Sept. 3, 1968 J. H. HABRA 3,400,322

X-BAND BALANCED FREQUENCY DOUBLER

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Fig. 1

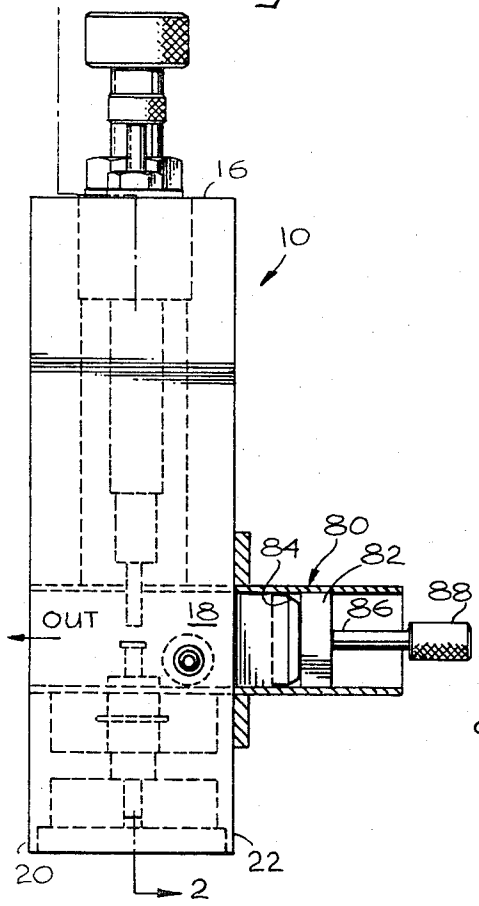
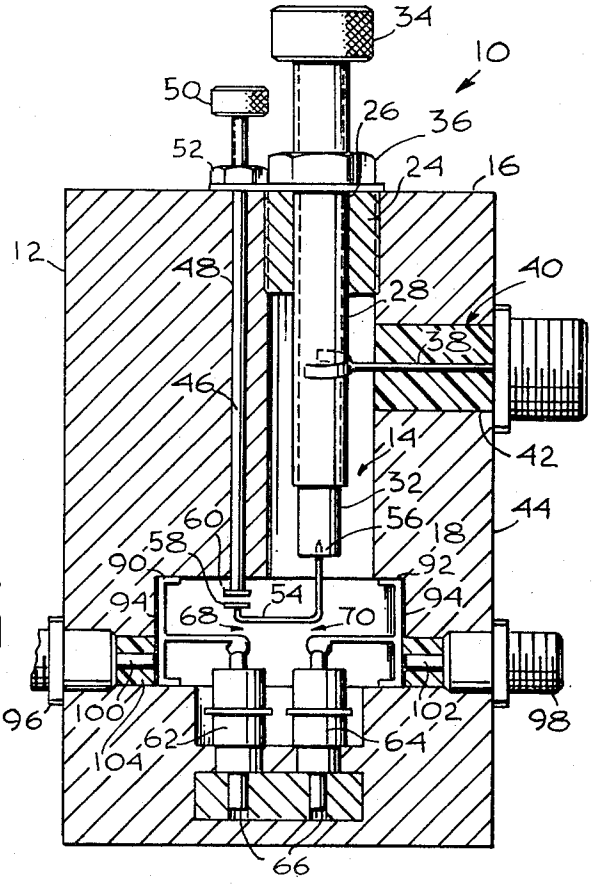


Fig. 2



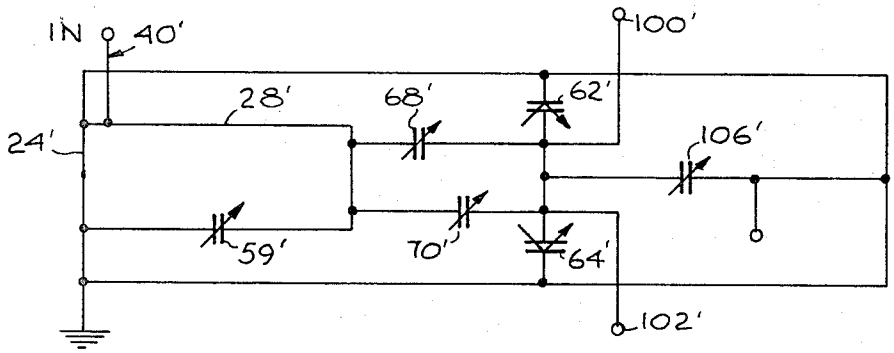


Fig. 3

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X-BAND BALANCED FREQUENCY DOUBLER

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ABSTRACT OF THE DISCLOSURE

An X-band frequency doubler circuit of a balanced configuration employing dual varactors each having a separate variable bias source. The bias source varying the varactors impedance and maximizing the output power.

This invention relates generally to frequency multipliers and more particularly to frequency doublers capable of providing output signals of frequencies in the X-band range, i.e., approximately from 8 to 12.5 gigacycles.

Various devices are known in the prior art suitable for providing an output signal of frequency 2ω in response to an input signal of frequency ω. However, many of these devices are not capable of satisfactorily operating at frequencies as high as the X-band range. Moreover, those devices which are capable of operating at these frequencies are not usually capable of providing signal outputs as high as 1 watt at reasonable levels of efficiency.

In view of the foregoing, it is an object of the present invention to provide an improved frequency doubler capable of efficiently operating at X-band frequencies to provide a signal power output on the order of 1 watt or more.

In accordance with a preferred embodiment of the invention, a doubler structure is provided having a resonant input section which is coupled to an output waveguide by a balanced pair of variable nonlinear reactance elements, preferably varactors. The input section is formed by a coaxial line comprised of a central conductor supported within a hollow conductor or resonant cavity. A variable capacitor is provided in the central conductor to enable the input section to be tuned. In order to maximize efficiency, input energy is coupled into the coaxial line at a low impedance point. The energy in the coaxial line is coupled to the varactors through variable capacitances. Inasmuch as the varactors comprise nonlinear impedances, they generate harmonics of the input signal frequency. The waveguide is dimensioned to prefer the second harmonic of the input frequency.

In order to assure maximum efficiency, the varactors are matched to the waveguide by a sliding waveguide short. In addition, means are provided for applying a variable bias signal to the varactors to thus enable their impedance to be varied and the output power to be maximized.

It is pointed out that the use of a balanced multiple varactor frequency doubler provides significant advantages over single varactor doublers which have been employed in the prior art. More particularly, for the same power output, use of multiple varactors enables more efficient operation while for the same level of efficiency, use of multiple varactors provides greater output signal power.

The novel features that are considered characteristic of this invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in connection with the accompanying drawings, in which:

FIGURE 1 is a side view of a preferred embodiment of the invention;

FIGURE 2 is a sectional view taken substantially along the plane 2—2 of FIGURE 1; and

FIGURE 3 is a diagram of an electrical circuit generally equivalent to that represented by the structure illustrated in FIGURES 1 and 2.

Attention is now called to FIGURES 1 and 2 of the drawings which illustrate the structure of a preferred X-band doubler in accordance with the present invention. More particularly, the doubler **10** illustrated in FIGURES 1 and 2 is comprised of a block **12** of electrically conductive material, e.g., aluminum. Although the overall dimensions of the block **12** are not critical, it is pointed out that a typical block can have a height on the order of 2.4 inches, a width on the order of 1.6 inches, and a depth on the order of .75 inch.

Prior to discussing the structural details of the preferred embodiment of the invention, its general mode of operation will be mentioned. The doubler **10** includes an input section which has a resonant means tuned to the frequency ω of an input signal applied thereto. Means are provided for coupling the input section signal energy to first and second nonlinear impedance devices for producing harmonics of the frequency ω. These harmonics are coupled to an output section comprising a waveguide which preferentially passes the second harmonic.

Now considering the structure of the preferred embodiment in greater detail, it is to be noted that a cylindrical aperture **14** is defined in the block **12** extending downwardly from the top surface **16** thereof. The aperture **14**, which it will be seen comprises a resonant cavity, communicates with a rectangular opening **18** (comprising a rectangular waveguide) extending between the front and rear surfaces **20** and **22** of the structure **10**. Supported within the aperture **14** adjacent the top surface **16** is a conductive bushing **24**. The bushing **24** defines a central opening **26**. Extending through the opening **26** is a conductive sleeve **28**. Slidably disposed within the sleeve **28**, and in electrical contact therewith is a conductive plunger **32**. The plunger **32** is physically coupled to a knurled knob **34**. The plunger **32** is externally threaded adjacent the upper surface **16** of the block **12**. A lock nut **36** is provided adapted to be threadedly engaged with the plunger **32** for retaining it in position.

Electrically connected to the conductive sleeve **28** is the central conductor **38** of a coaxial connector **40** which extends through an opening **42** from the surface **44** of block **12**. Preferably, the central conductor **38** terminates in a U-shaped contact adapted to bear against and electrically engage the conductive sleeve **28** proximate to the bushing **24**. In addition to the foregoing, a second plunger **46** is provided, being disposed in an aperture **48** extending through the block **12** between the upper surface **16** thereof and the rectangular opening **18**. A knurled knob **50** is secured to the upper end of the plunger **46** to enable it to be pushed through the aperture **48**, for reasons to be explained more fully hereinafter. A lock nut **52** is provided adapted to cooperate with the threads on the plunger **46** for locking it in position.

A flat U-shaped conductor **54** is connected to the lower end of the plunger **32** at **56**. The free end of the conductor **54** terminates in plate **58** opposed to plate **60** carried by plunger **46**. Plates **58** and **60** function as a capacitor whose capacitance value is of course determined by the spacing between the plates **58** and **60**. By moving the plungers **32** and **46** up and down together, the value of the capacitance defined between plates **58** and **60** will remain unchanged. However, by differentially moving the plungers, the value of the capacitance can be varied.

The elements thus far described generally can be considered as comprising the doubler input section with aperture **14** defining a resonant cavity or outer conductor of a coaxial line, with plungers **32** comprising the central conductor. Input energy of frequency ω is coupled

through the coaxial connector **40** to the conductive sleeve **28**. Inasmuch as the conductive bushing **24** acts to short the resonant cavity **14**, a position on the conductive sleeve **28** adjacent the bushing **24** will comprise a low impedance point thereby enabling an efficient energy transfer from the connector **40** to the input section. By moving the plungers **32** and **46** to adjust the capacitance between the plates **58** and **60**, the input section can be tuned to the input frequency.

As previously pointed out, the input signal frequency is coupled to the waveguide **18** through harmonic generating nonlinear impedances. In the preferred embodiment of the invention, first and second varactors **62** and **64** are used as nonlinear impedances. The first terminal **66** of each varactor is effectively grounded by being electrically connected to the conductive block **12**. The second terminal of each varactor is positioned proximate to the U-shaped conductor **54**. As a consequence, energy at the input signal frequency will be capacitively coupled from the conductor **54** to the first terminals of the varactors **62** and **64** through gaps **68** and **70**. The capacitance value of gaps **68** and **70** of course depends upon the dimensions of the gap which can be varied by movement of the plungers **32** and **46**. Thus, differential movement of the plungers **32** and **46** enables the capacitance between the plates **58** and **60** to be varied to thus enable the input section to be tuned. Coincidental movement of the plungers **32** and **46** on the other hand affects the capacitance between the input section and the varactors **62** and **64**. The varactors comprise variable nonlinear reactances which respond to the signal or frequency ω coupled thereto to provide harmonics thereof. These harmonics are coupled into the output waveguide **18** which preferably is dimensioned to preferentially pass the second harmonic.

In order to enable the waveguide to be matched to the varactors **62** and **64**, a waveguide extension **80** is provided. Mounted for slidable movement in the extension **80** is a shorting bar **82** having fingers **84** extending therefrom and bearing against the inner wall of the waveguide extension. A shank **86** is fixed to the shorting bar **82** and terminates in a knurled knob **88** which permits the shorting bar **82** to be manually moved in the waveguide extension **80**. In this manner, the waveguide can be matched to the varactors to thereby assure an efficient coupling of energy therebetween.

In order to maximize the power output of the frequency doubler of FIGURES 1 and 2, it is advantageous to be able to apply a selected bias potential to the varactors to thereby establish a preferred impedance level. In order to apply such a bias potential, first and second conductive channel members **90** and **92** are provided in the waveguide **18** bearing outwardly against the walls thereof. The outer surface of each of the channel members **90** and **92** is coated with an insulating layer **94**, such as Mylar, which electrically insulates the channel members from the block **12**. The upper terminals of the varactors **62** and **64** are however electrically connected to the members **90** and **92**.

Coaxial conductors **96** and **98** are mounted within the block **12**. The central conductors **100** and **102** thereof are insulated from the block **12** by insulation **104** but are connected to the channel members **90** and **92** by removing the insulation layer **94** adjacent thereto. In order to better form the electrical connection between the central conductors **100** and **102** and the channel members **90** and **92**, filamentary electrically conductive means, similar to steel wool for example, can be provided between the central conductors and the channel members.

FIGURE 3 illustrates a circuit diagram representing the circuit equivalent of the apparatus of FIGURES 1 and 2. In the circuit of FIGURE 3, the numeral **40'** is used to represent the input connection to the conductive sleeve represented by the numeral **28'** in FIGURE 3. It is to be noted that the input connection **40'** is made at a low impedance point proximate to the shorted end of the resonant cavity represented by the numeral **24'**. The input section is tuned by a capacitor **59'** which is analogous to the capacitance defined between the plates **58** and **60**. Variable capacitors **68'** and **70'**, analogous to gaps **68** and **70** in FIGURE 2, couple the input section energy to varactors **62'** and **64'** which are respectively biased by input terminals **100'** and **102'**. The output of the varactors can be considered as being coupled to the waveguide **18** through a capacitance **106'**.

From the foregoing, it should be appreciated that a frequency doubler structure has been shown herein which is relatively compact and simple in construction and therefore relatively inexpensive and highly reliable. Moreover, the frequency doubler structure illustrated is capable of operating to provide output signals of frequencies in the X-band range at relatively high power outputs, e.g., greater than 1 watt, and at relatively high efficiencies.

I claim:

1. A frequency doubler suitable for providing high power output signals at X-band frequencies, said doubler comprising:

a block of conductive material;

a first opening defining a waveguide extending through said block;

an aperture extending into said block and terminating in said opening;

a conductor centrally disposed in said aperture;

means for coupling signal energy to said central conductor;

variable reactance means responsive to signal energy coupled to said central conductor for coupling harmonics thereof to said first opening;

a first capacitor plate secured to the end of said centrally disposed conductor proximate to said first opening;

a second capacitor plate electrically connected to said block; and

means mounting said centrally disposed conductor for slidable movement parallel to said aperture whereby the spacing between said first and second capacitor plates can be varied.

2. The doubler of claim **1** wherein said variable reactance means includes first and second varactors each having first and second terminals;

means disposing said varactor first terminals proximate to said end of said conductor proximate to said opening; and

means electrically connecting said varactor second terminals to said block.

3. The doubler of claim **2** including means for biasing said varactors.

4. The doubler of claim **1** including a waveguide extension coupled to said opening; and

a shortening bar selectively positionable in said extension.

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