Determine Desired Pixel Range

Determine Family Of Pitches

Determine Moiré Modulation Over Pixel Range For Pitches

Select LCD Display Having Pitch In Range

Choose Best Choice Prism Pitch

Display Or Store Result

Construct LCD System

Title: PRISM PITCH OPTIMIZATION

Abstract: An optical display system is disclosed. The system has an optical light source, a microstructured optical component, and an optical display. The microstructured optical component has a plurality of microstructures, and a nominal microstructure pitch. The optical display is arranged relative to the microstructured optical component and has a plurality of pixels having a pixel pitch. wherein the microstructure pitch is such that an intensity of a Moiré pattern produced by the display due to interaction of light directed by the microstructured optical component from the light source is substantially zero.
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PRISM PITCH OPTIMIZATION

BACKGROUND OF THE INVENTION

The present invention relates generally to an optical display system where Moire effects are reduced. The optical system can be a liquid crystal display (LCD) illumination system.

Microstructured optical components are common in optical display systems such as LCD illumination systems. For example, LCD illumination systems may include optical components with microstructures such as patterned dots, micro lenses, or microprisms. Typically the patterned dots on the light guide are used to spread the light in the plane of the display, while microprism films having multiple microprisms are used to enhance the luminance of the display. Even though the individual microstructures of these components, such as prisms for the microprism films are small, diffusing layers are still necessary between component films. This is so because each microstructured film and the LCD display (containing numerous pixels) all contain ordered-periodic structures. Due to the close proximity of these components, interference patterns, such as Moire fringes, caused by the interaction of the component-to-component microstructures can be easily observed by a user.

In particular prismatic or microprism films are a major contributor to Moire fringes in LCD display systems. Prismatic or microprism films are optical devices that have one or more sides covered by an array of microprisms. Typically these prismatic films have a linear array of microprisms with a pitch in the range of tens of microns. Even if these prismatic films deviate from perfect linearity, they are typically at least substantially periodic and thus prone to producing Moire effects in optical illumination systems, such as LCD illumination systems.
SUMMARY OF THE INVENTION

According to one embodiment of the invention there is provided an optical display system. The optical display system comprises: an optical light source; a microstructured optical component having a plurality of microstructures, and having a nominal microstructure pitch; and an optical display arranged relative to the microstructured optical component and having a plurality of pixels having a pixel pitch, wherein the microstructure pitch is such that an intensity of a Moire pattern produced by the display due to interaction of light directed by the microstructured optical component from the light source is substantially zero.

According to another embodiment of the invention there is provided an optical display system. The optical display system comprises: an optical light source; a least one prismatic film having a plurality of prisms having a nominal prism pitch; and an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch, wherein the prism pitch is such that an intensity of a Moire pattern produced by the display due to interaction of light directed by the at least one prismatic film from the light source is substantially zero.

According to another embodiment of the invention there is provided a method of determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a display for an optical display system comprising an optical light source, a least one prismatic film having a plurality of prisms having a prism pitch, and an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch. The method comprises: determining a range of desired pixel pitches; determining a family of prismatic film pitches; calculating a Moire modulation over the range of desired pixel pitches for the family of prismatic film pitches; selecting an optical display having a particular pixel pitch within the range of desired pixel pitches; choosing a prismatic film pitch from the family of prismatic film pitches that exhibits the lowest Moire modulation for the optical display with the
particular pixel pitch as a best choice pitch; and displaying the best choice pitch on a
display or saving the best choice pitch in a computer memory.

According to another embodiment of the invention there is provided a method of
determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a
display for an optical display system comprising an optical light source, a least one
prismatic film having a plurality of prisms having a prism pitch, and an optical
display arranged relative to the at least one prismatic film and having a plurality of
pixels having a pixel pitch. The method comprises: determining a range of desired
pixel pitches; determining a family of prismatic film pitches; calculating a Moire
modulation over the range of desired pixel pitches for the family of prismatic film
pitches; selecting an optical display having a particular pixel pitch within the range of
desired pixel pitches; choosing a prismatic film pitch from the family of prismatic
film pitches that exhibits the lowest Moire modulation for the optical display with the
particular pixel pitch as a best choice pitch; and constructing the optical display
system having a prismatic film with the best choice pitch and an optical display
having the particular pixel pitch.

According to another embodiment of the invention there is provided a method of
determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a
display for an optical display system comprising an optical light source, a least one
prismatic film having a plurality of prisms having a prism pitch, and an optical
display arranged relative to the at least one prismatic film and having a plurality of
pixels having a pixel pitch. The method comprises: determining a first optical display
system and a second optical display system having a same Moire modulation, the first
optical display system having a Moire period less than 1.6 mm, the second optical
display system having a Moire period greater than 1.6 mm; choosing the first optical
display system as the chosen optical display system; and constructing the chosen
optical display system.
BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of an optical display system according to one embodiment of the invention.

FIG. 2 is a cross-sectional view of a prismatic film of the optical display system of FIG. 1.

FIG. 3 is a top view of the optical display of the optical display system of FIG. 1.

FIG. 4 is a top view of a portion of an exemplary sample of a prismatic film according to an embodiment of the invention.

FIG. 5 is a graph illustrating the relative Moire (RM) as a function of the prism random modulation ((standard deviation of the prism peak position/prism pitch) for both predicted and experimental values.

FIG. 6 is a digitized image of a modulated structure and of a linear array reference with the same nominal prism pitch.

FIG. 7 illustrates Moire fringes for different standard deviations of the peak position from the mean peak position.

FIG. 8 is a graph comparison of the Moire modulation for the horizontal direction for a system with a prismatic film with random modulation of the prism structures and for a system without random modulation of the prism structures.

FIG. 9 is a graph comparison of the Moire modulation for the vertical direction, for a system with a prismatic film with random modulation of the prism structures and for a system without random modulation of the prism structures.

FIG. 10 is a graph illustrating the Moire modulation for each individual prism pitch design of a family of three prism pitches as a function of pixel pitch for a system with random modulation of the prism structures.

FIG. 11 is a graph illustrating the Moire modulation for the best choice of prism pitch in the family of prismatic films of FIG. 10 and compared to the Moire modulation for a system without random modulation of the prism structures.

FIG. 12 is a graph illustrating the Moire modulation for each individual prism pitch design of a family of seven prism pitches as a function of pixel pitch for a system without random modulation of the prism structures.
FIG. 13 is a graph illustrating the Moire modulation for the best choice of prism pitch in the family of prismatic films of FIG. 10 for a system with random modulation of the prism structures compared to the best choice of prism pitch in the family of prismatic films of FIG. 12 for a system without random modulation of the prism structures.

FIG. 14 is a flow chart illustrating a method of determining the best choice of a family of prismatic films for used with a particular pitch and geometry.

FIGs. 15A and 15B illustrate replicant spectra for 153µm and 200 µm pitch pixel displays, respectively.

FIG. 16 illustrates the MTF as a function of vertical and horizontal prism pitch along with the pitches for which the Moire fringe period approaches infinity for one system.

FIG. 17 illustrates the MTF as a function of vertical and horizontal prism pitch along with the pitches for which the Moire fringe period approaches infinity for another system.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a perspective view of an optical illumination system, specifically an LCD illumination system 10. The system 10 includes an optical light source 20, at least one microstructured optical component, such as the prismatic film 30, and an optical display, such as the LCD display 40. The optical light source 20 illuminates the prismatic film 30 with light, which is directed by the prismatic film 30 to the LCD display 40. The optical light source 20 may be, for example, a backlight.

The prismatic film 30 includes a number of prisms 32 arranged in substantially a linear fashion, with a pitch Pf (See FIG. 2). While FIG. 1 illustrates the prismatic film 30 arranged between the optical light source 20 and the LCD display 40, the LCD display 40 may be arranged between the prismatic film 30 and the light source 20. Further, the prismatic film 30 may be arranged between the optical light source 20 and the LCD display 40, with a second prismatic film arranged on a side of the LCD display 40 opposite to the prismatic film 30, or even on the same side. The system may include a prismatic film with its prisms oriented along a perpendicular direction.
to the direction of the prisms in the prismatic film 30, i.e., one of the prismatic films may have prisms with a vertical orientation, and the other a horizontal orientation, for example.

The LCD display 40 includes a number of pixels 42, each pixel comprising subpixels 42a, 42b and 42c, where the subpixels 42a, 42b and 42c may be red, blue and green, respectively, for example. The subpixels 42a, 42b and 42c are positioned progressively along the horizontal direction.

As shown in FIG. 2, the array of prisms 32 of the prismatic film 30 are characterized by a pitch $P_f$, which is the distance between the peaks of adjacent prisms 32. FIG. 2 illustrates the array to be linear, but the array of prisms 32 may be substantially linear on even non-linear.

FIG. 3 illustrates the structure and geometry of the pixels 42 and subpixels 42a, 42b and 42c of the LCD display 40. For the sake of illustration, FIG. 3 illustrates only four pixels 42, but in general the display 40 may include many more pixels. The pixels 42 are arranged in a rectangular pixel geometry in FIG. 3, but in general the invention is not so limited to any particular geometry, and may be arranged in a hexagonal geometry, for example.

The pixels 42 in the rectangular geometry are characterized by a horizontal pixel pitch, $P_{ph}$, and a vertical pixel pitch, $P_{pv}$. The horizontal pixel pitch, $P_{ph}$, is the distance between corresponding points on adjacent pixels 42 in the horizontal direction, while the vertical pixel pitch, $P_{pv}$, is the distance between corresponding points on adjacent pixels 42 in the vertical direction.

The pixels 42 are characterized by both a horizontal fill factor, $F_{hf}$, and a vertical fill factor, $F_{vf}$. The horizontal fill factor represents the fractional distance of a pixel 42 covered by one of the subpixels, while the vertical fill factor represents the fractional distance covered by one of the pixels in the vertical direction. Typical pixel pitches
may be between 50 µm and 1000 µm, while typical fill factors may be between 0.1 and 0.99 (0.23 and 0.92 even more typically).

Presuming that the subpixels are the same size, the horizontal and vertical pixel pitches, $P_{ph}$ and $P_{pv}$ respectively, and the horizontal and vertical fill factors, $F_h$ and $F_v$ respectively, are given by:

$$P_{ph} = a + b, \quad F_h = a / (a + b)$$
$$P_{pv} = c + d, \quad F_v = c / (c + d),$$

where $a$ is the width of one subpixel, $b$ is the difference between the width of a pixel and one subpixel, $c$ is the length of one subpixel, and $d$ is the vertical spacing between adjacent subpixels.

The analysis for the case of a display system with a prismatic film will depend upon the orientation of the axis of the prismatic film relative to the pixels of the display. An analysis is now provided for the case where prismatic film is oriented with an axis in the horizontal direction, i.e., the prisms run in the horizontal direction, and for the case where prismatic film is oriented with an axis in the vertical direction, i.e., the prisms run in the vertical direction. For this analysis each color channel can be treated independently. The results can be summed to determine the overall effect.

The possible Moire patterns depend upon whether the prismatic film has a vertical orientation or a horizontal orientation: 1) the prisms with a horizontal axis will interact with the vertical pitch direction of the LCD display to produce gray fringes; and 2) the prisms with a vertical axis will interact with the horizontal pitch direction to produce color fringes. For situation 1), the fringes are gray because the color sub pixels are in-phase in the vertical direction. For situation 2), the fringes are colored because the color sub pixels are out of phase in the horizontal direction due to the spatial offset of each of the color channels. Situation 2) results in a relative phase shift in the Moire fringes between red, blue and green.

The pixel modulation transfer function (MTF) characterizes the ability of the pixels to transmit or resolve the Moire pattern due to the interaction of the light from the prism...
films with the pixels to produce visible fringes. This function has values between 0 and 1, where 0 indicates that no Moire pattern is produced and 1 indicates the maximum Moire pattern, i.e., maximum intensity of the fringes. The MTF provides a relative quantity, the absolute strength of the Moire pattern depends on many factors such as the specific geometric details of the prisms, the optical source, and prism refractive index, for example.

The MTF for the specific rectangular geometry described above depends on the pitch of the prisms, and the pixel fill factor and pitch as:

\[
MTF = \left| \text{sinc}\left[ \frac{P_r F}{P_f} \right] \right|
\]

where \(P_f\) is the prismatic film pitch, and \(F\) and \(P_p\) are the pixel fill factor and pixel pitch in a more generic form without horizontal and vertical subscripts. The sine function is given by

\[
\text{sinc} (x) = \frac{\sin(\pi x)}{\pi x}
\]

It can be seen that the MTF has values of zero, corresponding to no Moire pattern, when

\[
\frac{P_p F}{P_f} = m \quad \text{or} \quad P_f = \frac{P_p F m}{m}
\]

where \(m\) is an integer. The latter equation provides optimal values of prism pitch, i.e., no Moire pattern for a particular pixel geometry when the equation is satisfied.

For pixels with different horizontal vertical fill factors, a horizontal MTF, \(MTF_h\) and a vertical MTF, \(MTF_v\), may be expressed as:

\[
MTF_h = \left| \text{sinc}\left[ \frac{P_{ph} F}{P_{ph}} \right] \right| \quad \text{MTF} v = \left| \text{sinc}\left[ \frac{P_{pv} F}{P_{pv}} \right] \right|
\]

so that

\[
P_{jh} = \frac{P_{ph} F}{m_h} \quad \text{and} \quad P_{jv} = \frac{P_{pv} F}{m_v}
\]
are the relationships to satisfy for no Moire pattern for a horizontally and vertically oriented prismatic film, respectively, and \( n_{ih} \) and \( n_{iv} \) are integers.

While the relationship above illustrates the MTF being zero, and thus \( m, n_{ih} \) and \( n_{iv} \) being integers, this condition may be relaxed somewhat and \( m, n_{ih} \) and \( n_{iv} \) may be nearly integers so that the MTF is low, but not zero. For example, \( m, n_{ih} \) and \( n_{iv} \) may be integers \( \pm 0.2 \).

Further, in practice the prismatic films may be offset slightly from a perfectly horizontal or vertical orientation, so that they are substantially horizontal or vertical in orientation. In this case the horizontal prism pitch may be an effective horizontal prism pitch. The effective horizontal prism pitch will be the perfect horizontal prism pitch multiplied by \( l / \cos(\theta) \), where \( \theta \) is the rotation of prismatic film relative to perfectly horizontal. In a similar fashion, the horizontal prism pitch may be an effective horizontal prism pitch. The effective vertical prism pitch will be the perfect vertical prism pitch multiplied by \( l / \cos(\theta) \), where \( \theta \) is the rotation of prismatic film relative to perfectly vertical.

Further, while the above analysis describes a prismatic film with either horizontal or vertical orientation, in practice the optical display system may include two prismatic films, one with horizontal orientation and the other with vertical orientation such that both the conditions

\[
P_{\beta h} = \frac{P_{\beta h} F_0}{m_{\beta h}} \quad \text{and} \quad P_{\beta v} = \frac{P_{\beta v} F_0}{m_{\beta v}}
\]

are met.

Depending upon the geometry of the pixels and the prisms, it may not be possible to select a prism pitch that reduces the MTF to zero. In this case, however, the prism pitch may still be selected to reduce MTF to a minimum value. Also, the identical fill factor assumption may not hold in all cases. This may require a compromise solution, such as using the mean fill factor for all color channels as the effective fill factor, for example.

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In addition to minimizing Moire by a proper choice of prism and pixel pitch for a given geometry as described above, Moire may also be reduced using a randomization technique that randomly modulates the regular structure of the prisms of the prismatic film. This randomization technique may be combined with and complements the pitch selection technique described above to reduce Moire.

FIG. 4 is a top view of a portion of exemplary sample of a prismatic film where the regular prismatic structure has been randomly modulated. The sample prismatic film has a surface defined by an array of prism structures having a nominal pitch of approximately 37 µm (spacing between adjacent peaks of the prism structures). Each of the prism structures extends generally in the horizontal direction parallel to the other prism structures. The position of the prism peaks was modulated in the horizontal direction (the horizontal direction in the plane of the paper in FIG. 4) by approximately up to ± 18 µm. The position of the prism peaks may be modulated independently for different prisms. While FIG. 4 illustrates a prismatic film where the path of the prism peak position is randomly modulated laterally, the invention is not so limited, and other parameters of the prism structures may be modulated, such as the phase, peak height, and peak angle, for example.

The effect of random modulation on the Moire fringe pattern intensity may be expressed in terms of the relative Moire RM(σ), as RM(σ) = |Mm(σ)/Mm(0)|, where the σ is a measure of the amount of randomization and is the standard deviation in lateral prism peak position about the prism peak mean position, which corresponds to the nominal pitch. Mm(σ) = (Imax- Imm)/(Imax + Imm), where Imax is the maximum value of the intensity of the Moire fringe pattern and Imm is the minimum value of the intensity of the Moire fringe pattern. Mm(0) is a value for the amount of randomization σ, and Mm(0) is a value for no randomization, i.e., the prism structures are not modulated.

FIG 5 illustrates the RM as a function of the ((standard deviation of the prism pitch)/(prism pitch)). Both prediction values and experimental values are shown.
The RM of surface structures of this design was studied as a function of prism modulation standard deviation and compared to a linear array of the same nominal pitch. This was accomplished via the use of a backlight module and camera to photograph Moire patterns formed by the interaction of horizontally oriented prismatic films placed side-by-side underneath various LCD displays. The RM was computed from digitized images of a modulated structure and a linear array reference with the same nominal prism pitch and prism geometry photographed simultaneously. A representative image is shown in Figure 6. The reference array appears on the left hand side of FIG. 6 and is used to compute the RM of the right-side film.

The RM was computed as the amplitude of Moire fringes for the modulated prism structure (left side of FIG. 6) divided by the amplitude of Moire fringes for the linear array prism structure (right side of FIG. 6) with the same geometric parameters (nominal pitch and prism geometry). The RM indicates the ratio by which the modulated prism structure reduces Moire compared to a linear array in the same context.

For the predicted results in FIG. 5, it should be noted that a Moire signature for a film can be shown by simply sampling the surface in a way that is representative of the masking provided by the LCD display structure. For the results shown in FIG. 7, a 50 mm section of the simulated structure is sampled every 123 μms to simulate the effect of viewing the surface though an array of 123 μm pixels assuming a low fill factor in one dimension. The prism pitch is 31 μm so that the pitch of the fringes is expected to be 3.81 mm or 12 fringes across the image in FIG. 7. Each row in the image shown in FIG. 7 illustrates the Moire fringes for the aliased sampled cross section from a modulated surface. From bottom to top in FIG. 7, σ is increased from σ = 0 μm to σ = 32 μm. In the figure the predicted fringes are clearly visible for σ <10 μm.

The predicted results were plotted and compared to the experimental results of the structure of FIG. 6, and the comparison is shown in FIG. 5. The predicted curve shown is somewhat jagged due to the fact that a new random sequence for modulating
the prism structures is applied at each case. Additionally the particular random sequence used in the prediction model is not the same as for the experimental films. This jagged effect is more pronounced at larger standard deviations where the Moire fringes are substantially obscured. Each point on the predicted curve is the result of spatial analysis of the intensity of Moire fringes for each pixel row in the image shown in FIG. 7. FIG. 7 illustrates Moire fringes for different standard deviations of the peak position from the mean peak position. The experimental results are obtained similarly using the sum of the Moire fringe intensity for each column of each sample shown in Figure 6 (Note that the orientation of this image is rotated relative to Figure 7). Here it is shown that for ratio of standard deviation over pitch greater than 0.3 the RM is less than 0.1. This is due to the Moire fringes having been substantially eliminated.

The combined effect of the random modulation on prism structure and the prism pitch optimization can be expressed as the Moire Modulation, M-bar (symbolized by M with a bar thereover), where the subscripts h and v denote the Moire Modulation in the horizontal and vertical directions, i.e. due to prismatic films oriented in the horizontal and vertical directions, respectively:

$$\bar{M}_h = RM(\sigma) MTF_h = RM(\sigma) \left| \text{sinc} \left( \frac{P_{ih} F_h}{P_{ph}} \right) \right|$$

$$\bar{M}_v = RM(\sigma) MTF_v = RM(\sigma) \left| \text{sinc} \left( \frac{P_{iv} F_v}{P_{pv}} \right) \right|$$

The pitch and fill factor relationships are not changed by the addition of the RM term, but the range of Moire Modulation, M-bar, relative to MTF is reduced below 1 by relative Moire RM.

The parameters of optical display system may vary, but certain parameters are preferred. The RM is preferably less than 0.75, and more preferably less than 0.50. The Moire Modulation is preferably less than 0.04. The microstructure pitch $P_f$ is preferably between 1µm and 200 µm, and more preferably between 26µm and 48 µm.
The pixel pitch $P_p$ is preferably between 25µm and 10 mm, and more preferably between 50µm and 700µm. The fill factor $F$ is preferably between 5% and 100%, and more preferably between 14% and 100%.

FIGs. 8 and 9 are a comparison of the Moire Modulation for the horizontal direction and vertical direction, respectively, for a system with a prismatic film with random modulation of the prism structures and for a system without random modulation of the prism structures. The vertical fill factor for FIG. 9 is 0.89, while the horizontal fill factor for FIG. 8 is 0.27. The system with a random modulation has a nominal prism pitch of 37 µm, while the system without random modulation has a prism pitch of 50 µm. The maximum value of M-bar is assumed to be 0.5 for the system with random modulation, and 1.0 for the system with no random modulation. As shown in FIGs. 8 and 9, the average Moire modulation for the prismatic film with random modulation is about 0.04 for pixel pitches between 100 µm and 600 µm, while for the prismatic film without random modulation the average Moire modulation is about 0.12 over the same pixel pitch range. While the prism pitches are not the same for the systems with and without random modulation, it can be seen from FIGs. 8 and 9, that the random modulation significantly reduces the average Moire modulation.

The lower pitch and randomized design of the system using the randomly modulated prism structure results in substantially reduced Moire compared to the system without random modulation in most cases of pixel pitch. This is especially remarkable since the prismatic film with the random modulation has higher brightness than that without.

As discussed above, the Moire fringe intensity may be reduced to zero or near zero by choosing an appropriate prism pitch for a given pixel pitch and geometry. However it is also possible to obtain good performance across a wide range of pixel pitches and fill factors with only a limited choice in prism pitches. For example if the spatial frequency (one divided by $P_f$) of a starting prism design is given by $f_o$, then a family of film designs can be defined such that for $n$ different choices in the family
\[ f_i = f_o + \frac{f_o i}{n} \quad \text{where } i = 0, n - 1 \]

In this family of films the spatial frequencies are spaced equally between \( f_o \) and two others.

Results for this approach using 28.8 \( \mu \text{m} \), 36 \( \mu \text{m} \) and 48 \( \mu \text{m} \) pitches at \( f_o \) are shown in FIGs. 10 and 11.

FIG. 10 illustrates the Moire modulation for each individual prism pitch design as a function of pixel pitch for a pixel fill factor of 30\% for a family of three prism pitches for a system with random modulation of the prism structures. FIG. 11 illustrates the Moire modulation for the best choice of prism pitch in this family of three prismatic films (lowest Moire modulation for each pixel pitch) as compared to the Moire modulation for a prismatic film without random modulation of the prism structures.

As shown in FIG. 11, the average modulation for the best choice in the family of prismatic films is about 0.02 for pixel pitches between 100 \( \mu \text{m} \) and 600 \( \mu \text{m} \).

The concept of using a family of pitches can be also applied to prismatic films without random modulation of the prism structure as shown in FIGs. 12 and 13, where \( n \) is larger (\( n \) equals 7 in FIG. 12) to achieve a similar performance to that with random modulation. As shown in FIG. 13, the average Moire modulation for the best choice in the family of seven prismatic films without random modulation of the prism structures is about 0.02 for pixel pitches between 100 \( \mu \text{m} \) and 600 \( \mu \text{m} \). FIG. 13 illustrates the Moire modulation for the best choice of prism pitch for the family of three prismatic films (see FIG. 10) for a system with random modulation of the prism structures compared to the best choice of prism pitch in the family of seven prismatic films (see FIG. 12) for a system without random modulation of the prism structures.

As can be seen, the system with only three prismatic films and random modulation compares quite well to the system with seven prismatic films but no random modulation.
In general the procedure for determining the best choice of a family of prismatic films for use with a particular pixel pitch and geometry is as follows as illustrated in FIG. 14. In step 101, the range of desired pixel pitches is determined. A family of prismatic film pitches is then determined in step 102. Determining the family of prism pitches may be performed as discussed above using spatial frequency and equal spacing over a range of frequencies, or some other technique may be employed. In general, it is preferred that family of prism pitches be roughly evenly spaced over the range of prism pitches selected for the family. In step 103 the Moire modulation is determined over the range of desired pixel pitches for the prism pitches in the family of prism pitches, such as by the techniques discussed above for determining the Moire modulation. In step 104, an LCD display having a particular pitch in the range of desired pixel pitches is selected. In step 105, the prismatic film with a pitch exhibiting the lowest Moire modulation is chosen from the family of pitches as the best choice for selected LCD display having a particular pixel pitch within the range of the desired pixel pitches.

Steps 101 to 105 may be performed using an appropriate computer program embodied in a medium executable on a computer system. The results of the best choice prism pitch or the particular pixel pitch may be stored in a memory of the computer system or displayed on a display of the computer system, if desired, in step 106. In step 107, an LCD system is constructed using a prismatic film with the best choice pitch and the selected LCD display.

The Moire fringes of the Moire pattern are characterized by Moire frequencies of the fringes. The particular frequencies should also be considered when choosing the components (LCD display and prismatic film, for example) for the display system. The Moire frequencies due to a periodic prismatic film (or other periodic microstructured film) is given as

\[ F_m = m/P_p - l/P_f, \]

where \( P_p \) is the LCD pixel pitch in the direction under analysis (vertical or horizontal) and \( P_f \) is the pitch of the prisms, and \( m \) is an integer. The period that corresponds to
each frequency is given by $P_m = \sqrt[3]{F_m}$. Of particular interest is the lowest aliased frequency since this replicant will typically be the replicant that is observable.

Figures 15A and 15B illustrate the aliased period vs. periodic prism period for two different pixel pitches. FIGs. 15A and 15B illustrate replicant spectra for 153 µm and 200 µm pitch pixel displays, respectively. In interpreting this figure, one must consider that there is a complex interaction in the human eye to the pattern in the LCD display and the texture of the components in the display, such as the prismatic film, and how these components interact. The human visual system has the highest spatial contrast sensitivity to patterns with an angular frequency of 5 cycles/degree (spatially equivalent to 1.6 mm for a viewing distance of 18 inches) and decreased sensitivity for values above or below this angular frequency. As such it is advisable to avoid Moire fringes that have angular frequencies close to this value providing high spatial contrast sensitivity.

Given two displays that exhibit Moire Modulation of equal proportions, if one of the displays exhibits Moire Modulation with higher frequency artifacts, this display may be viewed as superior. In general it is best to choose a combination of $P_f$ and $P_p$ such that the period of Moire fringes is less than 1.6 mm when possible. This consideration can be combined with the aim of low Moire modulation as described above.

In general for a first optical display system and a second optical display system having a same Moire modulation, the best optical display system may be chosen and constructed as follows. First, the first optical display system and the second optical display system having the same Moire modulation are determined, where the first optical display system has a Moire period less than 1.6 mm, and the second optical display system has a Moire period greater than 1.6 mm. Then the first optical display system is chosen as the chosen optical display system, and the chosen optical display system is constructed.
For systems that include both a prismatic film with horizontal orientation as well as a prismatic film with vertical orientation of prisms where the prismatic films have the same pitch, the best choice system will involve choosing the prism pitch to reduce the MTF for both vertical and horizontal directions, while staying away from prism pitches that produce Moire fringes with a large period (low frequency Moire fringes).

FIGs. 16 and 17 illustrate this concept for two different systems, one where the vertical fill factor is an integer times the horizontal fill factor (FIG. 16), and one where vertical fill factor is not an integer times the horizontal fill factor (FIG. 17).

FIG. 16 illustrates the MTF as a function of film pitch both for horizontal and vertical orientation of a prismatic film. The system in FIG. 16 has an LCD display with a pixel pitch of 153 μm, a horizontal fill factor of 0.3, and a vertical fill factor of 0.9. The thin line illustrates the MTF as a function of prism pitch for a vertically orientated prismatic film, while the thick line illustrates the MTF as a function of prism pitch for a horizontally orientated prismatic film. The open circles in FIG. 16 represent the prism pitch that correspond to Moire fringe periods that approach infinity. Prism pitches near the open circles are to be avoided. In the system of FIG. 16, because the ratio of the vertical fill factor to the horizontal fill factor is an integer, a zero MTF value for a vertical prism pitch lines up with a zero MTF for a horizontal prism pitch. Of the prism pitches 23.0 and 45.9 that correspond to zero MTF for vertical (and horizontal) pitch, the best choice is 45.9 because it is further from one of the open circles corresponding to a large Moire fringe period.

FIG. 17 illustrates the MTF as function of film pitch both for horizontal and vertical orientation of a prismatic film, but where the ratio of the vertical fill factor to the horizontal fill factor is not an integer. The system in FIG. 17 has an LCD display with a pixel pitch of 153 μm, a horizontal fill factor of 0.27, and a vertical fill factor of 0.89. The thin line illustrates the MTF as a function of prism pitch for a vertically orientated prismatic film, while the thick line illustrates the MTF as a function of prism pitch for a horizontally orientated prismatic film. As in FIG. 16, the open
circles in FIG. 17 represent the prism pitch that correspond to Moire fringe periods that approach infinity (and are to be avoided). In FIG. 17 because the MTF zeros for the horizontal and vertical cases do not line up, the best choice for a pitch does not result in a zero MTF when the horizontal and vertical prismatic films have the same pitch, and thus the best choice has a low but not zero MTF. As an example of a best choice, a pitch of 43.2 results in a low overall MTF, but is not near an open circle (large Moire period).

FIGs. 16 and 17 could also be used to determine a best choice prism pitch if only a single prismatic film (vertical or horizontal) is to be used. In this case a pitch should be chosen such that the MTF value is zero, and the pitch is not near one of the open circles (large Moire period).

While the invention has been described with reference to several embodiments thereof, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed as the best mode contemplated for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims.
CLAIMS

1. An optical display system comprising:
   an optical light source;
   a microstructured optical component having a plurality of microstructures, and
   having a nominal microstructure pitch; and
   an optical display arranged relative to the microstructured optical component
   and having a plurality of pixels having a pixel pitch, wherein the microstructure pitch
   is such that an intensity of a Moire pattern produced by the display due to interaction
   of light directed by the microstructured optical component from the light source is
   substantially zero.

2. The optical display system of claim 1, wherein the pixels are arranged on the
   optical display to have a fill factor $F$, and the following relationship between the fill
   factor $F$, the microstructure pitch $P_f$ and the pixel pitch $P_p$ is satisfied:

   $$\frac{P_p}{P_f} \cdot F = m$$

   where $m$ is an integer.

3. The optical display system of claim 1, wherein the pixels are arranged on the
   optical display to have a fill factor $F$, and the following relationship between the fill
   factor $F$, the microstructure pitch $P_f$ and the pixel pitch $P_p$ is satisfied:

   $$\frac{P_p}{P_f} \cdot F = m$$

   where $m$ is an integer $\pm 0.2$.

4. An optical display system comprising:
   an optical light source;
a least one prismatic film having a plurality of prisms having a nominal prism pitch; and
an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch, wherein the prism pitch is such that an intensity of a Moire pattern produced by the display due to interaction of light directed by the at least one prismatic film from the light source is substantially zero.

5. The optical display system of claim 4, wherein the pixels are arranged on the optical display to have a fill factor $F$, and the following relationship between the fill factor $F$, the prism pitch $P_f$ and the pixel pitch $P_p$ is satisfied:

$$\frac{P_P}{P_f} = m,$$

where $m$ is an integer $\pm 0.2$.

6. The optical display system of claim 4, wherein the pixels are arranged on the optical display to have a fill factor $F$, and the following relationship between the fill factor $F$, the prism pitch $P_f$ and the pixel pitch $P_p$ is satisfied:

$$\frac{P_P}{P_f} = m,$$

where $m$ is an integer $\pm 0.2$.

7. The optical display system of claim 4, wherein the pixels each comprises subpixels progressively positioned along the horizontal direction, and the at least one prismatic film comprise a prismatic film having prisms oriented substantially along the horizontal direction, wherein a horizontal fill factor $F_h$ of the pixels, a horizontal pixel pitch $P_{ph}$ of the pixels, and an effective horizontal prism pitch $P_{βh}$ satisfy the relationship:

$$P_{ph} = \frac{P_{ph} F_e}{m_h},$$

where $m_h$ is an integer $\pm 0.2$. 
8. The optical display system of claim 4, wherein the pixels each comprises subpixels progressively positioned along the horizontal direction, and the at least one prismatic film comprise a prismatic film having prisms oriented substantially along the vertical direction, wherein a vertical fill factor $F_v$ of the pixels, a vertical pixel pitch $P_{pv}$ of the pixels, and an effective vertical prism pitch $P_{p}$, satisfy the relationship:

$$P_{pv} = \frac{P_{p} \cdot F_v}{m_v}, \text{ where } m_v \text{ is an integer } \pm 0.2.$$

9. The optical display system of claim 7, wherein the at least one prismatic film further comprises a second prismatic film having prisms oriented substantially along the vertical direction, wherein a vertical fill factor $F_v$ of the pixels, a vertical pixel pitch $P_{pv}$ of the pixels, and an effective vertical prism pitch $P_{p}$ of the second prismatic film satisfy the relationship:

$$P_{pv} = \frac{P_{p} \cdot F_v}{m_v}, \text{ where } m_v \text{ is an integer } \pm 0.2.$$

10. The optical display system of claim 4, where the optical display is a liquid crystal display (LCD) display.

11. The optical display system of claim 1, wherein the structure of the microstructures of the microstructured optical component is randomly modulated.

12. The optical display system of claim 4, wherein the structure of the prisms of the prismatic film is randomly modulated.

13. The optical display system of claim 7, wherein the structure of the prisms of the prismatic film is randomly modulated.
14. The optical display system of claim 8, wherein the structure of the prisms of the prismatic film is randomly modulated.

15. The optical display system of claim 1, wherein the Moire pattern has a Moire modulation of less than 0.04.

16. The optical display system of claim 1, wherein the Moire pattern has a period of Moire fringes less than 1.6 mm.

17. The optical display system of claim 3, wherein the microstructure pitch $P_f$ is between 1 µm and 200 µm.

18. The optical display system of claim 17, wherein the microstructure pitch $P_f$ is between 26 µm and 48 µm.

19. The optical display system of claim 3, wherein the pixel pitch $P_p$ is between 25 µm and 10 mm.

20. The optical display system of claim 19, wherein the pixel pitch $P_p$ is between 50 µm and 700 µm.

21. The optical display system of claim 3, wherein the fill factor $F$ is between 5% and 100%.

22. The optical display system of claim 21, wherein the fill factor $F$ is between 14% and 100%.

23. A method of determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a display for an optical display system comprising an optical light source, a least one prismatic film having a plurality of prisms having a prism...
pitch, and an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch, the method comprising:

determining a range of desired pixel pitches;
determining a family of prismatic film pitches;
calculating a Moire modulation over the range of desired pixel pitches for the family of prismatic film pitches;
selecting an optical display having a particular pixel pitch within the range of desired pixel pitches;
choosing a prismatic film pitch from the family of prismatic film pitches that exhibits the lowest Moire modulation for the optical display with the particular pixel pitch as a best choice pitch; and
displaying the best choice pitch on a display or saving the best choice pitch in a computer memory.

24. The method of claim 23, wherein the determining a family of prismatic film pitches comprises determining the pitches of the family to be \( X f_i \) where

\[
f_i = f_0 + \frac{f_o}{n} i, \quad \text{where } i = o, n - X,
\]

where \( i \) is between 1 and \( n \), the number of pitches in the family, and \( f_o \) is 1 divided by the largest pitch in the family.

25. A method of determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a display for an optical display system comprising an optical light source, a least one prismatic film having a plurality of prisms having a prism pitch, and an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch, the method comprising:

determining a range of desired pixel pitches;
determining a family of prismatic film pitches;
calculating a Moire modulation over the range of desired pixel pitches for the family of prismatic film pitches;
selecting an optical display having a particular pixel pitch within the range of desired pixel pitches;
choosing a prismatic film pitch from the family of prismatic film pitches that exhibits the lowest Moire modulation for the optical display with the particular pixel pitch as a best choice pitch; and

constructing the optical display system having a prismatic film with the best choice pitch and an optical display having the particular pixel pitch.

26. The method of claim 25, wherein the determining a family of prismatic film pitches comprises determining the pitches of the family to be $Xf_i$ where

$$f_i = f_o + \frac{f_i}{n}, \text{ where } i = o, n - X,$$

where is $i$ between 1 and $n$, the number of pitches in the family, $n$ of $f_o$ is 1 divided by the largest pitch in the family.

27. A method of determining an optimum prism pitch of a prismatic film for a selected pixel pitch of a display for an optical display system comprising an optical light source, at least one prismatic film having a plurality of prisms having a prism pitch, and an optical display arranged relative to the at least one prismatic film and having a plurality of pixels having a pixel pitch, the method comprising:

- determining a first optical display system and a second optical display system having a same Moire modulation, the first optical display system having a Moire period less than 1.6 mm, the second optical display system having a Moire period greater than 1.6 mm;

- choosing the first optical display system as the chosen optical display system; and

- constructing the chosen optical display system.

28. The optical display system of claim 1, wherein the relative Moire (RM) is less than 0.75.

29. The optical display system of claim 28, wherein the relative Moire (RM) is less than 0.50.
Fig. 14

1. Determine Desired Pixel Range
2. Determine Family Of Pitches
3. Determine Moire' Modulation Over Pixel Range For Pitches
4. Select LCD Display Having Pitch In Range
5. Choose Best Choice Prism Pitch
6. Display Or Store Result
7. Construct LCD System