW
- WEIGHT
  - ❑ AS LOW AS POSSIBLE
- VOLUME
  - ❑ HIGHLY CONSTRAINED
- PERFORMANCE
  - ❑ WIDE TEMPERATURE RANGE
  - ❑ SHOCK/VIBRATION
  - ❑ SEVERE EMC
- DISPLAY FORMAT
  - ❑ CLEAR, WELL FORMED CHARACTERS
  - ❑ EFFECTIVE USE OF COLOUR

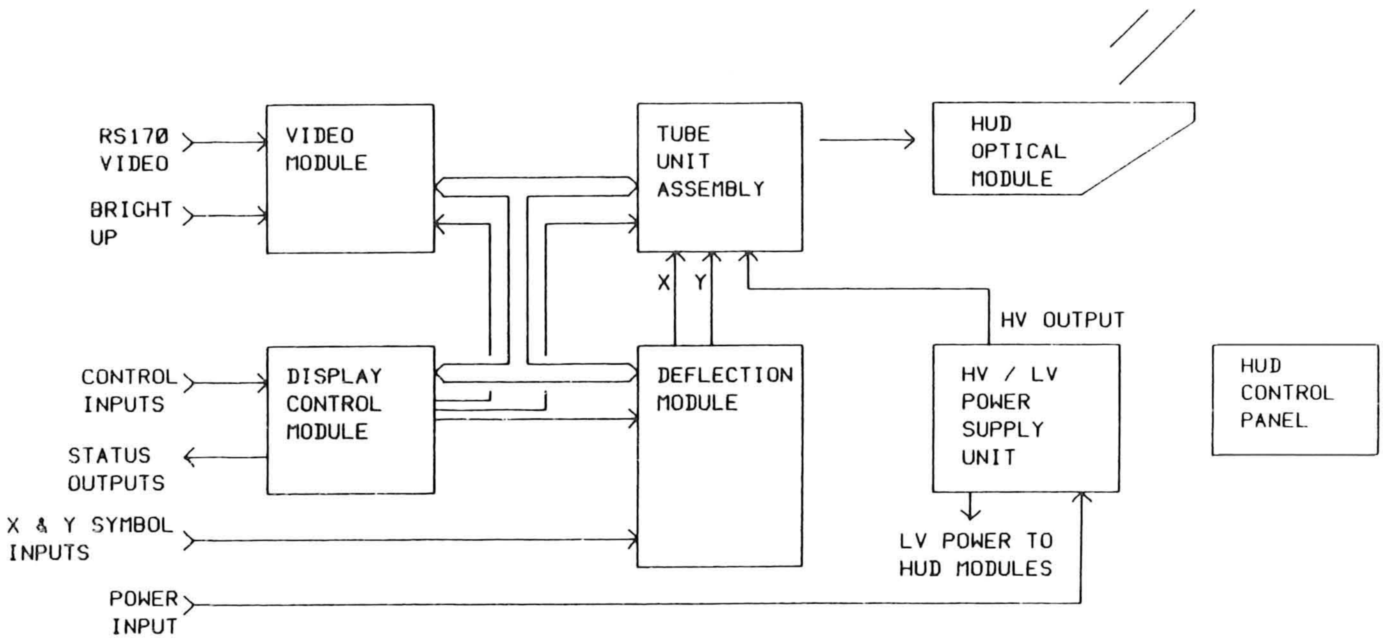
HEAD UP AND ELECTRONIC UNIT



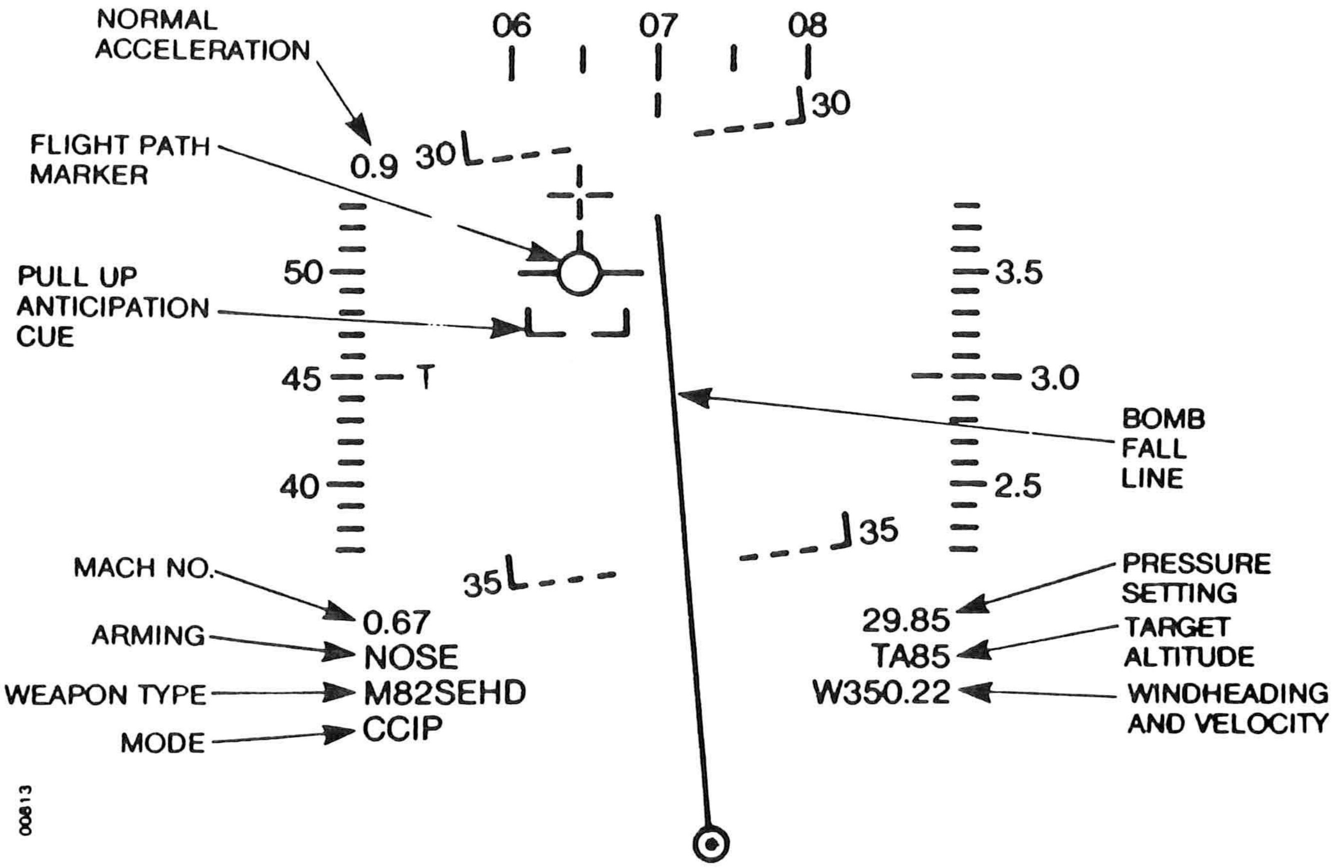
THEORY OF THE HEAD UP DISPLAY (HUD)



HUD BLOCK DIAGRAM



CCIP MODE (BOMBS)



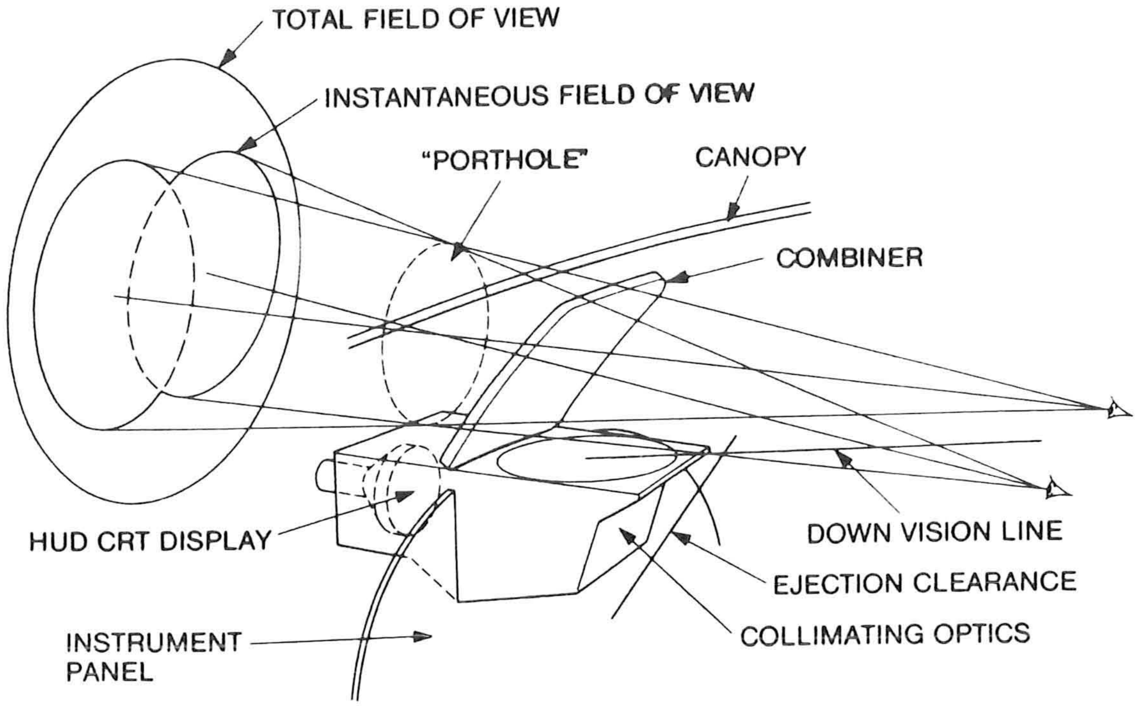
A TYPICAL HUD DISPLAY

HEAD UP DISPLAY

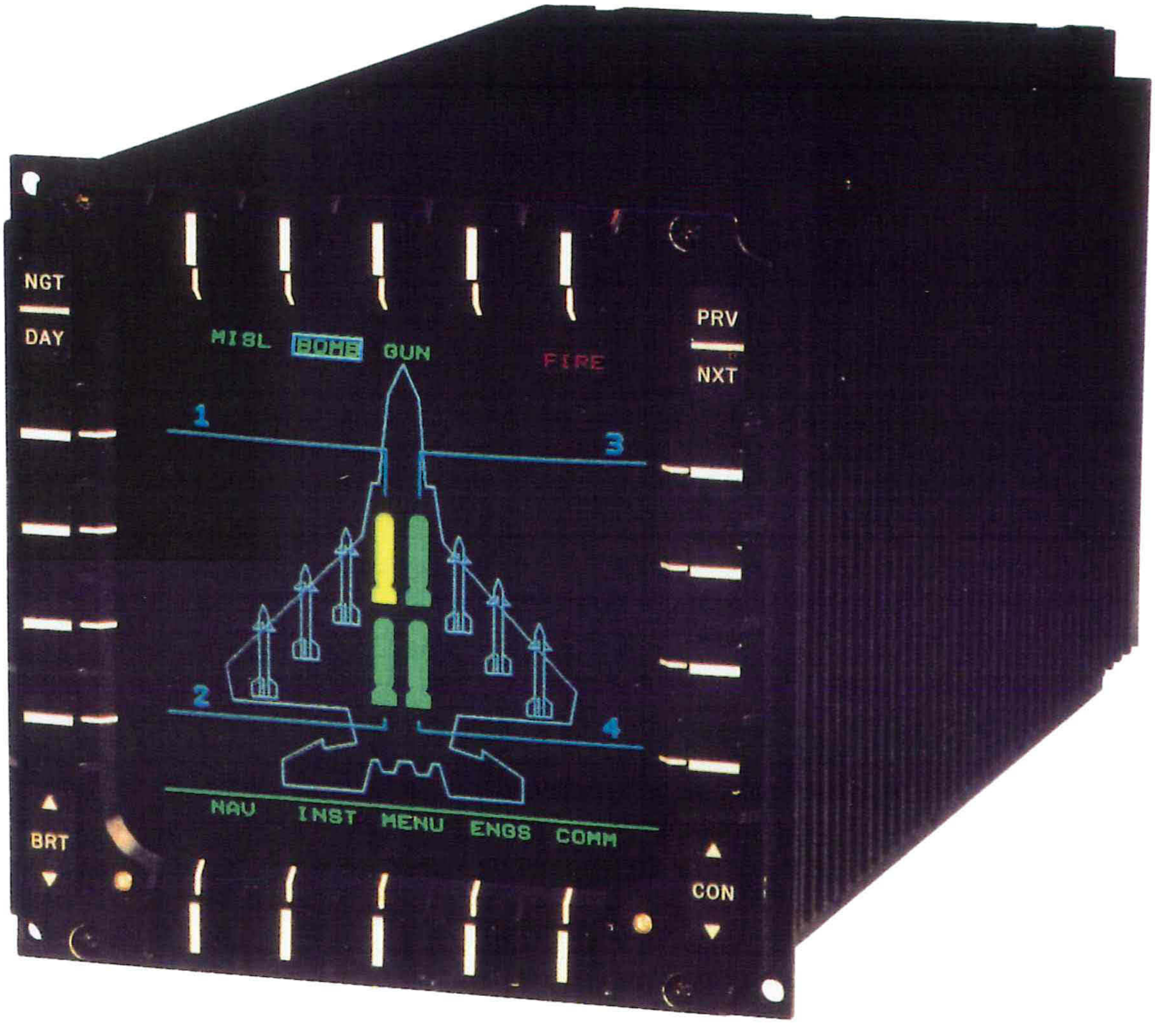
TYPICAL CHARACTERISTICS

• OUTLINE DIMENSIONS:	31.75 x 7.25 x 12.00 INS
• WEIGHT:	47 LBS APPROX.
• COOLING:	CONVECTION 85W RASTER MODE <85W CURSIVE MODE
• MOUNTING:	ALIGNMENT PIN AND JACKING BOLTS
• POWER INPUT:	PLUS/MINUS 20V (PRE-REGULATED POWER) MAXIMUM INSTANTANEOUS CURRENT ON EITHER RAIL, 5 AMPS
• FIELD OF VIEW:	TOTAL 25° IFOV FROM DESIGN EYE 17° 15' AZIMUTH 14° 45' ELEVATION, +4° 45' -10° 00'
• OPERATING MODES:	DAY MODE CURSIVE, NIGHT MODE VIDEO RASTER WITH CURSIVE SYMBOLOGY OVERLAY
• VIDEO STANDARD:	525 LINES, 60HZ FIELD, 30HZ FRAME 2:1 INTERLACE, TO RS170
• STANDBY SIGHT:	CRT GENERATED ELECTRONIC SIGHT
• MTBF:	2390 HOURS
• CRT PHOSPHOR:	P53
• NVG COMPATIBILITY:	TO GEN III IMAGE INTENSIFIERS
• ENVIRONMENT:	COCKPIT ENVIRONMENT MIL-E-5400, CLASS 1 OPERATING TEMPERATURE -40°C TO +55°C

HUD INSTALLATION CONSTRAINTS & FIELDS OF VIEW



<u>A SHADOWMASK CRT DISPLAY WITH INTEGRAL SYMBOL GENERATOR AND PROCESSOR, AND A COLOUR MFD WITH DIGITAL MAP DISPLAY</u>

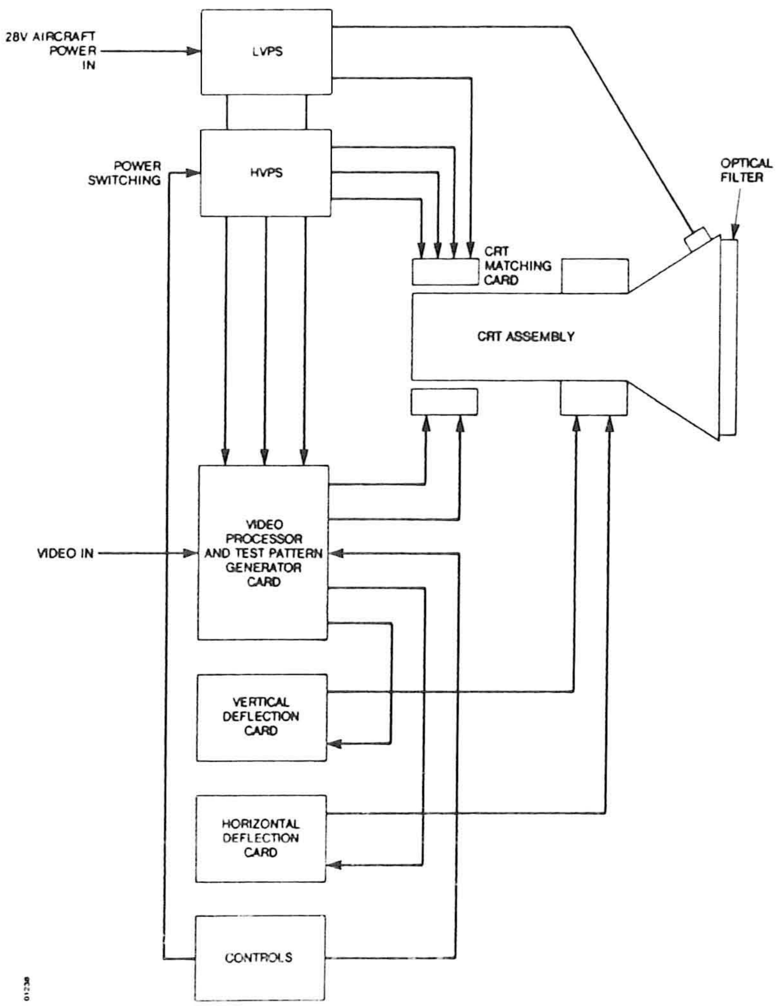


COLOUR HEAD DOWN DISPLAY

TYPICAL CHARACTERISTICS

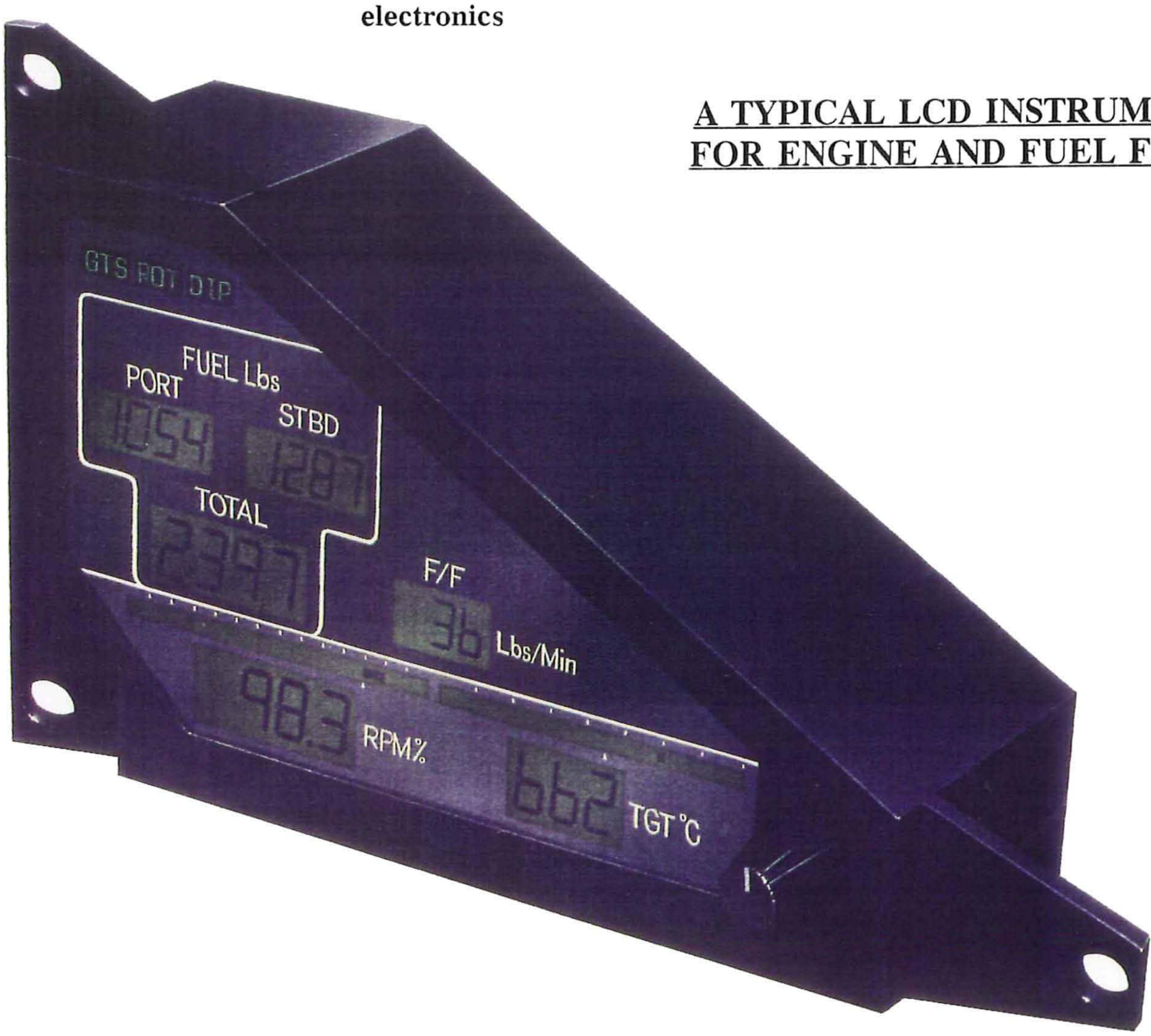
• OUTLINE DIMENSIONS:	6.75 x 7.07 x 15.25 INS	
• WEIGHT:	26 LBS APPROX.	
• POWER CONSUMPTION:	130W AT 28V DC	
• CRT SCREEN SIZE:	5 X 5 INCHES	
• CONTRAST RATIO IN AMBIENT LIGHT OF:	2k FtL	10k FtL
• STROKE MODE:		
GREEN	10.00	2.82
BLUE	1.33	1.14
RED	3.75	1.55
• RASTER MODE:		
WHITE	5.43	1.88
GREEN	4.42	1.68
• VIDEO AMPLIFIER BANDWIDTH:	10MHz	
• ANODE VOLTAGE:	25kV	
• SCAN DENSITY:	525 LINES	
• TV SCAN RESOLUTION:	70 LINES PER INCH	
• MEAN TIME BETWEEN FAILURES:	1000 HOURS	
• COOLING REQUIREMENTS:	AIRPLANE COOLING AIR SUPPLY REQUIRED	

BLOCK DIAGRAM OF HEAD DOWN DISPLAY



ENGINE AND FUEL DISPLAY PERFORMANCE SUMMARY

Display Technology:	Polycrystalline Active Matrix Liquid Crystal Display
Display Dimensions:	3.8 x 6.5 x 4.75 ins, includes interface electronics, power supply and controls.
Display Interface:	Customer specified. Dedicated Seral Link
Display Viewing Angle:	+45° (design aim)
Display Brightness:	Better than 200FtL White
Minimum Brightness:	Brightness Range 2000:1
Contrast Ratio at 0 & 10kFtL Ambient:	0FtL (20:1), 10FtL (4:1)
Display Resolution:	100 pixels/inch, monochrome, horizontal and vertical
Active Area Size:	4.0 ins vertical by 7.75 ins horizontal
Cooling Requirements:	Thermal mounting to cold wall
Power Requirements and Consumption:	28V d.c., 115V a.c. single phase, or 115V a.c. three phase at 400 Hz Customer Option Power consumption 40W - includes backlight and heater 30W (Heater operates at low temperature only)
Writing Rate:	Display graphics over whole screen at 60Hz
MTBF:	Design aim of 3000 hours per separate display
Weight:	4lbs including power supply, backlight and interface electronics

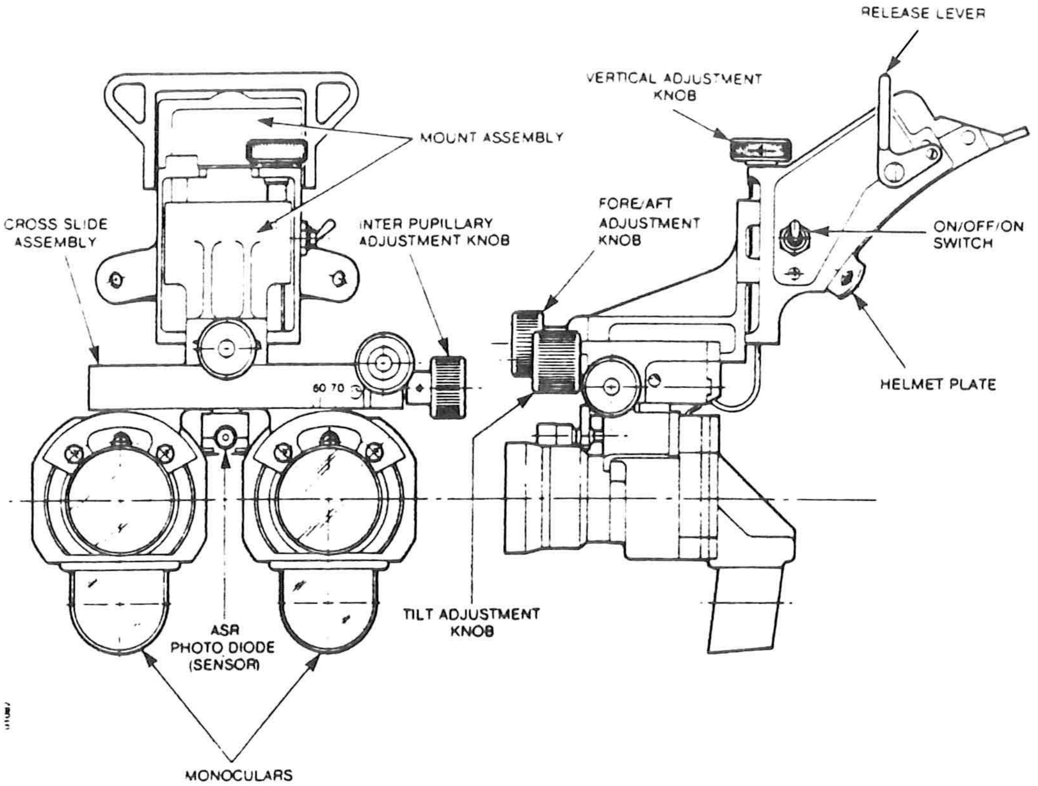


A TYPICAL LCD INSTRUMENT FOR ENGINE AND FUEL FLOW

PICTURE OF CATS EYES ON HELMET

HELMET MOUNTED SIGHT

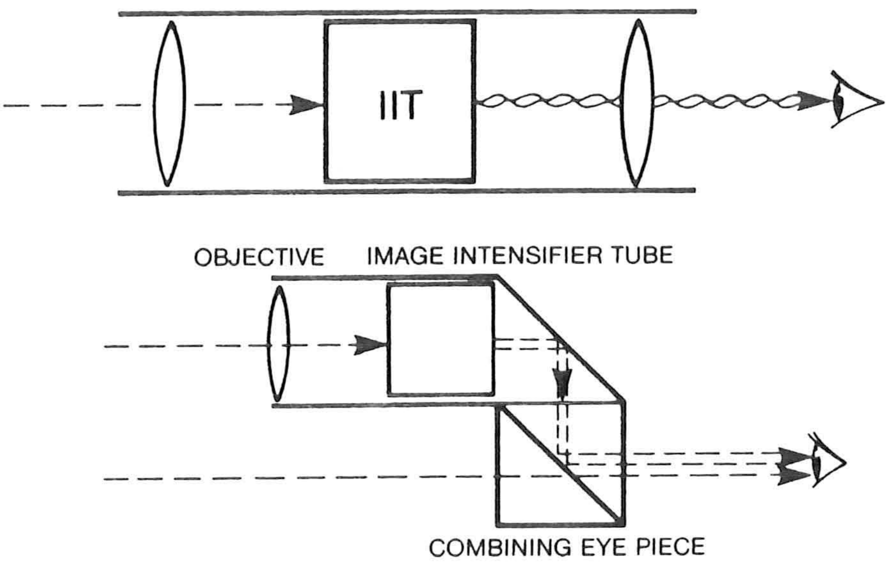
CATS EYES COMBINER TYPE NVG



HELMET MOUNTED DISPLAYS

PRINCIPLES OF STRAIGHT THROUGH GOGGLES AND CATS EYES

- Straight through ANVIS
- Combiner type 'Cats Eyes'



Both types may be fitted with Generation II or Generation III tubes

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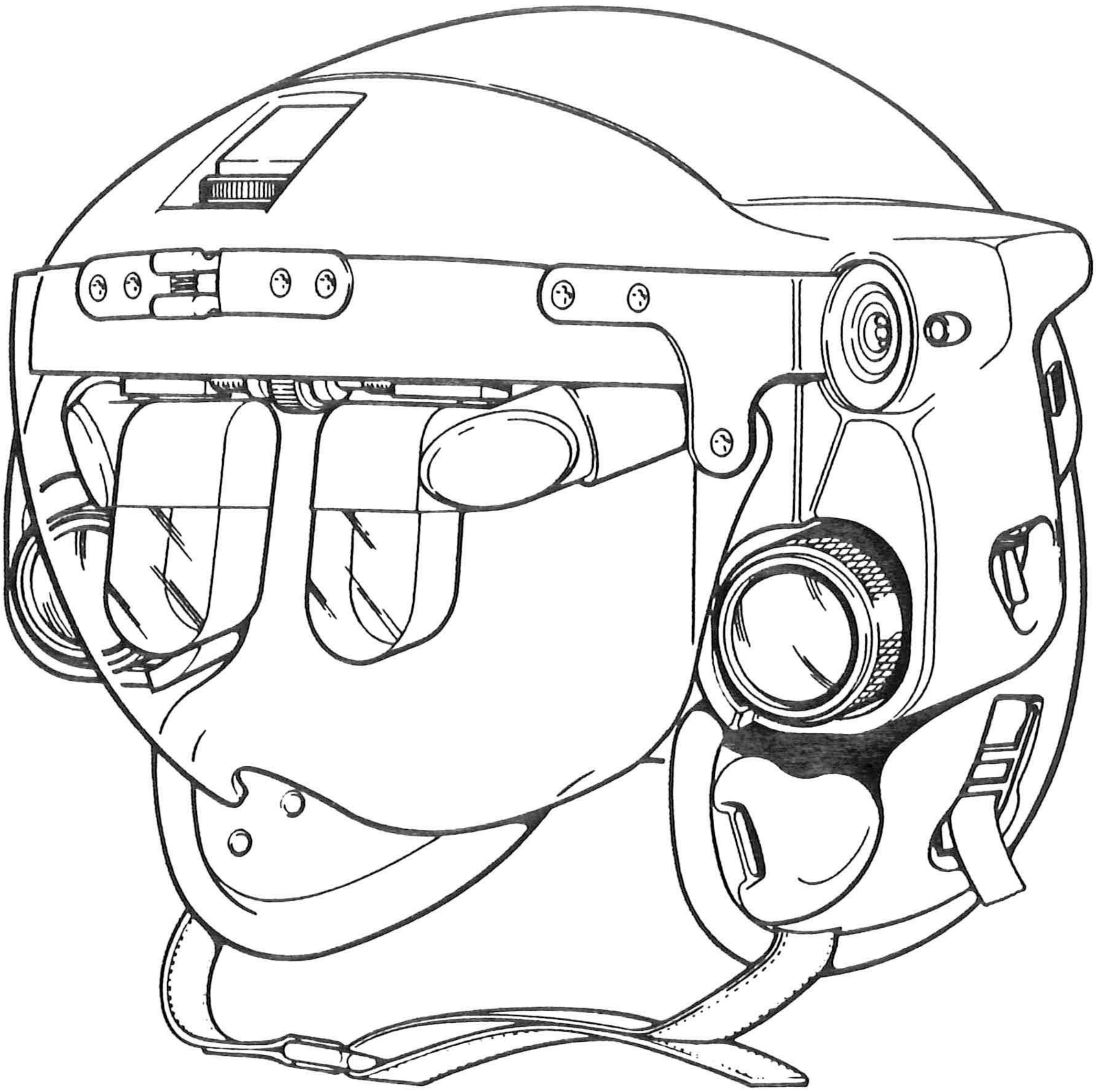
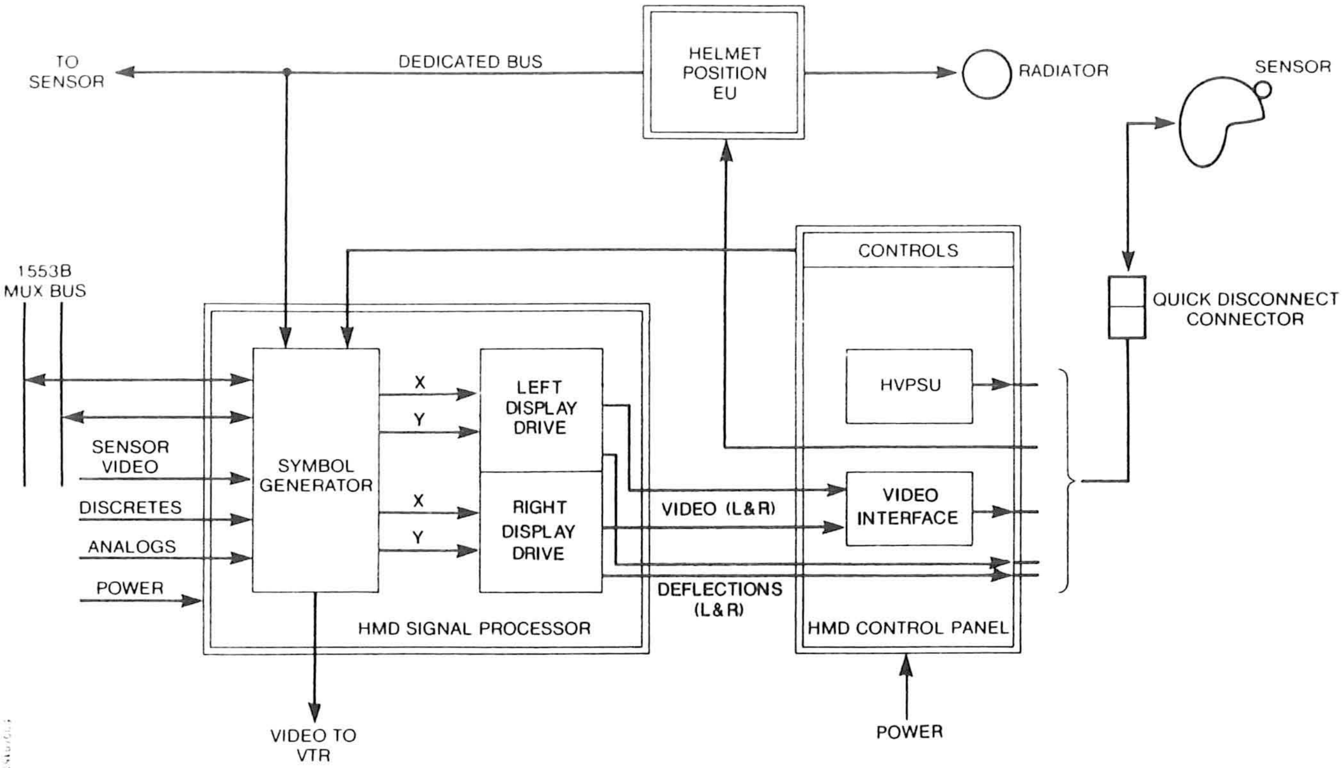
A GEC AVIONICS HELMET



HELMET MOUNTED DISPLAY SYSTEM BLOCK DIAGRAM



TYPICAL CHARACTERISTICS

• SYSTEM:	NVG AND CRT
• HMD WEIGHT:	0.5 LBS
• OPTICAL SYSTEM:	BINOCULAR
• FIELD OF VIEW:	35° CIRCULAR
• EYE RELIEF:	1.0 INCHES
• EXIT PUPILS:	0.25 INCHES CIRCULAR
• REAL WORLD TRANSMISSION:	50%
• OPTICS ADJUSTMENT:	INTERPUPILLARY
• CRT:	1 INCH MAGNETIC
• CRT PHOSPHOR:	P53
• VIDEO STANDARD:	525/875 LINE 60 HZ
• IMAGE INTENSIFIERS:	GEN III 18MM P20 PHOSPHOR – LONG PERSISTENCE
• CRT LUMINANCE:	50FT.L

THE MILITARY ENVIRONMENT

A DESIGN EXAMPLE - THE HEAD UP DISPLAY

ENVIRONMENTAL FACTORS

ALL AVIONIC EQUIPMENT MUST BE CLEARED FOR FLIGHT BY A QUALIFICATION PROGRAMME, INVOLVING SUCH FACTORS AS :-

• VIBRATION	AERODYNAMIC FLOW AND GUNFIRE TYPICALLY 20 - 2000Hz MAX $0.04g^2/Hz$ RANDOM VIBRATION
• SHOCK	15g TYPICAL
• CRASH SAFETY	HUD MUST REMAIN IN PLACE WITH 30g CRASH LANDING
• BIRDSTRIKE	10LB BIRD STRIKING CANOPY AT 350 KNOTS
• EXPLOSIVE DECOMPRESSION	LOSS OF CANOPY AT EXTREME ALTITUDE
• SUNSHINE EFFECTS	HIGH TEMPERATURE AND LONG EXPOSURE TO SUNLIGHT. TEMPERATURE CAN EXCEED 95°C
• MOISTURE AND RAIN	100% HUMIDITY AND WIND BLOWN RAIN
• MOULD GROWTH	MUST NOT ALLOW FUNGUS GROWTH UNDER TROPICAL CONDITIONS
• ELECTROMAGNETIC INTERFERENCE	CONDUCTED AND RADIATED EMISSION TEST, VERY HIGH FIELD STRENGTHS
• EXPLOSIVE ATMOSPHERE	MUST NOT CAUSE IGNITION IN A FUEL RICH ENVIRONMENT
• SAND AND DUST	MUST WITHSTAND BLOWN SAND AND DUST PARTICLES
• RELIABILITY	GUARANTEED MTBF RELIABILITY DEMONSTRATION TESTING TEST ANALYSE AND FIX (TAAF) TEST UNTIL OPERATIONAL PERFORMANCE

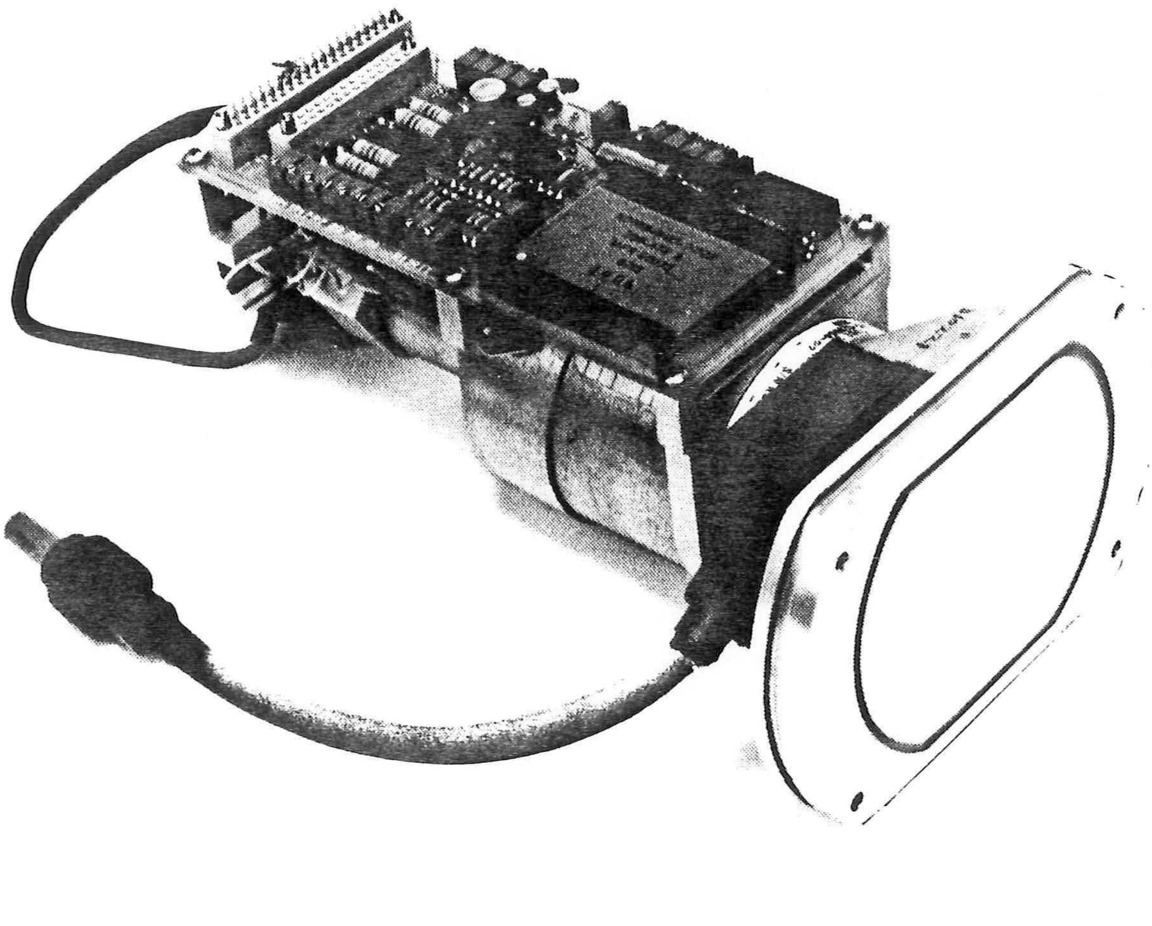
DISPLAY DEVICES

(1) CATHODE RAY TUBES

- MONOCHROME
- COLOUR
  - SHADOWMASK
  - BEAM INDEX
  - PENETRON
  - LCD SHUTTER
- FLAT CRT
  - CHANNEL PLATE

(2) FLAT PANEL DISPLAYS

- LIQUID CRYSTAL
- ELECTROLUMINESCENT
- VACUUM FLUORESCENT
- LED



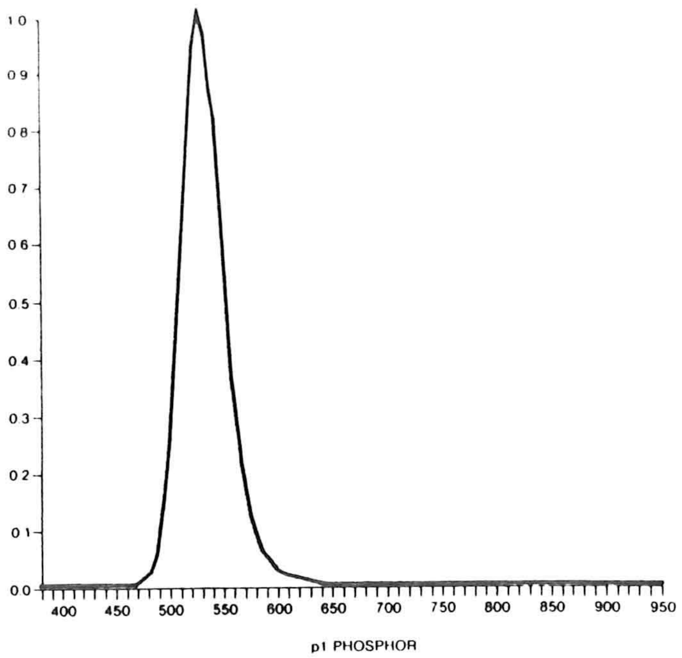
TYPICAL TUBE UNIT ASSEMBLY

TYPICAL CRT SPECIFICATIONS

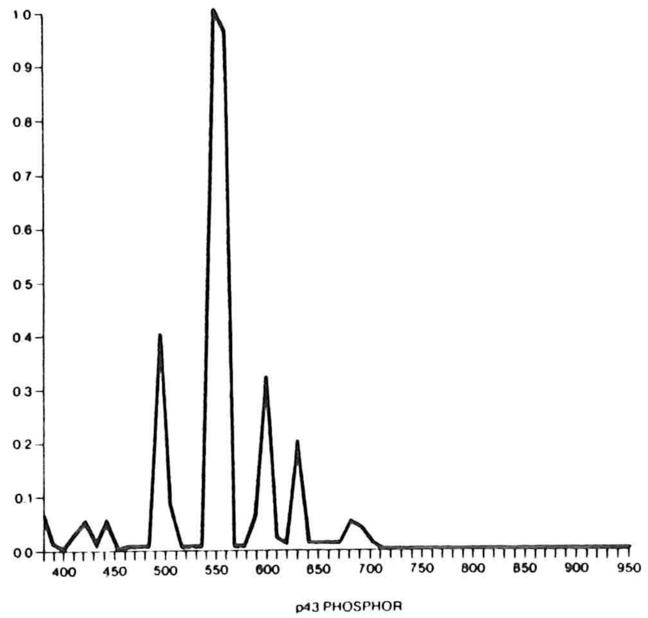
EXTRACTS OF CRT SCD AND SCS FOR HUD CRTS

PROJECT	1	2	3
WEIGHT	1.1 kg	1.1 kg	1.05 kg
LENGTH	8.2 ins	8.2 ins	7.75 ins
COIL HSG DIA	2.4 ins	2.4 ins	2.40 ins
NECK DIA	1.25 ins	1.25 ins	1.50 ins
USEFUL SCR	78mm DIA	78mm DIA	62.5mm
REFRESH	60Hz	60Hz	60Hz
PHOSPHOR	P53	P1	P43
A3	18kV	18kV	18kV
A2	3 TO 5kV	2.96 TO 4.76kV	3.1 TO 4.94kV
A1	847 WRT k	847 WRT k	847 WRT k
DRIVE	DIFF G- K+	DIFF G- K+	DIFF G- K+
CUT OFF	50 TO 90V	42 TO 84V	42 TO 84V
CURSIVE WRITING SPEED	182m/s	75m/s	45m/s
LINE WIDTH	0.19mm (70%)	0.3mm (50%)	0.15mm (50%)
LUMINANCE BRT 2	18000FtL 27000FtL	7900- 11400FtL	7400- 11200FtL
CURRENT 2	A3 600 A2 350	A3 300 A2 480	A3 300 A2 480
RASTER SIZE	58 * 75	64 * 86	37 * 49
BRT	1200 TO 1800FtL pk	760 TO 1140FtL	1350 TO 2000FtL pk

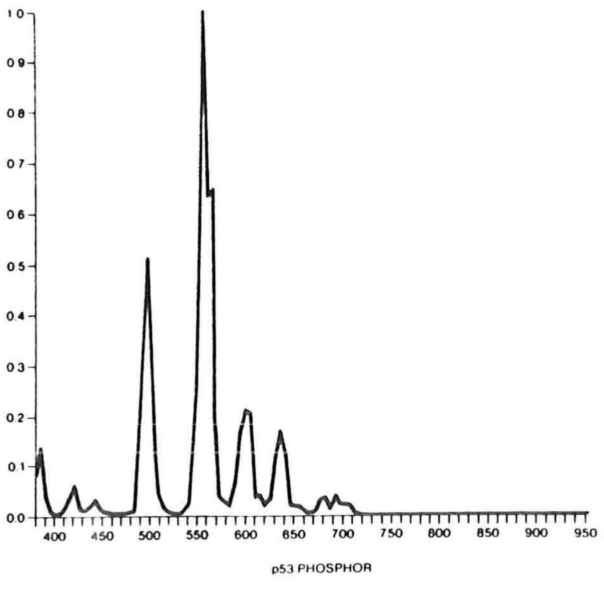
SPECTRAL OUTPUT OF P1 PHOSPHOR



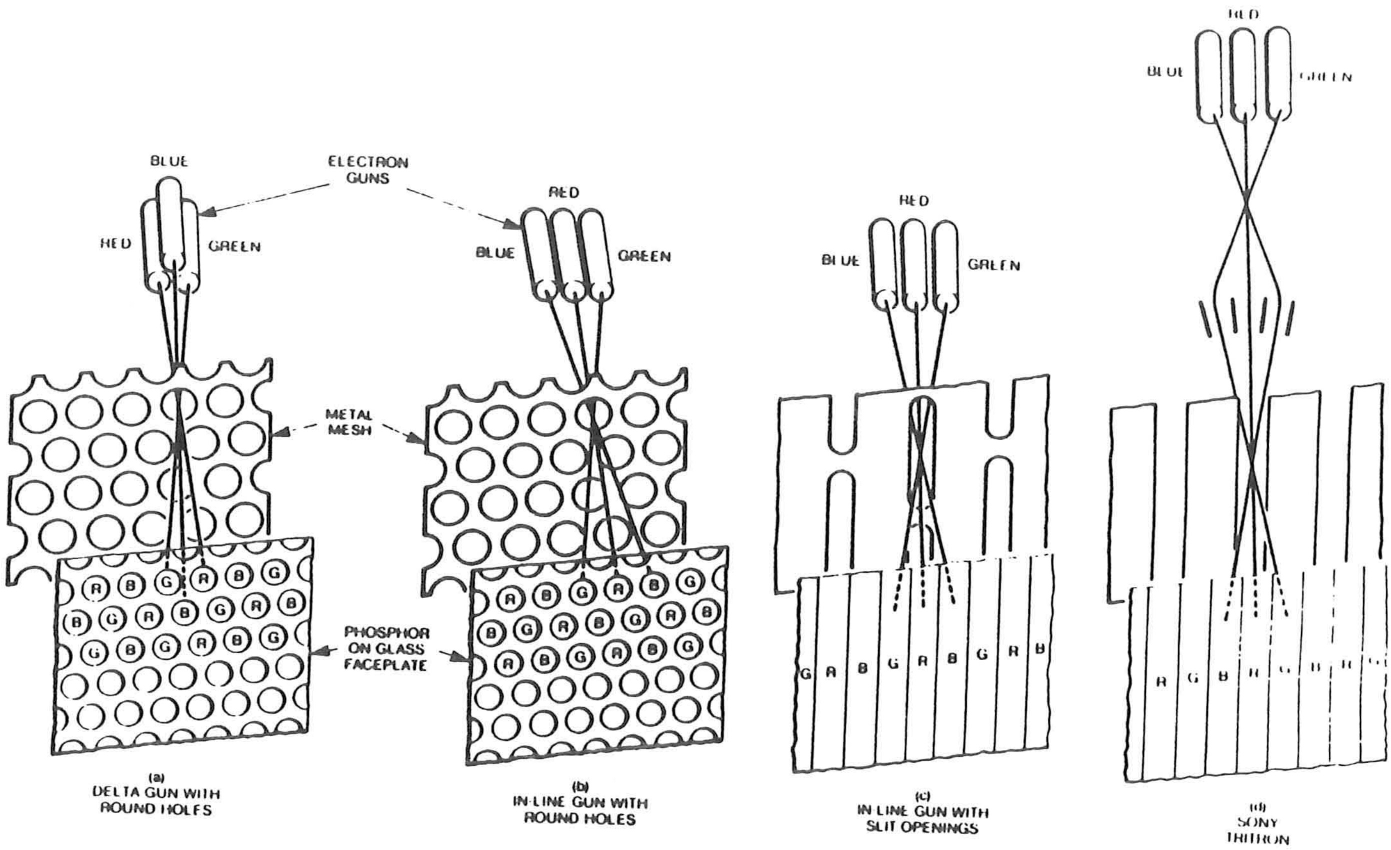
SPECTRAL OUTPUT OF P43 PHOSPHOR



SPECTRAL OUTPUT OF P53 PHOSPHOR



SHADOWMASK CONSTRUCTION TECHNIQUES



SHADOWMASK DISPLAYS

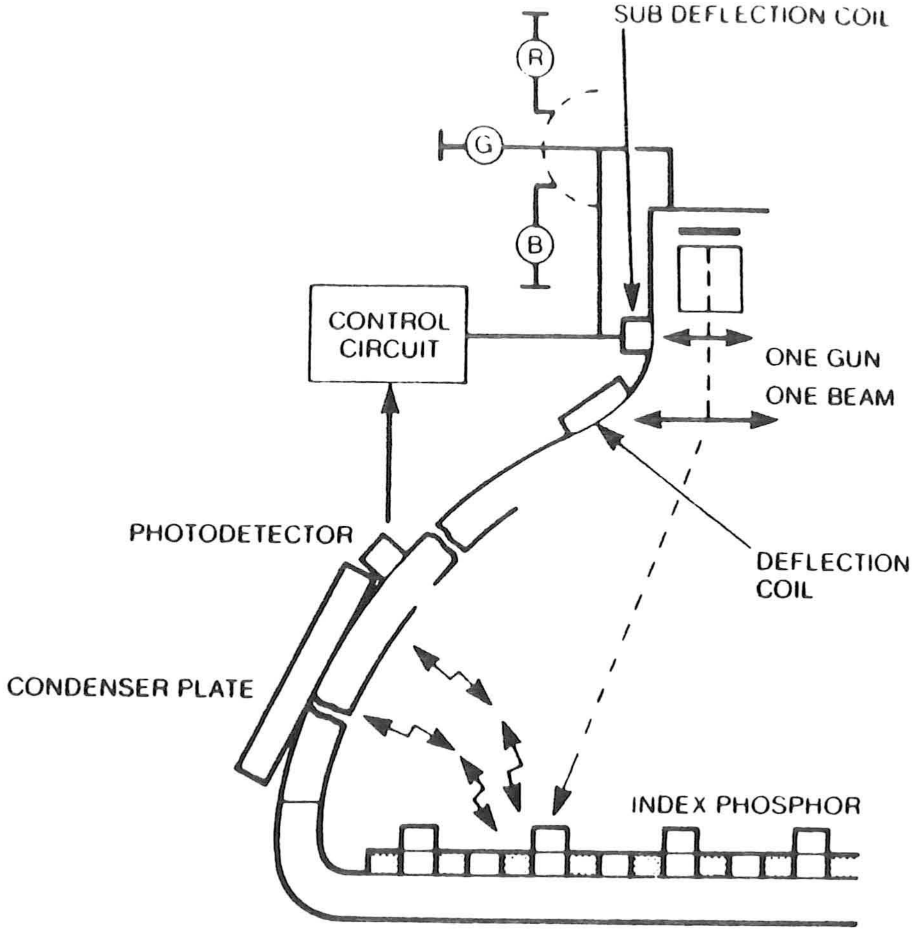
THE KEY FEATURES OF THE SHADOWMASK CRT ARE:

- SIMPLE ANALOGUE INTERFACE, IDEAL FOR RASTER MODES
- GOOD SATURATED COLOURS WITH A FULL RGB DISPLAY
- WIDE BRIGHTNESS RANGE. SUITABLE FOR NIGHT OPERATION
- HIGH COST CRT, BUT LOW COST DRIVE CIRCUITS

THE DRAWBACKS OF SHADOWMASK ARE:

- BRIGHTNESS LIMITED BY SHADOWMASK
- SIZE OF DISPLAY LIMITED BY VIBRATION PERFORMANCE
- PACKAGING CONSTRAINED BY TUBE LENGTH AND MASK SUPPORT
- COLOUR CONVERGENCE ERRORS AT EDGES AND CORNERS
- HIGH DEFLECTION AND H.V. POWER LEVELS

BEAM INDEX DISPLAY



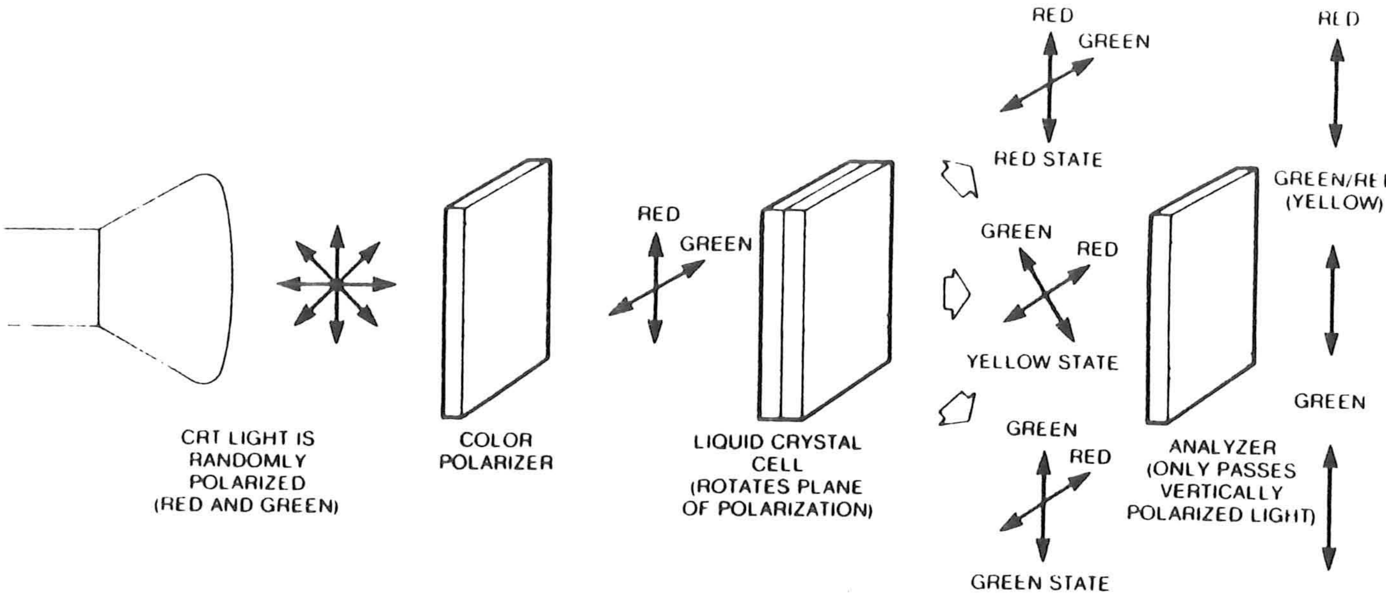
THE ADVANTAGES OF A BEAM INDEXING DISPLAY ARE AS FOLLOWS:

- HIGH BRIGHTNESS > 1700 cd/m^2 WHITE (AFTER FILTER)
- MECHANICAL PERFORMANCE OF CRT IS SIMILAR TO A MONOCHROME TUBE
- NO CONVERGENCE PROBLEMS
- REDUCED GEOMETRIC DISTORTION COMPARED WITH A SHADOWMASK CRT

HOWEVER, THIS SYSTEM SUFFERS FROM MAJOR DRAWBACKS AS FOLLOWS:

- COMPLEX CRT DRIVE CIRCUITS
- HIGH EHT TO RETAIN SPOT SIZE - 30kV TYPICAL
- RASTER DISPLAY ONLY - CURSIVE WRITING IMPOSSIBLE
- BRIGHTNESS CONTROL RANGE IS LIMITED TO LESS THAN ABOUT 200:1
- THE USEFUL SCREEN AREA IS RESTRICTED DUE TO THE NEED FOR "RUN-IN" AREA

LIQUID CRYSTAL SHUTTER



THE LIQUID CRYSTAL COLOUR SHUTTER (METHOD OF OPERATION)

THE ADVANTAGES OF THIS TECHNOLOGY ARE:

- SIMPLE MONOCHROME CRT
- OPTIMUM PACKAGING
- HIGH CONTRAST DISPLAY - BUILT-IN FILTER
- GOOD BRIGHTNESS - 300FtL YELLOW, 200FtL GREEN
- RESOLUTION IS EQUIVALENT TO MONOCHROME CRT (NO MATRIXING THEREFORE NO ALIASSING PROBLEMS)

THE MAJOR DRAWBACKS TO THIS APPROACH ARE:

- LIMITED COLOUR PALETTE. RED THROUGH YELLOW, TO GREEN
- HEATER POWER FOR THE LCS AT TEMPERATURES BELOW +10°C OF TYPICALLY 40W
- THE DOUBLE FRAME RATE REQUIRED, NECESSITATES COMPLEX ELECTRONICS IF THE INPUT IS RGB VIDEO. A TV FIELD STORE MUST BE PROVIDED
- LIMITATION OF VIEWING ANGLES

ACTIVE MATRIX LCD DISPLAY

THE KEY FEATURES OF AN LCD DISPLAY ARE:

- HIGH CONTRAST. GOOD PERFORMANCE IN HIGH AMBIENT LIGHT
- BRIGHTNESS DETERMINED BY PERFORMANCE OF BACKLIGHT, WITH NO MAXIMUM OR MINIMUM LIMITATIONS OF THE LCD
- LOW VOLUME PACKAGE
- LOW WEIGHT
- EFFICIENT USE OF THE DISPLAY AREA WITH NO DEGRADATION OF RESOLUTION AT THE EDGES

HOWEVER, THERE ARE DRAWBACKS WITH THIS TECHNOLOGY:

- THE DISPLAYS ARE PIXEL LIMITED, AND THEREFORE REQUIRE DATA PROCESSING TO REMOVE ALIASSING PROBLEMS
- THE RESPONSE SPEED OF THE LC ELEMENT OF THE DISPLAY MUST BE OPTIMISED FOR VIDEO APPLICATION (CURRENTLY SWITCHING SPEEDS OF 20ms ARE ACHIEVABLE)
- THE MATURITY OF THE TECHNOLOGY

DISPLAY TECHNOLOGY CHARACTERISTICS

	BEAM INDEX CRT	SHADOWMASK CRT	LCD SHUTTER + CRT	LC ACTIVE MATRIX PANEL
CONTRAST RATIO IN 10^4 FT. CANDLES	3.4 WHITE	3.2 WHITE 3.0 GREEN	3.9 YELLOW 3.0 GREEN	4.0 TO 8.0 GREEN SUN FRONT/REAR
HORIZONTAL RESOLUTION DISPLAYABLE PIXELS/WIDTH	250	381	500	400+
TRIAD SIZE	0.016"	.0095" (SLOTS) .008" (DOTS)	0.011"	0.0157" (3 COLOR)
SCREEN CORNER RADIUS	ZERO	16.3mm	16.3mm	ZERO
BRIGHTNESS AT FRT FACE (cd/m^2)	5950 WHITE	2900 WHITE	11,900 YELLOW	N/A
AFTER FILTERING (CD/M^2)	1740 WHITE 920 GREEN	815 WHITE 1015 GREEN	1025 YELLOW 685 GREEN	685 GREEN
COLOR RANGE	FULL RGB	FULL RGB	LIMITED RYG	FULL RGB
POWER REQUIREMENTS	150W	130W (RASTER ONLY) 190W (RASTER/ CURSIVE)	<100W	160W INCLUSIVE BACKLIGHT
PRODUCTION COST	V. HIGH	MODERATE TO HIGH	MODERATE	POTENTIALLY V. LOW
CIRCUIT COMPLEXITY	V. HIGH	MODERATE	LOW	LOW
HV FOR CRT	32KV	27KV	22KV	NO HV REQUIRED
VIEWING ANGLES	$\pm 60^{\circ}$	$\pm 75^{\circ}$	$\pm 30^{\circ}$	$\pm 40^{\circ}$
LIMITATION	BRIGHTNESS RANGE, NEEDS NIGHT FILTER	CONVERGENCE ERRORS. RUGGEDNESS	TEMPERATURE RANGE $+60^{\circ}$ SEQUENTIAL COLOR SWITCHING	TEMPERATURE RANGE $+85^{\circ}$ MAX
PACKAGING	VERY DENSE. NEEDS EXTENSIVE HYBRIDIZING OF CIRCUIT FUNCTIONS	DENSE DUE TO CRT NECK COMPONENTS AND BULB SIZE	MODERATE TO HIGH. SIMILAR TO BI.CRT	LOW DENSITY EXTENSIVE USE OF INTEGRATED CIRCUITS AND FLEXI-SUBSTRATES
RISK ASSESSMENT OF MANUFACTURE	HIGH TESTING IN MANUFCTURE NEEDS V HIGH STANDARDS - TIGHT TOLERANCES ON SPOT SIZE AND LINEARITY	MODERATE TESTING FOR CONVERGENCE ERRORS IS COMPLEX	MODERATE CONVENTIONAL TESTS ONLY	MODERATE EASY TESTING BUT IMMATURE TECHNOLOGY (MID 1988)