July 5, 1960 P. D. LACY 2,944,224

HIGH SPEED BINARY COUNTER

Filed May 10, 1957 2 Sheets-Sheet 1

FIG_1_

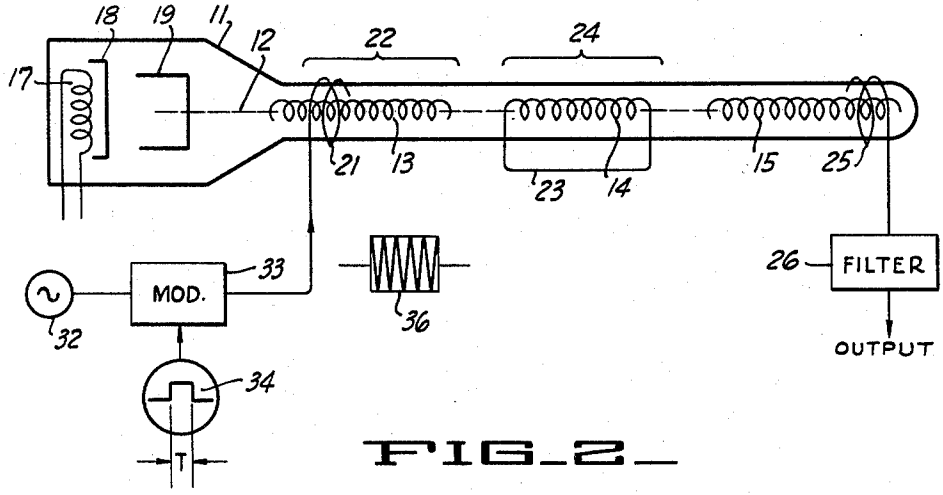


FIG_2_

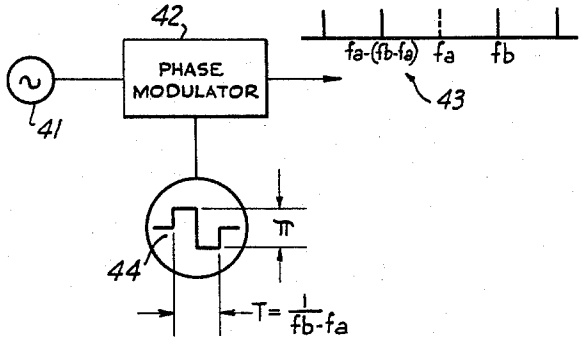
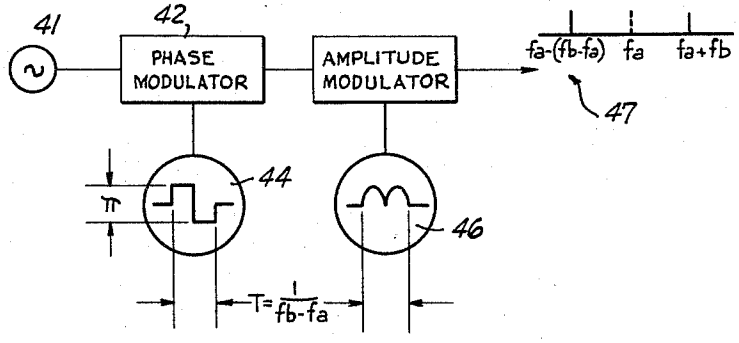


FIG_3_



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HIGH SPEED BINARY COUNTER

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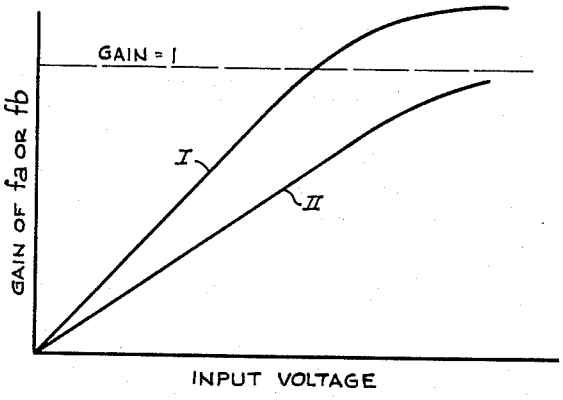
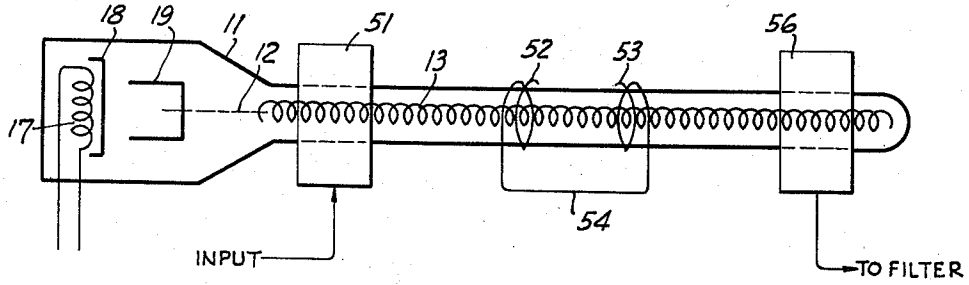


FIG_4_

FIG_5_



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United States Patent Office 2,944,224 Patented July 5, 1960

2,944,224

HIGH SPEED BINARY COUNTER

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Filed May 10, 1957, Ser. No. 658,337

12 Claims. (Cl. 331—82)

This invention relates generally to a high speed binary counter and more particularly to a high speed binary counter making use of a bistable oscillator.

Advances in the fields of nuclear studies and high speed digital computers have created a demand for high speed counters capable of counting random phenomena separated in time by a few millimicroseconds.

It is essential in the counting of random phenomena that the counter have memory, accuracy and speed of response.

It is a general object of the present invention to provide an improved high speed binary counter.

It is another object of the present invention to provide a high speed counter making use of a bistable oscillator and having high speed of response, memory and reliability.

It is another object of the present invention to provide a high speed binary counter in which an oscillatory loop adapted to oscillate at predetermined modes is coupled to an electron beam with switching from one mode to another being controlled by the excitation of the electron beam.

It is a further object of the present invention to provide a high speed binary counter which employs an oscillator including a helical transmission line coupled to an electron beam, the oscillator being adapted to oscillate at predetermined modes and having the helical transmission line coupled to an electron beam. The excitation of the electron beam serves to control the oscillatory mode.

It is a further object of the present invention to provide a high speed binary counter which employs a tube of the traveling wave type having a plurality of sections with one of said sections forming a bistable oscillator.

It is a further object of the present invention to provide a high speed binary counter which employs a traveling wave tube having a plurality of sections, said tube including a section which is adapted to oscillate on predetermined modes coupled to the electron beam and a front section serving to introduce a switching signal onto the electron beam whereby the same is excited to effect control of the mode of oscillations of the oscillator section.

These and other objects of the invention will become more apparent from the following description read in conjunction with the accompanying drawing.

Referring to the drawing:

Figure 1 shows one embodiment of my invention;

Figure 2 shows a means for forming a suitable signal for exciting the beam prior to entry into the bistable oscillator;

Figure 3 shows another means for forming a signal suitable for exciting the beam prior to entry into the oscillatory loop;

Figure 4 shows curves of output voltage as a function of input voltage for a beam coupled to the bistable oscillator; and

Figure 5 shows another embodiment of the invention.

Referring to Figure 1, a high speed binary counter is shown. The counter illustrated includes an evacuated envelope 11. An electron beam 12 is projected concentrically through helical transmission lines 13, 14 and 15 which are disposed in the envelope and which support electromagnetic waves. Suitable means (not shown), for example, a solenoid is employed to keep the beam focused in its travel through the helical transmission lines whereby the beam does not impinge upon the helix. The beam is formed and projected by the combination of the heater 17, cathode 18 and plate 19. See for example Pierce, Travelling Wave Tubes, D. VanNostrand Co., 1950.

As is well known, electromagnetic waves are propagated along a helical transmission line at less than free space velocity. The velocity along the axis of the helical transmission line depends upon the radius and pitch of the helix and is generally much less than the free space velocity. When the electron beam velocity is correctly adjusted so that it coincides with the phase velocity of the wave carried by the helix, the two are in synchronism. Under these conditions, there is coupling between the fields of the beam and those on the helix and the alternating current waves on the beam and the helix grow at the expense of D.-C. beam energy. The wave carried by the helix is amplified as a result of the interaction. The wave carried by the beam serves to excite alternating current waves on a helix coupled thereto as a result of the interaction.

A variety of ways exists for coupling a wave on and off a traveling wave tube helix. For example, waveguide input and output couplers may be employed. The coupling may also be effected by use of contrawound helices placed concentrically to the main helix. The helix then forms a directional coupler with uniform coupling being achieved over a broad band of frequencies. A suitable coupler is described in copending application entitled "Helix Directional Coupler," Serial No. 403,172, filed January 11, 1954, now abandoned.

In Figure 1, the switching signal which serves to control the degree and nature of beam saturation (the excitation) entering the oscillatory portion of the counter is coupled onto the section of helical transmission line 13 by means of the contrawound directional coupler 21. The section of the tube designated generally by the bracket 22 comprises an amplifier section which serves to amplify the applied control signal and to modulate or excite the beam in accordance therewith. The bistable oscillatory circuit is formed by the short section of helical transmission line 14 and the line 23 which interconnects the ends of the transmission line. The portion of the tube designated generally by the bracket 24 forms a high speed bistable oscillator. The helical transmission 14 is coupled to the electron beam and waves are excited thereon by the coupling between the waves on the beam and the helix. The waves induced on the helix 14 are coupled to the beam whereby they further excite or modulate the beam in accordance therewith.

By controlling the delay in the feedback in the portion 24, oscillations having the desired mode frequency separation Δf may be obtained. The prevailing relationship for the mode separation is $\Delta f = 1/T$ where T is the time delay in the feedback path. As the delay T is reduced, Δf the frequency separation is increased. If the available bandwidth is B, then the theoretical number of modes available is determined by the bandwidth B. Preferably, in operation the oscillatory modes are spaced as much as possible in frequency.

The helical portion of the oscillator section serves to modulate the beam traveling therethrough, as previously described. An indication of the mode of oscillation of the bistable circuit may be obtained by coupling a signal

off the beam after it has been excited or modulated in its passage through the oscillatory section. For example, the helix portion **15** has a signal induced thereon by the beam and it amplifies the signal and increases the beam modulation to provide an output signal on the beam and on the helix. The signal on the helical transmission line **15** may be coupled off by means of a directional coupler **25**. The output is then applied to a filter **26** which serves to filter out all components except the desired modes, as will be presently described. An output signal may also be obtained by introducing a resistor in series with the collector and coupling off the high frequency voltage appearing across the resistor. The section of the tube designated generally by the bracket **24** forms the output section of the electron tube.

For purposes of discussion, assume that the oscillator portion of the binary counter, including the transmission line **14** and feedback path **23**, is adapted to oscillate at two distinct frequencies separated by the frequency Δf. The frequencies may be designated as f_a and f_b. The loop gain is adjusted so that the oscillator can only oscillate at one or the other of the frequencies f_a or f_b, but not both frequencies, the bistable condition.

As previously described, by properly adjusting the degree and nature of beam saturation (excitation) upon entry into the oscillator portion, the loop gain in the bistable oscillator is controllable to effect switching from one oscillatory mode to the other. For example, if the beam is modulated by an appropriate signal in the forward gain section **22**, the beam will have the requisite degree and nature of saturation on entry into the oscillatory loop **14**.

Fundamentally, the switching from one oscillatory mode to another for the bistable oscillator consists in disabling the oscillator for one given mode and exciting the oscillator for the desired mode. The oscillation is stopped in any manner that allows the small signal loop gain to be reduced to a value below unity. The desired mode is excited by a signal of appropriate frequency having a magnitude which is greater than that of the remaining undesired mode frequency. By properly modulating (exciting) the beam upon entry into the helical transmission line **14**, forming a part of the bistable circuit, heterodyning of the oscillating mode with the frequency on the beam produces signal components of various types. If the frequencies and amplitudes are properly adjusted, the heterodyning, or non-linear mixing, will produce signal components at the operating frequency of the bistable oscillator which serve to reduce the loop gain in the oscillating mode to a value below one and allow signal components to build up in the other desired mode. Thus, if the oscillator is operating at the frequentcy f_a, the signal components will reduces the gain at frequency f_a below one and excite the frequency f_b.

When the signal applied to the forward gain section is removed, the oscillator will then continue to oscillate at the frequency f_b. By appropriately choosing the signal applied to the forward gain section, a reverse process can be carried out with an identical applied switching signal. Thus, upon excitation of the beam by application of a second pulse to the forward gain section, the loop gain for frequency f_b will be reduced below one and the frequency f_a will be excited.

An appropriate beam gain characteristic for bistable operation is shown in Figure 4. Oscillations are sustained when the beam gain is given by the curve I and oscillations are not sustained when the beam gain is given by the curve II. Operation along the curve I is obtained when only one frequency f_a or f_b is present. Operation along the curve II is obtained for f_a or f_b weak and f_b or f_a strong, respectively.

A suitable switching signal for application to the forward gain section **22** is a pulse with the carrier having the sum frequency of f_a and f_b. Referring to Figure 1, a signal generator **32** generates a continuous signal having frequency f_a+f_b. The frequency is applied to a modulator **33** which acts as a switch. Upon application of a pulse **34** to the modulator, an output will appear at the modulator which has a pulse envelope as shown at **36** with the frequency f_a+f_b as the carrier. This signal is then applied and amplified by the forward gain section. Heterodyning produces a difference frequency which when combined gives strong and weak frequency components, as previously described, to switch the oscillating mode f_a or f_b, whichever is present, from curve I to curve II. The period of the pulse **34** should be approximately equal to the loop delay whereby the heterodyning takes place and the other mode is generated before the pulse is terminated. If the period is much less or much longer than this, switching will not be reliably effected.

Other types of switching signals are suitable for performing the switching. Thus, suppressed carrier phase modulation may be employed. A suitable signal generator **41**, Figure 2, generates a continuous wave of frequency f_a and applies the same to the phase modulator **42**. The modulator **42** is square wave modulated. The output of the phase modulator is a suppressed carrier signal having frequency components of the type shown at **43**, that is, $f_a \pm n(f_a - f_b)$. The suppressed carrier phase modulator may be modulated by a single square wave of the type shown at **44** which has sufficient amplitude to vary the phase through π radians and a period T which is approximately equal to the loop delay.

The output from the phase modulator of Figure 2 may be applied to an amplitude modulator which is then modulated by a signal of the character shown at **46**. This serves to form an output signal which has a single pair of side bands $[f_a \pm (f_a - f_b)]$ as shown at **47**.

Any of the signals described when employed to excite an electron beam traveling through the helical portion of the bistable oscillator will serve to switch the bistable oscillator from one mode to another. The latter signals employ difference frequencies to switch while the former employs the same frequency.

The bistable oscillator may be formed in a manner other than that illustrated in Figure 1. Referring to Figure 5, for example, the signal is shown applied to the forward gain section by means of a waveguide coupler **51**. A pair of contrawound helical couplers **52** and **53** are coupled to a portion of the helical transmission line and include a feedback path **54**. The couplers form the bistable oscillator. An output signal is obtained by a second directional coupler **56**.

The essential feature is that a bistable oscillator be formed which is coupled to an electron beam and which is adapted to oscillate at predetermined mode frequencies separated by a frequency Δf. The oscillator should be responsive to beam excitation whereby one or the other of the modes may be excited.

The output signal may be applied to a filter having suitable pass characteristics. For example, assume that f_a is less than f_b, then when the oscillator is operating on the mode frequency f_b, the output signal will have frequency components $f_a \pm (f_a+f_b)$ and $2f_a+f_b$. When operating at the mode frequency f_a, the output will have the frequency component f_a+2f_b. Other frequencies will appear but will have such small amplitudes that they may be disregarded in this analysis. If a high pass filter which will pass a frequency f_a+2f_b but will reject $2f_a+f_b$ is used, an output signal will be present at the filter when the bistable oscillator is switched from f_b to f_a but not when switched from f_a to f_b. Thus division by two is performed by the circuit. For each two input pulses a single output pulse is obtained.

I claim:

1. A high speed binary counter comprising means forming an electron beam and means serving to receive said beam, a bistable oscillator coupled to said beam and adapted to oscillate at predetermined modes said oscil-

lator adapted to oscillate at only one mode at one time, means for exciting the electron beam prior to coupling to the bistable oscillator to switch the oscillator from one oscillatory mode to another.

2. A high speed binary counter comprising a traveling wave tube having means forming an electron beam and means serving to receive the same, a bistable oscillator including a helical transmission line coupled to said beam and adapted to oscillate at predetermined modes, said oscillator adapted to oscillate at only one mode at one time, means for exciting the electron beam prior to coupling to the oscillator to switch from one oscillatory mode to another.

3. A high speed binary counter comprising a traveling wave tube having means forming an electron beam and means serving to receive the beam, an oscillatory loop coupled to said beam and adapted to oscillate at predetermined modes, said loop being adapted to oscillate at only one mode at one time, and means for modulating the electron beam prior to coupling with the loop to switch the oscillatory loop from one mode of oscillation to another.

4. Apparatus as in claim 3 wherein said means for modulating the beam comprises a slow wave structure coupled to said beam and serving to receive and amplify an input signal and modulate the electron beam in accordance therewith.

5. A high speed binary counter comprising a traveling wave tube having means forming an electron beam and means serving to receive said beam, a first gain section coupled to said beam and adapted to receive an input signal, a second section coupled to said beam and connected to form an oscillator adapted to oscillate at predetermined mode frequencies, said oscillator adapted to oscillate at only one mode at one time, means for applying a switching signal to said first gain section whereby the electron beam is modulated prior to coupling with said second section, said modulation serving to control the grain of the second section to switch the section from one oscillatory mode to another in response to the input signal.

6. A high speed binary counter comprising a traveling wave tube having means forming an electron beam and means serving to receive said beam, a first gain section coupled to said beam and adapted to receive an input signal and excite the beam in accordance therewith, a second section coupled to said beam and connected to form a bistable oscillator adapted to oscillate at the frequencies f_a or f_b but not both, means for forming a switching signal having frequency components f_a and f_b, means for applying said signal to the first gain section to modulate the beam in accordance therewith, said modulated beam serving to control the gain of the second section to switch the frequency of oscillation from one frequency to the other.

7. Apparatus as in claim 6 wherein said switching signal comprises a pulse having a carrier frequency f_a+f_b.

8. Apparatus as in claim 6 wherein said switching signal is a suppressed carrier phase modulated signal having the frequency characteristics $f_a \pm n(f_a+f_b)$, where n is an integer.

9. Apparatus as in claim 6 wherein said switching signal has the frequency characteristics $f_a \pm (f_a+f_b)$.

10. A high speed binary counter comprising a traveling wave tube having means forming an electron beam and means serving to receive said beam, a bistable oscillator section coupled to said beam and adapted to oscillate at predetermined mode frequencies, means for exciting said beam prior to entry into said bistable oscillator section, means forming a switching signal for application to said last named means, and means for coupling an output signal from said beam after its passage through the bistable oscillator.

11. Apparatus as in claim 10 together with filter means connected to receive the output signal and pass predetermined frequencies whereby the oscillating mode of the bistable oscillator may be sensed.

12. A high speed binary counter of the type adapted to be triggered by input pulses comprising a travelling wave tube having means forming an electron beam and means serving to receive said beam, a first gain section including a slow wave structure coupled to said beam, said gain section serving to receive an input signal and modulate the beam in accordance therewith, a second section including a slow wave structure coupled to said beam and connected to form a bistable oscillator adapted to oscillate at the frequency f_a or f_b but not both, means connected to receive the input pulse and serving to form a switching pulse having frequency components f_a and f_b, means for applying said pulse to the first gain section to modulate the beam in accordance therewith, said modulated beam serving to control the gain of the second section to switch the frequency of oscillation from one frequency to the other in response to successive pulses.

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