(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
5 January 2012 (05.01.2012)

PCT

(10) International Publication Number
WO 2012/002907 Al

(51) International Patent Classification:
H01M 2/02 (2006.01) *H01M 6/42* (2006.01)
H01M 10/50 (2006.01) *H01M 10/0585* (2010.01)
H01M 2/30 (2006.01)

(21) International Application Number: PCT/SG2011/000029

(22) International Filing Date: 24 January 2011 (24.01.2011)

(25) Filing Language: English

(26) Publication Language: English

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:

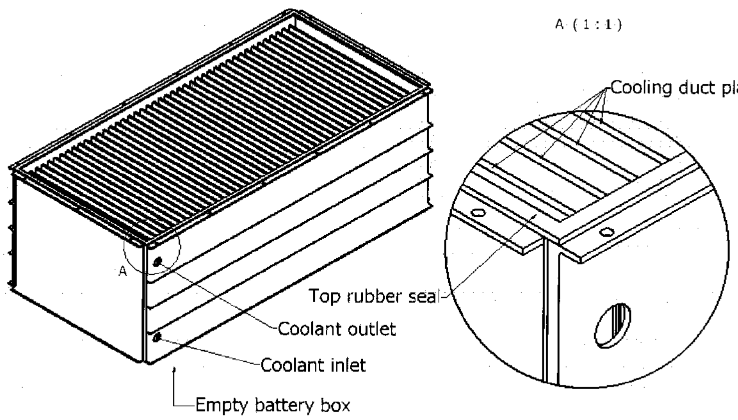
— *with international search report (Art. 21(3))*

— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

— *upon request of the applicant, before the expiration of the time limit referred to in Article 21(2)(a)*

(54) **Title:** POWER BATTERY PACK COOLING APPARATUS

FIG. 17



(57) Abstract: Using a simple structure to facilitate a flow path delivering coolant in an even and well-distributed manner, providing efficient and effective cooling for power battery packs in electric vehicles. The heat exchange apparatus is composed of an array of cooling duct plates, with ducts for coolant to flow within, with front and back covers and their respective rubber sheets facilitating the changing of direction of the coolant, providing a pathway for the coolant to flow throughout the array. Individual cells of the battery pack will be fitted in the spaces between these ducts, connected in series by a novel system of electricity-conducting clips, forming a structure where a comprehensive, well- distributed and compact cooling pathway can exist within the battery pack. The concept and structure of this power battery pack cooling apparatus can also apply to other future implementations and applications requiring compact and lightweight battery packs, or applications requiring effective cooling systems under space constraints.

WO 2012/002907 A1

POWER BATTERY PACK COOLING APPARATUS

Introduction

The supply of fossil fuels is slowly being exhausted, and burning gasoline is causing much environmental pollution. Electric vehicles (EVs) are the future of transportation, but their batteries have some critical shortcomings: short range of vehicles, short service life, and high costs, preventing widespread consumer adoption. Regulating the battery temperature during continuous charge and discharge is a major challenge.

For most Li-ion batteries used in EVs, their temperature specification is normally as follows:

Operating temperature: - 20 °C to 60 °C

Charging temperature: 0 °C to 45 °C

Storage temperature: -10 °C to 45 °C

They can achieve their rated capacity at 20~25°C and their capacity will drop ~10% for every increase of 10 °C.

During winter, when temperatures can easily fall below 0 °C, it will be difficult or totally impossible for charging.

During other seasons, under continuous high current charge/ discharge, the battery working temperature can easily reach 60 °C, making it difficult for discharging. Higher temperatures can also cause battery degradation, shortened service life, or present safety hazards.

The specific characteristics of Li-ion cells require well-adapted and well-designed battery temperature management and control systems.

In the subsequent paragraphs, for simplification, the word 'cooling' will represent heat exchange, be it cooling or heating, and the word 'coolant' will represent a liquid that has anti-freeze, non-flammable, non-corrosive and anti-fungal properties for heat exchange of the battery cells, be it for cooling or heating.

Drawbacks of existing battery packs

Present-day battery packs are constructed by connecting a number of battery modules, each module consisting of several cells connected side by side. The result is that cells in the center of each module are more thermal insulated, resulting in more difficult heat exchange.

Existing battery cooling solutions normally consist of the battery modules sitting on or attached to a heat sink (a flat metal plate) that is cooled by a coolant loop. The drawbacks are that the cooling efficiency is low, and the effectiveness is poor, since only a small part of each module receives the cooling effect. Also, the heat sinks are generally thick and heavy due to the coolant loop. The result is that temperatures will differ from module to module, cell to cell. Even within the same cell, different regions may have different temperatures. If heat sinks were to be used to cool each cell, it would result in a battery pack with impractical weight and volume.

Consistency and uniformity of each cell in a battery pack is very important for its durability and effectiveness. Once the cells are produced and assembled into battery packs, the only factor that is able to affect its consistency and uniformity is the temperature of each cell. Temperature changes can affect the cells' internal resistance, and changes to internal resistance can in turn affect the rate of temperature change. The existence of a temperature gradient between cells will cause different rates of cell ageing, resulting in certain cells having shorter lifespans. With the failure of a single cell, the operation of the entire battery pack is compromised as all cells are interlinked to work together.

Battery packs used in EVs are constrained by space and weight, so cooling systems for the battery packs must be compact and lightweight, yet meeting the power and energy capacity requirements.

A more compact, lightweight and longer lasting power battery pack solution

Based on the above observations, I studied and worked out a unique battery pack cooling apparatus suitable for EV requirements. Although the design below is intended for applications in an EV and is a proof-of-concept for realistic application in an EV, it does not and will not limit or affect the claims about its novel concept, principles, and structure for other applications.

The following drawings form part of this description,

Fig. 1/31 is a large-format laminated battery cell (100Ah, 3.7V);

Fig. 2/31 is a 2S-cell (2 battery cells connected in series);

Fig. 3/31 is a small clip;

Fig. 4/31 is a big clip;

Fig. 5/31 is an end clip;

Fig. 6/31 is a cooling duct plate;

Fig. 7/31 is a cooling duct end plate;

Fig. 8/31 is the cooling grid array;

Fig. 9/31 is a front rubber sheet;

Fig. 10/31 is a front cover;

Fig. 11/31 is a front cover with front rubber sheet;

Fig. 12/31 is a back rubber sheet;

Fig. 13/31 is a back cover;

Fig. 14/31 is a back cover with back rubber sheet;

Fig. 15/31 is a bottom plate;

Fig. 16/31 is a side plate;

Fig. 17/31 is an empty battery box;

Fig. 18/31 is a battery box with multiple 2S-cells;

Fig. 19/31 is a detail view-C of Fig. 18/31;

Fig. 20/31 is a detail view-D of Fig. 18/31;

Fig. 21/31 is a top cover;

Fig. 22/31 is a battery pack box;

Fig. 23/31 is flow direction diagram;

Fig. 24/31 is cooling grid array front view with front rubber sheet;

Fig. 25/31 is a detail view-A & C of Fig. 24/31;

Fig. 26/31 is cooling grid array back view with back rubber sheet;

Fig. 27/31 is a detail view-A of Fig. 26/31;

Fig. 28/31 is cooling grid array top view with front and back rubber sheet cut-out space;

Fig. 29/31 is a front view-B of Fig. 28/31 to show coolant flow direction at front rubber sheet cut-out space;

Fig. 30/31 is a back view-C of Fig. 28/31 to show coolant flow direction at back rubber sheet cut-out space;
Fig. 31/31 is a detail view-D & E of Fig. 28/31 to show coolant flow direction at bottom flow duct layer.

For the battery cell type and cell specifications, I have selected laminated cells. Compared to cylindrical cells, laminated cells have lower internal resistance and therefore lower heat generation upon charging and discharging. Also, it has a higher energy / power density. Because of its flat geometry and higher exposed surface area, it is easier for heat exchange to take place.

I have designed the battery pack to have 86 pieces of large-format laminated cells (100Ah, 3.7V, as shown in Fig. 1/31). The battery cells are connected by means of a novel clip system, outlined below, which provides for electrical connectivity under space constraints.

Two cells are connected face-to-face in series (Fig. 2/31), with one of the terminals connected to the opposite terminal of the other cell, by a small clip (Fig. 3/31). This will be one 2S-cell. Both sides of the 2S-cell will be in contact with the cooling duct plate (Fig. 18/31) for heat exchange.

2S-cells are connected in series, with the terminals of each 2S-cell in identical orientation. A big clip (Fig. 4/31) connects the terminals between each 2S-cell, straddling the cooling duct plate (detail-D of Fig. 18/31), which is between the two 2S-cells once they are inserted into place.

End clips (Fig. 5/31) are used at the positive terminal of the first cell of the first 2S-cell (Fig. 20/31), and the negative terminal of the last cell of the last 2S-cell, for connection to main power cables. All clips are made of metallic materials with electrical conductivity.

This will achieve the voltage (320V) and energy capacity (32kWh) for purely electric driving for a range of 120~150km (the range of 90% of daily urban commuters).

To lower the cost of the battery pack box, extruded aluminum alloy construction will be used for the box construction plates wherever possible.

Fig. 6/31 depicts the cooling duct plate. The divided hollow flow ducts are for the coolant to pass through and for heat exchange to take place with the 2S-cells.

Both ends of the cooling duct plates are inserted into the cooling duct end plates cut-out slot (Fig. 7/31), resulting in a flushed outside surface. Friction Stir Weld (FSW) will be used to make a leak-proof joint, forming a homogenous and regular structure - the cooling grid array, depicted in Fig. 8/31 , consisting of multiple cooling duct plates arranged in a row and attached to cooling duct end plates. The cooling duct plate also supports the battery cell and keeps the battery cell in its position and maintains its shape.

The front rubber sheet (Fig. 9/31) will sit in the recess of the front cover (Fig. 10/31). The final configuration, as viewed from the side where the rubber sheet is, is shown in Fig. 11/31 .

The back rubber sheet (Fig. 12/31) will sit in the recess of the back cover (Fig. 13/31). The final configuration, as viewed from the side where the rubber sheet is, is shown in Fig. 14/31 .

The cut-out patterns of the front and back rubber sheets are slightly different. The front rubber sheet has narrow cut-outs on its left and right (with different layouts for the left and right narrow cut-outs) and wide cut-outs for the rest. The narrow cut-out will open out to two flow ducts laterally (1x2 or 2x2 configuration) while the wide cut-out will open out to four flow ducts (1x4 configuration) (Fig. 24/31 and Fig. 25/31). The narrow cut-outs exist in two configurations, namely the large narrow cut-out and the small narrow cut-out (Fig 25/31). The large narrow cut-outs can open out to four flow ducts (2x2 configuration), while the small narrow cut-outs can open out to two flow ducts (1x2 configuration). The back rubber sheet has only wide cut-outs throughout (Fig. 26/31 and Fig. 27/31). This arrangement of cut-outs will facilitate the directional change of the coolant flow (Fig. 28/31 to Fig. 31/31). The rubber sheets also have the function of sealing the space between flow ducts.

The novel structure of the apparatus, having a cooling grid array, a front cover with a front rubber sheet having a special cut-out pattern and a back cover with a back rubber sheet having a special cut-out pattern, is what allows the coolant to flow in a path that results in even and effective cooling throughout the apparatus, at the same time keeping the apparatus compact and lightweight.

Friction Stir Weld (FSW), or any other suitable connection method, can be used for these connections:

- Front cover with front cooling duct end plate (must be a leak-proof joint)
- Back cover with back cooling duct end plate (must be a leak-proof joint)
- Bottom plate (Fig. 15/31) with front & back cooling duct end plate
- Two side plates (Fig. 16/31) with front & back cooling duct end plate and bottom plate.

The construction of the final empty battery box is shown in Fig. 17/31.

After the 2S-cells have been inserted in the spaces between the cooling duct plates (Fig. 18/31), with the laying of necessary insulation sheets and spacers and the connection of the small, big and end clips (as described above), battery management system (BMS) connections and cables can be laid.

The top cover (Fig. 21/31) has slots that can accommodate a BMS. It is also equipped with various sockets like a 12V DC connection for the BMS, a main power socket and two Can-bus 2.0 terminals. It also can be equipped with a quick-release coolant connector at the coolant inlet and outlet. All these make it easy for plug-and-play operation with any EV.

With a top rubber seal (Fig. 18/31) between the top cover and the battery box secured by fasteners, the entire battery pack box (Fig. 22/31) will be an IP65-rated enclosure, suitable for EV application.

Fig. 23/31 shows the schematic flow of the coolant in the cooling grid array in the battery pack. For simplification, the single cylindrical pipe-like structure represents the path of two flow ducts. The locations of the flow ducts are depicted in Fig. 24/31 to Fig. 27/31. With the connection of both the front and back cover with their respective rubber sheets, the flow of the coolant will be able to change direction at the rubber sheet cut-out space. How the front rubber sheet is able to change the flow direction is depicted in Fig. 29/31, and how the back rubber sheet is able to change direction is depicted in Fig. 30/31. Fig. 31/31 shows the flow direction at the bottom flow duct layer.

Conclusion

This apparatus is able to carry coolant to each individual cell evenly, effectively and efficiently in a simple design, extending the lifespan of the battery and enhancing its safety.

The total weight of the battery pack (Fig. 22/31), including ~13kg of coolant, is ~ 350kg.
Its dimensions are L=1031mm, W=509mm, H=445mm.

The battery pack is lightweight but strong, with a voltage of 320V, energy capacity of 32kWh, energy to weight ratio of ~91Wh/kg, and an energy to volume ratio of ~137Wh/L. These specifications will be able to meet requirements in most EV applications.

Possible future implementations

The present-day EV battery packs are produced by the various carmakers in a variety of forms. This results in higher costs from a lack of economies of scale, and no interchangeability of batteries between cars from different manufacturers.

If battery packs were standardized, it would be able to be easily adapted to fit different vehicles. The state grid can possibly produce a standardized battery pack rather than the carmakers themselves, and there are benefits to be reaped in a number of ways.

Centralized facilities for producing, charging and maintaining battery packs will result in economies of scale, giving cost savings to both consumers and producers. Battery packs can be charged at power stations during off-peak hours and delivered to petrol kiosks. In place of filling up petrol, consumers can merely replace their batteries at petrol kiosks, leaving their flat batteries to be picked up and charged by the state grid. This will also extend the range of EVs.

With a central charging facility delivering fully-charged battery packs to petrol kiosks, governments need not spend money to build charging stations at different locations, resulting in substantial savings. Also, consumers need not worry about the serviceability and maintenance of their batteries, as the state grid will handle these.

This approach will reduce the price of EVs dramatically and hence promote market growth. Carmakers only need to design future cars to be able to accommodate a standard battery pack.

The concept and structure of this power battery pack cooling apparatus can also apply to other future implementations and applications requiring compact and lightweight battery packs, or applications requiring effective cooling systems under space constraints.

Claims

The embodiments of the invention in which an exclusive property or privilege is claimed are as defined as follows:

1. A power battery pack cooling apparatus, comprising:

   a cooling grid array where heat exchange take place,

   a front cover (having a cooling inlet and outlet which enables the coolant to flow into and out of the cooling apparatus) with an attached front rubber sheet which facilitates the flow and the change of direction of the coolant through the spaces created by the cut-outs,

   a back cover with an attached back rubber sheet which facilitates the flow and the change of direction of the coolant through the spaces created by the cut-outs.

2. A clip system for electrical connectivity between battery cells, comprising:

   big clips which provide electrical connectivity between two 2S-cells across cooling duct plates,

   small clips which provide electrical connectivity within a single 2S-cell between the two battery cells,

   end clips which are attached to the positive terminal of the first 2S-cell and the negative terminal of the last 2S-cell for connection to main power cables.

FIG 1

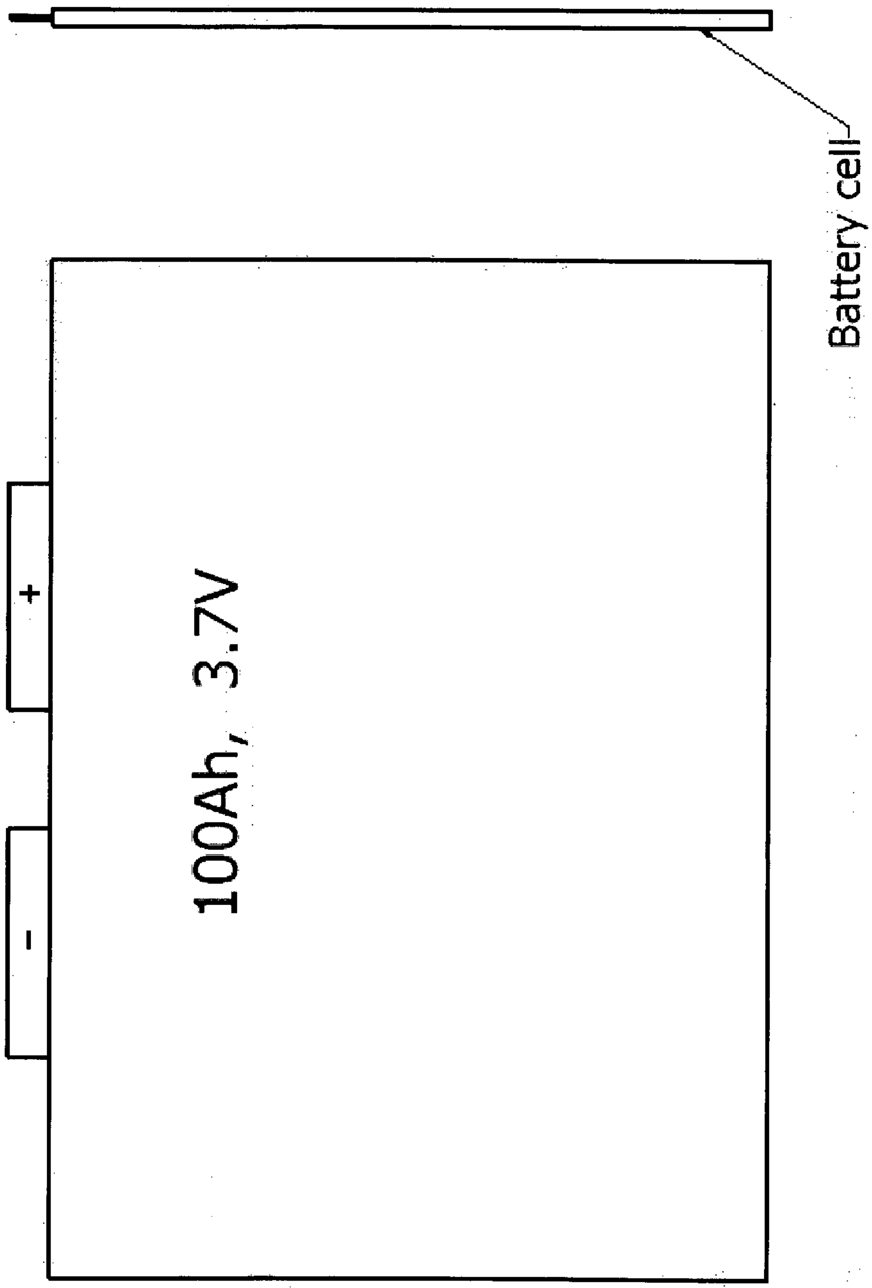


FIG 2

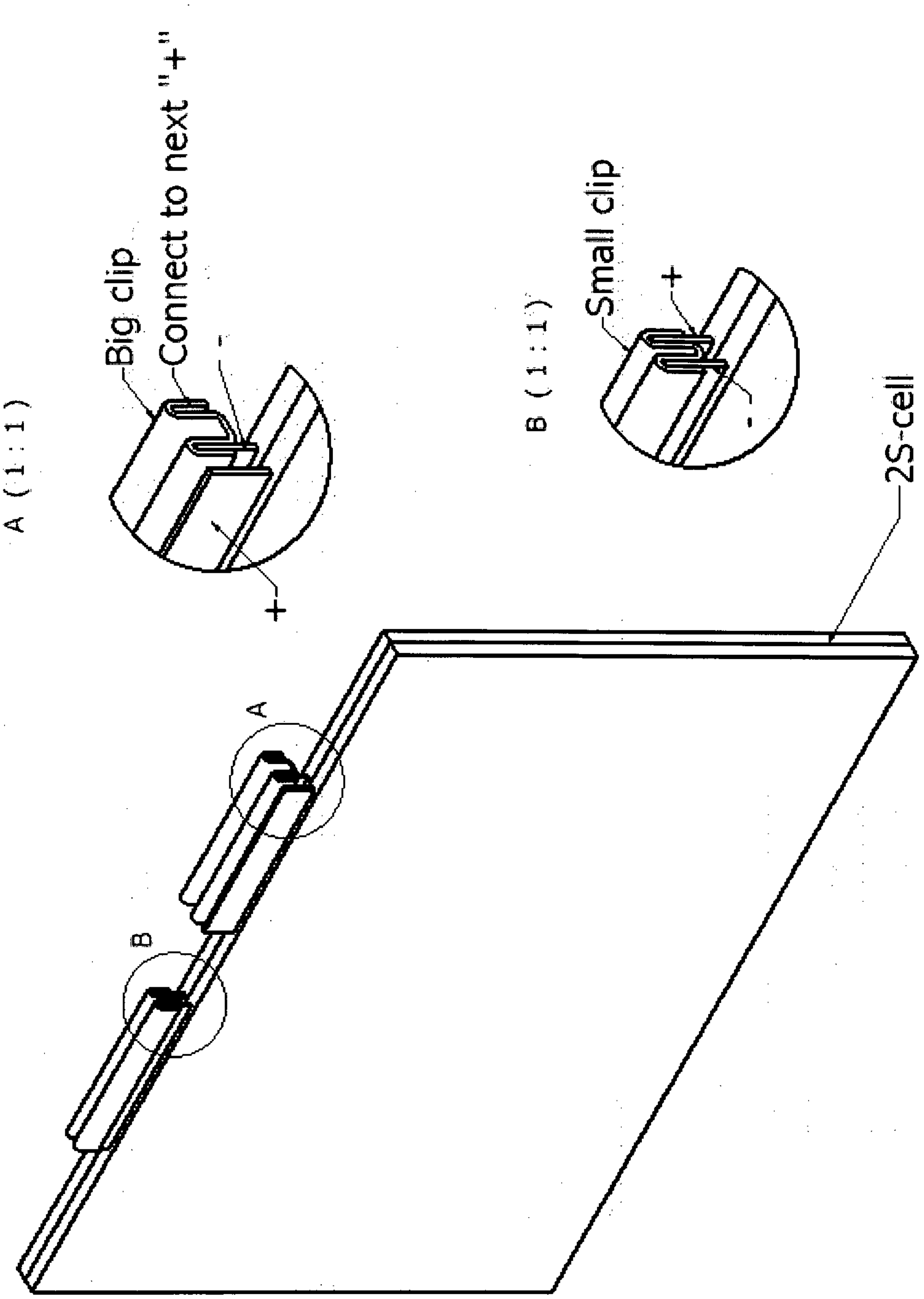


FIG 3

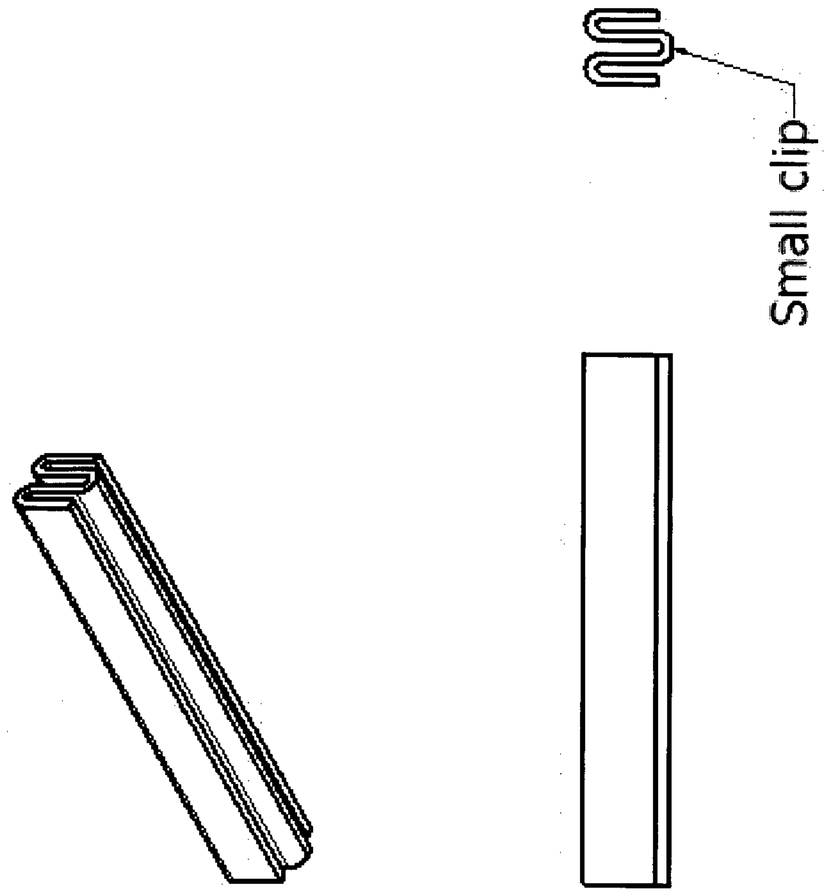


FIG 4

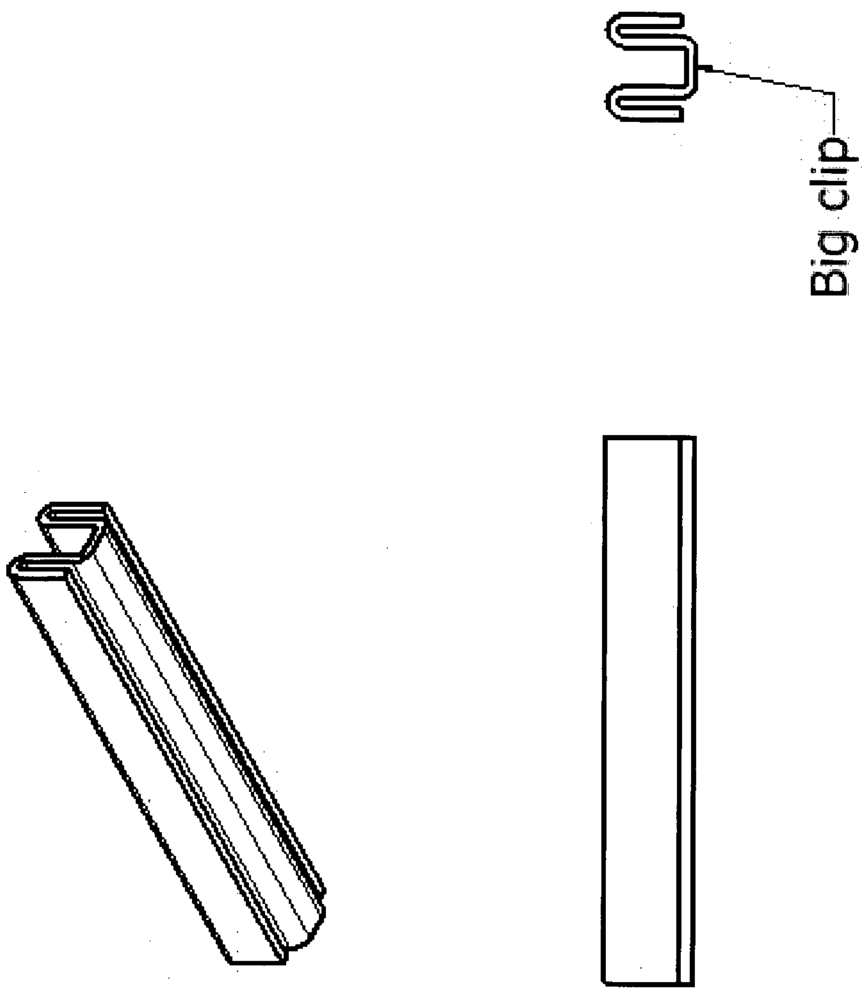


FIG 5

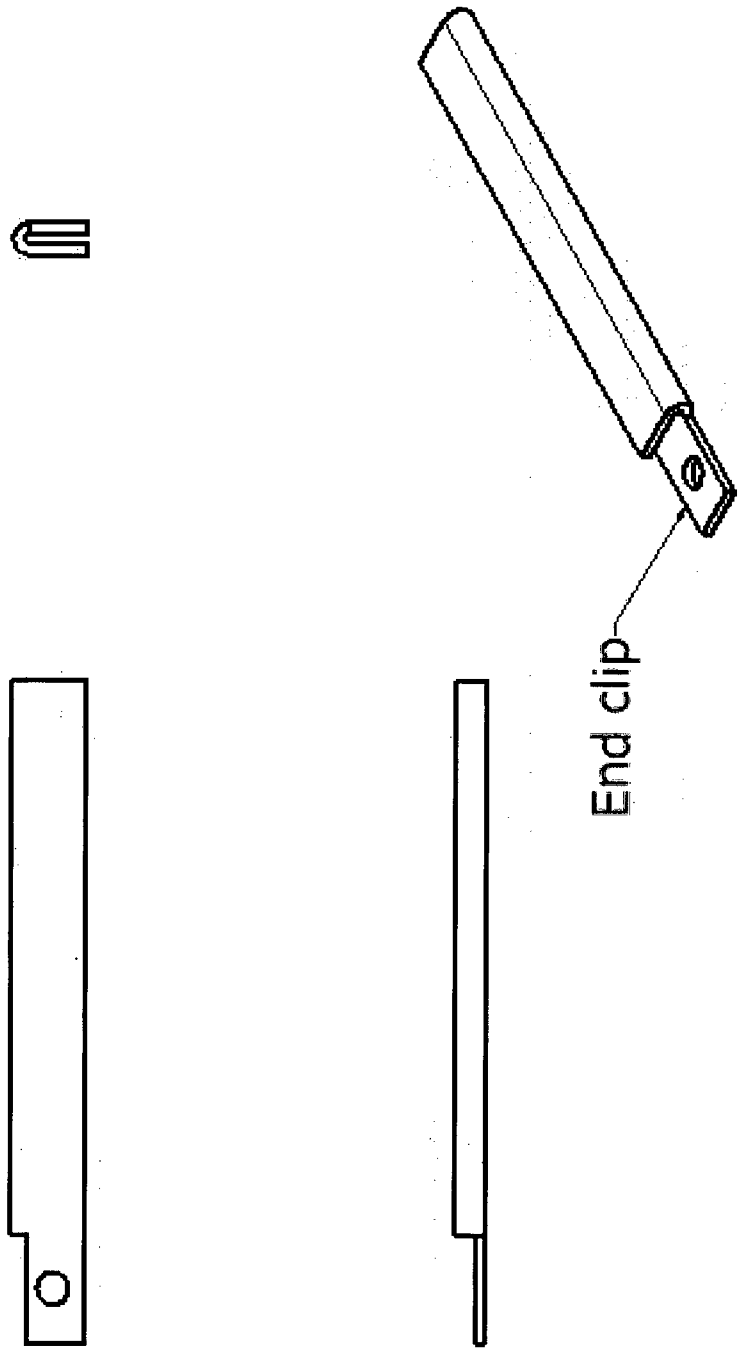


FIG 6

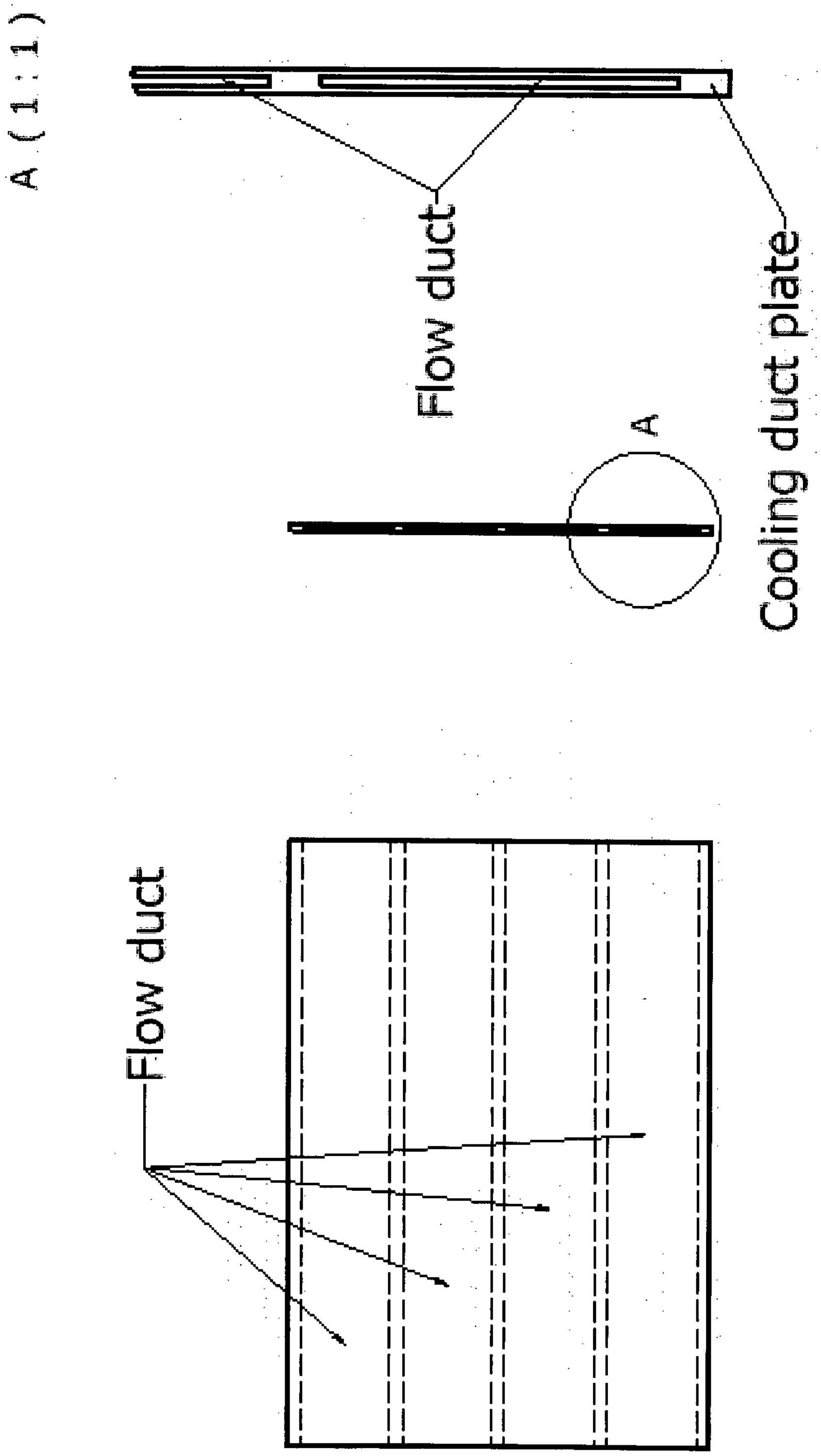


FIG 7

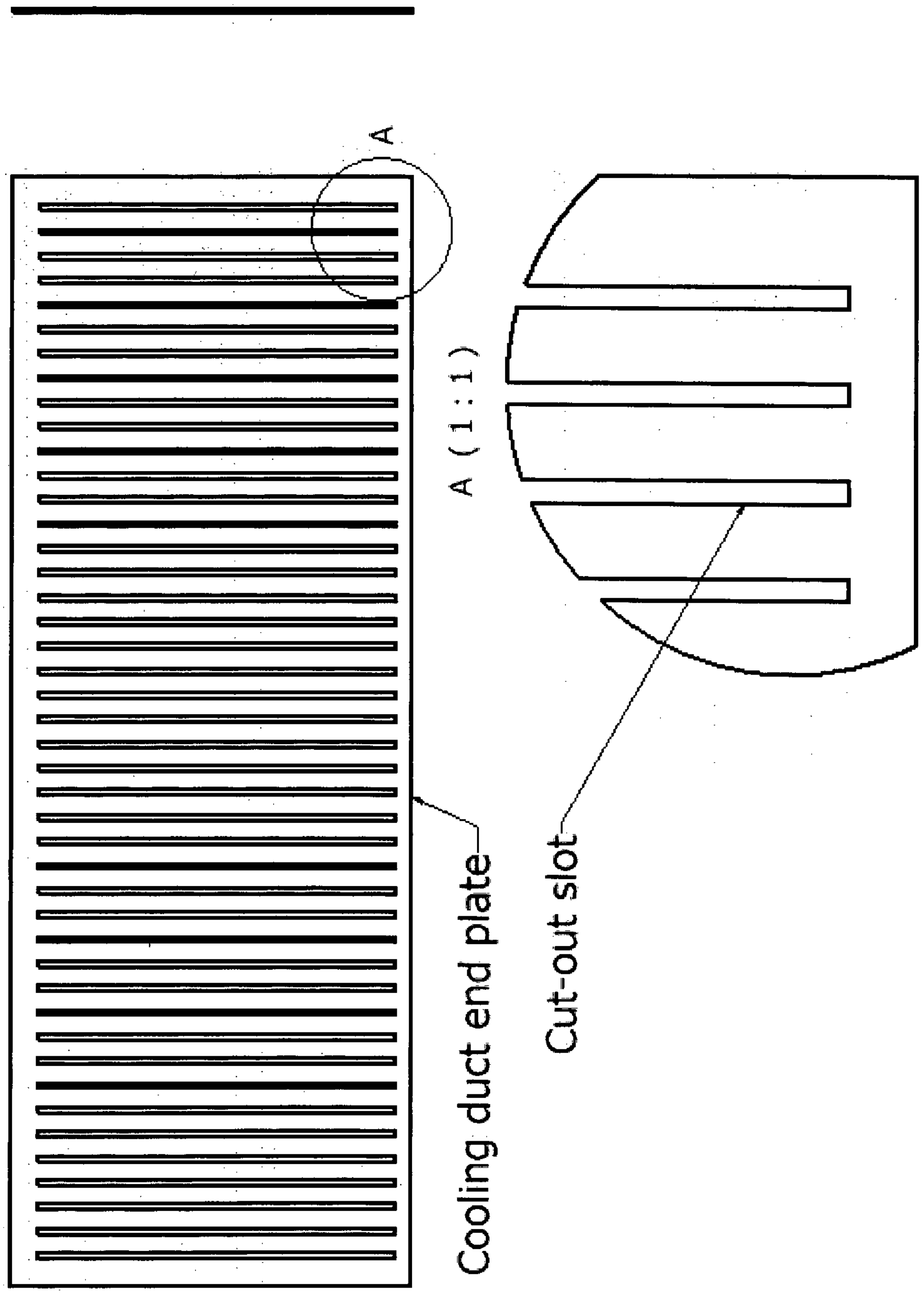
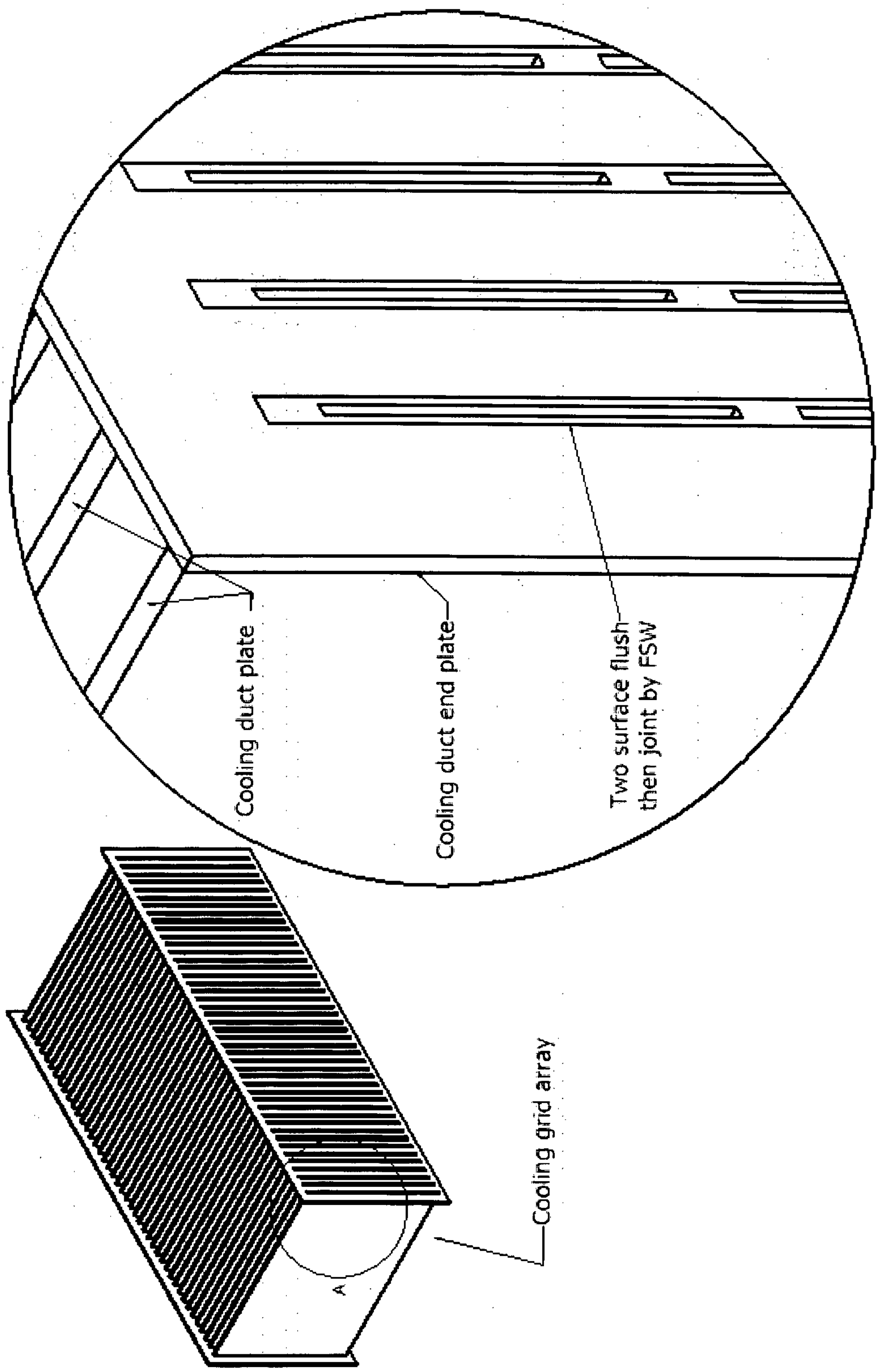


FIG 8


Cooling duct plate
Cooling duct end plate
Two surface flush
then joint by FSW
Cooling grid array
A

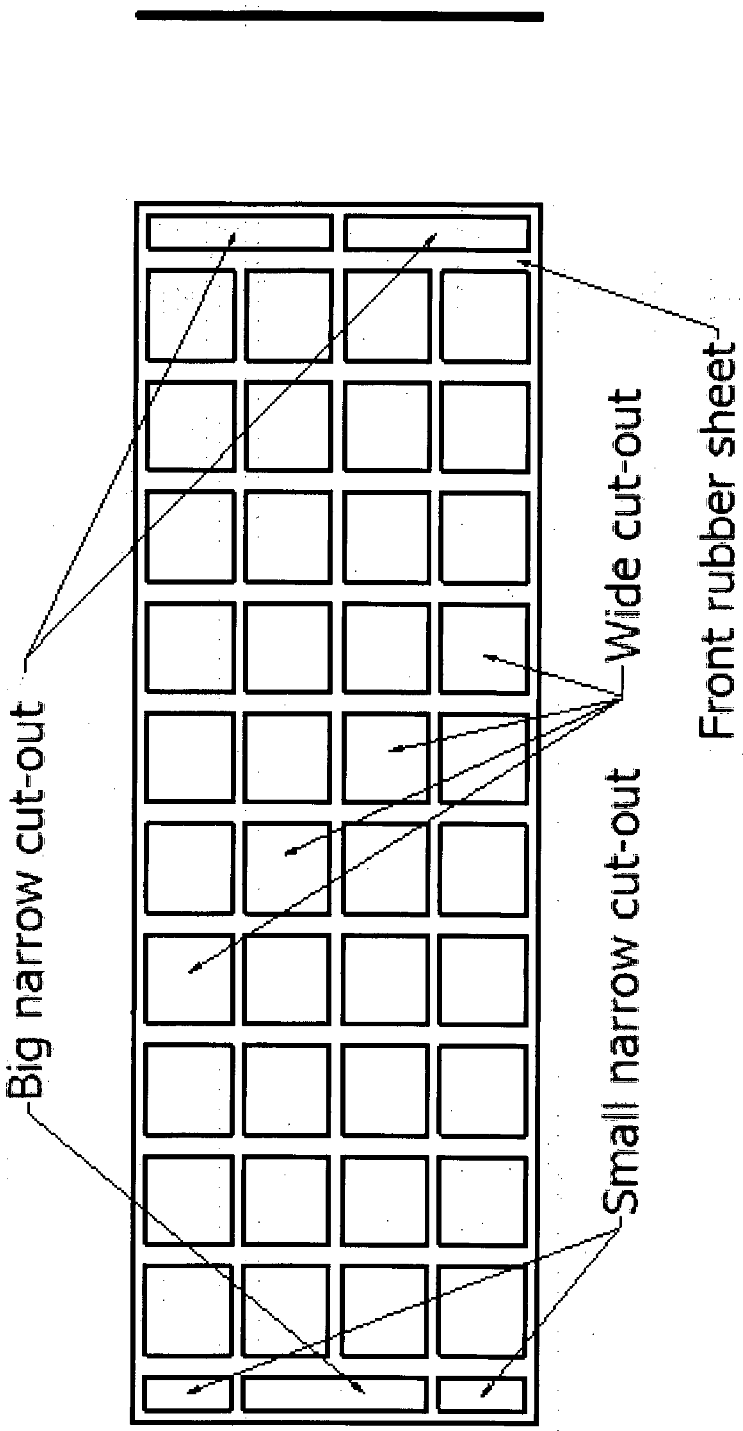

Front rubber sheet
Wide cut-out
Big narrow cut-out
Small narrow cut-out

FIG 9

FIG 10

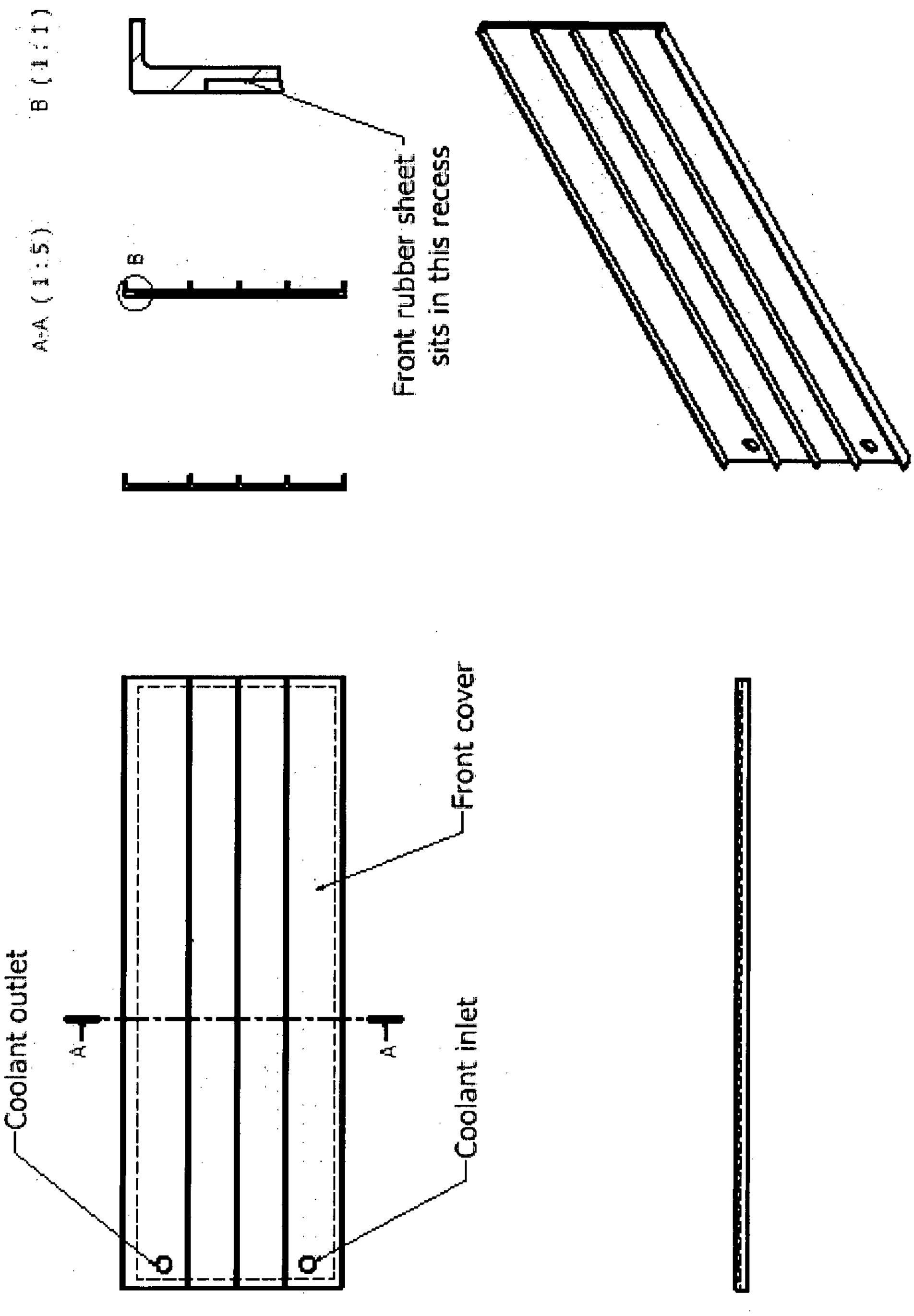
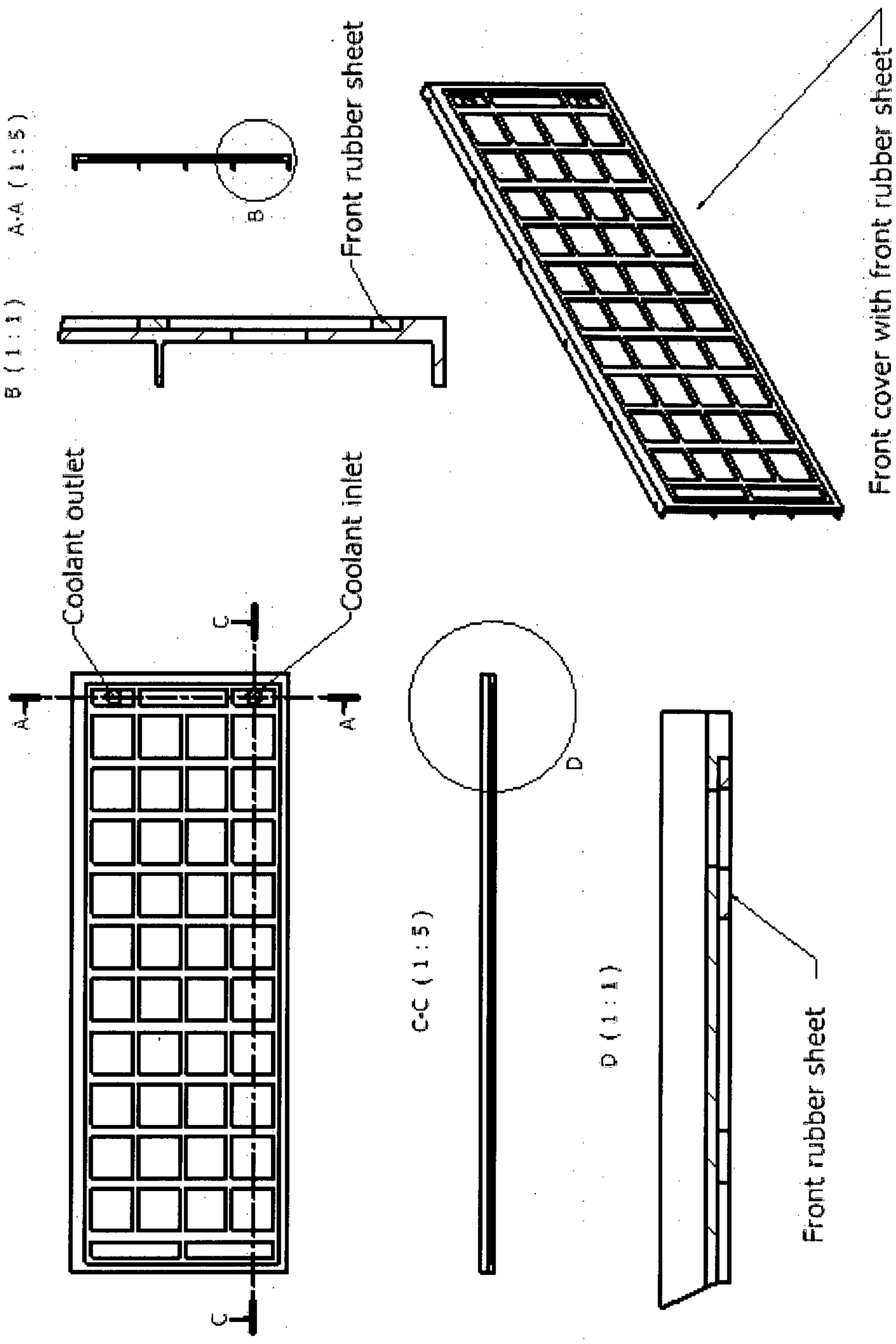

B (1:1)
A-A (1:5)
B
Front rubber sheet sits in this recess
Coolant outlet
A
A
Coolant inlet
Front cover

FIG 11


Coolant outlet
Coolant inlet
A
A
C
C
A-A (1 : 5)
B
B (1 : 1)
Front rubber sheet
C-C (1 : 5)
D
D (1 : 1)
Front rubber sheet
Front cover with front rubber sheet

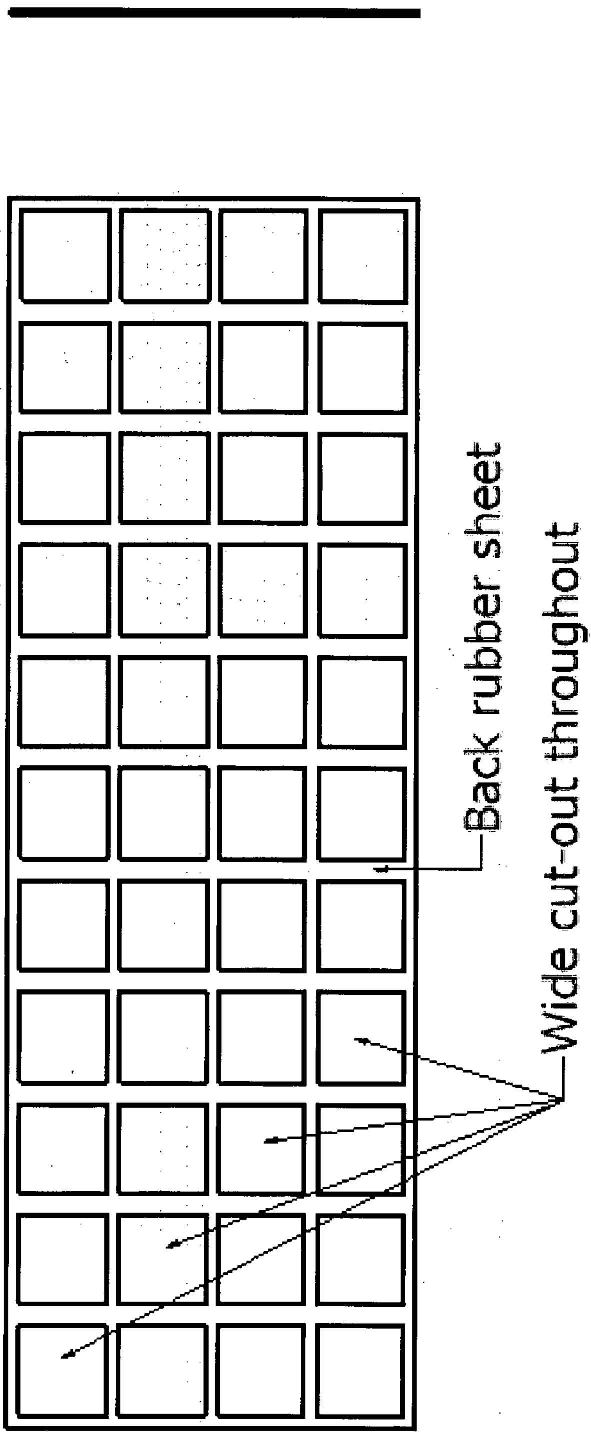


FIG 12

FIG 13

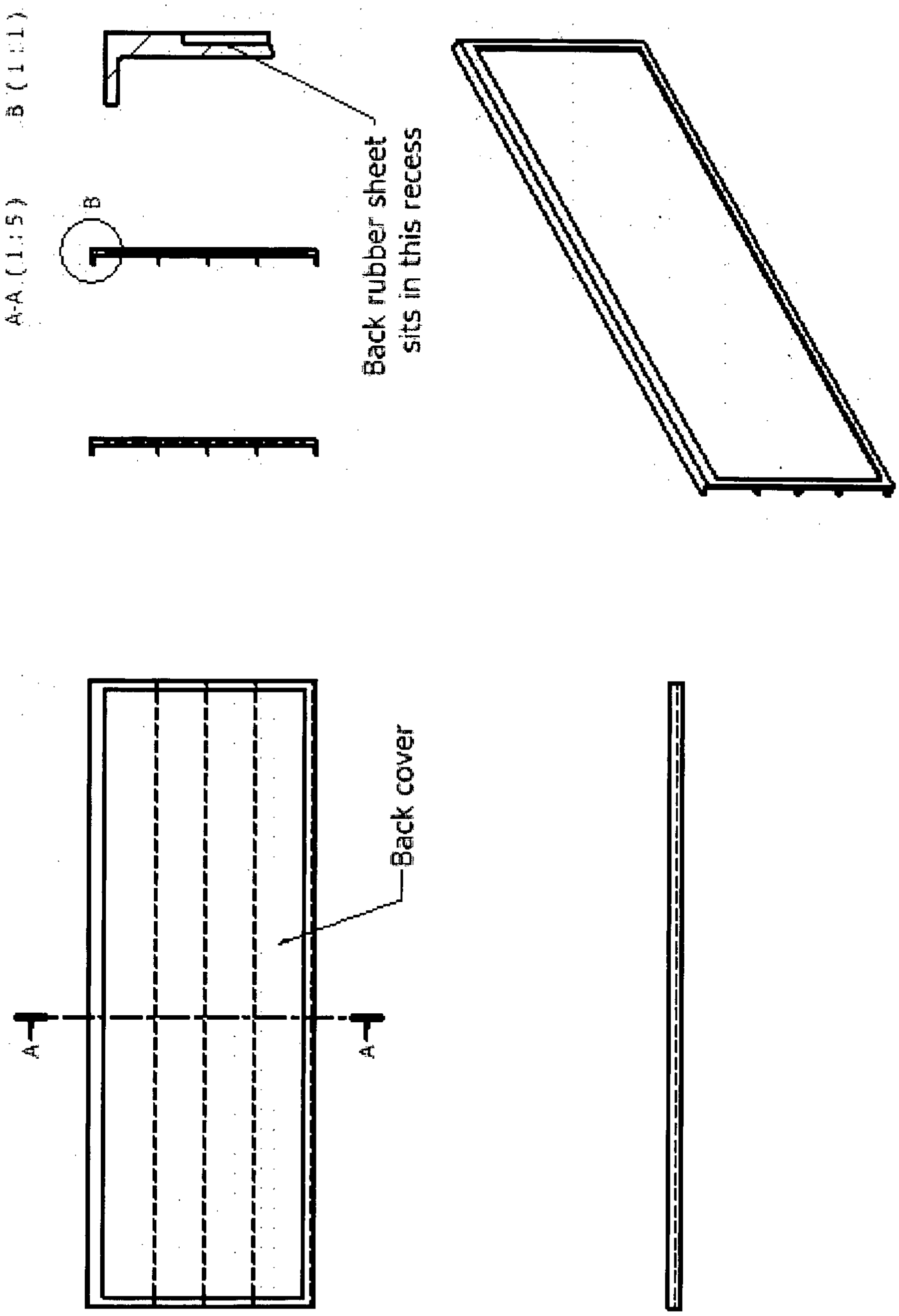

A-A (1:5)
B
B (1:1)
Back rubber sheet sits in this recess
A
A
Back cover

Fig 14

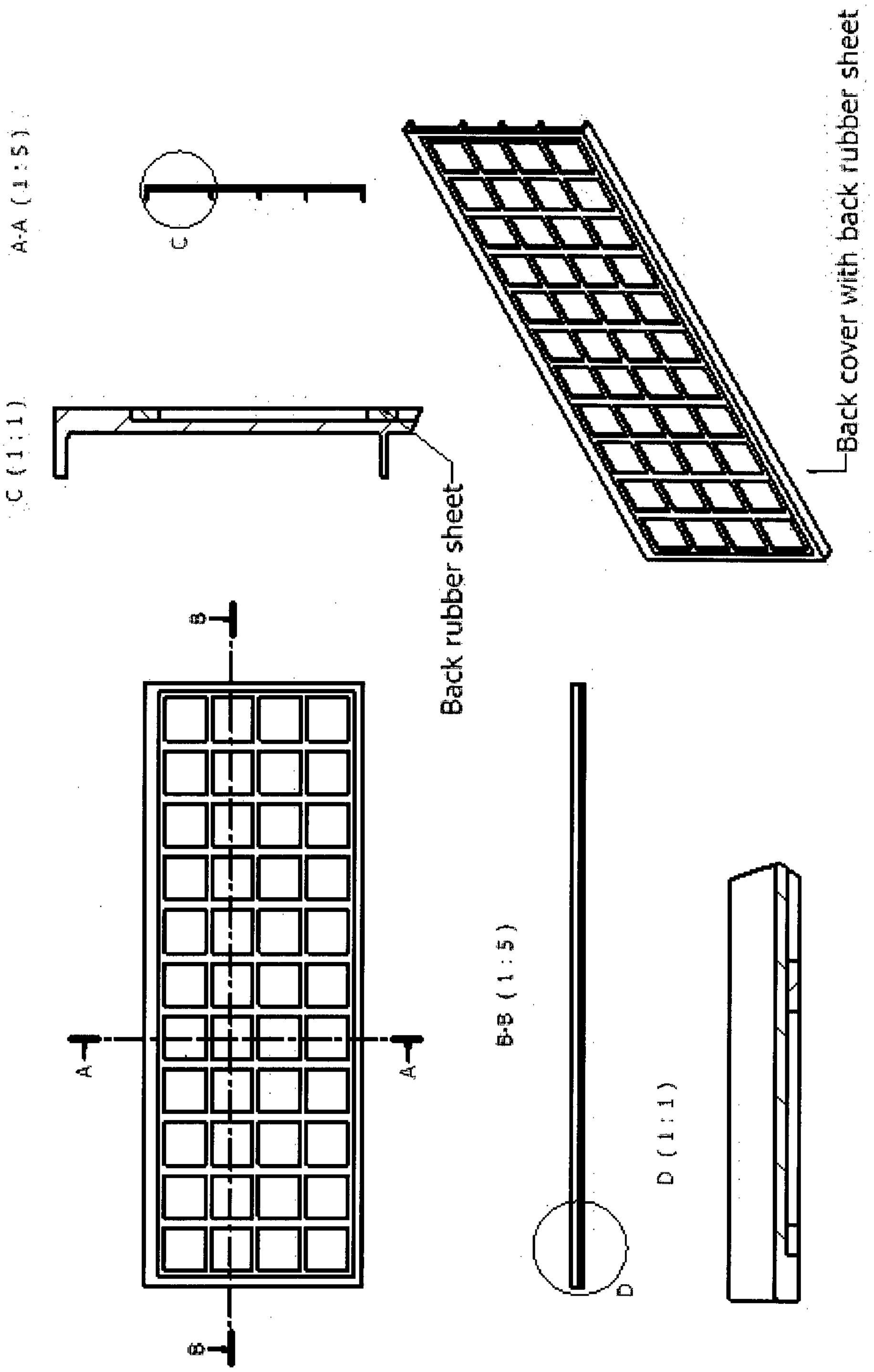

A-A (1:5)
C
C (1:1)
Back rubber sheet
Back cover with back rubber sheet
B
A
A
B
B-B (1:5)
D (1:1)
D

FIG 15

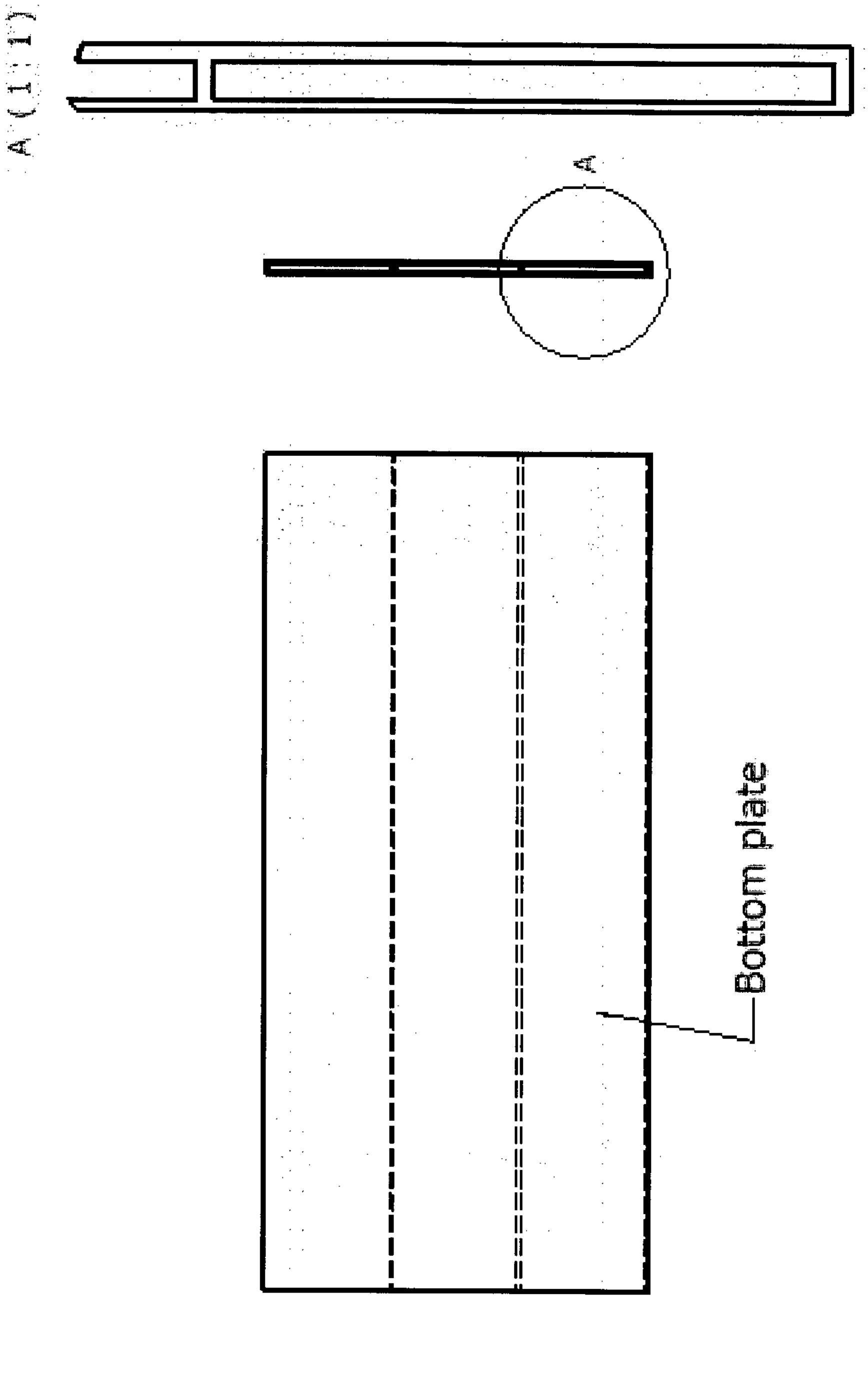


FIG 16

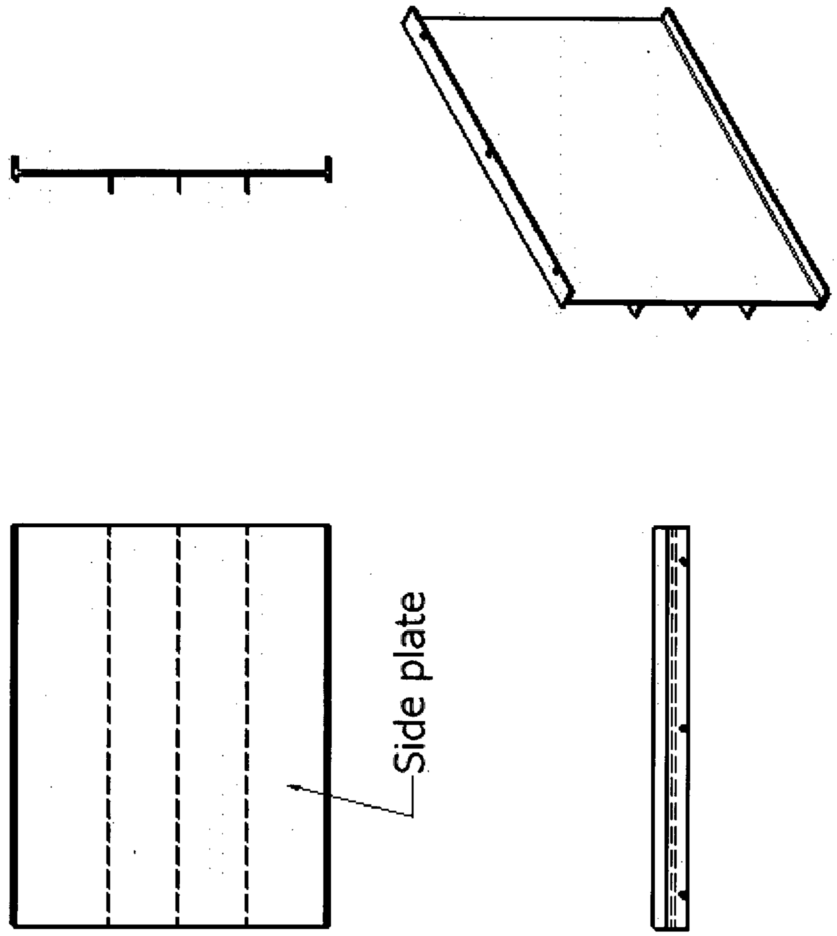


FIG 17

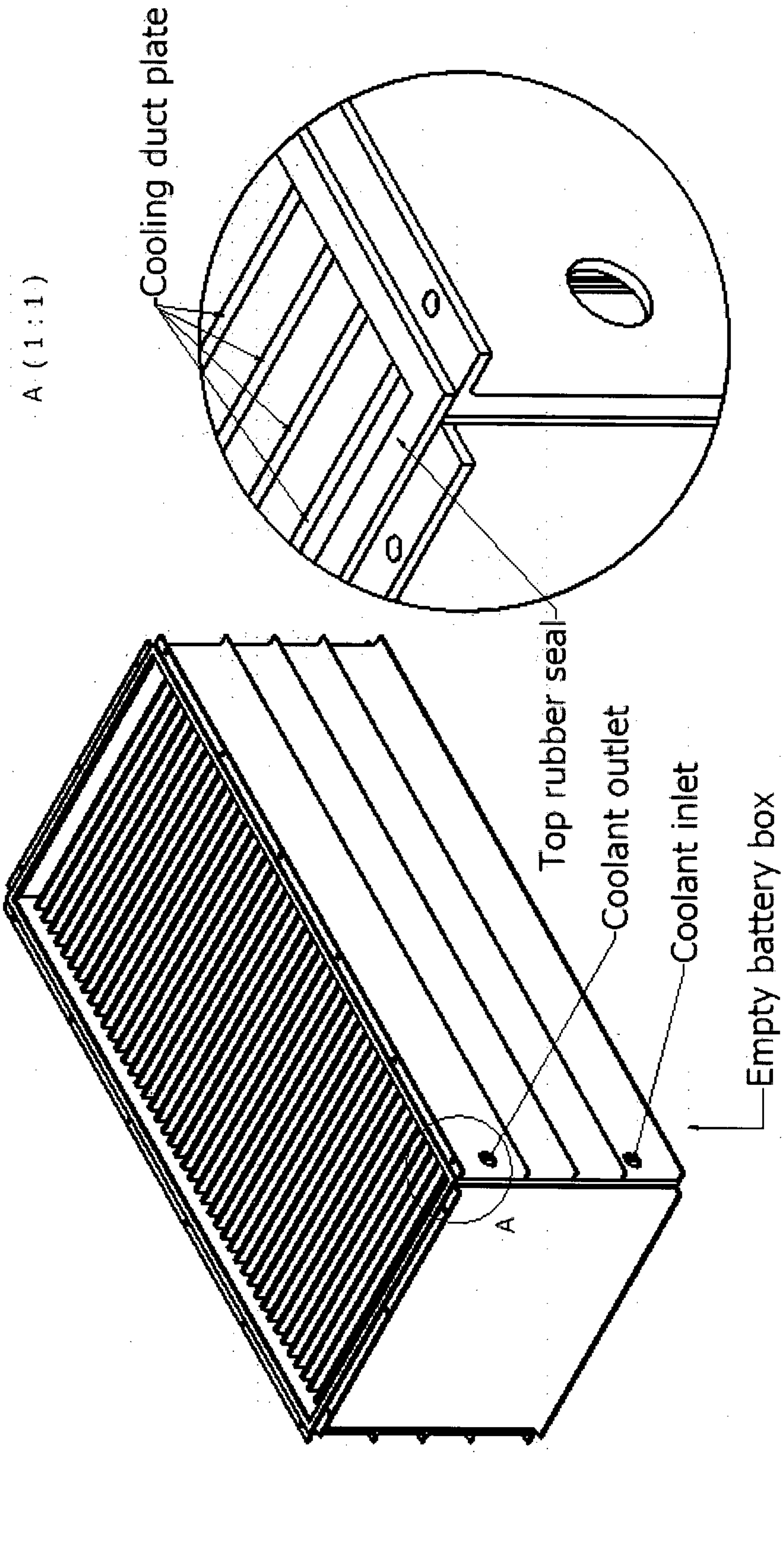

A (1 : 1)
Cooling duct plate
Top rubber seal
Coolant outlet
Coolant inlet
Empty battery box
A

FIG 18

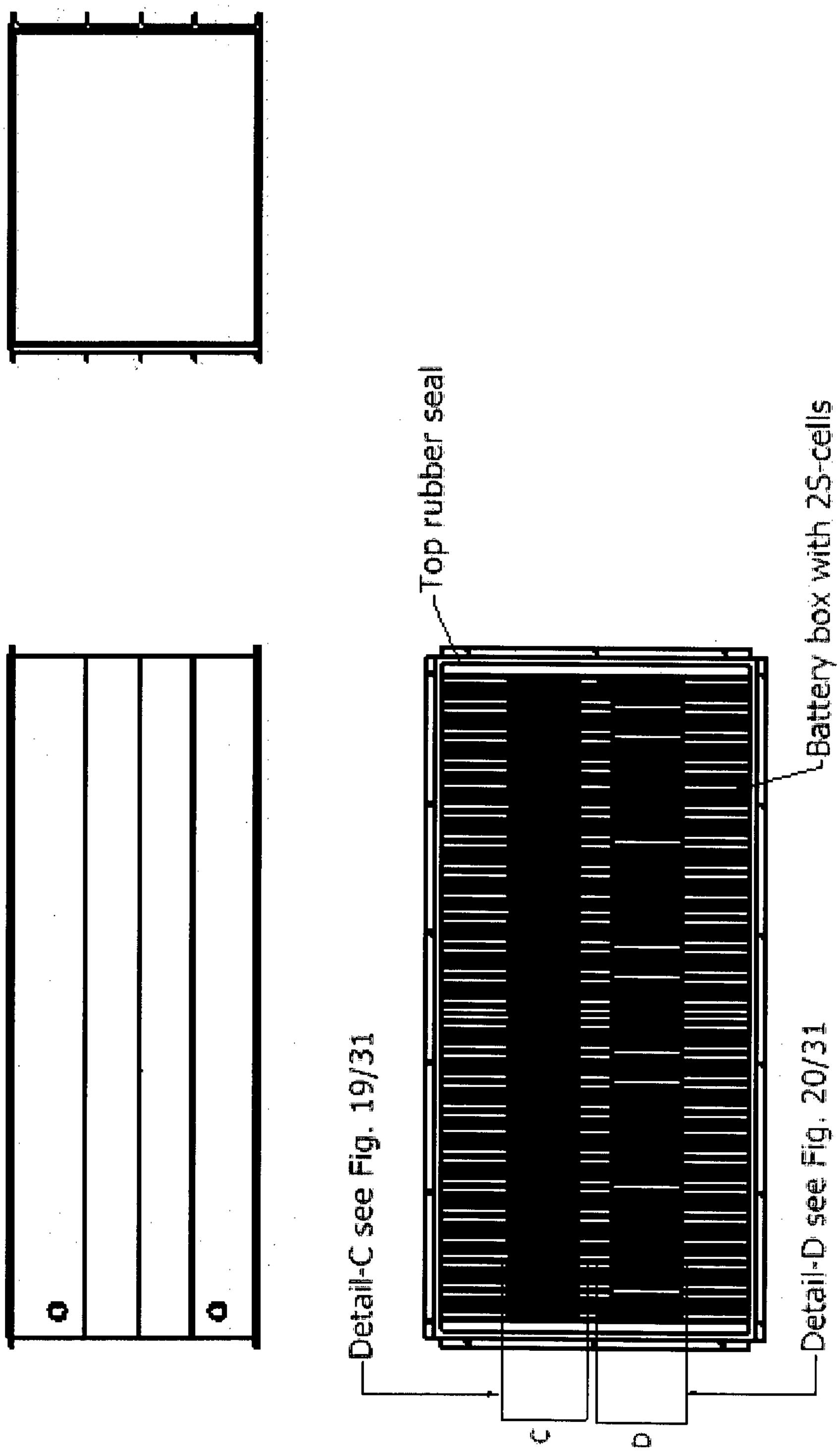
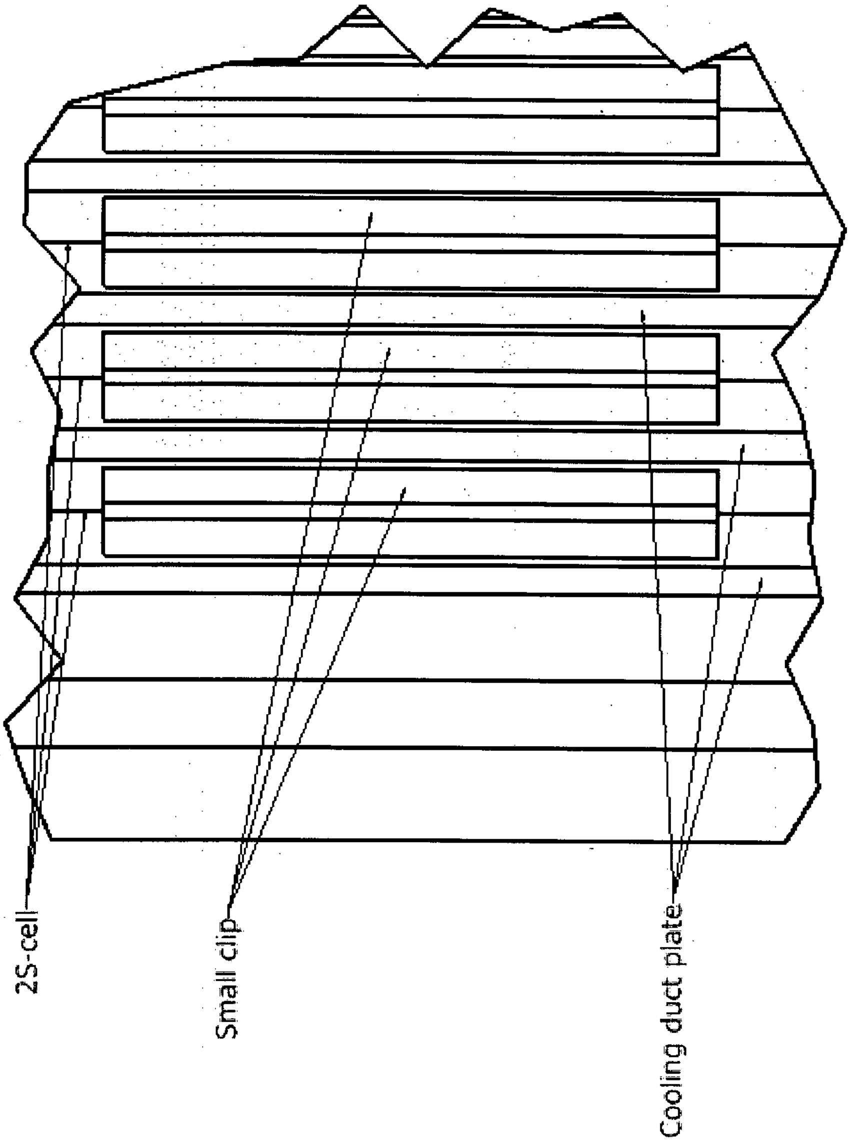

Top rubber seal
Battery box with 25-cells
Detail-C see Fig. 19/31
Detail-D see Fig. 20/31
C
D

FIG 19

C (2:1)



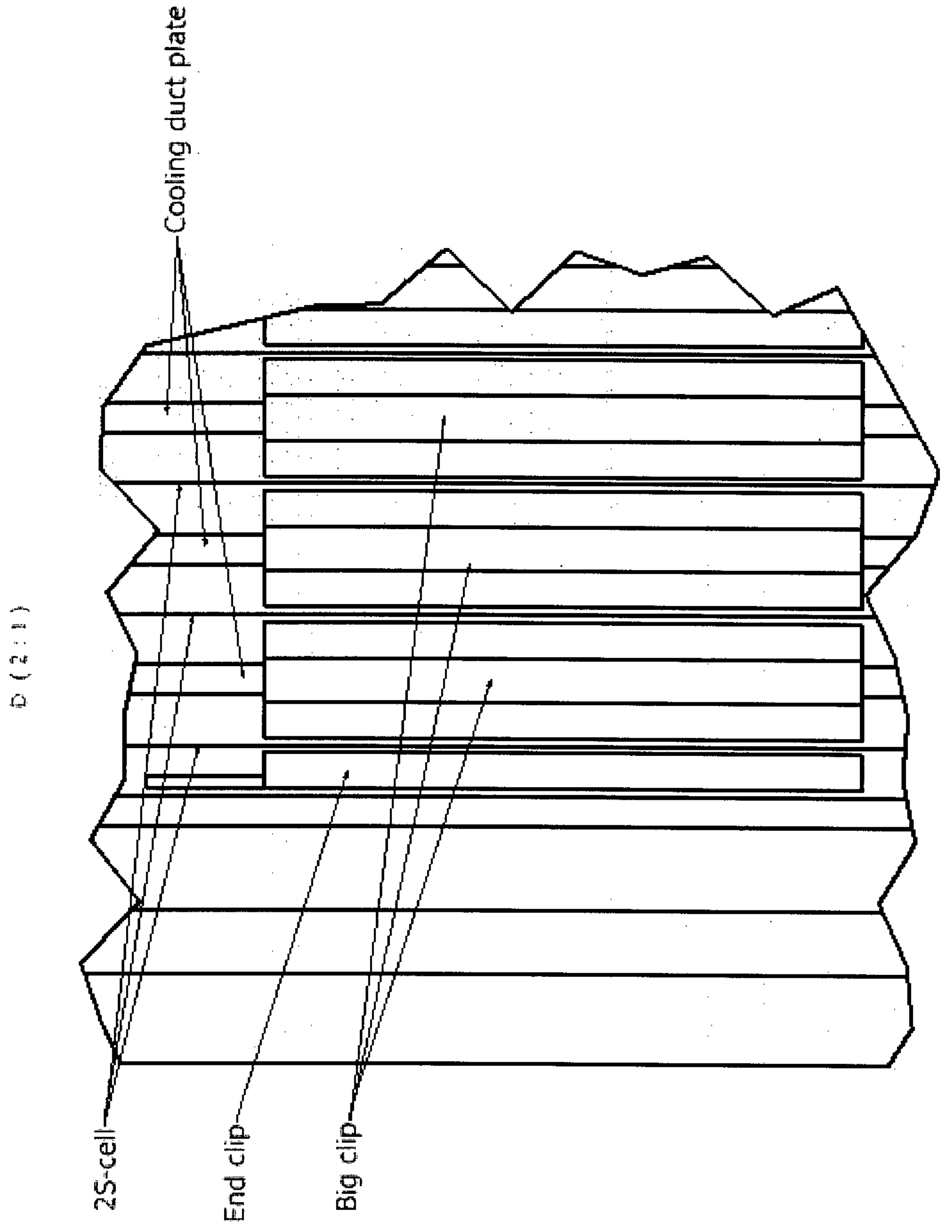


Fig 20

FIG 21

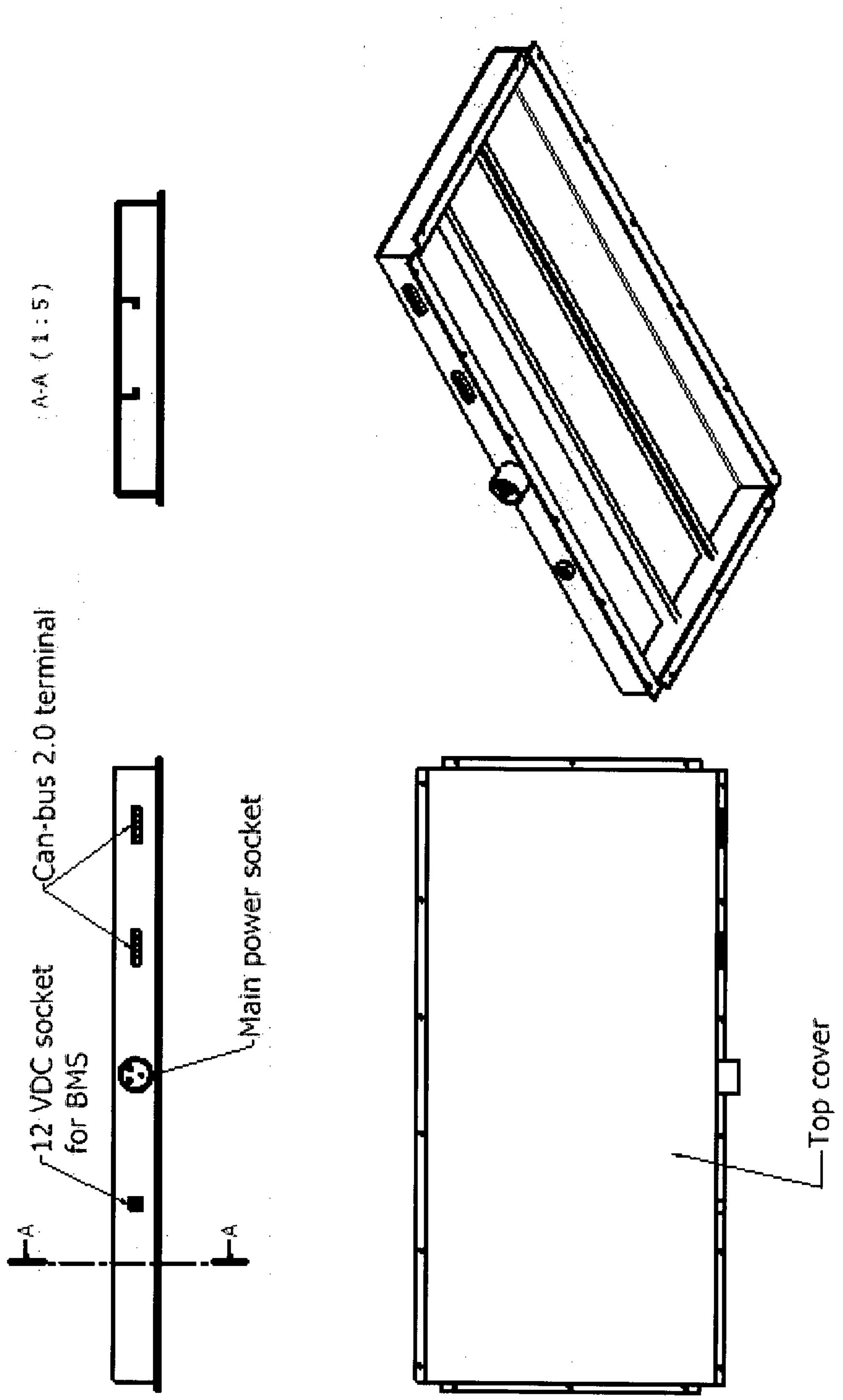

A-A (1 : 5)
Can-bus 2.0 terminal
12 VDC socket
for BMS
Main power socket
A
A
Top cover

FIG 22

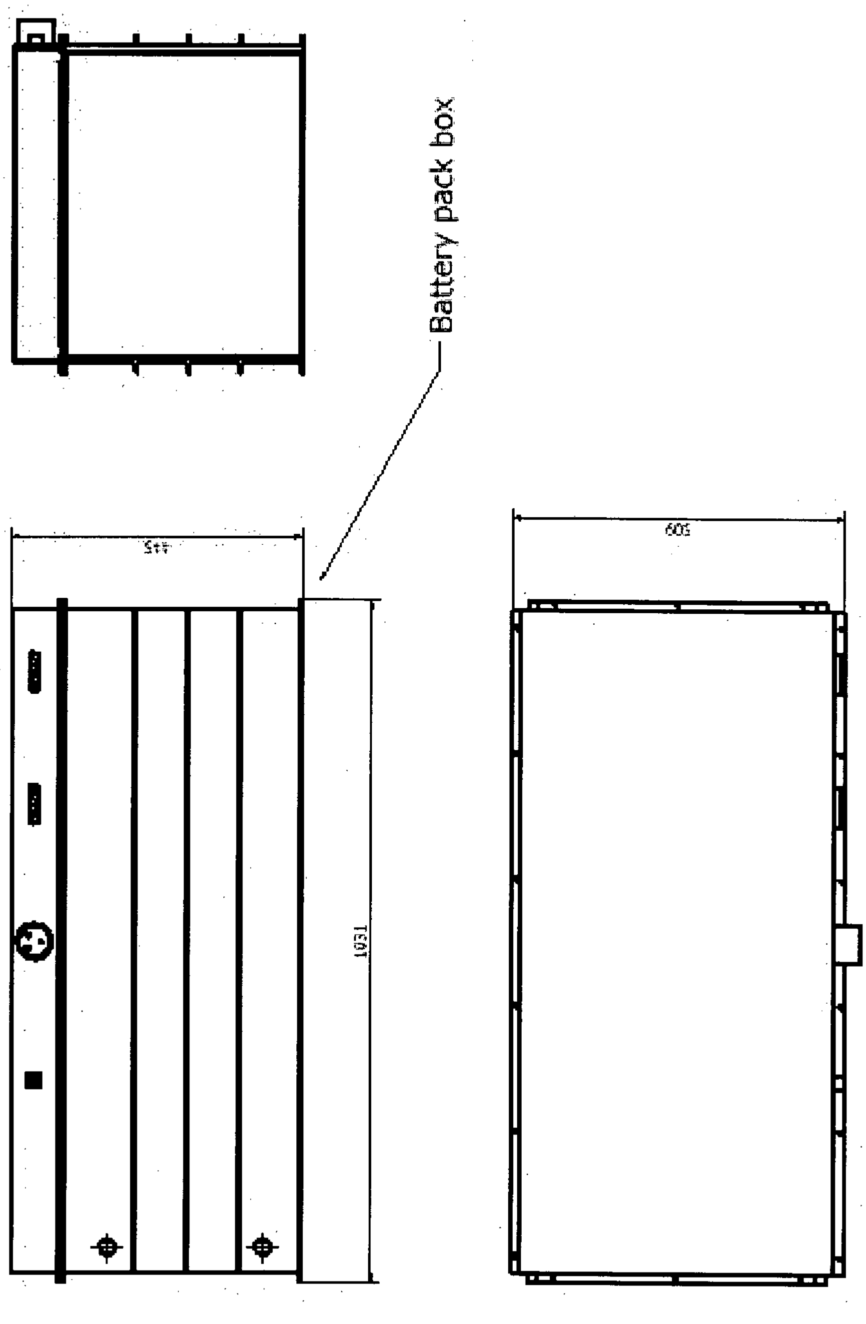


FIG 23

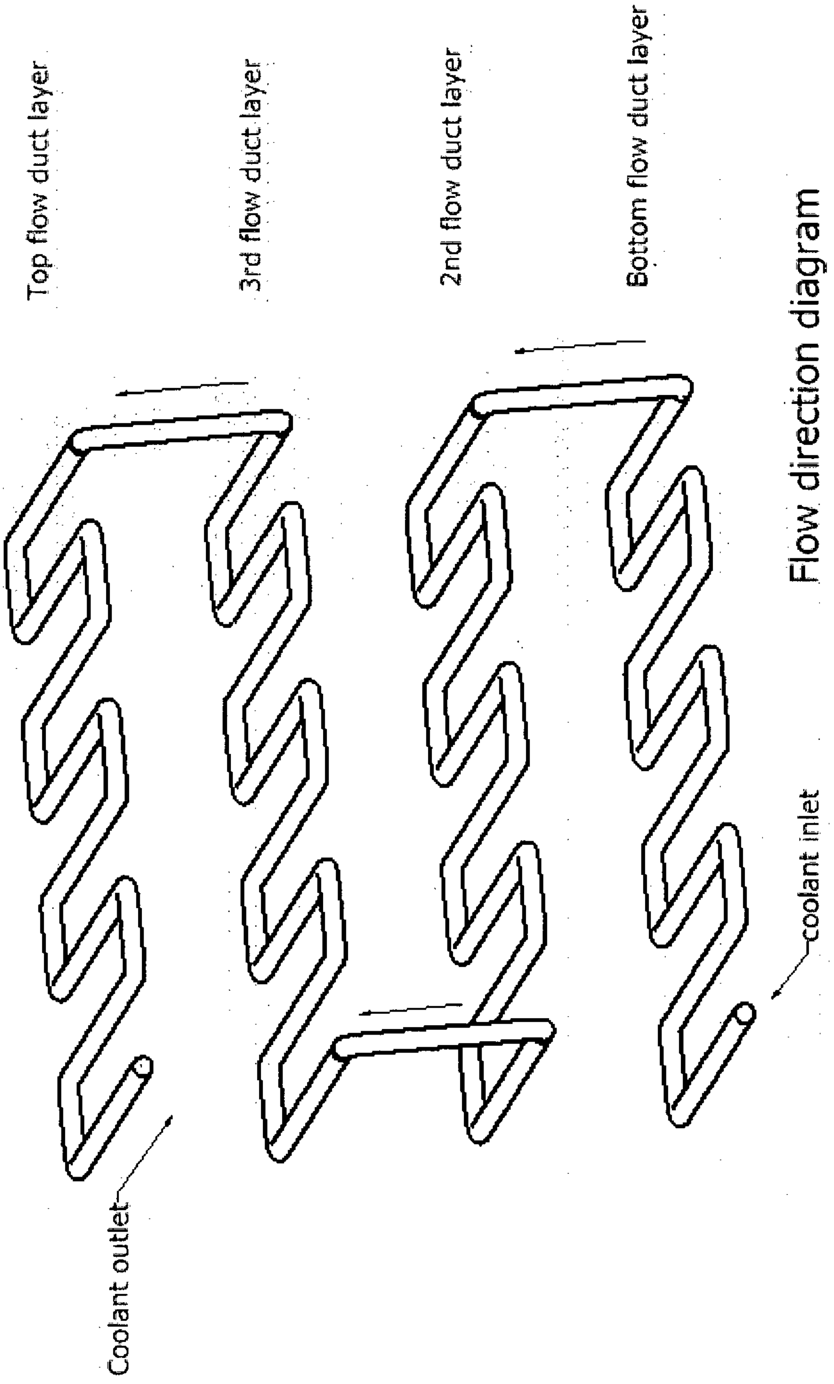
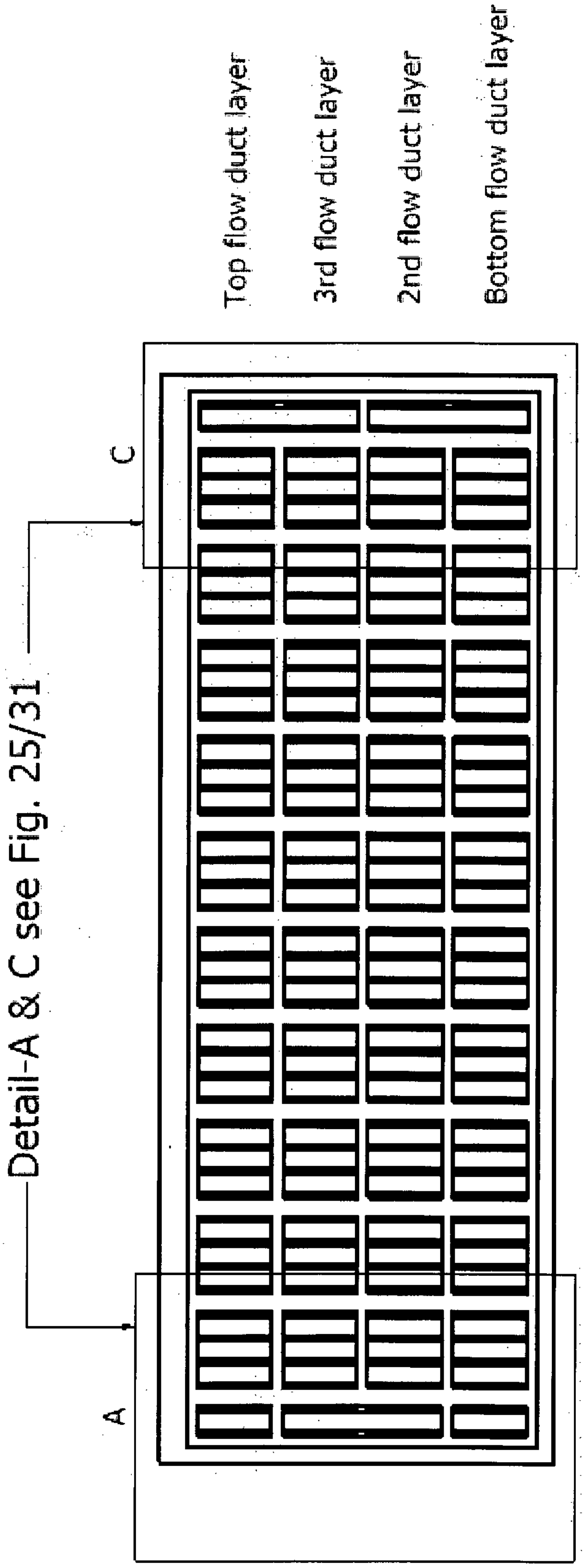
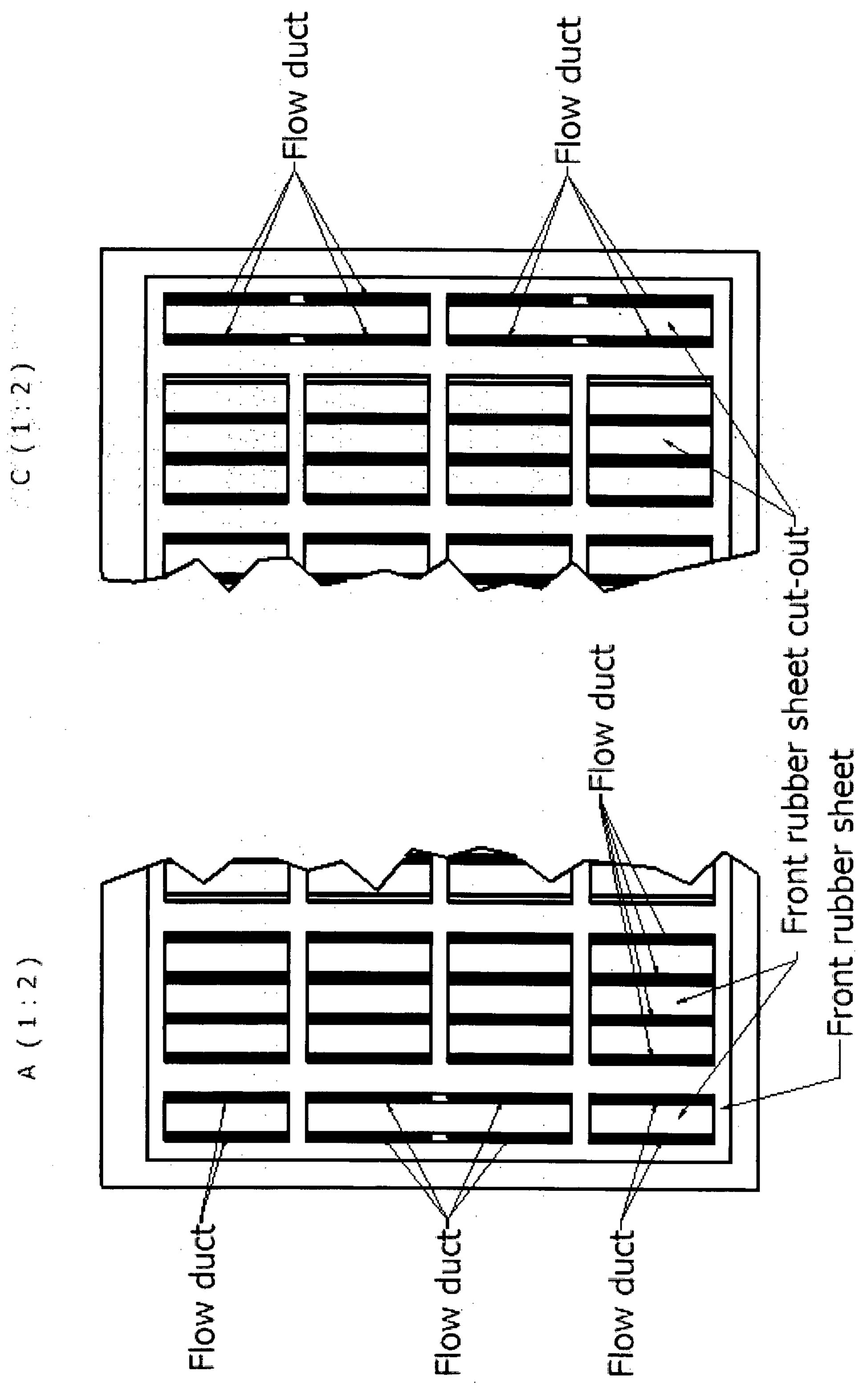

Top flow duct layer
3rd flow duct layer
2nd flow duct layer
Bottom flow duct layer
Flow direction diagram
coolant inlet
Coolant outlet

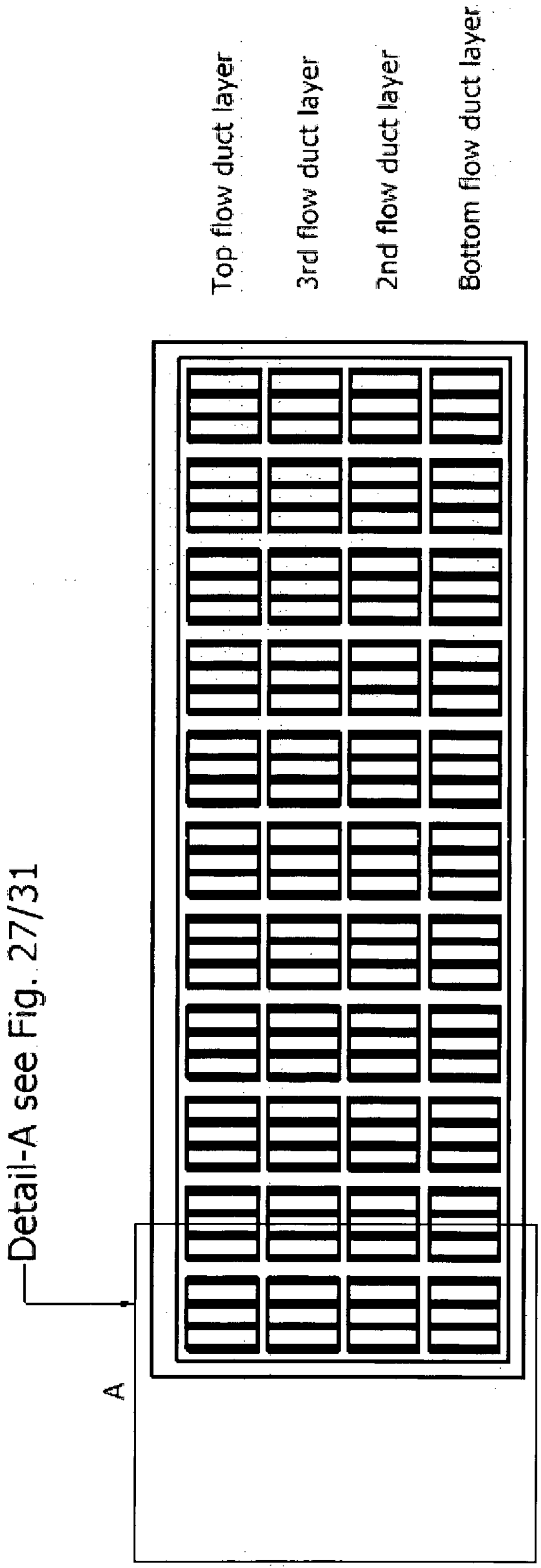
FIG 24



Cooling grid array front view with front rubber sheet

FIG 25


C (1:2)
Flow duct
Flow duct
Front rubber sheet cut-out
A (1:2)
Flow duct
Front rubber sheet
Front rubber sheet
Flow duct
Flow duct
Flow duct



Cooling grid array back view with back rubber sheet

FIG 27

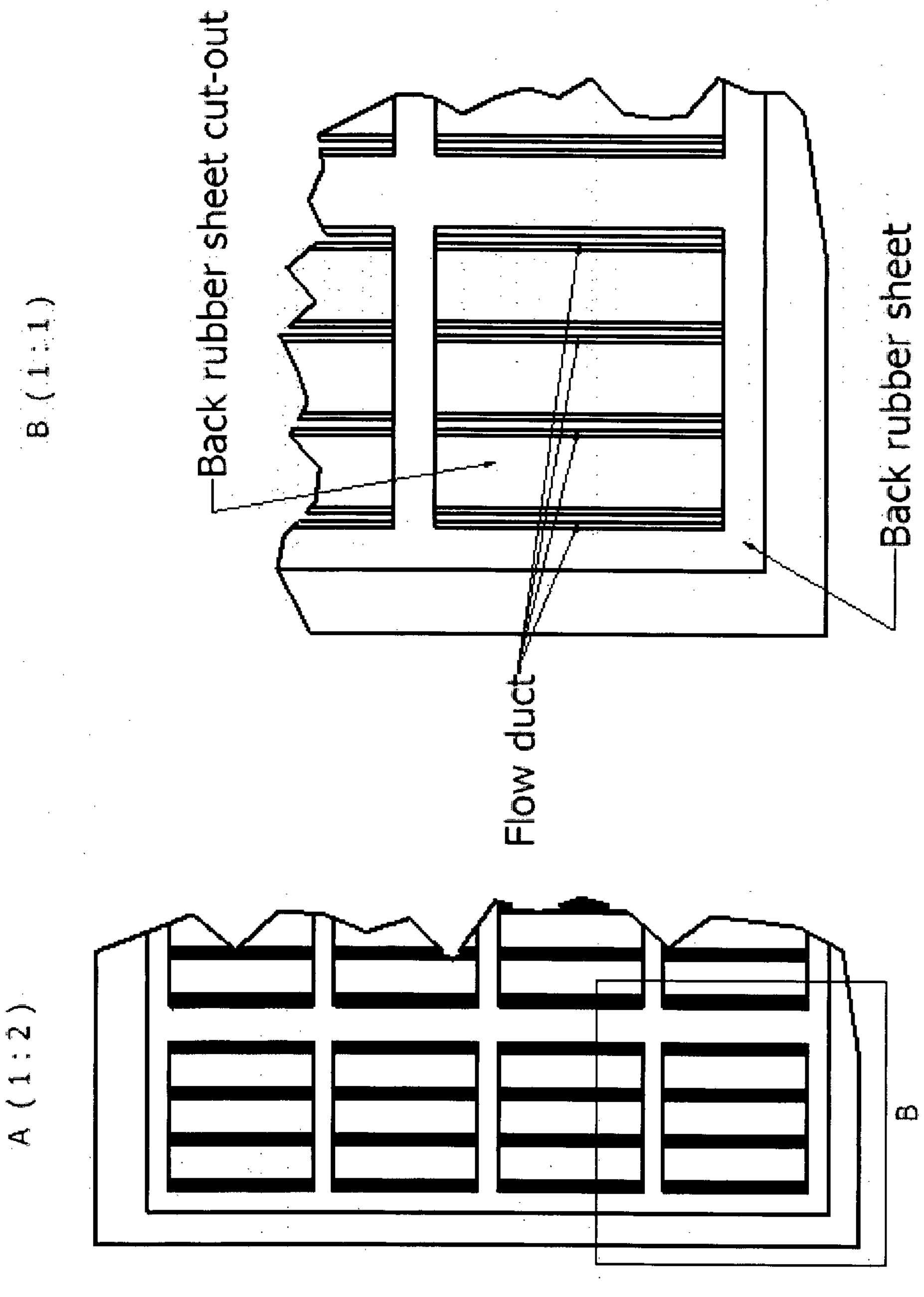
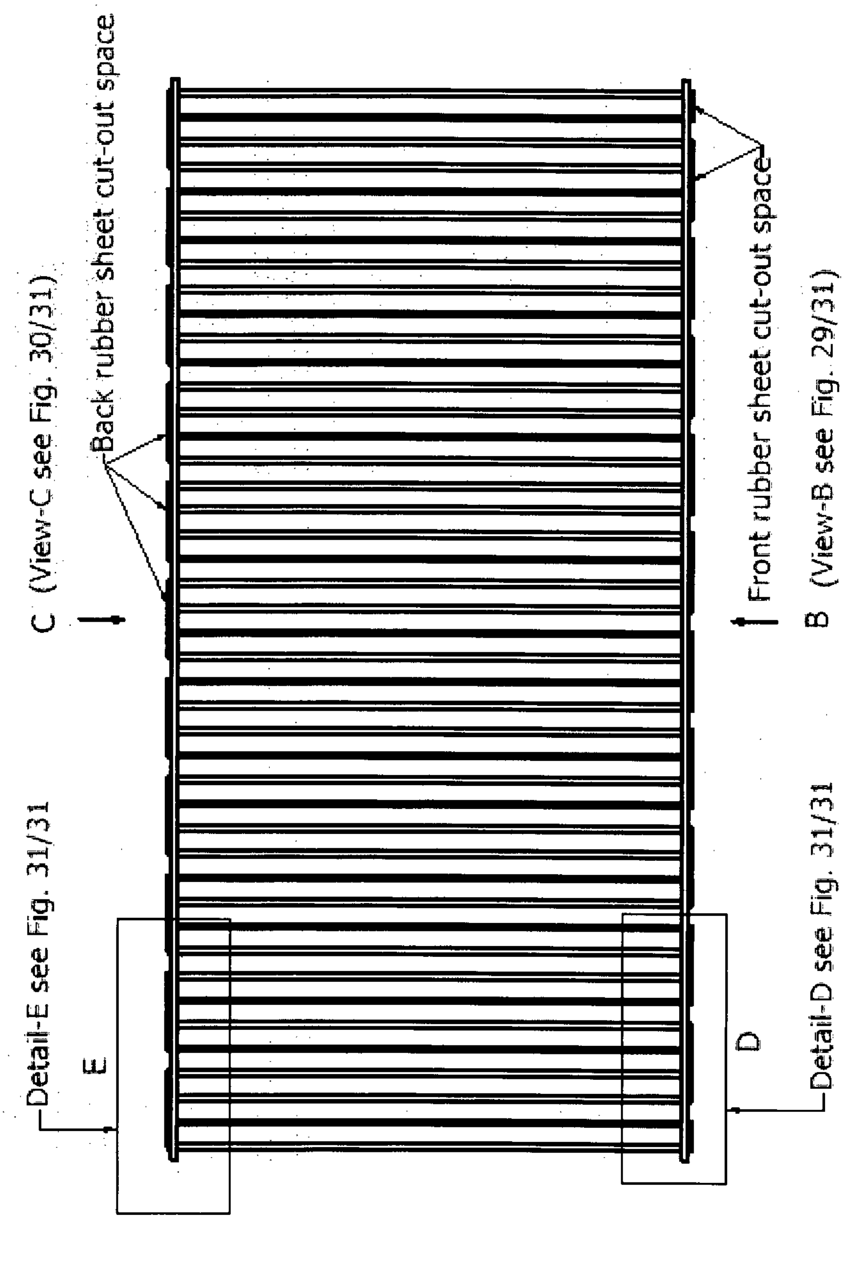

B (1:1)
Back rubber sheet cut-out
Back rubber sheet
Flow duct
A (1:2)
B

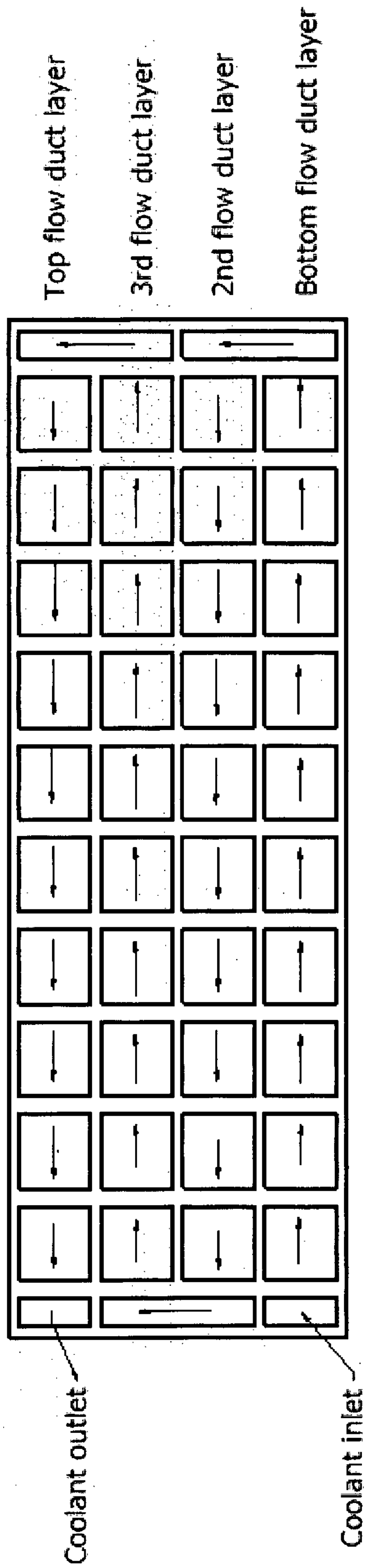
FIG 28



Cooling grid array top view with show of front and back rubber sheet cut-out space

FIG 29

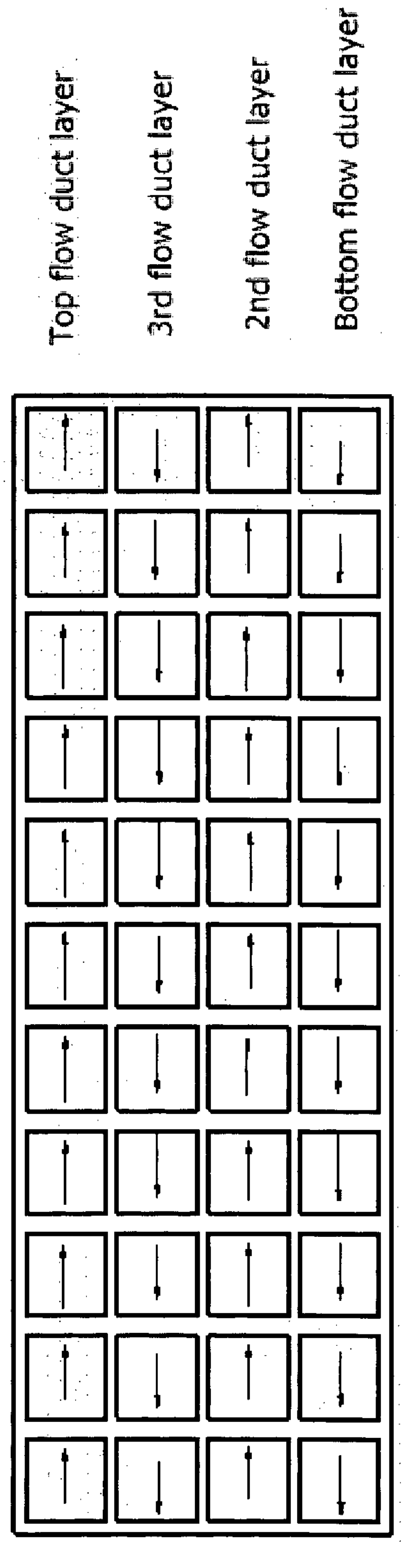
B (1 : 4)



Coolant flow direction at front rubber sheet cut-out space

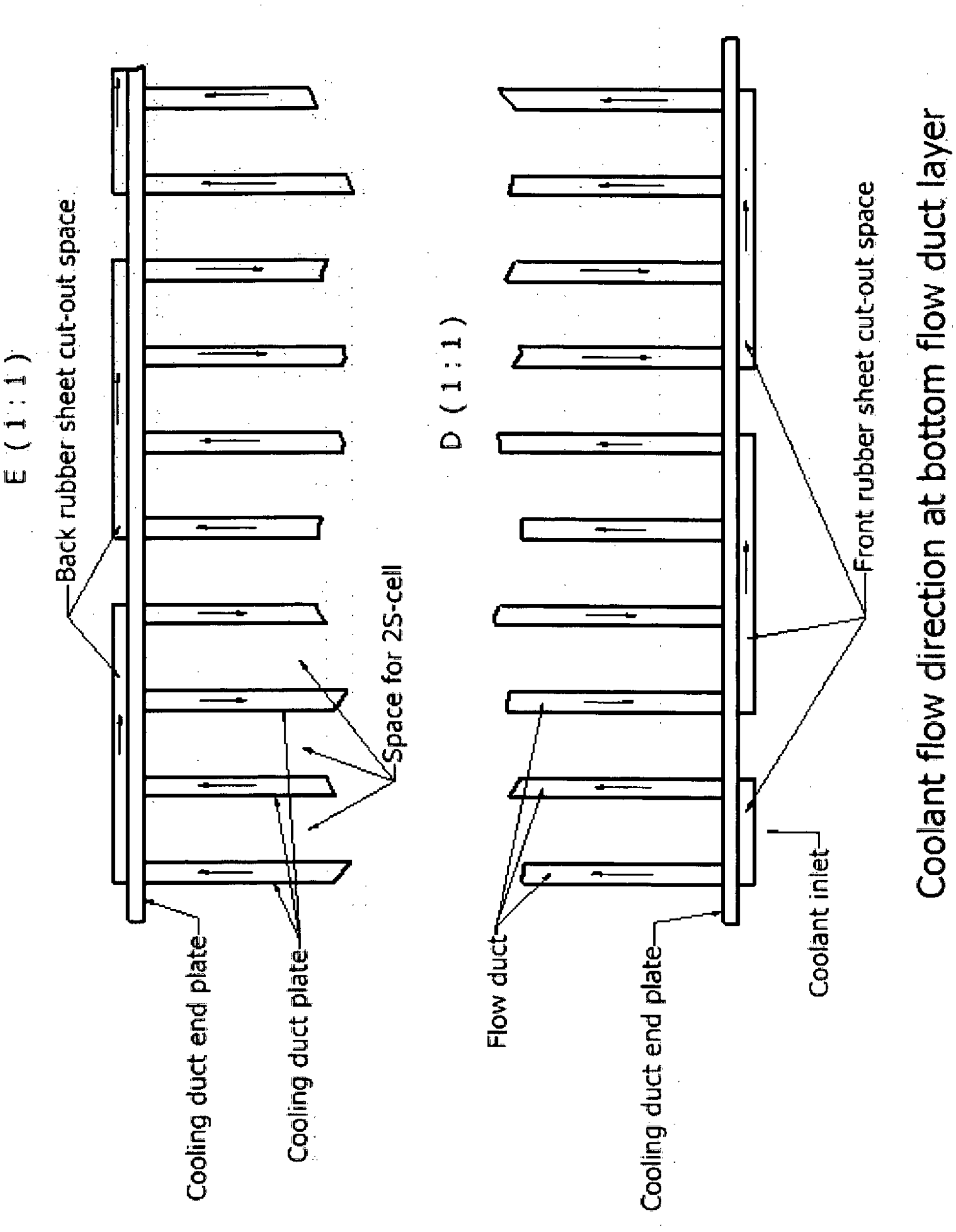
FIG 32

C (1:4)



Coolant flow direction at back rubber sheet cut-out space

FIG 31


E (1 : 1)
Back rubber sheet cut-out space
Space for 2S-cell
Cooling duct end plate
Cooling duct plate
D (1 : 1)
Front rubber sheet cut-out space
Flow duct
Cooling duct end plate
Coolant inlet
Coolant flow direction at bottom flow duct layer

INTERNATIONAL SEARCH REPORT

International application No.

PCT / SG 2011/000029

A. CLASSIFICATION OF SUBJECT MATTER

IPC: ***H01M 2/02*** (2006.01); ***H01M 10/50*** (2006.01); ***H01M 2/30*** (2006.01); ***H01M 6/42*** (2006.01); ***H01M 10/0585*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

H01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI, X-FULL, IPDL

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008098555 A1 (Temic Automotive Electric Motors GmbH) 21 August 2008 (21.08.2008) Abstract; Description, p. 5, pas. 2, 3; Fig. 2, 3; Claims 1, 6 - 8	1
A	US 2009025052 A1 (Koetting et al.) 31 December 2009 (31.12.2009) Abstract; Description, [0014] - [0017]; Fig. 1 - 3	1
A	DE 102008059966 A1 (Daimler AG) 10 June 2010 (10.06.2010) Abstract; Description, [0044] - [0048]; Fig. 1, 2; Claims 1 - 10, 16	1
A	DE 10101050 A1 (Delphi Technologies, Inc.) 26 July 2001 (26.07.2001) Abstract; Description, col. 4, l. 11 - 44; Fig. 1c; Claims 1 - 5, 7	2

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
22 September 2011 (22.09.2011)	27 September 2011 (27.09.2011)
Name and mailing address of the ISA/AT Austrian Patent Office Dresdner Straße 87, A-1200 Vienna Facsimile No. +43 / 1 / 534 24-535	Authorized officer AIGNER M. Telephone No. +43 / 1 / 534 24-458

INTERNATIONAL SEARCH REPORT

International application No.

PCT / SG 201 1/000029

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
   because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
   because they relate to parts of the national application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
   because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. Ill Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Independent claim 1 concerns a cooling apparatus for a power battery back, independent claim 2 concerns a clip system for battery cells. According to rule 13 under the Regulations under the PCT, claims 1 and 2 have to be considered to concern two different groups of inventions.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. S As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is only those claims for which fees were paid, specifically claims Nos.:

Remark on Protest

Q The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT / SG 201 1/000029

Patent document cited in search report			Patent family member(s)			Publication date
WO	Al	2008098555	DE	A l	102007007986	2008-09-04
			DE	A5	112008000341	2009-1 1-05
			WO	A l	2008098555	2008-08-21
us	Al	2009025052	CA	A l	2637163	2009-01-1 8
			CN	A	10135091 1	2009-01-21
			KR	A	20090009126	2009-01-22
			KR		100966212B	2010-06-25
			KR	B l	100966212	2010-06-25
			US	A l	2009025052	2009-01-22
DE	Al	102008059966	DE	A l	102008059966	2010-06-10
			DE	B4	102008059966	201 1-06-22
DE	Al	10101050	DE	A l	10101050	2001-07-26
			US	B l	6423441	2002-07-23