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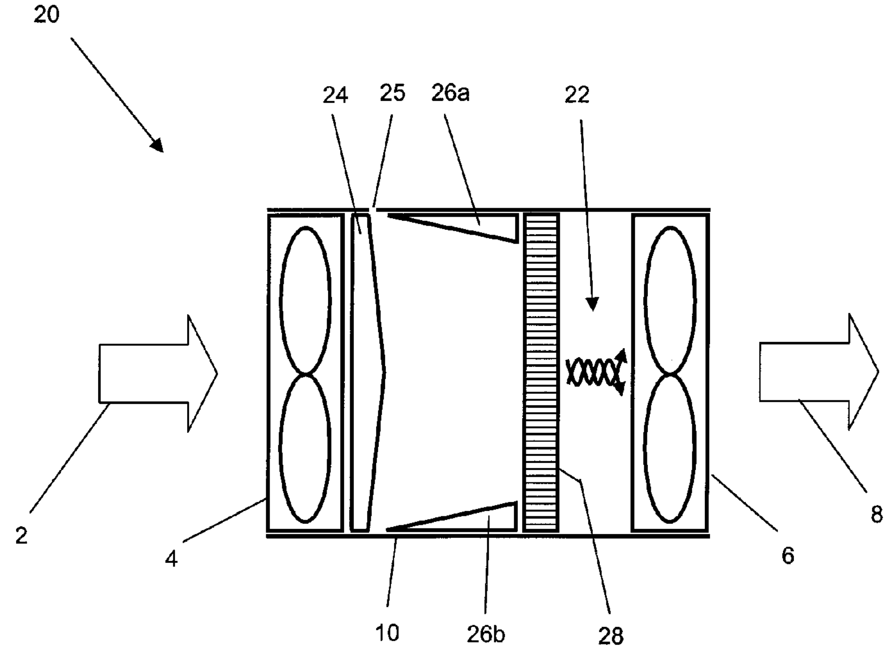
[Continued on next page]

(54) Title: MULTISTAGE FLOW OPTIMIZER

Figure 2



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(57) Abstract: A fan configuration having at least two fans in series, having a plurality of flow optimizing elements in a chamber between said two fans. Also disclosed is a fan finger guard having optimized flow characteristics, and a parallel fan configuration having flow optimizing elements upstream of the fans.

Multistage Flow Optimizer

Disclosed is a multistage flow optimizer for series and parallel fans. This application claims priority from US 61/109,599, filed October 30, 2008, and US 61/234,994 filed August 18, 2009, both of which are incorporated herein by reference.

Background of the Invention

As depicted in Figure 1, primary fan 4 and secondary fan 6 may be configured in series, with the air flowing from primary fan 4 to secondary fan 6 through channel 10. Inlet airflow 2 enters primary fan 4, which introduces swirl 12 into the airflow. Swirl 12 reduces the efficiency of secondary fan 6, since both primary fan 4 and secondary fan 6 are designed for laminar flow at their respective inlets. Hence outlet airflow 8 does not reach the theoretical static pressure maximum, which is normally considered to be the sum of the static pressures of primary fan 4 and secondary fan 6, at any given flow rate.

Brief Description of the Drawings

Figure 1 provides an overview of a series fan configuration.
Figure 2 presents an overview of a multistage flow optimizer with two fans,
Figure 3 presents a cross sectional view of a multistage flow optimizer channel,
Figure 4 presents an overview of a pull apart multistage flow optimizer,
Figure 5 depicts a traditional fan guard,
Figure 6 depicts a fan with aerodynamic struts,
Figure 7 depicts a traditional fan guard mounted on a fan with aerodynamic struts,
Figure 8 presents a high performance fan guard with fan specific cross braces,
Figure 9 presents a high performance fan guard with fan specific cross braces mounted on a fan with aerodynamic struts,
Figure 10 presents a high performance fan guard insert,
Figure 11 presents a fan guard frame,

Figure 12 presents a high performance fan guard insert configured with a fan guard frame,

Figure 13 presents a parallel configuration of multistage flow optimizers with fans,

Figure 14 presents an automatically deployed shutter mechanism,

Figure 15 illustrates the mechanism for the automatic deployment of an automatically deployed shutter mechanism,

Figure 16 provides a top perspective view of a preferred embodiment of a multistage flow optimizer,

Figure 17 provides a bottom perspective view of a preferred embodiment of a multistage flow optimizer,

Figure 18 illustrates a process for implementing the various stages of flow optimization in a multistage flow optimizer, and

Figure 19 illustrates the performance gains that may be achieved by implementing a multistage flow optimizer between two fans.

Detailed Description

As depicted in Figure 2, multistage flow optimizer 20 is designed to manage the swirl between primary fan 4 and secondary fan 6, such that outlet airflow 8 is optimized, reaching and exceeding the theoretical static pressure maximum as defined above. Inlet airflow 2 enters primary fan 4, which introduces swirl into the airflow. However in this configuration the airflow must first pass by stator 24 before moving down channel 10 towards secondary fan 6. This represents the first of multiple airflow and swirl management stages within multistage flow optimizer 20.

Stator 24 is designed to deflect the swirl downstream, converting a portion of the swirl kinetic energy into axial kinetic energy, thereby contributing to an increased outlet airflow 8. The stator also introduces drag, which detracts from airflow performance. Hence the stator may be optimized by configuring it to deflect only a portion of the swirling air downstream, say 25% or 50%. The optimum percentage may be defined as the one that produces the maximum airflow performance, net of the incremental drag.

Stator 24 may be designed in light of the fan blade geometry, fan speed and hub characteristics of primary fan 4, such that a relatively constant percentage of the air coming off the fan blade is deflected downstream, across the radius of the fan blade and at the outlet of primary fan 4. Generally speaking, the rotational component of the airflow is greater at the tip of the blade than at the hub. Hence the air coming off the tip of the blade does not travel as far downstream as the air at the hub, for any fixed amount of time. Stator 24 may be designed accordingly, extending a lesser distance downstream at the extremities of channel 10 than at the center section of channel 10. In practice the slope of stator 24 is not necessarily linear, and may be contoured to match the actual airflow characteristics of primary fan 4 for optimum performance gains, for example as shown in Figure 16.

The airflow must next pass by perimeter fins 26a and 26b before entering diffuser 28. Recalling that stator 24 deflects only a portion of the swirl downstream, perimeter fins 26a and 26b deflect an additional portion of the swirl downstream. Perimeter fins 26a and 26b may be most effectively positioned along the (inside of) the walls of channel 10, where there is the greatest amount of swirl. It has been found that the general shape of perimeter fins 26a and 26b as shown in Figure 2, with an increasing protrusion into channel 10 as the distance downstream along channel 10 increases, is effective; however other shapes, configurations, and quantities of perimeter fins 26a and 26b may be found to be more effective with different fans and fan configurations. For example perimeter fins 26a and 26b may have a parabolic shape which extends with increasingly further protrusion into channel 10 as the distance downstream along channel 10 increases.

Stator 24 and perimeter fins 26a and 26b together act to remove a portion of the swirl introduced by primary fan 4, and to create a more uniform level of swirl in the airflow as it moves downstream through channel 10, as measured across the cross sectional area of channel 10. Further, channel 10, as viewed in cross section from its inlet as depicted in Figure 3, may have octagonal corners 42, longitudinal troughs 27, longitudinal ridges

29, and/or other features to remove additional swirl from the airflow before it reaches diffuser 28 (reference Figure 2). The unused space between octagonal corners 42 and the square corners of channel 10, i.e. auxiliary spaces 31a, 31b, 31c and 31d, may be used to house other fan related components such as indicator lights, temperature or pressure sensors and fan controllers, or thermal components such as recirculating pumps, spreader plates and thermal batteries. Further, octagonal corners 42 may also be configured to serve the additional function of being an internal support feature for diffuser 28, for example as shown in Figure 17.

With reference once again to Figure 2, the airflow passes through the initial swirl reduction stages represented by stator 24 and perimeter fins 26a and 26b, and then enters diffuser 28 as a final stage before reaching secondary fan 6. Diffuser 28 serves to reduce the swirl down to residual swirl 22, which is an amount of swirl that may be left in the airflow while (i) not negatively affecting the airflow performance of secondary fan 6 or, in some cases, (ii) actually contributing to the increased performance of secondary fan 6 due to inlet conditions that are better than laminar flow. In the latter case residual swirl 22 may be considered as a favourable amount of pre-swirl for secondary fan 6, rendering secondary fan 6 more efficient because it does not need to initiate the rotational motion of the air.

Diffuser 28, when viewed from the inlet of channel 10, may be of honeycomb or some other geometry that is suitable for the purpose of removing additional swirl from the airflow and making residual swirl 22 more consistent across the inlet of secondary 6, while minimizing the incremental drag. The depth of diffuser 28, as measured along the axis of primary fan 4 and secondary fan 6, the cross sectional geometry and the porosity may be selected to suit a particular application or fan configuration. Diffuser 28 may also have different depths across the inlet of secondary fan 6. A shorter depth would be more effective in areas of lower swirl and lower airflow velocity, for example close to the hub of the fan, whereas a longer depth would be more effective in areas of higher swirl and higher airflow velocity, for example at the extremities of the blades. The net effect of this approach is to minimize the total drag introduce by diffuser 28 while making residual swirl 22 more consistent across the inlet of secondary fan 6. It has been found that such a variable depth diffuser 28 may be manufactured, for example, by machining aluminum honeycomb in its pre-expanded form, such that the correct depth will be achieved at any point on a variable depth diffuser 28 once the aluminum honeycomb has been expanded.

Diffuser 28 may also be configured as a finger guard on the inlet side of secondary fan 6. This may be a very useful feature when channel 10 is configured to pull apart, leaving the combined finger guard / diffuser 28 attached to secondary fan 6, for the safety of service personnel.

The combined features of multistage flow optimizer 20, as described above, may be configured to reduce the swirl down to residual swirl 22 within the shortest possible length of channel 10 between primary fan 2 and secondary fan 6. Further, these combined features may be configured to reduce the swirl down to residual swirl 22 within a length of channel 10 that is shorter than possible with a subset of these features, for example by using only diffuser 28. However stator 24, perimeter fins 26a and 26b, diffuser 28, channel 10, and various features of channel 10, as previously described, may be used separately or configured in various combinations to achieve some level of airflow performance improvement for a given application.

In some cases channel 10 may be extended to create an additional distance between diffuser 28 and secondary fan 6. This gap reduces the “chopping” of the air as it leaves diffuser 28 and therefore reduces the acoustic noise; hence this may be referred to as an acoustic gap. Further, it should be noted that the combined features of multistage flow optimizer 20 may be configured such that the speed of primary fan 4 approximately matches that of secondary fan 6 at the desired operating point, substantially removing the beat frequency, harmonics and other types of acoustic noise that are caused by the fan speed differential generally associated with series fans that are not configured with flow optimizers. This approach also substantially precludes the requirement for a specialized fan controller and the algorithms that must be implemented to reduce this fan speed differential. Further, this approach maximizes the airflow since both fans may run at full capacity, i.e. one fan does not have to be slowed down to match the speed of the other.

It should be noted that many of the components of multistage flow optimizer 20 may be ideally suited as heat exchange components, particularly diffuser 28, and more particularly if diffuser 28 is comprised of a heat conductive material such as aluminum honeycomb or some other type of effective radiator. In such cases channel 10 may be configured with a thermal interface for connection to an external heat source or heat sink, and the components of multistage flow optimizer 20 that are intended to be heat exchange components may be configured to be in thermal communication with channel 10 so configured. Further, it should be noted that diffuser 28 may also be configured as an EMI shield, particularly if diffuser 28 is made of aluminum honeycomb. In this case care must be taken to ensure proper electrical conductivity between diffuser 28 and channel 10, and channel 10 may be configured with the appropriate EMI seals.

Viewed from the inlet of channel 10, stator 24 may be configured to be straight, for example stretching diagonally across channel 10 as depicted in Figure 16, or it may be curved to match the shape of the motor mount struts or other features of primary fan 4, the latter configuration generally being considered to introduce less incremental drag into the system. Further, single or multiple stators 24 may be configured along with concentric wires or other features that would, in combination with single or multiple stators 24, create a finger guard on the outlet side of primary fan 4. This may be a very useful feature when channel 10 is configured to pull apart, leaving the combined finger guard / stator 24 attached to primary fan 4 for the safety of service personnel, as shown in Figure 4. The pull apart configuration may also be designed to leave diffuser 28 attached to secondary fan 6, again for the safety of service personnel, as previously discussed. Similarly fan guards 50a and 50b may be mounted at the inlet of primary fan 4 and the outlet of secondary fan 6, respectively, to provide complete protection for service personnel.

In some applications the maximum airflow performance of multistage flow optimizer 20 may be increased by creating an intentional performance slit 25, which is an opening in the otherwise sealed walls of channel 10. While this may improve airflow performance for very low static pressure loads, the trade-off in most cases is a drop in airflow performance for high static pressure loads. Hence the implementation of performance slit 25 tends to be very application specific.

As depicted in Figure 5, traditional fan guard 51 may be configured with four mounting eyelets 52, diagonal cross braces 54, and a series of concentric rings 56 to prevent fingers from pushing past traditional fan guard 51. It should be noted that diagonal cross braces 54 do not cross at the center point. This allows diagonal cross braces 54 to be affixed to one side of concentric rings 56 while remaining flat to the surfaces of concentric rings 56. Also, traditional fan guard 51 is completely symmetrical, such that it may be “flipped over” to be used on the inlet or the outlet of a fan.

Traditional fan guard 51 may be designed for use with fan 60, as depicted in Figure 6. It should be noted that fan 60 is configured with aerodynamic struts 62, to maintain the position of hub 64. Hub 64 may contain a motor, bearings, and other components necessary for the operation of fan 60. The rotation of blades 66 causes the movement of air past aerodynamic struts 62 and hub 64. Fan 60 may be further configured with mounting holes 68

Figure 7 depicts traditional fan guard 51 mounted on fan 50. Mounting eyelets 52 may be aligned with mounting holes 68 such that traditional fan guard 51 may be affixed to fan 60 with bolts or some other suitable fasteners. In this case the rotation of blades 66 causes the movement of air past aerodynamic struts 62, hub 64, concentric rings 56, and diagonal braces 54. Diagonal braces 54 cause a relatively large increase in the resistance to airflow, i.e. the incremental static load of traditional fan guard 51, because the geometry is not consistent with the axial flow of the air or the swirling motion thereof.

Figure 8 depicts high performance fan guard 71 with fan specific cross braces 74 and concentric rings 56. Again, fan specific cross braces 74 may be designed to *not* overlap at the center point, allowing both to be mounted on the same side of concentric rings 56. However in this case high performance fan guard 71 is not symmetrical, hence fan specific cross braces 74 may be affixed to the other side of concentric rings 56 for mounting on the inlet or the outlet of the fan, as the case may be.

High performance fan guard 71 may be mounted on fan 60 as depicted in Figure 9. In this case it may be seen that fan specific cross braces 74 have been designed to match the geometry of, i.e. to run along the center line of, aerodynamic struts 62. In this case fan specific cross braces 74 will not cause any incremental resistance to the airflow, since they are in the "shadow" of aerodynamic struts 62. Hence fan specific cross braces 74 allow for the increased performance of fan 60 while still retaining all of the safety aspects of a fan guard. It is important to note that fan specific cross braces 74 may be of different geometry to suit different fans.

In this case fan specific cross braces 74 may be affixed to the "far" side of concentric rings 5, i.e. the side of concentric rings 56 that is closest to fan 60, in order that fan specific cross braces 74 may rest directly on fan 60 and further to keep concentric rings 56 as far from the rotating components as possible. The latter may also have advantages from a flow development perspective. It is important to note that a high performance fan guard 71 configured for mounting on the other side of fan 60 may have the fan specific cross braces affixed to the "near" side of concentric rings 56, for the same reasons. This would also ensure that the fan specific cross braces 74 at the inlet of fan 60 remain aligned with the fan specific cross braces 74 at the outlet of fan 60, when viewed along the axis of fan 60, hence contributing to improved airflow characteristics for the overall assembly.

Figure 10 depicts high performance fan guard insert 81. In this case modified fan specific cross braces 84 do not have mounting eyelets. All other aspects of high performance fan guard insert 81 remain substantially the same as high performance fan guard 71 (with reference to Figure 8).

High performance fan guard insert 81 may be designed for use with fan guard frame 91, as depicted in Figure 11. Fan guard frame 91 may be configured with fan guard clips 94 and frame mounting holes 92, the latter being designed to align with mounting holes 68, for attachment to fan 60 (with reference to Figure 6). Alternatively fan guard frame 91 may be configured with clips that attach to perimeter of the fan or, in cases where the fan is attached to a multistage flow optimizer, other mating features that attach to the fan, channel 10, and/or other multistage flow optimizer components.

High performance fan guard insert 81 may be configured with fan guard frame 91, as depicted in Figure 12. In this case modified fan specific cross braces 84 may be attached to fan guard clips 94 to form a complete high performance fan guard assembly. It should be noted that different fan specific cross braces 84, suitable for use with different fans, may be attached to fan guard clips 94 in a similar manner, hence adapting the configuration for a variety of fans. Further, fan guard frame 91 may be configured with, or configured to mate with, fan mounting points, wiring connectors or connection points, indicator lights, or other features suitable for a particular application.

The high performance fan guards of the present invention may be made of a variety of materials, including wire and/or plastic. Further, the high performance fan guards of the present invention allow for many applications. These additional uses include, but are not limited to, the use of fan guard frames with multiple high performance fan guard inserts for parallel fan installations, or the use of fan guard frames with high performance fan guard inserts in conjunction with inlet flow development and/or other multistage flow optimization features, as previously described herein, thereby increasing the overall airflow performance of the optimized configuration when the finger guards are in place.

In some applications, as depicted in Figure 13, multiple fans or multiple fan pairs may be configured in parallel to boost airflow and improve cooling performance. However in many cases the overall performance does not reach the theoretical parallel maximum, generally understood to be the sum of the airflow performance of the underlying fans or fan pairs at any given static pressure. This occurs primarily because the inlet airstreams are in competition with each other, particularly when the parallel fan or fan pair inlets are configured close to each other, therefore reducing the efficiency of the overall configuration.

In parallel configurations channels 10a and 10b may be extended upstream, beyond the inlet of primary fans 4a and 4b, to form inlet flow development channels 30a and 30b. Inlet flow development channels 30a and 30b reduce the airflow conflicts between inlet airflows 2a and 2b, thereby allowing primary fans 4a and 4b to operate more efficiently. Further, inlet flow development channels 30a and 30b may be configured with additional features such as inlet tapers 32a and 32b to smooth the transition from square or rectangular inlet flow development channels 30a and 30b to the inlet baffle cut-out profile recommended by the manufacturers of primary fans 4a and 4b. Other features, such as ridges or rotating splines, may be configured within inlet flow development channels 30a and 30b to enhance flow development and reduce the airflow conflicts between inlet flow development channels 30a and 30b.

In some applications an asymmetrical upstream projection of channels 10a and 10b, with an extended projection in between primary fans 4a and 4b and a retracted projection at the outside of primary fans 4a and 4b, may improve the flow development at the inlet of primary fans 4a and 4b, and improve the overall performance of the parallel configuration.

In some applications it may be advantageous to extend channels 10a and 10b downstream beyond the outlets of secondary fans 6a and 6b, to avoid airflow conflicts between outlet airflows 8a and 8b, and/or to direct the respective airflows to specific areas or downstream components.

In some applications primary fans 4a and 4b may be replaced by a blower, to facilitate a right angle turn in the airflow at the inlet. In these cases secondary fans 6a and 6b may be operated at different speeds, and/or the multistage optimizer components contained within channels 10a and 10b may be of different design, to compensate for the characteristically inconsistent airflow velocities across the outlet of the blower. As a result outlet airflows 8a and 8b will become much more consistent, easing the thermal design of other downstream components such as heat sinks.

In many applications it may be advantageous to fit an airflow shut-off mechanism within channel 10a, between primary fan 4a and secondary fan 6a, to be activated upon the failure of primary fan 4a and secondary fan 6a, and to fit an airflow shut-off mechanism within channel 10b, between primary fan 4b and secondary fan 6b, to be activated upon the failure of primary fan 4b and secondary fan 6b. Such a configuration would prevent the backflow of air through the channel 10a or 10b associated with the failed fans, thereby preventing the potentially catastrophic failure of downstream components in the event of the aforementioned failure scenarios. The airflow shut-off mechanism may be configured as a shutter, an airbag, or some other means to stop the impending reverse flow of air in the event of such a failure. Further, the airflow shut-off mechanism may be triggered through a reverse airflow sensor, current or rpm sensors connected to the fans, a pressure sensor, or differential pressure sensors across diffusers 28a and 28b that would immediately sense and be able to respond to a reverse airflow situation in the event of such a fault. The differential pressure sensors across diffusers 28a and 28b, or indeed across any or some combination of the components of multistage flow optimizers 20a and 20b, may also be used to monitor flow during normal mode operation.

In one implementation the airflow shut-off mechanism may be configured as automatically deployed shutter 49, as depicted in Figure 14. Automatically deployed shutter 49 may be configured with multiple small shutter sections 45 and multiple large shutter sections 47, such that the combined small shutter sections 45 and large shutter sections 47, when in the closed position, cover a substantial portion of the cross section of channel 10. The uncovered portion in the middle of channel 10 is not as critical as the outer regions because the middle of channel 10 aligns with the hubs of primary fan 4 and secondary fan 6 (reference Figure 2) where the airflow is minimal. Hence the coverage provided by the combined small shutter sections 45 and large shutter sections 47, when in the closed position, will block a substantial portion of the air flowing back through channel 10, hence providing adequate protection from the backflow of air through channel 10 when the fans have failed.

Figure 15 illustrates the mechanism for the automatic deployment of automatically deployed shutter 49. During normal operation inlet airflow 2 will flow from left to right, as indicated. Large shutter section 47 may be rotatingly attached to channel 10 with shutter hinge 55; shutter hinge 55 being located close to the inlet edge of channel 10. Large shutter section 47 may be further configured with shutter flap 57, located at the downstream edge of large shutter section 47 and protruding at an angle into the airflow. Similar shutter flaps may also be configured on small shutter sections 45. Inlet airflow 2 will impinge against shutter flap 57, pushing large shutter section 47 against the inside wall of channel 10, thereby retaining automatically deployed shutter 49 in the open position. However when both fans fail, the reverse airflow will impinge on the other side of shutter flap 57, causing large shutter section 47 to swing into a closed position within channel 10, thereby blocking the reverse airflow until such time as the fan situation can be resolved.

Figure 16 provides a top perspective view of a preferred embodiment of multistage flow optimizer 20. Primary fan mounting plate 40 allows for the attachment of a primary fan (not shown), by means of fan studs 46, or through some other means. Primary fan inlet 41 may be configured as a circle, a circle with two chords, or as any other shape adapted to substantially seal against and contain the airflow from the primary fan or blower affixed to primary fan mounting plate 40.

Stator 24 may be seen through primary fan inlet 41. Stator 24 may be contoured according to the particular characteristics of the primary fan, as previously described. Perimeter fin 26a and diffuser 28 may also be seen through primary fan inlet 41.

Inlet channel 10 may be configured with a primary channel portion 10a and a secondary channel portion 10b, to facilitate the mounting and enclosure of the internal components of multistage flow optimizer 20 during the manufacturing process, and/or to allow for the separation of primary channel portion 10a and secondary channel portion 10b by service personnel, as previously described. Further, the inside of channel 10 may be configured with octagonal corners 42a, 42b, 42c and 42d (latter three not shown) to improve flow control and to further reduce swirl.

For greater clarity Figure 17 provides a bottom perspective view of a preferred embodiment of multistage flow optimizer 20, with secondary fan mounting plate 50 and secondary channel portion 10b shown transparently to more clearly reveal the internal components. Secondary fan mounting plate 50 allows for the attachment of a secondary fan (not shown), by means of fan studs 46, or through some other means. Secondary fan outlet 51 may be configured as a circle, a circle with two chords, or as any other shape adapted to substantially seal against and contain the airflow into the secondary fan or blower affixed to secondary fan mounting plate 50.

Diffuser 28 may be seen through secondary fan outlet 51. Diffuser 28 may be constructed of aluminum honeycomb, or some other combination of material and geometry. It should be noted that there is a gap between diffuser 28 and secondary fan outlet 51, forming the aforementioned acoustic gap. The gap distance may be maintained by means of spacer blocks 53 located between secondary fan outlet 51 and diffuser 28, a spacer plate located between secondary fan outlet 51 and diffuser 28, or through some other means.

Stator 24, perimeter fin 26b and octagonal corner 42b may be seen through diffuser 28. Further, triangular shelf 43b may be seen through diffuser 28. Triangular shelf 43b forms a surface between the bottom edge of octagonal corner 42b and the proximal square corner of secondary channel portion 10b. Triangular shelf 43b, together with triangular shelves 43a, 43c and 43d (not shown), may be further configured as mounting surfaces for diffuser 28, which may have a rectangular outer shape. Perimeter fins 26a (not shown) and 26b may also be configured as support points for diffuser 28, reducing the tendency for diffuser 28 to flex due to airflow, vibration, or other external forces.

Figure 18 illustrates a process for implementing the various stages of flow optimization in a multistage flow optimizer, described in more detail as follows;

1) Determine geometry for diagonal corners

The geometry for the diagonal corners may be determined by drawing a 45 degree line that is tangent to the desired primary fan outlet geometry or secondary fan inlet geometry, whichever is largest, in each one of the corners. This will minimize any air expansion within the channel, while still having the desired effect of reducing swirl within the channel. It is important that all four diagonal corners be the same to maintain the symmetry of the channel.

2) Test to determine minimum length for channel

The minimum length of the channel may be determined by starting with a length that is approximately equal to the fan diameter divided by three, then conducting iterative tests at incrementally shorter lengths until there is an observed drop in performance.

In practice a variable length channel may be developed by configuring the channel as a shroud that fits around the perimeter of each fan, allowing the fans to slide there within and be separated by a varying number of spacers. This approach may be used for testing and/or production purposes.

3) Test to determine optimum perimeter fin geometry

Various perimeter fin geometries may be tested to experimentally determine the optimum shape, for example by starting with a protrusion equal to 2% of the fan diameter at the upstream end of the fin and 4% of the fan diameter at the downstream end of the fin, with linear and parabolic progressions between the two dimensions.

4) Determine stator geometry and test to determine optimum deflection percentage.

The stator geometry may be determined by using the airflow vectors along the radius of the fan blade, based on the corresponding airflow velocity and blade angle, to calculate the distance downstream that a deflection point would have to be located to deflect a given percentage of the airflow in the downstream or axial direction. This can be followed by iterative testing to determine the optimum percentage of the airflow that must be deflected, typically in the range of 25% to 50% to produce the maximum net positive effect when one take into account the effects of drag.

Different combinations of perimeter fins and stators will have an effect on overall performance as well as the shape of the performance curve (reference Figure 19). Hence different combinations of perimeter fins and stators may be used to optimize the flow for a particular application, for example by maximizing performance along a system curve to achieve a particular operating point. It has also been found that various combinations of perimeter fins and stators may produce more stable performance in a particular region, in applications where stability may be more important than maximum airflow.

5) Test to determine maximum acoustic gap.

This may be determined by introducing a gap between the outlet of the diffuser and the inlet to the secondary fan, typically beginning with 1 or 2 mm and then adding incremental distance until a drop in overall performance has been observed. In most cases the acoustic gap may actually be much larger than required for commercial applications.

6) Design inlet channel, if parallel fan configuration

In parallel configurations the inlet channel geometry may be determined by extending the channels by 1 – 2% of the fan diameter upstream, then conducting tests at incremental distances until an optimum length has been determined. In most cases a chamfer around the inside perimeter of the inlet channels, to smooth the transition between the rectangular or square geometry of the inlet channel and the desired inlet cut-out for the primary fan, will reduce the required inlet channel length and improve performance. Also, in most cases the outside channel length may be further reduced relative to the portion of the channel that forms a partition between the fans.

7) Design fan guards, if required

If fan guards are required then the design may be optimized by matching the fan strut geometry, as previously described.

8) Implement shutters, if required

Backflow shutters may be implemented, as previously described. These devices will actually reduce performance when the fans are operating normally, due to the incremental drag introduced by the shutter flaps; however they will optimize performance when in failure mode.

The multistage optimization process described above involves multiple variables and a substantial amount of iterative testing. This process may be simplified by developing software models of the geometry and the airflow, to more closely predict the optimum set of parameters before testing begins, or, as the software models become more accurate, to preclude the requirement for some or all of the testing. It has been found that reasonable software models may be developed based on a representation of the swirl kinetic energy of the airflow as it leaves the primary fan, and a modeling of the reduction of this swirl kinetic energy as the airflow passes through each of the multiple flow optimization stages until it reaches the desired residual swirl kinetic energy for maximum performance of the secondary fan. In most cases the design will be optimized for the shortest possible distance between the primary and secondary fans.

Figure 19 illustrates the performance gains that may be achieved by implementing a multistage flow optimizer between two series fans. The chart is a typical fan performance chart and plots static pressure (inches water gage) vs. flow (CFM) Lines 100 and 102 represent the primary and secondary fan performance, respectively. Line 104 represents the theoretical maximum performance available from this pair of fans, normally considered to be the sum of the static pressures developed by each fan at a given flow rate, or more generally 2x the static pressure of one such fan at a given flow rate. It may be observed that line 106, which represents the performance of the two fans in series without a multistage flow optimizer, lies well below line 104, i.e. well below the theoretical maximum. This is because the swirl introduced by the primary fan substantially reduces the efficiency of the secondary fan, as previously discussed. It may be further observed that line 108, which represents the performance achieved by installing a multistage flow optimizer between the two fans, lies above line 106 (series performance) at all flow rates and also lies above line 104 (theoretical maximum) across the normal operating range of the fans. It may therefore be concluded that a multistage flow optimizer, designed according to the principles described herein, has the desired effect of increasing the efficiency and performance of the fans, thereby optimizing the flow. The multistage flow optimizer design process has been repeated many times using a wide range of fan types and sizes, including those with and without an integrated stator, from a wide variety of fan manufacturers, with very similar increases in airflow performance relative to the performance of the underlying fans.

In many applications the increased airflow provided by a multistage flow optimizer and is useful for providing increased cooling while still using the same underlying fans, as depicted by line 108. However in other applications the increased fan efficiency may be used to save fan power in the following manner. A reduction in the power applied to the fans will cause the optimized performance, i.e. line 108, to move towards the origin. It follows that a certain reduction in the power applied to the fans will cause the optimized performance to approximate the series performance, i.e. line 106. In practice it has been found that fan power may be reduced by somewhere in the range of 20 – 23% while still achieving the underlying series performance. This approach also reduces fan speed, which in turn reduces fan noise and also extends the expected life of the fans.

The multistage flow optimizers of the present invention allow for many applications. Although reference is made to the embodiments listed above, it should be understood that these are only by way of example and to identify the preferred use of the invention known to the inventors at this time. It is believed that the multistage flow optimizers have many additional uses that will become obvious once one is familiar with the fundamental principles of the invention. These additional uses include, but are not limited to, the use of multiple multistage flow optimizers (reference Figure 2) in configurations of three or more series fans, the use of multiple multistage flow optimizers with parallel features (reference Figure 13) with three or more groups of series fans in parallel, the use of multistage flow optimizers with various combinations of blowers and fans, and the use of multistage flow optimizers with single fans or blowers to reduce the swirl at the outlet, thereby increasing the natural convection efficiency of other downstream components such as heat sinks.

Claims:

1. A series fan assembly comprising:

a) a primary fan;

b) a secondary fan in series with said primary fan;

c) a plurality of flow optimization elements, configured to reduce swirl;

d) a connecting sleeve;

wherein said connecting sleeve directs the output of said primary fan through said flow optimization elements and into said secondary fan.

2. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements are mounted within said connecting sleeve and between said primary fan and said secondary fan.

3. The series fan assembly of claim 1 wherein the primary fan is mounted between the connecting sleeve and at least one of said plurality of flow optimization elements.

4. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a stator which deflects the swirl downstream and converts a portion of the swirl kinetic energy into axial kinetic energy.

5. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a pair of perimeter fins.

6. The series fan assembly of claim 5 wherein the perimeter fins have a parabolic shape.

7. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a set of four octagonal corners within the connecting sleeve.

8. The series fan assembly of claim 1 wherein the space between the four octagonal corners and the connecting sleeve contains at least one flow monitoring component.

9. The series fan assembly of claim 1 wherein the space between the four octagonal corners and the connecting sleeve contains at least one fan control component.

10. The series fan assembly of claim 1 wherein the space between the four octagonal corners and the connecting sleeve contains at least one thermal component.

11. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a set of longitudinal troughs or a set of longitudinal ridges.

12. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a performance slit

13. The series fan assembly of claim 1 wherein at least one of the plurality of flow optimization elements is a diffuser within the connecting sleeve.

14. The series fan assembly of claim 13 wherein the diffuser has a non-uniform thickness.

15. The series fan assembly of claim 13 wherein the diffuser is configured as an EMI shield.

16. The series fan assembly of claim 13 wherein the diffuser is configured as a heat exchanger.

17. The series fan assembly of claim 1 wherein a flow optimization element is configured as a heat exchanger.

18. The series fan assembly of claim 1 wherein the connecting sleeve is configured as a thermal interface.

19. The series fan assembly of claim 1 wherein a residual amount of swirl is retained to improve the performance of the secondary fan.

20. The series fan assembly of claim 1 wherein the flow optimization element causes the speed of the primary fan to more closely match that of the secondary fan.

21. The series fan assembly of claim 1 wherein the primary fan and the secondary fan run at reduced power while still achieving the same flow as compared to a fan configuration having identical primary fan and secondary fan characteristics, but lacking flow optimization elements.

22. The series fan assembly of claim 1 wherein the connecting sleeve extends past a final flow optimization element before connecting with the secondary fan, and wherein said configuration reduces noise from operation of the series fan assembly.

23. The series fan assembly of claim 1 wherein the flow optimization elements are modelled in software based on their effect on swirl kinetic energy of airflow within the connecting sleeve.

24. The series fan assembly of claim 1 wherein the flow optimization elements stabilize the combined output of the primary fan and the secondary fan.

25. The series fan assembly of claim 1 wherein the length of the channel is modified with at least one spacer to enable interchangability of said primary fan and/or said secondary fan.

26. The series fan assembly of claim 1 wherein the connecting sleeve is designed to pull apart for servicing.

27. The series fan assembly of claim 26 wherein at least one of the plurality of flow optimization elements is a diffuser within the connecting sleeve and is configured as a finger guard on an inlet side of the secondary fan.

28. The series fan assembly of claim 26 wherein at least one of the plurality of flow optimization elements is a stator within the connecting sleeve and is configured as a finger guard on an outlet side of the primary fan.

29. The series fan assembly of claim 1 wherein said secondary fan is a heat sink.

30. The series fan assembly of claim 1 wherein said primary fan is a blower.

31. The series fan assembly of claim 30 wherein said secondary fan is two or more fans configured in parallel.

32. The series fan assembly of claim 31 wherein said two or more fans configured in parallel operate at different speeds from one another.

33. A series fan assembly comprising:

a) a primary fan;

b) a secondary fan in series with said primary fan;

c) a connecting sleeve, directing the output of said primary fan into said secondary fan; and

d) an airflow shut-off mechanism, within the connecting sleeve;

wherein the airflow shut-off mechanism prevents air flow from the secondary fan to the primary fan but allows air flow from the primary fan to the secondary fan.

34. The series fan assembly of claim 33 wherein the airflow shut-off mechanism is a shutter.

35. The series fan assembly of claim 34 wherein the shutter is activated through a reverse airflow sensor, a current sensor connected to the secondary fan, a pressure sensor within the connecting sleeve, or a differential pressure sensor within the connecting sleeve.

36. The series fan assembly of claim 34 wherein the shutter comprises a shutter section having a shutter flap at a downstream edge, said shutter section rotatingly attached to the connecting sleeve through a shutter hinge, wherein airflow from the secondary fan in the direction of the primary fan will impinge against shutter flap, thereby rotating the shutter section and closing off air flow through the connecting sleeve.

37. The series fan assembly of claim 34 wherein the shutter comprises a plurality of said shutter sections, each with said shutter flap, which combine to close off substantially all air flowing from the secondary fan in a direction of the primary fan.

38. A finger guard for a fan having a frame, a hub, a plurality of struts connecting the hub to the frame, and a plurality of blades connected to the hub and capable of rotation in relation to said hub, said finger guard comprising:

at least two cross braces extending from a first side of the frame to a second side of the frame and capable of being affixed thereto; and

a series of concentric rings, spaced close enough together to act as a barrier such that a finger can not pass through, and connected to the cross braces such that said finger can not access the blades through an aperture in said concentric rings;

wherein the cross braces are shaped such that, when affixed to the frame, they run along the struts and thus do not cause any incremental resistance to airflow when the blades are in rotation.

39. The finger guard of claim 38 wherein the frame further comprises frame mounting holes, and the cross braces are affixed to the frame utilizing a set of fan guard clips affixed to said mounting holes.

40. The finger guard of claim 38 wherein the frame further comprises frame mounting holes, and the cross braces are affixed to the frame utilizing a set of fan guard clips affixed to a fan guard frame that is affixed to said mounting holes.

41. The finger guard of claim 38 wherein the cross braces are affixed to the frame utilizing a set of fan guard clips affixed to a fan guard frame that clips on the perimeter of the frame.

42. The finger guard of claim 38 wherein the frame further comprises frame mounting holes and the cross braces further comprise mounting eyelets, said mounting eyelets being affixed to said mounting holes.

43. The finger guard of claim 38 wherein one or more of said cross braces is a stator.

44. A parallel fan assembly, comprising:

a) a first fan;

b) a second fan, located parallel to said first fan;

c) an inlet development channel located upwind of said first and second fan, wherein said inlet development channel interrupts air flow interference between said first fan and said second fan.

45. The parallel fan assembly of claim 44 wherein the inlet development channel is chamfered to direct the flow into said first fan and said second fan.

46. The parallel fan assembly of claim 44 wherein the inlet development channels extend a further distance upstream between said first fan and said second fan then at the extremities of said first fan and said second fan.

Figure 1

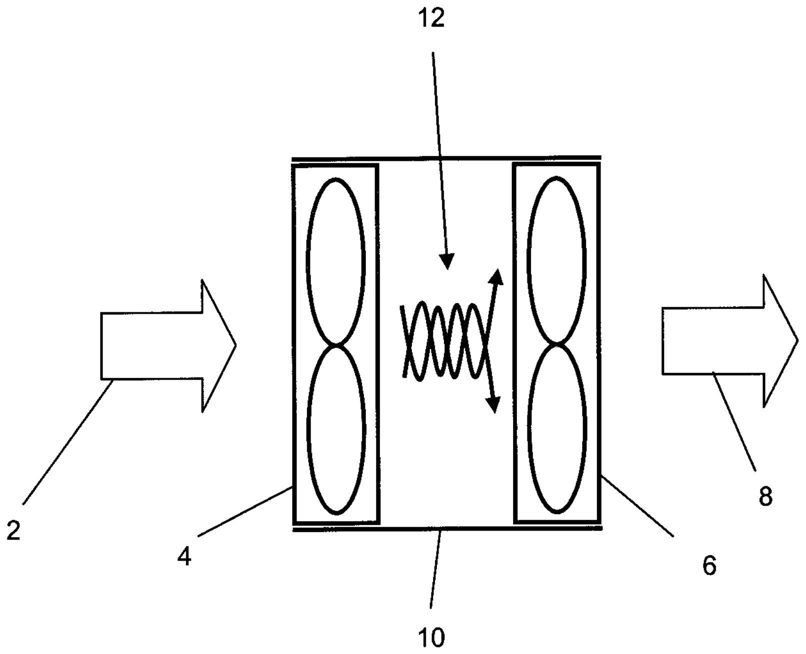


Figure 2

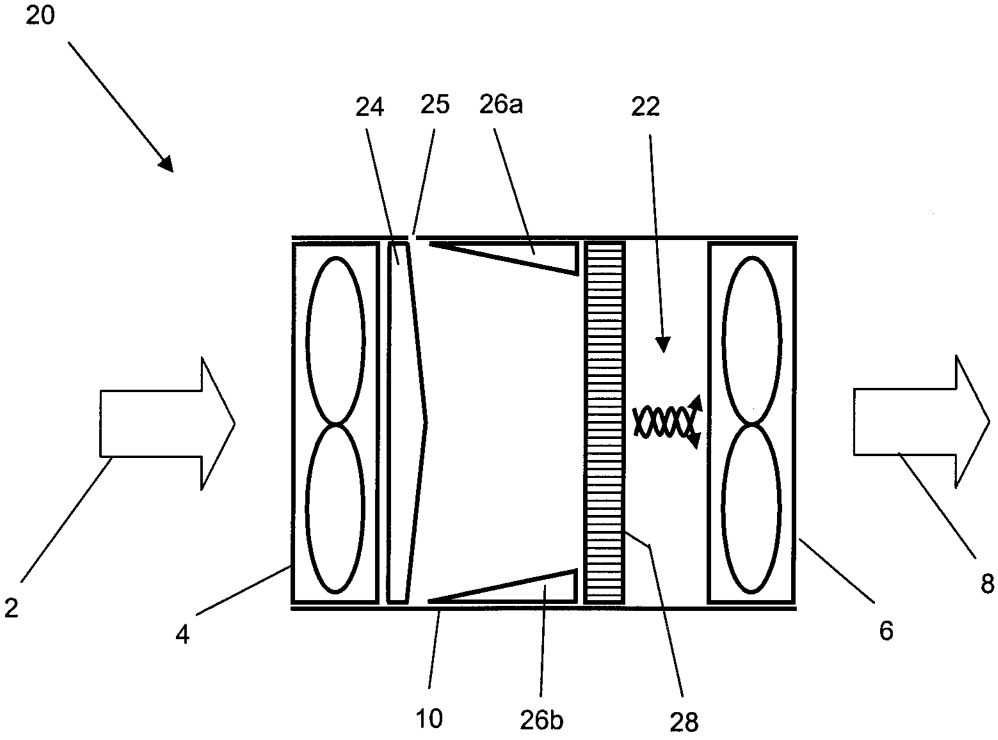


Figure 3

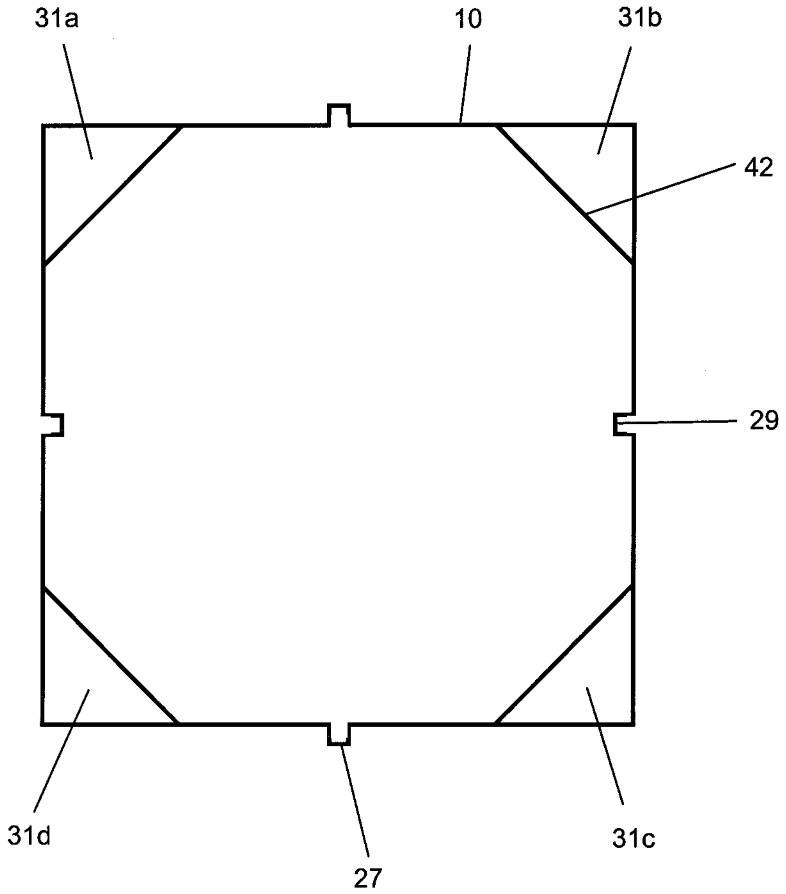
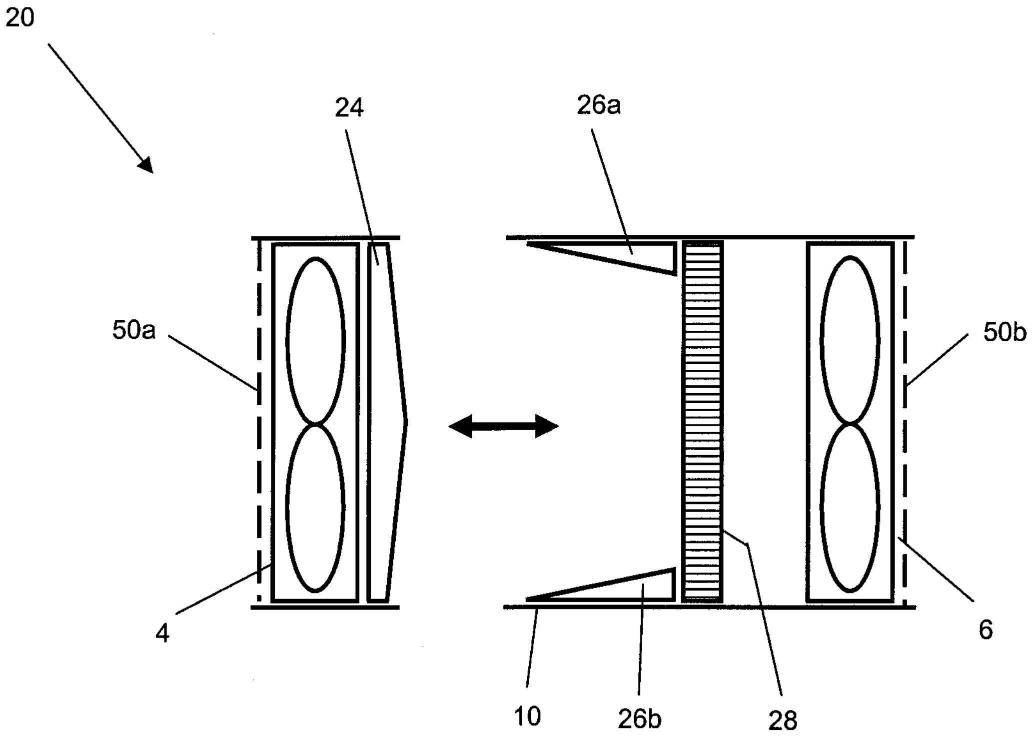


Figure 4



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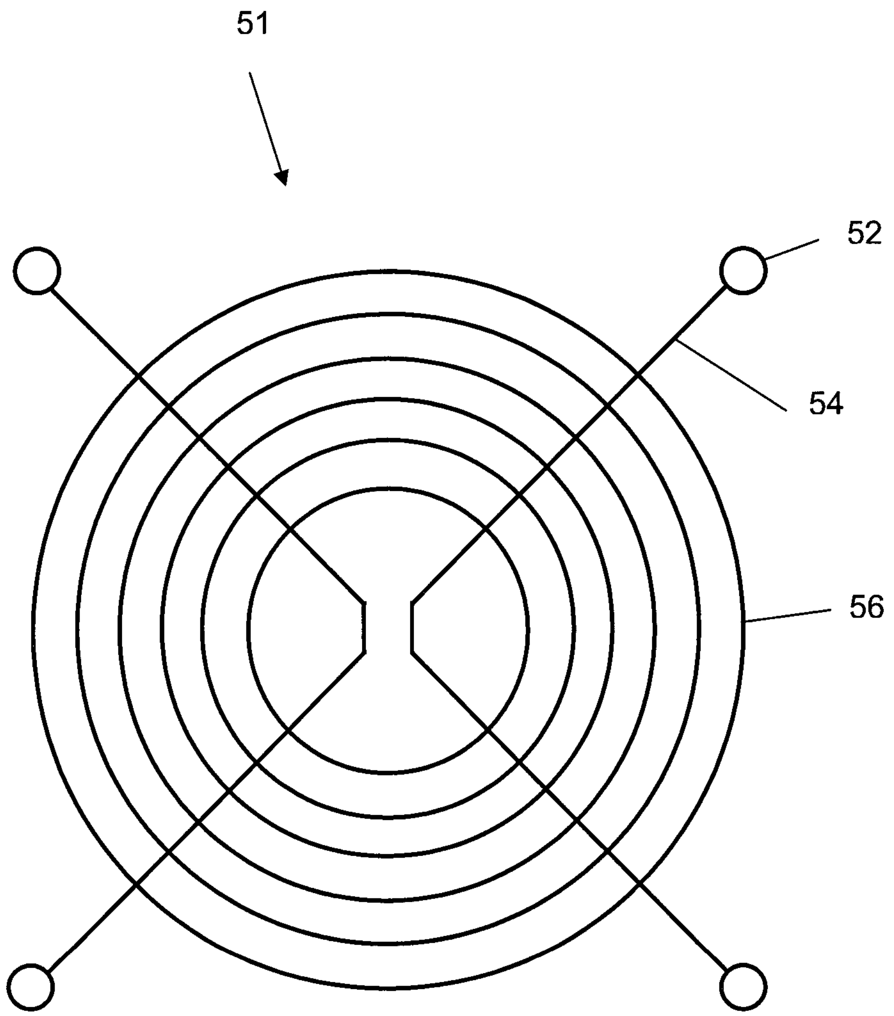
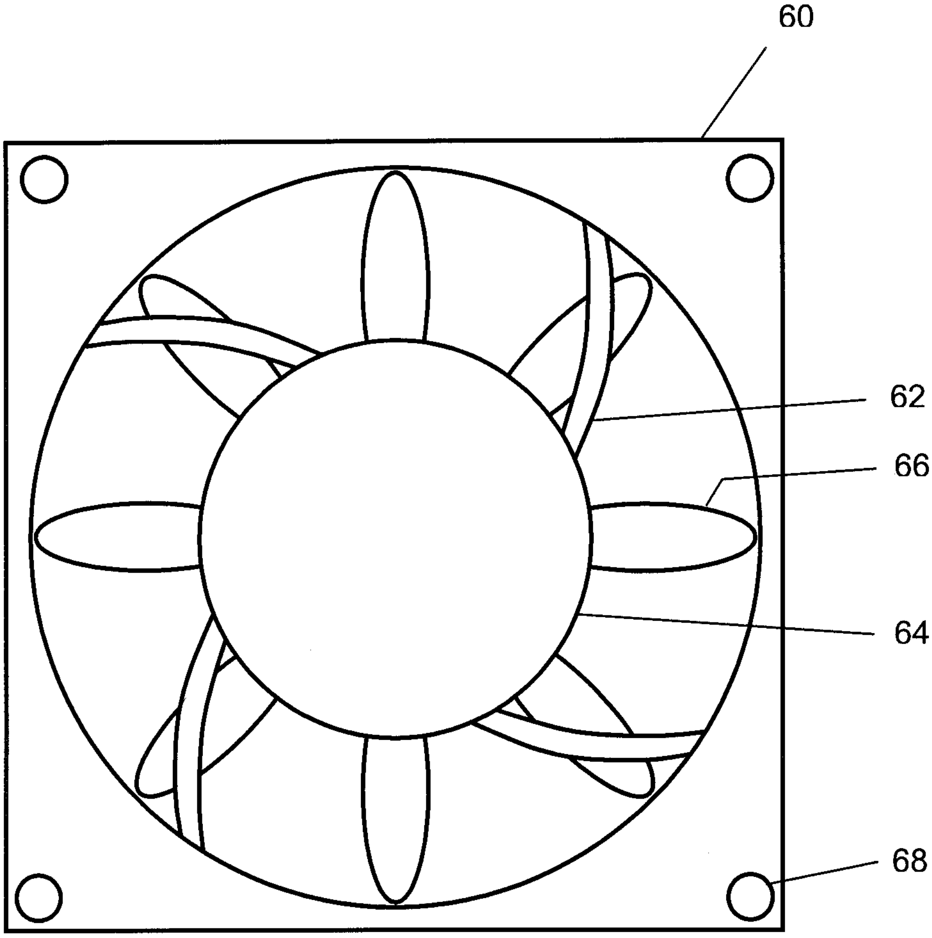


Figure 6



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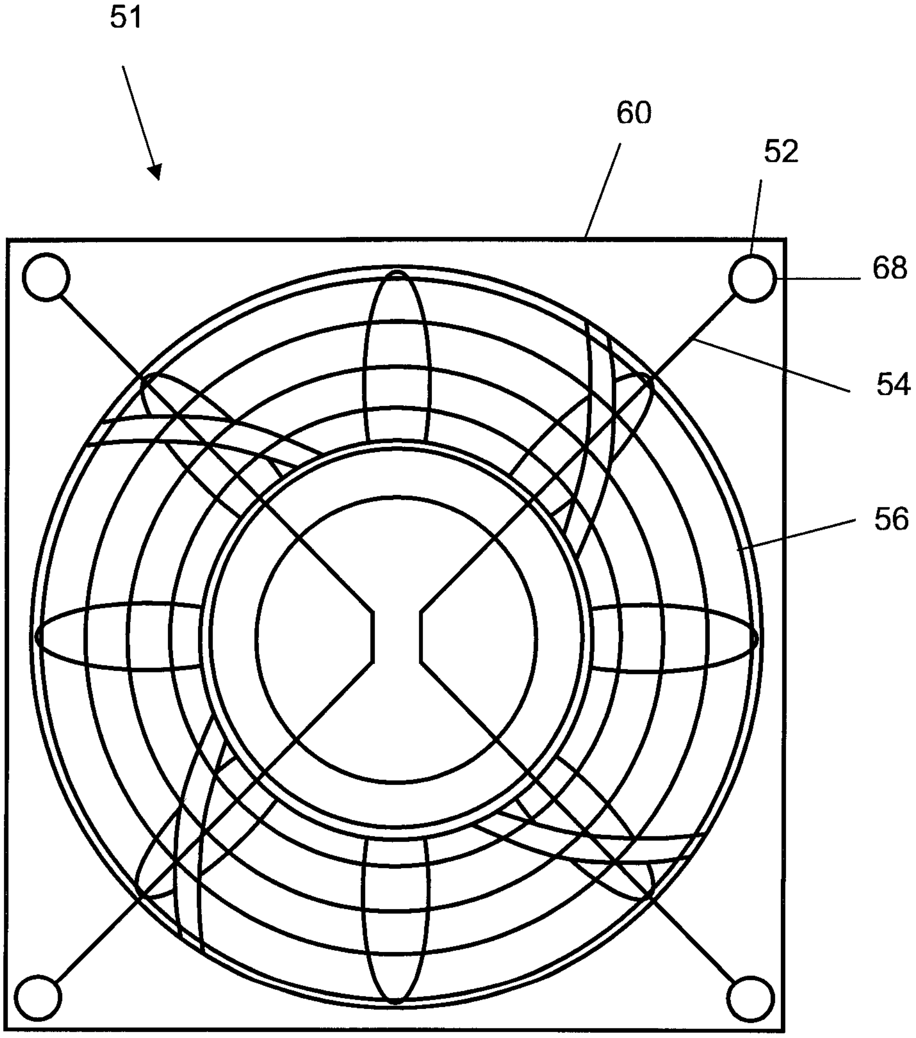
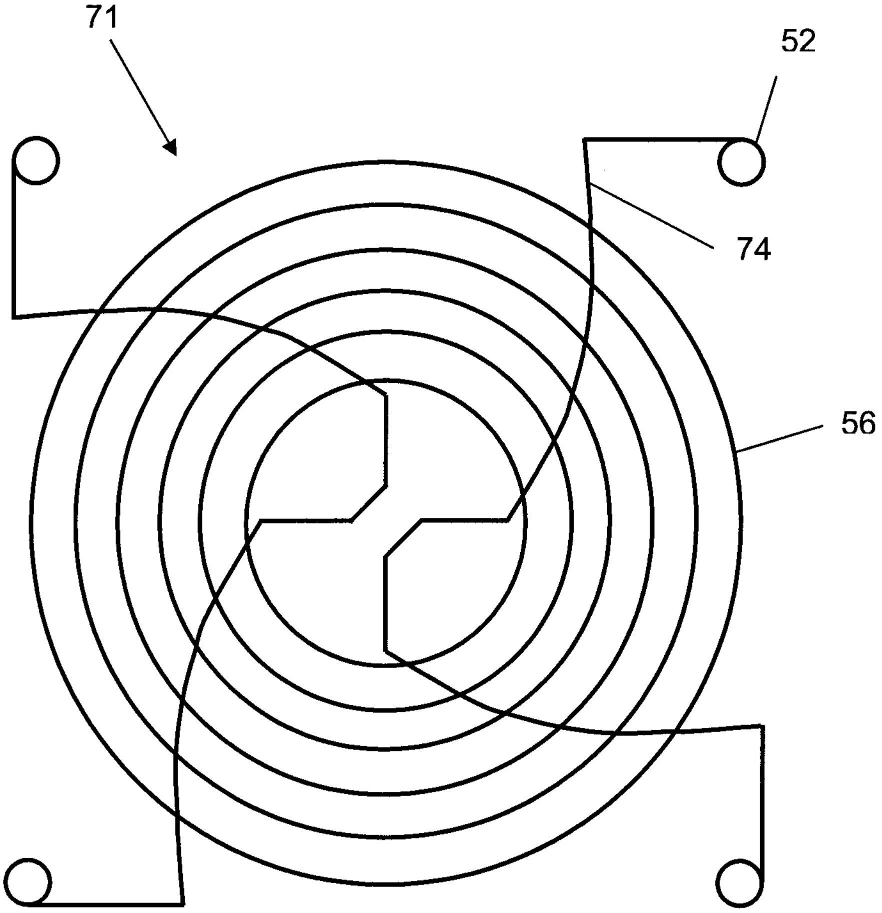


Figure 8



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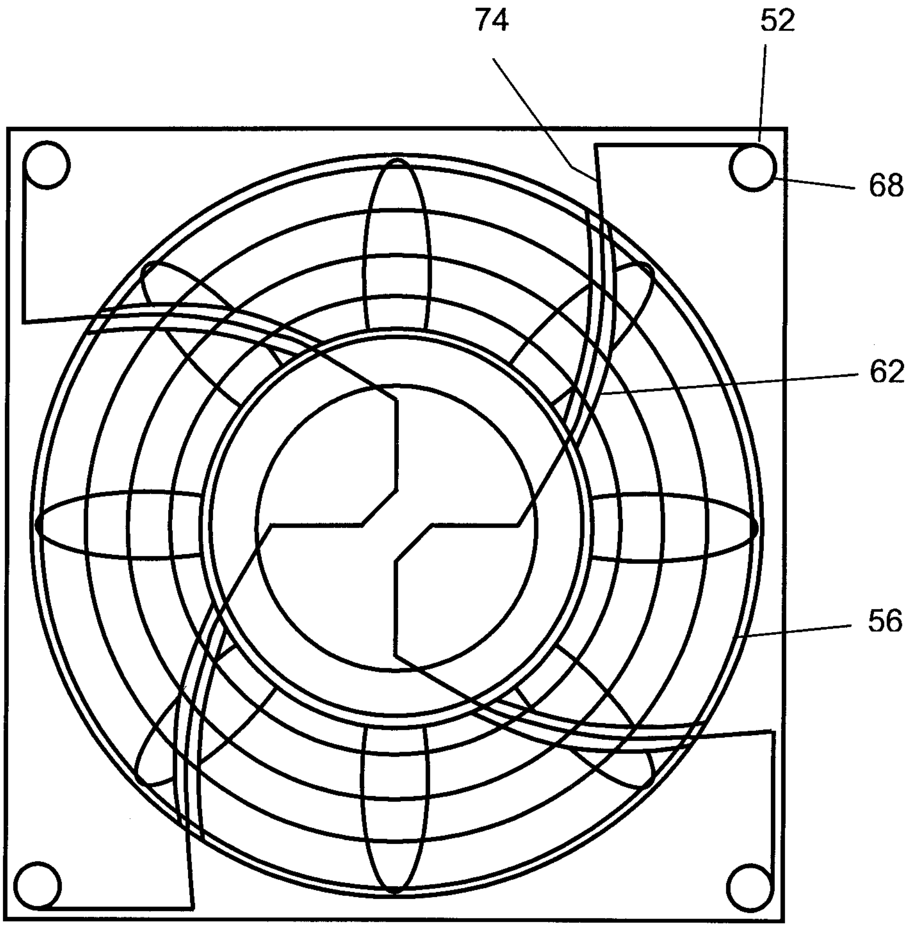


Figure 10

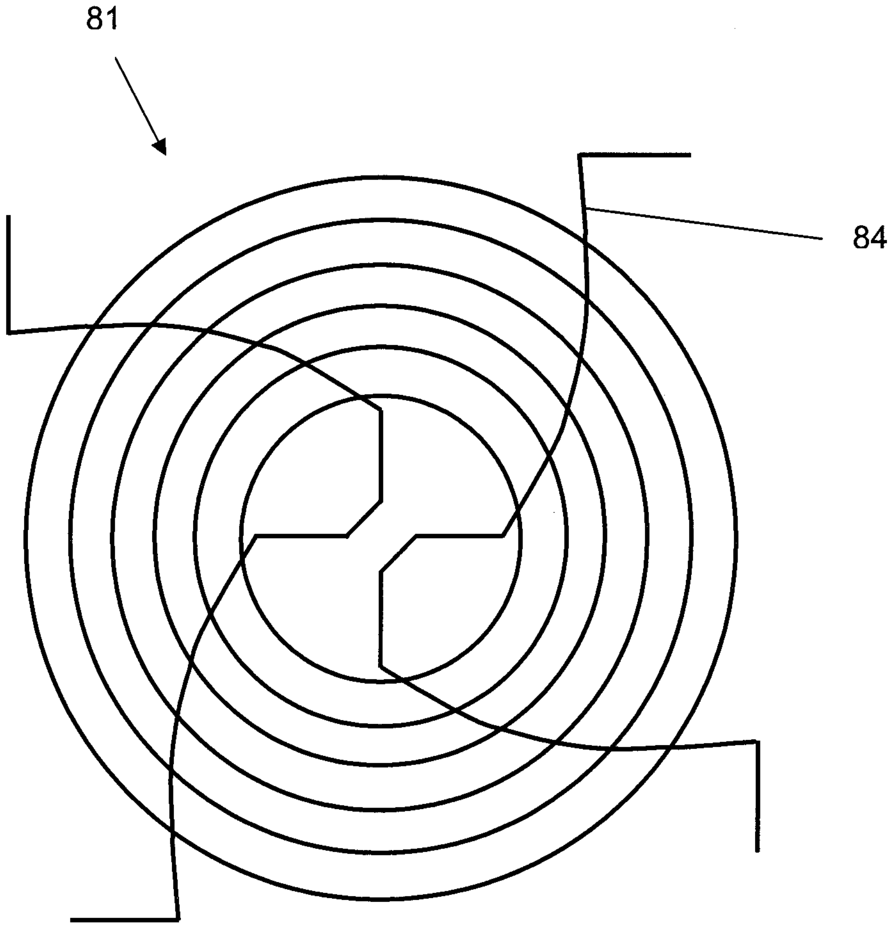


Figure 11

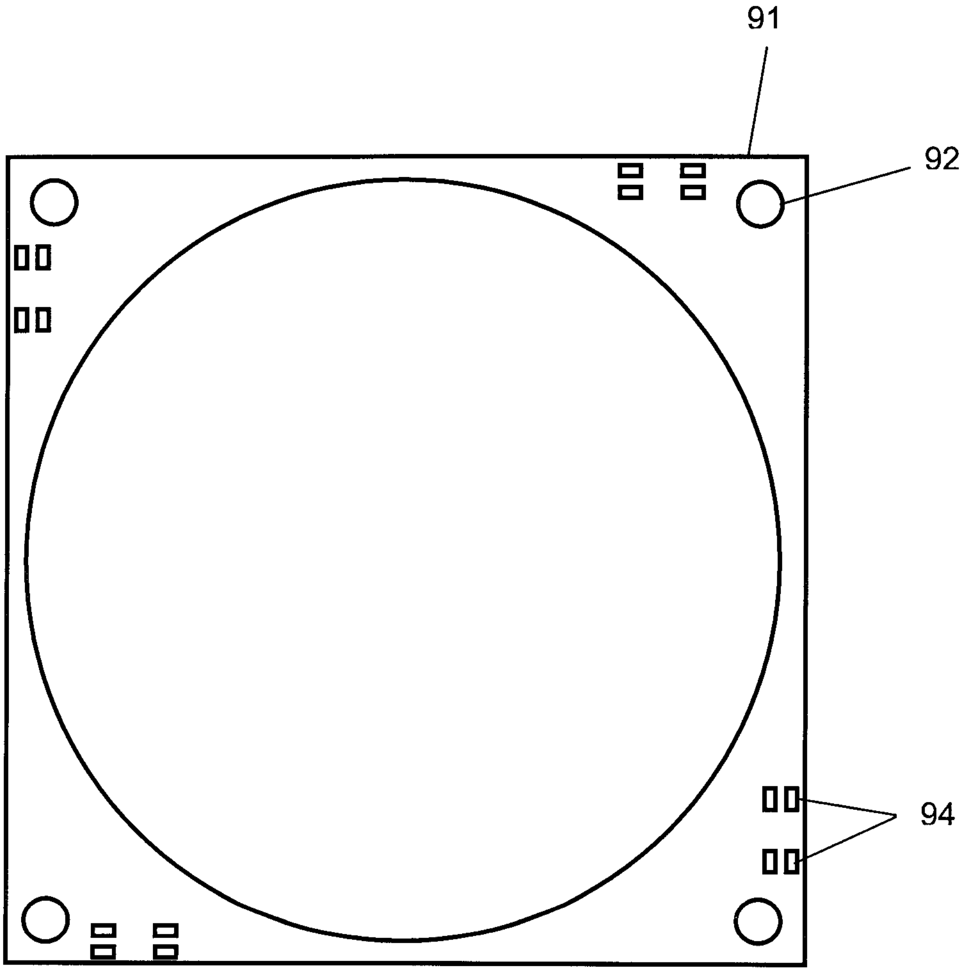


Figure 12

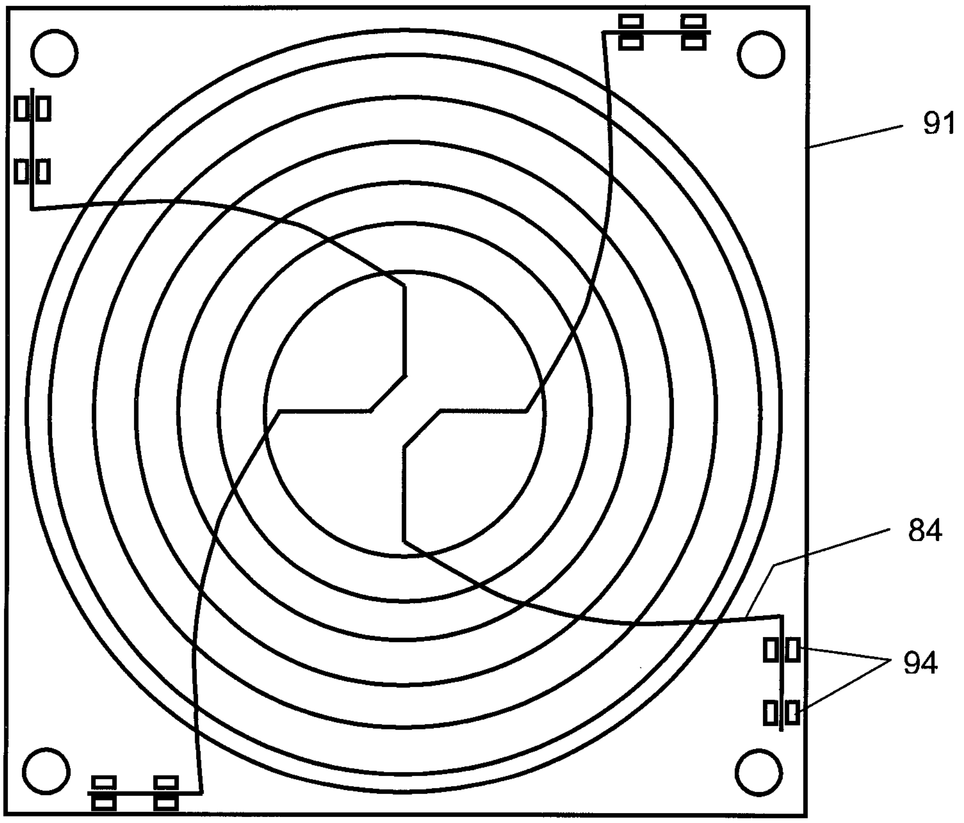


Figure 13

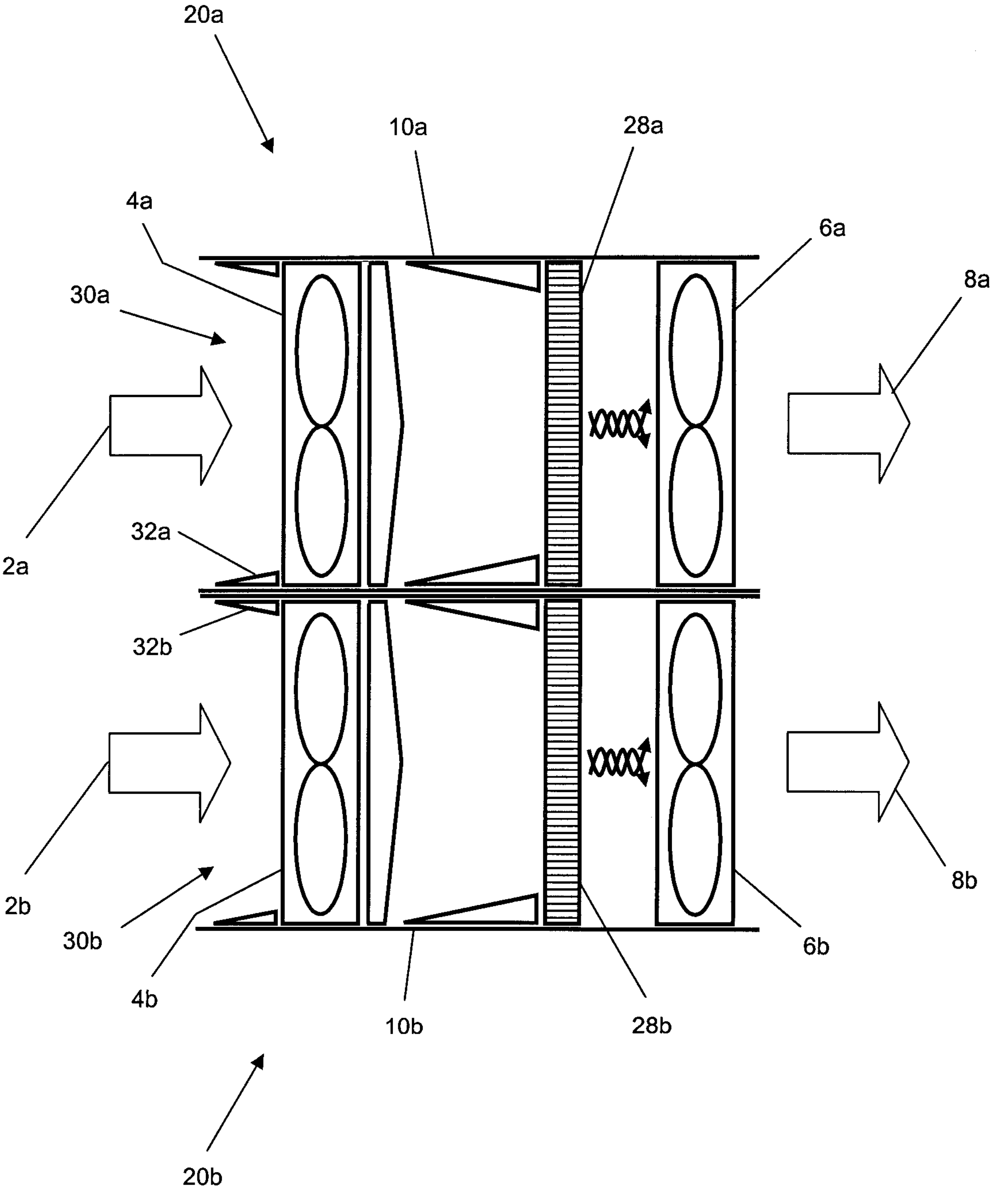


Figure 14

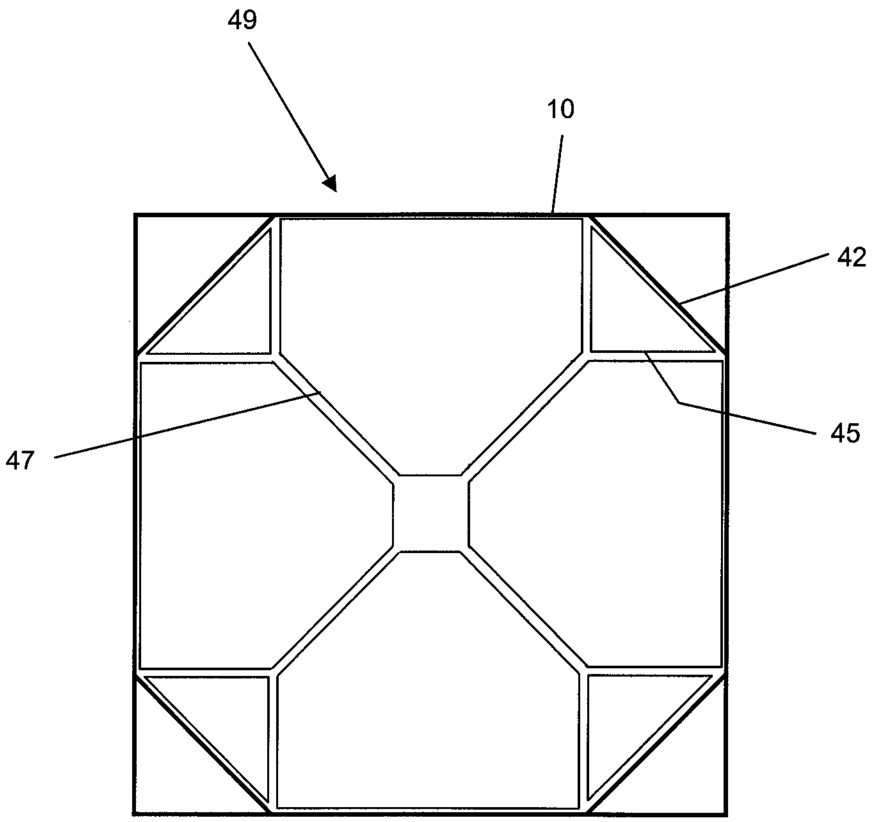


Figure 15

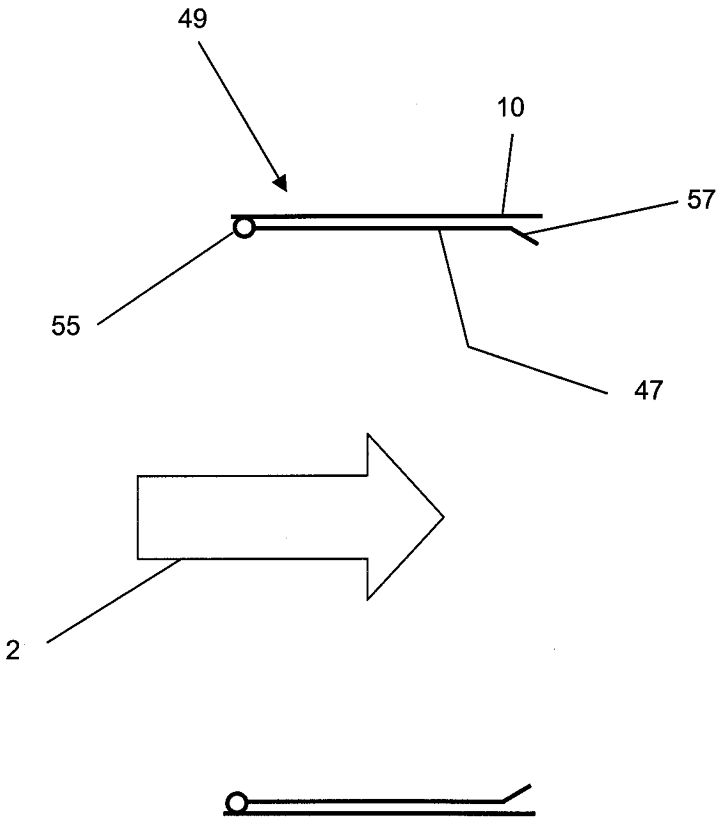


Figure 16

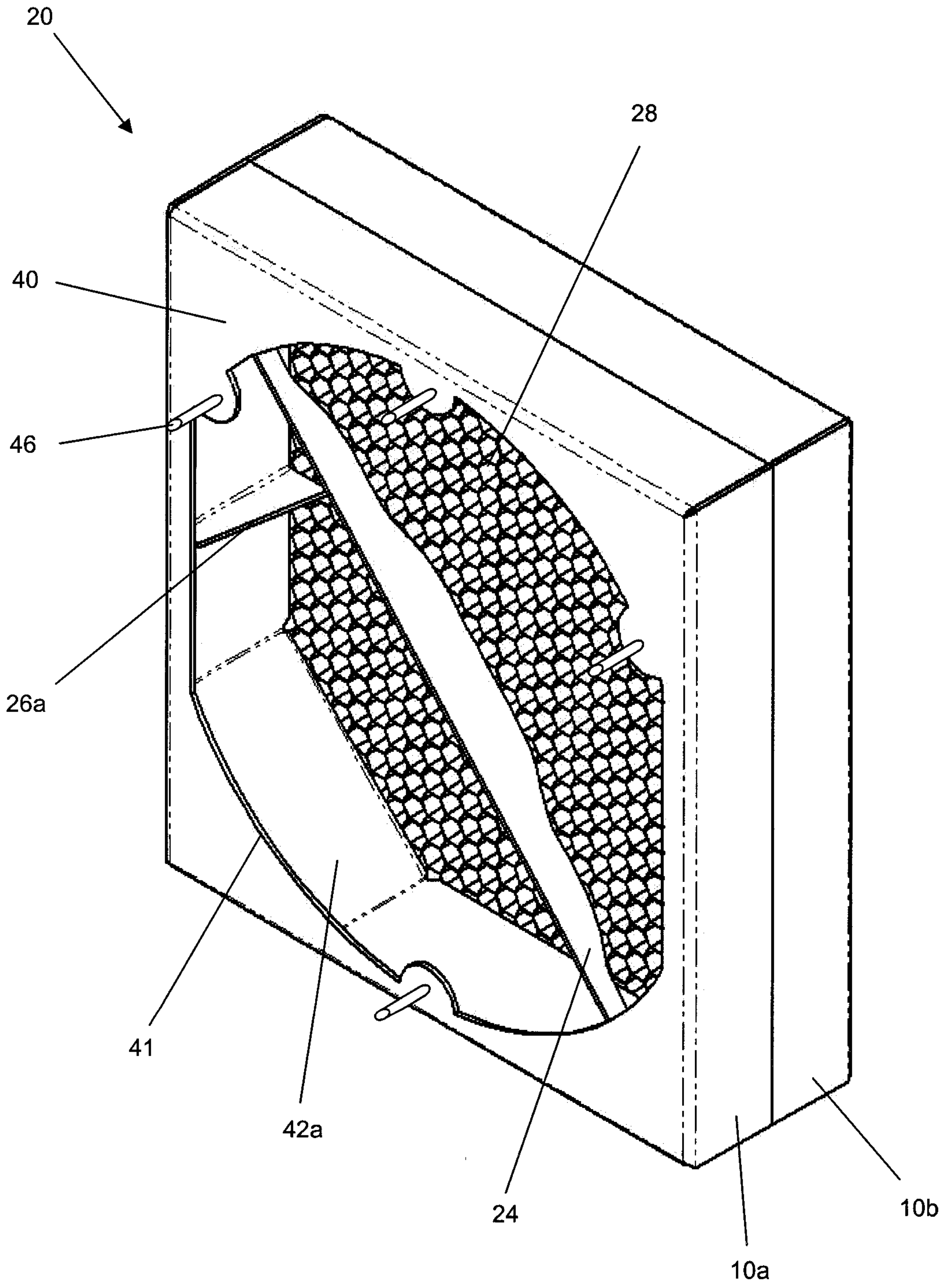


Figure 17

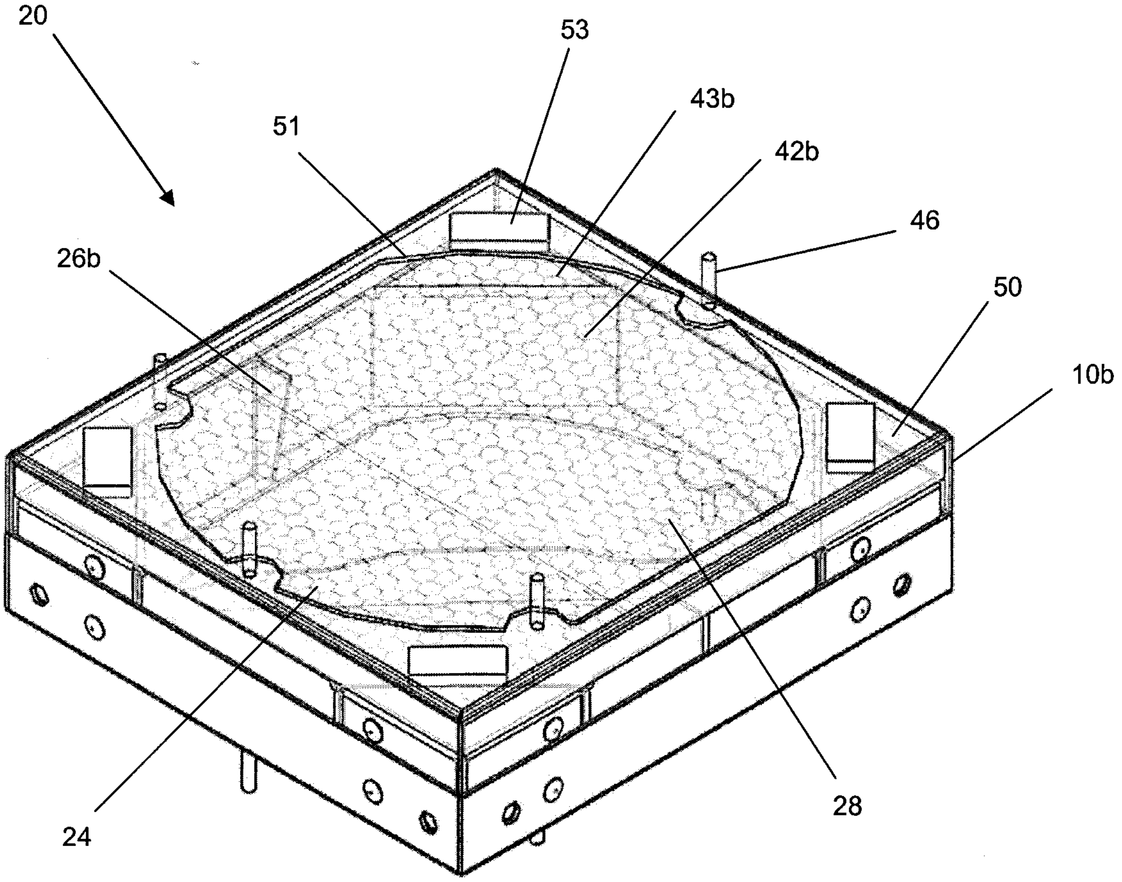


Figure 18

Multistage Flow Optimizer – Design Process

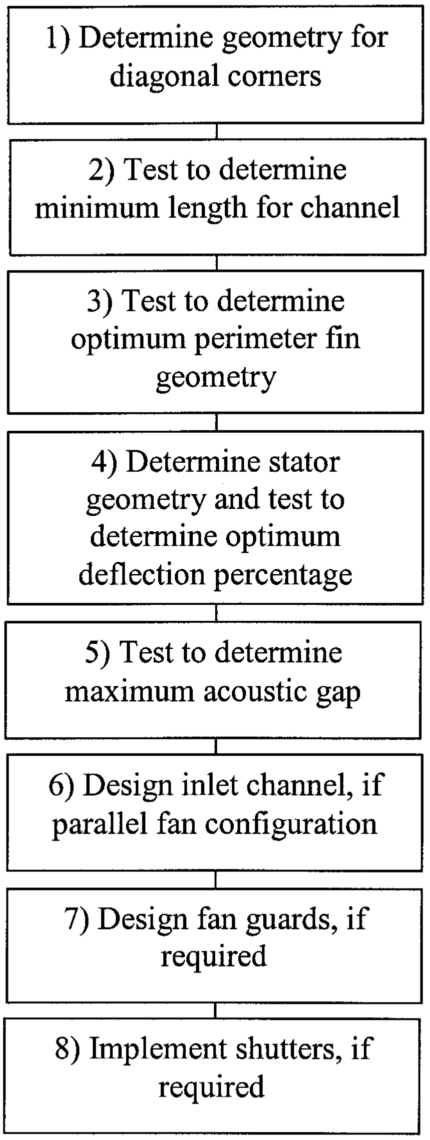
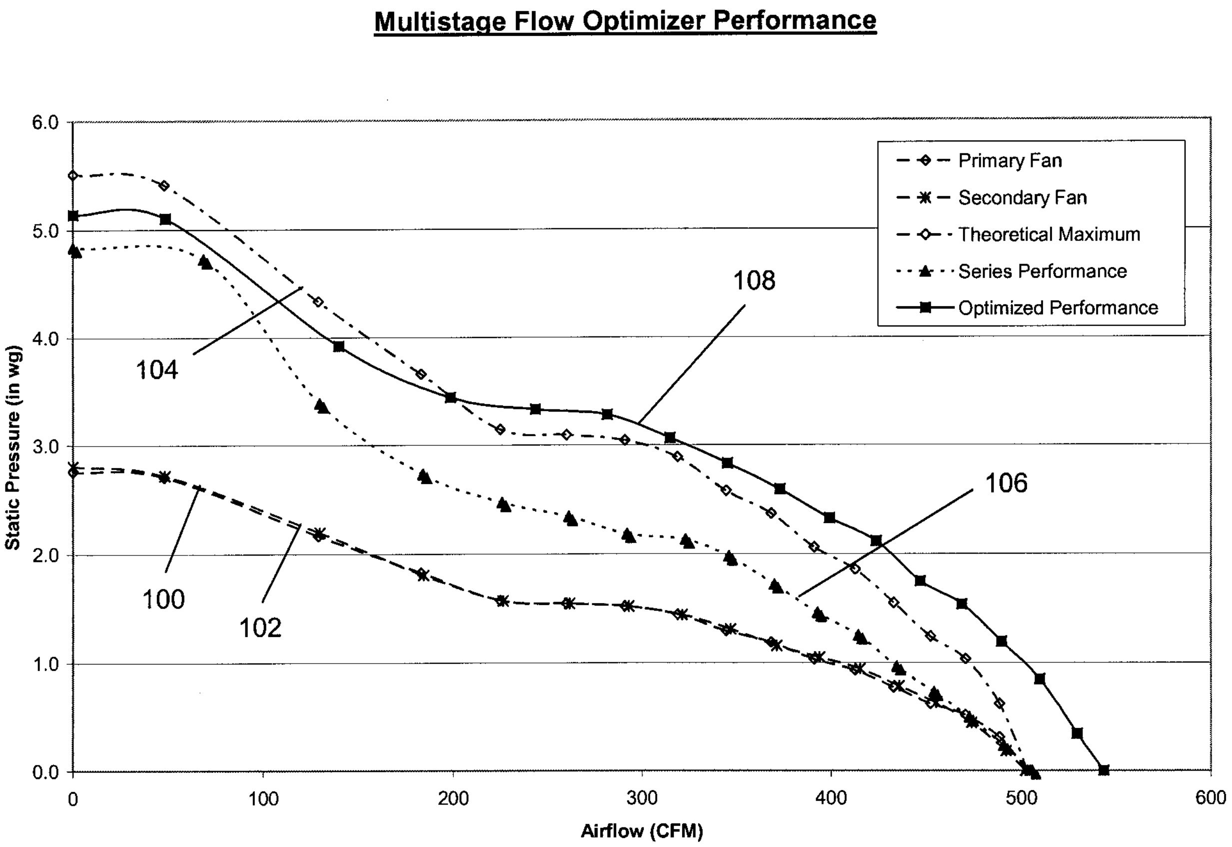


Figure 19


Multistage Flow Optimizer Performance
Static Pressure (in wg)
Airflow (CFM)
0.0
1.0
2.0
3.0
4.0
5.0
6.0
0
100
200
300
400
500
600
Primary Fan
Secondary Fan
Theoretical Maximum
Series Performance
Optimized Performance
100
102
104
106
108