

- [54] **GAIN CHANGE CONTROL CIRCUIT FOR TIME SYNCHRONIZATION**
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343/112 CA
- [51] Int. Cl. **G01s 9/56**
- [58] Field of Search.....235/150.2-150.27, 92 DM,
235/92 CC, 92 PL; 343/7.5, 112 CA, 225

3,636,336 1/1972 Everett et al. 235/92 PL

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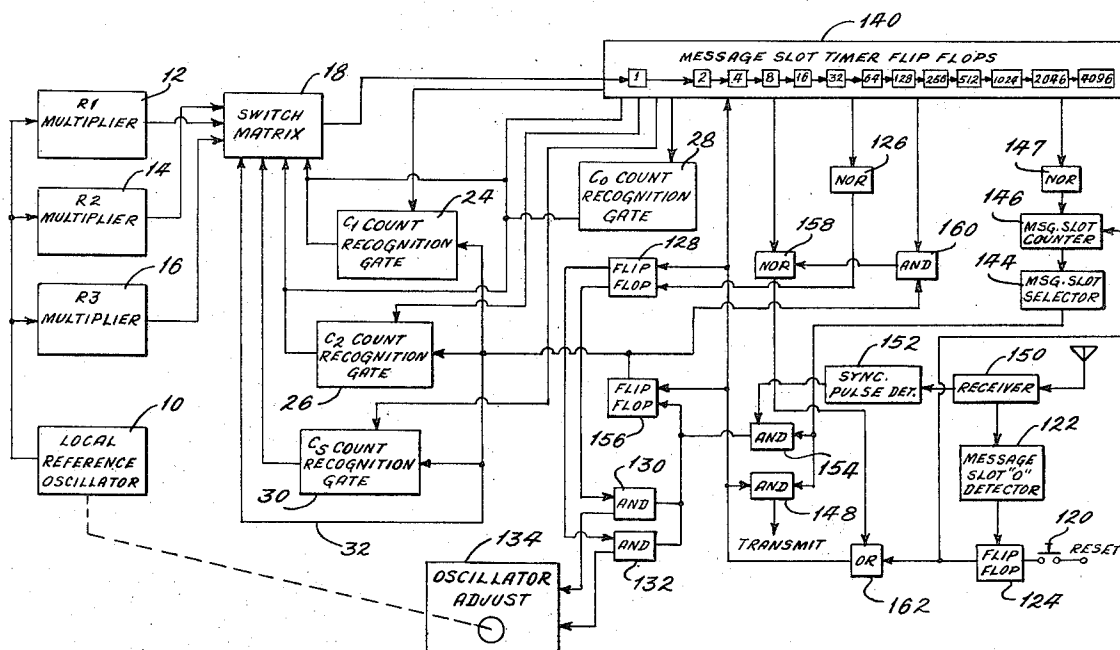
[57] ABSTRACT

The present gain change means represent an improvement over the time synchronization means for remotely positioned timing devices. The present improvement includes means for changing the gain so as to provide multiple correction factors in time synchronization means, and the present means have particular application where an error correction gain of less than unity is of advantage particularly in controlling group synchronization. This is also true in situations where it is desired to improve the convergence of synchronization toward a common time base. The present means also have application to group resynchronization of members that have previously arrived at a common time base or index by restricting the relative timing error between cooperating members as they change from one time base to a new time base. The present means also include means to limit the maximum amount of correction applied during any one exchange of resync data.

15 Claims, 4 Drawing Figures

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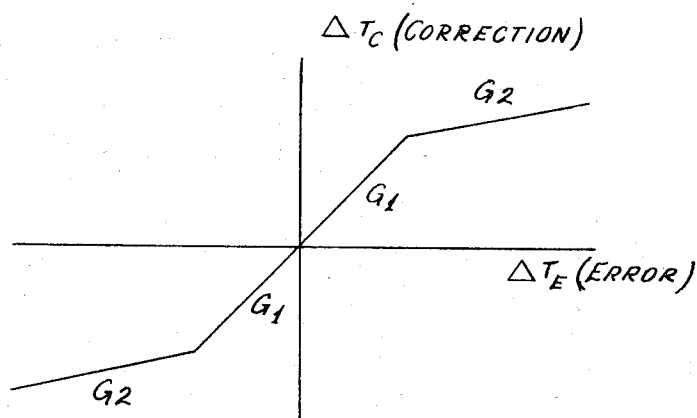


FIG. 1

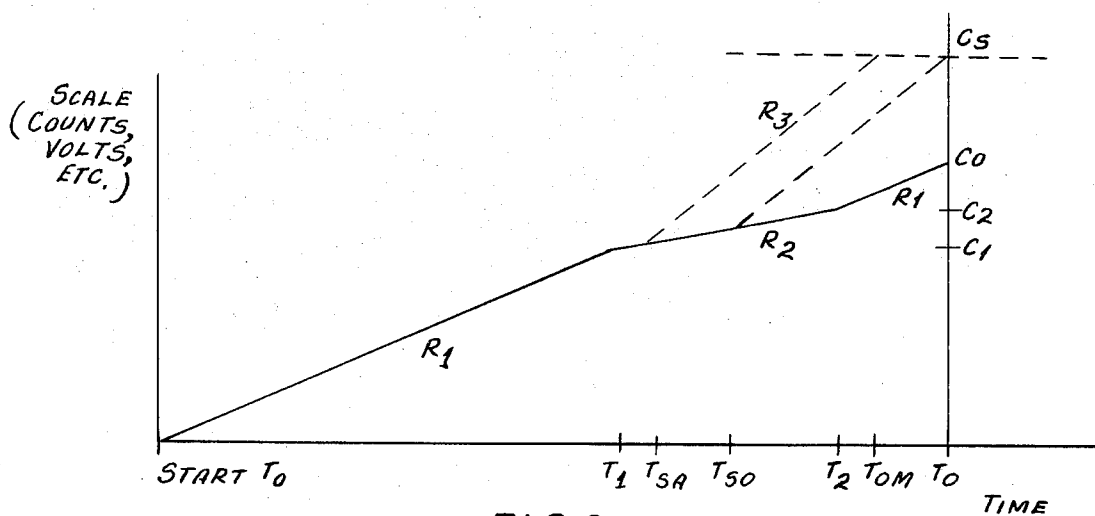


FIG. 2

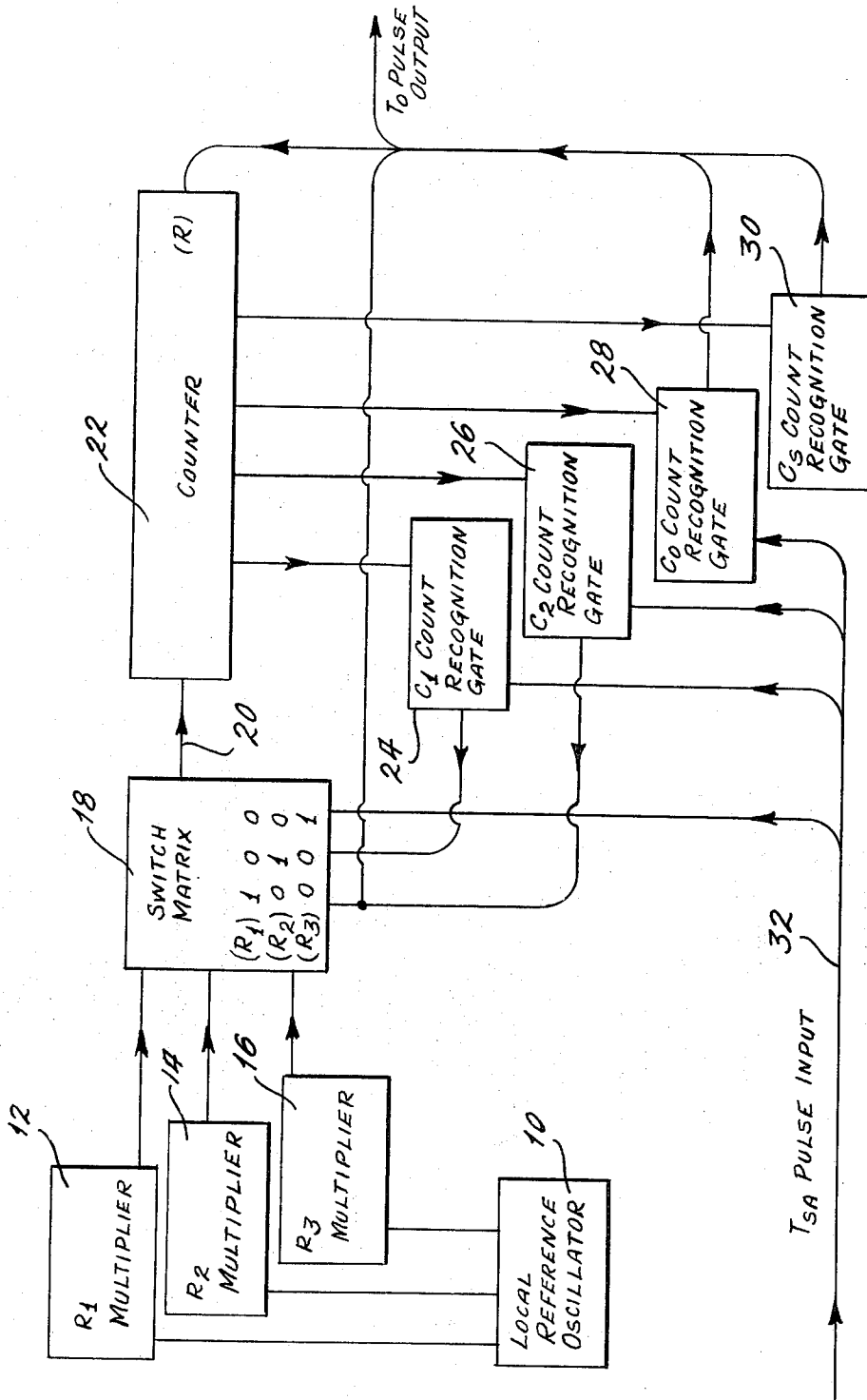


FIG. 3

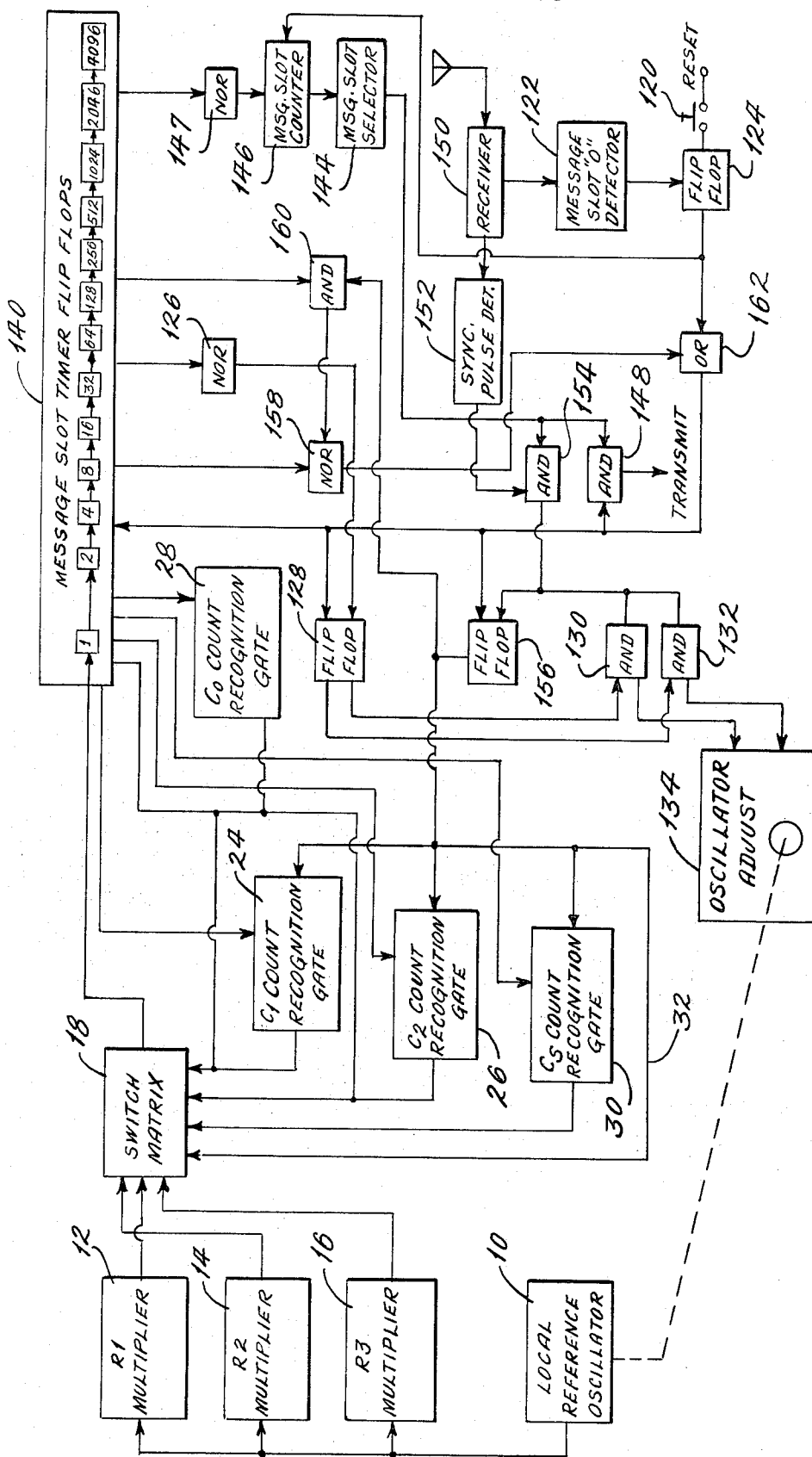


FIG. 4

GAIN CHANGE CONTROL CIRCUIT FOR TIME SYNCHRONIZATION

CROSS-REFERENCES

Perkinson et al U.S. Pat. No. 3,250,896 entitled Synchronizing Means For Remotely Positioned Timing Devices discloses a construction wherein corrections are introduced to place the unit being synchronized into exact synchronism with the unit to which it is being synchronized. This reference patent is incorporated into the subject specification by reference.

Watson and Mohr U.S. patent application, Ser. No. 272,472, filed July 17, 1972 discloses means for making partial corrections of out-of synchronism conditions but does not disclose means for producing different percentage partial corrections for different amounts of out-of-synchronism conditions that are sensed.

The need to to provide collision avoidance protection and particularly such protection that is based on a cooperative universal time index or base as well as for other purposes has long been recognized, and considerable development work to this end has taken place. The above referenced Perkinson et al. United States Letters Patent teaches the construction and operation of means for achieving precise time synchronization between two or more cooperating units such as between aircraft and/or between aircraft and a master station. To provide universal synchronization using the teachings of the Perkinson et al construction, however, has presented certain practical difficulties, not the least of which is to maintain all of the master or ground stations located at different places around the world exactly synchronized to each other. The practical difficulties of achieving this ideal condition have been recognized, and various means and methods have been devised to overcome it including the means disclosed in Applicants' above referenced copending application which discloses a form of convergent synchronization system in which aircraft and/or master stations make only partial corrections of their timing means when an out-of-synchronism condition is detected so that all cooperating units will gradually continuously and repeatedly converge toward a common synchronized condition without necessarily ever being able to actually achieve the idealized condition in which all units are exactly synchronized to each other.

The present gain change means represent a further improvement to the systems disclosed in the aforementioned patent and application by which it is possible to provide multiple gain change factors that are functions of the amount of time error or out-of-synchronism that exists between cooperating units. The present improvements have special advantage in controlling group synchronization and in improving convergence of the group members to a common time base. Furthermore, when synchronizing a group of cooperating units which previously have arrived at a common time base or index, it is often desirable to restrict the relative timing errors between adjacent cooperating members or units as they change from one time reference or base to another different time reference or base. The present invention teaches means for achieving this by limiting the maximum magnitude of the gain change that can be applied for any one exchange of synchronizing data therebetween.

It is therefore a principal object of the present invention to provide multiple gain change factors for use in a cooperative time synchronization system, which factors are functions of the amount of time error that is present.

Another object is to provide synchronizing means which make use of error correction factors of less than one.

Another object is to provide improved means for group synchronizing and convergent synchronizing.

Another object is to limit the relative timing error that can occur between cooperating units.

Another object is to limit the maximum amount of correction that can be applied during any one exchange of information between cooperating units.

Another object is to provide relatively simple gain change means for use with time synchronization systems.

Another object is to provide means capable of providing a variety of gain change curves or schedules selectable for use with time synchronizing systems.

Another object is to increase the versatility and flexibility of a time synchronizing system.

Another object is to provide a time synchronizing system wherein the gain change factors employed can be made to be symmetrical or asymmetrical relative to the zero error condition.

Another object is to devise synchronizing means which can be made to make use of a number of counting or time keeping rates.

These and other objects and advantages of the present invention will become apparent after considering the following detailed specification which describes a preferred embodiment in conjunction with the accompanying drawings wherein:

FIG. 1 is a graph of time correction plotted as a function of time error;

FIG. 2 is a graph of count values as a function of time during a finite length time interval or message slot;

FIG. 3 is a block diagram of a gain change control circuit constructed according to the present invention; and

FIG. 4 is a block diagram similar to FIG. 9 of the drawings in U.S. Pat. No. 3,250,896 but with the elements of the subject improvements as disclosed in FIG. 3 connected therein.

The subject invention is an improvement over known time synchronizing means such as those disclosed in Perkinson et al U.S. Letters Pat. No. 3,250,896, issued May 10, 1966 and entitled Synchronizing Means For Remotely Positioned Timing Devices and in copending Watson et al. U.S. application, Ser. No. 272,472, filed July 17, 1972 and entitled Means For Synchronizing Remote Positioned Timing Devices. The subject improvements are important because they provide for the possibility of multiple gain change or correction factors and combinations thereof, which factors are or may be made to be functions of the out-of-synchronization time error ΔT_c . The present means are important because they add versatility and flexibility to the known synchronizing means by making it possible to use less than a full correction of a synchronizing error under certain circumstances. Furthermore, when the present means are used to resynchronize a group of units that have previously arrived at a common index or time base, it is often desirable to restrict the relative timing error between these units as they are changed to a new

time base. This is achieved by limiting the maximum amount of change that can take place for any one exchange of data. The present invention therefore provides means for selecting different values of gain, usually less than unity, so that a change factor will reach a saturation value that will limit the maximum real time change that can be applied at any one time.

FIG. 1 shows two different change factors G_1 and G_2 that are applied under different situations, namely, for different amounts of time error ΔT_E . The center of the graph of FIG. 1 at the "G" axis represents the condition where there is no synchronizing error, and on both sides of the center for a predetermined amount of error the correction factor G_1 is used. This portion of the gain curve is relatively steep and hence, when the amount of error is in this range, each correction that is made will be relatively large in relation to the error. This means that a unit being synchronized which has a synchronizing error which is relatively small will be synchronized relatively rapidly. As the error gets larger, the gain factor curve becomes relatively more flat which means that for large errors relatively smaller gain will be made in relation to the size of the error during each synchronizing operation. This also means that the resulting value of the time correction ΔT_C will be a saturation value that limits the maximum gain change that can be applied at any time. This is especially desirable in a convergent type synchronizing system where reciprocal corrections are made in cooperating units. However, when the error is so small that the device operates in the G_1 portion of the curve the reciprocity factor has less effect and larger proportional corrections toward the common time base can be safely made. In some cases, such as where a group of synchronized units enter the region of another unit having a different time base, the present type system will minimize the change in the said different base which otherwise might be excessively changed toward the base of the group. In fact, the G_2 portions of the curve can be made to have almost any slope including a slope to represent a zero correction factor, if desired. As will be explained, the values of G_1 and G_2 can be varied substantially from those shown as desired to meet specific situations, and it is also possible to have different slopes for the two G_2 portions of the curve.

FIG. 2 depicts what takes place in a typical message slot assigned to a particular unit that is to be synchronized timewise to some remote unit. Synchronized in the sense used means that the two units, the one to be synchronized (syncee) and the one to which it is to be synchronized (syncor), are to have time periods subdivided into message slots, each of which occur simultaneously at both units. The particular message slot shown in FIG. 2 is the message slot at the syncee. This message slot starts at time t_0 and ends at time t_0 for the next succeeding message slot. At exactly time t_0 in the syncee's message slot, the syncee commences transmitting a signal which is received at the other cooperating stations including a station which is the syncor. At the same time, t_0 at the syncee, other means start counting preferably at a uniform rate designated in the drawing as rate R_1 . Various means are known and can be used to produce this uniform counting rate including various pulse counting means, capacitor charging means, and other similar means. If the syncee transmits its signal at time t_0 but does not receive a reply signal at a later time in the same message slot for synchronizing purposes, it

will simply continue to count at the initial counting rate R_1 until the count reaches some arbitrary final count which is designated as occurring at time T_1 and at count C_1 . At this particular time and under these circumstances, the counting rate automatically changes from counting rate R_1 to counting rate R_2 which is shown as being a slower counting rate. The counting means continue to count at rate R_2 until a still later time designated as time T_2 where there will have been accumulated in the counting means a count represented as count C_2 . When the counter reaches count C_2 , the counting rate again changes this time changing back to the original rate R_1 . Thereafter, the counting rate R_1 is maintained until a final count designated as the count C_0 is reached which causes the counting means to reset to "zero" count when the process repeats itself for the next succeeding message slot. The situation described as indicated is for the condition wherein no reply synchronizing signal is received at the syncee from the syncor, and the entire operation takes place only during the particular message slot assigned to the syncee.

The second situation is the situation when a response is transmitted by the syncor under conditions where the syncor and syncee are in exact synchronism with each other. This means that the time error ΔT_E is zero. For this situation, there will be a reply signal transmitted by the syncor, and this reply signal will be transmitted at a time such that it will arrive at the syncee at the time designated in FIG. 2 as time t_{so} . For this condition, the operation of the subject means may be substantially the same as described in Perkinson et al U.S. Letters Pat. No. 3,250,896 except that in the present case the syncee will have its counting rate changed to a third possibly still different counting rate designated as rate R_3 , and will continue to count at this new rate R_3 until a final count designated as count C_s is achieved. Referring again to FIG. 2, it can be seen that the count C_0 occurs when the syncor and syncee are exactly synchronized so that the times t_0 and C_0 occur simultaneously as if no return signal was transmitted and received. However, the count C_s , like counts C_1 , C_2 and C_0 is an arbitrary count which is selected depending upon the counting rates employed, the length of the message slots and other convenience factors. Where a reply signal is received at the time t_{so} the counting means will reset at the same time as if no reply has been received. This is true even though the count C_s is substantially larger than the C_0 in the above example, because the counting rate R_3 is selected to be a faster rate than either of the rates R_1 or R_2 . The value of C_s is therefore selected so that no shift or change in the time index, and hence, no synchronizing change occurs when a reply from the syncor is received at the syncee at time t_{so} . Therefore, the counting means will reset when it reaches count C_s which is the same reset time as time C_0 under circumstances where no reply signal is received. The mathematical relationship between the counts C_s and C_0 under the above circumstances can be expressed by the following equation:

$$C_s = C_0 - R_1(t_0 - T_2) - R_2(T_2 - t_{so}) + R_3(t_0 - t_{so}) \quad 1.$$

where,

C_s is the final count required for reset when a response signal from the syncor is received from the syncee.

C_0 is the final count when no response signal is received.

R_1 is the initial counting rate at the syncee.

$(t_o - T_2)$ refers to the time interval between time T_2 and the end of the message slot. In FIG. 2 this is the second counting interval at the initial counting rate R_1 and represents the difference between the counts C_o and C_2 .

R_2 is the second counting rate of the syncee.

$(T_2 - t_{so})$ is the time period between times t_{so} and T_2 or the interval between the time when the synchronizing reply is received at time t_{so} and the end of the period of counting at rate R_2 . For the synchronized condition the time t_{so} is the time when the counting rate R_3 is begun.

R_3 is the counting rate initiated by receipt of a reply signal from the syncor.

$(t_o - t_{so})$ is the time interval between the time t_{so} and the end of the message slot, during which the counting rate R_3 is used.

It can be seen that equation 1 satisfies the synchronized situation where the initial counting rate R_1 commences at the beginning of the message slot and continues until time T_1 when the counting rate changes to rate R_2 and continues so until time t_{so} when the replay signal from the syncor is received. At time t_{so} the counting rate changes from rate R_2 to rate R_3 , unlike the situation where no response is received, and continues at rate R_3 until the final count C_s is reached. This will occur at time t_o when the syncor and syncee are synchronized.

For the more generalized situation where the reply synchronizing signal is received at any time between the times T_1 and T_2 the following mathematical relationships as expressed by the equations 2-8 apply.

$$\Delta T_C = t_{om} - t_o \quad (2)$$

$$C_s = R_1 T_1 + R_2 (t_{su} - T_1) + R_3 (t_{om} - t_{su}) \quad (3)$$

$$t_{om} = [C_s - R_1 T_1 - R_2 (t_{su} - T_1) + R_3 t_{su}] / R_3 \quad (4)$$

$$C_s = R_1 T_1 + R_2 (T_{so} - T_1) + R_3 (t_o - T_{so}) \quad (5)$$

$$t_o = [C_s - R_1 T_1 - R_2 (T_{so} - T_1) + R_3 t_{so}] / R_3 \quad (6)$$

$$\Delta T_C = t_{om} - t_o = [R_3 (t_{su} - t_{so}) - R_2 (t_{su} - t_{so})] / R_3 \quad (7)$$

$$\Delta T_C = (R_3 - R_2 / R_3) (t_{su} - t_{so}) \quad (8)$$

In these equations:

T_C represents the time correction or synchronizing correction factor necessary to produce synchronism.

t_{om} is the generalized time when the accumulator reaches the count C_s and may occur at different times than t_o if a synchronizing correction is required.

t_{su} is any time in the period from time T_1 to time T_2 when the response from the syncor is received.

It is apparent from the above equations that if the reset count C_s is reached at a different time at the syncee than at the syncor some correction is required. The correction under these circumstances is represented by the time difference between the time of occurrence of the count C_s and the time of occurrence of the count C_o , or by the expression $t_{om} - t_o$. In equation 8 this time difference is multiplied by a factor based on the counting rates R_3 and R_2 . In the Perkinson et al. U.S. Pat. No. 3,250,896, in which $R_2 = R_1$ and $R_3 = 2 R_1$, this is expressed by equations 9 and 10 as follows:

$$T_C = (2R_1 - R_1/2R_1) (t_{su} - t_{so}) = \frac{1}{2} (t_{su} - t_{so}) \quad (9)$$

or

$$\Delta T_C = -G_1 (t_{su} - t_{so}) \text{ with } G_1 = (R_3 - R_2/R_3) \quad (10)$$

In equation 10, G_1 is a gain factor and is a constant term that is based on the selected counting rates.

It is also possible for a replay signal to be received at the syncee at or before the time T_1 in which case the following equations apply:

$$\Delta T_C = T_{om} - t_o \quad (11)$$

from FIG. 2

$$C_s = R_1 t_{su} + R_3 (t_{om} - t_{su}) \quad (12)$$

which is reorganized

$$t_{om} = [C_s + (R_3 - R_1) t_{su}] / (R_3) \quad (13)$$

from FIG. 2

$$C_s = R_1 T_1 + R_2 (t_{so} - T_1) + R_3 (t_o - t_{so}) \quad (14)$$

which is reorganized

$$t_o = [C_s - R_1 T_1 - R_2 (t_{so} - T_1) + R_3 t_{so}] / R_3 \quad (15)$$

subtracting equation (15) from equation (13) yields

$$\Delta T_C = t_{om} - t_o = (R_3 t_{su} - R_1 t_{su} + R_1 T_1 + R_2 t_{so} - R_2 T_1 - R_3 t_{so}) / (R_3) \quad (16)$$

$$= (R_3 t_{su} - R_1 t_{su} + R_2 t_{so} - R_3 t_{so}) / (R_3) + (R_1 T_1 - R_2 T_1) / (R_3) \quad (17)$$

$$\Delta T_C = t_{om} - t_o = (R_3 - R_1/R_3) t_{su} - (R_3 - R_2/R_3) t_{so} + [(R_1 - R_2) T_1] / R_3 \quad (18)$$

Depending on the operation of the syncor the following equations also apply:

$$t_{su} - t_{so} = -2 \cdot \Delta T_E \quad (19)$$

$$t_{su} = -2 \cdot \Delta T_E + t_{so} \quad (20)$$

substituting equation (20) into equation (18) yields

$$\Delta T_C = -2 (R_3 - R_1/R_3) \cdot \Delta T_E + (R_3 - R_1/R_3) t_{so} - (R_3 - R_2/R_3) t_{so} + (R_1 - R_2/R_3) T_1 \quad (21)$$

which reduces to

$$= -2 (R_3 - R_1/R_3) \cdot \Delta T_E - (R_1 - R_2/R_3) t_{so} + (R_1 - R_2/R_3) T_1 \quad (22)$$

which is rewritten as

$$\Delta T_C = -G_2 \Delta T_E + K_1 \quad (23)$$

where

$$G_2 = 2 (R_3 - R_1/R_3) \quad (24)$$

and

$$K_1 = (R_1 - R_2/R_3) (T_1 - t_{so}) \quad (25)$$

In the above equations the time error ΔT_E is a negative term when the time at the syncee is early relative

to the time at the syncor, and is positive when the syncor is late relative to the syncor. Also, in the above equations the correction factor ΔT_c is negative for a change early (advance time) and positive for a change late (retard time).

In a similar manner the equation for the correction that is required when t_{so} is greater than (occurs after) T_2 can be expressed:

$$\Delta T_c = -G_2 \cdot \Delta T_E + K_2 \quad (26)$$

with

$$G_2 = 2 (R_3 - R_1/R_3)$$

and,

$$K_2 = (R_1 - R_2/R_3) (T_2 - t_{so})$$

To summarize the above equations, when:

$$\Delta T_E \geq (t_{so} - T_1/2) \quad (a)$$

The correction factor is represented by the expression:

$$\Delta T_c = -G_2 \Delta T_E + K_1$$

where,

$$G_2 = 2 (R_3 - R_1/R_3)$$

and,

$$K_1 = (R_1 - R_2/R_3) (T_1 - t_{so})$$

And when,

$$(t_{so} - T_1/2) \geq \Delta T_E \geq (t_{so} - T_2/2) \quad (b)$$

$$\Delta T_c = -G_1 \cdot \Delta T_E$$

and

$$G_1 = 2 (R_3 - R_2/R_3)$$

And when,

$$\Delta T_E \leq (t_{so} - T_2/2)$$

$$\Delta T_c = -G_2 \cdot \Delta T_E + K_2$$

and

$$G_2 = 2 (R_3 - R_1/R_3)$$

and

$$K_2 = (R_1 - R_2/R_3) (T_2 - t_{so})$$

Thus it can be seen that where a synchronizing error is greater than a certain amount one correction factor, namely G_2 , is used, and where the correction factor is less than a certain amount but greater than zero, a different gain factor, namely G_1 , is used. This is clearly illustrated by the graph in FIG. 1 which shows the gain factor G_1 used on either side of the center synchronized condition, and the gain factor G_2 being used when the error is greater than some predetermined amount. Thus, it is possible with the present device to provide a variety of different gain change or error correction curves or schedules similar to that shown in FIG. 1 and the particular ones shown are for illustrative purposes only.

A special case which is of some interest is the situation where the rate R_3 is the same as rate R_1 . In this case the gain factor G_2 is zero thereby substantially limiting the amount of correction that can be provided for synchronizing errors. As a general rule this situation is not desired because it is usually desired to have some even small amount of correction for each occurrence of an out of synchronization condition. It is also usually desired to provide a larger correction factor when the synchronizing error is relatively small. The graph of FIG. 1 illustrates this fact and is taken about the error condition which corresponds to the reply signal arriving at the syncor at time t_{so} in FIG. 2. The situation shown in FIGS. 1 and 2 is also shown as being symmetrical about the zero error condition so that the G_1 gain regions extends an equal distance on each opposite side thereof. It is not necessary to have symmetry in this sense and sometimes it may not even be desirable. If it is desired to make the system asymmetrical, this can be achieved relatively simply by changing the count values C_1 and C_2 and the complementary values of counts C_0 and C_3 . Many variations and extensions of the asymmetrical configuration are possible including situations where the counting rate used between the times T_2 and the end of the message slot t_o is other than R_1 and where the count rate between the time t_{so} and T_2 is other than the rate R_2 . Other variations are also possible and contemplated.

FIG. 3 shows a possible physical embodiment of the subject gain change means. The device includes a local reference oscillator or frequency standard 10 which has its outputs connected to three different counting rate generating multiplier circuits 12, 14 and 16. The reference oscillator 10 and the multiplier circuits 12, 14 and 16 can be of conventional construction including being similar to those disclosed in Perkinson et al. U.S. Pat. No. 3,250,896. The output of the multiplier 12 is a signal that represents or corresponds to the counting rate R_1 , the output of the multiplier 14 is a signal that represents or corresponds to the counting rate R_2 , and the output of the multiplier 16 is a signal that represents or corresponds to the counting rate R_3 . The three different count rate signals are fed to a switch matrix device 18 which controls which counting rate will be fed on its output 20 to counter or time keeping circuit 22. The switch circuit 18, which may be in the nature of a gate circuit, is in turn controlled by various inputs it receives under control of other gate circuits 24, 26, 28 and 30. The switch 18 and the gates 24, 26 and 28 also receive signals which are from the syncor and appear on input lead 32, labeled lead T_{so} Pulse Input.

The gate circuit 24 is the C_1 count recognition gate and responds to the occurrences of a C_1 count in the counter 22 to control the switch 18 and the counting rate fed thereby to the counter 22 (140 in FIG. 4). In FIG. 2, the C_1 count occurs at time T_1 to change the counting rate from rate R_1 to rate R_2 .

The gate 26 is the C_2 count recognition gate and responds to occurrences of a C_2 count in the counter 22, which count occurs at time T_2 under circumstances when no reply synchronizing signal is received. The gate 26 controls the switch circuit 18 to cause a R_1 count rate to again be applied to the counter 22.

The gate 28, labeled C_0 Count Recognition Gate, responds to occurrences of count C_0 in the counter 22 to reset the counter to zero count when no input synchro-

nizing signal is received. The gate 28 also restores the counter 22 to its initial counting rate R_1 and may perform other functions necessary to set up the following message slot.

The gate 30, labeled C_s Count Recognition Gate, responds to the final count C_s in the counter 22 during message slots when a synchronizing reply signal is received, and this is done regardless of when the synchronizing signal is received. The gate 30, like the gate 28, resets the counter 22 in readiness for the succeeding message slot and reestablishes the initial counting rate R_1 through a connection to the switch circuit 18.

All of the gates 24, 26, 28 and 30 can be of conventional gate circuit construction having input and output connections as required. In the drawings, the synchronizing reply signals received at the syncee are fed to the switch matrix circuit 18 and also as inhibit inputs to the gates 24, 26 and 28. These gates, as well as the gate 30, also receive other inputs from the counter 22, as aforesaid.

FIG. 4 shows one way to incorporate the subject gain change control circuit means into a known prior art embodiment such as into the embodiment shown in FIG. 9 of Perkinson et al U.S. Pat. No. 3,250,896. The circuit of FIG. 4 includes most of the elements shown in FIG. 9 of the patent drawing and these elements are numbered similar to the corresponding elements in the patent and for the most part operate in the same way as the patented construction. These elements are located to the right in FIG. 4. The elements added to the patented circuit are similar and operate similarly to the elements shown in FIG. 3. It is therefore not deemed necessary to describe the construction and operation of the elements taken from the patented device.

It should also be clear that it is contemplated to incorporate the present gain change means as part of an existing synchronized system to provide added flexibility and variable gain change means. This becomes ever more important as global synchronized systems are used for collision avoidance protection and for other purposes, and the present means also have applications in space travel systems and any synchronized system where time is shared and where distances and other information is calculated on time of arrival of signals and so forth.

Thus there has been shown and described a novel means for producing gain change to maintain two or more cooperating units in extremely close real time synchronization with each other, which gain change means are particularly useful in group and global synchronization systems and in synchronization on a convergent basis such as to a common time base, which means fulfill all of the objects and advantages sought therefor. Many changes, modifications, alterations, and other uses and applications for the subject gain change means will, however, become apparent to those skilled in the art after considering this specification and the accompanying drawings. All such changes, modifications, variations and other uses and applications which do not depart from the intention and scope of the invention are deemed to be covered by the invention which is limited only by the claims which follow.

What is claimed is:

1. In a synchronized system having a plurality of spaced system units each including time keeping means and means for subdividing the time being kept into recurring time periods each of which includes a plurality

of distinct message slots assignable to respective ones of the system units, said synchronized system including means at selected ones of the units for transmitting signals commencing at the beginning of message slots assigned thereto, means at other of the system units for receiving said transmitted signals from units within communication range thereof and for transmitting reply signals which are received at the aforesaid transmitting units for synchronizing the time keeping means thereat so that the time keeping means at the transmitting and receiving units are maintained in synchronism, the improvement comprising means for making selected partial corrections of each detected out-of-synchronized condition at a unit receiving a replay resynchronizing signal, said last named means including means for selecting between at least two different percentage error correction factors including making a greater percentage partial correction of an out-of-synchronism condition when the out-of-synchronism condition is less than a predetermined amount than when the out-of-synchronism condition is greater than said predetermined amount.

2. In the synchronized system defined in claim 1 each system unit includes means for causing the counting of time at at least two different time keeping rates, and means for switching between said time keeping rates, said switching means including means responsive to the occurrence of predetermined counts to shift from one counting rate to another, and other means for changing from one time keeping rate to another upon receipt of a reply signal from another cooperating unit.

3. In the synchronized system defined in claim 1 said means for selecting between percentage error correction factors include time counting means, means for selectively controlling the counting means so that the counting means will count at different time keeping rates, means responsive to the occurrence of different predetermined counts in the time counting means to effect a change in the time counting rate, and other means to effect a change in the time counting rate in response to receipt of reply signals from other cooperating system units.

4. In the synchronized system defined in claim 3 further including means to reset the time counting means to an initial condition whenever the counting means has a predetermined final count therein.

5. In the synchronized system defined in claim 4, said reset means respond to a first predetermined final count when a reply signal is received from another cooperating unit and to a second predetermined final count to reset the counting means when no reply signal is received.

6. Means for synchronizing a plurality of spaced units each of which includes means capable of keeping time in the same length repeating time periods, means for assigning a different distinctive one of the time periods to each cooperating unit as its synchronizing time, means included in each unit for establishing an initial counting rate commencing at the beginning of each occurrence of its assigned time period, means at selected ones of said units for transmitting a signal therefrom beginning at the beginning of each occurrence of its assigned time period, means at other of said cooperating units within range of said transmitting unit for receiving said signal and for transmitting a synchronizing reply signal at a later time in the same time period based at least in part on the time of receipt of each such trans-

mitted signal, means at each of said units for changing the time counting rate thereat in response to the time of receipt of the reply signal in a direction to correct any synchronizing error that may exist between the time keeping means at the cooperating units, the improvement comprising means for making a partial correction of each detected out-of-synchronism condition, said last named means include first means capable of making a first partial percentage correction of an out-of-synchronism condition and second means capable of making a second different partial percentage correction of an out-of-synchronism condition, and means for selecting between said first and said second percentage error correction means depending on whether the detected out-of-synchronism condition is greater than or less than a predetermined amount.

7. Means for synchronizing two or more remotely positioned timing devices each of which includes means for keeping time in preselected time periods, said periods having finite beginnings and endings; transmitting, receiving and counting means operatively connected respectively to each of said timing devices, the counting means at each timing device counting time in increments from the beginning to the end of each time period, means for changing the counting rate of said counting means, means for assigning respective ones of said time periods to selected ones of said cooperating timing devices as their respective synchronizing time periods, means at one of said selected timing devices for energizing the transmitting means thereat to transmit a signal at a predetermined time relative to the beginning of its assigned time period, each of said transmitting signals being received at other timing devices within range thereof at a later time in the same time period depending upon the distance between the devices, means at a receiving device for transmitting a reply signal at a still later time in the same time period depending at least in part on the time of receipt thereof of each such received signal for synchronizing purposes, each of said selected timing devices including means to control the counting means thereat to count at a first predetermined counting rate commencing at the beginning of each occurrence of its assigned time period, means responsive to the counting means reaching a predetermined count to effect a change in the counting rate from one counting rate to a different counting rate, said counting means continuing to count at said different counting rate until a second predetermined count is reached under conditions when no reply signal is received from another cooperating timing device, the improvement comprising means for effecting a still different change in the counting rate when said second predetermined count is reached, and means to reset the timing device when a predetermined final count is reached.

8. The synchronizing means defined in claim 7 wherein each of said timing devices include a precision time standard capable of keeping time at a predetermined rate, wherein the said means for effecting a still different change in the counting rate includes means for multiplying the time keeping rate of the time standard to produce higher order time keeping rates which are multiples of the time keeping rate of the standard, and means for selecting between the different time keeping rates including switch matrix and associated gate circuit means, said gate circuit means including means responsive to predetermined counts in the tim-

ing device to control the switch matrix and to select a particular time keeping rate.

9. The means defined in claim 8 wherein said switch matrix is responsive to the receipt of reply signals from other cooperating timing devices to aid in the selection of the time keeping rate.

10. Means for synchronizing a plurality of remotely positioned timing devices comprising a plurality of remotely positioned timing devices capable of keeping time in equal duration succeeding time periods, transmitting means, receiving means and counting means capable of counting at different selectable counting rates operatively connected respectively to each of said timing devices, means for making each of said timing devices effective in a different preselected one of said time periods for synchronizing purposes, a plurality of remotely positioned time standards capable of keeping time in the same time periods, transmitting, receiving and counting means operatively connected respectively to each of said time standards, said counting means at the standards counting at a preselected counting rate commencing at the beginning of each time period, means associated with each timing device for transmitting a signal at the beginning of each occurrence of its assigned time period, said signals being received at time standards within the range thereof at later times in the same time periods depending on the propagation distances therebetween, means associated with said time standards for transmitting a return signal to the respective timing devices when the counting means thereat reach a predetermined count based at least in part upon the time of receipt of a signal from the respective timing devices, said return signals being received at the respective timing device at later times in the assigned time periods depending upon the respective propagation distances thereto, the time of receipt of said return signals at each respective timing device being an indication as to the extent of any out-of-synchronism condition that exists thereat, the improvement comprising means at the respective timing device for producing a plurality of different counting rates, means for effecting a change in the counting rate thereat when a return signal is received, said last named means including means to select between the several different counting rates to be effected based on the extent of the indicated out-of-synchronism condition, and means for resetting the counting means at the timing devices when the counting means reaches a predetermined count.

11. The means for synchronizing defined in claim 10 including other means for effecting a change in the counting rate at each timing device when no return signal is received from a cooperating time standard, said means including means responsive to the occurrence of another preselected count in the counting means.

12. The means for synchronizing defined in claim 10 wherein said counting means at each of the timing devices are caused to count at first, second, and third counting rates, said first and second counting rates being used when no return signal is received from a cooperating time standard, and said third counting rate being used when a return signal is received from a cooperating time standard.

13. The means for synchronizing defined in claim 10 wherein said means responsive to the count in the counting means at the time of receipt of a return signal includes means to distinguish between out-of-synchronized conditions that are greater than and less

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than a predetermined amount, said last named count responsive means selecting between the different available counting rates to effect a first percentage correction factor of an out-of-synchronism condition when the synchronizing error is greater than said predetermined amount and a different percentage correction factor when the out-of-synchronism is less than said predetermined amount.

14. The synchronizing means defined in claim 13 wherein the selected counting rate produces a greater percentage correction factor when an indicated out-of-

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synchronism condition is less than said predetermined amount.

15. The means for synchronizing defined in claim 10 wherein the time keeping means at each of the timing devices includes a reference oscillator having a predetermined frequency that represents one of the said counting rates, and means for generating at least one counting rate corresponding to an harmonic of said oscillator frequency to produce another counting rate.

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