Quartz Clocks Synchronized by LF Time Signals

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Abstract

The general availability of LF time signals, the compactness and simplicity of the receivers, and C-Mos integrated circuits make it possible to design reliable, inexpensive and unattended synchronized clocks. Battery-operated models have an autonomy of 3 years and an accuracy of 10 msec. Models with temperature-controlled crystal oscillators have an accuracy of 100 μsec.

Introduction

There are 5 LF-stations, 4 of which are in Europe [1], transmitting time signals and precision carriers continuously (fig. 1); several more stations transmit time signals regularly but not continuously (Japan, USSR). All these transmitters can be used to synchronize clocks in a straightforward way. It is the purpose of this paper to show that such clocks can be made very reliable and at low cost.

The clocks to be described here are quartz clocks, which are synchronized by the time signals and run with the rate of their quartz in the absence of a useful signal.

Frequency	Call sign	Country	Format of second and minute markers
40 kHz	JG2AS	Japan	
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100 kHz	LOR.C		

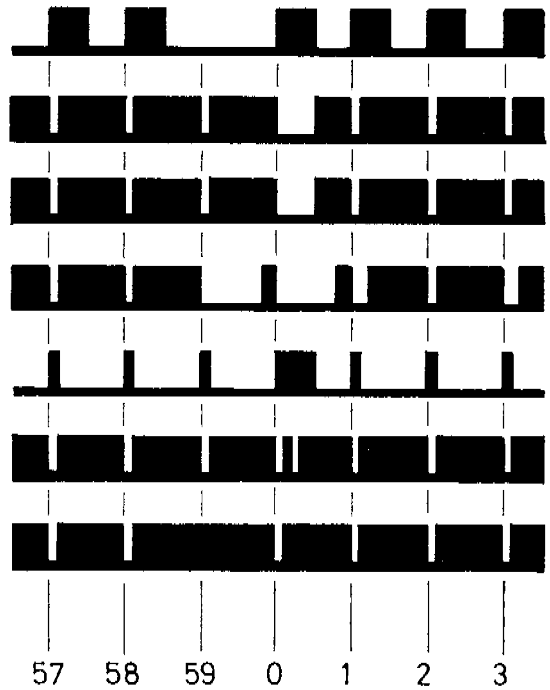

Fig. 1: Time Signal Transmitters in the LF-Band.

Properties of LF-time signals

The accuracy of LF-time signals is in the 100 µsec range; this modest accuracy is sufficient for a great number of public and industrial applications.

Range. With antenna powers around 10 kW, the useful range of the transmitters is 3000 km. Thus transmitter WWVB covers the contiguous United States adequately, whereas the 4 European transmitters are in effect largely redundant.

Receivers. LF-waves can be received inside most buildings and penetrate many meters underground. The antenna can therefore be mounted on the same printed circuit board as the receiver (fig. 4), and only in rare cases is it necessary to separate antenna and receiver by a cable.

Noise and interference. A distinct advantage of the LF-band compared to short waves is the nearly total absence of mutual interference, because of the small number of transmitters. Fading is also either nonexistent or so slow as to be harmless. Noise, on the contrary, is abundant in the LF-band, and it is both man-made and natural (from thunderstorms). Fortunately strong and steady noise sources are rare; the typical steady background noise is equivalent, in a 10 Hz bandwidth, to a field strength of 100 µV/m in a noisy building, 30 µV/m in a city street, and 1 µV/m in rural areas.

Reception of the time signals is not continuous but intermittent, even in the vicinity of the transmitter. There are several reasons for this: 1) Scheduled shutdowns of the transmitters are necessary for maintenance, and accidental failures do occur. 2) Noise, man-made or natural, may temporarily obliterate the signal. 3) Beyond 3000 km a useful signal is available only at night. 4) Fading may occasionally cancel the signal at distances as short as 500 km, especially at sunrise and sunset.

The intermittent character of the received time signals was taken into account in the specifications of our clocks[2]: a useful signal must be present only about 10 % of the time and interruptions as long as a few days may occur.

The local time base of a synchronized clock must therefore be able to bridge an interruption of the signal during a few days and restore correct synchronization when reception of the signal is resumed.

A quartz clock without temperature control will drift by several parts in 10^5 in the worst case. This means a drift of several seconds, but less than 30 seconds even during an interruption lasting several days. Thus the clock will be correctly updated if it locks itself to the nearest minute. However, it would clearly fall out of step if it were simply locked to the nearest second pulse. Its "normal" accuracy, during continuous reception, will of course be much better, say $\pm$ 10 msec.

For applications where a millisecond accuracy must be preserved also during interruptions of the time signals, we must impose rather severe specifications on the local time base. Since less than one millisecond in several days means a frequency accuracy of the order of one part in 10^9, the local oscillator will have to be a very good quartz, with digitally memorized frequency control.

We will discuss below in more detail these two cases.

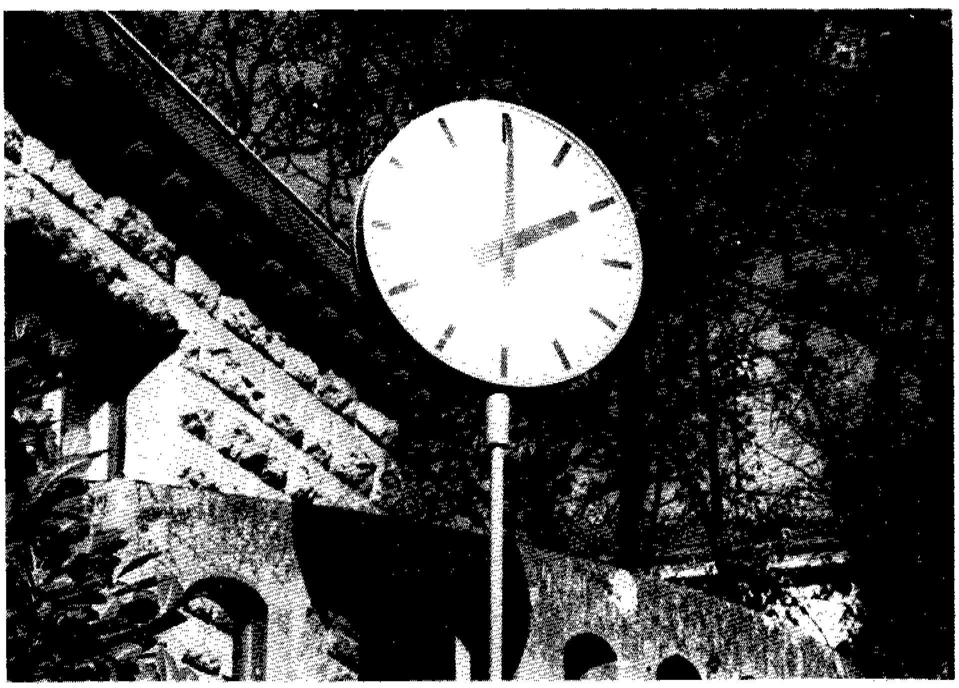

Fig. 2 : Battery operated public clock.

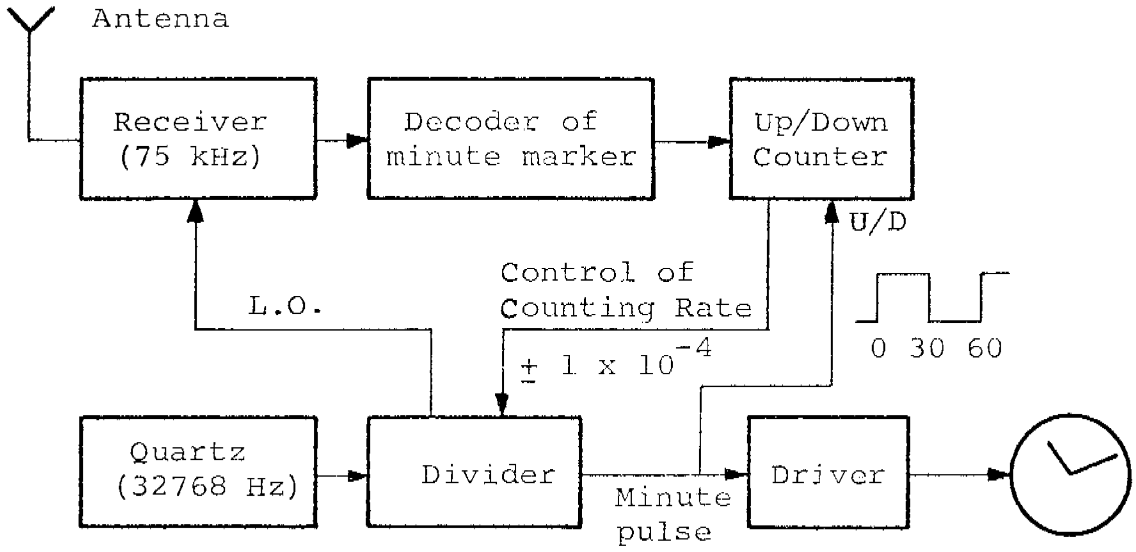

Fig. 3 : Schematic diagram of public clock.

<u>Street Clock</u>

The first clock is for general time display to the public (figs. 2, 3). The clock has two dials with a diameter of 90 cm; its advantage is that it is completely autonomous and does not need any connecting wires from outside. It is powered by 3 type D dry cells and has an autonomy of about 3 years. The electronic part consists of one printed circuit board (fig. 4), including receiver, antenna, internal clock, and an output stage to drive the hands. The internal time base is an uncompensated quartz at the watch frequency of 32768 Hz. The receiver is designed to be as simple and compact as possible: The antenna, a ferrite rod, is followed by a preamplifier stage at 75 kHz and two IF-stages at 1272 Hz. The local oscillator frequency is derived from the time base oscillator, the tuned circuits are ferrite pot cores, the overall bandwidth is 12 Hz. The minimum field strength for correct operation is 50 µV/m, a sensitivity sufficient for HBG throughout

Europe. A better sensitivity, down to about 2 µV/m, can be achieved with a better antenna, but the increase in cost and size is hardly warranted, as the lower limit is generally set by external noise rather than by receiver noise.

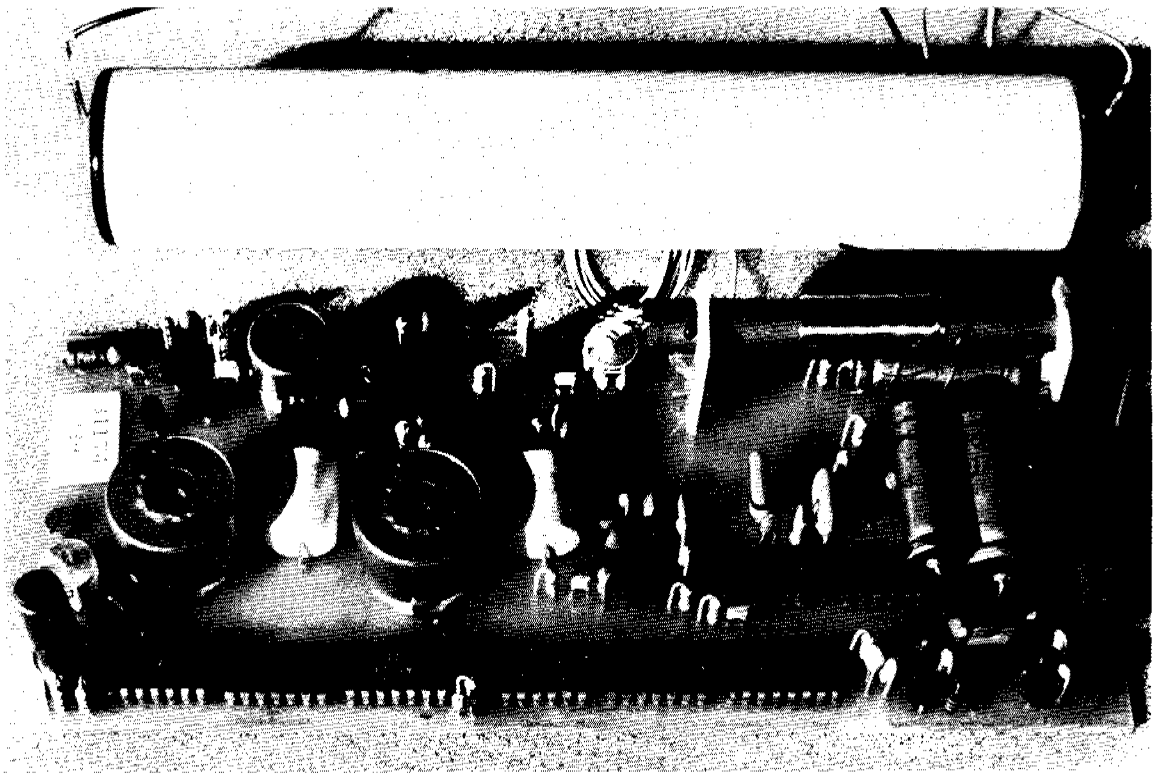

Fig. 4 : Electronic module of a synchronized clock.

The envelope of the carrier is detected and the minute-marker is identified among the second pulses. The format of the minute markers is different for each transmitter.

The quartz frequency is divided down to the minute; the divider has two counting rates, one faster and one slower than the nominal by 1 part in 10^4. If the minute pulses from the transmitter precede the minute pulse of the local time base, the divider is maintained in the fast state, and vice versa. Synchronization is thus approached at the rate of 0.36 second per hour. In the presence of noise or in the absence of the signal, spurious minute markers will be detected. To discriminate against these, the incoming minute pulses are counted in an up/down counter, up during the first half of the hour and down during the second half; at the end of the hour the sign of the resulting count is transferred to control the rate (fast or slow) of the time base divider. Since the spurious minute signals are random in time, their effect will cancel.

The power consumption of the electronic part, excluding the output stages, is 50 μA at 4 Volts. The output stages which drive the hands consume about four times more. The stepping motors which drive the minute hands or, in another model, the second hands, are conventional secondary clock movements.

The number of components has been kept as low as possible, to improve reliability and also to minimize costs. There are about 100 components, including 15 transistors and 6 C-Mos integrated circuits. The failure rate, as estimated from a sample of 300 clocks, operated during three years in different climates and environments, is 2 % per year and per clock.

The printed circuit board requires about half an hour to assemble. The low cost of this clock is apparent from the fact that the cost of the electronic module (typically $100) is only a small part of the total hardware, i.e. casing, dials and hands.

In what respect could this public clock be improved ?

First, the autonomy of 3 years can be prolonged. It is now limited by the power needed to drive the hands and by the shelf life of alcaline dry cells. The longer shelf life of lithium batteries would be an advantage, but these are not yet available at reasonable cost. The efficiency of the electromechanical motors could also be improved. Liquid crystal displays are a more remote possibility.

Second, all integrated circuits could be replaced by one single custom made chip. But, even if it becomes economical, this solution is warranted only if receiver and

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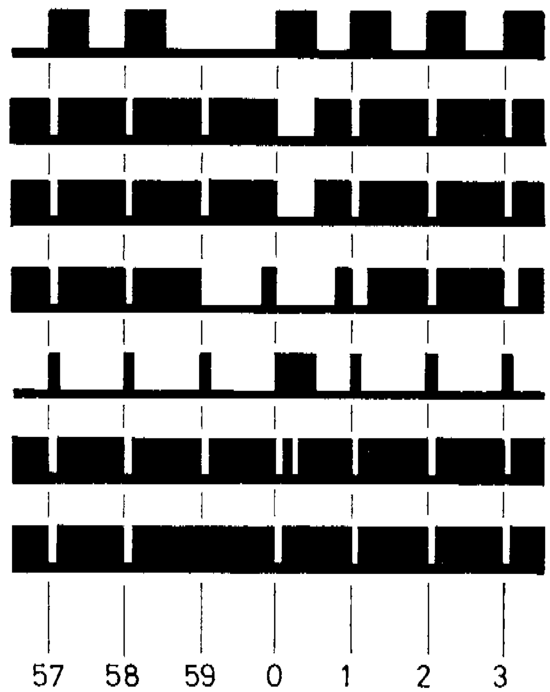

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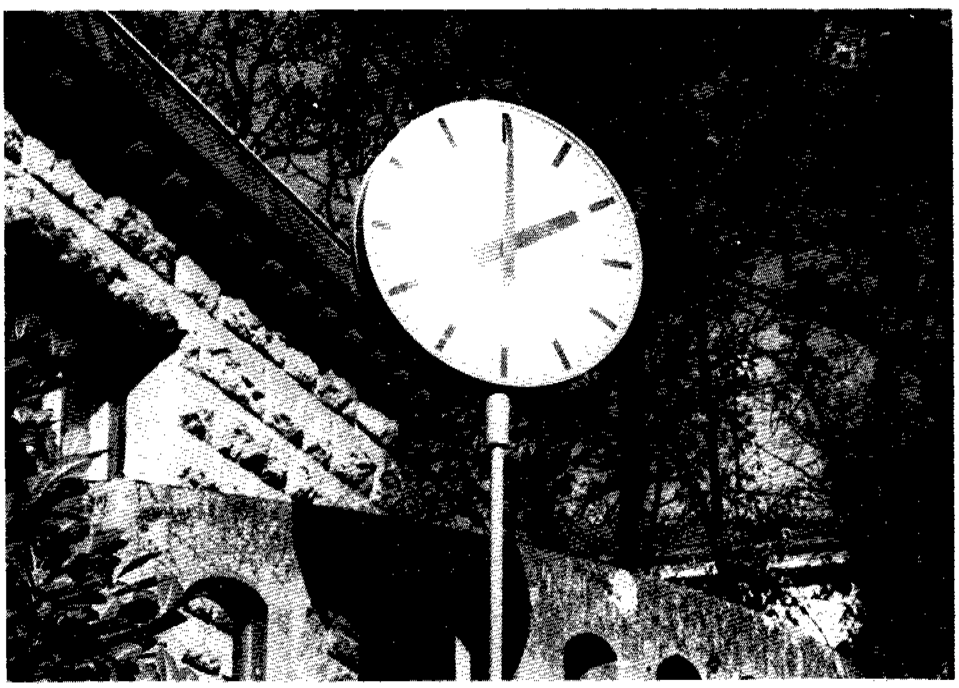

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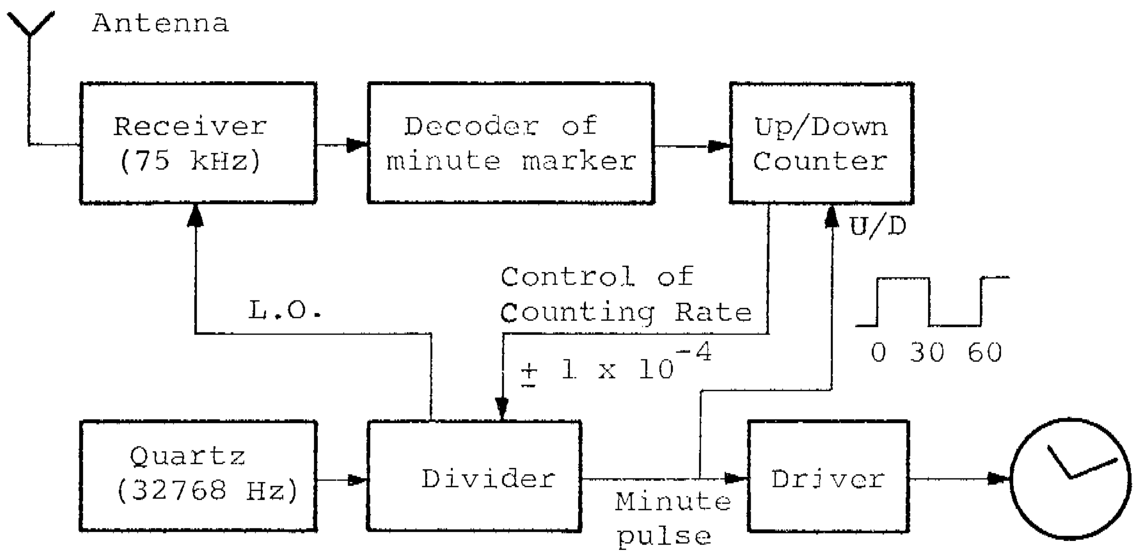

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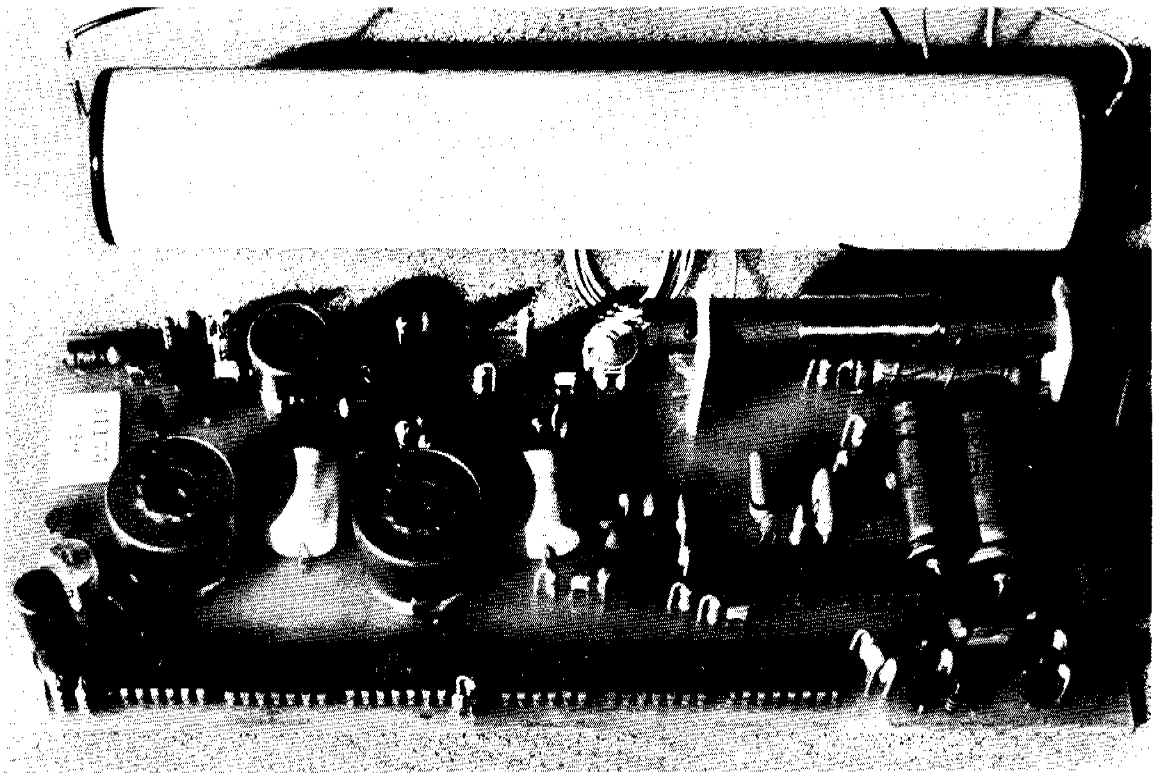

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The radiated power of the LF-transmitters is now about 10 kW. One might think that increasing this power would be helpful to the users. The experience we have accumulated over several years with more than 500 clocks in several countries indicates that there was no instance where power was the limiting factor. The few cases, where signal was insufficient because of shielding by the building, were solved by placing the antenna in the vicinity of a window, but they could not have been solved by a tenfold increase in power. Increasing the power thus appears as a useless waste of energy.

Summer Time

An important option which is available with the type of clock discussed above is the automatic setting of daylight saving time. With a coded message from the HBG transmitter the clocks are advanced or retarded by exactly one hour. As the dates of the time change are not the same in different countries in Europe, each country is addressed by a different code. The code consists of 8 bits produced by lengthening to 0.2 sec the second pulses number 3 to 10 of each minute. It is repeated each minute during the night of the time change.

The decoder in the clock is made in such a way as to receive the correct message with a fair probability also in the presence of noise, but so as to make it nearly impossible for strong noise to simulate a spurious order for a time change. This system has been tested and installed successfully in several European countries.

Time Codes

Several LF-transmitters, including WWVB, transmit a time code in addition to the time signals. These time codes convey once every minute the complete information about time, date and year in a BCD format, by prolonging the second pulses by varying amounts. These time codes are intended for the timing of events without the need for a complete clock. We contend that these time codes bring more drawbacks than advantages:

- Although a clock which is set by a time code does not need an initial setting as is required by a clock that is locked on the nearest minute marker, the former clock is much more complex and therefore less reliable than the latter. Experience shows that if the latter is set correctly when switched on, it will never fail unless a component fails, and in this case updating by a time code would not be a remedy either.

- In some cases the time code impairs the quality of the minute markers. Indeed, the format of the minute markers should have the two properties, of being easily recoverable in the presence of noise but not easily simulated by noise. The minute markers of WWVB are particularly unfavorable in this respect, due to the presence of the time code.

- A time code fills up the information channel available to the LF-transmitter. This information capacity could be used more efficiently to broadcast less redundant messages of general public interest, e.g. automatic forewarnings of storms and other emergencies for many different regions which can be addressed individually or collectively.

Clock with 100 microsecond accuracy

An accuracy of 100 μsec in a noisy environment can be obtained with an automatic receiver clock, at the cost of an approximately tenfold increase in complexity and price. Fig. 5 is a schematic diagram of one of our designs; we will not discuss it in detail but only outline its main features:

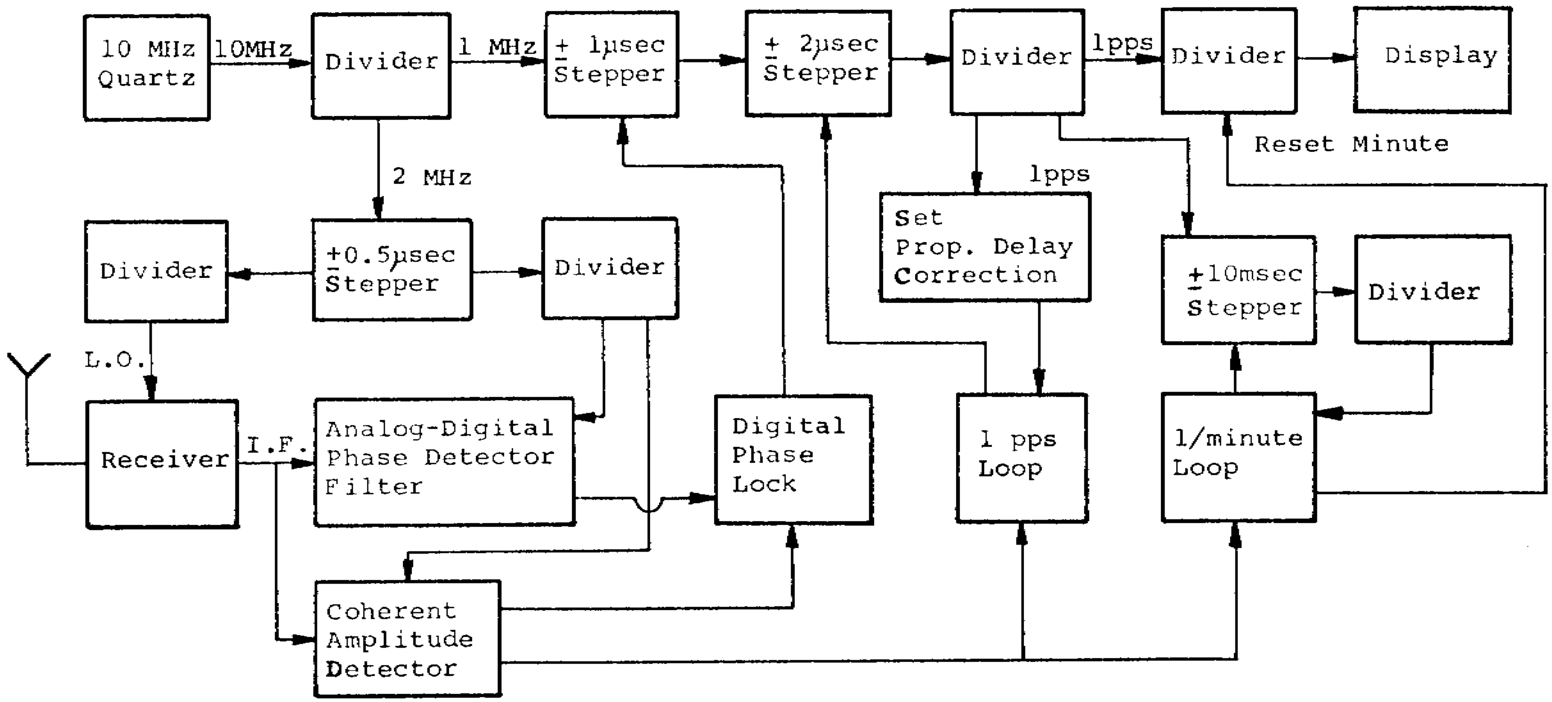

Fig. 5 : Schematic Diagram of 100 μsec Receiver Clock.

- Temperature controlled 10 MHz oscillator with aging rate less than 1 part 10^9 per day.

- Digital frequency control of the local time base, to hold the frequency during interruptions of the signal.

- Wide band receiver.

- Coherent detection of the carrier envelope.

- Separate handling of the second markers and minute markers.

- Slow correction rate of 1 part in 10^6 (1 μsec per second).

This clock has been implemented with about 60 C-Mos integrated circuits. Work is in progress to achieve the same goal by means of a microprocessor, but there are no results to report yet; the difficulty is due to the fact that C-Mos microprocessors, necessary here because of their low power drain, are not yet sufficiently sophisticated to allow a significant simplification of the clock.

Loran-C Clocks

We have also designed quartz clocks tied to the Loran-C signals (fig. 6). Since even the very best crystal oscillators will not hold the correct cycle of 100 kHz during an interruption of the transmitter, our clocks contain two quartz oscillators, each locked to a different Loran-C station. If one station goes off, the corresponding oscillator locks to the other oscillator. Since simultaneous failures of two Loran-C stations are extremely unlikely, the resulting clock is very reliable. Its low power consumption (0.5W), low cost and submicrosecond accuracy cannot be matched by any commercial atomic clock.

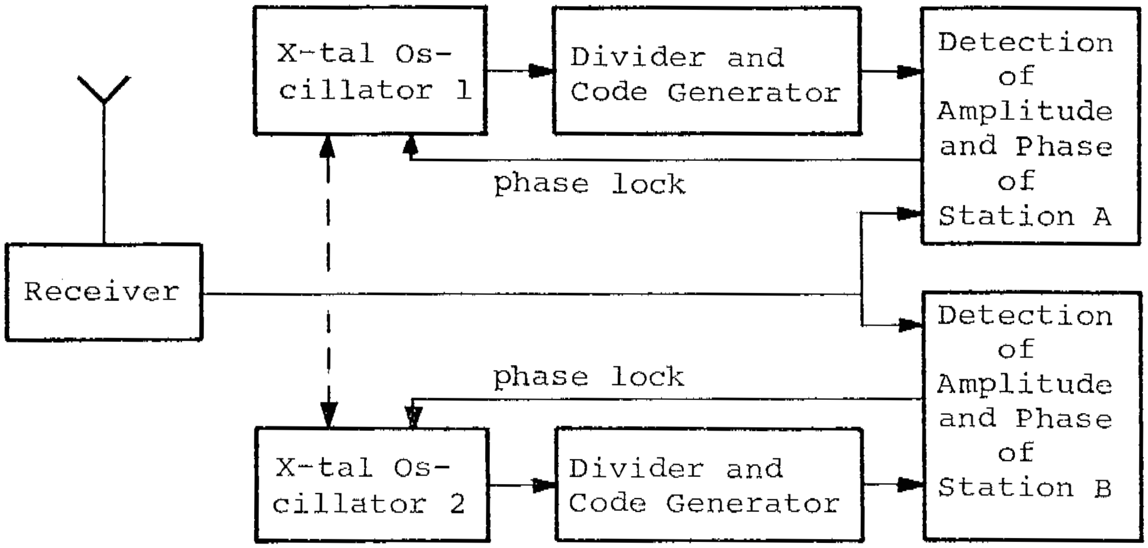

Fig. 6 : Schematic Diagram of Loran-C clock tied to two different Loran-C stations.

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1) Bureau International de l'Heure, Observatoire de Paris.

2) J. Bonanomi et P. Schumacher, La Suisse Horlogère No. 11, March 1976.

3) J. Fellrath, Suisse Horlogère et Revue Internationale de l'Horlogerie, No. 1, March 1969.