PTTI TECHNOLOGY IN SOUTH AFRICA AND SPECIFIC PROBLEMS GERMANE TO THIS GEOGRAPHIC AREA

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ABSTRACT

A brief historical survey of the development of time and frequency services in South Africa is followed by an account of some of the techniques presently employed at the NPRL to control the signals from radio station ZUO. Short descriptions are given of several devices which have been developed for local time dissemination, including one which transmits coded hour, minute and second data as part of the time signals themselves, a simple solar-to-sidereal time converter, and the ZUO morse code generator.

HISTORICAL SURVEY

Time in South Africa has traditionally been the responsibility of the astronomical observatories: in Cape Town the Royal Observatory (est. 1820) and in Johannesburg the Transvaal Observatory (est. 1903). The Royal Observatory distributed time from an early date by the daily firing of a naval gun, intended mainly for the benefit of shipping in Table Bay.

In Johannesburg the first hourly time signals from the observatory were sent in 1908 by landline to the Central Telegraph Office, from where they were distributed throughout the province. After the union of the four provinces in 1910 three Riefler clocks were installed at what had now become known as the Union Observatory, and the distribution network was extended to Durban, where - if all went well - a time ball was dropped at noon by a remote signal from Johannesburg.

In Cape Town time was measured astronomically as part of the meridian program, but Johannesburg had at first only a small 65 mm refractor, received on loan for a latitude observation program. The resulting time signals could seldom be relied on to better than about 0.5 second, and they might be worse after a period of cloudy nights. As early as 1923 it was found that much better results could be obtained by using the long wave radio time signals from Bordeaux and Rugby, and the astronomical observations were discontinued, to be replaced by the more accurate - if second-hand - radio time. In later years the possible installation of a Photographic Zenith Telescope has been discussed on numerous occasions, but until today there has been no basic change in this approach.

Precise time in its modern form may be said to have started in 1948, when the first quartz crystal clock was built at the Union Observatory. Although consisting mainly of discarded war surplus components, it immediately improved timekeeping accuracy by a factor of at least 100, and rendered all other clocks obsolete.

In 1949, at the request of surveyors and geophysicists who needed accurate time in the field, continuous radio time signal transmissions were started from a small portable transmitter, soon increased in size to 100 watt. The call sign of the new station - ZUO - where "UO" represented Union Observatory, has remained unchanged till the present day. ZUO is still the only time and standard frequency station on the continent of Africa, and in a very large part of the southern hemisphere.

In 1972 the time department was detached from the observatory in Johannesburg, and moved to Pretoria to become part of the Precise Physical Measurements Division of the National Physical Research Laboratory.

In 1974 it was formally laid down that, in terms of the Measuring Units and National Measuring Standards Act of 1973, the South African standard of time should be the cesium clock maintained for this purpose at the NPRL.

TIME AND FREQUENCY STANDARDS

In 1953 a set of six quartz oscillators using GT crystals, with associated frequency dividers, was obtained from the British Post Office, followed two years later by one Essen ring crystal. The ring crystal still remains in use today, but most of the others have long since stopped functioning, apparently due to failure of the solder connections.

A cesium beam standard was installed in 1966, and this has, with minor interruptions, controlled the South African time service until the present day. During this period the beam tube had to be changed on two occasions, after 26 and 61 months respectively. The cesium standard was from the beginning adjusted to give an AT output. For time signals the offset in use before 1972 was achieved by a special phase shifter, while the ZUO carrier frequency was broadcast without offset.

A second South African cesium clock (not counting temporary installations for specific projects) was acquired by the S.A. Bureau of Standards at the beginning of 1975. The two clocks, which are located some 10 km apart, are now being regularly intercompared. All the same, one cannot feel altogether secure with a national time service which relies on two basic standards only - one of them at a distance.

Apparatus for generating the ZUO and other time pulses has always been designed and constructed locally, and we have by now gone through all the various stages, from vacuum tubes through cold cathode tubes and transistors to integrated circuits. The most recent unit combines all the following functions - very nearly the complete time service - in a single enclosure:

- Frequency dividers: 1 MHz to 1 pulse per day
- Provision for resetting and adjusting all stages
- Digital time display: both UT and SAST
- DUT1 code, with preset switching (*)
- Leap second preset switching (*)
- Morse code: ZUO and time, every 5 or 15 minutes
- Coded pulse output for controlling slave clocks in building
- Various other time pulses, e.g. "6 pips" every hour for broadcast stations.

(*) Preset on previous day, to obviate need for manual switching at 2 a.m.

TIME COMPARISON

The great distance between South Africa and the major centers of research which determine AT and UT - mostly in the northern hemisphere - leads to special problems in time coordination, and make the regular intercomparison of time signals, by every practical method, essential.

Between 1945 and 1960 the local clocks were checked daily with reference to the HF signals from WWV and WWVH. To keep the time signals in step with WWV without adjusting the oscillators, a motor-driven continuous phase shifter was constructed in 1955, which could modify the oscillator frequency from -20 to $+20\times10^{-9}$ in steps of 1×10^{-9}.

When in December 1960 the ZUO time signals were coordinated with those of other stations, the phase shifter was improved by the addition of an electronic drive, to give it a range of from -99 to $+99 \times 10^{-10}$, in steps of 1×10^{-10}. (A new adjustable phase shifter built recently provides for adjustment between -999 and +999 microseconds per day, in steps of 1 microsecond per day.)

VLF Comparisons

The next step was to build two VLF receivers, permanently tuned to GBR and NBA. Phase measurements were made with the aid of a CRO, and manual adjustment. Used in conjunction with the phase shifter, these receivers now made it possible to keep the ZUO time signals within 1 millisecond of UTC, and to keep the mean ZUO frequency within about 5 parts in 10^{10} at all times.

Continuous VLF phase recordings are at present made by means of two commercial receivers, normally tuned to GBR and NAA, the two stations which in this region have proved to be the most reliable. By making use of the corrections published by the USNO it is usually possible to reconcile the various measurements to within a few microseconds.

Except for occasional disturbances due to lightning, this system has proved to be most reliable over long periods. It has sometimes been suspected that the results might be affected by seasonal variations in propagation time, but until now there has been no completely uninterrupted period sufficiently long to enable one to draw a definite conclusion.

Travelling Clocks

Absolute time differences have since 1966 been based almost wholly on the travelling cesium clocks which have been sent from time to time from the USA by the USNO and other organisations. Because such comparisons have often been motivated by the needs of particular projects, they have often taken place at rather irregular intervals, and with the recent closure of the local STADAN station there is some concern as to the future. It is highly desirable that these comparisons should continue, but it is also appreciated that one cannot expect other organisations to bear the full cost indefinitely. Future travelling clock comparisons will therefore probably have to be arranged by ourselves.

The emphasis will probably be strongly in favour of light and simple portable clocks, which should, if at all possible, have to travel by air unattended. Even if this meant that some stability might have to be sacrificed, this might well be compensated for by faster return times and more frequent journeys.

Loran C

This has for some years been used by the STADAN station. As the distance to the nearest station (Lampedusa) is too large to make use of ground waves, accuracy is of the order of ±5 microseconds. The system therefore provides a valuable check on local time standards, and would give immediate rough synchronization after a complete interruption, but it cannot compete with travelling clocks for precision.

Satellites

More or less the same applies to the TRANSIT satellite comparisons made at the French Tracking Station, which can at present be relied on to within about 50 microseconds.

Local Comparisons

A portable rubidium clock has for the last year been used to make regular monthly time comparisons with the few organisations in the neighbourhood of Pretoria who need microsecond accuracy, viz. the French Tracking Station, the S.A. Bureau of Standards, and (until October 1975) the STADAN station at Hartebeeshoek. These comparisons have proved to be of great mutual benefit, and, if the demand warranted it, they could well be extended to other parts of the country.

The new television network at present being established offers good possibilities for time intercomparison, not only for local use, but perhaps over the whole country. At present, however, it is still too early to give results.

TIME DISTRIBUTION

ZUO Radio Signals

The ZUO signals in their present form date from the middle 1950's when, shortly before the start of the IGY, it was realised that the distribution of time in southern Africa was far from satisfactory. As it was impractical to emit radio signals at high power direct from the observatory, near the centre of Johannesburg, the South African Post Office took responsibility for time broadcasts from its new station at Olifantsfontein, about half-way between Johannesburg and Pretoria. Clocks and other time equipment remained at the observatory, while the time signals, together with a 100 kHz standard frequency, were transmitted to Olifantsfontein by a 100 MHz radio link. At the receiver the standard frequency and time signals were separated, the former being multiplied to 5 MHz to provide the carrier frequency of the HF transmitter, which was then modulated by the latter.

New equipment installed around 1970 uses a frequency of 141 instead of 100 MHz, and the original 100 MHz transmitter was modified to transmit time signals only, as a useful service to the general public. When in 1972 the clocks were moved to their new location in Pretoria, the same equipment was used to transmit the signals to Olifantsfontein - almost the same distance as before, but now in the opposite direction. At the same time the 10 MHz transmission from Johannesburg was discontinued, and replaced by one on 2.5 MHz, which gives far more consistent results at night over the greater part of the country.

The question is asked from time to time whether such an indirect transmission system does not lead to a loss in accuracy, and the answer is, of course, that to a small extent it does. The delay between clock and 5 MHz transmitter output was measured to be about 270 microseconds, and radio propagation time accounts for about 100 of these. There are bound to be fluctuations, but users of HF signals will in any case have to contend with very much larger changes in the travel time of the HF signals themselves.

Present users of time in South Africa, and probably elsewhere, can be conveniently classified in three groups:

(A) Those who demand an accuracy in the microsecond region and beyond;
(B) Those who need millisecond accuracy, e.g. surveyors, geophysicists, astronomers;
(C) The rest, usually satisfied with an accuracy of 1 second or more.

Groups (B) and (C) are both adequately served by the ZUO transmissions, and it is only group (A) which requires special attention. It is as yet a very small group, confined to those who maintain clocks of accuracy comparable to that of the cesium clock, e.g. for satellite tracking. In the immediate neighbourhood of Pretoria these users have sometimes been able to use the 141 MHz transmissions direct, but on the whole a portable clock comparison has been more satisfactory.

Other time distribution systems

Two systems intended primarily to serve group (C) are the broadcast hour signals, and the "Speaking Clock" service provided by the telephone department. Before 1972 both signals were controlled by the observatory clocks. This came to an end when the clocks were moved to Pretoria, and since then both the S.A. Broadcasting Corporation and the Post Office have generated their own time signals, with varying degrees of success. Neither signal can at present be relied on to supply precise time.

What follows are brief descriptions of three items of apparatus developed by the author for time service use.

CODED TIME PULSE UNIT

The use of coded hour and minute data in conjunction with time signals is fairly common (as, for instance, in the case of transmissions from WWV and DCF77) but no cases are known of the time pulses themselves being used to transmit hour, minute and second data. The unit to be described, which uses this method, was developed for time distribution by line within the laboratory. It provides a digital hour, minute and second display, together with audible second and minute pulses, without any distracting audible code.

A BCD time code requires 7 bits each for minutes and seconds, and 6 bits for the hours : a total of 20. The second signals are therefore made to consist of 20 pulses, at a rate of 2000 Hz, i.e. a total length of 10 milliseconds per second. Each pulse is either short, representing "0", or long, representing "1".

The coded pulse generator is shown in the simplified schematic diagram of Fig. 1. A 20-stage parallel-in serial-out shift register is preset every second by a preset enable signal from the controlling clock. Also obtained from the clock are the sequences of 2000 Hz pulses: 20 at every second and 1000 at every minute. The output pulses are produced by two monostable multivibrators, which produce pulses of duration 50 and 250 microseconds respectively. Every input pulse produces a 50 μs. output pulse, but a 250 μs. pulse is produced only when the shift register output is "1". The output is therefore a sequence of pulses which are short or long depending on the state of the shift register output.

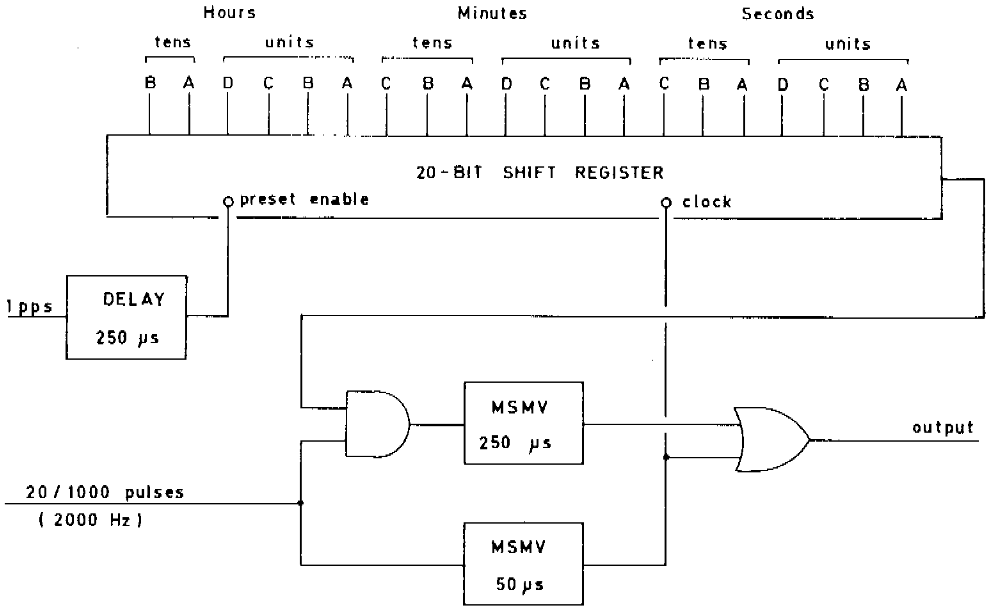

Fig. 1-Coded time pulse encoder
(master clock unit)

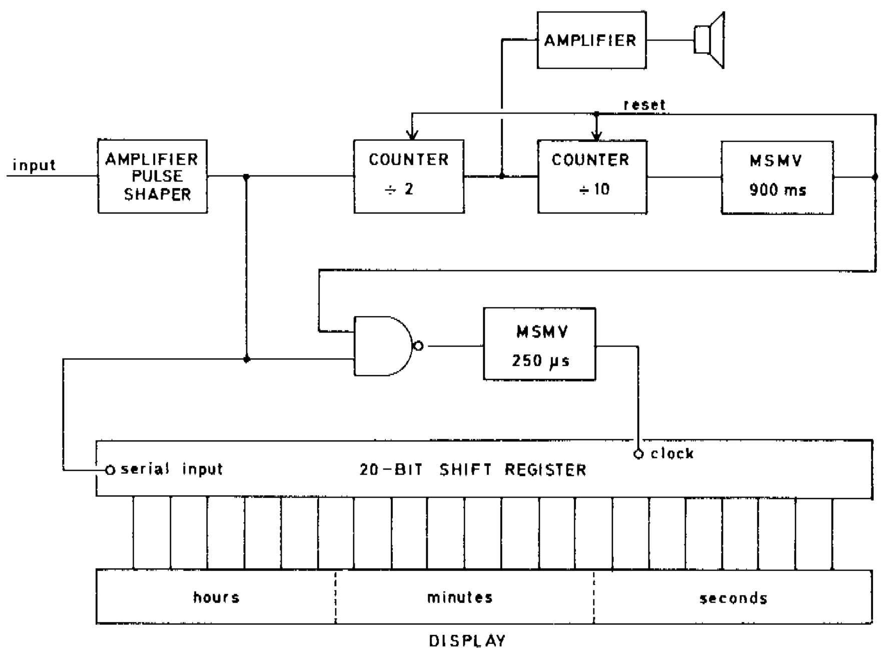

Fig. 2-Coded time pulse decoder
(remote unit)

Figure 2 shows the decoding and display unit, which uses a serial-in parallel-out shift register. Two counter stages dividing by 2 and 10 respectively trigger a monostable multivibrator after the 20th pulse, which resets and disables the counters for a period of just under a second, and prevents any further pulses reaching the 'clock' input of the shift register. When a minute signal occurs, therefore, only the first 20 pulses will be registered.

The loudspeaker is fed from the output of the first counter (divide by 2) so that the audible second signal consists of ten identical 1000 Hz pulses, irrespective of whether the incoming pulses are short or long.

SOLAR-TO-SIDEREAL TIME CONVERTER

Solar-to-sidereal time converters have a very long history. Dondi's astronomical clock of 1360 was probably the first instrument which used mechanical gears to indicate solar and sidereal time simultaneously. The ratio used was the simple one of 366/365, but since Dondi's time numerous other ratios of ever increasing complexity have been proposed, many of them ingenious rather than practical.

It is understandable that the first electronic converters tended to be designed on similar principles, with frequency dividers and multipliers now taking the place of mechanical gears. One of the first units of this kind, which had an accuracy of 1×10^{-12}, was built by the author as long ago as 1949 (Hers, J., Nature, vol. 164, 841).

Digital circuitry has now suggested a much simpler approach, based on the same principle as the adjustment of the calendar by the introduction of leap years. A first correction is made by adding an extra pulse to the clock input after every count of, say, A pulses, where A is the nearest appropriate count obtained within the clock itself, or a count closely related to it. If this correction proves to be too much (or too little) a second correction is made by deleting (or inserting) a pulse after count P (or count B), and the process may be continued indefinitely until the required accuracy is reached. Normally each additional stage will increase the accuracy by a factor of about 100.

Figure 3 shows two possible arrangements. In the upper diagram the pulses from the various divider stages of the clock are fed back to the input of the clock itself. The output therefore consists of sidereal time pulses only.

In the lower diagram the correcting pulses for the sidereal output are obtained from a parallel solar time divider, so

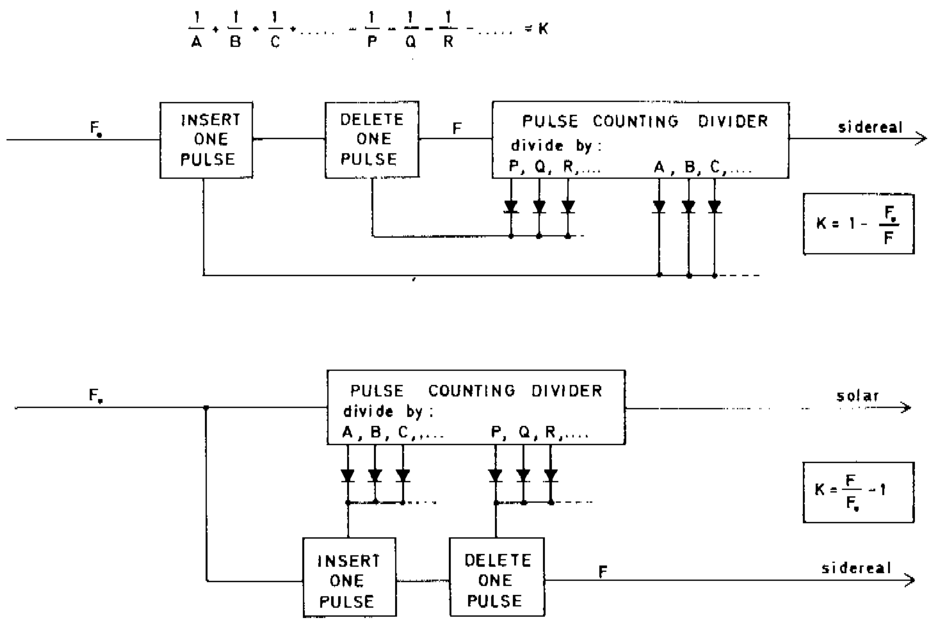

Fig. 3-Solar-to-sidereal time converter
Principle of operation

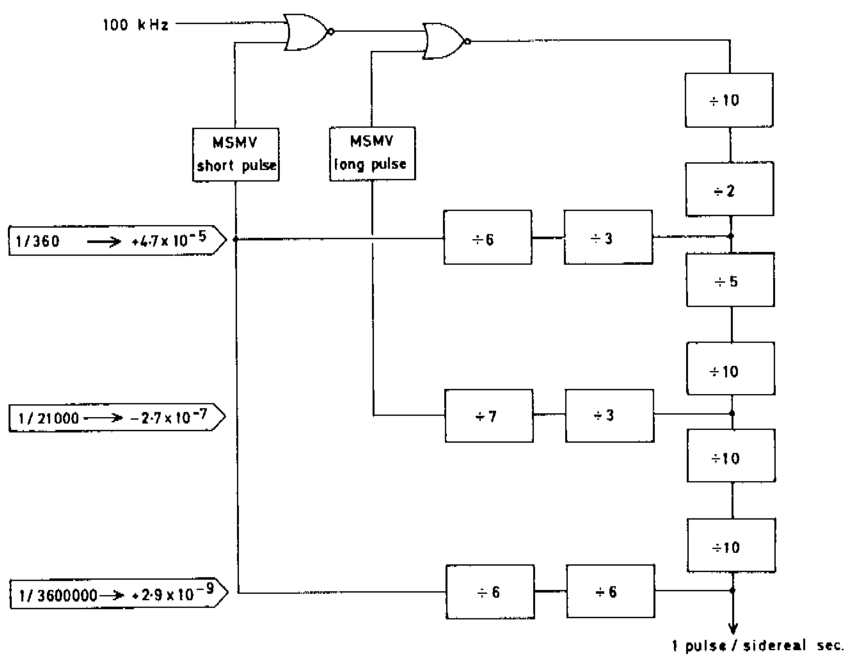

Fig. 4-Solar-to-sidereal time converter
Example of a practical design

that both solar and sidereal time pulses are obtained. (Sidereal time divider not shown.)

A practical circuit is shown in Fig. 4. Here the input consists of a 100 kHz square wave, which triggers the first counter on the high-to-low transitions. After every count of 360 a monostable multivibrator applies a pulse, which is short in relation to the input pulses, to the first NOR gate, thus inserting one extra pulse, and increasing the total count by 1.

After every count of 21 000, a second multivibrator feeds a long pulse - approximately $1\frac{3}{4}$ times the duration of one cycle of the input frequency - to the second NOR gate, which suppresses the next pulse, and decreases the total count by 1. After a count of 3 600 000, a pulse is once again inserted.

The average rate of the output pulses is:

$4.7x10^{-5}$ high after the first correction,
$2.7x10^{-7}$ low after the second correction,
$2.9x10^{-9}$ high after the third correction,

and the error may be made as small as desired by adding further stages.

ZUO MORSE CODE GENERATOR

In a bilingual country such as South Africa time announcements would have to be made in both official languages, and it was therefore decided at an early stage that the ZUO transmissions should use morse code rather than voice announcements. The original code generator used mechanical contacts to produce, every 15 minutes, the announcement:

ZUO ZUO ZUO (followed by hours and minutes)

and this was kept in operation for nearly 20 years, although it was never as reliable as it should have been.

In 1973, therefore, a new all-solid-state unit was developed, which not only was capable of giving time announcements every 5 instead of every 15 minutes, but which proved to be simpler and more versatile than any similar device of which descriptions could be found.

It is based on the principle that in the morse code the digits 0 to 9 are represented by a group of 5 dots and/or dashes, arranged in a regular progressive sequence, as shown in Fig. 5. If, therefore, a 10-stage shift register is made to generate a continuous sequence of 5 dots followed by 5 dashes, any digit may be obtained by entering the ring at the appropriate point, and stopping after the fifth stage.

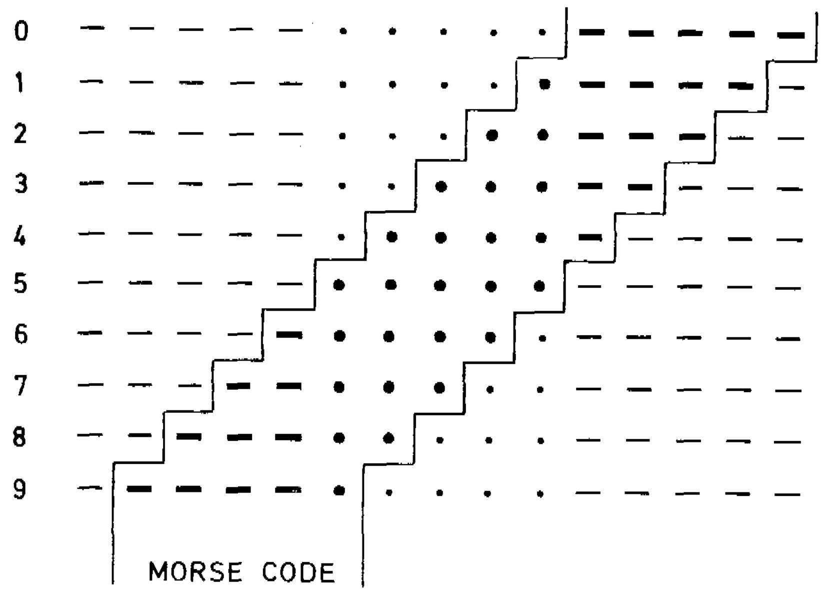

Fig. 5-Morse code characters for digits

If, instead of counting 5 consecutive symbols, one counts 4, 3, 2 or 1, the same system may be used to obtain 17 out of the 26 letters of the alphabet, as shown in the large rectangle of Fig. 6. The remaining 9 letters may be formed by combining two simpler characters, e.g. Q can be formed by M followed by A. In the case of ZUO this was fortunately not necessary.

The simplified block diagram of Fig. 6 can best be explained by starting at the end of the chain, with the SYMBOL GENERATOR. This is a 4-stage shift register which produces an output of either a dash followed by a space, or a dot followed by a space, depending on whether the sequence is started at A or at C. This shift register is clocked at a constant rate of about 10 Hz, designated in the diagram as "clock 1". (In the case of ZUO it is 8.33 Hz.)

A sequence of 'preset' pulses, to produce the sequence of dots and dashes which correspond to the required morse code characters, is derived from the CHARACTER GENERATOR, i.e. the 10-stage shift register already mentioned. Five stages

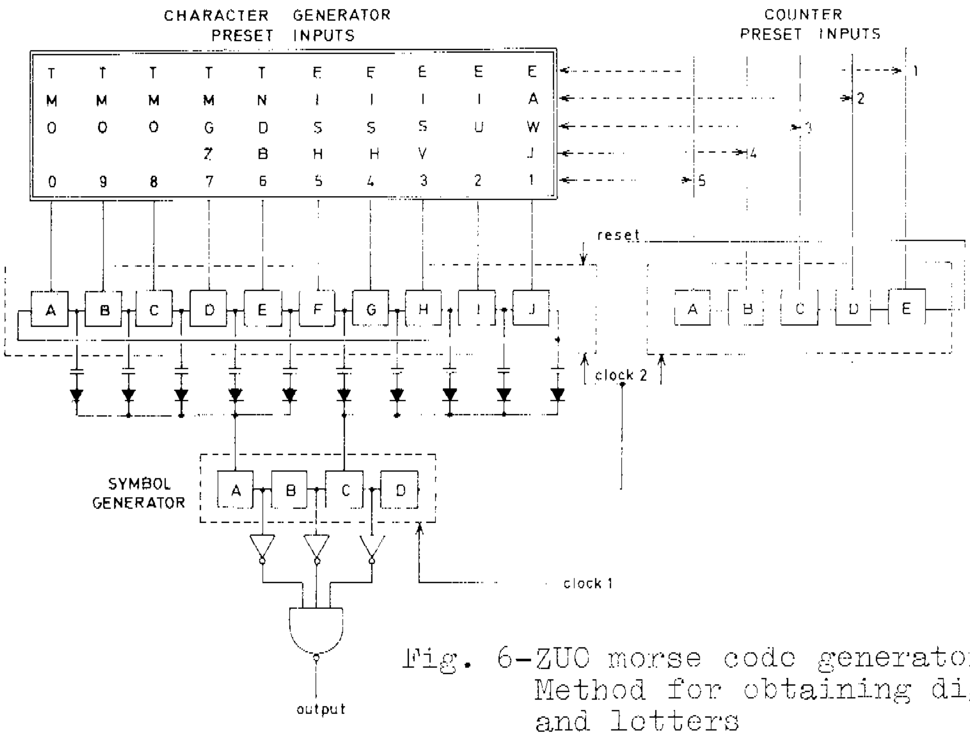

Fig. 6-ZUO morse code generator
Method for obtaining digits
and letters

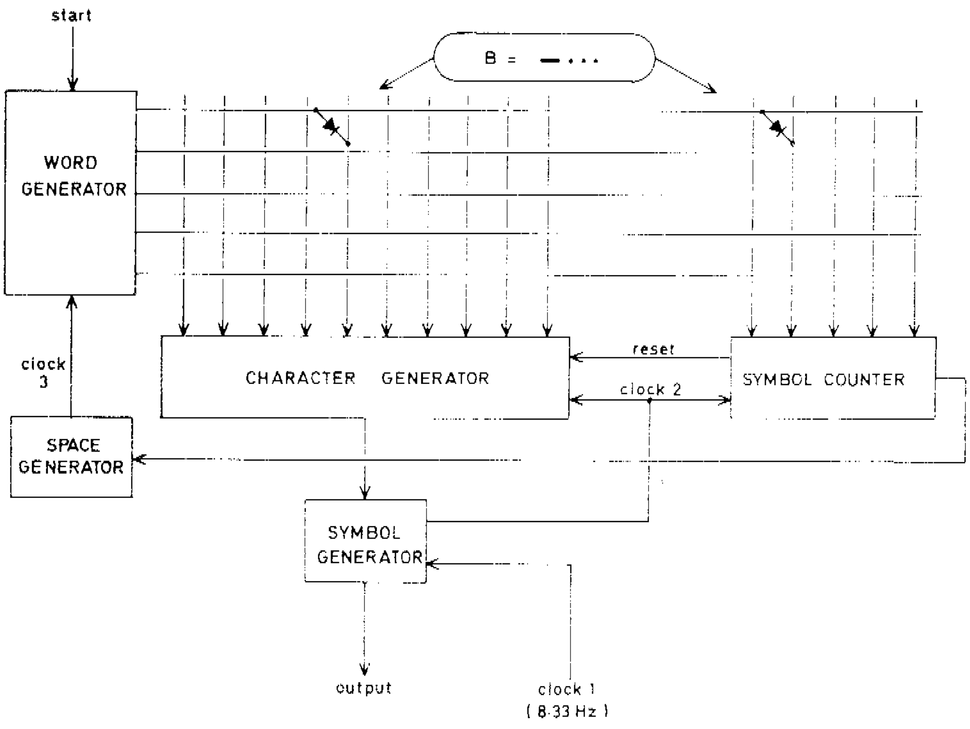

Fig. 7-ZUO morse code generator
Simplified block diagram

of this trigger the 'dash preset' input of the SYMBOL GENERATOR (A), while the other five trigger the 'dot preset' input (C). It operates in conjunction with the COUNTER, which determines the number of symbols in each character. Both CHARACTER GENERATOR and COUNTER are clocked at the "clock 2" rate, obtained from the SYMBOL GENERATOR output.

At the end of each character an output pulse from the COUNTER enables the SPACE GENERATOR to insert an additional space between characters, and feed a "clock 3" pulse to the WORD GENERATOR (Fig. 7). This again consists of a series of shift registers containing as many stages as there are characters to be transmitted. Each stage is connected, through a diode matrix, to one of the preset inputs of the CHARACTER GENERATOR and to one of the COUNTER inputs. As an example, the diagram shows the connections necessary to generate the morse code symbols representing the letter B.

The complete unit for generating the ZUO code, which includes the decoding necessary for the various 5 minute time announcements, consists of 34 type 74 IC packages, mounted on three 100x160 mm boards. Since it was put into service nearly two years ago there has not been a single instance of malfunctioning, a notable improvement on the previous unit.

QUESTION AND ANSWER PERIOD

DR. KLEPCZYNSKI:

The paper is a historical survey of South African time system. I am sure the paper has reflected these problems and pitfalls correctly.

MR. SMITH:

Smith, Royal Greenwich Observatory.

I would like to ask a question and Dr. Klepczynski needn't worry, it is not going to embarrass him in any way, I am sure. It concerns the original abstract which was given of Jan Hers' paper concerning the BCD code for giving the time signals.

Now, a similar suggestion has been put forward by Dr. Becker. He has proposed that time signals should carry a BCD coding giving the difference between the signals in UTC and the UT-1. It does appear that the navigators for whom the DUT-1 code was originally suggested are not, in fact, making use of it. It seems to have a very limited application indeed.

Nevertheless, there must be many people who would like to know the difference on a current basis between UTC and UT-1. It may, therefore, well be a better proposition to use a BCD coding rather than the very simple system which was intended for oral use by the navigator. I wondered whether at this meeting it might be possible to get any expression of opinion; first of all as to whether the DUT-1 code is proving of any practical value whatever in the form in which it was recommended by CCIR; whether there is any need for current information on the difference between the signals in UT-1; and whether CCIR should give consideration to whether this can best be given on the signals in a BCD coding.

This is a very urgent problem because the CCIR will be meeting early in the new year and one of the tasks of study group 7 will be to consider any possible modifications of the present system. Thank you.

DR. KLEPCZYNSKI:

Does anybody in the audience care to make a comment on Mr. Smith's proposal?

First of all, has anybody here in the audience utilized the DUT-1 audible code? Do we have users of that in the audience right now? Seriously, if in any way you use this code, please say so right now because this could have serious repercussions.

DR. BEEHLER:

Beehler, National Bureau of Standards.

I am not really a user, of course, of the DUT-1, a supplier rather. But, I might mention that the National Bureau of Standards recently conducted a major survey of its users and the conclusions from that, at least one conclusion, was that while there is a small group of people who said yes, the DUT-1 code is important to us, it is a very small group, at least as indicated by this survey, and there are some numbers that I could give. I don't have them on top of my head, but if someone is interested, I can get those numbers.

But, it was by far the least-used service of eight on the WWV and WWVH format. So, our conclusion is that it is, indeed, a very small group that we seem to be serving with the present technique.

DR. KLEPCZYNSKI:

I have a question. Of those who responded, who did use the audible signal. Could they in turn use a coded signal?

DR. BEEHLER:

The distribution of the users that said it was important to them seemed to show no particular trend. That is, they weren't navigators in particular, as you might expect. It was just almost down in the noise for all of the 14 user categories that we looked at, the weighting of these user categories were almost constant in their use of DUT-1. There was no peak for navigators or any other particular group. I think the group that included seismologists was actually the largest.

DR. KLEPCZYNSKI:

That is interesting. I think you recall a study made by Japanese navigators -- they do use DUT-1 code for navigation.

DR. WINKLER:

I would like to comment on that also. I think, number one, that no users can be expected to be representative here. Number two, the navigators, evidently in the large majority, do not use the DUT-1 code because for regular celestial navigation it is not important. It is below or at the level of other inaccuracies. The accuracy of a sextant sight is 1 minute of arc which would translate into several seconds of time, so a fraction of a second of time is really not their concern unless they want to be perfectionists, and there are only about 5 percent perfectionists in any profession.

Another point is another group of users, the geodesists, which would require the DUT-1 correction, are not aware of it. They don't even know about it. This surfaced during the last meeting in Grenoble of the International Union for Geodesy and Geophysics, at which discussion revealed the fact that there is a considerable need for education of these people. They are not even aware of it.

That leads me to a reply to Dr. Smith's comments. I would take the position that whether there is any use or not, it should not be changed within the next five years because the learning period seems to be on the order of between five to 10 years and if you make a change every two, three or four years you will always lose all of these users. Whatever you do, I think we must have the courage and the perserverance to hold on to a system which, fortunately, we have been able to agree upon internationally. It is a sensible system. It may not be the best one. In fact, I don't think it is the best one of all possible systems, but to change it again, after only three or four years, I think would be sheer madness and I am strictly against that, whether it is used or not.