Part One
Backlights by Use
1

Technical Trends and Requirements/Specifications for LCD TV Backlights

S. Y. Lee

SAMSUNG Electronics

1.1 Introduction

Information display devices play a major role in the transition to information-oriented and ubiquitous societies. The global move toward information societies is causing a sharp increase in the demand for information display devices. Liquid crystal display (LCD) is competing fiercely with plasma display and digital light processing technologies for the large-screen TV market. Until now, the TV market has been expected to be divided into two segments: plasma technology will dominate large screen sizes – above 30 inches – while LCDs will primarily address the smaller size market. Contrary to this prediction, however, the rapid development of LCD technology and the resulting price competitiveness have allowed it to penetrate into the 40-to 50-inch segment as well as the 30-inch range.¹ Some market researchers
forecast that the demand for LCDs will outnumber that for PDPs in the 40-inch TV market by 2009. Although LCDs are more expensive than PDPs, that prediction can be made mainly because of an advantage of LCD TVs over PDP TVs: LCD TVs can deliver full high definition (HD) resolution, see Table 1.1.

In order to increase profitability and market share, the LCD industry is speeding up efforts to develop new technologies. However, it has difficulty in ensuring price competitiveness because the material costs of LCD modules are higher than those of PDPs. To overcome this, researches are being conducted on technologies for (1) lowering costs of LCD panels by increasing the size of mother glass, (2) reducing costs of backlight units that account for about 40% of the total material costs of LCD modules and (3) improving quality.

The backlight unit is a light source for LCDs which are not self-luminous. It accounts for around 90% of the total power consumption and 40% of the material costs. As LCDs become larger and have higher resolution, backlight units are getting more important in both performance and cost-effectiveness. Currently, LCD TVs require brightness of at least 500 cd/m². Since both larger screens and higher resolution decrease the transmittance of LCD panels, the light sources need to be brighter than 500 cd/m² while consuming less power than competing display technologies. In addition, research on advanced backlight driver technologies such as scanning, local dimming and field sequential technologies is being carried out to improve picture quality. To meet such requirements, desirable backlight units of LCDs should have the following features: lower power consumption, higher brightness, wider color gamut, etc. This chapter describes basic components of and requirements/specifications for backlight units and reviews trends of backlight technologies.

| Table 1.1 Comparison of resolution of LCDs and PDPTVs. |
|---|---|---|
| Size | Type | LCD | PDP |
| 30-inch range | HD 1366 × 768 | SD 640 × 480 |
| 40-inch range | HD 1366 × 768 | HD 1024 × 768 |
| 50-inch range | FHD 1920 × 1068 | HD 1366 × 768 | FHD 1920 × 1080 |
1.2 Structure of LCD TV Backlights

Backlight units should satisfy the standards covering: (1) electrical characteristics such as power consumption, leakage current, energy efficiency and electromagnetic interference; (2) external appearance; (3) optical properties such as brightness, color uniformity and color gamut; (4) mechanical properties such as weight and thickness and (5) other aspects including reliability, mass productivity and quality of services.

Based on the location of the light source, backlights for LCDs can be divided into direct types and edge-lit types. Typically, direct types are used for TVs while edge-lit types are used for monitors and notebook computers.[4]

As shown in Figure 1.1, LCD TV modules of the direct type backlight units consist of multiple layers. Considered as a one-dimensional light source, lamps are placed linearly on the bottom chassis with reflective sheets. A diffuser plate and a diffuser sheet are mounted over the lamps to generate a uniform distribution of light, so that finally backlights can provide a two-dimensional distribution of light. In addition to spreading light from the lamps, the diffuser plate made of polymethylmethacrylate (PMMA) also functions as a support for holding up diffuser sheets. A prism sheet is used to increase the brightness measured normal to the surface after light is scattered through the diffuser sheet. Since the light passing through the prism sheet is not polarized, a reflective polarizer is added to recycle light lost to absorption, by controlling polarization and reflection.[5] Figure 1.2 shows how light distribution changes when light passes through each optical sheet used in a backlight unit. Typical backlight inverters are attached on the back of the bottom chassis, but recently those integrated with TV driving boards are also available in the market.

As stated above, optical sheets are needed to convert one-dimensional light sources into two-dimensional ones and to increase the brightness of LCDs. However, because they are expensive, research and development efforts are ongoing to minimize the use of optical sheets by merging multiple optical sheets into one or two sheets or by increasing the brightness of lamps. In particular prism sheets and reflective polarizer sheets, both of which are costly, need to be replaced or removed. Since they are also closely related to the performance of light sources, efforts are being made to improve existing light sources and develop new ones. In addition, the industry is conducting a number of activities to improve optical materials including the development of multifunctional sheets.
1.3 Trends in LCD TV Backlights

Candidate light sources for backlights include cold cathode fluorescent lamps (CCFL), external electrode fluorescent lamps (EEFL), flat fluorescent lamps (FFL), light emitting diodes (LED), hot cathode fluorescent lamps (HCFL) and field emission lamps (FEL). Regardless of the type of light source used, currently some of the optical sheets mentioned above are chosen and combined depending on brightness and uniformity.

1.3.1 CCFL, EEFL, and HCFL

A cold cathode fluorescent lamp, used in most LCD TVs, has hollow cathode electrodes at both ends. The inside of a borosilicate glass tube with outside diameter of about 3–4 mm is coated with phosphors and a protective layer; then the tube is filled with neon, argon and mercury at 7–9 kPa (50–70 Torr). When a voltage is applied to the electrodes at the ends of the glass tube, electrons are accelerated by an electric field. When electrons collide with mercury vapor, they cause the vapor to emit ultraviolet light at 185 nm and
253.7 nm. Phosphors absorb the ultraviolet light and glow. Almost all backlights except those for cell phones use a CCFL. Compared with HCFLs, CCFLs have advantages of small diameter (up to 3–5 mm), high luminance and proven productivity and reliability.

However, it should be noted that for TV applications a certain number of lamps are needed to ensure high luminance and uniformity, depending on the size of the displays. Due to the negative resistance characteristic of plasma in discharge tubes, each lamp requires a transformer for over-current protection, leading to higher cost. Recently research is being conducted to drive several lamps simultaneously. Some companies have developed and
commercialized the parallel circuitry which makes it possible to operate two to four lamps simultaneously.

As an alternative to the CCFL to reduce the backlight cost of LCD TVs, the EEFL has electrodes on the outside of the wall at both ends of the glass tube and operates using the wall charge generated when AC power is supplied. The basic principle of visible light emitted by the EEFL is almost the same as that of the CCFL. However, the glass bulb serves as a ballast capacitor and the electric current of negative-characteristic plasma can be controlled. In this sense, the EEFL can offer a major advantage in that it is possible to run all the lamps with just one or two transformers, resulting in cost reduction. In addition, the assembly process of EEFL-based backlights may be simplified by using a clip style, external electrodes give longer life and eventually the EEFL may be more reliable and easier to mass produce than the CCFL. Figure 1.3 shows the structural differences of backlights and inverters between the CCFL and the EEFL.

In spite of all these advantages, the EEFL has a serious problem of pinhole formation. As shown in Figure 1.4, high voltage and high current create pinholes around electrodes on the glass bulb.\textsuperscript{7,8} Two mechanisms have been reported to be the cause of pinhole formation: dielectric breakdown due to

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1_3.png}
\caption{Structure of backlight and inverter of (a) CCFL and (b) EEFL.}
\end{figure}
heat generation of electrodes and the following Joule heating and thermal breakdown due to simple thermal runaway.\cite{9} The detailed mechanism is still unclear and further investigation is required. However, it is clear that a sufficient margin of operating power range can be obtained just by reducing the heat generation of electrodes, which can be easily achieved through careful electrode and system design.

It was expected that the EEFL would in due course replace the CCFL because of its several advantages at the early stage of development. However, the CCFL still keeps its position as the major light source for LCD backlight units. This has been possible through continuous cost reduction and performance improvement of the CCFL. For example, the two in one and/or four
in one inverters using fewer transformers were introduced and alternative lamp assembly systems such as socket types were suggested. In other words, the CCFL is benchmarking the EEFL continuously. Furthermore, the EEFL has limitations in its applicable size. For large-size LCDs the operating voltage of the EEFL needs to be increased, but regulations limit the operating voltage of backlights to 2 kV to prevent ozone pollution. This may be overcome by increasing the area of electrodes if we neglect another potential problem of increases in bezel size.

To lower the cost, some LCD companies are trying to remove optical sheets by increasing lamp luminance. When the inner diameter of a lamp is decreased from 3 mm to 2 mm, its luminance increases due to the increase of electron temperature in the plasma state, and higher brightness can be achieved without the help of a prism sheet or reflective polarizer. However, UV and heat generation rate also increase and the increased flux of UV and heat may be harmful to several polymer materials, especially to polycarbonate (PC). Mold frames and reflective polarizer adhesives, mainly made of PC, show yellowing after long-term operation, decreasing reflectivity and transmittance and leading to defects. Several methods have been suggested to reduce yellowing: improving additives such as UV stabilizers, using UV cutting glass, coating lamp glass with TiO₂, etc..

Recently, Phillips and some other companies have tried to apply the HCFL of diameter under T5 (16 mm), typically used for general lighting, to LCD backlight. The HCFL has a very small cathode fall which is the main energy loss in glow discharge. Therefore it is more efficient and costs less than the CCFL. It was also reported that scanning does not decrease brightness, leading to better picture quality. However, current HCFL backlight systems have the disadvantage of generating a large amount of heat and their lives are shorter than those of CCFLs. Blackening of electrodes is another problem which results in the decrease in active area of panels and the increase in bezel size. To use the HCFL as a light source in LCD TV backlights, acceptable thermal management and the development of electrode materials and parallel operation technologies are priorities.

1.3.2 FFL

As a new approach, a two-dimensional light source has been studied for use in LCD TVs. The technology of a surface light source is intended to achieve further cost reduction by decreasing the number of sheets used in existing backlights. Unlike the CCFL and the EEFL shown in Figure 1.3, a flat fluorescent lamp is a two-dimensional built-in type light source as described in
Figure 1.5; therefore, it may possibly increase luminous flux and achieve higher efficiency. It is also desirable from an assembly point of view because backlight manufacturing processes can be simplified and automated.

Surface light sources can be classified in various ways according to their shape and the gases used. This chapter focuses on those currently available in the market: mercury and non-mercury FFLs. In 1946, the first surface light source was introduced, using the serpentine structure and the structure filament terminals at both ends.\(^\text{[10]}\) For life and efficiency improvement, there have been changes in electrodes such as hollow cathodes and external electrodes. A surface light source with the serpentine structure is advantageous: it simplifies manufacturing processes and reduces weight because the discharge space can be kept between the top and bottom molding glasses without a separate spacer. However, there are many shortcomings: it is hard to secure the technology related to the glass formation process; because electrodes are at the ends of the serpentine structure, a high voltage is necessary; sputtering of electrodes causes extra power consumption and leakage current; there may be non-emissive areas between channels and it is also hard to apply to large sizes.

As a result of recent studies, a 32-inch surface light source has been introduced.\(^\text{[11]}\) Compared with a non-mercury lamp that uses xenon, a mercury lamp is a better choice because ultraviolet light is emitted better and it is converted into visible light more efficiently.

To prepare against environmental regulations about various pollutants in RoHS (Restriction of Hazardous Substances) which became effective in July
1, 2006, research efforts have been made to develop non-mercury lamps. Compared to mercury that provides longer wavelength (253.7 nm), xenon gas provides 147 nm and 173 nm. This difference in the wavelength of UV light causes low efficiency because the conversion losses are substantial. Also the higher ionization potential of Xe atoms results in energy loss due to elastic collisions between electrons and Xe atoms. In spite of these shortcomings, in 2004 Osram announced a 30-inch non-mercury surface light source that uses xenon discharges. Unlike PLANON I which has spacers between the top and bottom glasses, PLANON II has simplified the structure for manufacturing processes by introducing the reformation of the top glass and rearranging the electrodes with outside terminals.\textsuperscript{[12]} Despite the superiority of the manufacturing technology itself, it has the disadvantages of huge heat due to the low efficiency (35 lm/W) and high power consumption. However, demand for non-mercury lamps keeps increasing and the development of non-mercury backlights along with LEDs is required.

To use FFLs in backlights for LCD TVs, there are several problems to solve. Improvement of lamp efficiency is a top priority. Without efficiency improvement, there is no way to remove optical sheets, resulting in no cost benefits. In the manufacturing process of FFL backlights, of course, cost reduction through the automation of assembly process can be promising. Because the material cost for the FFL is higher than that for the CCFL, it should be noted that the FFL’s competitive power comes from efficiency improvement. Another important issue is the brightness stabilization time. It is normally required that the brightness level should rise up to 90% of the maximum brightness level within one minute after being turned on. In the case of surface light sources, there is a shortcoming that the brightness stabilization time at low temperatures (0 °C) tends to be increased because its heat capacity becomes bigger as the thickness and dimension of glasses increase. To compensate for this problem, high current needs to be applied at the early stage of the brightness stabilization time. However, in an external electrode type FFL which is under consideration for commercialization, high currents may cause a pinhole problem. Therefore, it is necessary to consider an advanced mechanical and structural design as well as material optimization.

1.3.3 LED

Since 2003, there has been a great deal of interest in LEDs as a next generation light source in backlights for TVs. An LED is a semiconductor device that converts electrical power to incoherent narrow-spectrum light. Nor-
mally, it uses III-V or II-VI compound semiconductors. Compared to other light sources, an LED has a longer life and requires a lower forward voltage. An LED has enough advantages to direct our attention to consider it as an advanced light source in backlighting. Its advantages include short response time, excellent color reproduction (>100%) if RGB LEDs are used, environmental-friendliness, durability and the degree of freedom for design.\textsuperscript{[13]}

Recently the efficiency of LEDs, which is a major drawback for adoption in the field, has greatly improved and the future of LEDs is becoming more promising. LEDs can be used in an LCD application in three ways: (1) white LED using blue LEDs with yellow phosphor, (2) white LED using UV LED and RGB phosphor, and (3) red, green and blue single-colored LEDs to make white. For LCD TVs, application of RGB single-colored LEDs is more favorable than the others because of its superiority in color reproduction.

In the usage of RGB single-colored LEDs as a cluster, there are many variations including: multiple chips in a package, RRGGB, RGGB and RGB combinations for a cluster. Small size LEDs require a larger number of LEDs. Basically, all these approaches are competing and coexist. It is difficult to forecast which one is going to be a winner, because the performance of LEDs is still advancing and cost effectiveness is improving very fast. The application of small size LEDs with a larger number of LEDs has its own advantages on color mixing and thickness reduction, more localization for local dimming, whereas it has disadvantages in packaging, assembly and cost effectiveness. Thus, the choice between small LEDs and large LEDs should be made based on a kind of trade-off between the cost and performance requirements, and also it is strongly dependent on the chip technology and other component technologies for LED backlight units.

So far, the advantage of the color reproduction of LED backlights has mainly been promoted for LCD TVs. By using RGB single-colored LEDs, the color gamut can be extended up to 105% or more compared to the CCFL backlights that have a color gamut of about 72% of NTSC standards. Because wide color expression which becomes possible by the color gamut extension can help reproduce true color, it may contribute to picture quality improvement. Since the selection of LEDs binning process is unavoidable to satisfy the requirements of the dominant wavelength and full width at half maximum (FWHM) for reliable color reproduction using LED, it becomes a critical factor that decreases the efficiency of the chip production and thereby increases cost. Besides, color gamut can be extended to 92% by improving the characteristics of phosphors for the CCFL and it can be expected to be improved further up to 100% soon. For this reason, the color reproduction as one of the merits of LED becomes less appealing. However, there is a kind
of trade-off between color gamut and power consumption. In general, we need more electrical power as the color gamut increases. In other words, wide color gamut CCFLs consume more power than the normal CCFLs do. Therefore, as the efficiency of LEDs increases, LEDs can have more advertisement columns emphasizing lower power consumption.

It can be considered as a very strong point of LED backlights that a high contrast ratio and lower power consumption can be achieved by local dimming technology. By considering an LED as a point light source, the local dimming of LEDs increases the contrast ratio dramatically, which CCFLs and FFLs can do only slightly. However, for the local dimming, LEDs have to receive video signals in advance and feedback the converted signals into the backlight unit. So there are several things to be carefully considered such as the complex circuitry, appropriate radiation pattern of light and additional components.

Since a large number of LEDs, each of which is considered as a point light source in the LCD backlights, need to spread light to have enough uniformity and color mixing, we need some additional considerations to overcome such as color mixing and color shifting. Color shifting is color variations from one LED to another depending on the grouping of LEDs, and also from temperature dependency of LEDs. A more difficult part is that the temperature dependencies of LEDs differ from the colors of LEDs. However, the biggest hurdle is the higher cost caused by low efficiency, resulting in large number of LEDs to have the required brightness. To achieve comparable cost, there should be various efforts and trials such as higher chip yield rate, better materials and structures, higher efficiency, advanced LED packaging techniques, removal of redundant components for thermal management and elimination of optical sheets.

1.4 Requirements/Specifications for LCD TV Backlights

Table 1.2 shows the general specifications for the backlights in LCD TVs.

1.4.1 Luminance

LCD TVs in general require brightness of 500 cd/m². Table 1.3 shows the brightness requirement for the backlight unit (BLU), assuming that the transmittance of the LCD panel is 3.5%. The brightness of a diffuser sheet and a reflective polarizer means that the brightness is measured at the top of the reflective polarizer. By considering polarization characteristics of the reflective polarizer, there is a gain of about two through its recycling when photons
travel to the LCD panel. Due to the increase in resolution of LCD TVs, for example, from HD (1366×768) to FHD (1920×1080), the aperture ratio drops by 15%. To compensate for the drop, the brightness requirements described in Table 1.2 need to be increased by an additional 15% to fulfill the specification of the full HD.

In the near future LCD TVs will require a brightness of 600 cd/m². This requirement can be met by improving the transmittance of the LCD panel and/or by increasing the brightness of backlights. In either case, a trade-off between cost and performance, an optimization of the power budget of the backlight and the development of advanced optical sheets to increase brightness should be considered.

### 1.4.2 Color Reproducibility

#### 1.4.2.1 Improvement of the Color Reproducibility of the CCFL

Recently, Sony and Kasei Optonics have reported the improvement of the CCFL color gamut from 72% to 92% by applying a newly codeveloped phosphor. Figure 1.6 shows its emission spectrum compared with that of normal CCFLs. In the figure, the same blue phosphor is used. In the spectrum of red phosphors, the main emission peak shows 5 nm red-shift and the second

---

**Table 1.2** General specifications of LCD modules for TVs.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Year 2006</th>
<th>Year 2010</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance (cd/m²)</td>
<td>500</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td>Color reproduction (% NTSC)</td>
<td>72</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Correlated color temperature (K)</td>
<td>10000</td>
<td>13000</td>
<td></td>
</tr>
<tr>
<td>Life (hour)</td>
<td>50000</td>
<td>75000</td>
<td></td>
</tr>
<tr>
<td>Thermal management (max. °C)</td>
<td>50</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Power consumption (W)</td>
<td>150</td>
<td>70</td>
<td>40-inch</td>
</tr>
</tbody>
</table>

**Table 1.3** Brightness of LCD TV backlights (requirement varies with panel transmittance).

<table>
<thead>
<tr>
<th>Diffuser sheet only</th>
<th>Diffuser sheet + DBEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brightness of BLU (cd/m²)</td>
<td>14000</td>
</tr>
</tbody>
</table>
sub-peak of 586 nm disappears. In the case of green phosphors, the second sub-peak of 490 nm, which degrades the color gamut by transmitting both green and color filters, has been removed. As a result, the color gamut is enhanced by about 20% higher than that of normal phosphors. However, luminance and life of the wide color gamut CCFL are reduced by 25% and 40% respectively, compared to the normal phosphors. Additional improvement of the color gamut even to 100% is also possible if the color filter thickness and materials are further optimized. However, an improvement of the color gamut by increasing the color filter thickness may result in a decrease of panel transmittance, followed by high power consumption of the backlights.

1.4.2.2 Improvement of Color Reproducibility with LED

Emission spectra of the normal CCFLs and RGB LEDs are compared in Figure 1.7. Each LED shows a single main emission peak: red at 630 nm, green at 530 nm and blue at 450 nm. Showing of no other sub-peak, which is often observed in the spectrum of CCFL, indicates that the emission spectrum of the LEDs is well-matched with the absorption spectrum of the color

![Figure 1.6](image_url)  

**Figure 1.6** Comparison of transmission characteristics through color filter of CCFLs with 72% and 92% color reproducibility.
filter. The color gamut of LEDs is about 104%, improved by over 30% higher than that of normal CCFLs. Figure 1.8 shows the enhancement of color gamut by introducing LED BLU in the CIE1931 color space. The color gamut of CCFLs is also shown for comparison.

### 1.4.3 Correlated Color Temperature

Table 1.4 describes the corresponding color coordinates on BLU and lamps in order to make the LCD module color temperature 10000 K. Considering chromaticity changes from the lamp to the BLU, it is possible to notice that the change in the direction of $y$-chromaticity is greater than one in the $x$-chromaticity direction. It is due to more absorption of the short wavelength through the diffuser plates, diffuser sheets, prism sheets, and reflective polarizers. Considering the change in chromaticity from the BLU to the module, this can be explained from the optical characteristics of red and blue color filters of Figures 1.6 and 1.7. A blue color filter absorbs more photons of short wavelength, while a red one absorbs relatively fewer photons of long wavelength. In other words, because the transmittance of light of short
Figure 1.8 Comparison of color gamut of backlights adopting CCFLs with 72% and 92% color reproducibility and LEDs (104%).

Table 1.4 Color coordinates of lamps and backlights to satisfy the color coordinates of an LCD module.

<table>
<thead>
<tr>
<th></th>
<th>Module</th>
<th>BLU</th>
<th>Lamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color coordinate</td>
<td>(0.280, 0.290)</td>
<td>(0.265, 0.235)</td>
<td>(0.245, 0.205)</td>
</tr>
</tbody>
</table>

wavelength is lower than that of light of long wavelength, the chromaticity change in y-direction is greater than that in the x-direction.

As shown in Table 1.4, the corresponding chromaticity for the lamps leans to the bluish side. Therefore, the higher color temperature we need at the LCD panel, the lower is the efficiency of the lamps. For example, to set the color temperature of an LCD module to 13000K, the chromaticity coordinates for a lamp is approximately (0.235, 0.185). This makes a lamp very bluish, significantly lowering the lamp efficiency.

1.4.4 Thermal Management

Generally, the operating temperature of LCD TVs ranges from 0°C to 50°C and the temperature in liquid crystals also needs to be less than 65°C. Considering that the phase transition temperature of liquid crystals is generally
about 70 °C, it is obvious that the temperature margin is not enough. The temperature increase of the backlight unit is caused by both the driving of lamps and TV sets but mostly by the heat generated by lamps. Therefore, thermal management of the backlight units is essential for protection against heat. This can be achieved by improving lamp efficiency and mechanical structure.

1.5 Conclusions

Our discussion covers the requirements and technology trends for various kinds of light sources in backlights for LCD TVs. So far the CCFL has dominated the backlight market, while today’s LCD backlight market shows transition to the next generation with advanced light source technologies including EEFL, FFL and LED. This is the result from the LCD industry’s continuous development efforts to gain an advantage over competing technologies such as PDPs. The CCFL is expected to keep its position for some time. EEFLs and FFLs are claiming their own advantages and will maintain their position with a certain portion of the market. However, they are not enough for a paradigm shift of light source technology. As a light source in the backlight unit, LEDs may become more popular and can be a potential choice to offer the paradigm shift. The advantages of the LEDs have been promising and also many companies are investigating their possibilities. However, for real implementation, further cost reduction of the LEDs is necessary. In the high-end products with small volume, an early market entry of the LED is possible. To position LEDs as the mainstream light source in LCD TVs, LED manufacturers and customers still need to wait till LEDs arrive at prices comparable to CCFLs.

In conclusion, it is expected that CCFLs and LEDs will be the major competing technologies for now and in the future. The key factors are: how fast these two different light sources can absorb technical advantages from each other, how to improve their performance and how to optimize the relationship between price and performance. Such an effort can become meaningful when LCDs have a better position than other flat panel displays in the large-size TV market.

References