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THE SIMORAMIC ANALYSER AS THE INVERSE OF THE MULTIPLEX SPECTROMETER

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Abstract. — The Simoramic analyser is a commercially available analogue Fourier transformer in which the amount of hardware is economised by an ingenious use of re-circulation. Unlike an ordinary scanning wave-analysers (for example) it is multiplex and phase-sensitive. These properties favour its use as an inverse to a multiplex interferometric Fourier spectrometer, but there are also some difficulties, and it appears to be useful mainly for high-speed applications.

Special-purpose Fourier transformers can be very valuable in multiplex spectrometry, but it is concluded that low cost is essential if they are to compete with modern general-purpose digital computers. This is so especially because Fourier inversion is only one step in the interpretation of an interferogram, and this is itself only a step towards analysing the resultant spectrum.

Résumé. — L'analyseur Simoramic est un transformateur de Fourier analogique, commercialement disponible, dans lequel le volume de circuits nécessaires est réduit grâce à l'emploi ingénieux d'une circulation en boucle fermée. À la différence d'un analyseur harmonique ordinaire à balayage (par exemple), c'est un dispositif multiplex et sensible à la phase. Ces propriétés rendent avantageux son emploi comme inverseur de l'interférogramme produit par un spectromètre multiplex interférentiel de Fourier ; cependant quelques difficultés se présentent et l'appareil semble utile surtout pour des applications à vitesse élevée.

Des transformateurs de Fourier spécialisés peuvent être très utiles en spectrométrie multiplex, mais nous concluons qu'un bas prix de revient est essentiel pour qu'ils puissent entrer en compensation avec les calculateurs digitaux modernes non spécialisés. Ceci vient essentiellement du fait que la transformation de Fourier est seulement une étape dans l'interprétation de l'interférogramme, qui elle-même, est une étape dans l'analyse du spectre ainsi produit.

1. Introduction. — In the proceedings of the Colloquium, there now follows a series of papers concerned with various kinds of special-purpose Fourier inverters for use with multiplex spectrometers. The authors of these papers have the advantage over me that they have actually built something ; I am merely describing a principle which has already been incorporated in a commercially-manufactured instrument.

The principal reason for so doing is that the Simoramic analyser appears to have (either actually or potentially) almost every advantage that can be obtained from a special-purpose Fourier transformer.

Accordingly it forms a good example about which to discuss the usefulness and merits of such machines in general.

The decision whether to use such machines will be influenced by the fact that a Fourier transformer is not of itself a complete system for interpreting interferograms; rather, it is a component, though a very important one, of such a system. Before the Fourier transform is performed, it is in general first necessary to perform editing and data-assembly operations of the kind that are common to most reductions of digital data. It is then usually necessary, as several papers of this Colloquium have brought out, to make adjustments which are equivalent to identifying the zero of path difference and adjusting the phases accordingly. In most cases, a further process of reduction and interpretation still needs to be performed on the spectrum after it has been derived from the interferogram.

The general-purpose digital computer has the advantage that it is equally capable of performing all these various operations. To say this is not to deny, however, that there may be many circumstances in which the use of a special-purpose analogue or digital Fourier converter may be invaluable.

2. Description and Operation. — The Simoramic analyser is the subject of United States Patent No. 3,013,209 dated 12th December 1961 (filed 9th June
1958) granted to H. J. Bickel. The name « Simoramic » is the trademark of the Federal Scientific Corporation, who manufacture various versions of the instrument.

Suppose that we wish to calculate the Fourier transform of a set of $N$ ordinates (which we shall call the input ordinates) $y_0$ to $y_{N-1}$. The process of transformation can be described by saying that $y_0$ «looses off» a constant component proportional to the amplitude that the $r$-th ordinate $y_r$ gives rise to a component having frequency $r/T$. These components are then added to give the required transform.

In figure 3, the path of the $r$-th signal is shown by itself. It suffers delay $rT$, and a total frequency shift $r/T$. The total effect is exactly the same as if the line of delay $TN$ and the array of frequency changers has been «folded up» in the manner shown in figure 4. Here of $y_0$, $y_1$ similarly loses off a component which oscillates once in a time which we shall call $TN$, $y_2$ a component which oscillates twice in time $TN$, and in general $y_r$, a component which oscillates $r$ times in this interval (see Fig. 1). The output ordinates are then obtained by summing these components in columns at intervals of time $T$.

This operation could be performed by means of a delay line and frequency changers in the manner shown in figure 2. The signal enters a line having total delay $TN$. At a suitable moment, the input ordinates are represented by voltages on the line in the manner diagrammed in the figure. These voltages are connected to frequency changers, as shown, in such a manner that the $r$-th component $y_r$ of the input signal passes through short line of delay $T$, and after being acted on by a frequency changer of frequency $1/T$, is fed back to the input of the line, where it is added to the

![Diagram](https://example.com/diagram.png)

**Fig. 1.** — Pictorial representation of the structure of Fourier transformation.

![Diagram](https://example.com/diagram.png)

**Fig. 2.** — Fourier transformation by delay line and frequency changers.

![Diagram](https://example.com/diagram.png)

**Fig. 3.** — Path of the $r$-th signal sample abstracted from figure 2.
next component of the incoming signal and recirculated. Assuming that the $y_{n-1}$ signal enters this system first, at the moment when the $y_0$ signal arrives it is easily seen that each $y_r$ has suffered a total delay $rT$, and a total frequency change $r/T$, exactly as in figure 2.

This is, in broad outline, the principle realised in the Simoramic analyser.

The following ranges and resolutions are amongst those available in the manufactured form of the analyser:

<table>
<thead>
<tr>
<th>Resolution</th>
<th>Total sample time</th>
<th>Frequency range</th>
<th>Number of resolved elements $N$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 c/s</td>
<td>1 second</td>
<td>200 c/s</td>
<td>200</td>
</tr>
<tr>
<td>5 c/s</td>
<td>200 milliseconds</td>
<td>1,000 c/s</td>
<td>200</td>
</tr>
<tr>
<td>500 c/s</td>
<td>2 milliseconds</td>
<td>100,000-400,000 c/s</td>
<td>200-800</td>
</tr>
</tbody>
</table>

These instruments have found particular application in the time-frequency analysis of speech.

3. Advantages and some limitations. — The principal advantage of the Simoramic method is, of course, that it saves equipment; only one frequency changer, and a line of delay only $T$, is needed. Accordingly it is much cheaper than an equivalent bank of contiguous multiple filters.

In common with the multi-bank filter, and in contrast to a scanning wave-analyser, it is capable of making use of a whole of the input waveform. In this sense, it may be described as multiplex.

In contrast to either a multi-bank filter or a scanning wave-analyser, the Simoramic analyser preserves phase information in the spectrum. This is important in relation to "chirp" and to problems of the zero of path difference in interferograms.

It has the further advantage that a waveform is available, and can be displayed on an oscilloscope, giving the latest available resolution. As more signal arrives, the Simoramic analyser updates this estimate and displays the increasing resolution as it becomes available. This facility can, of course, be obtained in some other systems also; for example, by a suitable digital program.

On the other hand, although the analyser uses a principle which avoids multiplicity of equipment, the delay line and frequency changer have the task of recirculating the signal $N$ times (where $N$ may range from some hundred upwards) without introducing unacceptable distortion. Accordingly, these components need to be sophisticated, and the overall system is not particularly cheap. 1963 prices were in the range $50-100,000$. For the optimum de-coding of low signal-to-noise ratio frequency-modulated telemetry signals from satellites, for example, the Simoramic analyser is far cheaper than equivalent multi-bank filters. For some other purposes, other systems may be cheaper than the Simoramic.

4. Problems in applying the Simoramic analyser to multiplex spectrometry. — The primary difficulty is that the signal needs to circulate in the analyser for a time equal to the total duration of the scan, which may be 1,000 seconds or more for multiplex spectrometry. The length $T$ of the delay line is equal to the reciprocal of the bandwidth of the input signal, which may be many seconds in this application. These times are longer than can conveniently be realised with an ordinary travelling-wave analogue delay device.

The necessary delay can be obtained with magnetic tape or drums. In this case, however, one immediately begins to think of impressing the signal on the magnetic medium in frequency-modulated form in order to preserve accuracy. This further suggests that signal may be recorded digitally, and that one might as well use a digital frequency changer (i.e. a digital multiplier) in order to avoid continual conversion and reconversion into and out of digital form each time the signal circulates. The logical conclusion of this line of reasoning is that the digital delay might just as well be realised by the use of a random-access store, such as a ferrite core store. At this stage, it will be recognised...
that the system has become identical with a general-purpose digital computer (1).

This conclusion reinforces the previous arguments, particularly those relating to versatility, in suggesting that a general-purpose computer would normally be the first choice as a means of transforming interferograms. Such computers can now be bought for less than $20,000. The special-purpose Fourier transformer may, however, be preferred if there are special reasons for doing so.

A powerful reason may be cost. A special-purpose machine which could be sold for substantially less than $20,000 would be extremely useful in providing a quick-look facility directly associated with the interferometer, even where the final reduction were done on a general-purpose digital computer.

Another important reason is the ability to work in real time. In order to match the performances shown for the analysers listed in table 1, a digital computer would be required to multiply in times of respectively 5 milliseconds, 1 millisecond, 10 microseconds and 2.5 microseconds. Even the smallest modern computers easily match the low speed end of this range, but only the most costly machines can compete at the high speed end. Most interferometry, in contrast to such applications as telemetry and speech analysis, pertains to a time-scale which would not exploit the real-time capability of the Simoramic analyser; it is not difficult to think of exceptions however.

INTERVENTIONS

J. N. A. RIDYARD. — How many elements does the Simoramic Analyser compute?

P. FELLGETT. — The number of elements is equal to the frequency quoted; i.e. if Δf = 1c/s f = 200 c/s and thus there are 200 elements.