arrays at the short wavelengths and do not appear to suffer from the persistence and "glow" problems of these arrays under extremely low background conditions. Among the first instruments equipped with such an array is the Caltech infrared camera for the Keck telescope which has already achieved a 1σ K′ (2.1 μm) limit of 22 mag./sq. arcsec in 20s of integration time. Unfortunately, the well capacities of the first devices are rather low ($\sim 2 \cdot 10^5$e) for ground-based L (3.8 μm) and M (4.8 μm) broadband imaging. At ESO, however, we are currently preparing to test an engineering array of this type and expect delivery early next year of a science grade array with higher well capacity if current experiments with higher doping at SBRC are successful. Cincinnati Electronics also presented their new 256×256 InSb array which yields higher well capacities of $\sim 10^6$e at the expense of higher dark current and read noise and could be of great interest for long-wavelength imaging. The big news, however, was that both Rockwell and SBRC have now started development of 1024×1024 arrays, i.e. jumping the previously anticipated next step in format. Both plan to utilize four quadrant read-out chips so that 512×512 arrays should also be available if required and offer a fallback if yield of the full arrays proves to be a major problem. Both companies appear to be more concerned, in fact, by yield (and hence cost) than technical performance aspects although Rockwell plan a concerted attack on the persistence problem and hope also to increase quantum efficiency and reduce the read noise of the new devices to ~5e. The prospect now, therefore, is not only of much larger formats but also improved sensitivity and hence a considerable overall performance gain. One of the VLT infrared instruments still in the definition phase at ESO – the cryogenic infrared echelle spectrometer – actually requires arrays of this size for a reasonable echelle format and will clearly profit from any improvement in noise performance as such an instrument should be detector limited over much of its wavelength range. Technically, it is also not too late to plan for the use of these larger format arrays in ISAAC and CONICA. Although the present 256×256 arrays were baselined even before these arrays became commercially available, the optical designs of both instruments were specified to accommodate 512×512 arrays in anticipation of future developments. An expansion to 1024×1024 now appears possible without major optomechanical changes if and when they become available.

Considerable progress was also reported on the development of longer wavelength arrays which cover the 10 and 20 μm atmospheric windows and are of interest for the VLT mid-infrared imager/spectrometer for which ESO has contracted a Phase A study to a consortium of institutes led by the Service d'Astrophysique, Saclay (see *The Messenger*, 73, 8). Performance of the high well capacity ($\sim 10^7$e) 64×64 Ga:Si photoconductor array developed by LETI/LIR in France for ground-based use in the 10 μm window was demonstrated to good effect by an image of the β Pic disk obtained by P.O. Lagage using TIMMI at the ESO 3.6-m and voted one of the conference scientific highlights by Mark Morris in his closing summary. The follow-on development of this device to a format of 128×192 pixels being managed by INSU and with ESO participation was also presented. A novel feature of this array, appreciated by many participants, is the possibility of switching between high and low values of the charge capacity in order to optimize its performance under different background conditions (e.g. imaging and spectroscopy). Both SBRC and Rockwell have also developed low-noise, high-capacity (10^7e), As:Si IBC/BIB (Impurity Blocked Conduction/Blocked Impurity Band) arrays with formats up to 256×256 which are sensitive throughout the 10 and 20 μm windows although it has yet to be established that such devices can be exported outside the United States. Rockwell also reported progress with As:Si solid-state photomultipliers which have high q.e.'s (~0.7) and are capable of counting single photons with a response time of 50ns. Although the present formats are small (10×10), these devices may be of interest in the future for very low background (e.g. high-resolution spectroscopy) applications and the measurement of fast transient phenomena.

This is obviously an exciting and probably exceptional period in the history of infrared array development. If, as expected, the detectors highlighted here materialize within the next few years, infrared astronomers will have evolved from using noisy single detectors to almost "perfect" arrays of one million pixels within a period of little more than a decade. Coupled with the new instrumental opportunities created and the larger telescopes now under development, they will clearly open the way for the next big step in our exploration of the infrared universe.

Current CCD Projects at ESO and Their Relation to the VLT Instruments

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1. Introduction

The following is a brief description of CCD detectors foreseen to be used with VLT instruments currently under study or design and of the contracts under way to procure them.

In the actual sequence of work, the requirements on the detectors to be used are set in the instrument design phase and this is the starting point for the procurement activities. In this presentation, it is more convenient to describe the various developments now under way and then state their relevance to the different VLT instruments.

Different strategies of procurement are necessary because large CCD detectors for application in advanced astronomical instrumentation are not available as off-the-shelves products. Moreover it is not possible to define a standard CCD device, because the requirements change from instrument to instrument depending on its scientific aim. One can differentiate between the following types of CCDs:

- Well-specified "catalogue products" where a design and manufacturing process already exist and the device is to a basic extent tested at the manufacturer. For large sizes, however, the manufacturing itself still implies a number of risks (e.g. in thinning) thus making the delivery unforeseeable.

- Devices on a best-effort contract with detailed specifications but without manufacturer's guarantee to meet them and mostly without any manufacturer's involvement in device testing and characterization.
- Unique prototypes to test new developments which, when successful, can lead to the definition of new catalogue products.

It will be impossible to describe and compare all parameters of the various CCDs here, so that this article is focusing on the physical device format, pixel size, buttability, number of outputs, thick or thin version, the latter being the fundamental requirement to reach high quantum efficiency over the spectral range from UV to NI. The performance in read-out noise, well capacity, uniformity, etc. is equally important but would require a detailed discussion which is outside the scope of this article. The relevance of these parameters change also very much depending on the specific, astronomical application they are intended for.

2. 2048^2, 15-μm Pixel Size CCDs from Thomson TCS

Based on scientific requirements for current and future instruments, all main parameters of a CCD were set up in a baseline specification in November 1991 to look for a supplier being able to accept certain risks in the development of a thinned product of the required size.

After a formal call for tender procedure, Thomson TCS, Grenoble, was selected in June 1992 for the development of this product. The intention was to establish a specified product being characterized almost completely by the manufacturer himself, thus providing a "standard" product with guaranteed performance.

The specifications were developed in co-operation of ESO and TCS as a trade-off between scientific requirements and technical solutions – risks the manufacturer could accept in terms of predictability, yield and accuracy. The result is the product Thomson THX 7397 M, which – assuming the development is successful – is intended to be offered also to other customers.

It features a 2048^2 detector with 15-μm pixel size, 3-side buttable, two outputs and will be thinned with subsequent surface treatment not requiring UV flooding for optimal operation. The specifications are summarized in Table 1.

Table 1: *Summarized Specification for the main parameters of the thinned Thomson 2048^2, 15-μm Pixelsize devices*

PARAMETER	GUARANTEED PERFORMANCE
* CHIP TOPOLOGY	
Operation mode	Frame transfer, single field
Readout mode	– At least two identical on-chip output amplifiers on one chip side offering the possibility of simultaneous readout to reduce the overall readout time – The entire charge pattern of the light sensitive area may be read through either one of those output amplifiers or simultaneously through all of them, if so required
* GEOMETRICAL CHARACTERISTICS	
Pixel size	15 micron square format 100 % aperture
Pixel number	2048 × 2048
* MECHANICAL CHARACTERISTICS	
Flatness of light sensitive area	15 micron peak to peak
Package and Chip design	Three-side buttable
Dead surface gap	Less than 400 micron between sensitive areas (mounted in TMS package) of the specified CCDs
* ELECTRICAL PERFORMANCE	
Readout noise in slow scan operation	Less than 4 e^- (target): 10 e^- (upper limit) at Data rate 50 KHz with C.D.S. measurement performed at −40 °C
Full well capability	More than 100000 e^- measured at −80 °C (Design goal 130000 e^-)
Charge transfer efficiency per clock cycle	Better than 0.99995 measured at −80 °C (Design goal 0.99999)
Dark Current (D.C.)	Less than 0.1 e-/min/pixel at −80 °C Measurement performed at +20 °C: D.C. (−80 °C) = 3.10^{-6} × D.C. (+20 °C)
Additional Features	Binning facility for 2 × 2 pixels with full signal (design goal) Nominal operating mode is MPP Either Inverted or Non-inverted mode operation is possible
* OPTICAL PERFORMANCE	
Quantum efficiency	> 20 % at 350 nm (design goal: 30 %) > 45 % at 450 nm (design goal: 50 %) > 60 % at 600 nm > 25 % at 900 nm (design goal: 30 %) All QE values measured at −80 °C
Uniformity of QE across light sensitive area	Within 30 % peak to peak over the whole light sensitive area Typical value of High Frequency Photo Response Non Uniformity: ± 3 % Measurement at −80 °C
Cosmic Ray Sensitivity	< 3 events/(cm^2 * minute) at a CCD temperature of −80 °C
Defects	Not more than 10 bad columns Less than 500 hot or dark pixels

A number of mechanical/electrical samples and an engineering grade are to be delivered until January 1994 followed by the final delivery until May 1994 of five devices fully meeting all specifications.

Figure 1 shows a first frontside illuminated (thick) sample shown in the course of the CCD workshop 4/5 October in Garching. Looking at the photograph you might notice the rather unconventional package construction of the CCD, attempting to implement mechanical requirements for mosaicking right from the design start with minimal mechanical adjustment needs.

The final use of these detectors is foreseen at the echelle spectrographs (UVES) under construction for the Nasmyth foci of the VLT. One of the instrument configurations under study is based on the use of a 3 × 1 mosaic. If the manufacturing is successful, these devices could also be used to upgrade La Silla instrumentation and be implemented in second-generation VLT instruments. A mosaic of 2 × 2 devices of this type can also be considered as a backup solution for the Focal Reducer spectrographs for the VLT (FORS1 and FORS2).

3. 2048^2, 24-μm Pixel Size CCDs from SITE

The CCD department of Tektronix was sold in November 1993 to SITE (= Scientific Imaging Technologies), a wholly owned subsidiary of CBA Int. Three "catalogue" devices TK2048EB featuring 2048^2 format, 24-μm pixel size, non buttable, 2 (4) outputs, thinned, not requiring UV flooding are on order. The possibility to apply a special UV coating to even improve the quantum efficiency of the thinned CCD mainly between 300–350 nm is still investigated but, as a drawback, would require UV flooding. As this is a "catalogue" product, the devices are characterized partly by SITE.

The final use is foreseen at the red camera of EMMI at the NTT and the Focal Reducers at the VLT (FORS1 and 2).

The delivery of these devices is crucial, since EMMI red has been waiting for it for a number of years, thus operating presently at only 50 % of the foreseen efficiency. Envisaged delivery dates are January 1994, January 1995 and July 1995 but may change so that here the establishment of a reasonable backup solution is necessary.

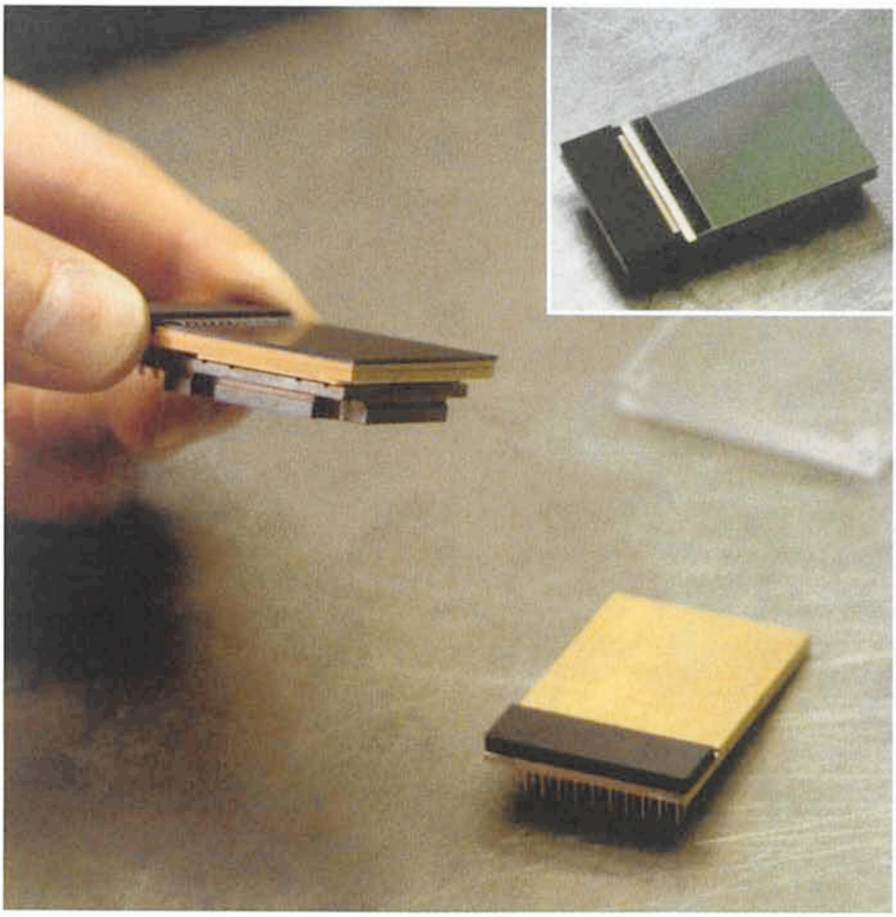

Figure 1: *The first-front side sample of the described Thomson 2048^2 CCD during inspection at ESO (left), together with a "package sample", i.e. the support without the chip (lower right). A view of the sample almost face-on is shown in the insert.*

4. 2048^2 Format, 15-μm Pixel Size and 2048^2 Format, 24-μm Pixel Size CCDs from LORAL South

In order to establish a backup solution for devices of 2K format with 15-μm pixel size, a foundry run of an existing design was ordered in June 1993 at LORAL. The design of this device was done by John Geary, Harvard Smithsonian Inst., and has the following main characteristics: 2048^2 detector with 15-μm pixel size, 3-side buttable, two outputs. Devices produced by LORAL are thick devices and can at LORAL only be enhanced with lumigen coating (not requiring UV flooding). As a consequence, the quantum efficiency in the blue is poor and could be improved by means of thinning and surface treatment. In this case the foundry approach basically delivers only the processed wafers of which by preliminary tests a selection of the CCDs must be done for frontside (thick) packaging, lumigen coating or for later thinning as described in the next paragraph. No device characterization or packaging solution for buttability is offered by the manufacturer, so that the customer has to find his specific solution. Delivery of the raw wafers is foreseen at the beginning of 1994.

Figure 2 shows another custom design of a special CCD under way at LORAL for ESO since April 1993. It features the following characteristics: 2048^2, 24-μm pixel size, 4 outputs, non buttable together with the following tracker CCDs on the same chip: 2 guiding CCDs of format 180×200 active imaging zone, 24-μm pixel size, 1 output and 2 guiding CCDs of format 180×400 active imaging zone, 24-μm pixel size, 1 output. Here the design was partly done by LORAL and partly at ESO in-house in a very flexible co-operation. Again the devices are thick and solutions for packaging, testing, enhancement, etc. have to be provided by the customer. These CCDs are intended to be mounted in the two direct CCD cameras which are foreseen as testing devices for the optical quality and the operation of the VLT Unit Telescopes. The field covered by the scientific CCD corresponds to approximately 1.5×1.5 arcmin. Besides the standard readout, the CCD will be used in 2×2 or 4×4 binned mode (pixel size 0.08 and 0.16 arcsec respectively).

Other possible uses of the devices are to serve as a backup solution for the CCDs of the FORS instruments (single use of the scientific CCD) and to be used for tests of the improvements in image quality by rapid guiding with one of the four small frame-transfer CCDs accommodated at the four corners on the same die (i.e. wafer substrate) as the scientific CCD (Figure 2). Delivery of the raw wafers is envisaged for March 1994.

5. CCD Thinning at Steward Observatory, University of Arizona

The group led by Mike Lesser at the Steward Observatory has been working extensively on the actual thinning process and surface treatment for about 10 years and demonstrated very promising results in 1992 with the thinning of Loral South CCDs. Although being capable of reaching high quantum efficiency, the devices do presently require UV flooding as the surface treatment is not a permanent solution in terms of the energy conditions for surface charge. At that time ESO placed a contract to thin and optimize four LORAL devices of 2K format, 15-μm pixel size, 2-side buttable design, and first results are expected until the end of 1993.

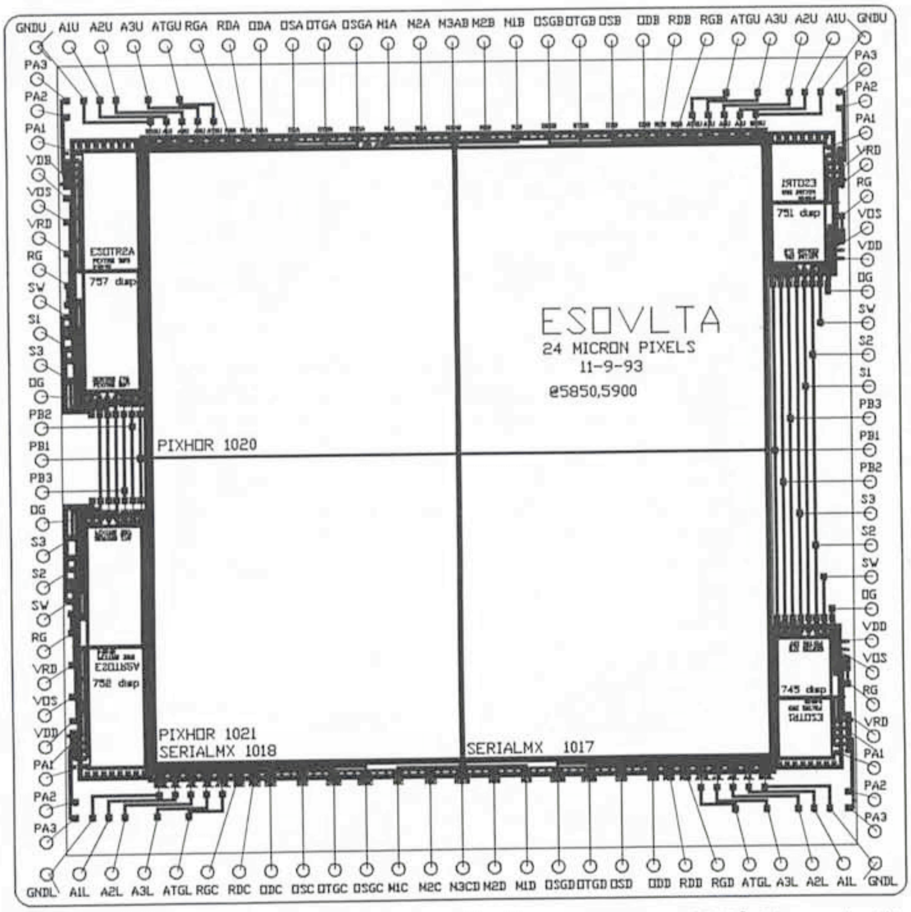

Figure 2: *Sketch of the CCD design foreseen for the VLT test camera: a 2048^2, 24-µm scientific CCD, surrounded by four tracker CCDs, of two different sizes.*

Currently, a follow-up contract for thinning and optimization of six 2048^2, 3-side buttable LORAL South CCDs (described in the previous paragraph) is in preparation. It foresees the delivery of the final thinned CCDs, requiring UV flooding, in June 1994. A packaging construction with similar mechanical interface as for the Thomson CCDs of identical format (described above) is under study in order to simplify potential exchanges of the two.

As a consequence, these devices represent an alternative to the Thomson CCDs and could be used in all applications for which these are planned.

6. Concluding Remarks

The more recent main CCD procurement activities for the VLT have been described here in a summarized form. The assessment of the probability of a given development to be completed successfully has to be updated on a weekly basis depending on the technical results obtained by the manufacturers in the various phases of their processing. Another source of worry is the fact that the CCD field has – especially in 1993 – undergone dramatic changes concerning the future of major suppliers, with recurring announcements of closures of manufacturing lines and of change of property.

The limitation on ESO manpower and budget considerations necessarily limit the number of parallel developments we can carry out, but the floating situation forces us, as well as any other group working in this field, to systematically explore alternative routes of procurement in industry and in research laboratories. These might become the single alternative solution of the future.

In many observing modes of the VLT, the photons collected by the 8-m mirrors end up on the few square cm of the CCD detectors and the success or failure of the best scientific programme of European astronomy can depend on the final performance of these devices. While sometimes one feels the weight of this responsibility, this is what ultimately makes the work in this field so exciting and any result towards better detectors so much rewarding.