June 29, 1954 R. P. MORK 2,682,616

FREQUENCY DIVIDING SYSTEM

Filed Jan. 11, 1952

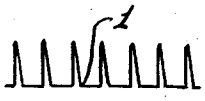


FIG. 1.



FIG. 2.



FIG. 3.

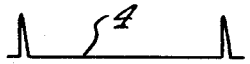


FIG. 4.

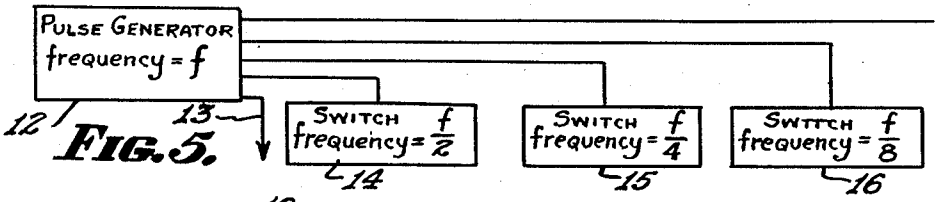


FIG. 5.



FIG. 7.

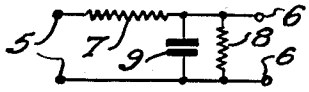


FIG. 6.

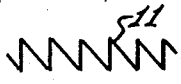


FIG. 8.

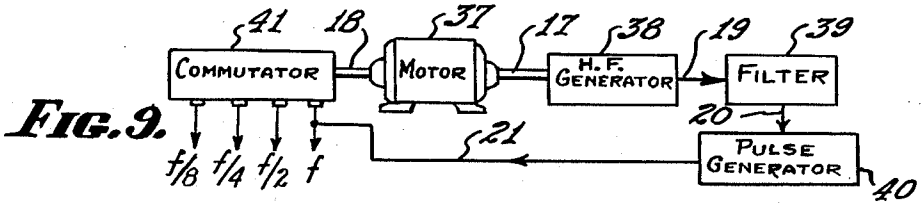


FIG. 9.

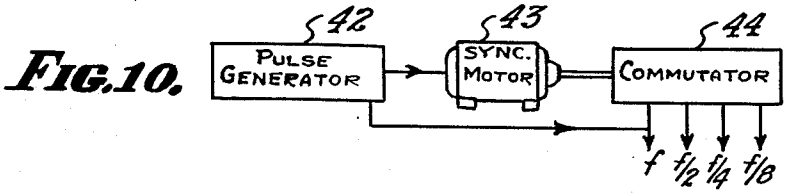


FIG. 10.

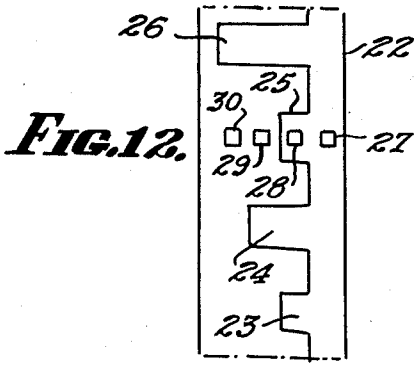


FIG. 12.

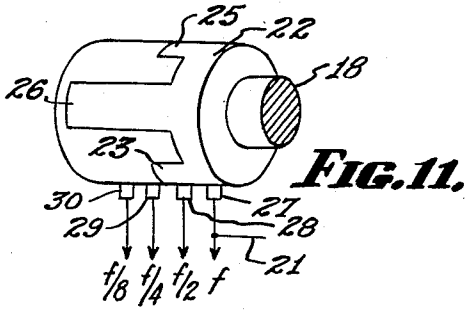


FIG. 11.

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Patented June 29, 1954

2,682,616

UNITED STATES PATENT OFFICE

2,682,616

FREQUENCY DIVIDING SYSTEM

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Application January 11, 1952, Serial No. 265,980

12 Claims. (Cl. 307—106)

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This application is a continuation-in-part of my copending application of the same title, Serial No. 60,807, filed November 18, 1948, now abandoned.

My invention relates to the generation of harmonically related pulsations. It is particularly applicable to the production of electric pulsations for musical tones in electrical musical instruments. For convenience, therefore, in this specification I shall describe it as directed to such instruments, particularly to instruments of the organ type in which a large number of musical tones must be producible at will or selectively combinable, at various pitches and timbres in accordance with the requirements of a musical composition.

An object of the invention is to provide a system for producing electric pulsations of a plurality of frequencies in exact harmonic relationships, wherein pulsations of a desired frequency are not clouded by noise elements or other detracting quantities such as subharmonic frequencies.

Another object of the invention is to provide a system, in keeping with the above object, which will handle pulsations of considerable intensity. In this connection the invention is especially applicable to electro-mechanical devices for producing pulsations, such as rotating commutators, vibrating reeds or tuning forks provided with contacts, or the like. Such devices are usually prone to the production of electrical noise elements through sparking or arcing, and even if noise due to these is removed by special means, statistical variations in frequency remain and appear as extraneous noise due to mechanical inaccuracies in the devices. My invention seeks by its inherent nature the removal of such detracting effects.

Still another object of the invention is to provide a system for producing pulsations in which pulsations of a plurality of frequencies are not only in exact harmonic relationships but also exactly in phase. This in-phase feature of my invention renders it susceptible of use in several applications, such as radar systems wherein the overcoming of or accounting for small time delays presents a problem.

Still a further object of the invention is the provision of a system in which a series of harmonically related frequencies can be stabilized from a single source.

Various types of electro-mechanical devices have hitherto been sugested for producing pulsations of energy at selected frequencies, which pulsations could be converted into sound waves.

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For example, in photoelectric instruments a beam of light may be interrupted at a desired frequency, and the interrupted beam caused to impinge on a photoelectric cell. An electrical current flowing in a conductor may be interrupted at desired frequencies by electro-mechanical means such as rotating commutators, vibrating reeds or tuning forks provided with contacts, and in other ways. Pulsating currents may be produced by electro-mechanical means which cause variations in capacity or inductance in a suitable circuit, or which produce similar results by varying the effective separation of a magnetic material and a coil.

Certain of these systems have a disadvantage in that the power generated is undesirably limited, requiring much amplification to raise it to useful levels, and making for a high noise level since the noise content is amplified along with the signal. All of these systems have the disadvantage that the cleanliness of the tones generated depends either on the stability and accuracy of operation of mechanical means, or upon the accuracy of configuration of essentially mechanical elements, or both. Inaccuracy or inconstancy in either of these particulars may result in lack of stability in the frequency and amplitude of the pulsations generated; but inaccuracy in the configuration of mechanical means is likely to become evident in extraneous noise in the tones. The photoelectric organ has not attained wide commercial development, and one reason for this undoubtedly lies in the difficulty of producing light interrupting and wave form modifying means for sufficient accuracy to give pure and noise-free tones. The type of generating system in which a magnetic pick-up is mounted adjacent a rotating, configured, magnetic disc has been developed primarily as one in which simple or sine wave pulsations are generated, which must then be combined by elaborate interconnections to give rich tones of high harmonic content.

Electronic oscillators, on the other hand, produce relatively clean tones of controllable richness or harmonic content and have been successfully used in various instruments. For an instrument of the organ type, where the number of tones which must be generated is large, the electronic equipment is greatly multiplied and becomes complex and expensive. It is true, however, that electronic oscillators have been adequately stabilized as to frequency and amplitude, although in some applications the power produced in undesirably small. Individual amplification of the oscillations produced by each gen-

erator obviously unduly increases the complexity of the electronic equipment in an organ in which there must be at least one generator for each note within the entire range.

Electro-mechanical instruments making use of various forms of frequency dividers have hitherto been suggested, but while frequency division has the advantage of tying together octavely related oscillations or pulsations, each element of an electro-mechanical frequency divider network usually adds its own extraneous noise to the system, while the interaction of elements upon each other in such a network is often productive of sub-octave frequency or amplitude modulation, and sometimes, directly, of noise. Electro-mechanical devices of the make-and-break type have, as is well known, various mechanical deficiencies including bouncing of the contacts at the instants of make and break, and various electrical difficulties such as high frequency surges, and the like.

It is an object of this invention to provide a system in which electro-mechanical frequency dividers may be employed without encountering any of the above-mentioned disadvantages.

To the extent that I may employ electronic oscillators in my system, it is an object of the invention to provide a system in which the electronic equipment is simplified and held to a minimum.

It is an object of my invention to provide a generating system employing electro-mechanical frequency dividing means, which nevertheless is productive of pure tones, relatively free of extraneous noise, and devoid of objectionable interactive effects.

These and other objects of my invention, which will be set forth hereinafter or will be apparent to one skilled in the art upon reading these specifications, I accomplish in that system of operating elements, and in that mode of operation of which I shall now describe certain exemplary embodiments. Reference is made to the accompanying drawings wherein:

Figures 1 to 4 inclusive are diagrammatic representations of wave forms illustrative of the derivation of octavely related frequencies.

Figure 5 is a diagrammatic representation of the relationship of elements in a type of frequency dividing system within the invention.

Figure 6 is a diagram of a wave form modifying circuit, while Figures 7 and 8 respectively diagrammatically illustrate the wave forms of the input and output respecting such a circuit.

Figure 9 is a diagrammatic representation of a specific generator and frequency divider system.

Figure 10 is a diagrammatic representation of a somewhat modified system.

Figure 11 is a view of a commutator such as may be employed in the systems of Figures 9 and 10.

Figure 12 shows the surface of the commutator developed from the cylindrical to a planar representation.

Briefly, in the practice of my invention, I provide a main frequency generator for each of the notes in one octave of a desired musical scale, for example, the so-called tempered musical scale. In this event there will be twelve such main generators. Since frequency division is to be employed, these generators will produce oscillations of frequencies in a high register, either higher than the highest octave within the range of the instrument, or within that octave, the latter arrangement being preferred for economy, since in this event the output of the main generators may directly be employed for the tones of the highest octave of the instrument.

The main frequency generators may take various forms, and I am not limited in this respect. I may employ mechanical contact means to interrupt electric currents at the desired frequencies; and in the application of the teachings herein to the photoelectric type instrument, the main generators will comprise means for interrupting beams of light such, for example, as pitch tracks on a rotating disc or cylinder. Excepting in photoelectric musical instruments, my preference is for the use of electronic oscillators as the main frequency generators, since, as is well known, oscillators of this class have been developed having very great frequency and amplitude stability as well as dependability. Since there will be but twelve of the main frequency generators, it is economically possible in my invention to employ individual amplification means at each such source if a high initial power output is desired. It is also within the scope of my invention to employ generators in which electronic means are combined with electro-mechanical means, such as reeds or tuning forks driven by electronic oscillators.

In the practice of my invention, however, it is essential that the main generators produce at the desired individual frequencies, sharp pulses of energy having substantial intervals therebetween, the pulses preferably but not necessarily being of a duration less than the intervals between pulses. In a photoelectric system this condition can be attained if a beam of light is caused to impinge upon a uniformly moving element bearing a pitch track in which narrow light slits recur at uniform spacings with opaque areas between the light slits, the beam being of such width that it can pass through only one slit at a time. In electrical terms, the condition will be obtained in a circuit in which substantially straight-sided voltage pulsations occur at regular intervals, the pulses preferably but not necessarily being of substantially shorter duration than the intervals, there being in the circuit little or no voltage during the said intervals.

It is well known that voltages may be derived from electronic oscillators having substantially the wave forms shown at **1** in Figure 1. Make-and-break contact means including vibrators, commutators and the like, can be caused to produce pulsations of substantially the same wave form, although if the contact elements operate at theoretical perfection, the pulses will be square-topped.

The diagrammatic wave form shown in Figure 1 is characterized by brief pulses and substantial intervals between pulses, irrespective of the specific frequency involved. Pulsations of this character are well adapted for frequency division since, if a switching means, i. e. a pulse passing means, is set up which will pass to an output circuit every other pulse, as at **2** in Figure 2, the frequency will be halved. If a switching mechanism is arranged to pass every fourth pulsation as at **3** in Figure 3, a frequency two octaves below the original frequency will be obtained. Similarly, a switching mechanism which will pass every eighth pulsation in the initial wave form, as at **4** in Figure 4, will provide the next lower octave, and so on throughout the range of the instrument.

Assuming that such frequency division can be adequately accomplished, it will be noted that

the wave forms produced are essentially similar. Each is characterized by pulses of brief duration separated by substantial intervals in which no energy is transmitted; the duration of the pulses remains the same in the octavely related wave forms; and the intervals between pulses become increasingly longer as the frequency becomes less. This type of wave form, however, is not desirable, either for direct conversion into sound, or for voicing by means of filter circuits. If directly converted to sound, the tone will be highly acid and generally displeasing excepting possibly for special voices. For the production of distinctive voices in great variety by the application of filter circuits, outphasing and the like, a wave form is desired which is rich in harmonics and controlled as to harmonic content. But if a series of brief pulses at a given frequency is impressed upon a circuit containing properly related resistive and capacitative elements, the wave form of the pulsations will be changed. In Figure 6 I have diagrammatically shown a circuit having input terminals 5 and output terminals 6 connected by suitable leads. In one of the leads I have indicated a resistor 7. The leads are shunted by a resistor 8 and a capacity 9 in parallel. With the constants properly chosen in such a circuit, an input wave form diagrammatically illustrated at 10 in Figure 7 will be converted by the circuit to an output wave form indicated at 11 in Figure 8. The latter wave form is one rich in harmonics and suitable for voicing by means including filters. Thus the spaced-pulse nature of my initial tones is not a detriment to the production of final tones of other and more desirable characters.

It may be stated at this point that it is desired to accomplish the frequency division of the generated tones when they have the spaced-pulse character, for reasons which will hereinafter be given. Hence the conversion of these tones to ones of other wave form should follow the frequency division in the generating system. In an instrument in which a common return, namely ground is provided for all pulsations, a lower lead 6 in circuit diagram of Figure 6 may be considered as ground.

Advantages of accomplishing the frequency division of spaced-pulse type of tones will now be explained. The frequency division itself may be accomplished by mechanical or electro-mechanical means. Where the tones are generated as electrical pulsations, frequency division may be effected by make-and-break contact means, inclusive of commutators, vibrating reeds or tuning forks, and the like. These constitute mechanically operated switches running in synchronism, i. e. in exact harmonic relationships and in phase with each of the main frequency generators, as will be evident. In the case of a photoelectric instrument, the "switches" may be additional pitch tracks placed in the path of the initially interrupted beams, and acting essentially as commutators for light instead of electric current. The term "mechanical switches" is a convenient one to use in this connection; and from the explanation above it will be evident that if the first switch lets through only every other pulse of the initial wave form, the frequency will be halved; if it lets through every fourth pulse, the frequency will be one-fourth of the initial frequency, and so on.

Referring to Figure 5, which is a diagrammatic illustration of such a system, 12 indicates a main

generator of the type to which I have referred. A plurality of leads is drawn from this generator. The first lead, 13, is a lead from which may be derived the frequency of the main generator itself. The other leads go respectively to switch mechanisms designated at 14, 15 and 16, etc., which operate in the way described to divide the frequency developed by the main generator and provide sub-octavely related frequencies.

The various switch mechanisms 14, 15, 16 etc. may be tied together mechanically as desired, or may be otherwise synchronized. It is not necessary that the generator feed pulses directly to each of the switch mechanisms in parallel as indicated in Figure 5. Instead the switch mechanisms may be arranged in series, one feeding pulses to the other as well as providing an output means from which its own frequency may be derived. Thus switch mechanism 14 may serve to divide the frequency generated by the main generator in half, and deliver pulses at half frequency to switch mechanism 15. If switch mechanism 15 operates to halve the delivered pulses, it will produce a frequency which is one-quarter of the frequency provided by the main generator, and so on throughout the system.

The frequency dividing switches will run in synchronism with the frequency of the main generator in any such system; but regarding the frequency dividing switches as gates which let through individual pulses provided by the main generator, it will be evident that so long as these gates open at the proper times to let the desired pulses through and stay open long enough for this purpose, other inaccuracies in their operation are nugatory. Suppose, for example, a particular frequency dividing switch or gate is in the nature of a commutator. So long as electrical contacts are made at the commutator during times etxending before, during and after the desired passage of pulses, the system will operate perfectly. There may be inaccuracies in the commutator segments such that if the commutator alone were relied upon to produce a musical tone, this tone would be full of extraneous and undesired noise, and would be entirely unsuitable for use in an electric musical instrument. When, however, the individual pulses are transmitted as described, there will be no noise or inaccuracy in the tone which is the result of frequency division, other than that which was present in the tone generated by the main generator. The individual pulses are separated by substantial intervals as has been described, and the changes in the contacts of the switches, commutators or other frequency dividing means occur wholly during these intervals. Under these conditions, inaccuracies or variations in the operation or the construction of the switches, commutators or the like cannot affect the shape of the pulses which they allow to pass from the generator to their respective output circuits. Hence, they cannot introduce extraneous noise, sub-octave coupling, or other tonal defects. It will now be evident why there should be, in the initial train of pulses, no energy at all or only a very small level of energy in the intervals between pulses, since if any appreciable energy is transmitted during such intervals, inaccuracies in the construction or operation of the frequency dividing switches will be productive of noise. It will further become clear at this point to those skilled in the art that pulsations of various frequencies through frequency division in this invention are

in exact harmonic relationship and exactly in phase.

Various other advantages inhere in my procedure and apparatus. In an electrical system, since the make and break of the contacts at the frequency divider switches occurs during periods of no current flow, arcing, sparking, high frequency surges and like difficulties are avoided. In all of the modifications referred to, sub-octave frequency modulation in any of the tones which are the result of frequency division is avoided entirely. Nor is any real difficulty encountered with sub-octave amplitude modulation. Such modulation would be present only if a key switch one or more octaves below the switch for a desired divided frequency were simultaneously pressed, in which case the modulation would not be objectionable. In any event, sub-octave amplitude modulation can be made small by keeping the impedance of the main generator low or by electrically inserting dummy impedance loads on the generator with respect to those pulses of the original tone which are not used in any particular divided tone.

In the event electronic oscillators are employed as main generators, even if amplification is provided at the source, the electronic equipment of the electrical musical instrument is kept simple and inexpensive since there will be only twelve such main generators in all. The mechanical or electro-mechanical equipment for frequency division can also be kept simple and inexpensive. In Figure 9 I have shown a simple system which is operative for the purpose. As marked in the figure, the system includes a motor **37**, high frequency (H. F.) generator **33**, filter **39**, pulse generator **40** and commutator. The motor may be energized from any suitable electric current, such as commercial sixty-cycle current, and through shafts **17**, **18** drives the high frequency generator and the commutator.

The high frequency generator may take several forms. For example, it may consist of a multiple poled alternator generating electric oscillations at a frequency corresponding to a note in a high octave register of a musical scale. Electrically connected in series to the generator through connections **19**, **20** are a filter **39** for removing undesired electrical effects in the generator output and an electronic pulse generator **40** for converting the generator oscillations into sharp electrical pulses as wanted. The commutator, in turn, is electrically connected through **21** to the pulse generator and synchronized therewith via the motor and the proper angular locations of the commutator elements.

As shown in detail in Figure 11, the commutator has a main metallic slip ring **22** having equispaced metallic extensions **23**, **24**, **25** and **26** extending to various lengths along the commutator. The slip ring **22** is continuously contacted by a brush **27** to which the connection **21** from the pulse generator is attached. Further in surface contact with the commutator are the brushes **28**, **29** and **30** so interspaced that the brush **28** is contacted successively by all four of the metallic extensions of the commutator, the brush **29** is contacted only by the alternate extensions **24** and **26** and brush **30** is contacted only by the longest extension **26**. This arrangement is shown more clearly in the developed form in Figure 12. Each of the extensions is of such a width that its contact time, in passage, with a brush is appreciably longer in duration than the time of a single pulse from the pulse generator. Furthermore, the commutator is arranged to rotate at such a speed that the extensions contact the brush **28** at a rate corresponding to a frequency one-half the frequency *f* of the generated pulses, extensions **24** and **26** contact the brush **29** at one-fourth the generator frequency, and extension **26** contacts the brush **30** at one-eighth frequency.

Connected to the several brushes are respective leads for deriving pulses at the several frequencies *f*, *f*/**2**, *f*/**4** and *f*/**8**, and I have so marked these leads. It will thus be seen that through the system, pulses are obtained at desired frequencies, which in this case I have shown as successively octavely related frequencies as particularly applicable in a musical instrument. It will further be clear through the design, that pulses are transmitted and obtained from the generator, at the several divided frequencies, without change in form of phase, all frequencies being in phase and in exact relationships. It will be understood that the leads *f*, *f*/**2**, *f*/**4** and *f*/**8** may be suitably branched if required for use in an instrument containing a plurality of keyboards.

The modified system of Figure 10 employs the pulse generator **42** to energize the motor **43** for rotation as well as providing pulse energy for the commutator **44**. Otherwise, the system of Figure 10 is similar to that of Figure 9.

Modifications may be made in my invention without departing from the spirit of it. Having described my invention in certain exemplary embodiments, what I claim as new and desire to secure by Letters Patent is:

1. A system for producing a series of harmonically related electric oscillations comprising in combination a pulse generator having a frequency equal to the highest in said series, and a series of intermittent contact devices in connection therewith and receiving pulses produced by said generator and acting to pass certain of said pulses to output circuits and to block others whereby to effect frequency division, means for operating said intermittent contact devices in timed relationship with the pulses produced at the generator, the generator producing pulses of short duration separated by substantial intervals, and said intermittent contact devices having contact times substantially longer than the duration of individual pulses, whereby said contact devices pass series of pulses of divided frequency which series are unmodified by specific inaccuracies in the operation of said intermittent contact devices.

2. The system claimed in claim 1 in which said output circuits contain impedance combinations for modifying the harmonic content of the several series of passed pulsations.

3. The system claimed in claim 1 in which the pulse generator comprises an electronic oscillator.

4. The system claimed in claim 1 in which the pulse generator comprises an electronic oscillator, and in which said intermittent contact devices are rotary devices driven in timed relationship to the frequency of the generated pulses.

5. The system claimed in claim 1 in which the pulse generator comprises an electronic oscillator, and in which the output of the pulse generator is fed directly to each of the intermittent contact devices in the series.

6. The system claimed in claim 2 in which the pulse generator comprises an electronic oscillator, and in which the output of the generator is fed to the first intermittent contact device of the series, the output of the second to the third and so on, and in which each successive intermittent

contact device operates to block every other pulse of the pulsations fed to it.

7. In an electrical musical instrument a series of twelve main generators each producing pulses at a frequency responding to the frequency of a note in the tempered musical scale in a high register, said pulses being of short duration and high energy level, and separated by substantial intervals at substantially zero energy level, and frequency dividing means operating in timed relationship with each of said generators and of the character of intermittent contact devices, said devices closing respectively in phase with said pulses and at rates related to said frequency by inverse integral powers of two, the contact times of said intermittent contact devices having a duration substantially longer than the duration of individual pulses, whereby to accomplish frequency division without the introduction of extraneous noise.

8. A system for producing a series of harmonically related electric pulsations, comprising in combination a pulse generator having a frequency at least as high as the highest in said series, and a series of intermittent pulse passing devices receiving pulses produced by said generator and acting to pass certain of said pulses and to block others whereby to effect frequency division, means for operating said devices in timed relationship with the pulses produced at the generator, the generator producing pulses of short duration separated by substantially longer intervals, and said pulse passing devices having passage times substantially longer than the duration of individual pulses, whereby said devices pass series of pulses of divided frequency which series are unmodified in pulse shape or phase.

9. In a frequency dividing system for producing octavely related musical tones, a source of periodic, short duration pulses of energy of a given frequency, a plurality of pulse passing switches in connection with said source, and actuating means for said switches synchronized with said source, the respective switches being closed by said means in phase with said pulses and at rates related to said given frequency by inverse integral powers of two and for durations greater than the duration of said pulses.

10. A system as claimed in claim 9, in which said source is a generator of electric pulses and said switches are electric contact devices.

11. A system as claimed in claim 10, including an output circuit in connection with said switches, said circuit containing an impedance network for converting individual pulses to wave forms of controlled harmonic content.

12. A process of producing a series of harmonically related musical tones which comprises the steps of producing pulsations of energy at a given frequency, the individual pulsations as produced being of brief duration with intervals between of substantially greater duration than the pulses themselves, and passing certain of the individual pulsations and blocking others by operating frequency dividing means in phase with said pulses and in passing condition for a time substantially longer than the duration of the individual pulses, whereby individual pulses are passed by the frequency dividing means without modification.

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