United States Patent

[11] **3,549,949**

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[54] **SOLID-STATE MODULAR MICROWAVE SYSTEM**
22 Claims, 25 Drawing Figs.

[52] **U.S. Cl.** **317/100,** 317/101; 165/80
[51] **Int. Cl.** **H05k 7/20**
[50] **Field of Search** .... 317/100, 101; 343/854, 100.6; 165/47.80 Electrical Digest

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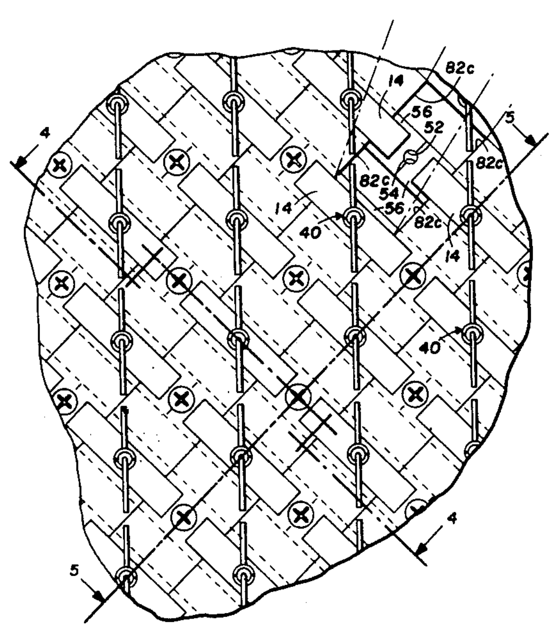
ABSTRACT: A solid-state, modular microwave transmitter-receiver assembly made up of a large number of transmit-receive modules each having an antenna. Each of the modules has functional electronic blocks mounted on both sides of a center mounting plate contained within a hermetically sealed package. 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.



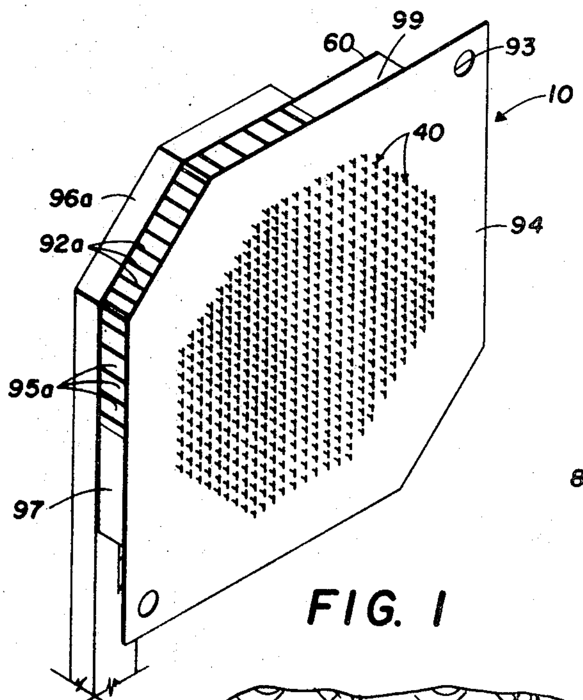


FIG. 1

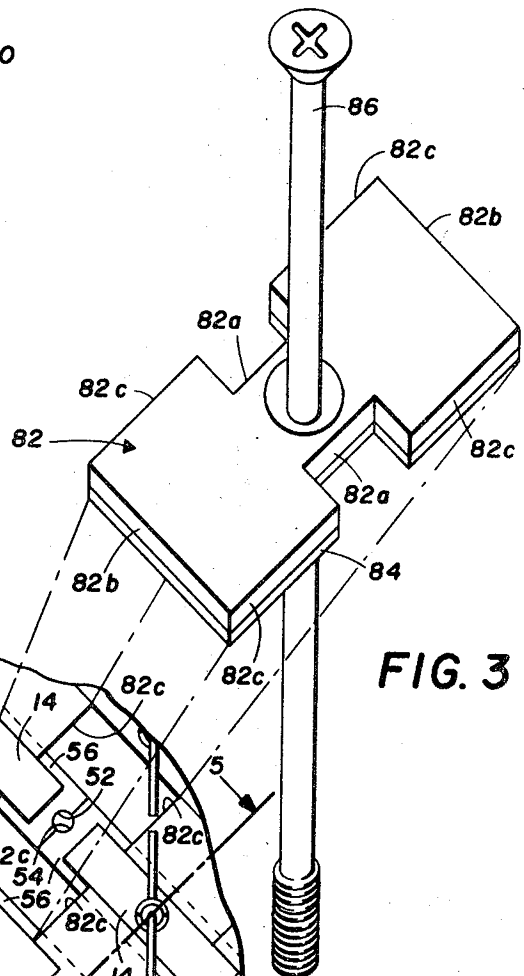


FIG. 3

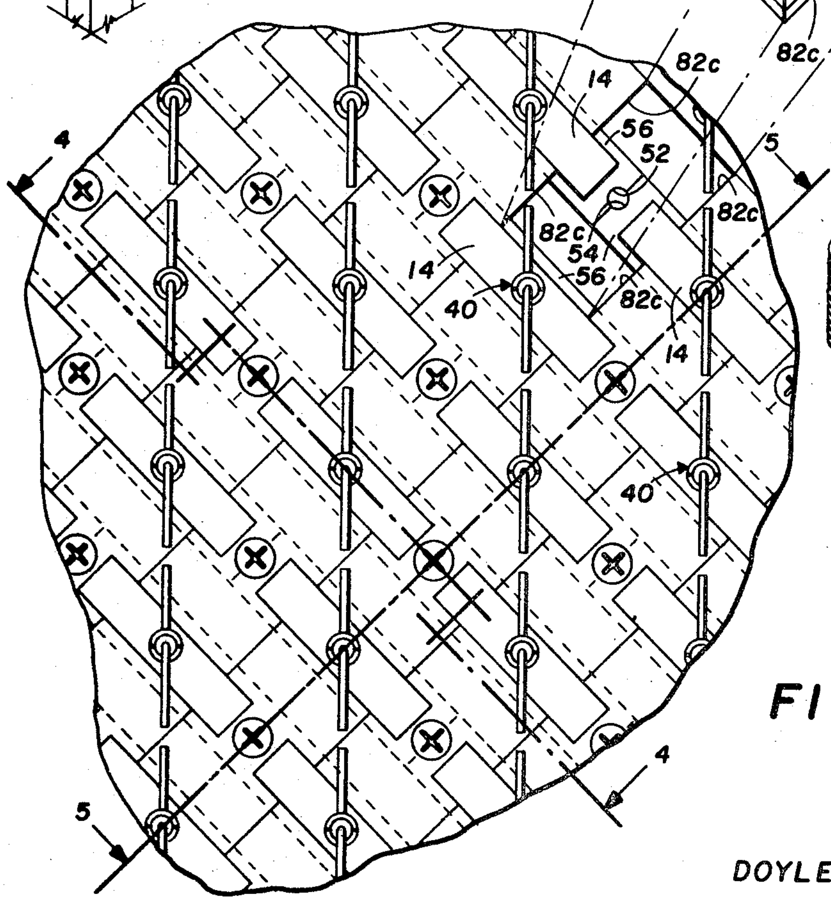


FIG. 2

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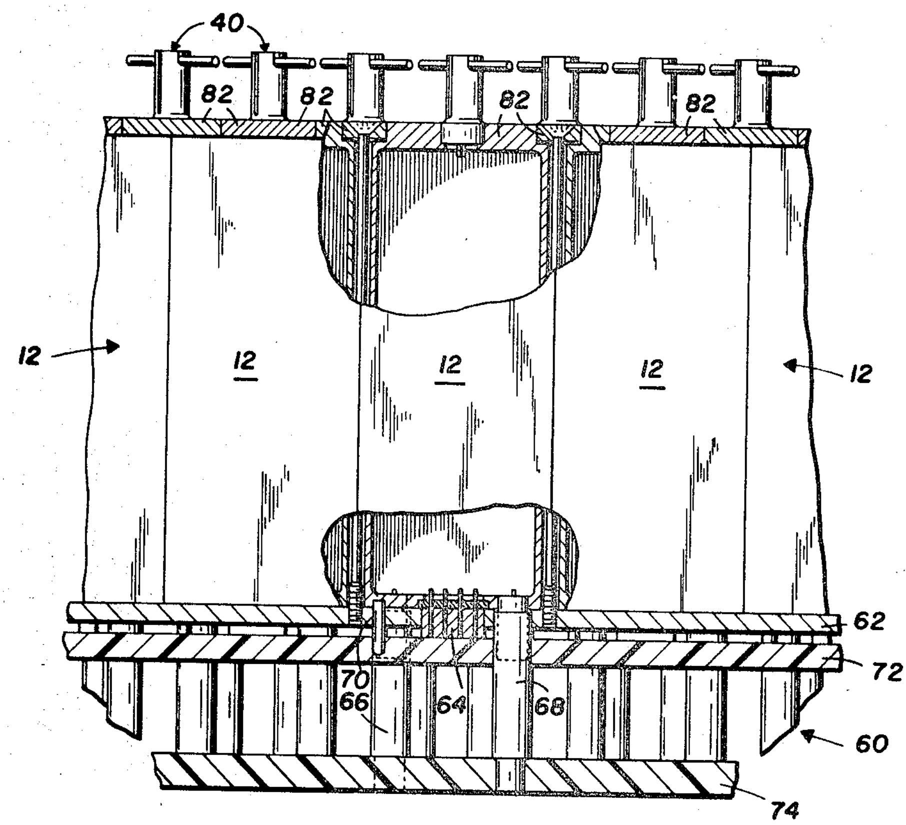

FIG. 4

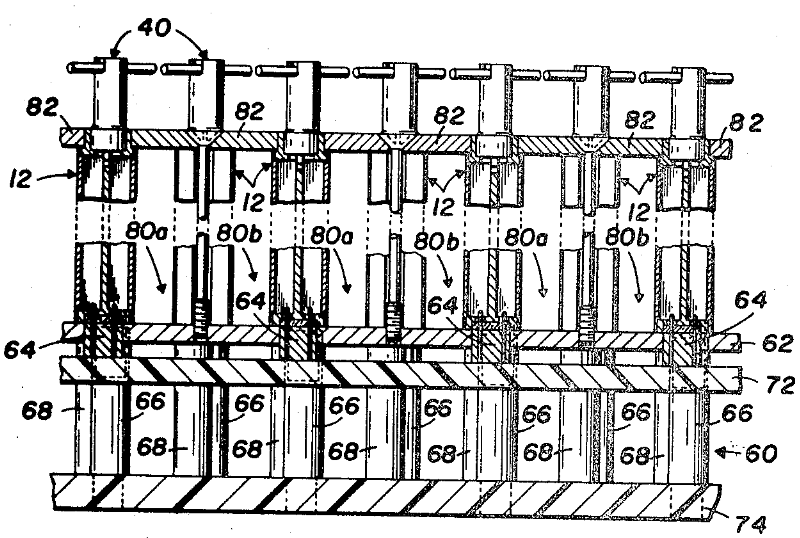

FIG. 5

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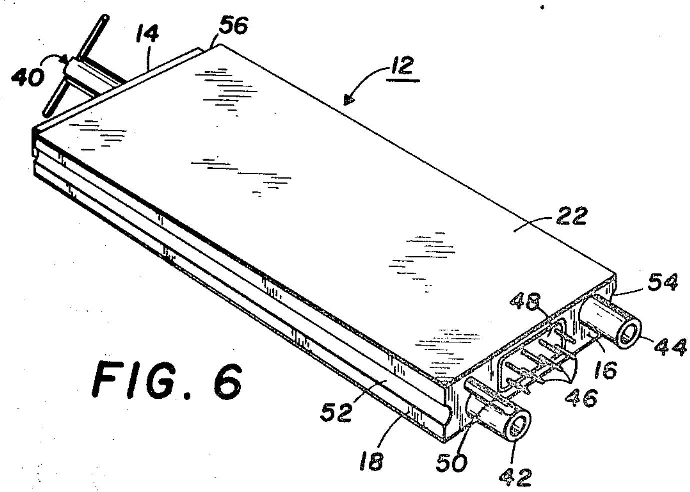

FIG. 6

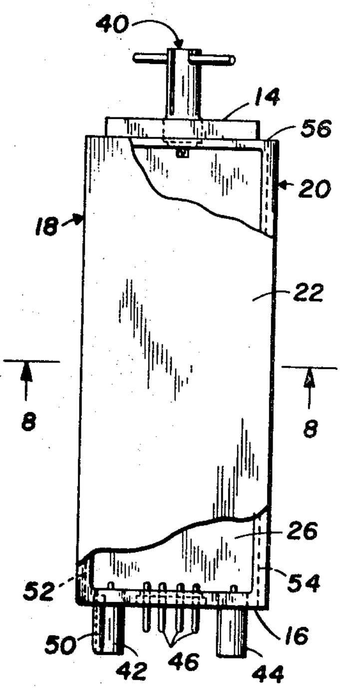

FIG. 7

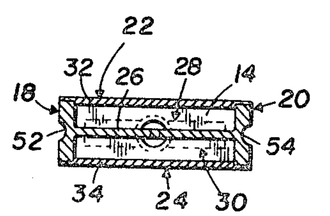

FIG. 8

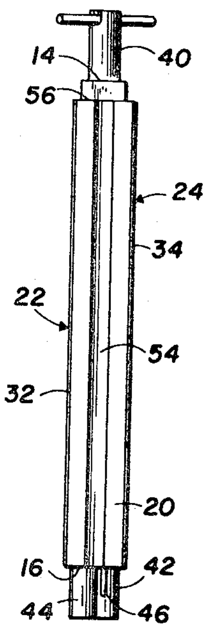

FIG. 9

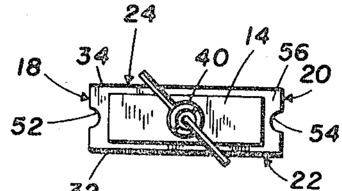

FIG. 10

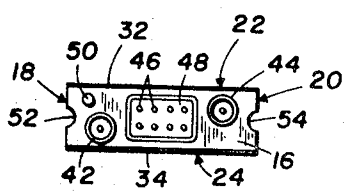

FIG. 11

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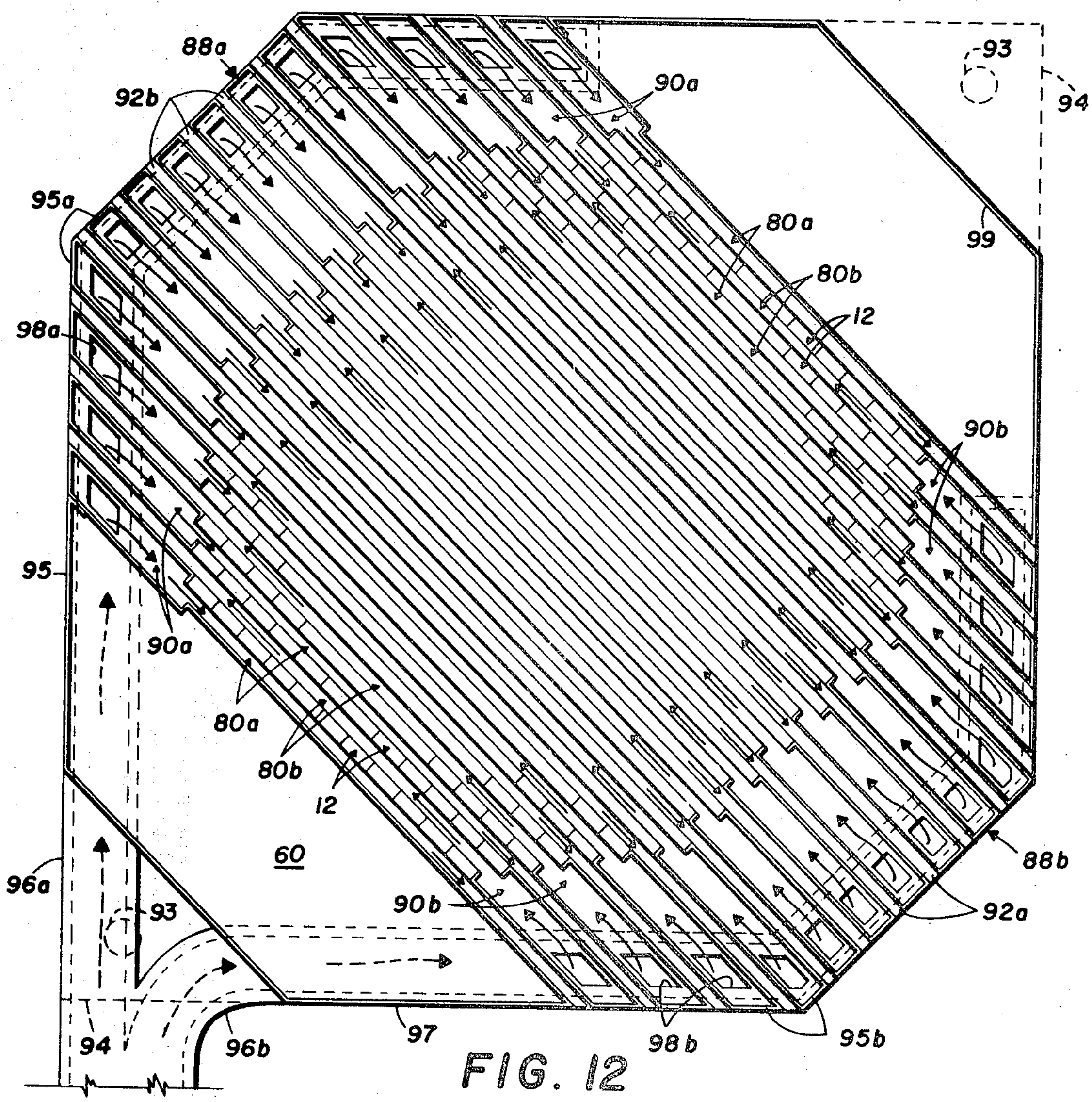

FIG. 12

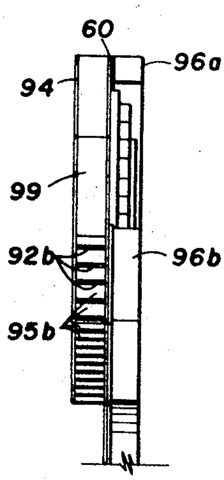

FIG. 13

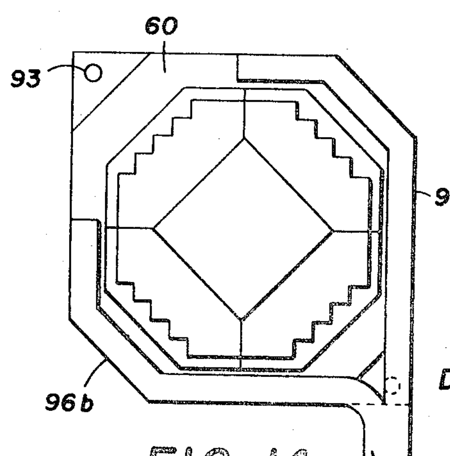

FIG. 14

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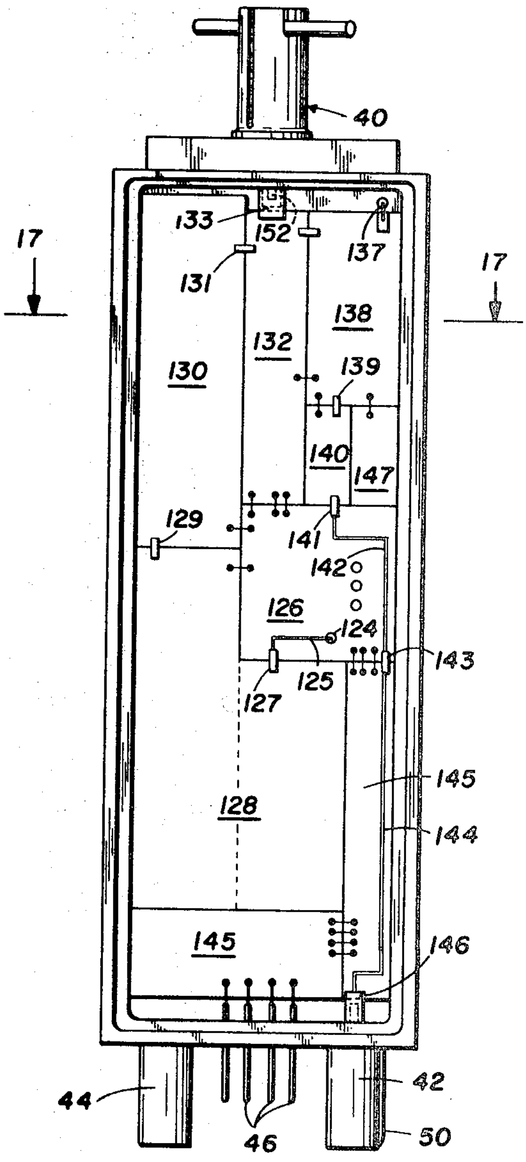

FIG. 16

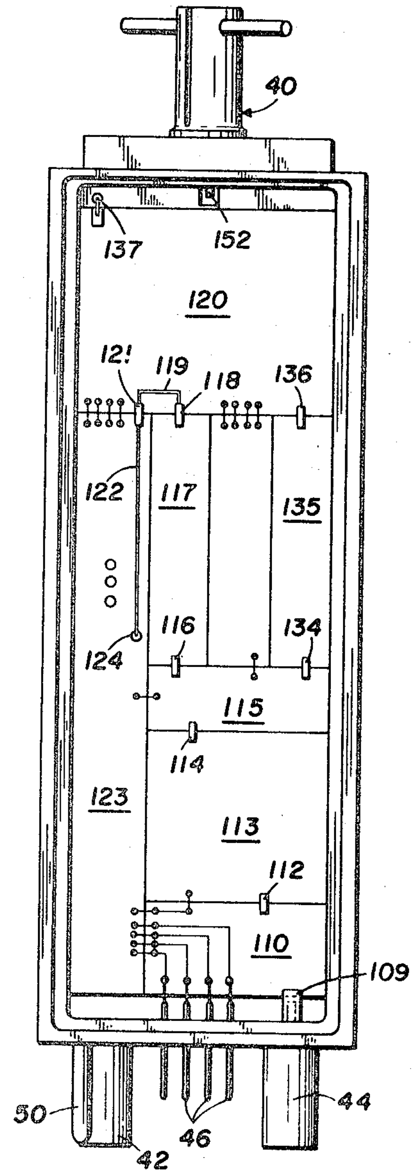

FIG. 15

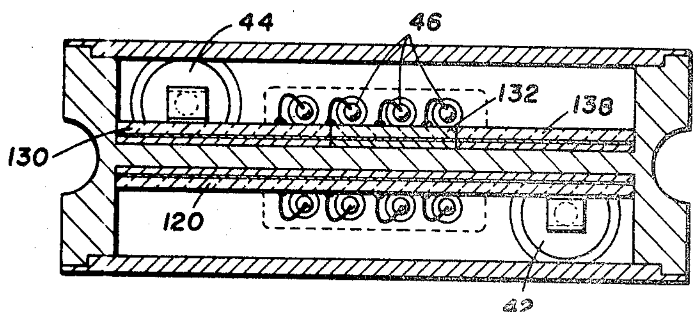

FIG. 17

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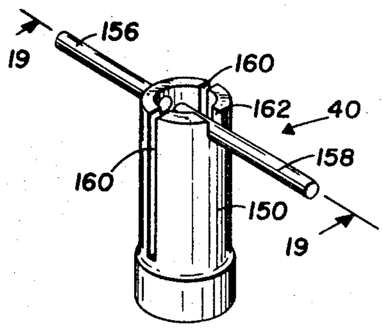


FIG. 18

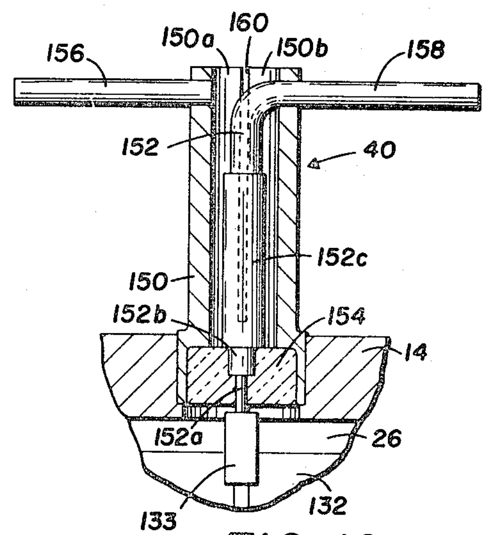


FIG. 19

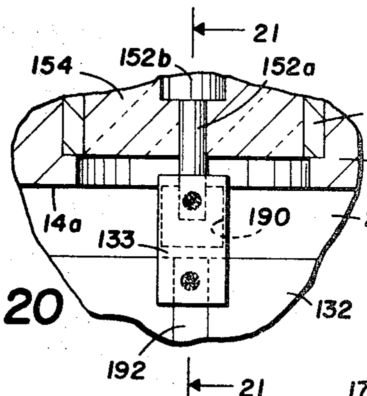


FIG. 20

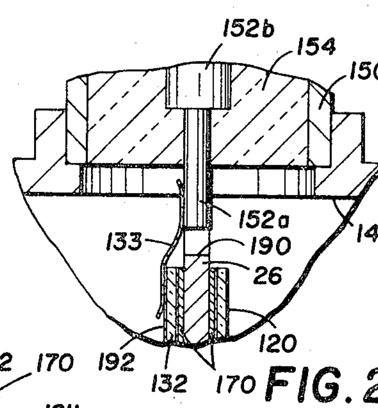


FIG. 21

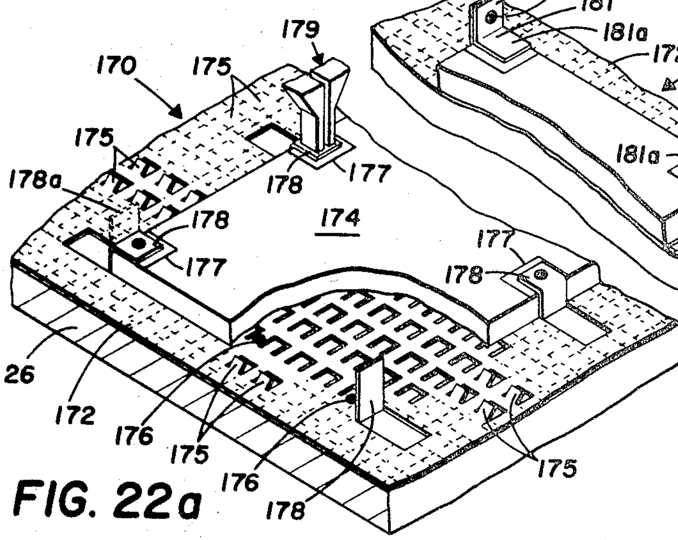


FIG. 22a

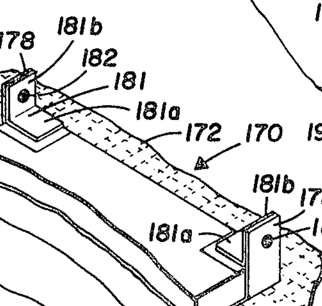


FIG. 22b

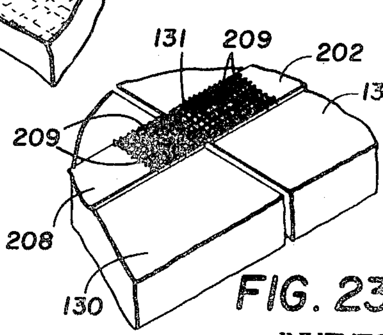
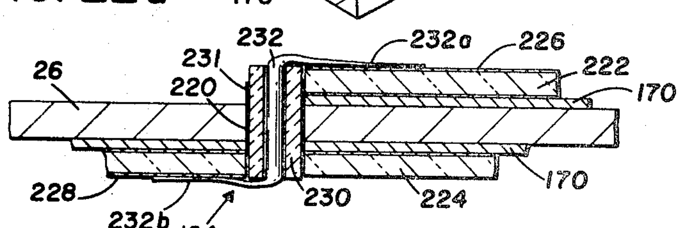


FIG. 23



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SOLID-STATE MODULAR MICROWAVE SYSTEM

This invention relates generally to microwave transmitting 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 unreliable because of the many mechanical parts, such as rotary joints, motors, synchros, gears and other servo components normally essential 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 frequencies 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 applications Ser. No. 397,519, filed Sept. 18, 1964, now U.S. Pat. No. 3,454,945, entitled "Modular Integrated Electronics Radar," filed on behalf of Tom M. Hyltin, Ser. No. 397,472, filed Sept. 18, 1964, now U.S. Pat. No. 3,345,631, entitled "Phased Array Radar Antenna Scan Control," filed on behalf of Leo A. Chamberlin, Jr., and Ser. No. 397,491, filed Sept. 18, 1964, now abandoned, 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 microwave transmitter and receiver. Each module includes the necessary circuitry for amplifying relatively low RF carrier energy applied simultaneously 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 received 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 1 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. Support means for securing the modules in position in the array also forms the ground plane for the antenna array, and also two opposite walls of the cooling fluid ducts, and achieves this without obstructions within the cooling fluid ducts.

The invention is further concerned with an antenna assembly which mechanically supports a dipole in the proper position, transfers the RF energy through the wall of the hermetically sealed module package, and provides the necessary impedance and balun transformation between the internal transmission line and the radiating elements.

The invention is also concerned with a means for mounting the functional electronic blocks on the mounting plate of the module package, interconnecting functional electronic blocks mounted on the same side of the mounting plate, interconnecting functional electronic blocks mounted on opposite sides of the mounting plate, and interconnecting the blocks and hermetically sealed conductors extending through the wall of the package.

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 DC male connectors **46** extend through a ceramic block **48** and provide DC 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 DC 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 DC 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 DC sockets **64** are mounted on a DC 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 submanifold **74** and extend through the DC wiring board **72** and partially through the support plate **62**.

When the modules **12** are plugged into the sockets 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 88a supplies cooling fluid, typically ambient air, under pressure to ducts 80a through inlet ports 90a, and exhausts cooling fluid from ducts 80b through exhaust ports 92a. Similarly, a header 88b supplies cooling fluid under pressure to ducts 80b through input ports 90b and exhausts the cooling fluid from ducts 80a through exhaust ports 92a. The ports 90a and 92a and 90b and 92b are formed by plates 95a and 95b 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 96a and 96b extend around the rear surface of the rear support plate 60. Manifold 96a communicates with inlet ports 90a through openings 98a in plate 60, and manifold 96b communicates with inlet ports 90b through openings 98b in plate 60.

Thus, it will be noted that cooling fluid passes through manifold 96a, openings 98a, input ports 90a, ducts 80a, and exhausts through ports 92a, and passes through manifold 96b, openings 98b, input ports 90b, ducts 80b, and exits through exhaust ports 92b. 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 88a and 88b 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 disc 154, and a pair of antenna elements 156 and 158. The ceramic disc 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 152a 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 50 ohm characteristic impedance. The center conductor has portions 152b and 152c of enlarged diameter for transforming the 50 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 150a and 150b 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 150a 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 50 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. Pat. application Ser. No. 606,427, filed Dec. 30, 1966, now abandoned 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 ship 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 DC 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 DC connections are made to the DC 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. 122A, 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 nickel 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 tonguelike spring members 175 are also cut from the plate 172 and bent upwardly at an angle of approximately 45° or slightly less. The spring members 175 are disposed generally uniformly over the entire base plate 172. The base plate 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 plat against the mounting plate 26 and are themselves 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 50 ohm characteristic impedance, to a microstrip transmission line, also having a 50 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 50 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 50 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 a 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 should 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.

I claim:

1. In a microwave system, the combination of:
- a plurality of RF modules, each module having opposite front and rear end walls;
- an antenna assembly extending from the front end wall of each module having an antenna spaced from the front end wall;
- electrical connector means disposed at the rear end wall;
- a rear support assembly having an electrical connector means mating with the connector means on each module, the modules being arranged in a plurality of spaced rows with the modules in each row disposed in adjacent relationship such that each two adjacent rows of modules form two opposite side walls of a cooling fluid duct with the rear support assembly forming the rear walls of the ducts; and
- a plurality of retaining plate means engaging the modules adjacent the front end wall and each connected to the rear support assembly for retaining the modules in place, the retaining plate means engaging to form the front walls of the cooling fluid ducts.

2. The combination defined in claim 1 wherein: the antennae of the modules are arrayed in a common plane and the front surfaces of the retaining plate means form at least a part of a ground plane for the antenna array.

3. The combination defined in claim 1 wherein: each retaining plate means is connected to the rear support assembly by means extending between adjacent modules in the same row of modules.

4. The combination defined in claim 3 wherein:
- each module has a forwardly facing shoulder formed at those edges of the front face that are disposed adjacent the two adjacent modules in the same row of modules;
- each retaining plate extends over and engages the forwardly facing shoulders on two adjacent modules; and
- each retaining plate is connected to the rear support plate by a screw passing through the retaining plate and between the modules and threaded into the rear support plate.

5. The combination defined in claim 4 wherein:
- the antennae are arrayed in rows and columns, and the rows of modules are disposed diagonally of the rows and columns of antennae;
- each module has a forwardly facing shoulder formed around the periphery of the front wall;
- each retaining plate extends over the adjacent shoulder of the adjacent modules in the two adjacent rows of modules;
- the retaining plates collectively form the front walls of the cooling fluid ducts; and
- the front surfaces of the retaining plates and the front surfaces of the front walls of the modules collectively form a continuous ground plane for the array of antennae.

6. The combination defined in claim 1 wherein each antenna assembly comprises:
- a tubular sleeve hermetically sealed in a bore extending through the front wall of the module, the sleeve extending approximately one-quarter wavelength from the front wall of the module and being split into generally semicircular halves for a length of approximately one quarter wavelength;
- an antenna element electrically and mechanically connected to the front end of each half of the split sleeve;
- a center conductor extending from a point within the module through the tubular sleeve and electrically connected to the front end of one of the halves of the split sleeve; and
- a dielectric body hermetically sealed around the center conductor and within the tubular sleeve.

7. The combination defined in claim 6 wherein the diameter of the center conductor is varied to provide an impedance transformer matching the impedance of the coaxial transmission lines formed by the center conductor and the portion of the tubular sleeve passing through the front wall with the impedance of the antenna when disposed in the array of antennae.

8. The combination defined in claim 1 wherein each module comprises:
- a hermetically sealed package having a mounting plate therein;
- at least one functional circuit block comprised of solid-state circuit means formed on a substrate; and
- means mounting the circuit block on the mounting plate comprising a thin metallic sheet having a planar base portion disposed between the circuit block and the mounting plate and a plurality of strap portions each disposed adjacent an edge of the circuit block and extending away from the base portion to a point beyond the circuit block, and a gusset connected to each strap at a point beyond the circuit block and extending over and engaging the surface of the circuit block to secure the circuit block in place on the mounting plate.

9. The combination defined in claim 8 wherein: each gusset is formed from a strip of metal sheet material bent to form first and second plate portions disposed at a right angle, the first plate portion engaging the upper surface of the circuit block and the second plate portion being welded to the respective strap at a point above the top surface of the circuit block.

10. The combination defined in claim 8 wherein the base portion is further characterized by: a plurality of spring means spaced generally uniformly over the base portion for springingly engaging the undersurface of the circuit block to insure good heat transfer between the circuit block and the mounting plate.

11. The combination defined in claim 1 wherein each module comprises:
- a hermetically sealed package having a mounting plate therein;
- at least one functional circuit block comprised of solid-state circuit means formed on a substrate; and
- means mounting the circuit block on the mounting plate comprising a thin metallic sheet having a planar base portion disposed between the circuit block and the mounting plate and a plurality of strap portions each extending from the base portion past an edge of the circuit block and over the circuit block to retain the circuit block in place on the mounting plate.

12. The combination defined in claim 11 wherein: each of the straps is bonded to the top surface of the circuit block.

13. The combination defined in claim 11 wherein: each of the straps extends over a metallized pad on the surface of the circuit block and is welded to the pad.

14. The combination defined in claim 11 wherein the base portion is further characterized by: a plurality of spring means spaced generally uniformly over the base portion for springingly engaging the undersurface of the circuit block to insure good heat transfer between the circuit block and the mounting plate.

15. The combination defined in claim 1 wherein:

each module comprises a hermetically sealed package having a mounting plate therein;

at least two circuit blocks mounted on the mounting plate, each circuit block being comprised of a circuit formed on a substrate at least partially comprised of microstrip transmission lines formed by a metallized ground plane on the bottom surface of the substrate and a metal strip conductor of predetermined width on the top surface, the two substrates being mounted with the edges of the substrates in adjacent relationship and with the microstrip transmission lines extending to adjacent points at the adjacent edges of the substrates; and

a metal strap interconnecting the adjacent ends of the microstrip transmission lines, the width of the metal strap being selected to maintain substantially the same characteristic impedance as that of the microstrip transmission lines.

16. The combination defined in claim 15 wherein: the metal strap is a length of woven wire fabric at least as wide as the microstrip transmission lines which overlaps each of the microstrip transmission lines and is bonded to each by at least one weld.

17. The combination defined in claim 15 wherein the metal strip is a length of solid metal ribbon having a width substantially greater than its thickness, and the ends of metal ribbon overlie the ends of the microstrip transmission lines and are bonded to each by at least one spot weld.

18. The combination defined in claim 6 wherein:

each module comprises a hermetically sealed package having a mounting plate therein;

a TR circuit block mounted on the plate and disposed adjacent the end of the center conductor of the antenna assembly, the TR circuit having a microstrip transmission line formed by a metallized ground plane on the bottom side of the substrate and a strip conductor on the top side of the substrate, the microstrip transmission line extending to the edge of the substrate adjacent said center conductor; and

a metal strap interconnecting the center conductor and the microstrip transmission line, the metal strap having a width selected to maintain substantially the same characteristic impedance as that of the microstrip transmission line and the coaxial conductor formed by the center conductor and the tubular sleeve of the antenna assembly.

19. The combination defined in claim 18 wherein: the metal strap is at least as wide as the microstrip transmission line.

20. The combination defined in claim 1 wherein each module comprises:

a package having a mounting plate extending between midpoints of the front and rear walls;

a circuit block mounted on each of the opposite faces of the mounting plate;

a bore extending through the mounting plate and disposed adjacent an edge of each circuit block;

a tubular insulating sleeve disposed in the bore;

a metallic film coating the outer surface of the tubular insulating sleeve, the metallic film terminating before reaching the surface of the respective circuit block that is remote from the mounting plate;

a microstrip transmission line formed on each of the circuit blocks and terminating adjacent the bore; and

a cylindrical conductor extending through the insulating sleeve and having flattened ends bonded to the microstrip transmission lines on the circuit blocks;

the length of the metallized film on the tubular sleeve, the external diameter of the tubular sleeve, and the diameter of the conductor being selected to substantially match the characteristic impedance of one of the microstrip transmission lines to the characteristic impedance of the other microstrip transmission line.

21. In a modular electronic system, the combination of:

a plurality of modules each having opposite front and rear walls;

electrical connector means disposed at the rear end wall;

a rear support assembly having an electrical connector means mating with the connector means on each module, the modules being arranged in abutting relationship in a plurality of spaced rows such that each two adjacent rows of modules form two opposite side walls of a cooling fluid duct with the rear support assembly forming the rear walls of the ducts; and

a plurality of retaining plate means engaging the modules adjacent the front end wall and each connected to the rear support assembly for retaining the modules in place, the retaining plates engaging to form the front walls of the cooling fluid ducts.

22. The combination defined in claim 21 wherein: each retaining plate means is connected to the rear support assembly by means extending between two modules in the same row of modules.