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(54) **Led illumination method and apparatus**

(57) A method for driving an LED array with a plurality of section is disclosed, in which each section of the LED array comprises at least one LED device, wherein each section is supplied with power using pulse width modulation with a common frequency, wherein the power supplied to each section is phased relative to the other sections to reduce the maximum total power supplied to all sections, relative to supplying all sections with a common phase. An illuminator is disclosed comprising an LED array and a drive circuit, wherein the LED array comprises a plurality of sections, each section comprising at least one LED device, and the drive circuit is arranged to supplied each section with power using pulse width modulation with a common frequency, with the power supplied to each section being phased relative to the other sections to thereby reduce the maximum total power supplied to all sections, relative to supplying all sections with a common phase.

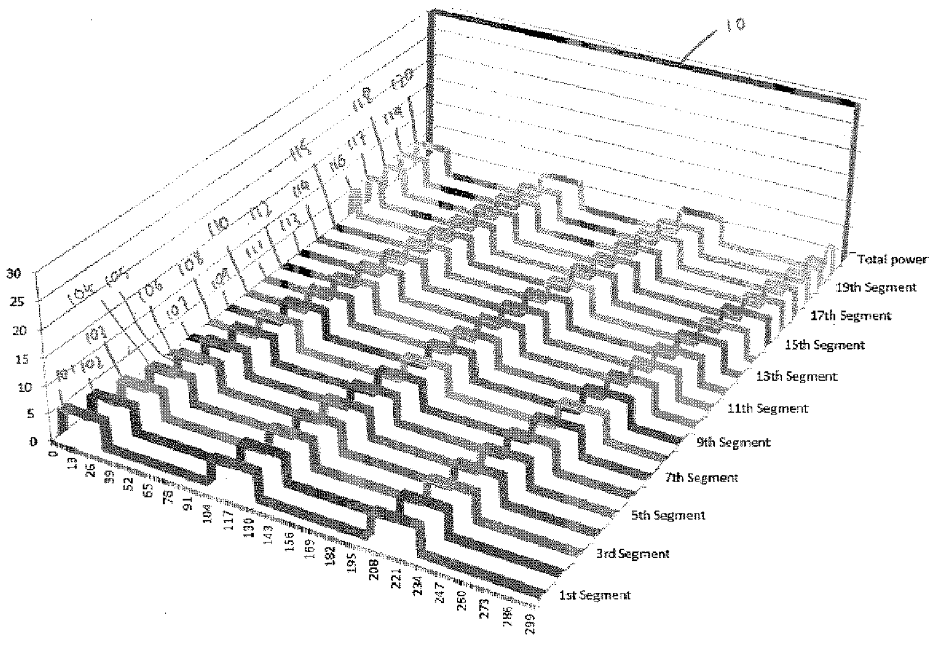

Figure 7

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Description

[0001] This invention relates to method of using a plurality of LED devices, and an arrangement comprising a plurality of LED devices.

[0002] LEDs (light emitting diodes) are in increasingly common usage in applications in which a light source is required. One such application is in the curing of inks and the like. In this application, a number of LEDs are arranged in an array, the array of LEDs being controllable to permit irradiation of an entire irradiable area (by operation of all of the LEDs) or irradiation of just selected regions of the entire area (by operation of just some of the LEDs). The LEDs used in the light source are of the type designed to emit light in the UV wavelengths. Whilst the use of UV LEDs in the curing of inks and the like is one application in which LEDs are used, it will be appreciated that they may be used in a wide range of applications, and the present invention is applicable to all such uses.

[0003] A known method for controlling the radiated power output from an LED array is to use pulse width modulation (PWM), in which the array is driven at a predetermined frequency, and is switched on for a fraction of each cycle. The amount of time that the array is switched on (duty cycle) can be varied between 0-100% of each cycle, and the average power output varied accordingly between zero power output, and the maximum continuous rated power output.

[0004] It is known to be advantageous to drive LEDs at a higher current with a reduced duty cycle, for example by increasing the current by a factor of two while decreasing the duty cycle by a corresponding factor of two, for example to achieve a higher maximum intensity of irradiation. When an LED is driven at a current higher than its nominal maximum rated current in this manner the duty cycle has to be reduced to avoid unacceptable damage to the LED.

[0005] The requirements for a power supply to drive an LED array are based on the maximum current requirement for the array. Driving an array at twice the nominal rated current over a 50% duty cycle therefore requires a power supply that is capable of delivering twice the nominal rated current for the array. However, the power supply will be switched off for 50% of the time.

[0006] One known arrangement for an LED array used for UV curing is that of a substantially 2D array in which a relatively narrow rectangular array is provided, suitable for use in a continuous process in which the substrate to be cured moves under the LED array. Such an array may comprise a plurality of individual LEDs and/or LED modules, each LED module comprising a plurality of LED die.

[0007] A method for driving LED arrays which minimises the maximum current requirements for the power supply would therefore be advantageous. It is important that any such method maintains a high uniformity of output irradiance and output radiant energy across the array.

[0008] According to a first aspect of the present invention there is provided a method for driving an LED array with a plurality of sections, each section comprising at least one LED device, wherein each section is supplied with power from a power source common to all the sections using pulse width modulation with a common frequency (or at frequencies chosen to achieve similar results), wherein the power supplied to each section is phased relative to the other sections, to reduce the maximum total power supplied to all sections relative to driving all sections with a common phase.

[0009] It will be appreciated that, for example, by doubling or halving the frequency of the power signal applied to one or more of the sections, it may be possible to achieve similar results to those achieved where the same frequency is applied to all sections.

[0010] Each section may have a substantially equal number of LED devices, each LED device being substantially identical.

[0011] The duty cycle of each section may be substantially identical. There may be *m* sections, with the phase difference between each section at least 180/m degrees. The *nth* section is driven at a phase of substantially (360/m) * (*n*- 1) degrees.

[0012] The sections may comprise a plurality of non-contiguous regions of the array. There may be *m* contiguous sections arranged in a substantially straight line, in sequence so that the first section is first, and the *mth* section last. The phase differences between the sections may be arranged so that the illuminated sections are scanned continuously along the array. The phase differences between the sections may be arranged so that the scan velocity is substantially constant. There may be at least 3 sections.

[0013] According to a second aspect of the invention, there is provided an illuminator comprising an LED array and a drive circuit, wherein: the LED array has a plurality of sections, each section comprising at least one LED device, wherein the drive circuit is arranged to supply each section with power using pulse width modulation with a common frequency (or at frequencies chosen to achieve similar results), with the power supplied to each section being phased relative to the other sections to thereby reduce the maximum total power supplied to all sections relative to an arrangement in which a common phase is supplied to each section.

[0014] Each section may comprise a substantially equal number of LED devices. The drive circuit may be arranged so that the duty cycle of each section is substantially identical.

[0015] There may be *m* sections, with the drive circuit arranged to provide a phase difference between each section of at least 180/m degrees. The drive circuit may be arranged to drive the *nth* section at a phase of substantially (360/m) * (*n*- 1) degrees.

[0016] The sections may comprise a plurality of non-contiguous regions of the array. There may be *m* contiguous sections arranged in a substantially straight line, in sequence so that the first section is first, and the *mth* section last. The drive circuit may be arranged to drive the sections so that the illuminated sections are scanned continuously along the array. The drive circuit may be arranged to provide phase differences between the sections so that the scan velocity is substantially constant. There may be at least 3 sections.

[0017] The invention will further be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a graph of power supplied to a single array under pulse width modulation according to the prior art;

Figure 2 is a graph of power supplied to a two section array under pulse width modulation according to the prior art;

Figure 3 is graph of power supplied to a two section array according to an embodiment of the present invention;

Figure 4 is a graph of power supplied to a three segment array according to an embodiment of the present invention;

Figure 5 is a further graph of power supplied to a three segment array according to an embodiment of the present invention;

Figure 6 is a schematic of the light distribution from two adjacent sections of an array;

Figure 7 is a graph of power supplied to a 20 section array according to an embodiment of the present invention; and

Figure 8 is a schematic of the light distribution from adjacent segments according to an embodiment of the present invention.

[0018] A known arrangement of PWM control of an LED array is to provide a plurality of LEDs (or a plurality of LED assemblies comprising multiple LEDs) which are connected in parallel or in series in a single array, and to power the single array using PWM. Figure 1 is a graph of the power supplied to an array comprising a single section (in Watts), plotted against the time (in microseconds). In this example the PWM frequency is 10kHz, and the maximum power supplied is 5W. The graph shows the first section power 1, and the total array power 10 (these being equal), over three PWM cycles.

[0019] Figure 2 is a graph of the power supplied to an LED array comprising two sections, both of which are powered using PWM at the same frequency and duty cycle. Each section may comprise a sub-array of individual LEDs or LED modules. The first section power 1, the second section power 2, and the total array power 10 are shown over three PWM cycles of 100μs. With both sections supplied with 5W at the same time, the peak total power supplied to the array is 10W, and the overall duty cycle is 50%, with the power supply is turned off for 50% of the time.

[0020] Figure 3 is a graph of power supplied to an LED array comprising two sections, according to an embodiment of the invention. The first section power 1, second section power 2 and the total array power 10 are shown over three PWM cycles. The array may, for example, be a substantially rectangular array comprising two adjacent substantially rectangular sections. According to this embodiment, the sections are each driven with a 50% duty cycle, with the second section power input being shifted in phase by 180 degrees relative to the first section, so that when the first section is on, the second section is off, and vica-versa. This results in the total power for the array being substantially constant, at 5W. Driving the array in this way therefore reduces the maximum power requirement by a factor of two over the prior art arrangement of Figure 2, without reducing the average total radiant power output. It will be appreciated that reducing the maximum power requirement allows a smaller, simpler power supply circuit to be used, since such circuits are designed and specified based on the maximum power requirement therefrom.

[0021] Figure 4 is a graph of power supplied to an LED array comprising three sections, according to an embodiment of the invention. The first section power 1, second section power 2, third section power 3 and the total array power 10 are shown over three PWM cycles of 100μs. The array may, for example, be a substantially rectangular array comprising three adjacent substantially rectangular sections which are arranged in a line. The first section may be adjacent to the second section, and the second section may be adjacent to the third section. According to this embodiment, the sections are driven with a duty cycle of one third, with the first section at 0 degrees phase, the second at 120 degrees phase, and the third at 240 degrees phase. The total power 10 is thereby substantially constant and equal to the maximum power provided to each individual section.

[0022] Figure 5 is a graph of power supplied to an LED array comprising three sections, according to an embodiment of the invention. The first section power 1, second section power 2, third section power 3 and the total array power 10 are shown over three PWM cycles of 100μs. According to this embodiment, the sections are driven with a duty cycle of two thirds, with the first section at 0 degrees phase, the second at 120 degrees phase, and the third at 240 degrees phase. The total power 10 is thereby substantially constant and equal to 10W, being twice the maximum power of 5W provided to each individual section.

[0023] Where different sections of an LED array are driven using pulse width modulation according to an embodiment of the invention, there is the potential for variation in the relationship between light intensity and duration of illumination. Specifically, points which lie under the edge of adjacent sections may experience a reduced maximum light intensity, and an increased duration of illumination, resulting in substantially the same total incident radiation energy from the array.

[0024] Figure 6 illustrates this, showing an array with a first section 21 and a second section 22, and a schematic of the illumination rays 23 originating therefrom. Three scenarios are depicted: a first scenario 31 with both sections 21, 22 switched on; a second scenario 32 with the first section 21 switched off and the second section 22 switched on; and a third scenario 33 with the first section 21 switched on and the second section 22 switched off. The first scenario 31 corresponds to that which is depicted in Figure 2, in which both arrays are driven using PWM with a common phase. The second and third scenarios 31, 32 correspond to that depicted in Figure 3, at t=25μs and t=75μs respectively.

[0025] Considering the light incident at a point 24, which is located under the edge of the adjacent sections 21, 22, it can be seen that in the first scenario 31 point 24 receives twice the intensity that is would in either the second or third scenario 32, 33. Under the drive arrangement of Figure 2, corresponding to the second and third scenarios 32, 33, it is also clear that the point 24 would be constantly illuminated at half the intensity it would receive under the drive scheme of Figure 1. As many curing reactions are sensitive to intensity (in addition to total energy dose), this variation in illumination intensity and duration under the array may result in a process artefact or defect in the product under illumination.

[0026] A number of techniques can be used to overcome this problem. Using a larger number of smaller sections tends to reduce the problem, since the difference in illumination conditions between locations adjacent to the centre and edge of a small section will be subject to less variation than would be the case in a large section.

[0027] A further method of reducing the variations in maximum illumination intensity and duration is to drive the sections so that the illuminated regions are scanned over the array, thereby increasing the uniformity of illumination.

[0028] The embodiment of Figures 7 and 8 illustrate an approach which combines the use of a larger number of smaller sections, with a drive method that results in scanning of the illuminated region of the array. In the example of Figure 7, a substantially linear array is divided into 20 contiguous sections arranged in order along the length of the array.

[0029] Figure 7 shows three cycles of PWM, and illustrates the power to each section 101 to 120 and the total array power 10. Each section is supplied with power using PWM at a common frequency and duty cycle. In this example, for each section the maximum power is 5W, the PWM frequency is 10kHz, and the duty cycle is 0.3. A phase difference of 5 degrees is provided between adjacent sections, with the first section at 0 degrees phase, and the last section at 95 degrees phase. This results in a constant total power of 30W applied to the array as a whole.

[0030] Figure 8 illustrates the illumination provided by the scanning drive scheme of Figure 7. In Figure 8, each section of the array comprises a single LED module, and eight sections 201 to 208 of the twenty section array of Figure 7 are shown. The illumination rays from each section 201 to 208 are shown at different times, from t=36μs to t=61μs in 5μs increments. The light incident on a point 24 between the fourth section 204 and the fifth section 205 is considered for illustration. At t=36μs the point 24 is under maximum illumination, with the illumination gradually reducing until t=56μs, at which time point 24 no longer has any illumination rays incident. Similarly, a point directly under the fifth section 205 will experience a substantially identical time variation in illumination to that of point 24 with the only difference being a time offset of 2.5μs (this being the phase delay corresponding to the different location). Referring to Figure 7, it is clear that over a full PWM cycle, all the points under the array will thereby receive substantially identical illumination history (i.e. intensity vs time).

[0031] In general, a drive scheme which minimises the maximum total array power is to use an array comprising *m* equal sections, with the *nth* section driven at a phase of substantially (360/m) * (n- 1) degrees. Although this drive method is that used in the embodiments of the drawings, it will be appreciated that this is an optional feature of the invention, and the appropriate phase difference between sections may be different to that described by the above formula, particularly where the sections do not comprise an equal number of LED modules, or are heterogeneous in geometry.

[0032] Applying a fixed phase difference between the heterogeneous sections of an array does not necessarily result in minimum total power consumption. For arrays comprising such heterogeneous sections, the optimum phase, duty cycle and maximum power applied to each section may vary, and should be adjusted according to the parameters of the sections.

[0033] As an alternative to using a greater number of smaller sections, uniformity of illumination may be improved by using array sections which comprise a plurality of non-contiguous regions. For example, an array with twenty LED devices arranged in sequence in a linear array may be split into two sections, the first section comprising all the odd numbered devices, and the second section comprising all the even numbered devices. The sections are thereby arranged so that each LED device is not adjacent to another LED device in the same section. Driving the two sections according to the invention thereby results in substantially uniform illumination across the array.

[0034] It will be appreciated that according to the invention, an array may be split into sections, each of which comprise a contiguous region of the array. Each section may further be split into non-contiguous sub-sections arranged so that each adjacent LED device of the section belongs to a different sub-section. Such an arrangement enables selectivity of illumination (by selectively driving only certain sections) and uniformity of illumination by the use of non-contiguous sub-sections.

[0035] It will be appreciated that, for example, by doubling or halving the frequency of the power signal applied to one or more of the sections, it may be possible to achieve similar results to those achieved where the same frequency is applied to all sections. The invention should be interpreted accordingly.

[0036] A number of other modifications and alterations may be made to the arrangements described herein without departing from the scope of the invention. Although the example embodiments described herein have a substantially constant total power, it will be appreciated that this is not a requirement, and varying the duty cycle to adjust the intensity may result in fluctuating total power.

Claims

1. A method for driving an LED array with a plurality of sections, each section comprising at least one LED device, wherein each section is supplied with power from a power source common to all the sections using pulse width modulation with a common frequency (or at frequencies chosen to achieve similar results), wherein the power supplied to each section is phased relative to the other sections, to reduce the maximum total power supplied to all sections relative to supplying all sections with a common phase.

2. The method of claims 1, wherein each section has a substantially equal number of LED devices, each LED device being substantially identical.

3. The method of claim 2, wherein the duty cycle of each section is substantially identical.

4. The method of any of claims 1 to 3, wherein there are *m* sections, and the phase difference between each section is at least 180/m degrees.

5. The method of any of claims 1 to 4, wherein there are *m* sections, and the *nth* section is driven at a phase of substantially (360/m) * (*n*- 1) degrees.

6. The method of any of claims 1 to 5, wherein the sections comprise a plurality of non-contiguous regions of the array.

7. The method of any of claims 1 to 5, wherein there are *m* contiguous sections arranged in a substantially straight line, in sequence so that the first section is first, and the *mth* section last.

8. The method of claim 7, wherein the phase differences between the sections are arranged so that the illuminated sections are scanned continuously along the array.

9. The method of claim 8, wherein the phase differences between the sections are arranged so that the scan velocity is substantially constant.

10. An illuminator comprising an LED array and a drive circuit, wherein:

    the LED array has a plurality of sections, each section comprising at least one LED device,
    wherein the drive circuit is arranged to supply each section with power using pulse width modulation with a common frequency (or at frequencies chosen to achieve similar results), with the power supplied to each section being phased relative to the other sections to thereby reduce the maximum total power supplied to all sections relative to an arrangement in which a common phase is supplied to each section.

11. The illuminator of claim 10, wherein each section has a substantially equal number of LED devices.

12. The illuminator of claim 11, wherein the drive circuit is arranged so that the duty cycle of each section is substantially identical.

13. The illuminator of any of claims 10 to 12, wherein there are *m* sections, and drive circuit is arranged to provide a phase difference between each section of at least 180/m degrees.

14. The illuminator of any of claims 10 to 13, wherein there are *m* sections, and the drive circuit is arranged to drive the *nth* section at a phase of substantially (360/m) * (*n*- 1) degrees.

15. The illuminator of any of claims 10 to 14, wherein the sections comprise a plurality of non-contiguous regions of the array, and/or wherein there are *m* contiguous sections arranged in a substantially straight line, in sequence so that the first section is first, and the *mth* section last.

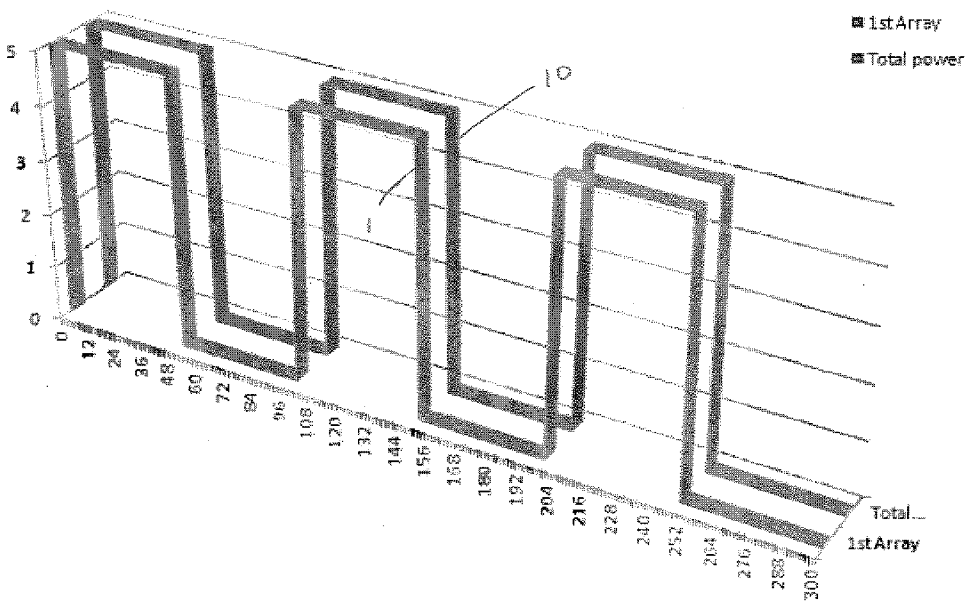


Figure 1 (prior art)

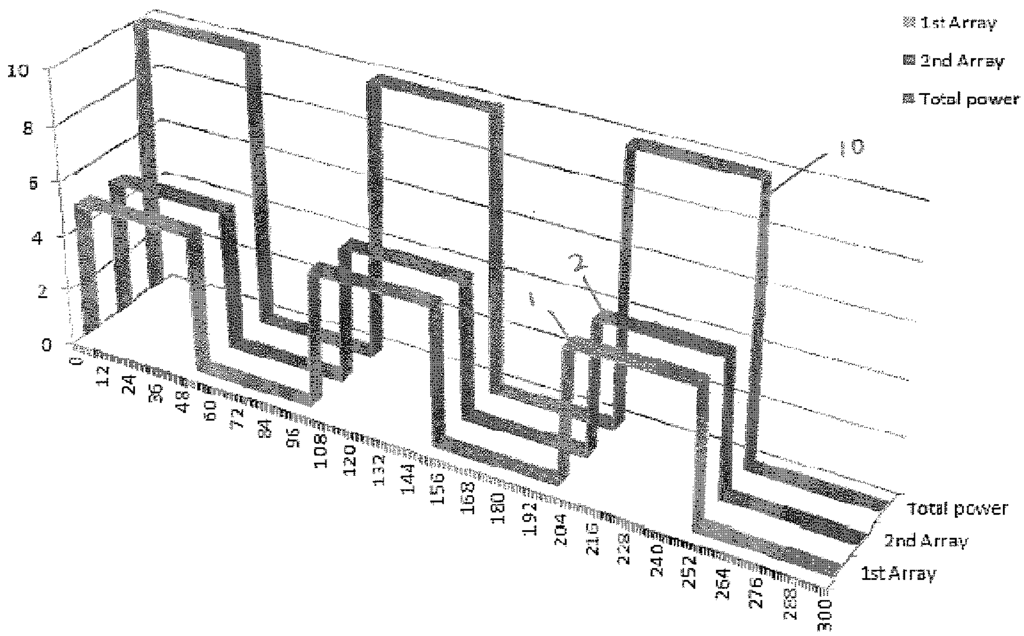


Figure 2 (prior art)

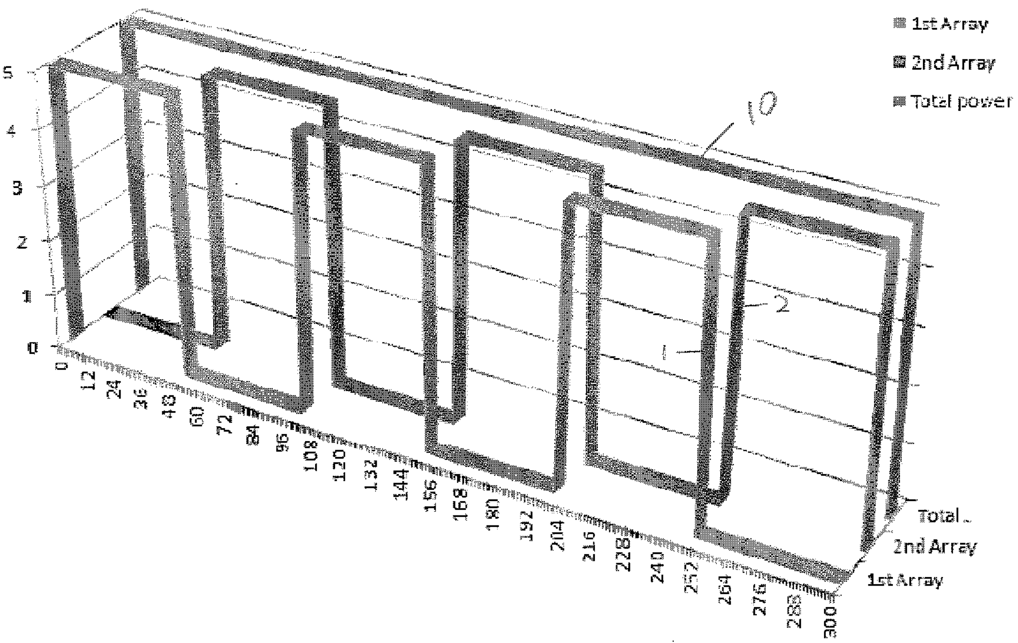


Figure 3

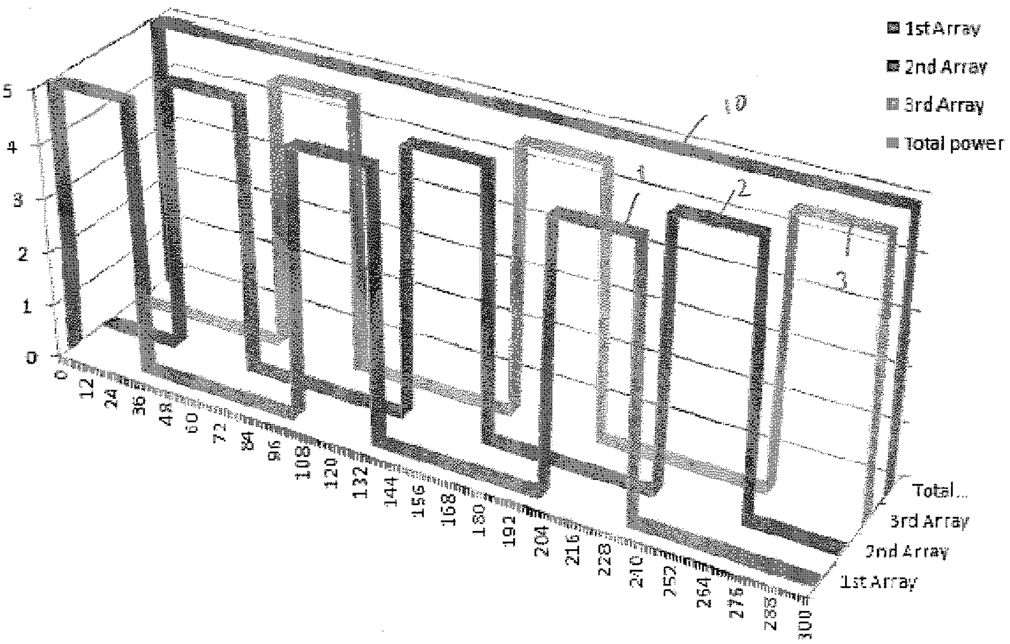


Figure 4

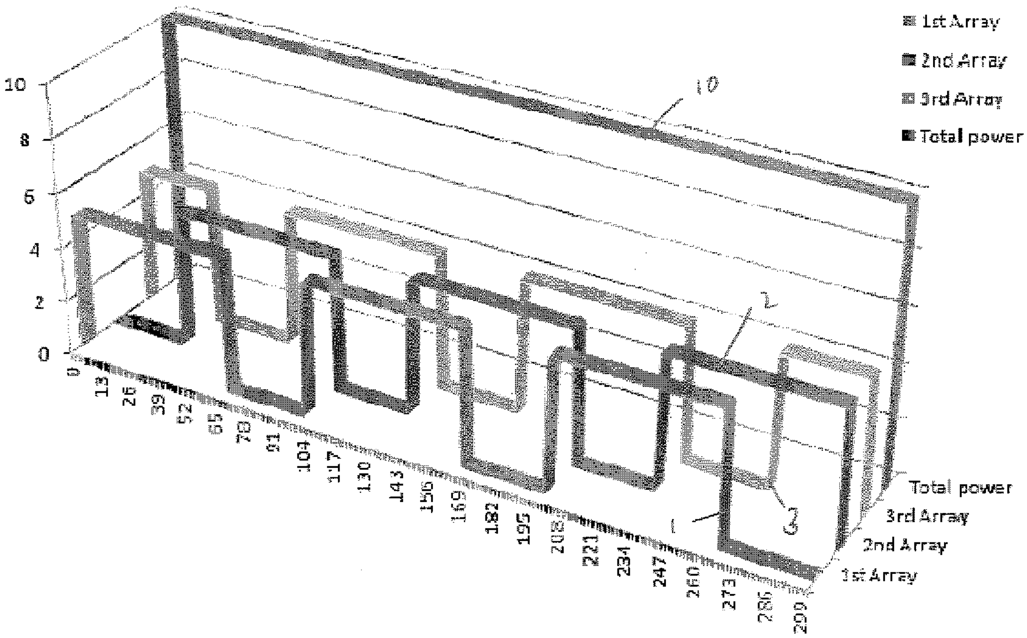


Figure 5

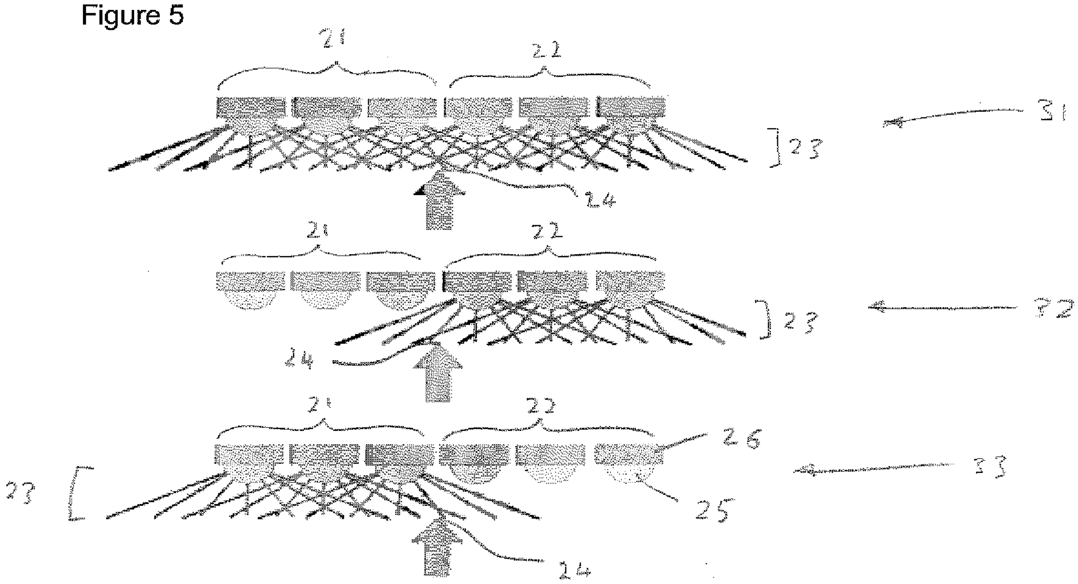
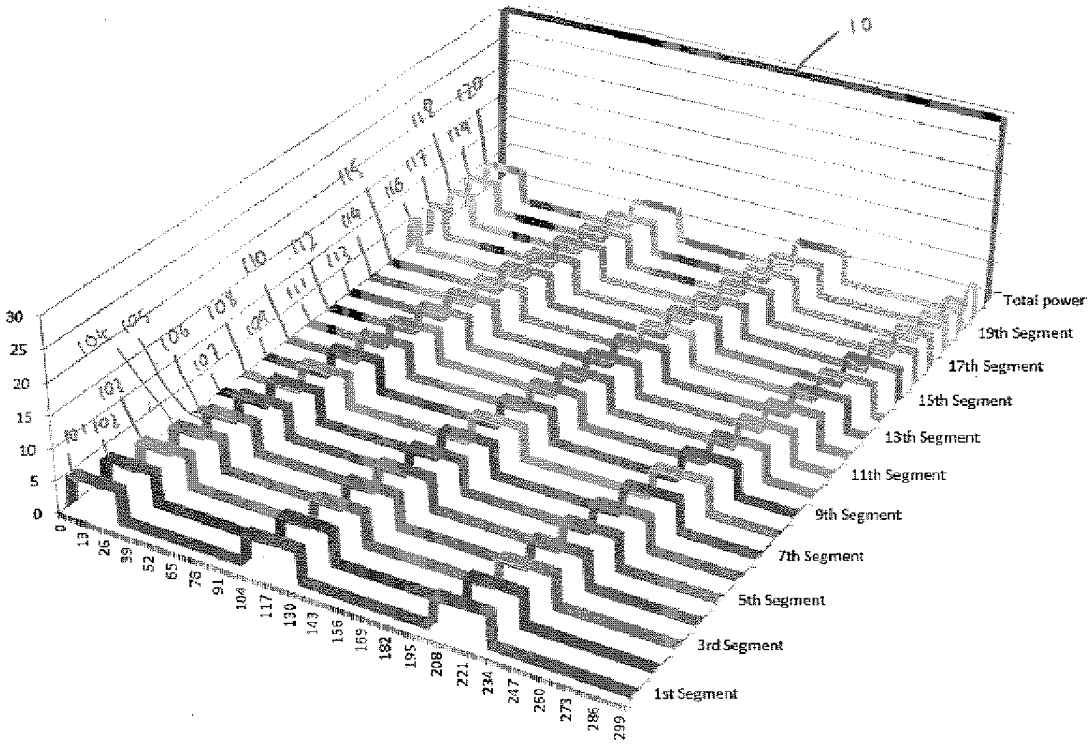


Figure 6


10
Total power
19th Segment
17th Segment
15th Segment
13th Segment
11th Segment
9th Segment
7th Segment
5th Segment
3rd Segment
1st Segment
30
25
20
15
10
5
0
0
13
26
39
52
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143
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Figure 7

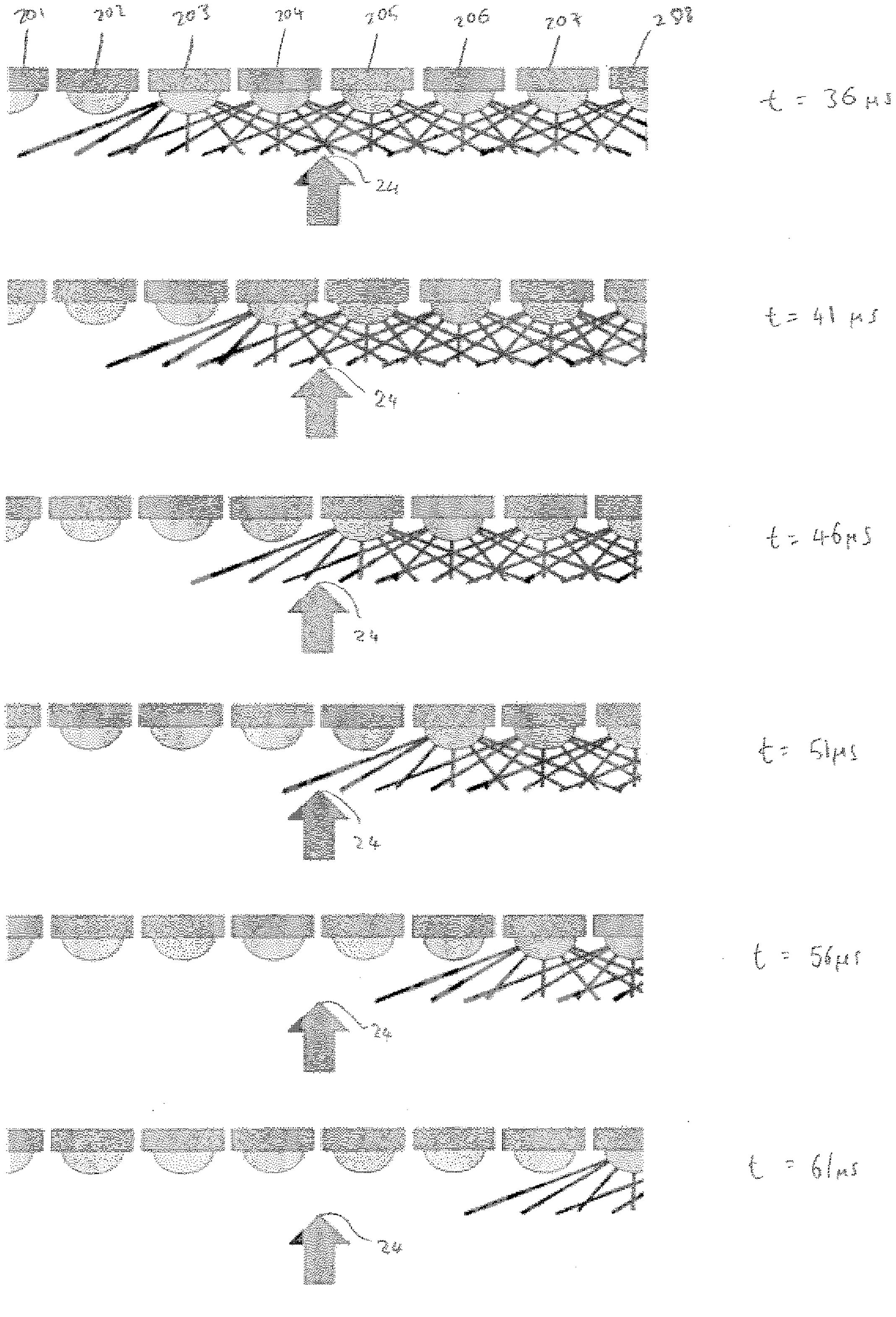
201
202
203
204
205
206
207
208
24
t = 36μs
t = 41μs
t = 46μs
t = 51μs
t = 56μs
t = 61μs

Figure 8

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EUROPEAN SEARCH REPORT

Application Number
EP 13 16 1351

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	22 July 2013	Brosa, Anna-Maria

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EUROPEAN SEARCH REPORT

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