Sept. 15, 1970 J. E. AUSTIN 3,528,492

SOLID STATE MODULAR MICROWAVE SYSTEM
AND COOLING MEANS THEREFOR

Filed April 3, 1967 6 Sheets-Sheet 1

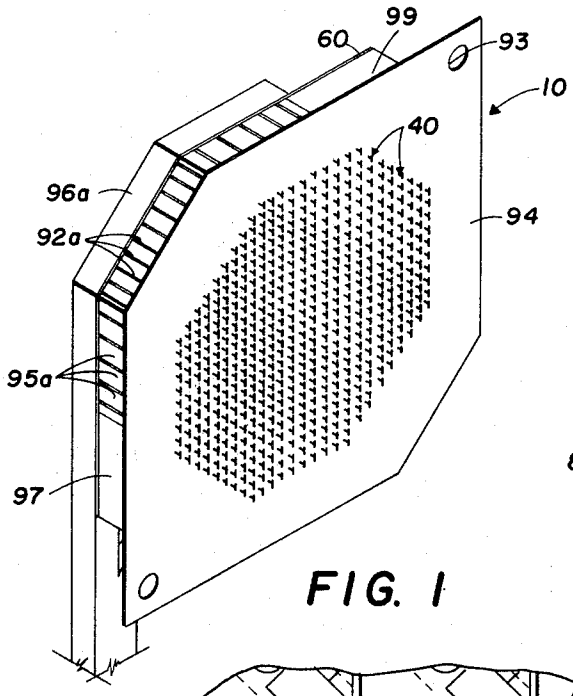


FIG. 1

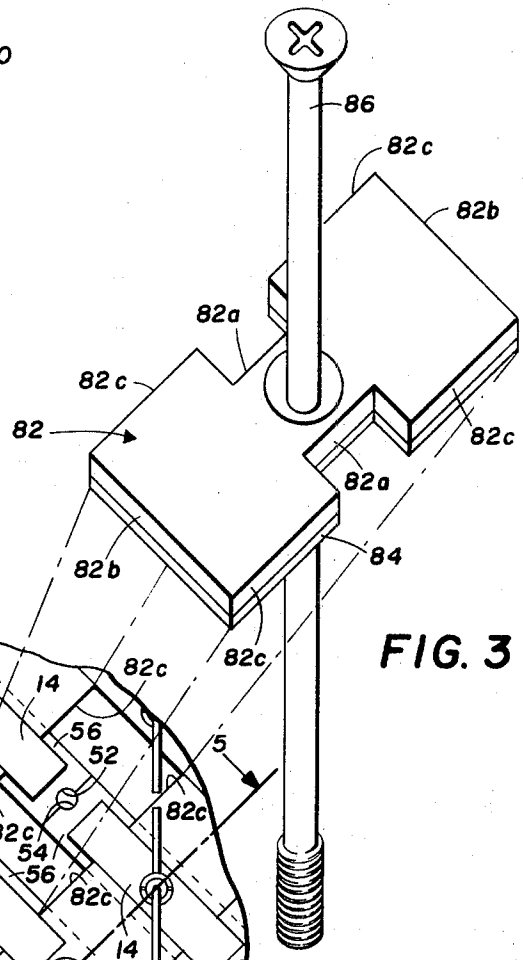


FIG. 3

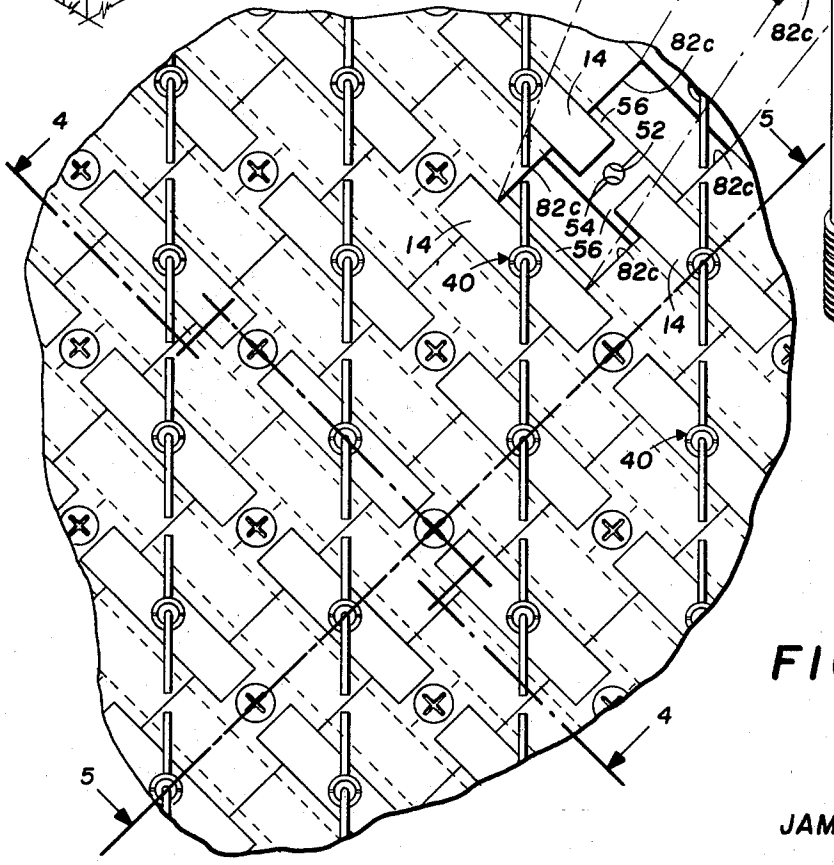


FIG. 2

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Sept. 15, 1970 J. E. AUSTIN 3,528,492

SOLID STATE MODULAR MICROWAVE SYSTEM
AND COOLING MEANS THEREFOR

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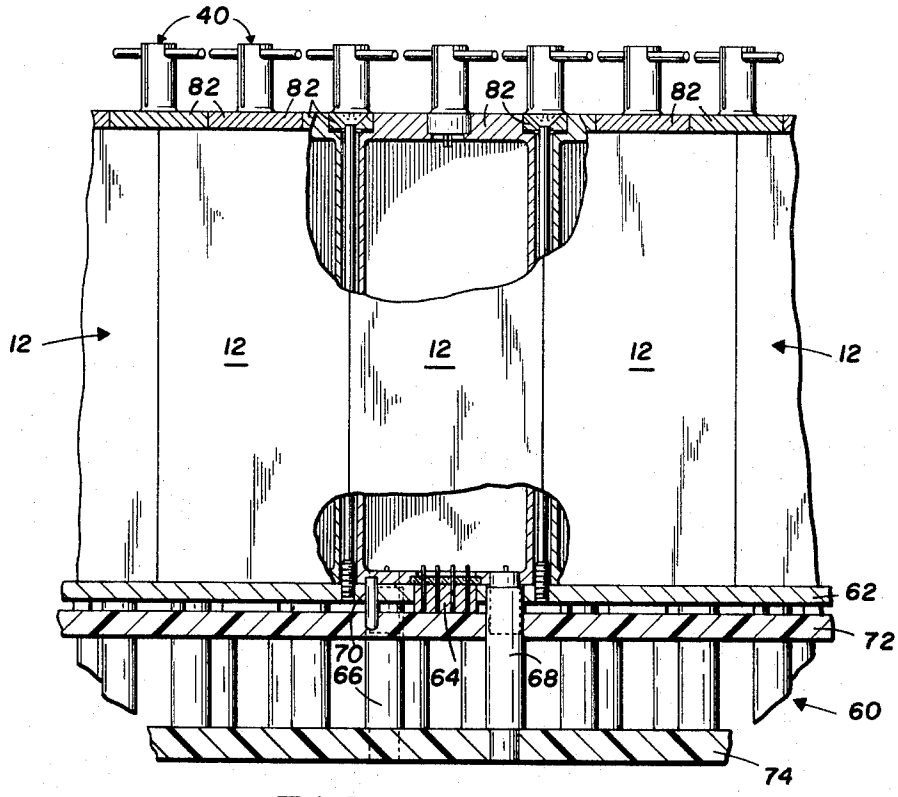


FIG. 4

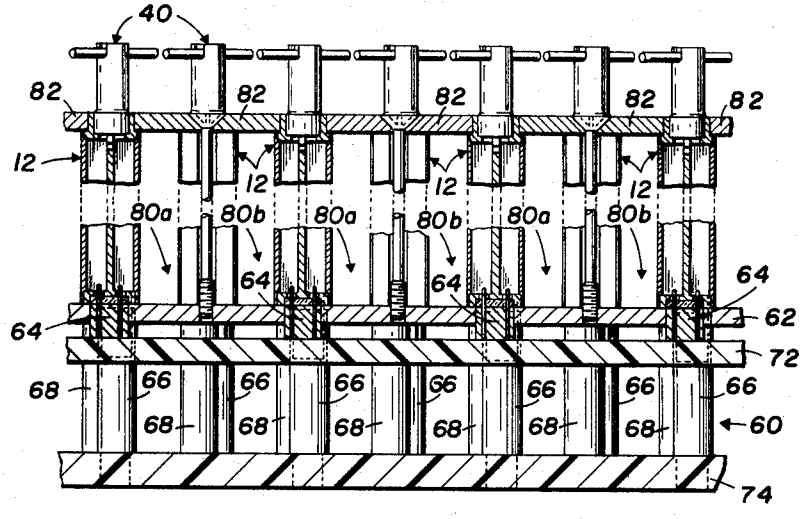


FIG. 5

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SOLID STATE MODULAR MICROWAVE SYSTEM
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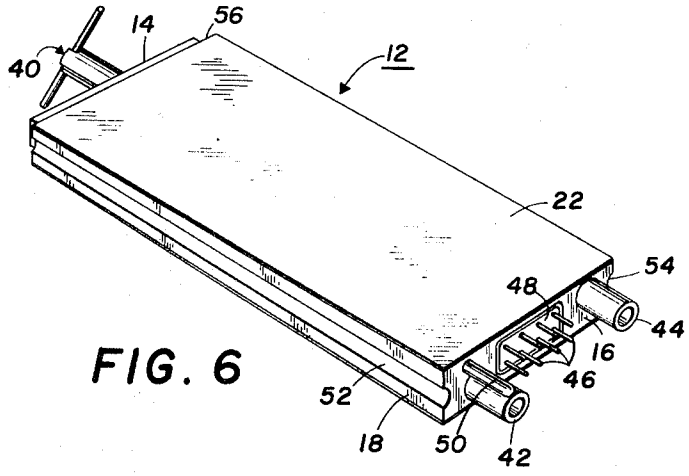


FIG. 6

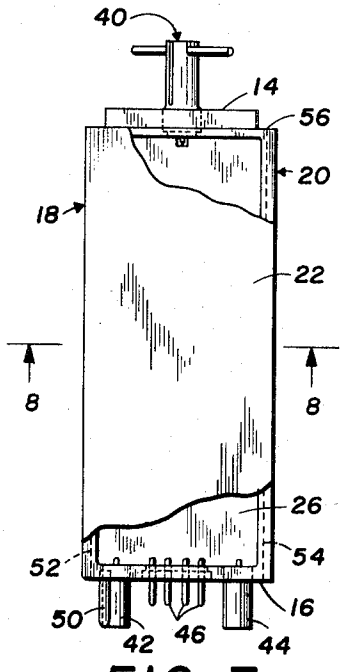


FIG. 7

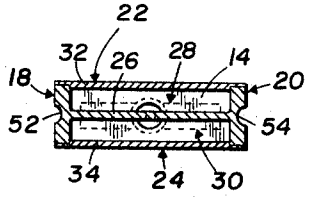


FIG. 8

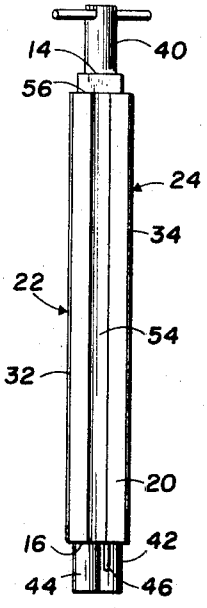


FIG. 9

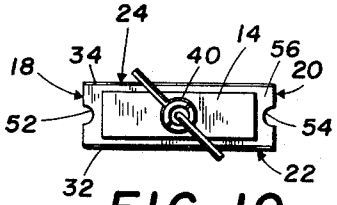


FIG. 10

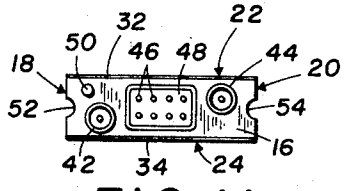


FIG. 11

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Sept. 15, 1970 J. E. AUSTIN 3,528,492
SOLID STATE MODULAR MICROWAVE SYSTEM
AND COOLING MEANS THEREFOR
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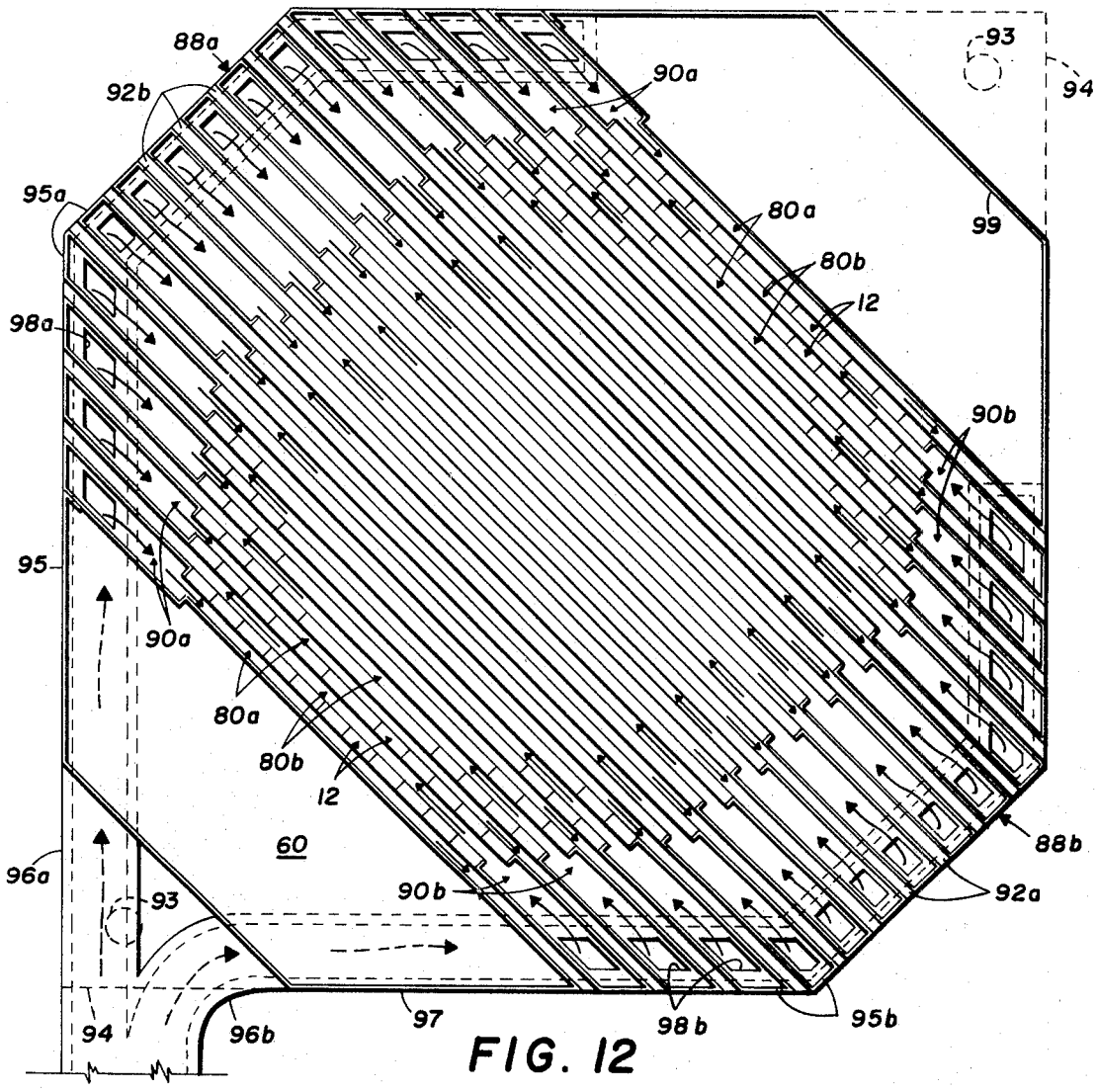


FIG. 12

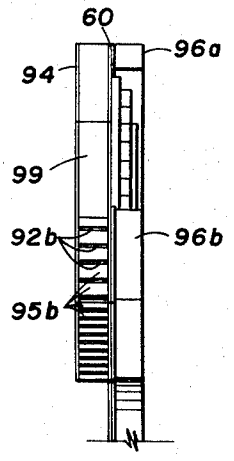


FIG. 13

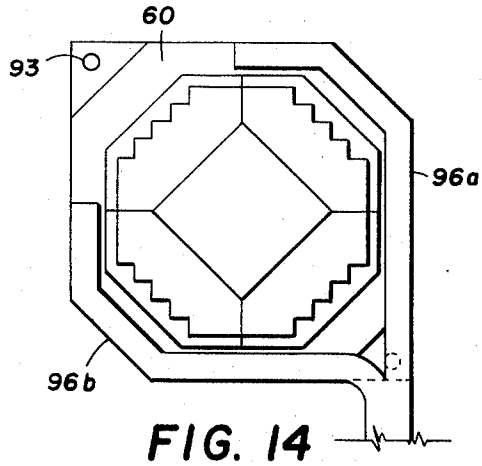


FIG. 14

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SOLID STATE MODULAR MICROWAVE SYSTEM
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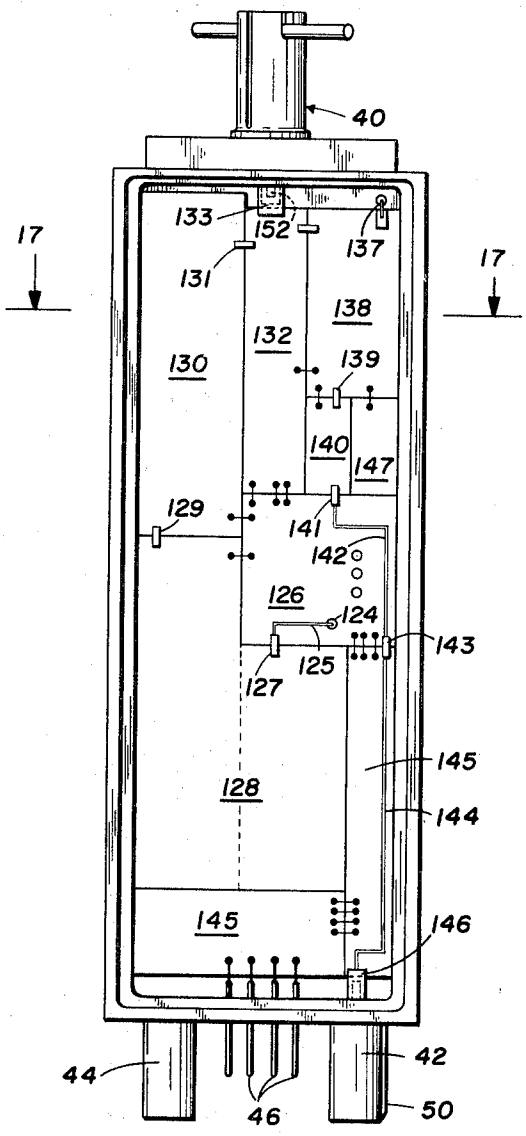


FIG. 16

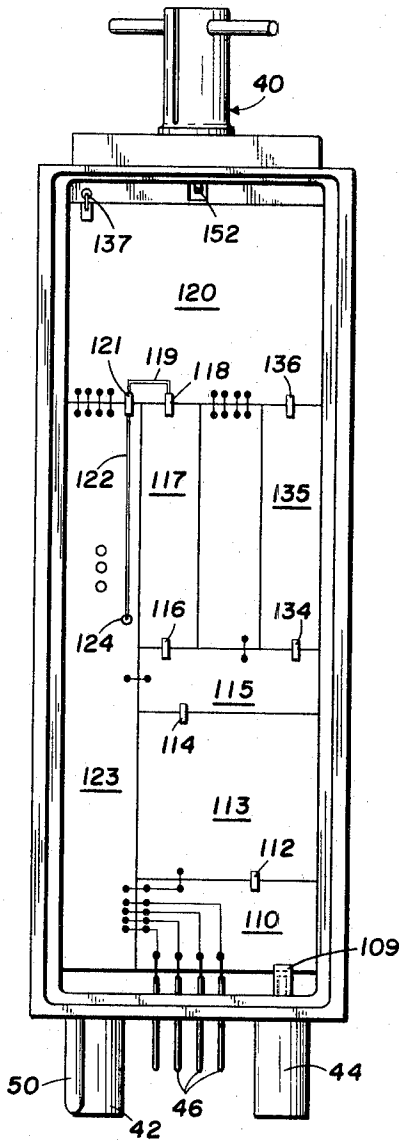


FIG. 15

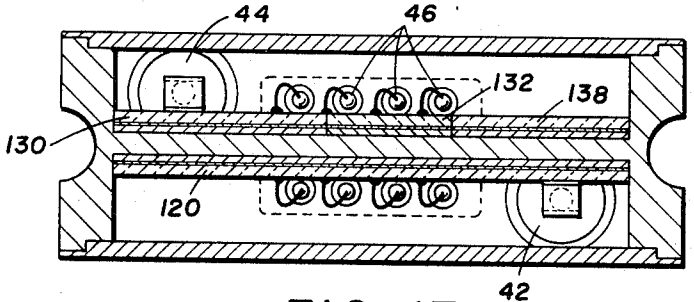


FIG. 17

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SOLID STATE MODULAR MICROWAVE SYSTEM
AND COOLING MEANS THEREFOR

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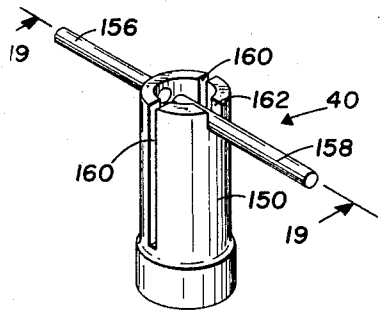


FIG. 18

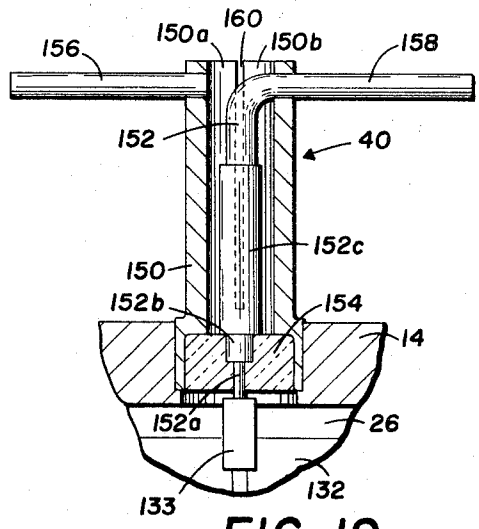


FIG. 19

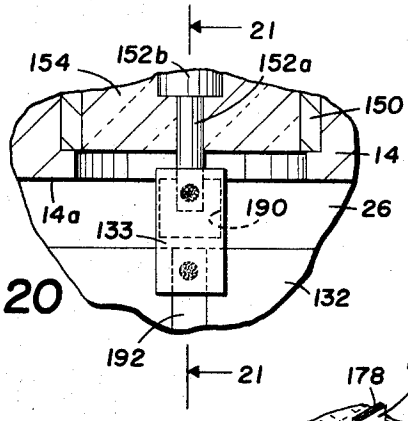


FIG. 20

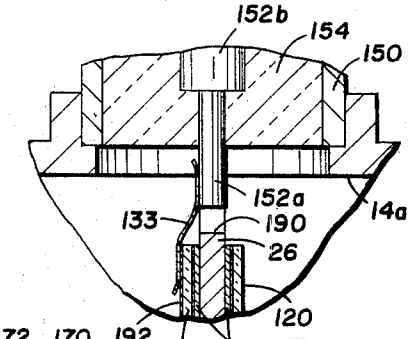


FIG. 21

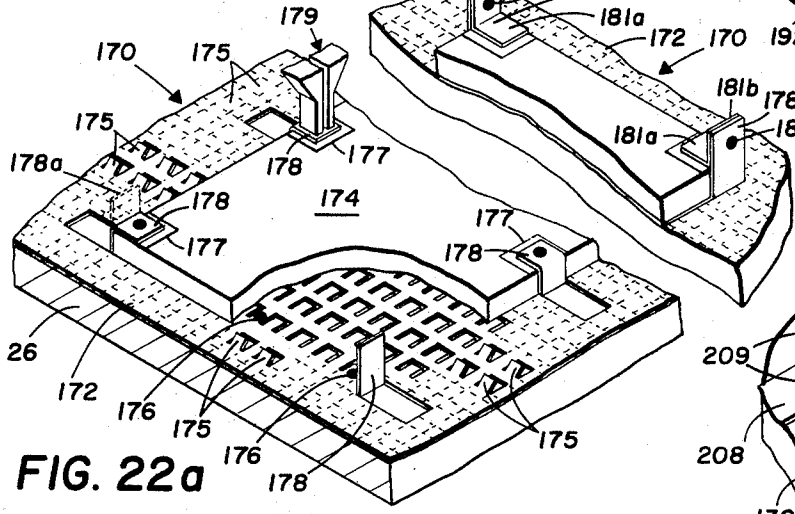


FIG. 22a

FIG. 22b

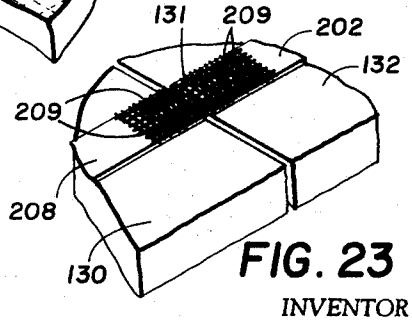


FIG. 23

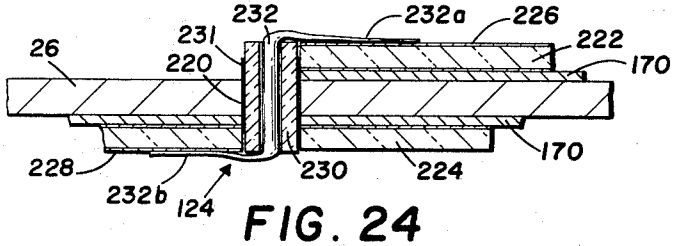


FIG. 24

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United States Patent Office 3,528,492
Patented Sept. 15, 1970

3,528,492

SOLID STATE MODULAR MICROWAVE SYSTEM AND COOLING MEANS THEREFOR

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Filed Apr. 3, 1967, Ser. No. 628,139
Int. Cl. F28f 7/00
U.S. Cl. 165—80 7 Claims

ABSTRACT OF THE DISCLOSURE

A solid-state, modular microwave transmitter-receiver assembly made up of a large number of transmit-receive modules each having an antenna. Each of the modules has functional electronic blocks mounted on both sides of a center mounting plate contained within a hermetically sealed package. The module packages generally conform to the center mounting plate and are elongated, with a greater width than thickness. The antenna extends from the front end of the module and connectors extend from the rear end. The connectors are plugged into a rear support structure and are retained in place by a series of retaining plates fastened by long screws to the rear support structure. The retaining plates also form the ground plane for the antenna array. The antennae are arrayed in horizontal rows and vertical columns, and the module packages are arranged in rows extending diagonally of the antenna rows and columns with the edges of the packages in each row abutting. A cooling fluid duct is formed between each adjacent pair of module rows by the walls of the module packages, the retaining plates and the rear support structure. A manifold and header assembly directs cooling fluid in opposite directions through alternate cooling fluid ducts. The antenna assembly of each module provides a hermetically sealed coupling between the antenna and the interior of the package, supports the dipole elements, and provides impedance and balun transforming. The functional electronic blocks are easily secured on the mounting plate by spot welded brackets and are replaceable. The hermetically sealed antenna assembly and coaxial input and output connections are connected to microstrip lines within the module by spot welded straps of solid ribbon or woven metal wire fabric, as are adjacent microstrip lines on adjacent abutting functional electronic blocks. Connections are made between functional electronic blocks on opposite faces of the mounting plate by a special coaxial structure extending through the mounting plate.

This invention relates generally to microwave transmitting and and receiving, and more particularly relates to solid-state microwave antenna arrays.

While the specific embodiment of the invention described herein is an airborne terrain-following radar, this invention is equally applicable to other radar systems, such as those used for ground mapping, search and detection, fire control, tracking and navigation, as well as to microwave transmitting and receiving generally.

Radar systems in general, and airborne radar systems in particular, have long required considerable servicing and have been somewhat uneliable because of the many mechanical parts, such as rotary joints, motors, synchros, gears and other servo components normally essentially to scanning the system, and the magnetrons used for transmitting, klystrons used for transmitting and local oscillator service, and the high power transmit-receive (TR) protection devices, for example. It is also difficult to achieve high power at higher frequences and the electronic components mentioned tend to be more unreliable and less practical as the frequency of the transmitted and received energy increases.

In copending U.S. patent applications Ser. No. 397,519, entitled "Modular Integrated Electronics Radar," filed on behalf of Tom M. Hyltin, Ser. No. 397,472, entitled "Phased Array Radar Antenna Scan Control," filed on behalf of Leo A. Chamberlin, Jr., and Ser. No. 397,491, entitled "Integrated Circuit Modular Radar Antenna," filed on behalf of Harry F. Cooke et al., all of which were filed on Sept. 18, 1964 and are assigned to the assignee of the present invention, a radar system is described which utilizes a large array of solid-state modules. Each module is substantially a complete micorwave transmitter and receiver. Each module includes the necessary circuitry for amplifying relatively low RF carrier energy applied simlutaneously to all of the modules, and multiplying the frequency to a higher frequency for transmission from the antenna. Each module also includes circuitry for processing high frequency energy reecived by the antenna to produce a lower frequency IF signal, which is also preamplified. In addition, each module includes phase shifting means for both the transmitted and the received energy so that the beam from the fixed antenna array can be electronically scanned. Although an X-band module transmitting at 9 gHz. (9×10^9 cycles per second) typically has a transmitting power of only about one watt, when a very large number of the modules transmit simultaneously, the total transmitting power is essentially the sum of the power of all of the modules. Arrays having on the order of thousands of modules are practical.

In order to operate at high frequencies, the individual antennae of the array must be spaced about one-half wavelength apart, which for X-band systems means that the antennae are arrayed in horizontal rows and vertical columns with about 0.7 inch spacing between the rows and columns. As a result, the frontal area of each module must be confined to a square about 0.7 inch on a side. Also, it is highly desirable to locate the electronic components as close to the antenna as possible, particularly the circuits operating at the higher frequencies. Merely obtaining sufficient space within the module to mount all the functional hybrid or integrated circuits, even though the circuits are highly microminiaturized, is a serious problem. Since very large numbers of modules are required, it will be appreciated that a very large number of relatively high power devices must be packed into a minimum volume, making it difficult to provide adequate cooling.

Also, there are very real problems associated with supplying high frequency signals to the module, transferring the high frequency signals between the various functional circuits within the module, transferring high frequency energy between the externally mounted radiating element and the internal circuitry, and getting the high frequency signals out of the module while maintaining the module hermetically sealed. Because of the number of components, it is also very desirable to be able to replace malfunctioning components during fabrication, rather than lose the entire module.

This invention is concerned with the structure of the array and individual modules required in order to achieve high component density and adequate cooling, economical fabrication costs, low maintenance requirements, and long service life. This is achieved by orienting the modules in spaced rows to form cooling fluid ducts between each two adjacent rows of modules. The rows of modules are preferably disposed diagonally of the rows and columns of antennae so that each module can have a maximum width, and thus maximum circuit mounting area for a given spacing between the antennae. The mounting area for the

circuits is further increased by a package having a mounting plate extending between midpoints of a peripheral wall with the solid-state functional electronic components mounted on both sides of the mounting plate and hermetically sealed by a pair of lids.

The novel features believed characteristic of this invention are set forth in the appended claims. The invention itself, however, as well as other objects and advantages thereof, may best be understood by reference to the following detailed description of illustrative embodiments, when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a front perspective view of a microwave antenna array in accordance with the present invention;

FIG. 2 is an enlarged front view of a portion of the antenna array of FIG. 1;

FIG. 3 is an exploded perspective view of the parts missing from the structure illustrated in FIG. 2;

FIG. 4 is a sectional view taken substantially on lines **4—4** of FIG. 2;

FIG. 5 is a sectional view taken substantially on lines **5—5** of FIG. 2;

FIG. 6 is an isometric view of an RF module of the array of FIG. 1;

FIG. 7 is a side view of the module of FIG. 6;

FIG. 8 is a sectional view taken substantially on lines **8—8** of FIG. 7;

FIG. 9 is an edge view of the module of FIG. 6;

FIG. 10 is a front end view of the module of FIG. 6;

FIG. 11 is a rear end view of the module of FIG. 6;

FIG. 12 is a somewhat schematic front view of the antenna array of FIG. 1 with a portion of the structure removed to better illustrate certain aspects of the invention;

FIG. 13 is a side view of the structure shown in FIG. 12;

FIG. 14 is a rear view of the structure shown in FIG. 12;

FIG. 15 is a somewhat schematic layout of the functional integrated and hybrid circuits mounted in one half of the module of FIG. 6;

FIG. 16 is a somewhat schematic layout of the functional integrated and hybrid circuits mounted in the other half of the module of FIG. 6;

FIG. 17 is a sectional view taken substantially on lines **17—17** of FIG. 16;

FIG. 18 is a perspective view of the antenna assembly of the module of FIG. 6;

FIG. 19 is a sectional view taken substantially on lines **19—19** of FIG. 18;

FIG. 20 is an enlarged view of a portion of FIG. 19;

FIG. 21 is a sectional view taken substantially on lines **21—21** of FIG. 20;

FIGS. 22A and 22B are somewhat schematic isometric views illustrating alternative means for mounting the integrated and hybrid circuits within the module of FIG. 6;

FIG. 23 is a somewhat schematic isometric view illustrating how the microwave circuits on adjacent substrates may be interconnected; and

FIG. 24 is a sectional view illustrating the manner in which the microwave circuits formed on substrates mounted in the different compartments of the module of FIG. 6 may be interconnected.

Referring now to the drawings, a microwave antenna array constructed in accordance with the present invention is indicated generally by the reference numeral **10**. The particular antenna array **10** herein described and illustrated is a solid-state, electronically scanned airborne radar system of the type described in the above-referenced U.S. patent applications. In such a system, a very large number of very small modules **12**, as shown in FIG. 6, are assembled in an array with the antennae of the modules disposed in a common plane. Each of the modules is essentially a separate microwave transmitter-receiver which includes solid-state circuitry for amplifying a relatively low frequency RF carrier signal, which can be more easily handled, then multiplying the frequency of the RF signal several times before it is radiated from the antenna during a transmit cycle. During the receive cycle, the high frequency RF signal is mixed with a local oscillator signal to produce an IF signal which is amplified before leaving the module. In addition, each module contains phase shift circuitry for both the transmit and receive cycles in order to electronically scan the beam from the fixed antenna array. For other applications, however, such as microwave relay applications, the modules may only transmit, or only receive, or may not utilize the phase shift networks for beam steering. This invention is concerned primarily with the structure of the modules rather than the electronic function of the modules.

Each of the modules **12** has a metal package with opposite front and rear end walls **14** and **16** which define a length, opposite edge walls **18** and **20** which define a width, and opposite side walls **22** and **24** which define a thickness. The opposite end walls **14** and **16** and opposite edge walls **18** and **20** are integrally formed and are of the same height, the height corresponding essentially to the thickness of the module package. A center mounting plate **26** extends between midpoints of the opposite edge walls **18** and **20** and the opposite end walls **14** and **16** and is preferably integral with the side walls to achieve the best possible heat transfer between the mounting plate and the walls. Walls **14**, **16**, **18** and **20** provide a continuous wall which extends around the periphery of the center mounting plate **26**, is normal to the plate **26** and extends beyond both of the opposite surfaces of the plate **26**, thus forming an integral body having a pair of oppositely facing, open topped chambers indicated generally by the reference numerals **28** and **30**. The chambers **28** and **30** are hermetically sealed by lids **32** and **34** which may be stitch welded or soldered around their entire periphery to the edges of the walls **14**, **16**, **18** and **20**. The two lids **32** and **34** and the four walls **14**, **16**, **18** and **20** then form a hermetically sealed package.

An antenna assembly, indicated generally by the reference numeral **40**, extends through and projects from the front wall **14** and is hermetically sealed therewith. A pair of hermetically sealed coaxial connectors **42** and **44** extend through and project from the rear end wall **16** to provide high frequency connections to the circuits located within chambers **28** and **30** and are also hermetically sealed. The connectors **42** and **44** are the male halves of a conventional plug-in type connector. Similarly, eight low frequency or D.C. male connectors **46** extend through a ceramic block **48** and provide D.C. connections to the interior of the module. The ceramic block **48** is hermetically sealed to the end wall **16** and is hermetically sealed around each of the connectors **46**. It will be noted that one of the coaxial connectors and four of the D.C. connectors extend into each of the chambers **28** and **30**. An indexing pin **50** also protrudes from rear end wall **16** to insure that the otherwise symmetrical package is inserted in the proper manner in the female receptacle for the connectors **42**, **44** and **46**. A pair of essentially semicircular grooves **52** and **54** extend the length of the edge walls **18** and **20**, respectively. A forward facing, recessed shoulder **56** is formed around the periphery of the front face **14** by machining for purposes which will hereafter become evident.

Each of the modules **12** is plugged into a female receptacle carried by a rear support structure indicated generally by the reference numeral **60** in FIGS. 4 and 5. The rear support structure **60** includes a support plate **62** which is coextensive with the octagonal housing as illustrated in FIG. 12. At each position where a module **12** is to be plugged in, the support structure **60** provides a D.C. socket **64** for the eight low frequency connectors **46**, a pair of female coaxial sockets **66** and **68** for the male coaxial connectors **42** and **44**, and a bore **70** for the indexing pin **50**. The D.C. sockets **64** are mounted on a

D.C. wiring board **72** and extend through an opening in support plate **62** to a point essentially flush with the front face of plate **62**. The coaxial sockets **66** and **68** are mounted on an RF sub-manifold **74** and extend through the D.C. wiring board **72** and partially through the support plate **62**.

When the modules **12** are plugged into the socket carried by support structure **60**, the modules are arrayed as illustrated in FIGS. 2 and 12. It will be noted from FIG. 2 that the antenna assemblies **40** are arrayed in orthogonally disposed horizontal rows and vertical columns with the center-to-center spacing approximately one-half wavelength, which at 9 gHz. is approximately 0.7 inch. However, the modules **12** are arrayed in rows extending diagonally of the rows and columns of the antenna assemblies **40**, and are disposed in substantially edge abutting relationship as best seen in FIG. 12. Since the width of each module is substantially greater than the thickness, the rows of modules **12** are spaced apart and the side walls of the modules in each adjacent pair of rows form the opposite side walls of cooling fluid ducts **80***a* and **80***b*. The ducts **80***a* and **80***b* are identical but are designated by different reference characters for purposes which will hereafter become more evident.

The modules **12** are secured in place in their respective sockets by means of a plurality of H-shaped clamp plates **82**, as best shown in FIG. 3. Each plate **82** is formed from metal and has an electrically conductive sealing gasket **84** over its rear face. The total thickness of each plate **82** is equal to the distance the shoulder **56** is recessed from the front surface of the front end wall **14**. Each plate **82** has a narrow center section **82***a* which is adapted to fit over the shoulders **56** at the adjacent ends of two adjacent modules. A relatively long screw **86** passes through each center section **82***a* and extends back through the passageway formed by the adjacent semicircular grooves **52** and **54** of the two adjacent modules and is threaded into the support plate **62**, as shown in FIGS. 4 and 5. The ends **82***b* of the plates **82** extend over the adjacent ducts **80***a* and **80***b* and engage the shoulders **56** of the modules in the two adjacent rows. Thus, a single plate **82** engages and secures four modules in place, and conversely each module is secured in place by four plates and four screws. Edges **82***c* of the plates extend into engagement with the corresponding edges **82***c* of the adjacent plates so that the combination of plates **82** provides a complete front wall for the cooling fluid ducts. It will be noted that plates **82** and the support plate **62** form the other two opposite side walls of the cooling fluid ducts **80***a* and **80***b*. The gasket material **84** prevents excessive leakage of the cooling fluid. In addition, the front surfaces of the plates **82** are coplanar with the front surfaces of the end walls **14** and the combined surface acts as the ground plane for the antenna array. The conductive gasket material **84** insures good electrical contact between the plates and the modules.

Referring once again to FIGS. 12, 13 and 14, a cooling fluid header **88***a* supplies cooling fluid, typically ambient air, under pressure to ducts **80***a* through inlet ports **90***a*, and exhausts cooling fluid from ducts **80***b* through exhaust ports **92***a*. Similarly, a header **88***b* supplies cooling fluid under pressure to ducts **80***b* through input ports **90***b* and exhausts the cooling fluid from ducts **80***a* through exhaust ports **92***a*. The ports **90***a* and **92***a* and **90***b* and **92***b* are formed by plates **95***a* and **95***b* which extend between the rear support plate **60** and a front plate **94** (see FIG. 13) which is coplanar with the retainer plates **82** (see FIG. 3) and which therefore provides a continuation of the ground plane. Mounting holes **93** are provided in plate **94** to support the device. Plates **97** and **99** may extend around the remaining peripheries of plates **60** and **94**. A pair of manifolds **96***a* and **96***b* extend around the rear surface of the rear support plate **60**. Manifold **96***a* communicates with inlet ports **90***a* through openings **98***a* in plate **60**, and manifold **96***b* communicates with inlet ports **90***b* through openings **98***b* in plate **60**.

Thus, it will be noted that cooling fluid passes through manifold **96***a*, openings **98***a*, input ports **90***a*, ducts **80***a*, and exhausts through ports **92***a*, and passes through manifold **96***b*, openings **98***b*, input ports **90***b*, ducts **80***b*, and exits through exhaust ports **92***b*. As a result, the cooling fluid flows in opposite directions in the ducts on either side of any one row of modules **12**. The modules **12** adjacent the headers **88***a* and **88***b* will therefore have relatively cool fluid flowing by one face and relatively warm fluid flowing by the other face, while the modules generally centered between the headers will have cooling fluid at an intermediate temperature flowing over both faces. As a result, the net cooling effect upon all modules is substantially the same so that all modules are maintained at substantially the same temperature.

The antenna assembly **40** is illustrated in detail in FIGS. 18 and 19. The antenna assembly **40** is comprised of a tubular sleeve **150**, a center conductor **152**, a ceramic disk **154**, and a pair of antenna elements **156** and **158**. The ceramic disk **154** is hermetically sealed within the end of the tubular sleeve **150** and also around the end of the center conductor **152** by vacuum-tight hard solder seals. The diameter of the input portion **152***a* of the center conductor is selected relative to the diameter of the adjacent portion of the tubular sleeve **150** so as to provide a coaxial transmission line having a fifty-ohm characteristic impedance. The center conductor has portions **152***b* and **152***c* of enlarged diameter for transforming the fifty-ohm characteristic impedance to the complex impedance required by the radiating elements **156** and **158** when positioned in the antenna array. The sleeve **150** is split into halves **150***a* and **150***b* to provide a balun transformation from the unbalanced coaxial transmission system to the balanced transmission system required to feed energy to the radiating elements **156** and **158**. The slits **160** which separate the sleeve **150** into halves are approximately one quarter wavelength long. Antenna element **156** is secured in one of the sleeve halves **150***a* by a hard solder connection, and antenna element **158** is simply a continuation of the center conductor **152**, but is also connected in a slot **162** by a hard solder connection. The antenna elements **156** and **158** are disposed one quarter wavelength from the ground plane. Thus, the antenna assembly **40** provides a hermetically sealed coaxial connection through the wall **14** of the module package, provides an impedance transformer for matching the standard fifty-ohm characteristic input impedance of the microstrip transmission of the internal circuit to the complex impedance required for the antenna, provides a balun transformer to convert from the unbalanced coaxial input to the balanced dipole antenna, and mechanically supports the radiating elements **156** and **158** approximately one quarter wavelength above the surface of the end wall **14**, which forms a portion of the ground plane for the antenna array.

The modules **12** may house, for example, the electronic circuitry described in copending U.S. patent application Ser. No. 606,427, entitled "Transmit-Receive Module for X-Band Phased Array Radar System," filed on behalf of Tom M. Hyltin and assigned to the assignee of the present invention. All of the functional blocks within the module are either hybrid circuits, in which case microstrip transmission lines and discrete semiconductor components are mounted on a ceramic substrate, or monolithic integrated circuits, in which case the active components are formed in a semiconductor substrate which also acts as the dielectric for the microstrip transmission lines. A typical layout for these circuits is shown in FIGS. 15–17.

During the transmit cycle a 2.25 gHz. carrier signal is applied through input coaxial connector **44** and is transferred by a strap **109** to a microstrip transmission line (not shown) on interconnector chip **110** and through interconnection strap **112** to an S-band preamplifier **113**.

The output of the preamplifier **113** is coupled by strap **114** to the input of a duplexer switch **115** which, during the transmit cycle, directs the signal through strap **116** to a transmit phase shifter **117**. The output of the transmit phase shifter **117** is connected by strap **118** to a microstrip transmission line **119** on the receive multiplier **120**, which in turn is connected by strap **121** to microstrip transmission line **122** on an interconnect chip **123**. Line **122** is coupled by feed through connector **124** to a microstrip transmission line **125** on micromodulator **126**, and by strap **127** to the input of a power amplifier **128**. The output of power amplifier **128** is connected by strap **129** to a transmit multiplier **130**, which increases the frequency to 9.0 gHz. The RF frequency signal is then applied by strap **131** to a TR switch **132** which, during the transmit cycle, directs the energy to the center conductor **152** of the antenna assembly **40** by way of a strap connector **133**.

During the receive cycle, a 2.125 gHz. signal is applied to input coaxial connector **44** and is passed through strap coupling **112** to the S-band preamplifier, strap coupling **114** to the duplexer, and strap coupling **134** to a receive phase shifter **135**. The output of the receive phase shifter is applied by strap coupling **136** to the receive multiplier **120** which increases the frequency to 8.5 gHz. The output of multiplier **120** is connected by feed through connection **137** to a mixer **138**. Also during the receive cycle, the TR switch connects the antenna to the mixer **138** where the 9.0 gHz. energy received by the antenna is mixed with the 8.5 gHz. local oscillator signal produced by multiplier **120** to derive a 500 mHz. IF signal. The IF signal is applied by way of strap connector **139** to IF preamplifier **140**. The output of the IF preamplifier is connected by strap connector **141** to a microstrip transmission line **142** on the micromodulator **126**, which in turn is connected by strap connector **143** to a microstrip transmission line **144** on interconnector chip **145**. The microstrip transmission line **144** is then connected to the output coaxial connector **42** by strap connector **146**.

The micromodulator **126** produces the high current pulses defining the transmit cycle which are required to operate power amplifier **128** and switch duplexer **115** and TR switch **132**. Choke **147** improves the operation of mixer **138**. A number of D.C. connections are illustrated on the drawings but will not be discussed in detail because they do not present an interconnection problem and are not an advance in the art. In general, the D.C. connections are made to the D.C. inputs **46** by ball bonded jumper wires, and all connections between strip conductors on the various substrates can also be made by ball bonded jumper wires.

Since all circuits are mounted on the body of the package and interconnected to the antenna assembly of the various connectors before the lids **32** and **34** are sealed in place, the circuit can easily be tested after it is assembled. Because of the large number of functional blocks, it is highly desirable to be able to replace one or more faulty circuits after the entire module is assembled and tested, rather than discarding all of the circuits if any one circuit is bad. By mounting the circuits on the center mounting plate **26** using the bracket indicated generally by the reference numeral **170** in FIG. 22A, rather than by the conventional method of soldering the circuits in place, the faulty modules can be removed and replaced after the entire module has been tested as a unit.

The bracket **170** is comprised of a thin metal plate **172**, 0.001 inch thick nicket foil, for example, which is substantially coextensive with the center mounting plate **26**. A number of straps **178** are cut from the foil and bent upwardly as shown in dotted outline at **178***a*. The straps **178** are located at points spaced around the peripheries of the various circuits, represented by circuit **174** in FIG. 22A, to be mounted by the bracket **170**. Where it is desirable to place two circuits in closely abutting relationship, the straps **178** may be received in notches cut in the sides of the circuits, or may even extend through holes cut through the circuits. The straps **178** extend upwardly from the plate **172** a distance substantially greater than the thickness of the circuits to be mounted. A large number of tongue-like spring members **175** are also cut from the plate **172** and bent upwardy at an ange of approximately 45° or slightly less. The spring members **175** are disposed generally uniformly over the entire base pate **172**. The base pate **172** is resistively spot welded to the mounting plate **26** at a number of points **176** generally spaced uniformly over its entire area.

The circuit **174** is placed in its proper position over the base plate **172** and between the appropriate straps **178**, then is forced downwardly to compress the spring members **175** back into the plane of the base plate **172**. The straps **178** are then bent over metallized pads **177** on the surface of the circuit. The pads **177** may be very thin vacuum deposited gold films, for example. The straps **178** are then welded to the pads **177** using a split tip or gap resistance welder **179**. The resulting weld is adequate to hold the circuit in place, but can be broken to remove a faulty circuit without damaging bracket **170**. The faulty circuit can then be replaced in the same manner.

The spring members **175** insure good thermal and electrical contact between the circuits and the mounting plate **26** because the springs bias the base plate against the mounting plate **26** and are therselves biased against the metallized ground plane on the bottom surface of the circuits.

An alternative method for securing the circuit in position on the bracket **170** is illustrated in FIG. 22B. Rather than bending the straps **178** over the edge of the circuit and welding it to the pads **177** as shown in FIG. 22A, a gusset **181** may be welded to each of the straps. The gussets **181** may be formed from the same sheet material as the bracket **170**. Each gusset has a first flange portion **181***a* which engages the top of the circuit and a second flange portion **181***b* which is disposed at a right angle to the first portion and is spot welded to the respective strap **178** at a point **182** above the top of the circuit. The welds **182** can also be broken to remove a faulty circuit without damaging bracket **170** and the circuit replaced.

The center conductor **152** of the antenna assembly **40** may be connected to the output of the TR switch **132** using the structure illustrated in FIGS. 20 and 21. The center conductor **152** of the antenna assembly extends beyond the inner edge **14***a* of the front end wall **14** and into a slot **190** formed in the center mounting plate **26**. Since the center conductor **152** has a diameter approximately equal to the thickness of the mounting plate **26**, the surface of the center conductor **152** is essentially coplanar with the surface of the mounting plate **26**. However, the substrate on which the TR switch **132** is formed is almost as thick as the mounting plate **26** and is resting on the bracket **172**. Therefore, the microstrip transmission line **192**, which is the output of the TR switch and which extends to the edge of the substrate upon which the TR switch is formed, is not only spaced from the end of the center conductor **152**, but is also spaced substantially above the plane of the center conductor. Thus, any interconnection between the coaxial transmission line and the microstrip transmission line will tend to create an impedance discontinuity due to the change from a ceramic dielectric to air and back to ceramic and due to the change in planes. Such an impedance discontinuity can reflect an intolerable amount of energy, particularly at 9 gHz.

In accordance with this invention, however, the center conductor **152** can be connected to the microstrip transmission line **192** by a metal strap **133**. The metal strap is preferably solid metal ribbon, but can also be woven wire mesh. The solid metal ribbon can be resistively welded to the coaxial center conductor **152** and to the

microstrip line **192**. In order to compensate for the dielectric and geometric discontinuities of the interconnection, the width of the strap **133** is increased to provide substantially the same characteristic impedance. For example, when connecting the coaxial transmission line from the antenna assembly **40**, which has a fifty ohm characteristic impedance, to a microstrip transmission line, also having a fifty ohm characteristic impedance, the strap **133** should be about 0.045 inch wide. This compares with a width of 0.020 inch required for the microstrip transmission line to provide a fifty ohm characteristic impedance when using a ceramic substrate 0.020 inch thick.

The woven wire fabric is not as mechanically stable as the solid metal ribbon, but has the advantage of being easily welded to the center conductor and to the strip transmission line using a heated tool having a very small tip to press the wire fabric against the center conductor and microstrip line.

It will be noted from FIGS. 15 and 16 that the entire surfaces of the mounting plate **26** are substantially covered by functional circuit blocks and interconnector chips, the interconnector chips merely providing the microstrip transmission lines necessary to interconnect the circuits and the coaxial connectors extending through the end wall. The circuit blocks and interconnector chips all have the same thickness and a metallized ground plane on the bottom face. Microstrip transmission lines are formed by strip conductors on the top surface of the substrate and the ground plane. The characteristic impedance of the microstrip transmission lines is determined by the thickness and dielectric properties of the substrate material and the width of the strip conductors, and these variables are customarily selected to produce a transmission line having a fifty ohm characteristic impedance. Since all of the substrates have substantially the same thickness, the microstrip transmission lines carrying the high frequency signals can be interconnected by connector straps as described in connection with FIGS. 15 and 16. For example, connector strap **131** which connects the output of the transmit multiplier **130** to the TR switch **132** may be formed as shown in FIG. 23. The microstrip transmission line **202** on the duplexer switch **132** extends to the edge of the circuit block. A microstrip transmission line **208** extends to the edge of the multiplier circuit block **130** and is aligned with the microstrip transmission line **202** on the TR switch. A strap of gold wire mesh **131** bridges the gap between the adjacent circuit blocks and extends over the adjacent ends of the microstrip transmission lines **202** and **208**. The strap is welded to the transmission lines by using the tip of a heated tool to press the wire mesh against the respective microstrip transmission lines to form localized welds **209**. Alternatively, a solid metal ribbon may be substituted for the wire mesh strap and welded using the split tip resistive welder illustrated in FIG. 22A.

The dielectric discontinuity resulting from the change from ceramic to air at the gap which must necessarily exist between the adjacent substrates may be compensated by increasing the width of the strap **131** in order to maintain the same characteristic impedance and thus eliminate impedance discontinuities which would reflect an intolerable amount of high frequency energy. However, for very close spacing between the circuit blocks, the strap may be the same width as the microstrip transmission lines.

In accordance with another aspect of this invention, the feed through connectors **124** and **137** (see FIGS. 15 and 16), for example, may be constructed as shown in the detailed sectional view of FIG. 24. A hole **220** is bored through the central mounting plate **26**. The bore **220** may be located immediately adjacent the edge of the two substrates to be connected, as illustrated by the relationship of the bore to substrate **222**, or may pass through both substrates, as illustrated by the relationship of the bore to substrate **224**, or may be a combination of the relationships as actually illustrated in FIG. 24. The substrates **222** and **224** may be mounted on the mounting plate **26** using the brackets **170** as illustrated. The microstrip transmission lines to be interconnected, for example strip line **226** on substrate **222** and strip line **228** on substrate **224**, extend to points immediately adjacent the bore **220**.

An insulating sleeve **230**, preferably made of quartz, is coated with a metallized film **231** around its mid portion, but is not coated adjacent the ends. The sleeve is then inserted in the bore **220**. A wire conductor **232** passes through the insulating sleeve **230** and the opposite ends are flattened at **232***a* and **232***b* until they are approximately the same width as the strip lines **226** and **228**. The flat portions of the conductor **232** are bent over the strip lines and spot welded using an electric gap welder as previously described.

Using a trial and error procedure, the characteristic impedance of the feed through connector can be adjusted by varying the length of the metallized film **231** on the insulating sleeve **230**, or the diameter of wire **232** adjusted, until any impedance discontinuity is reduced to an acceptable level for a given installation.

Although preferred embodiments of the invention have been described in detail, it is to be understood that various changes, substitutions and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.

What is claimed is:

1. In a microwave system, the combination of:
a plurality of electronic modules;
a dipole and antenna diagonally projecting from one end of each module; and
support means securing the modules in a plurality of spaced parallel module rows, the modules in each row being in adjacent relation such that each two adjacent rows of modules form two opposite side walls of a cooling fluid duct, and said antennae arrayed with said dipoles defining a plurality of spaced parallel antenna rows, said antenna rows being at an acute angle with respect to said module rows.

2. The combination defined in claim **1** wherein: the support means includes structure adjacent opopsite ends of the modules which forms the otehr two opposite side walls of the cooling fluid ducts.

3. The combination defined in claim **1** wherein:
each module has electrical connector means disposed at the end of the module opposite the antenna, and
the support means includes a mating electrical connector means for the electrical connector means on each of the modules.

4. The combination defined in claim **1** wherein each module comprises:
a body having walls forming the opposite edges and opposite ends of the module and a center plate extending between midpoints of at least two of the opposite walls to form a pair of oppositely facing open-topped chambers,
a lid covering each of the chambers and sealed around its periphery to the walls, the two lids forming the sides of the package, and
semiconductor circuits mounted on the center plate within each of the chambers.

5. The combination defined in claim **1** further characterized by header means for directing a cooling fluid through the cooling fluid ducts to cool the modules.

6. The combination defined in claim **5** wherein the header means directs the cooling fluid in the opposite direction through adjacent ducts whereby the cooling fluid will flow in opposite directions along the opopsite sides of the modules in each row.

7. In a modular electronic system, the combination of:
a plurality of electronic modules each having an electrical connector means at one end;

support means including a mating electrical connector means, for each module securing the modules in a plurality of spaced rows, the modules in each row being in adjacent relationship such that each two adjacent rows of modules form two opposite side walls of a cooling fluid duct, the support means including structure adjacent the opposite ends of the modules forming the other two opposite side walls of the cooling fluid ducts; and

means for directing cooling fluid in opposite directions through alternate cooling fluid ducts whereby the cooling fluid flowing on opposite sides of each row of modules will be flowing in opposite directions.

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