NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

NASA Pasadena Office

APR 28 1971

REPLY TO ATTN OF: GP

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No.	: 3,486,123
Government or Corporate Employee	: Calif. Inst. of Tech. Pasadena, Calif. 91109
Supplementary Corporate Source (if applicable)	: JPL
NASA Patent Case No.	: NPO-10548

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☑ No ☐

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . ."

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Dorothy J. Jackson

Enclosure
Copy of Patent cited above

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Dec. 23, 1969 T. O. PAINE 3,486,123
ACTING ADMINISTRATOR OF THE NATIONAL
AERONAUTICS AND SPACE ADMINISTRATION
HIGH-GAIN, BROADBAND TRAVELING WAVE MASER
Filed Nov. 12, 1968 2 Sheets-Sheet 1

FIG. 1

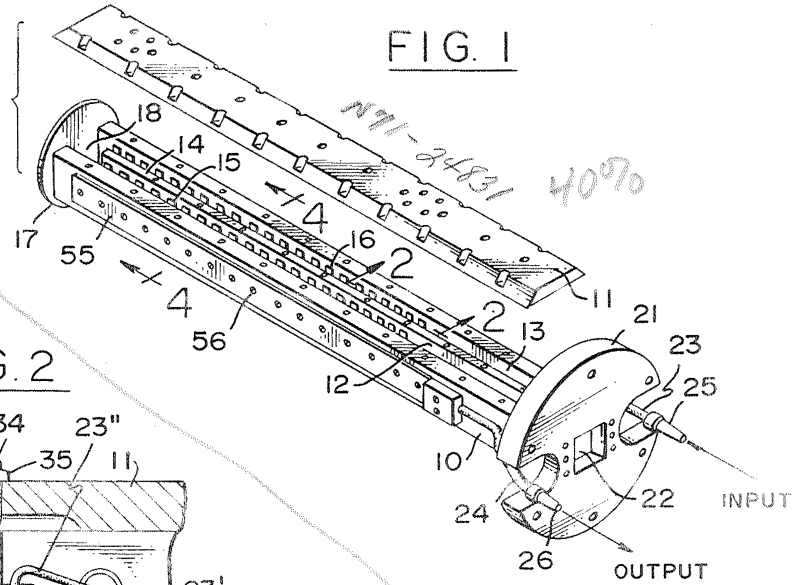


FIG. 2

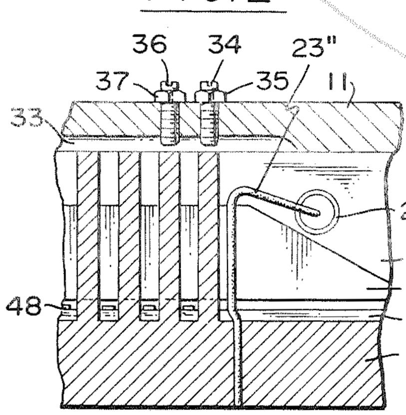
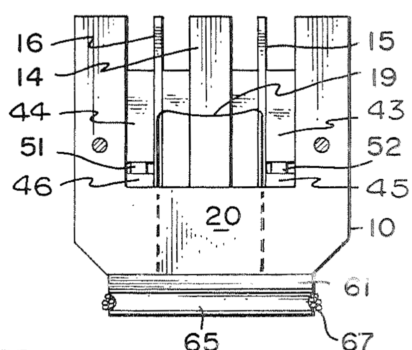


FIG. 3



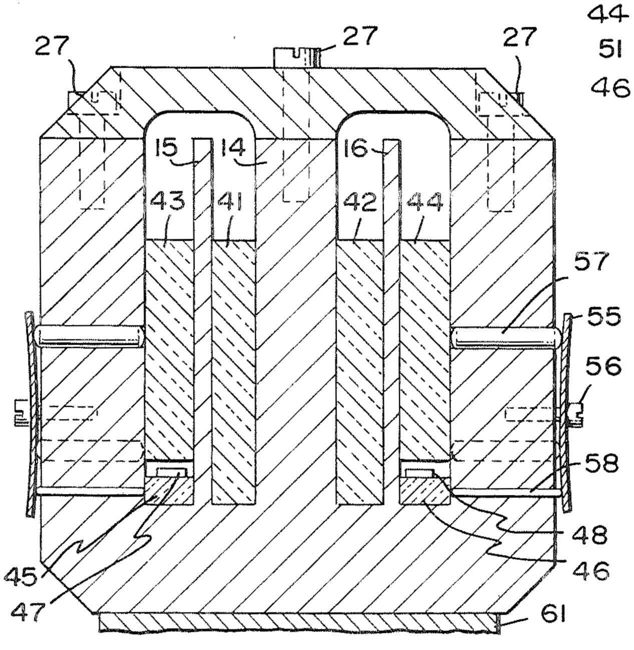


FIG. 4

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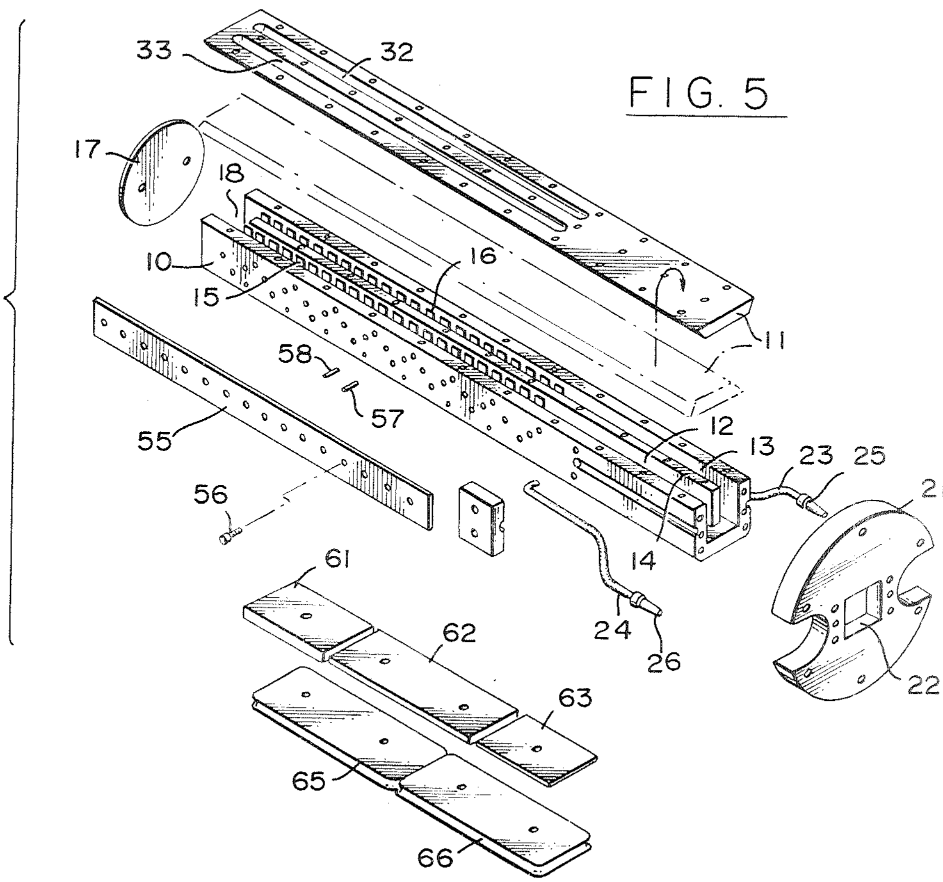
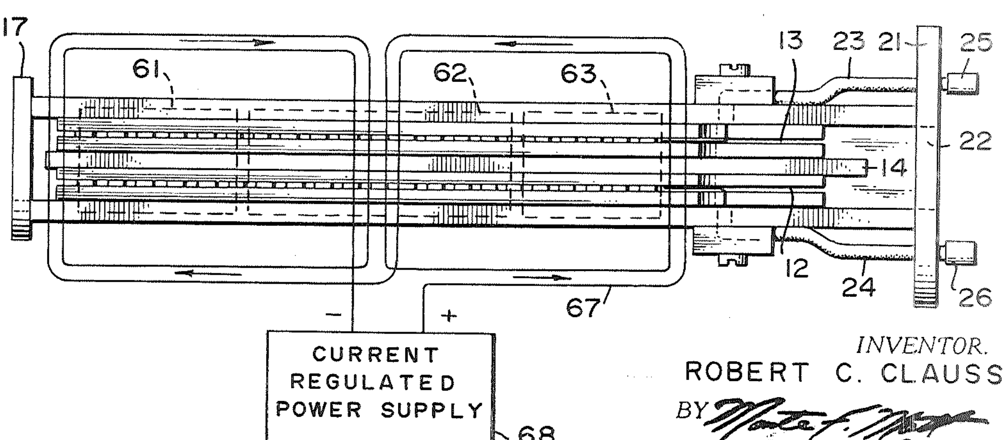


FIG. 5

FIG. 6



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United States Patent Office

3,486,123
Patented Dec. 23, 1969

3,486,123

HIGH-GAIN, BROADBAND TRAVELING WAVE MASER

T. O. Paine, Acting Administrator of the National Aeronautics and Space Administration, with respect to an invention of Robert C. Clauss, La Crescenta, Calif.

Filed Nov. 12, 1968, Ser. No. 775,072

Int. Cl. H01s *1/00*

U.S. Cl. 330—4 **29 Claims**

ABSTRACT OF THE DISCLOSURE

A high-gain, broadband traveling-wave maser of the folded-comb type is provided by a structure which increases gain, and structure which stagger tunes sections thereof with some sacrifice of gain in order to improve the bandwidth by a factor of about two. Gain is improved by: a unitary or integral comb and wave-guide structure; adjustable signal coupling loops; use of single crystal yttrium iron garnet isolators supported by active material of the same type and quality as the maser material; use of zero-degree Czochralski ruby as the active material; improved means for clamping active material in the comb and waveguide structure; and a comb shape design which optimizes the phase filling factor. Stagger tuning of sections of the folded traveling-wave maser is achieved by iron shims and conductive coils to selectively modify the external magnetic field for the desired band width.

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 USC 2457)

BACKGROUND OF THE INVENTION

This invention relates to a maser amplifier of the comb type, and more particularly to structure which provides an improved gain-bandwidth product and noise-temperature characteristic.

The three-level solid state traveling-wave maser (TWM), first described by R. W. De Grasse, et al., in The Bell System Technical Journal, vol. 38, (March 1959) at pages 305 to 334, is now well known and widely used. For greater amplification, a folded-comb structure of the type described in U.S. Patent 3,299,364 has been developed. However, an S-band traveling-wave maser of that construction has been found to provide a net gain of 26 db with a bandwidth of only 18 mHz. and a noise temperature of 12° K.

Extended space communications requirements call for a TWM with a low equivalent input noise-temperature characteristic and a high gain-bandwidth product. Large antennas have provided noise temperatures of less than 10°K. at S-band, for example. Accordingly, the TWM should have a very low noise temperature, preferably below 6° K. within the desired frequency range. It should also have a high gain-bandwidth product. Current requirements are for about 45 db net gain and a 1 db bandwidth extending from 2270 to 2300 mHz.

SUMMARY OF THE INVENTION

The preferred embodiment of the invention disclosed herein comprises a pair of parallel waveguide sections having a common wall, each with a unitary comb extending from a base and lying in a plane parallel to the com-

mon wall. Active material is placed on each side of the comb in both waveguides and pressed against the comb and the common wall by spring force. The channel between the comb and the common wall is filled with a slab of active material to approximately ⅔ the height of the comb such that the active material is in contact with the base from which the comb extends. The other channel of each waveguide section is similarly filled with a narrow slab of active material to support properly spaced isolators. The balance of the other channel is filled to approximately the same height as the one channel with a slab of active material. The two waveguide sections enter a short waveguide extension common to both. This short extension is covered at its remote end by a plate to close the assembly at the fold thereof. The two waveguide sections are coupled by an internal loop of conductive wire which passes through the waveguide extension. The other ends of the two waveguide sections are extended significantly beyond the first fingers of the combs to provide isolated input and output signal channels. Those two channels enter a common short waveguide extension which ends in a flange having a port for the mocrowave pump power. The flange is adapted to be securely fastened in close contact with a cryogenically cooled supporting plate.

The design of the comb fingers has been optimized to improve gain per unit length across a wide tuning range in a manner suggested by F. F. Chen and W. J. Taber, in the Bell System Technical Journal, vol. 43, (May 1964) at pages 1005 to 1033.

In accordance with a further feature of the present invention, the slabs of active material are cut from a zero-degree Czochralski ruby boule with their lengths along the C-axis of the boule.

In addition to the foregoing, the present invention provides as a further feature improved signal power coupling between input and output coaxial signal transmission lines and the comb-type slow wave structure, and between sections of the folded-comb structure. Each coupling consists of a loop of conductive wire grounded at the base of the comb just off the end thereof. In each instance, a substantial portion of the coupling loop lies in the plane of the adjacent comb. Adjustments for matched coupling between the input and output coaxial signals are made by simply bending the loops to vary the distance from the adjacent combs.

The bandwidth of the TWM is selected in accordance with still another feature of the invention by so modifying the DC magnetic field in various sections of the combs with shims of magnetic material and coils as to provide stagger tuning. DC current is adjusted in the coils to modify the DC magnetic field in various sections of the combs for fine adjustments in the stagger tuning arrangement. In that manner, some of the high gain provided by the foregoing features is traded for additional bandwidth. The resulting reduction in net gain causes an increase in noise temperature across the bandwidth, but not beyond the desired maximum noise temperature.

The various novel features embodied in the invention disclosed herein may also be used to advantage in a single waveguide section extended to the length required for the amplification desired, but two shorter sections in a folded arrangement is preferred. Accordingly, although a preferred embodiment is disclosed, the novel features considered characteristic of this invention are set forth with particularity in the appended claims. The invention will best be understood from the following description of the preferred embodiment with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is an isometric view of a TWM constructed in accordance with the present invention, but with its cover raised.

FIGURE 2 is a longitudinal section taken essentially on the line 2—2 of FIGURE 1.

FIGURE 3 is an end view of the TWM of FIGURE 1 with the end plate removed.

FIGURE 4 is a cross sectional view of the TWM of FIGURE 1 on the line 4—4 thereof.

FIGURE 5 is an exploded view of the TWM of FIGURE 1.

FIGURE 6 is a schematic plan view of the TWM of FIGURE 1 illustrating the manner in which stagger tuning is achieved by shims of magnetic material and a figure-8 coil.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In a preferred embodiment of the invention, a folded TWM is provided as shown in FIGURE 1. It includes a main body **10** and a cover **11** made of highly conductive non-magnetic material, preferably copper. The body **10** is machined to provide two longtudinal wave-guide sections **12** and **13** having a common or dividing wall **14**. The body **10** is also machined to provide unitary combs **15** and **16**, as will be described more fully with reference to FIGURES 2 and 4.

An end plate **17** provides a waveguide short to close the waveguide sections **12** and **13**. It should be noted that the dividing wall **14** and combs **15** and **16** do not extend to the end plate **17** in order to provide a short waveguide extension **18** common to both sections **15** and **16**. A loop **19** of electrically conductive, non-magnetic wire is provided in that extension **18** to couple one comb to the other around the dividing wall **14** as shown in FIGURE 3. Each end of the loop **19** is grounded in the base **20** of the main body **10** as represented by the dotted line extensions of the loop **19**.

A front flange **21** closes the waveguide sections **12** and **13** at the opposite end of the main body **10** from the end plate **17**. The front flange **21** is adapted to be connected to a pump power source (not shown) operating at a desired frequency so that energy passes through a port **22** into the waveguide sections **12** and **13** having the slow-wave structure comprising combs **15** and **16** end-coupled thereto. The microwave pump power is supplied to the port **22** in the flange by a waveguide which extends through a refrigeration system to a microwave power source at room temperature. The same flange **21** provides a sufficiently large mounting surface, for contact with a cryogenically cooled "cold plate." Cryogenic cooling is accomplished by conduction and the TWM is operated in a high vacuum which provides insulation from the room temperature environment around the cryogenic refrigerator.

The dividing wall **14** extends toward, but not to the flange **21**, as may be seen in FIGURE 6, in order that pump power passing through the port **22** will enter both waveguide sections **12** and **13**.

The combs **15** and **16** extend toward the flange **21** along the length of the dividing wall **14** to points in the waveguide sections **12** and **13** close to where input and output coaxial cables **23** and **24** are connected. Standard coaxial connectors **25** and **26** are provided on the cables **23** and **24** for connection to a signal-source and signal-detection apparatus (not shown). The external conductor of each cable, such as conductor **23'** of the cable **23** shown in FIGURE 2, is connected to the outside wall of a waveguide section. The internal conductor is then grounded by connection to the base of the unitary waveguide structure near the first resonant element (finger of the comb), as shown in FIGURE 2 for internal conductor **23''**. The space between the internal and external cable conductors is filled with a suitable dielectric material. Thus, coupling of the input and output cables to the slow-wave structure (combs **15** and **16**) is accomplished by using loops adjacent thereto in the same manner that loop **19** couples one slow-wave structure (comb **15**) to the other (comb **16**).

Signal coupling adjustments are readily made for maximum power transfer by bending the coupling loops, thereby changing the distances to the adjacent resonant elements of the slow-wave structures. For instance, to adjust the input signal coupling, the conductor **23''** is bent to the desired position with a substantial portion thereof in the plane of the slow-wave structure shown in longitudinal section in FIGURE 2. The loop **19** is similarly bent to a desired position with substantial portions in the planes of the slow-wave structures as shown in the end view of FIGURE 3. The opposite ends of the loop **19** are grounded to the base **20** of the main body **10** in the same manner as shown for the conductor **23''** in FIGURE 2, which is by soldering into bores in the base **20**. The loop **19** and the conductors of the coaxial cables **23** and **24** are made of highly conductive non-magnetic material, preferably copper.

In accordance with another even more important feature of the present invention, the resonant elements (fingers of combs **15** and **16**) are machined from the same bar of material as the main body **10** to provide a unitary or integral structure as shown in the crosssectional views of FIGURES 2 and 4. In that manner, joints are eliminated in the critical areas where the resonant elements (fingers) of the slow-wave structure meet the base **20** of the main body **10**. This improves the gain of the TWM because joints in the critical areas would result in loss of microwave energy due to possible leakage and power losses in such joints.

The unitary structure of the main body **10** and combs **15** and **16** is formed by first milling a bar of the proper length and then shapiting it with precision to a form having a uniform cross-section as shown in FIGURE 4 along its entire length. The fingers of the comb are then formed with precision by electric discharge machining to the form shown in the longitudinal section of FIGURE 2. In addition, the wall **14** is shortened at each end for reasons which will become more apparent.

The cover **11** is machined from a separate bar of the same material as the main body **10** and secured in place by screws **27** along the outside walls of the main body **10** and the dividing wall **14**. The cover **11** need not be secured to the main body with any better connection than is provided by the pressure of the screws **27** since virtually all of the microwave energy is being propagated by the resonators (fingers of combs **15** and **16**). Although the RF electric (E) field is maximum at the ends of the fingers, the RF magnetic (H) field is at a minimum and no current flows through the cover **11**.

It should be noted that suitable longitudinal slots **32** and **33** (FIGURE 5) are machined along the inside of the cover **11** to assure that the resonators are not grounded at their upper free ends where the maximum E field exists. Instead of machining the slots **32** and **33** in the cover **11**, the fingers of the combs **15** and **16** could be machined shorter, but it is preferred to have the fingers of the same height as the side walls of the waveguide sections **12** and **13**, and the dividing wall **14**, for ease of manufacture.

The capacitance (gap) between the cover **11** and the end of at least one finger at each end of the comb is adjusted for maximum power transfer into and out of the comb structure. For example, the gap between the cover **11** and the first finger of the comb **16** is adjusted by a screw **34** and a lock nut **35**. The second finger is similarly tuned by screw **36** and lock nut **35**. The last and penultimate fingers of the comb **16** are also tuned in the same manner.

The center frequency of the TWM can be shifted by adjusting the height of active maser material in the waveguide sections **12** and **13** on each side of the combs **15** and **16**. At 2300 mc., a height of 0.475 in. for the maser material is used with a finger length of 0.720 in. The center frequency shifts at a rate of 4 mc. per 0.001 in. of change in maser material height. The maser material should always rest on the base **20** of the comb structure, as shown in FIGURE 4, where the maximum H field exists.

In accordance with an important feature of the present invention, gain of the TWM is greatly improved by use of 0-degree ruby grown by the Czochralski process as the active material. Ruby crystal slabs are cut to fit slots beside the combs with close tolerances and with their C axis along their length. Gain is improved because the ruby slabs cut from the Czochralski grown boule are substantially free of flaws which would degrade the effective filling factor (F) and gain is determined by the following equation:

$$Gdb=27.3\ SNF/Qm$$

Where N is the active length of the TWM in free space wavelengths, Qm is the magnetic Q of the material, and S is the slowing factor computed as the ratio of light velocity to group velocity.

Ruby slabs of the desired width and thickness are placed between the dividing wall **14** and the combs **15** and **16**, as shown by slabs **41** and **42**. The slabs **41** and **42** are of sufficient length to extend beyond each end of the combs **15** and **16**. Similar slabs **43** and **44** are then provided on the other side of the combs **15** and **16**, but of lesser width in order to provide room below for isolator strips **45** and **46**.

The manner in which maser material is utilied to support isolators will now be described with reference to FIGURES 3 and 4. The isolator strips **45** and **46** are preferably also ruby slabs cut from a 0-degree Czochralski boule in order that the waveguides **12** and **13** be filled as much as possible with active material around the base of the combs **15** and **16** to improve the gain of the TWM. The isolators supported by the strips **45** and **46**, such as isolators **47** and **48**, are single-crystal YIG. A comparison of the single-crystal YIG and a polycrystalline YIG shows an improved figure of merit (ratio of reverse loss to forward loss). This also contributes to the greatly improved gain of the present invention. This is because a TWM configuration which obtains highest gain has been found to degrade isolator performance in such a way as to result in high forward loss with polycrystalline YIG. The high forward loss is reduced by the improved figure of merit for single-crystal YIG. Accordingly, the single-crystal YIG allows the use of a TWM configuration that yields higher gain than could be obtained with designs using polycrystalline YIG.

The shape of the comb fingers which yields highest gain forces the major component of the RF magnetic field to lie in a direction parallel to the C axis of the ruby maser material. Accordingly, the shape of the fingers is selected to be one having a rectangle cross-section with the longer dimension parallel to that C axis which extends parallel to the line of comb fingers. The final dimensions to be used are determined empirically. For example, for S-band amplification, optimum gain was achieved with combs having 40 fingers, each finger 0.080 in. wide and 0.030 in. thick, with a space between fingers of 0.070 in. For operation at 2300 mc., the finger length selected was 0.720 with a slab height of 0.475, as noted hereinbefore.

The resonant frequency of the isolator material is determined by the shape of the YIG and the applied magnetic field. For maser operation, the magnetic field required is determined by the active material employed. The YIG isolator shape is then adjusted for resonance at the proper frequency, normally by lapping the thickness of a YIG disc. In a preferred embodiment successfully tested, the isolator disc was selected to have a diameter of 0.045 in. The thickness was then adjusted for isolation over a frequency range of 2220 to 2350 mHz.

It is to be understood that an isolator disc is positioned opposite each space between fingers of a comb, although in practice one isolator is omitted at about the center of the comb structure and a thicker disc of passive material, such as alumina, substituted to space the crystal slab slightly above it (to avoid damaging the isolator discs when the slabs **43** and **44** are installed). Thus, with sufficiently long crystals **43** and **44** to extend the full length of the combs **15** and **16**, only three alumina spacers are required in each waveguide section, one at the center and one at each end, such as spacers **51** and **52** seen at the end shown in FIGURE 3.

The precision-fit slabs **41** to **46** are clamped by an improved spring assembly comprising a beryllium copper strips **55** on each side of the main body **10** secured thereto by a plurality of screws (such as screw **56**) evenly spaced along a straight line, as shown in FIGURE 1. Offset from each screw, and alternately above and below the line of screws, brass pins are inserted in bores through the side walls of the main body **10**, such as the pin **57** shown in the cross-sectional view of FIGURE 4. Each such pin is longer than the side wall is thick. When the screws **56** are tightened, each strip **55** functions as a plurality of leaf springs exerting force against pins to clamp the slabs **43** and **44** against the combs and toward the dividing wall **14**. Thus, pressure is transferred through the combs **15** and **16** to slabs **41** and **42** which in turn are pressed against the center wall **14**. Similar pins, but of smaller diameter, are inserted into bores through the side walls of the main body **10**, such as a pin **58**, through which the strips **55** clamp the isolator slabs **45** and **46** against the base of the combs **15** and **16**. In that manner all slabs of active material **41** to **46** are so clamped as to provide maximum area contact with the combs **15** and **16** and with the dividing wall **15** for maximum heat transfer through the main body **10** to the flange **21**.

An S-band TWM of the folded-comb type was successfully constructed with base features, and tested. It was found to have such significantly improved gain that, upon stagger tuning for a bandwidth of 46 MHz, it still had a net gain of 46 db with a noise temperature of about 6° K. That compared to a net gain of about 35 db for an S-band TWM of the best previously available which had a bandwidth of 18 mHz. and a noise temperature of about 12° K. The assembly of the component parts of such a greatly improved TWM may be better understood from the exploded view of FIGURE 5. In that view, the DC magnetic field (H_{DC}) is indicated schematically as being parallel to the fingers of the combs **15** and **16**. This field of about 2500 gauss is supplied by a 150 pound alnico magnet (not shown).

To provide efficient stagger tuning (one which trades excess gain for additional bandwidth efficiently), shims of magnetic material are employed along the length of the folded-comb TWM of any length required to achieve the bandwidth desired, such as a shim **61**, **62** and **63** shown in FIGURE 5. They are secured to the bottom of the TWM by suitable non-magnetic screws. In addition to the shims, which alter the permanent magnetic field (H_{DC}), conductive wire is so wound around forms **65** and **66** as to form a FIGURE 8, or two coils with oppositely wound turns. DC current is then adjusted to further provide magnetic field staggering for broad bandwidth tuning of sections of the TWM. This technique provides a more efficient gain versus bandwidth trade-off than the use of a single coil as in the prior art.

It should be noted that the forms **65** and **66** are made of non-magnetic material as are all other elements (pins, screws, etc.). Only the shims are of magnetic material. Since they are purposely made of different thicknesses, and it is desirable to provide an even surface for the coil forms **65** and **66**, non-magnetic shims (not shown) may be used to even the surface presented to the forms **65** and **66**.

FIGURE 6 shows in a plan view how the magnetic field (H_{DC}) is modified to provide four sections of amplification that operate alternately at four different frequencies F_1 through F_4. The shims **61**, **62** and **63** of different thicknesses are disposed along the length of the TWM with the thinest **63** on the input-output end and the thickest **61** on the opposite end. That provides three degrees of magnetic field concentration that may be referred to as light, medium and heavy. Current is then adjusted through the figure-8 coil **67** with the polarities shown to further decrease the density of magnetic flux in the area of the shim **63** and increase the flux in the area of the shim **61**. The area of the shim **62** is covered by both parts of the figure-8 coil; therefore, the right half has its flux density decreased while the left half has its flux density increased. The result is: a low flux density in the area of shim **63**; medium-low flux density in the area of the right half of shim **62**; medium-high density in the area of the left half of shim **62**; and high density in the area of shim **61**. Each field change slightly shifts the resonance frequency of the combs **15** and **16** and results in stagger tuning of the TWM with eight sections of amplification operating at four different frequencies. As the current through the figure-8 coil **67** is increased by means of a current regulated power supply **68**, the separation between the four areas (low, medium-low, medium-high, and high) is increased, thereby increasing the separation of the four frequencies and broadening the band width until the four frequencies are so separated that they begin to appear as separate peaks in the frequency response curve.

Although three shims have been illustrated in FIGURE 6, it should be understood that any number of shims may be employed to provide for various numbers of tuning sections. Additional coils may also be employed to adjust the separate sections.

What is claimed is:

1. In a traveling wave maser of the comb type, the combination comprising:

a waveguide section having parallel sidewalls and a comb structure therebetween, said side walls and comb being machined from a bar of electrically conductive, non-magnetic matérial with a common base;

a first slab of active maser material precision fit in said waveguide section between one of said walls and said comb with one edge thereof substantially in contact with said base;

a second slab of active maser material ruby precision fit in said waveguide section between the other one of said walls and said comb with one edge thereof substantially in contact with said base, said second slab extending up the side of the comb to a height substantially less than said first slab;

a plurality of isolators disposed along the upper edge of said second slab, each isolator being positioned opposite a space between fingers of said comb; and

a third slab of maser material precision fit in said waveguide section between the other one of said walls and said comb with one edge thereof spaced slightly away from said isolators, said third slab extending up the side of said comb to a height substantially equal to the height of said first slab.

2. The combination as defined in claim **1** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby.

3. The combination as defined in claim **2** wherein said slabs are cut with the length thereof along the C axis of said ruby.

4. The combination a defined in claim **1** wherein each of said isolators is made of single-crystal yttrium iron garnet.

5. The combination as defined in claim **4** wherein said comb is designed for optimum gain with fingers having a substantially rectangular cross-section with the long dimension thereof parallel to the line of the comb fingers.

6. The combination a defined in claim **5** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby, and each of said slabs is cut with its long dimension parallel to the C axis of said ruby.

7. The combination as defined in claim **6** including means for pressing said first, second and third slabs toward said one of said walls, whereby maximum contact with said one of said walls for said comb is provided through said first slab, and maximum contact of said comb with said first, second and third slabs is assured.

8. The combination as defined in claim **7** wherein said clamping mean comprises a strip of spring material secured to the outside of the other one of said walls and pins passing through ports in said other one of said walls beneath said strip, said pins being longer than said other one of said walls is thick, whereby pressure from said spring strip is transferred to said second and third slabs toward said comb and said first slab by said pins.

9. The combination as defined in claim **8** wherein:

at least one shim of magnetic material disposed near said comb along a section thereof in a plane perpendicular to fingers of said comb, whereby magnetic flux concentration is varied over said section of said comb;

a plurality of coils disposed near said comb along sections thereof in a plane perpendicular to fingers of said comb; and

mean for adjusting current amplitude through said coils, whereby magnetic flux density may be adjusted by sections to provide, in cooperation with said shims, stagger tuning of sections of said traveling wave maser.

10. In a high-grain traveling wave maser of the type having a comb in a waveguide section, the combination comprising:

at least one shim of magnetic material disposed near said comb along a section thereof in a plane perpendicular to fingers of said comb, whereby magnetic flux concentration is varied over said section of said comb;

a plurality of coils disposed near said comb along sections thereof in a plane perpendicular to fingers of said comb; and

means for adjusting current amplitude through said coils, whereby magnetic flux density may be adjusted by sections to provide, in cooperation with said shims, stagger tuning of sections of said traveling wave maser.

11. The combination of claim **10** wherein said high gain traveling wave maser is achieved by structure comprising:

a waveguide section having parallel sidewalls and a comb structure therebetween, said side walls and comb being machined from a bar of electrically conductive, non-magnetic material with a common base;

a first slab of active maser material precision fit in said waveguide section between one of said walls and said comb with one edge thereof substantially in contact with said base;

a second slab of active maser material ruby precision fit in said waveguide section between the other one of said walls and said comb with one edge thereof substantially in contact with said base, said second slab extending up the side of the comb to a height substantially less than said first slab;

a plurality of isolators disposed along the upper edge of said second slab, each isolator being positioned opposite a space between fingers of said comb; and

a third slab of maser material precision fit in said waveguide section between the other one of said wall and said comb with one edge thereof spaced slightly away from said isolators, said third slab extending up the side of said comb to a height substantially equal to the height of said first slab.

12. The combination of claim **11** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby.

13. The combination of claim **12** wherein said slabs are cut the length thereof along the C axis of said ruby.

14. The combination of claim **11** wherein each of said isolators is made of single-crystal yttrium iron garnet.

15. The combination of claim **14** wherein said comb is designed for optimum gain with fingers having a substantially rectangular cross-section with the long dimension thereof parallel to the line of the comb fingers.

16. The combination of claim **15** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby, and each of said slabs is cut with its long dimension parallel to the C axis of said ruby.

17 The combination of claim **16** including means for pressing said first, second and third slabs toward said one of said walls, whereby maximum contact with said one of said walls for said comb is provided through said slab, and maximum contact of said comb with said first, second and third slabs is assured.

18. The combination of claim **17** wherein said clamping means comprises a strip of spring material secured to the outside of the other one of said walls and pins passing through ports in said other one of said walls beneath said strip, said pins being longer than said other one of said walls is thick, whereby pressure from said spring strip is transferred to said second and third slabs toward said comb and said first slab by said pins.

19. In a traveling wave maser having two waveguide sections, each section having parallel walls and a comb structure therebetween, said sidewalls and comb being machined from a bar of electrically conductive, non-magnetic material with a common base between said side walls, one of said side walls being common to both sections and the other one of said side walls being on the outside, and said base being shared by both sections, the combination for each waveguide section comprising:

a waveguide section having parallel sidewalls and a comb structure therebetween, said side walls and comb being machined from a bar of electrically conductive, non-magnetic material with a common base;

a first slab of active maser material precision fit in said waveguide section between one of said walls and said comb with one edge thereof substantially in contact with said base;

a second slab of active maser material ruby precision fit in said waveguide section between the other one of said walls and said comb with one edge thereof substantially in contact with said base, said second slab extending up the side of the comb to a height substantially less than said first slab;

a plurality of isolators disposed along the upper edge of said second slab, each isolator being positioned opposite a space between fingers of said comb; and

a third slab of maser material precision fit in said waveguide section between the other one of said walls and said comb with one edge thereof spaced slightly away from said isolators, said third slab extending up the side of said comb to a height substantially equal to the height of said first slab.

20. The combination as defined in claim **19** including a short waveguide extension common to both of said sections and a loop of electrically conductive, non-magnetic wire disposed in said extension to couple one section to the other, one end of said loop being grounded near the comb of one waveguide section at the base thereof and in line with fingers of the comb, the other end of said loop being grounded near the comb of the other waveguide section at the base thereof and in line with fingers of the comb, a substantial portion of said loop being substantially parallel to the end finger of the comb in one section and another substantial portion being substantially parallel to the end finger of the comb in the other section, each of said portions being adjustable in position from its proximate comb for maximum power transfer, whereby one waveguide section is efficiently coupled to the other around said one common wall and through said loop in said waveguide extension.

21. The combination as defined in claim **20** including input and output coaxial cables, each cable having its outer non-magnetic conductor grounded through a side wall to said base and having its inner non-magnetic conductor passing through said side wall into a different one of said two waveguide sections where the end thereof is grounded near the comb therein at the base thereof at the end opposite to said loop and in line with fingers of the comb, a substantial portion of said inner conductor being substantially parallel to the finger of the comb at the end opposite said loop, said portion of said conductor being adjustable in position from its proximate comb for maximum power transfer between the coaxial cable of the inner conductor and the waveguide section of the proximate comb.

22. The combination as defined in claim **21** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby.

23. The combination as defined in claim **22** wherein said slabs are cut with the length thereof along the C axis of said ruby.

24. The combination as defined in claim **21** wherein each of said isolators is made of single-crystal yttrium iron garnet.

25. The combination as defined in claim **24** wherein said comb is designed for optimum gain with fingers having a substantially rectangular cross-section with the long dimension thereof parallel to the line of the comb fingers.

26. The combination as defined in claim **25** wherein said active maser material for said first, second and third slabs is 0-degree Czochralski grown ruby, and each of said slabs is cut with its long dimension parallel to the C axis of said ruby.

27. The combination as defined in claim **26** including means for pressing said first, second and third slabs toward said one of said walls, whereby maximum contact with said one of said walls for said comb is provided through said first slab, and maximum contact of said comb with said first, second and third slabs is assured.

28. The combination as defined in claim **27** wherein said clamping means comprises a strip of spring material secured to the outside of the other one of said walls and pins passing through ports in said other one of said walls beneath said strip, said pins being longer than said other one of said walls is thick, whereby pressure from said spring strip is transferred to said second and third slabs toward said comb and said first slab by said pins.

29. The combination as defined in claim **28** wherein:

at least one shim of magnetic material disposed near said comb along a section thereof in a plane perpendicular to fingers of said comb, whereby magnetic flux concentration is varied over said section of said comb;

a plurality of coils disposed near said comb along sections thereof in a plane perpendicular to fingers of said comb; and

means for adjusting current amplitude through said coils, whereby magnetic flux density may be adjusted by sections to provide, in cooperation with said shims, stagger tuning of sections of said traveling wave maser.

References Cited

UNITED STATES PATENTS

3,299,364 1/1967 Buchmiller et al. ------ 330—4

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