TIMING IN SWISSNET
SPECIFICATION, DEVELOPMENT, IMPLEMENTATION AND OPERATIONAL EXPERIENCE

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Abstract

This is a report on a team effort started in 1974. During the past 15 years two generations of frequency control and timing equipment have been developed. The installation of the second generation equipment started in 1985. The principles of the clock hierarchy is recalled and compared to more recent proposals. The Swiss Integrated Services Digital Network (SWISSNET) derives its timing from its own three geographically separated primary reference clocks. It is designed to comply with the relevant CCITT Recommendations at the second highest level of hierarchy, consisting of about sixty timing nodes. These in turn control the clock units of all digital switches. The switching equipment is supplied by three different vendors which all have been able to satisfy the specifications imposed on their timing equipment. Some examples of problems and how they were solved will be reported and offered for discussion.

1. Introduction

SWISSNET is the name of the evolving Integrated Services Digital Network (ISDN) in Switzerland. The country has a surface of 40'000 square kilometers, 6.3 million inhabitants and 3.6 million telephone subscribers. The telecommunications network is operated by the Swiss Post and Telecom Enterprise (PTT), owned by the Swiss Federal Government. PTT has a staff of 60'000, 40'000 in the Postal Department and 20'000 in the Telecom Department. The ratio of staff to customers served has been kept stable at about 5 per 1'000 during the last years through continuous high effort in management, planning and organization. The first ISDN version, SWISSNET 1, has started operating on a trial basis with a group of selected business customers in Summer 1988 and became a commercial service in Summer 1989 [1]. Further steps are following rapidly. Moreover, broadband switched services are being introduced at a rapid pace. On the international level, major efforts in standardization of new concepts are underway in the CCITT, this work being based on proposals from regional bodies such as the ANSI T1 committee in the U.S., the European Telecommunications Standards Institute (ETSI), created early in 1988 and from national telecom operators.

The history and current state of digital network timing developments are well documented in the April 1989 issue of the IEEE Communications magazine [2, 3] which contains five interesting review papers on network performance aspects. A few remarks on terminology are necessary at this point with the hope to reduce confusion among the many authors (and readers) in this field.

The term digital Network timing is used here in a general sense comprising other more restricted terms such as clock signal distribution, synchronization, frequency control etc. On the other hand, the current timing systems do not distribute time in the meaning of date on a time scale. They only perform frequency control on all clocks in the network in order to keep the clock rates within the limits required for acceptable performance of the transmission, storage and switching operations in the network.

2. Specification and development

2.1 General

There is a voluminous and evolving set of rules in the Swiss PTT for specification, development and procurement of hardware and software. Since we cover a period of over 15 years, space does not allow to discuss all aspects of this process. We limit the discussion to some key elements which illustrate the way of operation, some changes and possible future trends.

Being a public service/network operator the Swiss PTT does not manufacture any equipment. Compared to the larger European PTT's it is a small organization. The R + D laboratory with a staff of about 300 is in charge of much non - R + D work such specification, testing and consulting work. Therefore only about 60 of our Engineers are actively engaged in R + D work. The team working on the subject described here never exceeded 6 PTT engineers and was smaller during most of the time, some changes occurred due to promotion or shift to other activities.

We however had the advantage of being flexible, in close contact and not impeded by administrative barriers. Last but not least we started early and had the time required to get into the subject.

The classical cycle:

- setting specifications
- call for proposal
- development contract
- testing of prototype

- review and correction
- retesting
- quotation for procurement
- prototype approval testing
- production order
- delivery and installation
- acceptance test
- correction of faults if any

was followed, not only once but several times in an iterative manner. We did not have any legal problems concerning calls for proposals and contract awards. In each case, the amounts involved were far below the limit requiring a public "call for tender".

Whatever the type of contract, i.e. single source or competitive bidding, the prospective supplier must quote in detail. All offers are scrutinized by a special office in the material procurement division.

The invoices are checked again and all accounting operations are audited by an office called "Financial Inspectorate" (FISP) which is independent of PTT management but reports directly to the Government and can even be called to hearings before parliamentary committees. FISP can become very active in cases of real trouble with a project. Normally it also constitutes a safeguard and often helps the management in the choice of correct procedures. During the developments described in the following sections no problem ever occurred concerning these controlling offices.

2.2 First generation

The first informal talks concerning new developments of frequency generating equipment started early in 1973 between Engineers of the PTT Research Laboratory in Bern and the Oscilloquartz Company (OSA) in Neuchâtel. This company founded in 1949 as a small affitiate to a major watch manufacturer had supplied carrier frequency generating equipment for the PTT telephone transmission network since 1952. 20 years experience and an excellent record of performance and reliability had then already put it ahead of possible competitors. It was therefore logical that the PTT continued working with OSA.

The key technical persons participating in the initial contacts were Walter Neu, Hans Karl Pfyffer, Christian Stäger and the author all from the PTT R&D division and Erhard Graf and Bernard Walther from OSA.

Two problem areas were identified at that time. One concerned data transmissions using modems and analog Frequency Division Multiplex transmission systems. The existing carrier frequency generating equipment installed between 1962 and 1966 was designed for voice transmission (carrier telephony) with maximum carrier frequencies of 12 MHz, using master crystal oscillators on 124 kHz. Very reliable and aging less than 1 part in 10^{10} per day, these sources had too high phase noise for the operation of planned transmission systems with a bandwidth extended to 60 MHz.

The other, more long term problem was how to deal with the future switched digital networks. Here the situation as known from the then published literature and from contributions to the CCITT Special Study Group D (now known as CCITT SG XVIII) was confusing at best.

The time available to agree on specifications and develop prototype equipment was limited. Two major network capacity extension projects had already started:

- 60 MHz main coaxial cable trunk network
- PCM trunk Zurich-Berne-Geneva for leased data lines, gross bit rate 140 Mbit/s.

Early tests for these systems were then planned to start late in 1975. However, these large projects slipped towards 1977, so that the frequency generating equipment was ready in time.

The first rough specifications were drafted in 1974. The principal objectives were:

Frequency offset:	less than 1 part in 10^{-9}/6 months
Spectral purity:	$S_0(f)$ less than -105 dB for 50 Hz $<$ f $<$ 4 kHz
MTBF:	minimum 30 years for the master oscillator unit.

All other specifications, electrical, mechanical and environmental were to be conformal to all the other transmission line equipment, based on internal standards established in 1972.

Figure 1 shows a block diagram of a frequency generator unit proposed [4] in February 1974 to the internal expert team. Two Rubidium and one crystal oscillator generate each a 10 MHz signal. The oscillator frequencies are controlled in order to keep the three signals in phase. These signals can thus be combined on a common bus. The control unit contains phase comparators, amplitude monitors, D/A converters for step frequency control of the oscillators and an externed reference frequency input. This proposal was thoroughly discussed in the team and then abandoned. The decision to proceed with another design [5], shown in Fig. 2, was unanimous and based on a cautious assessment of the risks in its development. We would not have been able to meet the deadline. Keeping the pace of the evolution in the CCITT Recommendations would have been very difficult.

The Frequency generator rack developed during 1975/77 comprised two crystal oscillator units (OSA B5400) locked to each other and feeding two decoupled 5 MHz reference bus lines. These in turn feed up to 2x9 PLL synthesizer units generating the required output signals at 4, 12, 124, 2108, 2200 kHz for FDM analog systems and 2048, 4096 kHz for PCM systems.

The outputs are 75 ohm coaxial with a sinusoidal signal level of 0 dBm. Each equipment rack can have up to 440 output connectors; installed in the upper part of the rack. Each reference frequency signal is supplied twice over two independent outputs to the multiplexer racks. Switchover in case of failure is done on the receiving end.

The technical basis of the requirements of the specifications and the main features of the equipment have been presented in June 1977 at the 31st Annual Frequency Control Symposium [6, 7]. Compared to the 1974 specifications mentioned above two major enhancements were introduced:

Frequency uncertainty	: less than $\pm 1 \cdot 10^{-11}$
Spectral purity for the FDM outputs	: Sg (f) less than -117dB/Hz for 50 Hz $<$ f $<$ 4 kHz

The increased accuracy to be referred to the UTC timescale was a result obtained in the CCITT, contained in the then new Recommendation G.811. This feature was required only in the nodes along the PCM data line which at that time constituted only a few nodes of a total of about 60.

All other nodes having FDM systems only were installed with only the two crystal oscillators and without the cesium unit.

The increased spectral purity requirement was based on studies made by H.K. Pfyffer and reported in [6]. We were able to test this performance in the field with phase noise measuring equipment developed by Kurt Hilty [8].

During the two years design phase, the main effort was concentrated on reliability rather than highest technical performance. Therefore, a large part of the engineering man-hours spent at PTT and at OSA were devoted to subjects such as redundant power supplies, monitoring and alarm circuits, signal cut-off circuitry in out-of-lock states of the PLL's, minimizing the number of common elements (only passive elements allowed).

The contributions to this work by Max Suremann who edited and revised the specifications and by René Payern who brought in the experience from network operations are to be acknowledged.

2.3 Second generation

The first generation equipment installed and operating from 1977 onwards was satisfactory with respect to time of delivery and reliability. The short time available did however not allow to solve many problems recognized during this first phase. The team members which all had many other often more urgent tasks to do, felt that additional help was required. W. Neu, one of the initiators had moved to ISDN research. H.K. Pfyffer was even more drawn into Digital Network planning and standardisation activities which culminated in his election as Chairman of CCITT SG XVIII in 1983 and promotion to Deputy Director of Research at PTT in 1985. C. Stäger had returned to his microwave research already in 1974. On the OSA side, B. Walther left the company for a teaching position in an engineering college. Those who stayed on received help. On the research side, Pierre André Probst and Paul Vörös joined the team.

From the engineering division came Hans Ulrich Stettler and Hans Friederich.

The problem in 1977 was that, although we had clock units and all the associated equipment of superb quality and good reliability, we had no good network timing control concept. Academic research as known from the published literature was, in quantity and scientific quality biased towards sophisticated system theory using mutual synchronization. On the other hand all colleagues we knew that were already building networks used master-slave synchronization. As we had to build a network and be sure it works we followed this way.

One important concern was to introduce new concepts in an organic and evolutive process, well coordinated with the much larger effort devoted to the transition from the conventional telephone network to the future digital network.

One possibility for reference clock distribution was created in the period 1975-78 when an old standard frequency distribution system dating back to the fifties was replaced by new equipment. An accurate pilot signal at 4300 MHz is distributed over the coaxial cable trunk network to all nodes. Various standard frequency signals, including 5 MHz are derived at each node and used e.g. for periodic manual readjustment of the FDM carrier generators within the margin of $\pm$ 1 part in 10^8. This could have offered a temporary relief in case of urgency but would have left the new digital network dependent on a obsolescent infrastructure.

The solution to be developed was to use the 30 channel PCM multiplex with a bit rate of 2048 kbit/s from which a 2048 KHz reference frequency could be derived at any place in the network.

The main effort in the studies leading to the hierarchy depicted in Fig. 3 was carried by P.A. Probst and P. Vörös, with assistance from the other team members.

Results of these investigations were published in 1982 [9]. In the meantime revised specifications were introduced and discussed with OSA. The main problem was the definition of optimum filter characteristics of the slave osillator control system in order to reduce the effects of jitter present at the receiving end of the transmission system [10]. The PLL circuits of the first generation master oscillators had not been designed for this purpose and could not absorb the level of jitter encountered in practice. Another major difficulty was the impossibility of dealing with some states of oscillator failure locally when you have only two oscillators. If an abnormal phase excursion is detected, there is no arbiter to unambiguously and quickly decide which unit is in trouble. Finally, after lengthy deliberations and sometimes protracted discussions we came to the conclusion that there was only one safe way out, at the additional cost of a third unit. We thus introduced the triad principle with majority decision in the first and second order centers.

Figure 4 shows the first order center arrangement. A careful observer will notice that if all three cesium units, located in different places, simultaneously fail, the first level falls back into a mutual mode. Based on current experience and supposing proper maintenance, such an event may occur once in a thousand years.

The second order centers of which now 66 units are operating have three identical master oscillator units, as shown in Fig 5. The network concept and the design features of the second generation clock signal generator units have been described and presented at the 17th PTTI meeting in 1985 [11, 12].

The revised specifications for the development of the second generation concerned the following main items:

- Timing extractor. Input: PCM 2048 kbit/s, HDB3 Code, as in CCITT Rec G703, option 75 ohm, level attenuated to range 226...946 mVpp.
  Output: 2048 kHz sinusoidal, level to be fixed by the manufacturer of the system.

Alarms: Signal below minimum and detection of AIS (Alarm Indicator Signal sent on the PCM line).

- Jitter Transfer Function (see Ref [12]).

- Holdover: Frequency offset less than 5 parts in 10^{-10} during 18 hours.

- Out of lock: VCXO control voltage below 10 % or above 90 % of control range.

- Frequency Offset Detection: The unit which drifts away more than 4 parts in 10^{11} from either of the two others is disconnected from the bus and a non urgent alarm is generated.

As shown in the figures 4 and 5 the first and second order equipment racks are identical except that in Fig 4 the PLL B is replaced by a cesium standard and the reference signals for PLL A and C are derived from other first order clock generators.

3. Implementation

The first and second order clock signal generating equipment has been designed as a part of the digital trunk transmission network. All switching equipment is in the third order level of hierarchy. In this and the lower levels of hierarchy the PTT is dealing with several vendors and a large variety of customers. Until 1983 there was a project to develop a Swiss digital switch family. In June 1983 this project was abandoned. Specifications based on the then existing CCITT and CEPT recommendations were published and three vendors were selected:

Company	Type	Swiss representative
- Siemens	EWSD	Siemens-Albis
- Ericsson	AXE	Ascom
- Alcatel (ex-ITT)	S12	Standard Telephone and Radio

as suppliers for public digital switches.

For the third order clock units the minimum configuration principle is shown in Figure 6. The specifications are a very small part of the books containing the general switch specifications [13]. They are limited to standard (CCITT and CEPT) input and output signal levels, impedance and matching, jitter transfer function (CCITT Rec. G742, Chapter 6.1), Holdover (CCITT G.811, Table 2, Red Book 1984) specifications. One transit and one local switch of each Type were tested during 1988. These clock units contain oven controlled crystal oscillators with memory for holdover. The problems encountered during these tests were mostly non-technical. The people on site were not competent in our special field and usually had strict instruction not to touch these precious devices. Our engineers always succeeded finally to get hold of the right persons through the headquarters of the companies by using many telephone calls to find the way through the maze of organizational layers and divisional frontiers. Once a unit refused to lock. It was delivered with a gross misadjustment and our engineer's screwdriver solved the problem.

One important detail on which we had to fight a little bit with one supplier was the absence of a test point for getting at the VCXO output signal. The requirement was in the specifications but had been ignored.

Since we were not sure how the switch clocks would be made and behave, the hierarchy of Figure 3 was strictly adhered to. All reference links between the three first order centers and the second order centers do not pass through the switches but are sections of the fixed network constituted of PCM lines leased to large customers. The ensemble of the first and second order centers thus form a permanently connected network covering the whole country and bringing the high performance timing reference signal relatively close to the customer.

Slow path delay variations on the reference links have been investigated by means of a measurement system developed by K. Hilty and J.P. Mellana and described at the 19th PTTI Meeting in 1987 [14].

The first second order equipment rack of the second generation was installed at an Intelsat Business Service Satellite Earth Station in Vernier near Geneva in June 1986. It was locked to a PCM Signal from the Transmission Center of Rue du Mt. Blanc in Geneva, a few kilometers away, where a cesium controlled first generation rack was installed several years before.

The three new second generation first order reference sources were delivered in December 1986 and provisionnally installed in Berne for a burn-in and acceptance test period of ten months. The three units were dispatched to their final locations and became operational in December 1987.

In October 1989, 60 second order centers have become operational. Due to restructuring and extension of the digital trunk network the number of second order centers will be increased to 70 during the coming two years.

The maximum length of a time reference link is currently about 100 km, the average being about 50 km. The excellent stability of the links on those sections and nodes where there is no construction work in course, has allowed the network management to introduce some crossover links, i.e. these three reference lines entering each 2nd order unit do not all come from the same primary center. On the lower (3rd and 4th) levels, the network is still in an early state of implementation but has reached its maximum annual growth in order to reach total ISDN coverage in a few years. Many subscribers already receive their timing reference via 2048 kbit/s PCM lines or 64 kbit/s through synchronous demultiplexers.

4. Operational experience

During the first phase, from 1977 to beyond 1986, since first generation equipment is still operating now and during the coming years, the experience regarding reliability and performance, has been very satisfactory.

Especially the cesium units have shown better reliability than predicted from a worldwide survey made by the CCIR on commercial units [15]. Based on about 200 unit years of operation, the mean time before failure is about 6 years. Most of the first generation cesium tubes go down after 8 years, the cesium oven being exhausted. The repair records show that the most sensitive parts concerning outages are the monitoring and alarm circuits rather than the oscillators and amplifiers.

During this first phase, no remote controlled oscillators were used in the data network. The nodes were fed by free running cesium units. At the maximum we had 14 such sources in operation. One of the most important effects, not technical but psychological, was the demystification of the cesium unit. The term "atomic clock" was deliberately not used. The personnel now has gained good confidence in the equipment.

The second generation equipment still has a relatively short record of life but looks very good. The ten month burn-in and testing period of the three primary units has allowed to correct some bugs remaining in the hard- and software.

In the 150 PLL-Units during about 2 years we had 4 failures. Thus a first extimate of the MTBF is 75 years for one unit, however, the narrow statistical base indicates that the real meaning of such an estimate is doubtful.

On the other hand, we have lived two examples of the effect of failures.

Once a 5 MHz/2048 kHz synthetiser module went out of lock without signaling the alarm on the central panel. This module fed a multiplexer in the data lines in a local district near Lausanne. The usual second redundant line was not operative since the signal with a few ppm offset frequency was still on. The data traffic of a few banks, insurance and some other companies broke down until the culprit was found and removed from the rack.

The other case occurred a few months after the IBS satellite earth station mentioned above went into service. Some important businessmen had been invited to one of the first videoconferences between Geneva and the U.S. It was a flop because one intermediate network operating company apparently ignored the synchronization requirement. The next time, a few weeks later it worked since everybody involved had learnt the lesson.

The three 1st order master centers have currently been adjusted to within a few parts in 10^{13} by the operators. Otherwise they are free running.

Currently, the standard frequency distribution network mentioned before is being used for occasional checks. Its reference is derived from one of the cesium standards in our Research Laboratory, where the connection to UTC is provided.

We use TV time comparisons to the Swiss Federal Office of Metrology which also has a GPS-receiver, and directly to the LPTF in Paris via the French TV-Network. Finally, we still use LORAN-C and monitor two LF transmitters, HBG and DCF 77.

For special cases we still use portable units, one cesium and two rubidium devices. The latter are very convenient for short time operations and appear to be less sensitive to magnetic fields than some of the portable cesium units.

5. Conclusions and Outlook

When the concept was presented four years ago [11] the prototype development of the second generation timing reference generation and distribution equipment was just finished. Now it is operating very well. Even with only a part of the digital network already built, the investment in this equipment is a minute fraction of the many billions of dollars already invested in the optical fiber and radio relay network, the multiplexers and switches.

The backbone, i.e. the upper part of Figure 3, is characterized by a feature which I would like to call the Triad Principle, i.e. use three units not just for signal availability but for rapid failure detection. As far as we know at this time, no other network operator has yet followed this concept. It had its price but we feel very comfortable with it, now and for the foreseeable future.

The introduction of the new Synchronous Digital Hierarchy (SDH) by the CCITT, based on the SONET concept proposed by the U.S., will require only the development of synthetizer modules to generate the new frequencies. Starting with 5 MHz with the highest spectral purity now available, multiplication into the GHz range is feasible.

The work reported in this paper was not always easy but we had a few advantages. We are in a relatively small organization, are only a few individuals but with the background required: Digital transmission, frequency standards, reliability statistics, network planning and practical experience in transmission systems management. Finally we had the advantage of starting early, working out a preliminary solution under healthy pressure and improving it in the second phase.

6. Acknowledgments

The names of all the participants to this work have already been mentioned with their contributions, most of it published. However a special thanks is due to Hans Friederich from Network Operations, whose workload did not allow him to write papers. The author thanks all his colleagues and the past and present higher level managers who always supported our work.

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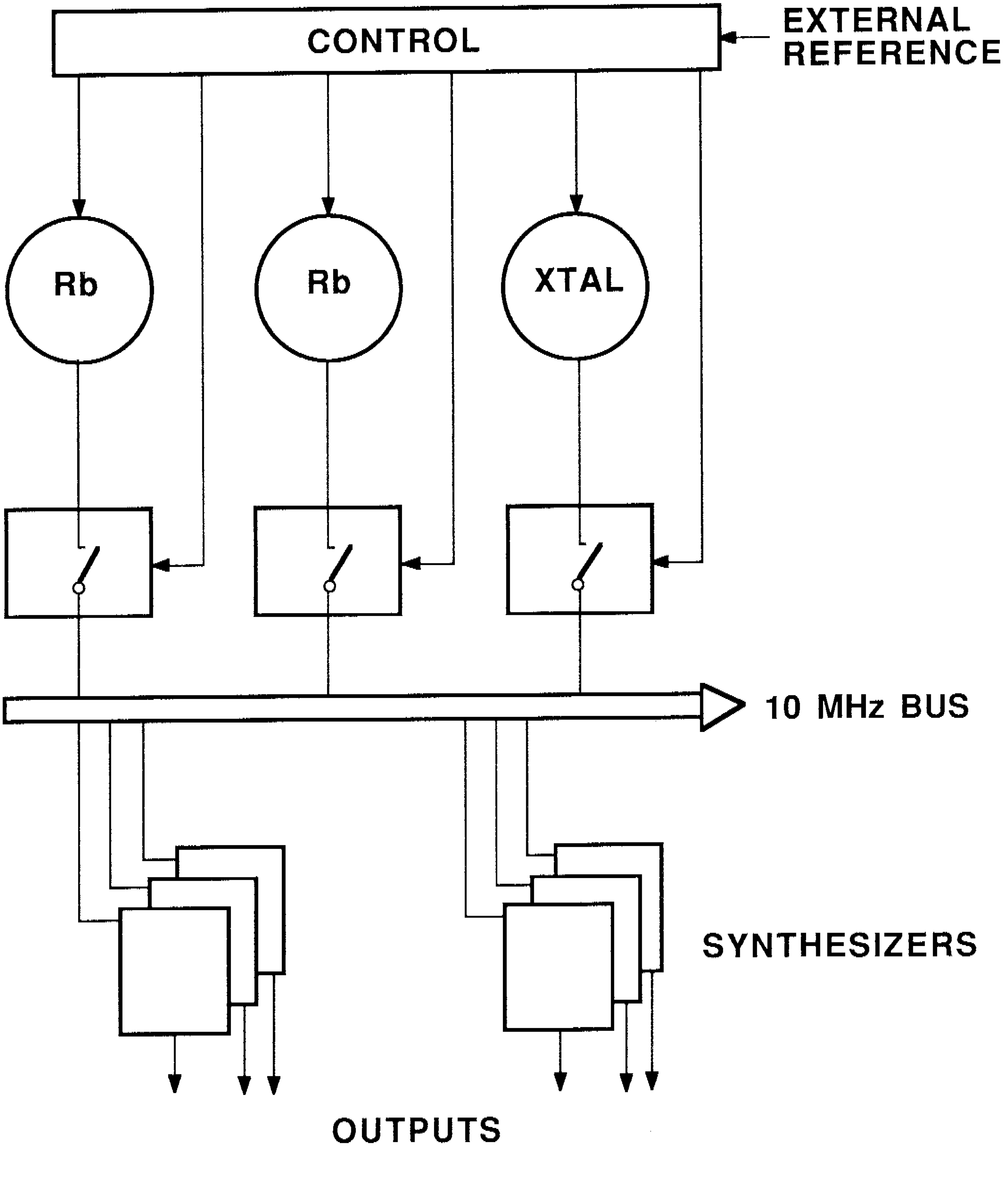

Fig. 1 Master Clock Unit, proposal February 1974

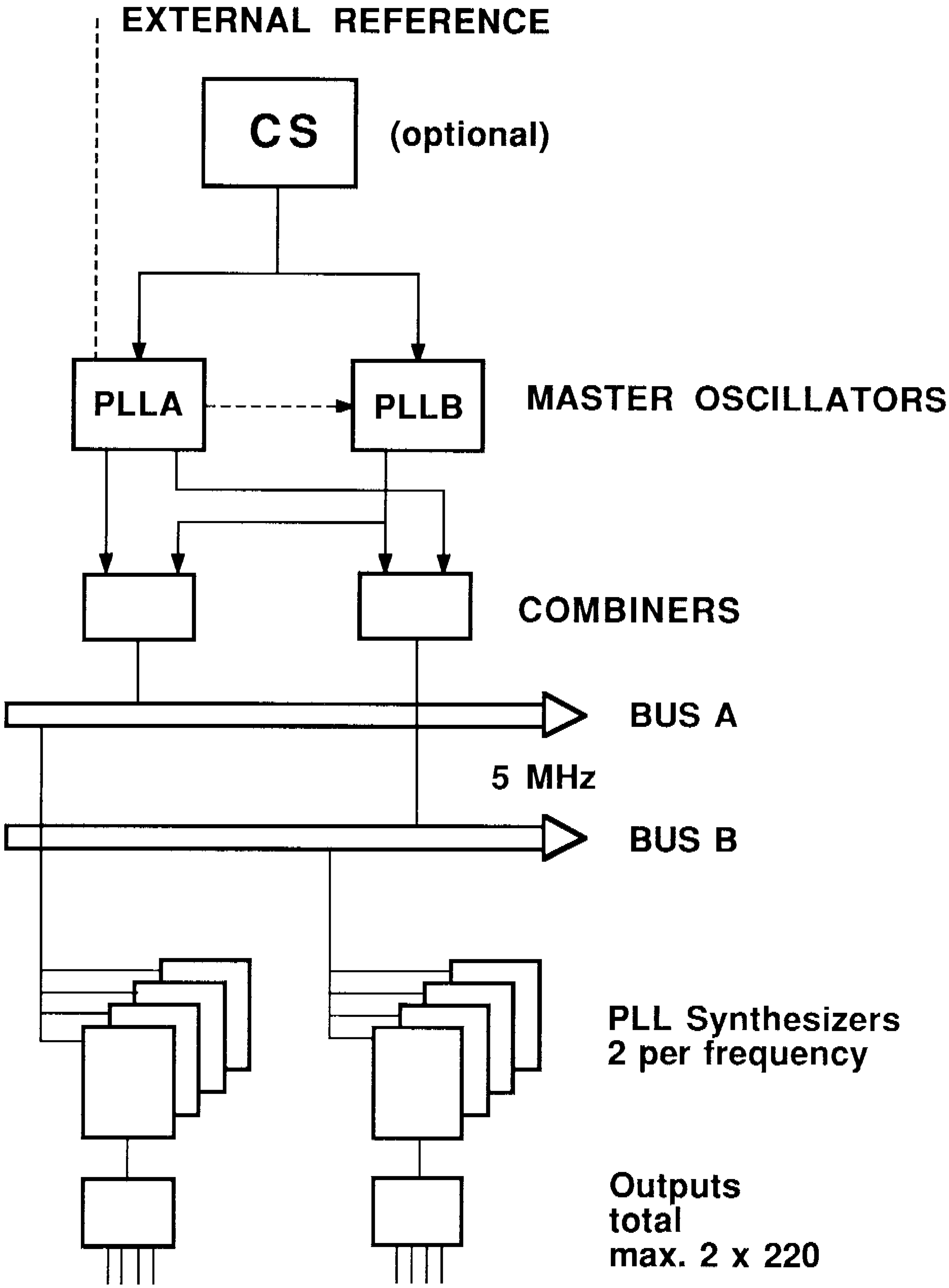

Fig. 2 First Generation Master Clock Unit with optional Cesium reference

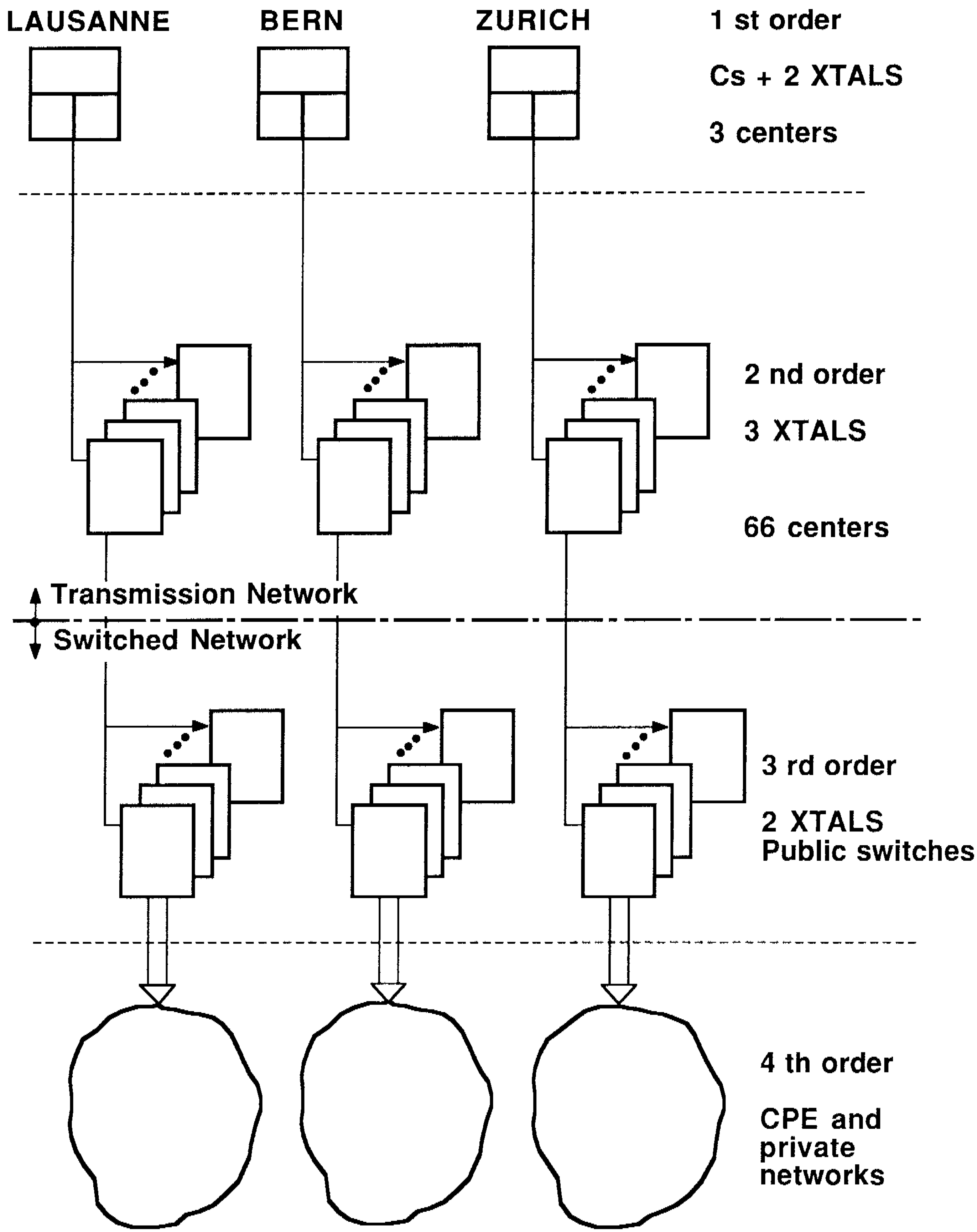

Fig. 3 Network Hierarchy for Clock Signal Distribution

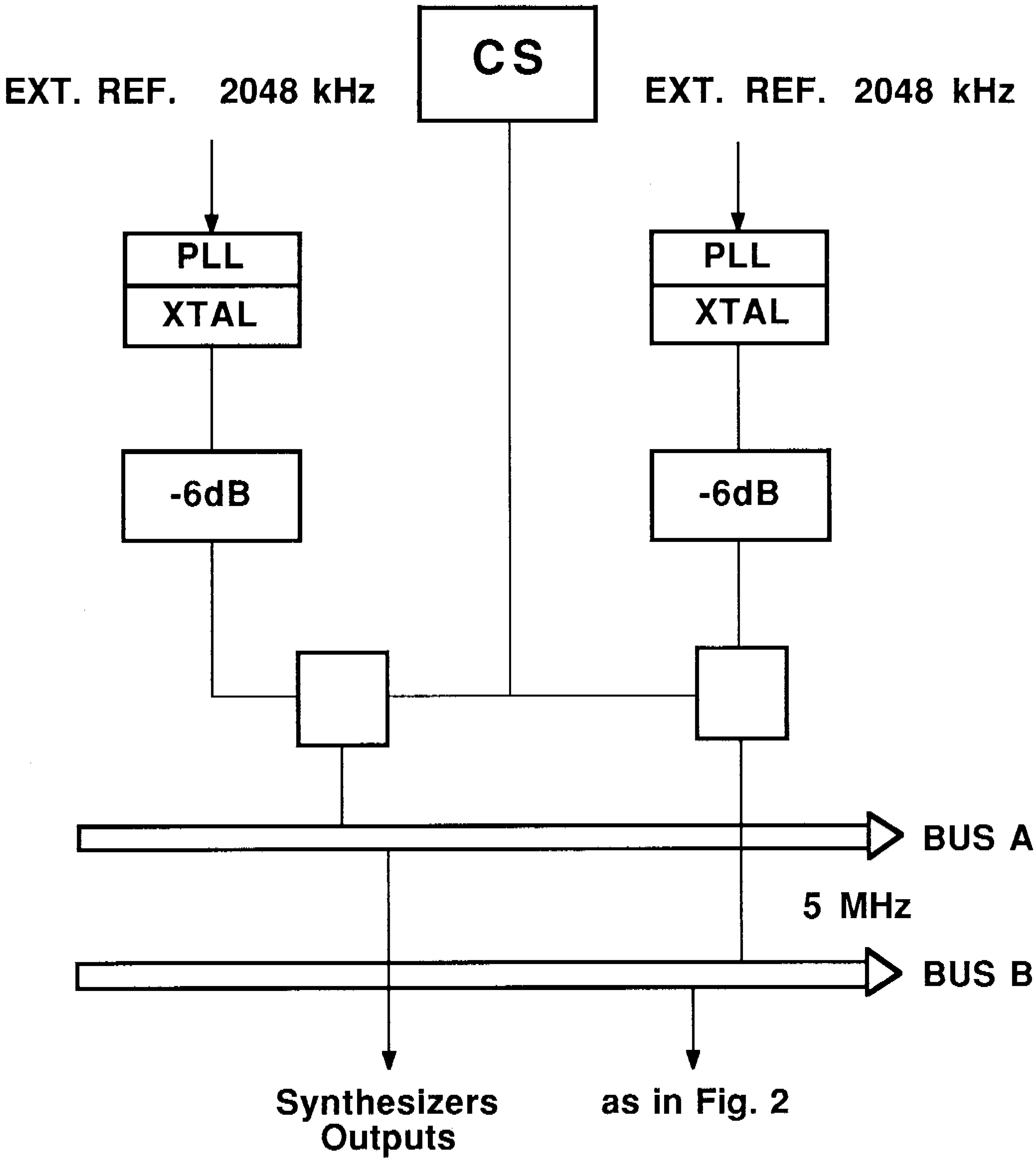

Fig. 4 First order clocks

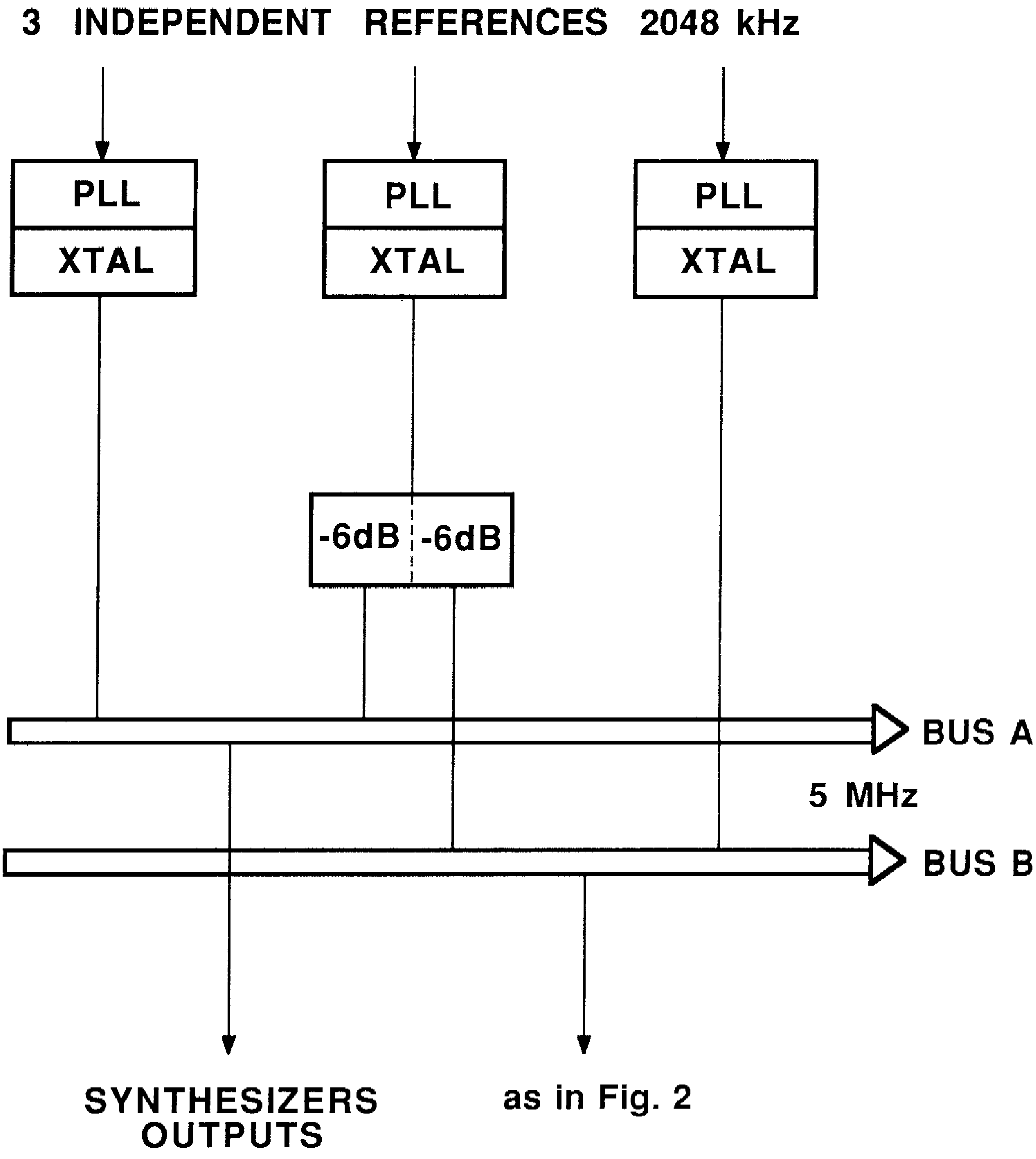

Fig. 5 Second order clocks

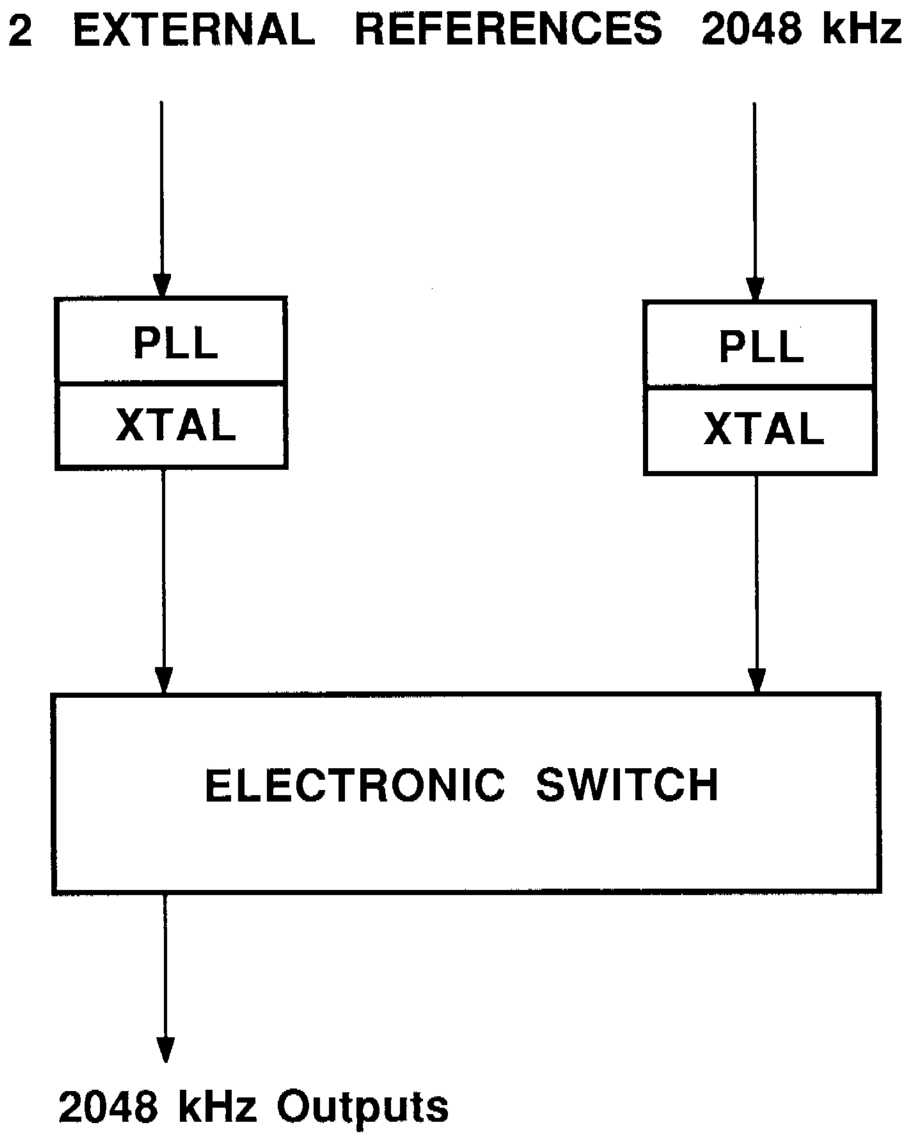

Fig. 6 Third order clocks