United States Patent

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[54] **DITHER TUNED MICROWAVE TUBE WITH CORRECTED TUNER RESOLVER OUTPUT**
6 Claims, 9 Drawing Figs.

[52] U.S. Cl. 315/39.61, 325/121, 315/39.77, 74/390, 325/25
[51] Int. Cl. H01j 25/50
[50] Field of Search 315/39.55, 39.61, 39.77; 331/178; 332/4, 25; 325/25, 121, 131, 132

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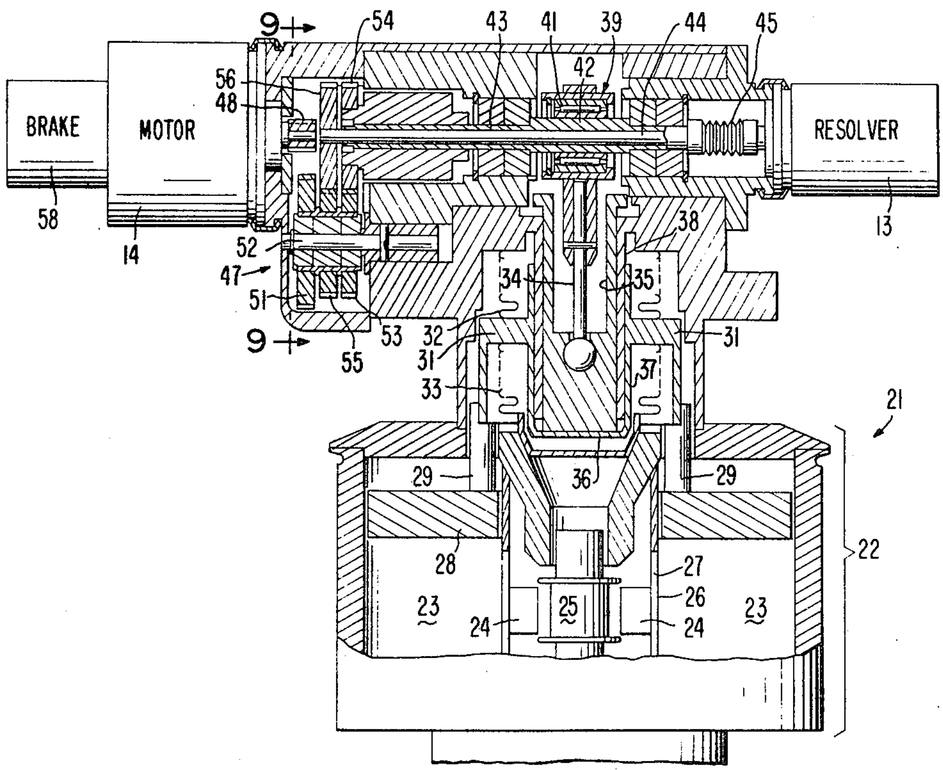
ABSTRACT: A dither tuned microwave tube having a corrected tuner resolver output signal is disclosed. A pair of eccentric gear compensators are employed in the gear train to drive the dither tuner and resolver from a motor. The pair of eccentric compensating gears may be employed in the gear train to change the resolver output to conform to the nonlinear tuning curve or, alternatively, the pair of eccentric compensating gears may be employed to change the tuning curve to match the linear resolver output.



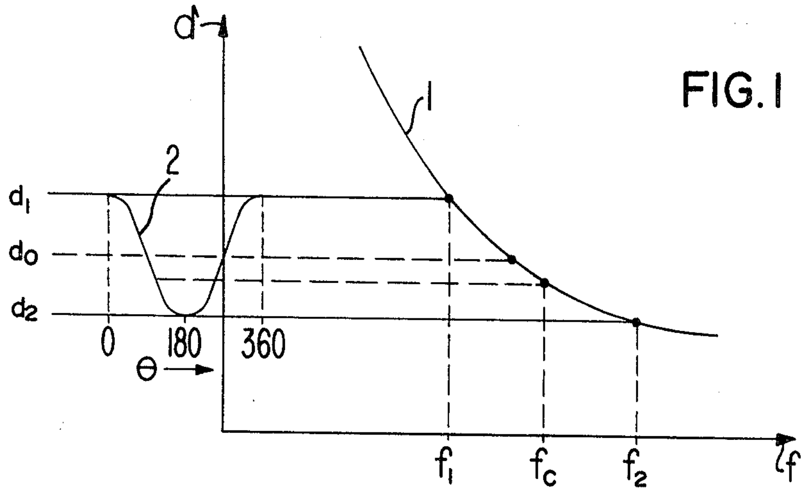


FIG. 1

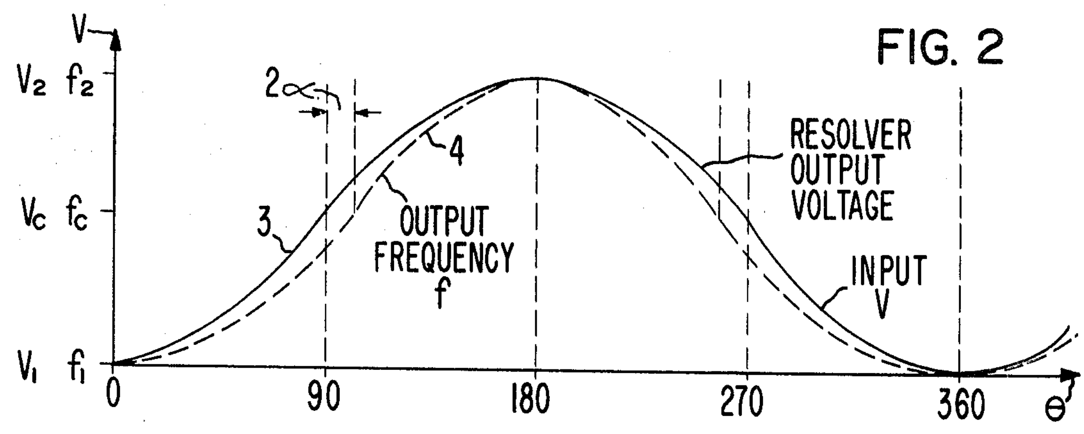


FIG. 2

FIG. 3

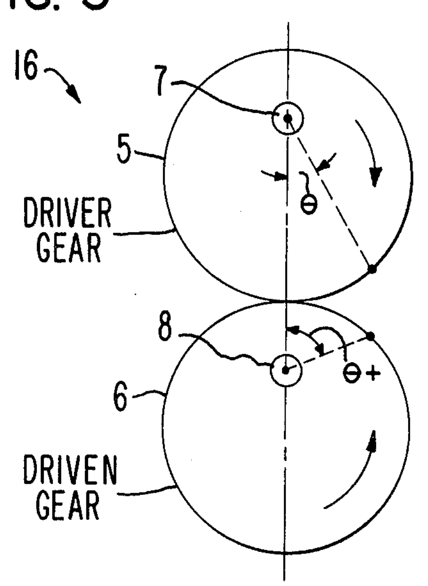


FIG. 4

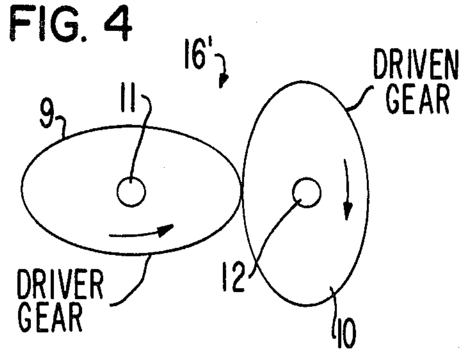


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FIG. 5

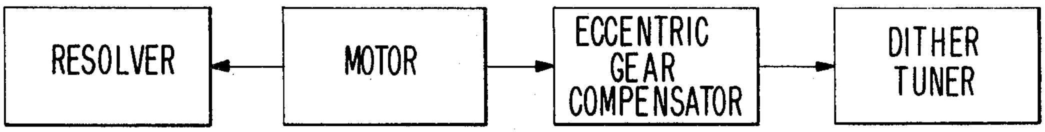


FIG. 6

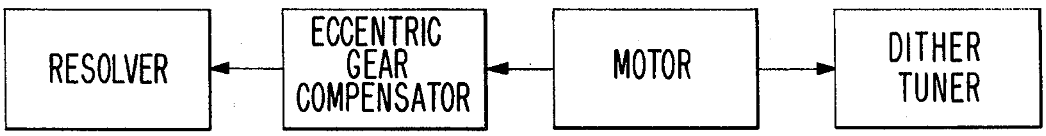
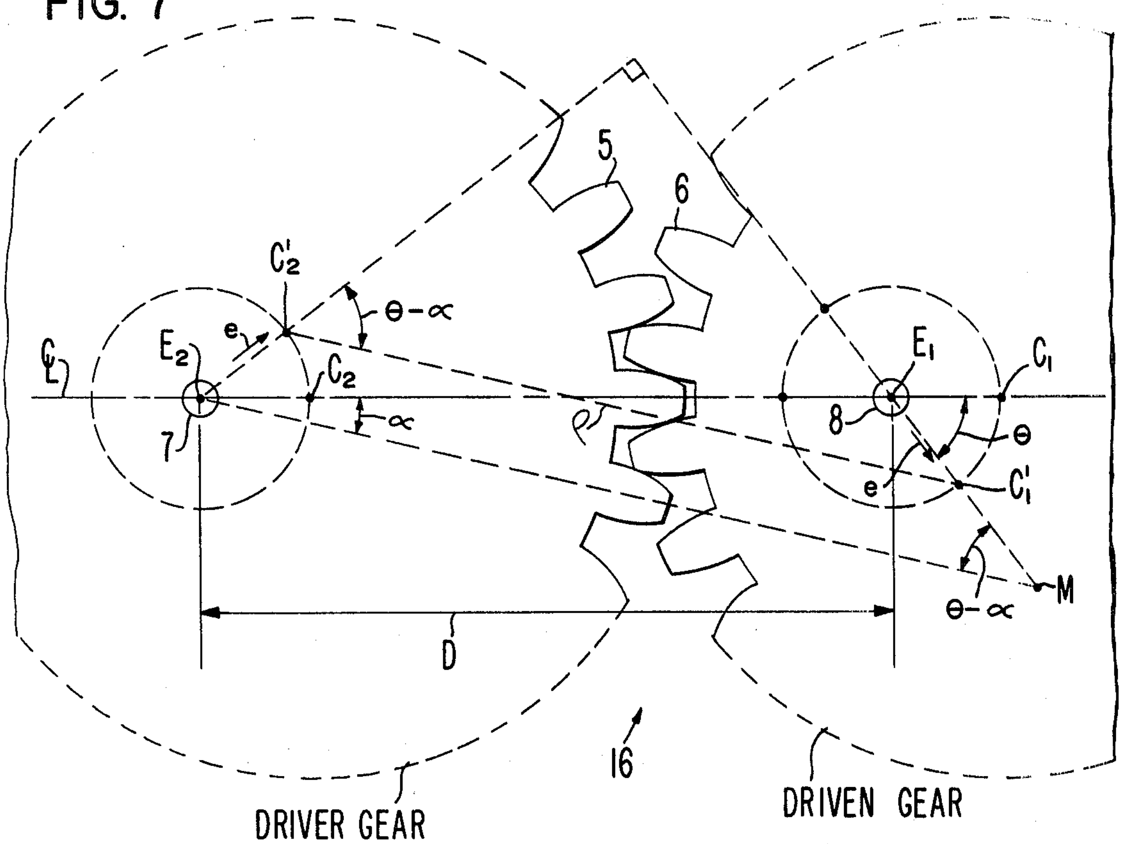


FIG. 7



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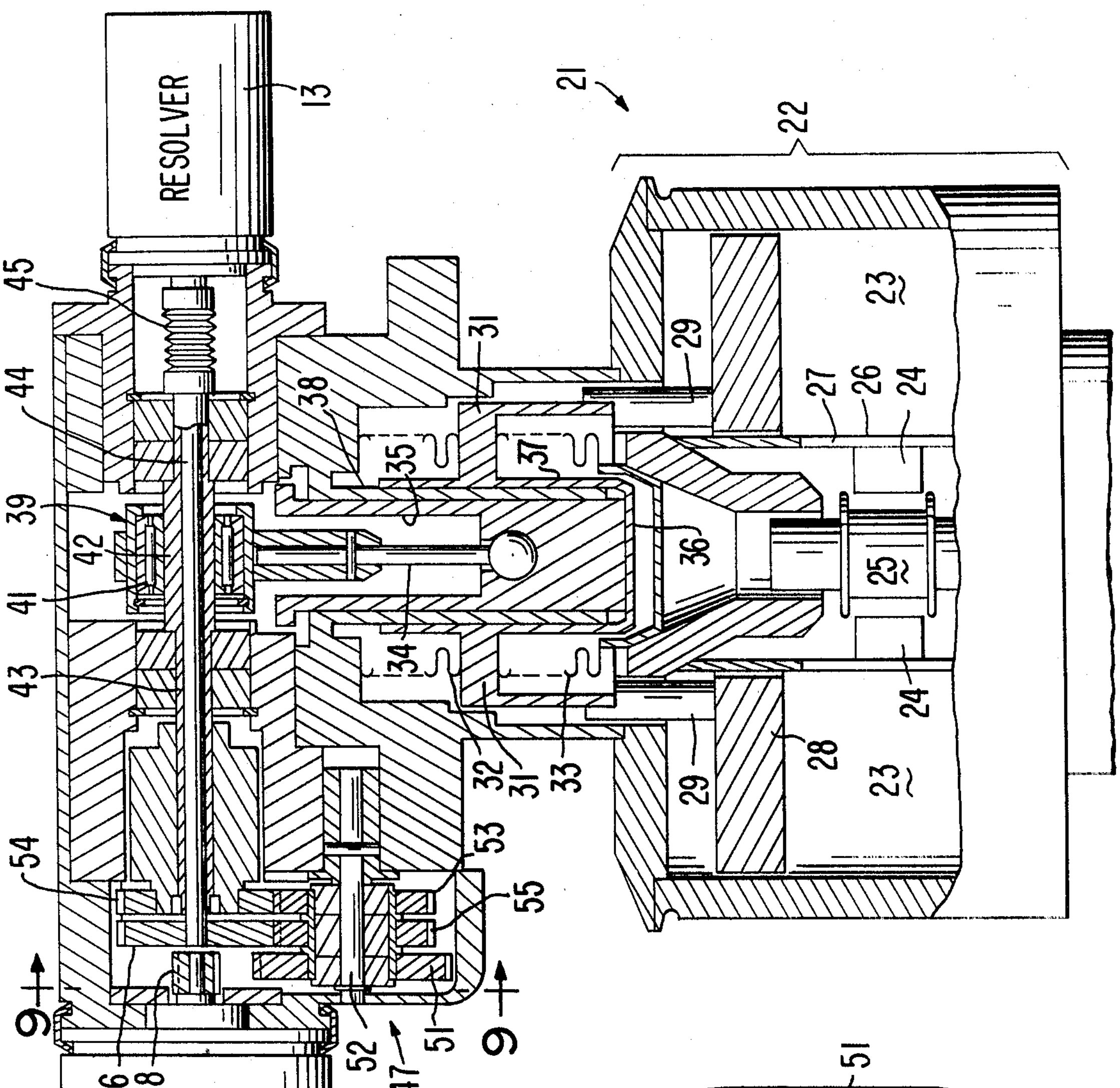

FIG. 8

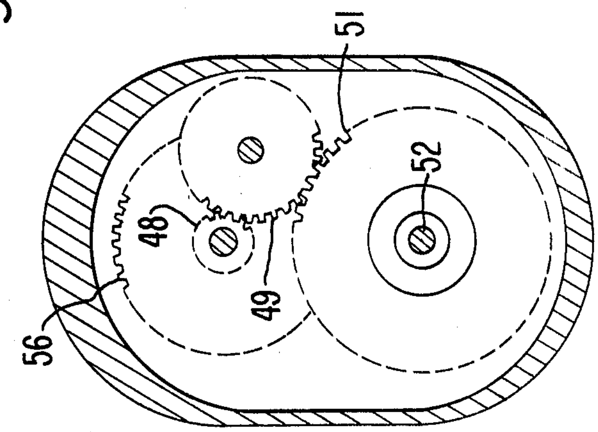

FIG.9

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DITHER TUNED MICROWAVE TUBE WITH CORRECTED TUNER RESOLVER OUTPUT

DESCRIPTION OF THE PRIOR ART

Heretofore, dither tuned microwave tubes such as coaxial magnetrons, have employed a motor for driving a crankshaft which cranks a tuning plunger to and fro within the microwave tube for dither tuning the output of the microwave tube. A resolver has been coupled to the crankshaft for deriving an electrical output signal corresponding to the instantaneous frequency of the dither tuned tube. Typical examples of such dither tuned tubes are disclosed in U.S. Pat. Nos. 3,414,761 issued Dec. 3, 1968; 3,441,794 issued Apr. 29, 1969; and 3,441,795 issued Apr. 29, 1969, all assigned to the same assignee as the present invention. The resolver output signal is typically fed to a voltage tunable local oscillator in a radar receiver such that the local oscillator frequency is varied in accordance with variations in the instantaneous frequency output of the dither tuned tube which is typically the transmitter tube. Dither tuning the transmitter tube and employing the output of the resolver for tracking the local oscillator frequency in the receiver produces a substantial gain in the receiver and greatly improves the signal to noise ratio of the radar. For example, if the receiver local oscillator frequency variations track the instantaneous frequency variations of the dithered tube within a 10 percent error, an equivalent 4 db. receiver gain is obtained as compared to a system without dither tuning and tacking. Such a dither tuned system is disclosed in copending U.S. application now U.S. Pat. No. 3,532,995 issued Oct. 6, 1970 Ser. No. 667,720 filed Sept. 14, 1967 and assigned to the same assignee as the present invention.

Although a 4 db. gain is obtained with a 10 percent error in the oscillator tracking of the dither tuned tube, if the tracking error can be reduced to one-half percent the effective receiver gain is increased from 4 db. to 8 db. In the prior art, the resolver tracking error was limited by the nonlinearity of the tuning characteristic of the microwave tube. In other words, over the range of physical displacement of the tuning plunger within the microwave tube, a given increment of tuner displacement at one end of the tuner movement produced a given frequency deviation, whereas an equivalent displacement of the tuning member at the other end of the range of tuner displacement produced a substantially different frequency deviation. It would be desirable to provide a dither tuned tube in which the resolver output tracked the instantaneous frequency of the tube to within an error of one-half a percent.

SUMMARY OF THE PRESENT INVENTION

The principal object of the present invention is the provision of an improved dither tuned microwave tube having a corrected tuner resolver output.

One feature of the present invention is the provision in a dither tuned microwave tube employing a resolver operatively interconnected with the dither tuning structure by means of a gear train of a pair of eccentric meshing bears for compensating the resolver output for the nonlinear tuning characteristic of the tuning structure, whereby the resolver output tracks the frequency deviation of the tube with a high degree of accuracy.

Another feature of the present invention is the same as the first feature wherein the pair of eccentric compensating gears are circular gears mounted eccentrically on a pair of shafts, one of the gears being a driver gear and the other being a driven gear, whereby the eccentric gear compensator structure is substantially simplified for ease of manufacture.

Another feature of the present invention is the same as any one or more of the preceding features wherein the gear train includes a pair of concentric outer and inner separately rotatable drive shafts, the outer shaft forming a crankshaft for the dither tuning mechanism and the inner drive shaft being coupled to the resolver for driving the resolver at the same instantaneous angular velocity as the inner drive shaft.

Another feature of the present invention is the same as the first feature wherein the pair of eccentric meshing gears are noncircular gears.

Other features and advantages of the present invention will become apparent upon a perusal of the following specification taken in connection with the accompanying drawings wherein:

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plot of tuner displacement d versus output frequency f of a dither tuned microwave tube and showing a nonlinear tuning curve,

FIG. 2 is a plot of resolver output voltage V and output frequency f versus angular displacement θ of the dither tuning drive shaft,

FIG. 3 is a schematic diagram of a pair of twin eccentric gears employed for compensating for the nonlinear tuning characteristic according to the present invention,

FIG. 4 is a schematic line diagram of an alternative pair of eccentric meshing gears for compensating for a nonlinear tuning characteristic according to the present invention,

FIG. 5 is a schematic block diagram for a dither tuned tube incorporating eccentric gear compensation of the present invention,

FIG. 6 is a schematic block diagram for an alternative eccentric gear compensated dither tuned system of the present invention,

FIG. 7 is a fragmentaRy schematic line diagram depicting twin eccentric meshing gears employed in the compensator of the present invention,

FIG. 8 is a fragmentary view, partly in section, of a dither tuned magnetron incorporating features of the present invention, and

FIG. 9 is a sectional view of the structure of FIG. 8 taken along line 9–9 in the direction of the arrows.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to FIG. 1, there is shown a typical tuning curve 1 for a microwave tube, such as a dither tunable coaxial magnetron of the type described and disclosed in the aforecited patents and applications. As the tuning element of the tube is displaced, in the manner as depicted by sinusoidal curve 2 oscillating between displacement d_1 and d_2 from a midposition d_o in accordance with a drive shaft angular displacement θ, the output frequency of the tube varies from a low frequency f_1 to a maximum frequency f_2. However, due to the nonlinearity of the tuning curve 1, the midpoint position d_o does not correspond to the center frequency f_c of the dither tuned band. As a result, for one tuning cycle, namely, 360° of angular displacement of the tuner drive shaft, the output frequency f will have a nonsinusoidal variation with angular displacement of the drive shaft as depicted by curve 4 in FIG. 2. Assuming the drive shaft drives a resolver having an output voltage which is a sinusoidal variation of the angular displacement θ, as depicted by the solid curve 3 of FIG. 2, it will be seen that the output frequency f lags the resolver output voltage V at the 90° position by an angular displacement of $2\alpha°$ leads the voltage curve 3 at the 270° position by 2α and that this is a near maximum lag or lead displacement. However, the voltage and frequency are in correspondence at θ=0° and 180° with zero error. Thus, there is a tracking error between the resolver output signal and the true instantaneous frequency of the tube having a maximum value of approximately $2\alpha°$. In the prior art tubes this tracking error had a maximum value of approximately 10 percent which allowed approximately 4 db. of equivalent receiver gain in a dither tuned radar system. It is desirable to reduce this tracking error to on the order of one-half a percent which will increase the effective gain of the receiver to approximately 8 db. and which is very nearly the theoretical maximum effective gain of 9 db. if perfect tracking were to be obtainable.

According to the present invention, a pair of eccentric gears, such as those depicted in FIG. 3 or 4, are employed in the tuner drive gear train coupling the dither tuner resolver and motor in the manner as schematically indicated in FIGS. 5 or 6 to correct for the nonlinearity of the tuning curve 1 in order to reduce the tracking error to on the order of one-half of a percent or better. A pair of eccentric gears, as utilized herein, is defined to include a pair of circular gears eccentrically mounted on a pair of drive shafts, as indicated in FIG. 3, as well as a pair of elliptical or noncircular gears 9 and 10 centrally or eccentrically mounted on a pair of drive shafts 11 and 12. In either case, the eccentric meshing gears have the characteristic that starting from a reference point the driven shaft as driven from the driver's shaft via the driver gear and driven gear can be caused to lag behind the driver shaft for the first 180° of rotation reaching a maximum lag at approximately 90° of rotation and from 180° to 360° to lead the driver shaft by a maximum lead angle occurring near the 270°. This is the compensation required to compensate for the nonlinear tuning curve 1 of FIG. 1.

Referring now to FIGS. 3 and 5 there is shown a system for compensating for a tracking error of the type depicted in FIG. 2. More specifically the tuner system includes a resolver 13 driven from the output shaft of a motor 14 for producing a resolver output voltage curve as shown by curve 3 of FIG. 2. The output shaft of the motor 14 also drives the dither tuner 15 via the intermediary of an eccentric gear compensator 16 of the type generally shown in FIG. 3. In order to compensate for the nonlinear tuning characteristic, as shown in FIG. 2, the dither tuner drive shaft needs to be driven in such a manner that a given angular displacement of the driver gear produces a correspondingly greater angular displacement of the dither tuner drive shaft. Thus, the output shaft of the motor drives shaft 7 of FIG. 3 which in turn drives driver gear 5 which meshes with driven gear 6 which in turn drives dither tuner shaft 8.

A similar compensating result can be obtained by the eccentric gear compensator 16′ of FIG. 4 where a given angular displacement of the driver shaft 11 produces a correspondingly increased angular displacement of the driven output shaft 12 for the first 90° of rotation from the position as shown. In the next 90° the angular lead achieved during the first 90° diminishes to 0 at 180° of rotation and then for the next 90° of rotation from 180° to 270° the driven shaft angular rotation lags the equivalent rotation of the driver shaft and in the rotation from 270 to 360 this lag decreases to 0.

Referring now to FIG. 6 there is shown an alternative embodiment of the present invention wherein the eccentric gear compensator 16 is disposed between the motor and the resolver 13 causing the resolver output to be corrected to the output tuning characteristic of the dither tuner 15. In this case, the compensator 16 is arranged such that for the first 90° of rotation of the output shaft of the motor as applied to the input of the compensator 16 the output shaft of the compensator reaches a maximum lag of $2\alpha°$, such lag then decreasing to 0 at the 180° position of the input shaft to the compensator 16. Such a result is obtained if the compensator 16 of FIGS. 3 and 4 is merely reversed such that the driven gear becomes the driver gear and the driver gear becomes the driven gear. Thus, in the eccentric gear compensator 16 for the system of FIG. 6, the motor drives shaft 8 of FIG. 3 and shaft 7 drives the resolver 13, whereas in the gear arrangement of FIG. 4 the motor drives shaft 12 and shaft 11 drives the resolver shaft.

Referring now to FIG. 7, it will be shown how to relate the eccentricity e to the required maximum angular lead or lag $2\alpha°$ required for the eccentric gear compensator 16 of FIG. 3. First, the amount of angular lead or lag required is first determined by plotting the output frequency of the tube as a function of the angular displacement θ of the dither tuner crankshaft. It is assumed that the resultant curve is curve 4 of FIG. 2. Assuming that the resolver output is linear as a function of its shaft rotation, which will be the case to a very high degree, a sinusoidal curve 3 is plotted for the resolver output, the angular displacement $2\alpha°$, at the center frequency point f_c, is then read from the plot. This angular displacement will hereafter be referred to as $2\alpha°$ and will be employed in the equations to follow.

In the diagram of FIG. 7 the gears 5 and 6 are circular having centers C_1 and C_2 for driven gear 6 and driver gear 5, respectively. The gears are eccentrically mounted on drive shafts with the axes of the drive shafts 7 and 8 intersecting the gears 5 and 6 at E_2 and E_1, respectively. The center of the shafts are displaced from the center of the gears by an equal amount of eccentricity e. The axes of the shafts are displaced by D. From the construction lines superimposed on the drawing of FIG. 7, the following relations are derived:

$$\sin\alpha=(2e/D), \quad \text{Eq. (1)}$$

$$D=(\rho/\cos\alpha) \quad \text{Eq. (2)}$$

If it is required that the output shaft 8 for the eccentric gear compensator 16 of FIG. 5 lead and lag the input shaft 7 from a minimum of 0° at the 0 and 180° positions of the input shaft 7 to a maximum of $2\alpha°$ as picked off the curves 3 and 4 of FIG. 2. Two twin gears 5 and 6 of any arbitrary diameter are chosen to operate at a center distance ρ at their closest position where ρ is slightly greater than the diameter of the gears. The distance D between centers of the shafts 7 and 8 is then derived from equation (2) by substituting ρ and cosine α into equation (2) where α is one-half of the maximum lag angle from the plot of FIG. 2. The required eccentricity e is found by substituting D and α into equation (1).

Similar design details for the noncircular eccentric gear compensator of FIG. 4 can be obtained from FIG. 2 and from formulae appearing in a text titled, "Gear Design and Applications" by Nicholas Cheronis, McGraw Hill (1967), pages 158—165.

Referring now to FIGS. 8 and 9, there is shown a physical realization of the systems of FIGS. 5 and 6. Microwave tube 21, of the type generally described in the aforecited U.S. Pat. No. 3,441,795, and only partially shown herein, includes a main body portion 22 housing a toroid-shaped cavity resonator 23 coaxially surrounding an array of vane resonators 24 which in turn surround a cathode emitter 25 to define an annular magnetron interaction region between the vane resonators 24 and the cathode emitter 25. The vane resonators are carried at their outer edges from a cylindrical anode wall 26 forming a common wall of the resonator 23 and the vane resonator system 24. An array of longitudinally directed coupling slots 27 are provided communicating through the common wall 26 with alternate vane resonators for locking the π mode of oscillation of the vane resonator system to a circular electric mode in the coaxial cavity 23.

The upper end wall of the cavity 23 is axially movable for tuning the resonant frequency of the resonator 23 and thus the frequency of the π mode and the output frequency of the tube. Movable end wall 28 is carried from the dependent legs 29 of a spider structure 31. The body portion 31 of the spider is an annular disc sealed to the body of the tube via a pair of bellows 32 and 33. The spider 31 is axially translatable via a piston rod 34 which is affixed at its lower extremity via a ball joint to an inner cylindrical slide 35 which is affixed at its inner end to the inner end 36 of an outer cylindrical slide bearing 37 which in turn is affixed to the body of the spider 31. A fixed cylindrical slide bearing 38 is affixed to the body of the tube for guiding the axially translatable slides 35 and 37. The piston rod 34 includes a yoke portion 39 containing a ball bearing assembly 41 which rides on an eccentric portion 42 of a transversely directed hollow cylindrical crankshaft 43. A second drive shaft 44 is coaxially mounted within the crankshaft 43 and is affixed at one end to the resolver 13 via a coupling structure 45. The motor 14 is affixed to a tuner housing structure 46 which houses the crankshaft 43, and drive shaft 44 and a gear train 47 which drives shafts 43 and 44 from the motor 14.

The gear train 47 includes a gear 48 (see FIG. 9) affixed to the output shaft of the motor 14 which in turn drives an idler gear 49 which in turn drives a main drive gear 51 for driving a power drive shaft 52 at a substantially reduced angular velocity compared to the output drive of the motor **14**. More particularly, the gears **48**, **49** and **51** serve to reduce the angular velocity of the drive shaft from 10,000 r.p.m. to approximately

In the embodiment of the invention schematically indicated in FIG. **5** where the dither tuning characteristic **4** is compensated to bring it into conformance with the resolver characteristic **3**, the eccentric compensator gears **16** comprise a pair of twin eccentric gears **53** and **54**, gear **53** serving to drive gear **54** from drive shaft **52**. The resolver drive shaft **44** is driven from the power drive shaft **52** via a pair of twin drive gears **55** and **56**. The driver gears **55** and **56** are selected to drive the resolver shaft at the same average angular velocity as the angular velocity of the tuner crankshaft **43**. The twin eccentric compensator gears **53** and **54** are chosen and arranged in the manner as previously indicated with regard to FIGS. **7** and **2** above.

In the alternative embodiment of the invention as depicted in FIG. **6** where the resolver output is compensated by the eccentric gear compensator **16** to bring it into conformance which the tuning characteristic, gears **55** and **56** are made to comprise twin eccentric gears, in the manner as above described, while gears **53** and **54**, in this case, are selected merely to drive the tuner crankshaft at the same average angular velocity as that of the resolver drive shaft **44**.

A brake **58** is affixed to the motor **14** for holding the position of the tuner and its associated gear train in a locked position for selectively operating the tube in a fixed tuned manner.

Although the tuner and resolver compensating arrangement of the present invention has been described as it is employed for compensating the nonlinear tuning effects of a coaxial magnetron, the invention is equally applicable to other types of tunable microwave tubes such as klystrons, triodes, and the like.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention can be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What I claim is:

1. In a tunable microwave tube apparatus, microwave circuit means for determining the operating frequency of the microwave tube, tuner means movable within the region of said circuit means for tuning said microwave circuit and thus the operating frequency of the tube, said tuning means having a nonlinear displacement versus tuning characteristic, means for moving said movable tuning means to and fro to dither tune the tube, resolver means for deriving an output representative of the instantaneous operating frequency of the tube, gear train means operatively interconnecting said resolver means and said dithering means for synchronizing the output of said resolver means with movement of said tuning means, THE IMPROVEMENT WHEREIN, said gear train means includes a pair of eccentric meshing gears for reducing error between the resolver output and the instantaneous frequency of the tube.

2. The apparatus of claim **1** wherein said pair of eccentric gears are circular and including a pair of shafts having said circular gears mounted eccentrically thereon, respectively.

3. The apparatus of claim **2** wherein said gears are an identical pair.

4. The apparatus of claim **1** wherein said gear train includes a pair of concentric outer and inner separately rotatable drive shafts, said outer drive shaft having an eccentric portion forming a crankshaft for said dither tuning means and said inner drive shaft being coupled to said resolver means at the same average angular velocity as said outer drive shaft.

5. The apparatus of claim **1** wherein said pair of eccentric meshing gears are noncircular gears.

6. The apparatus of claim **1** wherein said microwave circuit means includes a circular cavity resonator and said tuning means includes a circular tuning member axially translatable within said resonator for tuning the operating frequency of the tube.