

Capacitive Effect on Current Balancing of Cold-Cathode Fluorescent Lamps

The current imbalance between parallel-connected CCFLs is a common problem for a multi-lamp backlighting system, resulting in uneven lighting. However, current imbalance can be alleviated through a proper mechanical design of the lamp fixture.

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COLD-CATHODE fluorescent lamps (CCFLs) are widely used in backlighting for liquid-crystal displays (LCDs), such as PC monitors and TVs.^{1,2} In a multi-lamp backlighting system, significant current imbalance between lamps is often a problem that generates undesired non-uniform luminance. This imbalance is caused by mismatched lamp impedances due to lamp layout and component tolerances. Although current imbalance due to component tolerance can be minimized by using better-quality (*i.e.*, low tolerance) components, current imbalance due to layout is difficult to correct without costly hardware redesign. Understanding the cause of current imbalance due to layout is therefore essential in order to optimize the overall design.

Current Imbalance Due to Lamp Layout

In a typical backlighting system, square-wave voltage V_j is applied to N -parallel connected step-up (turns ratio = $1:n$) transformers via a series-connected blocking capacitor, which in turn are connected to a single lamp, as shown in Fig. 1(a). Each lamp, including the transformer, can be modeled as the parallel connection of lamp impedance R_{lamp} and lumped

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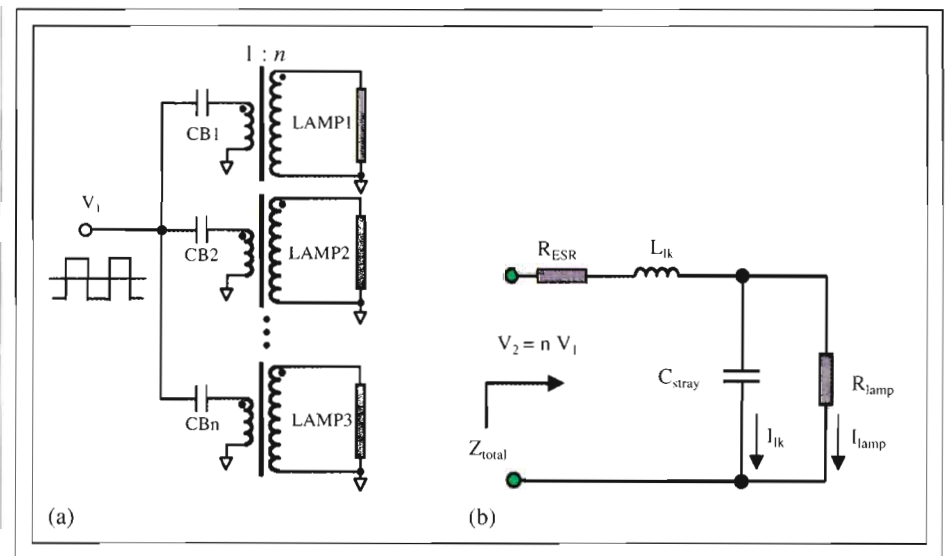


Fig. 1: (a) A typical driving scheme for CCFLs. (b) Equivalent lumped electrical model of a single CCFL.

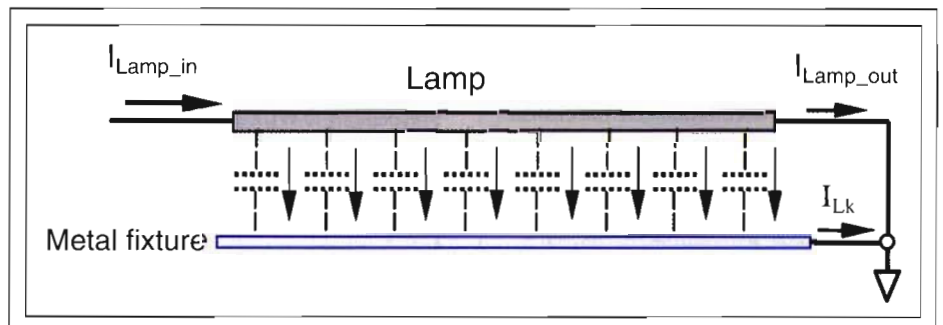


Fig. 2: A lamp with stray capacitance and leakage current.

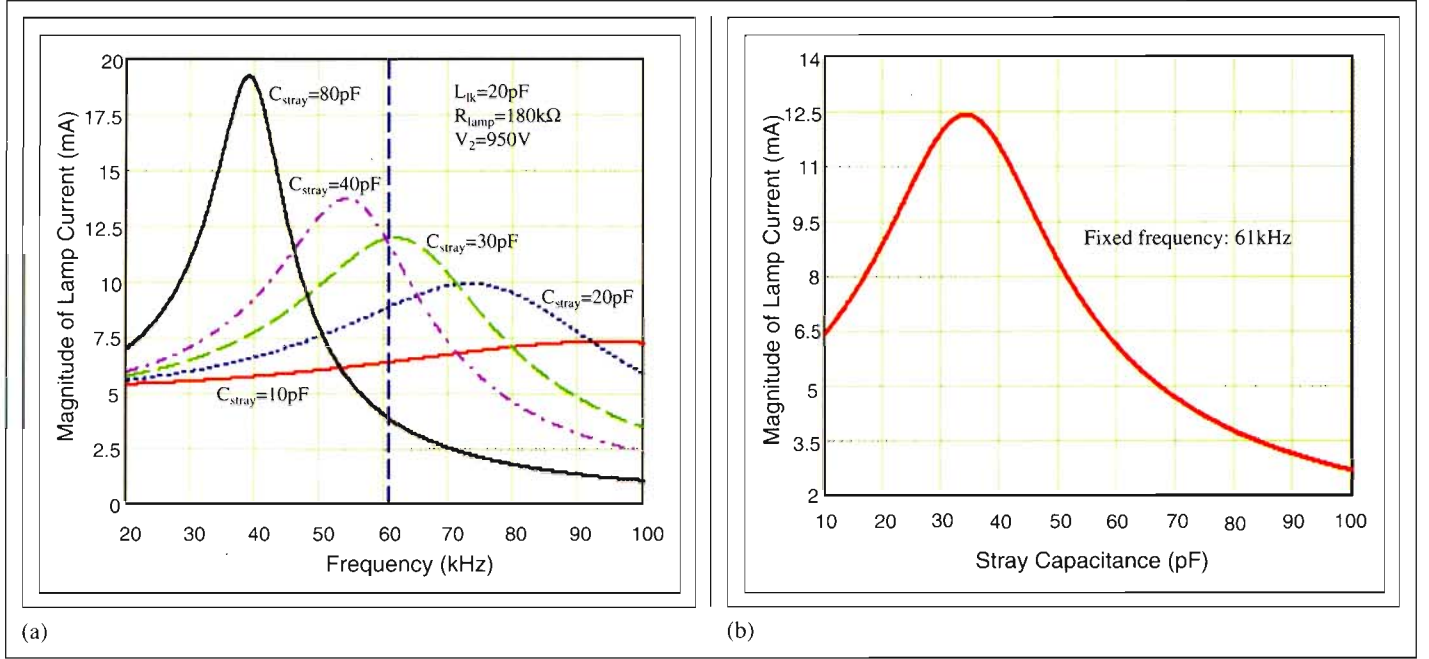


Fig. 3: (a) Lamp current vs. frequency for different lumped stray capacitance. (b) Lamp current vs. stray capacitance for fixed frequency.

$$z_{total} = \frac{R_{lamp} \cdot z_{C_{stray}}}{z_{C_{stray}} + R_{lamp}} + z_{L_{lk}} + R_{ESR} \approx \frac{R_{lamp} \cdot z_{C_{stray}}}{z_{C_{stray}} + R_{lamp}} + z_{L_{lk}}, \quad (1)$$

$$I_{lamp} = \frac{v_2}{|z_{total}|} \cdot \left| \frac{z_{C_{stray}}}{z_{C_{stray}} + R_{lamp}} \right| \quad (2)$$

$$= \frac{v_2}{\sqrt{L_{lk}^2 R_{lamp}^2 C_{stray}^2 \left[(2\pi f)^2 - \frac{2R_{lamp}^2 C_{stray} - L_{lk}}{2L_{lk} R_{lamp}^2 C_{stray}} \right]^2 + \frac{4R_{lamp}^2 L_{lk} C_{stray} - L_{lk}^2}{4R_{lamp}^2 C_{stray}}}},$$

$$I_{lamp}^{max} = \frac{2v_2 R_{lamp} C_{stray}}{\sqrt{4R_{lamp}^2 L_{lk} C_{stray} - L_{lk}^2}} \approx v_2 \sqrt{\frac{C_{stray}}{L_{lk}}} \quad (3)$$

$$f_r = \frac{1}{2\pi} \sqrt{\frac{1}{L_{lk} C_{stray}} - \frac{1}{2R_{lamp}^2 C_{stray}^2}}. \quad (4)$$

stray capacitance C_{stray} connected in series with leakage inductance L_{lk} and effective series resistance R_{ESR} , as shown in Fig. 1(b). Here, the primary side is reflected to the secondary side, $V_2 = nV_1$, and blocking capacitor C_{B1} is omitted since it is normally designed to have a constant dc voltage. For simplicity, R_{ESR} is also omitted since it is usually much less than the impedance of L_{lk} . The magnitude of lamp current I_{lamp} is shown to be a

function of applied voltage V_2 , operating frequency f , and impedances R_{lamp} , $Z_{C_{stray}}$, and $Z_{L_{lk}}$, as shown in Eqs. (1) and (2). From Eq. (2), in order to achieve equal lamp currents, the individual lamp impedances must be equal. The maximum lamp current expressed by Eq. (3) occurs when the operating frequency is equal to the resonant frequency, f_r , as expressed by Eq. (4).

Generally, L_{lk} and R_{ESR} are governed by the length and area of the current path and can be controlled somewhat by implementing a symmetrical design. (Leakage inductance results from non-ideal coupling of primary and secondary windings of the transformer, which means some energy will not be transferred to the secondary or primary side.) R_{lamp} is independent of layout, and variations between

lamps are due solely to tolerances. The hardest impedance to control – and which varies the most with layout – is C_{stray} . Shown lumped in Fig. 1(b), C_{stray} represents capacitance between the lamp and grounded metal fixture, as shown in Fig. 2. This capacitance can be modeled as a parallel-plate capacitance and is shown to be a function of distance between plates d , area of plates A , and permittivity of the medium between plates ϵ , as shown in Eq. (5).

$$C = \frac{\epsilon A}{d}. \quad (5)$$

The effect of C_{stray} on lamp current I_{lamp} is significant, as shown in Fig. 3, which is obtained based on Eq. (2). For example, at an operating frequency of 61 kHz, the lamp current nearly doubles as the stray capacitance increases from 10 to 30 pF.

The lamp current at resonance is a function of C_{stray} , L_{lk} , and lamp resistance, but is highly dependent on C_{stray} and L_{lk} , as shown in Eq. (3). The larger the stray capacitance, the higher the lamp current at resonant frequency. Qualitatively speaking, when the stray capacitance increases, the resonance frequency decreases, which results in a lower voltage drop across the leakage inductance and higher voltage drop across the lamp, hence higher lamp current.

backlighting

Figure 4 shows the electrostatic simulation result of the electric-field strength along a horizontal line l for a five-lamp system using

the Ansoft 2D Field Simulator.³ The lamp diameter is 4 mm and the voltage at the cross section of the lamp is 1200 V. It can be seen

that for both cases – with and without a grounded metal fixture – the electric-field strength distribution exhibits a “U” shape; the

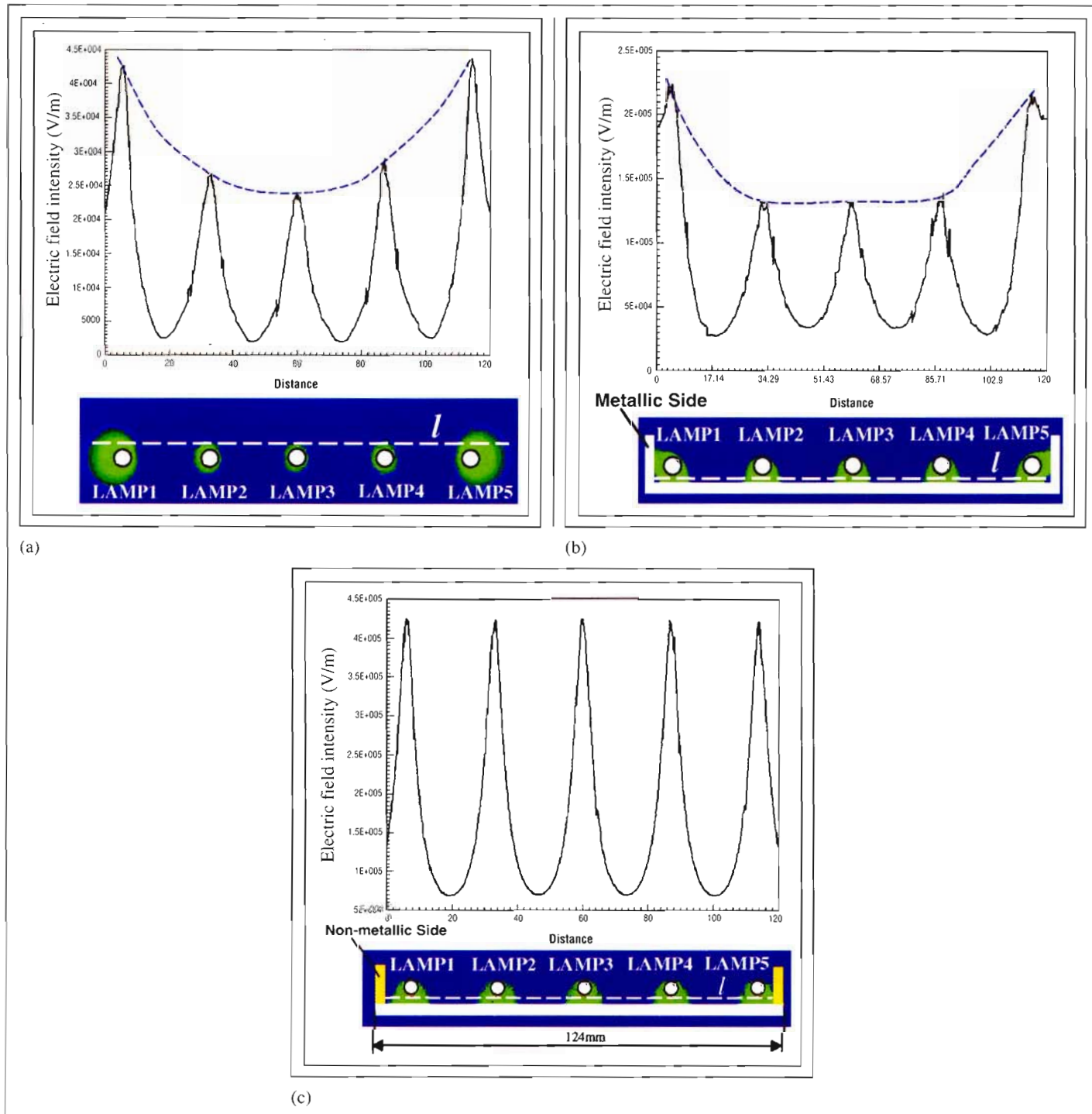


Fig. 4: Simulated electric-field strength of each lamp along a horizontal line (a) without a metal fixture, (b) with a grounded metal fixture, and (c) with a grounded metal fixture but with non-metallic sides.

outer lamps have a higher stray electric field in the surrounding, which means a higher stray capacitance. However, when the lamps are placed close to a metal fixture a much more uniform (within the central area) and higher electric field results, as shown in Fig. 4(b) than for the case without a nearby metal fixture. Finally, simulation shows a uniform electric-field intensity when the metal sides are replaced with nonmetallic sides, as shown in Fig. 4(c). From the simulation, we can conclude that the stray capacitance of the lamp depends on the relative position of each lamp and the distance between the lamp and metal fixture.

Measurements of individual lamp current were made for a 16-lamp backlighting system using a fixture with metallic sides, as shown in Fig. 5. Here, the outer lamps tend to have much higher current than the inner lamps when the space between the lamp and fixture is large (*i.e.*, 30 mm) and a more uniform current distribution when the space is small (*i.e.*, 12 mm).

Solutions

As described in the previous sections, the stray capacitance can cause severe current imbalance in a multi-lamp backlighting system. One possible way to alleviate this problem is to use current-balancing transformers as described in Ref. 4. However, this will inevitably add to the circuit complexity and cost while increasing the overall power loss. Another method is to design the metal fixture to include non-metallic sides, as well as holes beneath the lamps, as illustrated in Fig. 6. Figure 7 shows measurements comparing lamp currents ($I_{lamp-in}$) in a metal fixture with and without metallic sides. Without metallic sides, the lamp currents are balanced, represented by the green bars, because the stray capacitance of the outer lamps is reduced. In fact, it also results in reduced leakage currents. In addition, by employing holes beneath the lamps, the stray capacitance is reduced, thus improving the current balancing represented by the blue bars in Fig. 7 and reducing the difference in currents at both ends of each lamp, represented by the blue bars in Fig. 8. More-balanced currents among different lamps and a smaller difference in currents at both ends of each lamp will, in turn, improve the brightness uniformity across the screen.

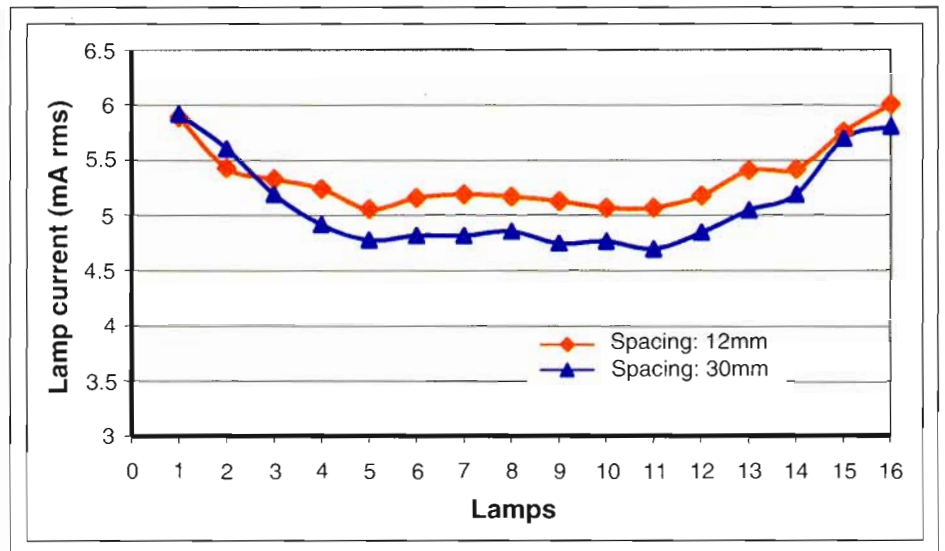


Fig. 5: Measured lamp-current distribution vs. position.

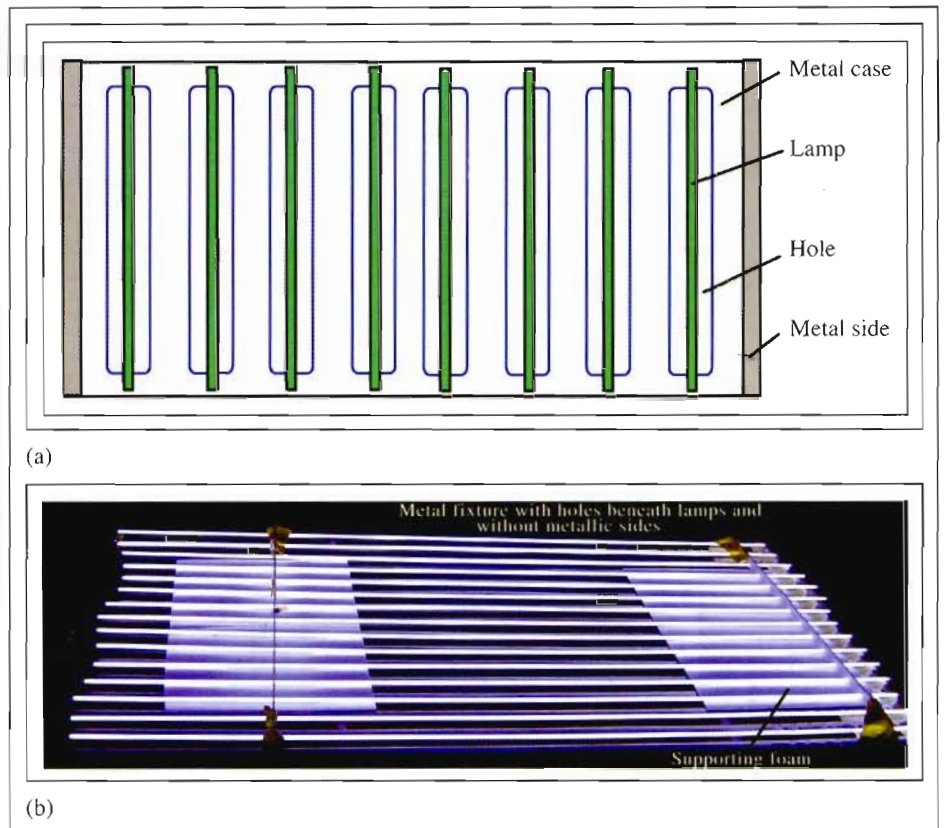


Fig. 6: (a) Metal frame with holes. (b) Experimental setup without metal sides but with holes beneath the lamps.

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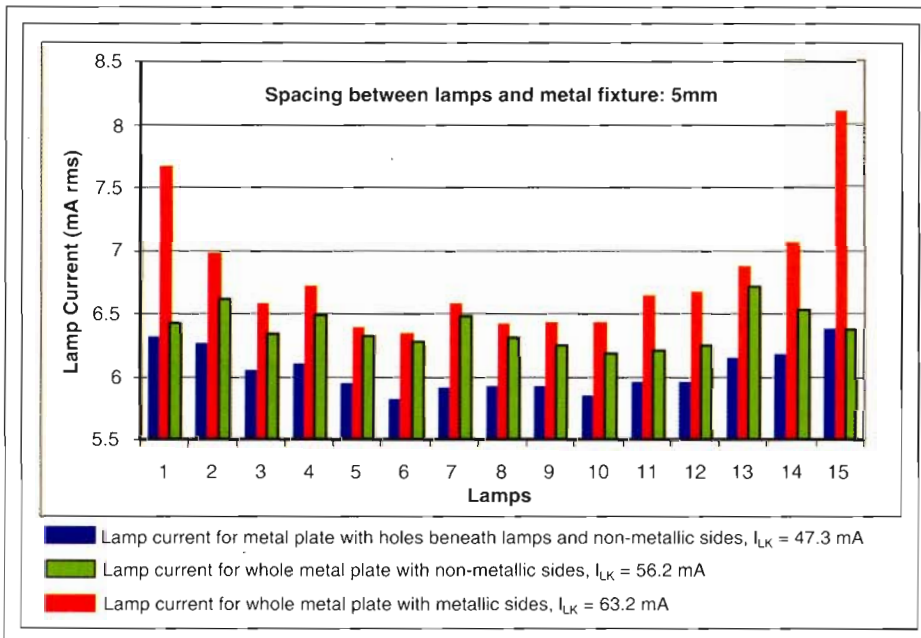


Fig. 7: Comparison of measured lamp currents at the hot ends for different numbers of fixtures. Note the suppressed zero value on the graph.

Conclusions

This work shows that the stray capacitance between the lamp and grounded metal fixture can cause severe current imbalance in a multi-lamp backlighting system. Reducing the distance between the lamps and metal fixture result in more balanced currents but higher leakage currents due to increased stray capacitance. Removal of metal sides or use of non-

metallic sides and cutting holes beneath the lamps can significantly alleviate the current-imbalance problem and improve the light uniformity.

Reference

¹G. Henry, "Improved efficiency for compact CCFLs," *Portable Design* (October 2004).

²J. Lambert and C. Smith, "A whole new way

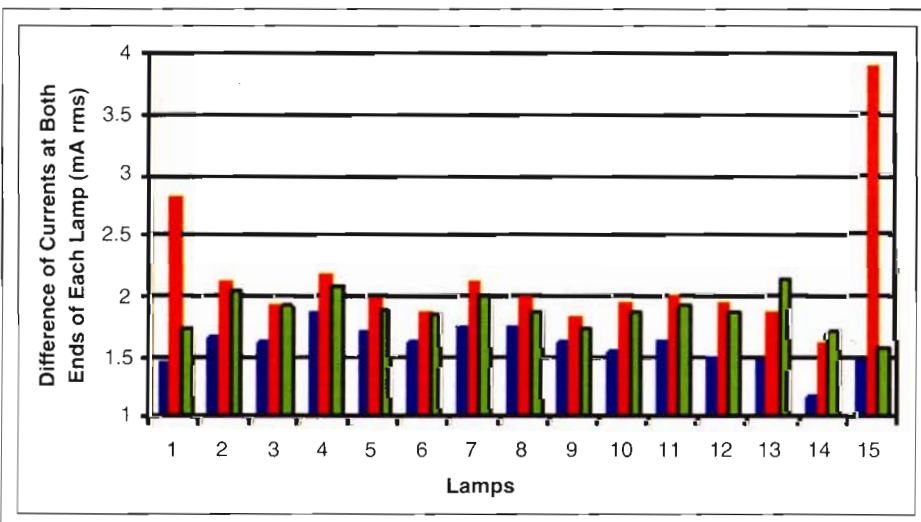


Fig. 8: Comparison of difference of measured currents at both ends of each lamp with different fixtures.

to design backlight inverters for mobile computing applications," *International IC - Taipei, Conference Proceedings, Vol. 29*.

³Maxwell 2D Field Simulator, Ansoft Corp.

⁴S. T. Lee, "Circuit structure for driving a plurality of cold-cathode fluorescent lamps," U.S. Patent No. 6781325 (Aug. 24, 2004). ■

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