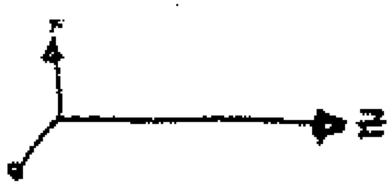
APPENDIX: EQUATIONS FOR MULTI-LAYER THIN FILM THEORY

IN GENERAL A MONOCHROMATIC PLANE WAVE IN A MEDIUM OF COMPLEX INDEX η WILL HAVE AN ELECTRIC FIELD AMPLITUDE

$$E(z,t) = E(z)\,e^{i\omega t} \qquad \omega = 2\pi f = 2\pi\left(\frac{c}{n\lambda}\right)$$

$$= a \exp\left[i\left(\omega t - \frac{2\pi}{\lambda}\eta z + \phi_1\right)\right] + b \exp\left[i\left(\omega t + \frac{2\pi}{\lambda}\eta z + \phi\right.\right.$$



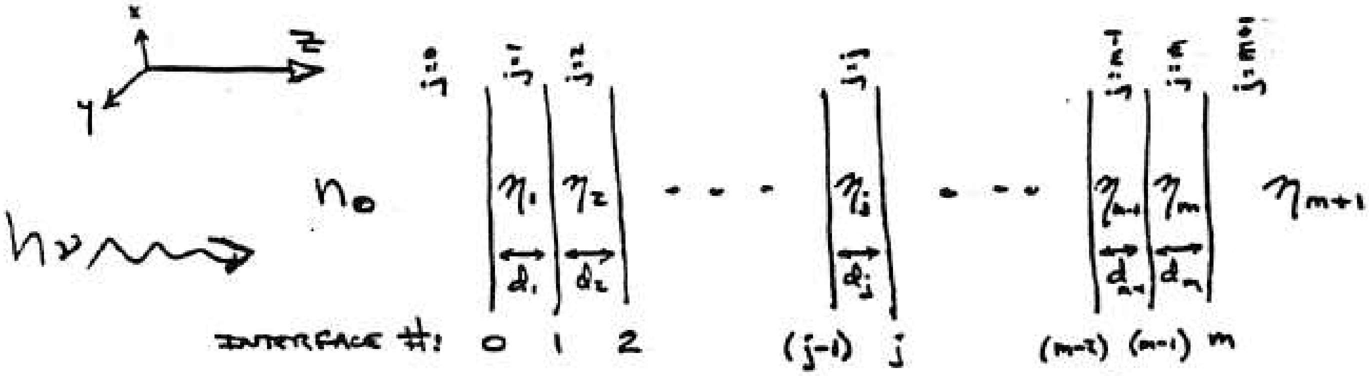
+z WAVES $\longrightarrow$ −z WAVES $\longleftarrow$

WHERE a, b, ϕ_1, ϕ_2 ARE CONSTANTS

TO SPECIALIZE TO THE CASE OF THIN FILMS, ONE DOES TWO THINGS; (1) IMPOSE BOUNDARY CONDITIONS AT EACH INTERFACE WHICH REQUIRE $E(z,t)$ [AND $H(z,t)$ AS WELL] TO BE CONTINUOUS, AND (2) CONSIDER ONLY THE TIME AVERAGED BEHAVIOR OF THE AMPLITUDE E. ONE CAN THEN WRITE A SYSTEM OF EQUATIONS FOR THE $E_j(z)$ WITHIN EACH LAYER j AND, IN PRINCIPLE, SOLVE FOR THE CONSTANTS a_j, b_j, ϕ_{1j}, ϕ_{2j} OF EACH WAVE TRAIN.

TO SIMPLIFY MATTERS LET ME INTRODUCE THE NOTATION OF P.H. BERNING IN _Physics of Thin Films_, v. 1 (1963) WHERE THE INTERESTED READER CAN ALSO FIND THE INTERMEDIATE STEPS IN DERIVING RESULTS I ONLY QUOTE HERE

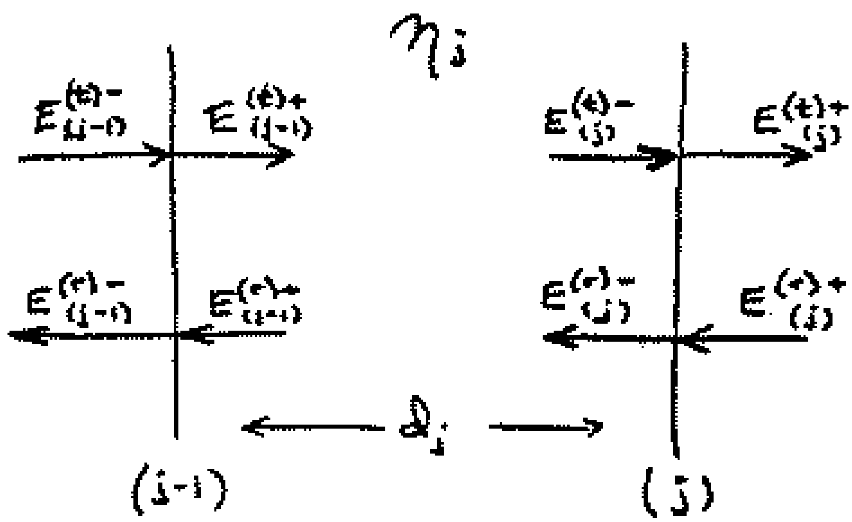
Consider m layers in a non-absorbing medium with refractive index n_0, which are followed by a medium of refractive index η_{m+1}. Assign to each layer a subscript "j" as follows



where also labelled are the layer thicknesses and the interfaces. Light is incident from the left. Again, we have complex refractive indices

$$\eta_j = n_j - i k_j$$

Now at each interface denote by a superscript (t) [transmitted] light going from left to right and by (r) [reflected] light going from right to left. The additional superscript "+" denotes the right side of the interface while "−" denotes the left. Hence at interfaces (j-1) and (j) one has electric field amplitudes ...



WHERE $E^{(t)-}_{(j-1)} \neq E^{(t)+}_{(j-1)}$ BECAUSE SOME OF THE INCIDENT ENERGY IS REFLECTED AND CONTRIBUTES THEREFORE TO $E^{(r)-}_{(j-1)}$. LIKEWISE $E^{(r)+}_{(j-1)} \neq E^{(r)-}_{(j-1)}$, AND THE SAME IS TRUE AT INTERFACE (j).

HOWEVER, IT IS POSSIBLE TO WRITE OUR SYSTEM OF EQUATIONS IN THIS NOTATION AND DERIVE RELATIONS BETWEEN THESE AMPLITUDES. THE BOUNDARY CONDITIONS REQUIRE OF COURSE THAT

$$E^{(t)-}_{(j)} + E^{(r)-}_{(j)} = E^{(t)+}_{(j)} + E^{(r)+}_{(j)}$$

AND
$$\eta_j \left[E^{(t)-}_{(j)} - E^{(r)-}_{(j)} \right] = \eta_{j+1} \left[E^{(t)+}_{(j)} - E^{(r)+}_{(j)} \right]$$

ALSO NOTE:
$$E^{(t)+}_{(j-1)} = E^{(t)-}_{(j)} \exp\left[i \left(\frac{2\pi}{\lambda} \eta_j d_j \right) \right]$$

AND
$$E^{(r)+}_{(j-1)} = E^{(r)-}_{(j)} \exp\left[-i \left(\frac{2\pi}{\lambda} \eta_j d_j \right) \right]$$

FOR SIMPLICITY DEFINE $\Phi_j = \left(\frac{2\pi}{\lambda}\eta_j d_j\right)$.
COMBINING THESE RELATIONS ONE CAN RELATE THE AMPLITUDES AT INTERFACE $(j-1)$ TO THOSE AT (j) AS FOLLOWS ...

$$E^{(t)-}_{(j-1)} = \frac{1}{2}\left(1+\frac{\eta_j}{\eta_{j-1}}\right)E^{(t)-}_{(j)}\exp\left[i\Phi_j\right] + \frac{1}{2}\left(1-\frac{\eta_j}{\eta_{j-1}}\right)E^{(r)-}_{(j)}\exp\left[-i\Phi_j\right]$$

AND LIKEWISE

$$E^{(r)-}_{(j-1)} = \frac{1}{2}\left(1-\frac{\eta_j}{\eta_{j-1}}\right)E^{(t)-}_{(j)}\exp\left[i\Phi_j\right] + \frac{1}{2}\left(1+\frac{\eta_j}{\eta_{j-1}}\right)E^{(r)-}_{(j)}\exp\left[-i\Phi_j\right]$$

SO THAT THE COMPUTER CAN SOLVE FOR THE ELECTRIC FIELD AMPLITUDES <u>RECURSIVELY</u> (AND IT'S GOOD AT THAT!).

THIS RECURSIVE SOLUTION MUST START AT THE m-th INTERFACE BECAUSE ONLY THERE DO WE HAVE THE ADVANTAGE OF KNOWING THAT $E^{(r)+}_{(m)} = 0$ ... NO LIGHT IS INCIDENT UPON THE LAST INTERFACE FROM THE RIGHT. $E^{(t)+}_{(m)}$ CAN BE SET $= 1$ AS A START AND ALL AMPLITUDES AND PHASES REFERENCED TO IT GOING FROM RIGHT TO LEFT UNTIL REACHING $j=0$.

WITH ALL THE $E_{(j)}^{(t,r)\pm}$ KNOWN, IT IS NOW A SIMPLE MATTER TO CALCULATE THE REFLECTION, TRANSMISSION, AND ABSORPTION OF THE LAYERS AS FOLLOWS ...

$$R = \left| \frac{E_0^{(r)-}}{E_0^{(t)-}} \right|^2$$

$$T = \frac{\mathrm{Re}\{\eta_{m+1}\}}{n_0} \left| \frac{E_m^{(t)+}}{E_0^{(t)-}} \right|^2$$

AND FOR THE ABSORPTION IN THE j^{th} LAYER ...

$$A_j = \frac{\mathrm{Re}\{\eta_j\}\left[\left|E_{(j-1)}^{(t)+}\right|^2 - \left|E_{(j-1)}^{(r)+}\right|^2 - \left|E_{(j)}^{(t)-}\right|^2 + \left|E_{(j)}^{(r)-}\right|^2 \right]}{n_0 \left|E_0^{(t)-}\right|^2}$$

$$+ \frac{2\,\mathrm{Im}\{\eta_j\}\left[\mathrm{Im}\left(E_{(j-1)}^{(r)+} E_{(j-1)}^{(t)+*}\right) - \mathrm{Im}\left(E_{(j)}^{(r)-} E_{(j)}^{(t)-*}\right) \right]}{n_0 \left|E_0^{(t)-}\right|^2}$$

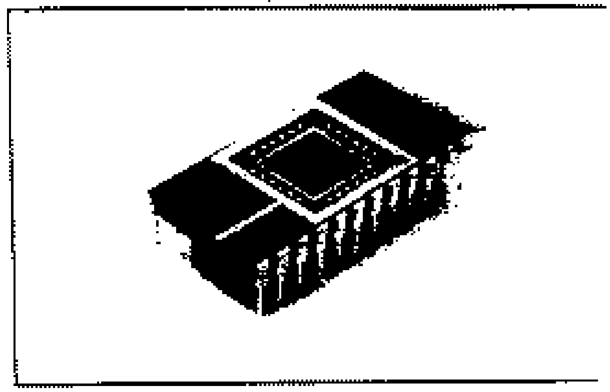
WITH NATURALLY GIVES

$$R + T + \sum_j A_j = 1$$

PRELIMINARY

Fairchild Imaging Sensors

CCD412
512 × 512 Element
Full Frame Image Sensor



FEATURES

- 512 × 512 Photosite Array
- 15μm × 15μm Pixel
- 7.68mm × 7.68mm Image Area
- 100% Fill Factor
- Multi-Pinned Phase (MPP) Option
- Readout Noise Less Than 7 Electrons
- Dynamic Range 10,000:1
- Single Output Channel
- Three Phase Buried Channel NMOS

GENERAL DESCRIPTION

The CCD412 is a 512 × 512 element solid state Charge Coupled Device (CCD) Full Frame area image sensor which is intended for use in high resolution scientific, industrial, and commercial electro-optical systems. The CCD412 is organized as a matrix array of 512 horizontal by 512 vertical CCD photosites. The pixel pitch and spacing is 15μm.

The imaging array may be operated in one of three modes, Buried Channel, Multi-Pinned Phase (MPP), and Surface Channel. The Buried Channel operation offers low noise performance and excellent charge transfer efficiencies. An additional implant under one vertical phase creates a virtual well which collects the photo-electrons with all Vertical clocks low during integration. This MPP mode decreases dark current down to 25 pA/cm² @ 25°C. The CCD412 may be operated in a Surface Channel mode, to increase full well capacity.

Excellent low noise performance is achieved by use of the buried channel CCD structure and a single stage low noise output amplifier.

Device processing is done using 2.5 micron design rules. The single metal, triple-poly process allows a photosite layout with smaller pixel geometries and fewer array blemishes.

FUNCTIONAL DESCRIPTION

The CCD412 consists of the following functional elements illustrated in the block diagram.

Image Sensing Elements: Incident photons pass through a transparent polycrystalline silicon gate structure and are absorbed in the silicon crystal structure creating electron hole pairs. The resulting photo-electrons are collected in the photosites during the integration period. The amount of charge accumulated in each photosite is a linear function of the localized incident illumination intensity and integration period.

The photosite structure is made up of contiguous CCD elements with no voids or inactive areas. In addition to sensing light, these elements are used to shift image data vertically. Consequently, the device needs to be covered during readout.

Vertical Charge Shifting: The Full Frame architecture of the CCD412 provides video information as a single sequential readout of 512 lines containing 512 photosite elements. At th[e] end of an integration period the ϕV_1, ϕV_2, and ϕV_3 clocks a[re] used to transfer charge vertically through the CCD array [to] the horizontal readout register. Vertical columns are separat[ed] by a channel stop region to prevent charge migration.

The Vertical Transfer Gate (VTG) is the final array gate befo[re] charge is transferred to the serial horizontal shift registers. F[or] simplified operation ϕVTG may be tied to ϕV_3.

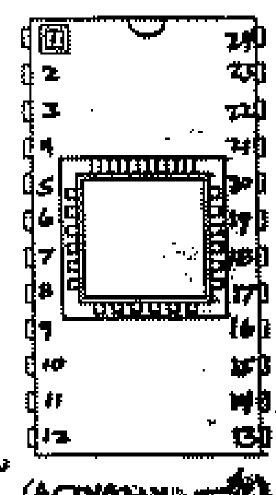
Horizontal Charge Shifting: ϕH_1, ϕH_2, and ϕH_3 are po[ly] silicon gates used to transfer charge horizontally to the ou[t]put amplifier. The horizontal transport register is twice the s[ize] of the photosite to allow for vertical binning. With binning t[he] array can be operated normally at full resolution, as a 256 [×] 512, 256 × 256, or some other resolution.

PIN NUMBER/NAME

1	ϕV1	13	VDD
2		14	VSS
3	ϕV3	15	
4		16	ϕH1
5		17	
6	ATGϕVTG	18	ϕH2
7	VOG	19	ϕH3
8		20	
9	ϕR	21	ϕVTG
10	RDVRD	22	
11		23	
12	Vvideo	24	ϕV2

NOTE THIS COLUMN INVERTED

PIN CONNECTIONS



Loral Fairchild Imaging Sensors
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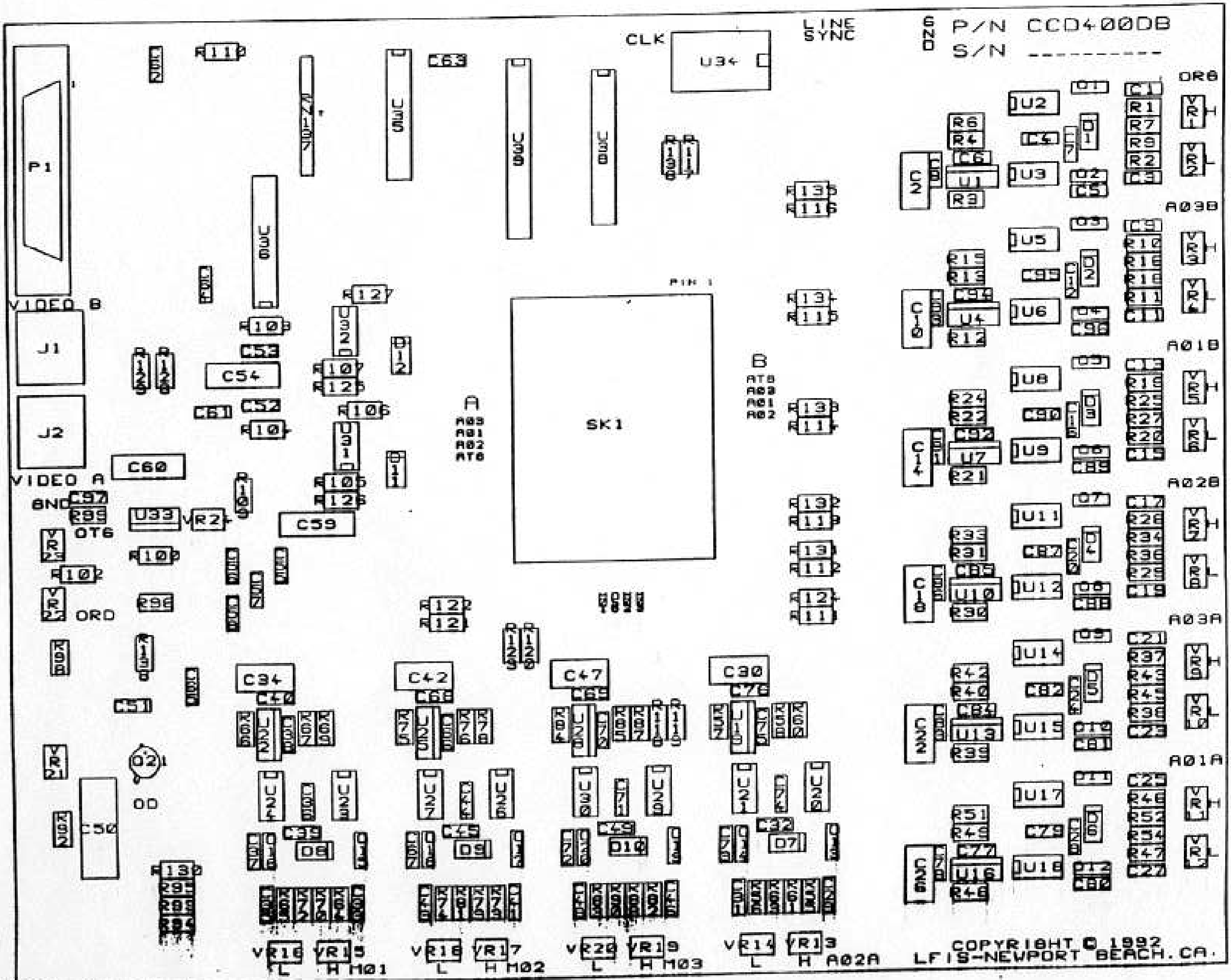
P/N CCD400DB
S/N ----------
LINE SYNC
CLK
SK1
VIDEO A
VIDEO B
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