GEORGES JENNY

THE ONDIOLINE

The design and development of an electronic musical instrument

Principles of Electronic Music
Introduction by E. AISBERG

Introduction to Electronic Instrument Making

Schematic of the Ondioline

Production and Development Details

Appendix : Device Enabling the Coupled Octaves Effect to be Obtained

FORGOTTEN FUTURES - NEW YORK

PRINCIPLES of ELECTRONIC MUSIC

INTRODUCTION BY

E. AISBERG

A Glimpse of the Past

When tracing the history of an invention, there is a tendency to go all the way back to the beginning of time. But the moment always comes when the growing vision, locked within a researcher's mind or trapped by laboratory walls, finally breaks free to see the light of day. We can easily and precisely identify this moment in the history of electronic music.

One evening in 1927, at the Paris Opera, a Russian radio-electrician with French roots, named **Theremin**, performed the first public recital of an electronic musical instrument. The very method of playing the "Theremin" was enough to impress the audience. Indeed, without touching any physical mechanism, he, who was both its inventor and skilled player, drew from it strange, yet embellished, sounds. By moving his right hand towards or away from a metal rod, this virtuoso was able to modify the pitch of the sound. At the same time, by raising or lowering his left hand over a metal ring, he caused the intensity of the music produced to change. He literally gave the impression that these magical hand-movements could successfully draw sound from thin air!

It is easy to imagine just what an effect this way of playing had on the minds of the journalists who endlessly exaggerated the story of "wave music," or "otherworldly sounds," etc.

The very serious "Revue des Deux Mondes" (Two Worlds Journal) published a study by the great geometrician Maurice **d'Ocagne** who foresaw a great future for electronic music; and he was certainly right about that.

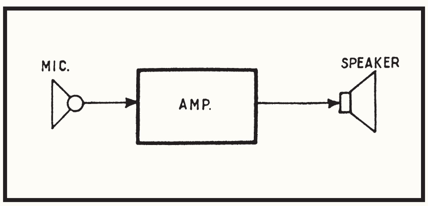
Shortly thereafter, a French inventor, M. **Martenot**, had his chance to present an instrument that, while less impressive, nevertheless allowed various musical works to be easily played. This time, the virtuoso's hand touched either a string or a key on a keyboard, similar to that of a piano. This enabled the player to develop a speed prohibited by the Theremin in principle. Next, at a Radio Show, at the Grand Palais, **Péchadre** introduced his "Ondium," an unassuming instrument composed primarily of a simple, low-frequency oscillator. Its notes could be continuously altered by adjusting the variable capacitor.

All of the above speaks to a great interest in electronic music, which continues to this day. This interest has resulted in quite a few serious achievements that are currently used either by soloists or as orchestral instruments.

However, as previously stated, we can always go back to when time began. Although, in this case, we can really only look back a century.

In fact, there were attempts made at producing music by purely electrical means, such as Cahill's Telharmonium which, in the late 1800s, proposed the use of small, low-power **alternators**, spinning at different speeds, to create musical sounds in a telephone receiver.

Well before then, tests were carried out on the properties of the first selenium **photocells**. Attempts were made at varying the intensity of an electrical current crossing one of these cells by means of a beam of light passing through the holes in a perforated disk to reach the cell. As the disk's rotation periodically cut off the beam of light, it changed the cell's resistance and, as a result, modulated the current, producing a musical tone in a receiver. The pitch of the sound could be altered by either changing the speed of the disk's rotation or arranging different circular rows, some having more perforations than others. The "Selenophone," a precursor of the "Cellulophone," invented many years later by Pierre **Toulon**, was thus built.



No! Capturing sounds by means of a microphone, amplifying the resultant currents, and broadcasting the strengthened sounds through loudspeakers have nothing to do with electronic music!

The most important, indeed fundamental, invention in this field was indisputably that made by Lee de **Forest**. Credited with inventing the first electronic three-electrode tube in 1906, he then had the idea, in 1915, to use it as an **oscillator**, producing low-frequency currents, capable of generating musical tones. Their pitch could be intermittently altered by way of a set of leakage resistors and capacitors using the appropriate grid of values. As discussed further in the next pages, the major electronic music devices that are currently in use depend on low-frequency oscillators. Therefore, we must once again praise the universal genius of Dr. Lee de **Forest**, founder of the electronic age.

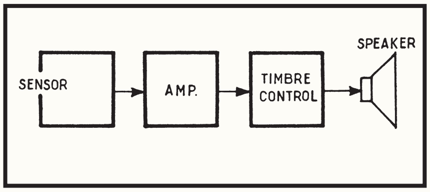
What is Electronic Music?

These days, we stand witness to a complete misuse of the term "electronic." In every field, clever businessmen are trying to benefit from the popularity of this word, plastering it on merchandise that contains absolutely nothing electronic. So, does it even fall within the field of music?

Indeed, can the simple broadcasting of sounds by the classic system forming the **microphone→amplifier→loud-speaker** chain be considered electronic music? What Americans call a "public-address" system certainly uses an electronic amplifier. But if we amplify the thin voice of, say, Tino Rossi in this way, so he can be heard by a thousand spectators (who are delighted, of course), it would be improper to refer to this as electronic music.

Let's take a step further and imagine an additional link that is inserted into the chain, described as a device that enables the **timbres** of musical instruments, the sounds of which are captured by the microphone, **to be modified**. This electrical intervention into the very nature of the sounds would begin to justify, to a small extent, the "electronic" designation.

Let's take another small step and imagine that in the place of a microphone, we have some type of sensor, that is to say a device capable of transforming mechanical vibrations into a variable electrical voltage. There are such electromagnetic sensors that can be attached above piano or guitar strings. By adjusting the reluctance, the vibrations of the strings in the electromagnet's air-gap determine the appearance of variable electromotive forces



The timbre controller inserted in the amplification chain constitutes an electronic intervention into music. Moreover, a "sensor" enables the mechanical vibrations to be translated into voltages without the use of sound waves from the air.

in the electromagnet's coils. These low voltages can then be amplified, their timbre might possibly be changed, and everything can be broadcast, with the desired volume, by the loud-speakers. Once again, we are at the outer limit of what can be considered electronic music. Unique instruments can also be devised in which the strings or the tines are caused to vibrate by **mechanical** (hammers) or **electrical** (maintained by electromagnet) means or even in which reeds are made to vibrate by a movement of air such as in organ pipes; and the sensors enable the translation of these vibrations into variable electrical voltages.

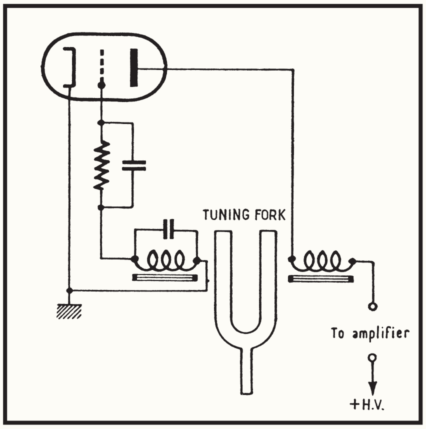
The sensor and the vibrating component would not necessarily have to touch, as this runs the risk of changing the speed of the oscillations. If the part is ferromagnetic, electromagnetic sensors are sufficient, and if it is made of a non-magnetic metal, capacitive sensors can be used with success.

In this way, Constant **Martin**'s electronic bells use the vibrations of metal tines maintained by electromagnetic processes and translated into variable voltages by means of electromagnetic sensors. The American inventor **Schulmerich** developed bells that use the vibrations of bronze tines maintained by a mechanical process and which are translated by means of capacitive sensors.

In this class of instruments, we begin to stray from traditional methods. Now electronics begin to play a more important role. New timbres can be created. Therefore, it is appropriate to consider that such instruments deserve to be called electronic music.

Another category would consist of instruments that reproduce previously recorded sounds, but which are chosen at will. These, of course, do not include traditional electromagnetic recording devices that precisely reproduce a piece of recorded music, but rather devices where each note was recorded from a traditional instrument.

We can include **Chancenotte's electronic bells** (1) in this category. Our compatriot, currently working in Canada (no man is a prophet in his own land...),



Tuning fork maintained by an electron tube oscillator. The oscillating circuit must be tuned to the frequency of the tuning fork.

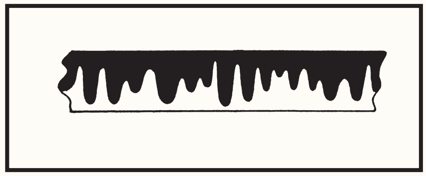
thought to first photographically record (as on a movie audio track) the sounds of our best church bells. Then, from these recordings, he engraved the corresponding oscillations into the surface of a steel cylinder, the depressions corresponding with the bright parts of the recording and the reliefs with the darker parts, for example. It is understood that when such a cylinder turns in front of an electromagnet, the reluctance in the air-gap between them varies and reveals electromagnetic forces, which ultimately translate the recorded sound of the bells.

Several Canadian churches have been cheaply equipped with this device, sounding the powerful voice of the Sacred Heart's "Savoyarde" in Paris, or the voices of its most famous sisters.

In yet another related category, we can file the attempts at **synthetic writing** made, with a measure of success, by certain inventors who had the patience of Benedictines. Rather than recording the sounds of a known instrument on a film track, they drew these tracks in ink. Though let it be said, upon reproduction, the result can be bizarre, to say the least.

(1) Read "Un nouveau procédé d'enregistrement électromagnétique du son" by J. Garcin. *Toute la Radio*, no. 126, June 1948.

As we said, everything listed above more or less deserves to be called electronic music. On the other hand, the devices that wholly deserve the name are those wherein the electrical fluctuations, responsible for creating the sounds that should be heard, are produced solely through electronic means. Whether using simple, low-frequency oscillators or more complicated devices, these instruments have the advantage of being more than mere translators; instead, they create 100% of the sounds, which can often be remarkably beautiful.



An example of "synthetic music," made by using ink to draw the audio track on a transparent tape and easily decoded by a photocell reader.

Before reviewing the main classes of such instruments, it is necessary to spend some time concentrating on the very nature of the sounds that they are expected to produce.

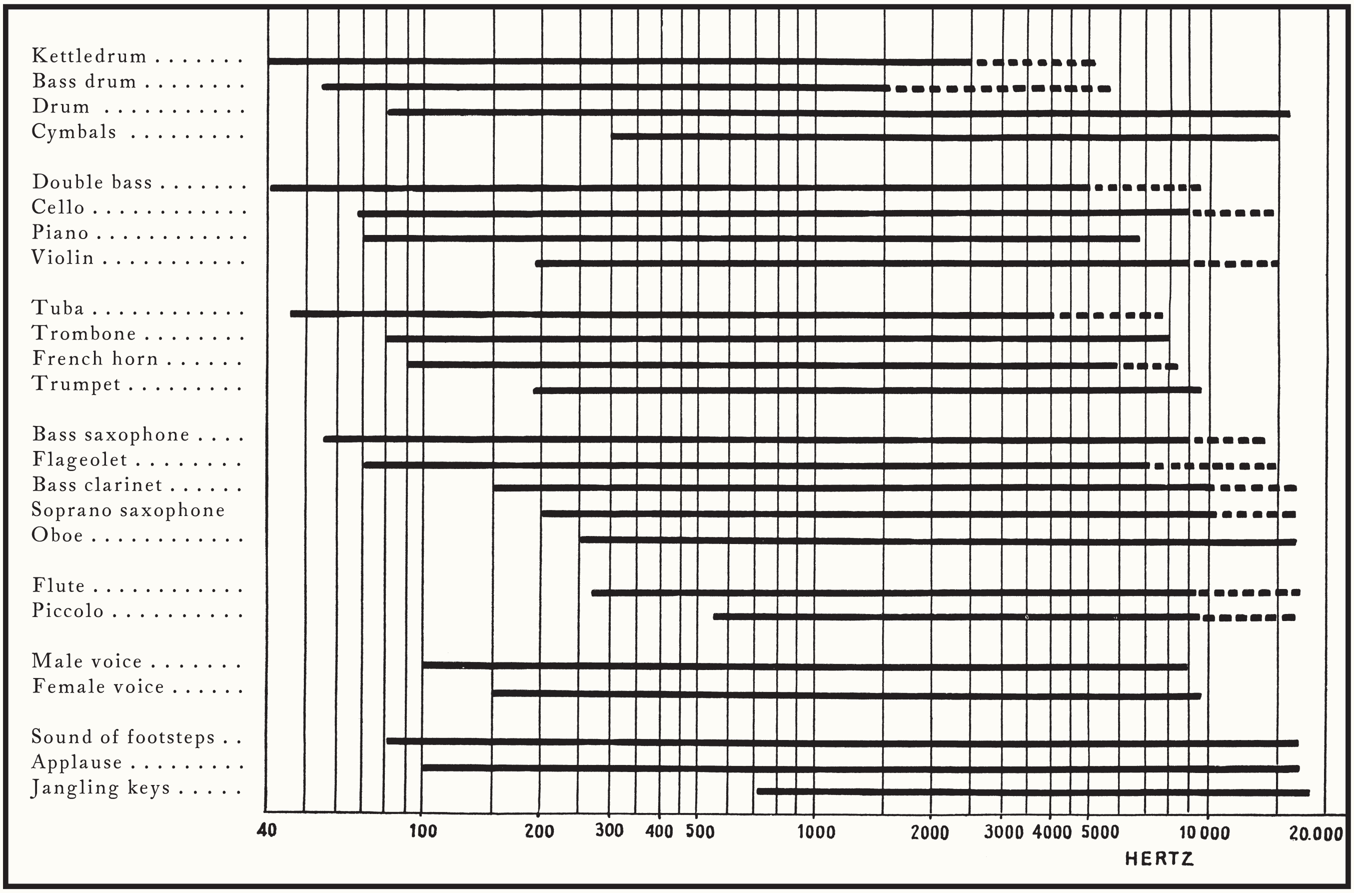
Characteristics of the Sound

Four key parameters characterize a given musical tone: its pitch, its loudness, its timbre, and the method of attack.

What we are talking about here are the subjective perceptions that the sound triggers within us. To the physicist, each of these characteristics corresponds to an entirely objective parameter, as discussed in the following paragraphs. Incidentally, the physicist might add a fifth parameter, calling it the phase, which only has meaning if we refer to a specific moment in time. Considering that the phase hardly leads to subjective perceptions (which is, by the way, debatable), we will ignore it at this time.

PITCH OF THE SOUND. — We know, by comparing different sounds, that they can be more or less low or high-pitched. This perception is caused by the **frequency** of the sound vibrations. If the human ear perceives only those oscillations between the 20 Hz (**hertz** or cycles per second) and 20,000 Hz range, no orchestral instrument entirely spans that interval; at least as far as their fundamentals are concerned (see table on page 3).

The instrument spanning the largest frequency range is the piano. Indeed, it covers the interval of approximately 30



FREQUENCY INTERVALS COVERED BY VARIOUS INSTRUMENTS

This graph illustrates all of the frequencies covered by each instrument, including both the fundamentals and the harmonics. The dotted lines indicate areas of uncertainty. (Diagram arranged according to Snow*).*

to 5,000 Hz. The double bass, on the other hand, makes do with a much more restricted interval, spanning only the 40 to 250 Hz range.

The difference in frequency between two sounds is called an **interval**. If the ratio of the frequencies of the two sounds is equal to 2, it is said to be an **octave**.

Notes that are spaced apart by one or more octaves sound almost the same to the ear; they are said to be in **unison**. Each of the subsequent octaves occupies a frequency interval double that of the previous one; the distribution of notes in a scale is evidently logarithmic. For this reason, in every treatise on acoustics and electroacoustics, logarithmic scales are used to represent the response curves, amplifier gain, sensitivities of microphones and ears, etc.

INSTRUMENT TIMBRE. — Two sounds with the same pitch but which are produced by different instruments can be easily distinguished by the ear. The third **C** of a flute bears no resemblance to the third **C** of a saxophone, and the third **A** of a high-quality violin differs from the note of the same frequency produced by a tuning fork.

These differences in timbre are due to the difference in the very **shape** of the oscillations produced by different instruments. These sounds are then translated (with the help of a microphone or other sensor) into electrical voltages, accurately amplified, and fed through an oscilloscope to observe the differences in their shapes. Though a tuning fork and flute will create oscillations that are roughly **sinusoidal**, a violin or a piano will produce voltages which, while certainly regular, are shaped very differently from a sine wave.

This is due to the large number of harmonics, some of which can even have a greater amplitude than that of the fundamental oscillation. Remember that harmonic oscillations are those oscillations with a frequency that is several times (twice, three times, etc.) greater than that of the fundamental oscillation. It is this presence of harmonics and the range of their intensities that enrich the timbres of certain instruments. The difference between a **Stradivarius**, which costs millions, and a crude violin is solely determined by their harmonic spectra.

Besides harmonics, the timbre is also determined by "formants," those oscillations forced from various parts of instruments which are not multiples of the fundamental frequencies. G. Jenny's paper highlights the importance of these generally (and wrongly!) unrecognized components.

LOUDNESS. — The French have no word that accurately translates the subjective impression of "loudness". In a pinch, they may refer to sound "volume," although this word is hardly satisfying.

Regardless, the acoustic sound level perceived by our ears can range from a few milliwatts, as in the case of a violin's **pianissimo** to 70 W in a flurry of music from a large symphony orchestra. A dynamic (sound level ratio) of 45 dB is observed. As for regular speech, it involves astonishingly low acoustic levels ranging from 10 μW to 1 mW.

It is obvious that, among electronic musical instruments, the loudness achieved largely depends on the amplifier and can be pushed as far as desired.

AN INSTRUMENT'S ATTACK. — Up to this point, we have considered the characteristics of sound when it is in a **steady state**, in other words, when it has already begun. However, all things must have a beginning and an end. And in order to start and to finish, sound must pass through more or less abrupt **transitional periods**.

Not only does modifying speed affect loudness, but it can also affect the timbre and occasionally even the pitch of the fundamental. The reproduction of the transitional periods poses truly difficult problems which are far from being completely solved.

Different Classes of Electronic Musical Instruments

A number of methods allow for various ways of classifying electronic musical instruments. They can, for example, be divided into two large groups: **monophonic** and **polyphonic** instruments. Those of the first group can produce only one note at a time, like the human voice. Those of the second can produce many notes simultaneously, like the piano or organ.

Depending on the end results, the instruments in question can also be classified as **imitative** instruments and **original** instruments. Indeed, some are only used to imitate the timbres of traditional instruments, while others enable previously unheard-of timbres to be produced, thereby opening a great many doors for aesthetic pursuits.

However, it would be difficult to justify this method of sorting as most of the perfected instruments pull both of these possibilities together; enabling the timbres of traditional instruments to be approached, while at the same time also offering a certain number of new possibilities.

From a purely **technical** standpoint, the most rational way of classifying them might be based on the **way in which the fundamental oscillations are produced**. Approaching from this angle, we can distinguish three main groups of electronic musical instruments (these categories are not comprehensive, but they do include the major devices currently in existence):

a) Electromagnetic instruments;

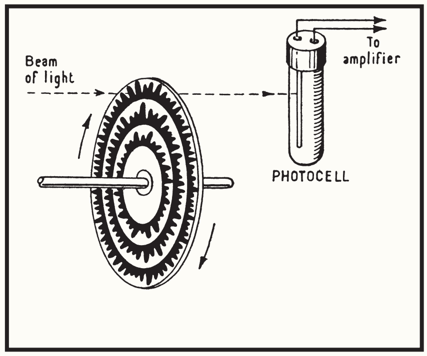
b) Optical instruments;

c) Electron tube or transistor oscillators.

Next we will quickly look at the key devices in each of these groups.

ELECTROMAGNETIC INSTRUMENTS. — Imagine the teeth of a circular saw scrolling past an electromagnet's air-gap. This electromagnet is composed of a permanent magnet serving as the core of a winding. It is clear that, by spinning the saw, we will create alternating current in the coils. The fundamental frequency thereby produced is equal to the number of teeth that cross the air-gap in one second and its timbre depends on the shape of the saw's teeth. Consequently, by amplifying this voltage and modifying the timbre as needed, we can obtain a musical note.

Now suppose that, on the same axis, we have several circular saws or, more generally, toothed wheels. Imagine that the number of teeth on these wheels is not the same. As a result, each of the wheels can produce a note with a different pitch. For that matter, we can envisage multiple axes, each one corresponding with an octave, and supporting 12 wheels (to account for all semitones). A very simple system of gears would allow each axis to move at twice the speed of the previous one. We would therefore have, at our command, all of the notes spanning several octaves. All that remains to have a true electromagnetic organ is to connect each electromagnet to a switch controlled by the keys on a



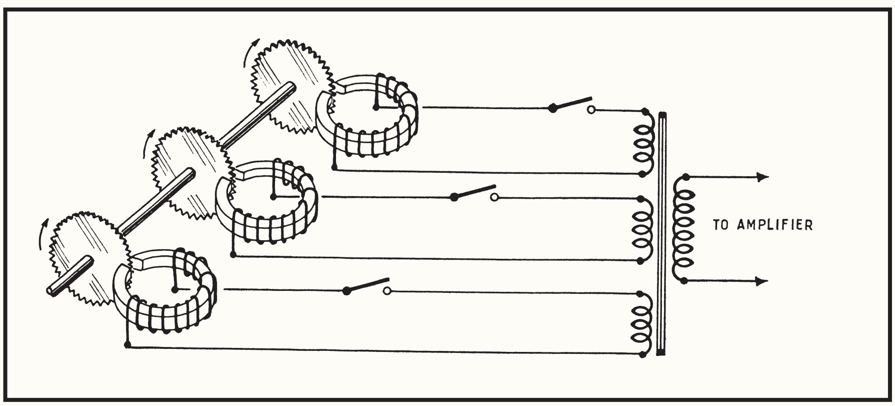
Principle of photo-electric instruments. The glass disk contains a number of concentric audio tracks

keyboard.

Naturally, a number of improvements to this system can be suggested. Accordingly, the shape of each air-gap could be made variable by means of appropriate magnetic caps, so as to reproduce the timbres of different instruments. Gradual contact systems would perhaps allow the attacks of various instruments to be imitated. On the other hand, it would be rather difficult to modulate the fundamental frequency in such a way as to imitate "vibrato," which lends a singular beauty to the sounds of certain instruments. Using the principle of toothed wheels, extremely sophisticated electronic organs, such as the very successful **Hammond** organ, were able to be created.

OPTICAL INSTRUMENTS. — In all optical instruments, oscillation is produced by a periodically interrupted beam of light, which is captured by a photocell, thereby generating periodic voltages.

As stated previously, upon discovering the photoconductive properties of selenium, the idea was born to use these properties to develop the "Selenophone," perhaps the earliest predecessor of all electronic musical instruments. Much closer to our own time, the same principle was applied to the creation of the "Cellulophone." According to Pierre **Toulon**'s proposal, the shape of the holes inside this device is determined using perfectly scientific methods based on a spectrogram of the sounds made by different instruments. In its current form, the "Cellulophone" was developed using glass disks on which, using the photographic method, audio tracks were transferred with increasing frequency, from the center out, in accordance with the increase in linear velocity. Truly ingenious techniques, making the most of the non-instant lighting of incandescent bulbs, enable, to a certain extent, the attacks of instruments to be imitated.



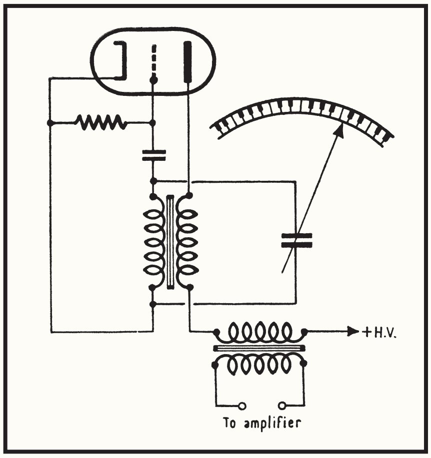
Musical voltages being produced using toothed wheels spinning in the electromagnets' air-gaps. The latter can be replaced by electrostatic sensors (capacitor armatures).

ELECTRONIC OSCILLATORS. — We turn now to the next group of instruments in question, which happen to be the most interesting as they are largely electronic. These are oscillators using electron tubes (and, undoubtedly using transistors in the near future) to produce oscillations that are more or less pure or, quite the opposite, non-sinusoidal. Their shape can, at any rate, be considerably changed in the later stages of amplification before they are sent to loudspeakers at the desired volume.

Once again we must distinguish between two very different categories:

a) **Low-frequency oscillators**, in which sound is directly produced using circuits tuned to the frequency in question;

b) **Beat-frequency oscillators**, wherein the desired sound is the result of the superimposition of two sufficiently high

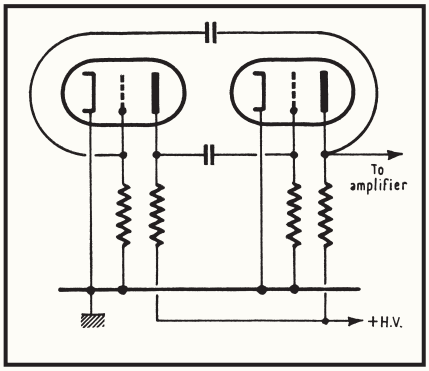


Low-frequency oscillator that uses a continuously variable frequency by means of a variable capacitor. The latter is controlled by a lever moved in front of a scale copying the piano's keyboard. (Péchadre's "Ondium")

frequencies that, on their own, would be inaudible.

Anyone wishing to study the various categories of possible oscillators, as well as those used in electronic music, would do well to refer to the book "Générateurs B.F." (Low-Frequency Generators) by F. Haas, which reviews all the arrangements used. They would also benefit from consulting J.P. Œhmichen's book "Circuits Electroniques" (Electronic Circuits) as the first section reviews all oscillators, not just those that produce sinusoidal voltages (1).

The first low-frequency oscillator used to produce electronic music was undoubtedly the one patented in 1915 by Dr. Lee de Forest, as mentioned in a previous section. There were numerous other instruments that used either vacuum tubes or gas-filled tubes, such as the "Trautonium." Invented in Germany, the latter basically consisted of a relaxation oscillator with a neon tube; the frequency was modified by variations in the resistor (for continuous variations) and in the capacitor (to switch from one octave to the next), with these two components determining the time constant of the oscillator. Again, the "Clavioline" uses a twin-triode L.F. generator mounted on a multivibrator. By changing the values of resistances and capacitances that determine the multivibrator's frequency, notes with different pitches are produced.

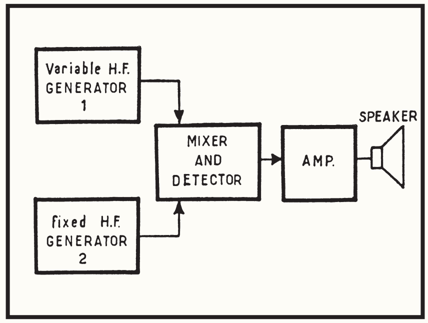


A multivibrator consists of two stage amplifiers with the output connected to the input.

The "Ondioline", a detailed description of which will be provided in the following pages, also uses a common-resistor cathode-coupled multivibrator. The slight variations in frequency are determined by changes in capacitance and the interval between one note and the next is set by variations in the associated circuits' resistors. But it is not our place to spoil the contents of the paper that follows, written by he who, thanks to his patient work, succeeded in designing and developing the most sophisticated instrument in its category. The reader will be able to enjoy the genius of its design, the care taken in its development, and the numerous possibilities offered by this infinitely flexible instrument.

We must still take the time to briefly look at the design of instruments using **beat-frequency oscillators**. The "Theremin" is the prototype of such instruments. Anyone who used a radio, circa 1925, undoubtedly has fond memories of the assembly that delighted them as children and which, despite its apparent simplicity, often enabled extraordinary results to be obtained. We are, of course, referring to the **grid-leak detector**.

In this assembly, maximum sensitivity was achieved when the regeneration was set to the highest feedback limit. And woe betide he who exceeded this limit! His receiver would begin to squeal. Was this squealing sound caused by our detector suddenly turning into a low-frequency oscillator? Certainly not! Its resonant circuit was tuned to a high-frequency and inaudible on its own. But since this frequency, on which the electron tube began to oscillate, was similar to that of the frequency of the transmitter that we wanted to receive, a "beat" was produced between these two oscillations, producing a differential frequency



Schematic composition of a beat-frequency oscillator such as the one used by the "Theremin."

that, when detected by the electron tube and amplified at low frequency, was perfectly audible and happened to manifest itself as that annoying squealing.

It was natural, when observing such phenomena, to consider putting them to use in producing musical tones. The idea was made all the more obvious by the fact that merely moving a hand towards or away from the detector was often enough to change the pitch of the squeal due to the additional capacitance introduced into the circuit by the operator's body.

Now you understand how the famous "Theremin" was built.

It contained two high-frequency oscillators, both of which were typically tuned to the same frequency. The oscillator associated with the first amplifier remained steady, while the one associated with the second could change as the player's hand neared a metal armature connected to one of the tuning capacitor's armatures. The first tuning capacitor's armature was grounded. Variations in capacitance caused by the approaching hand would cause the second oscillator to go out of tune. As a result, beats were produced between the two oscillations, which, when detected in a mixer tube, would produce a low-frequency current. This current was suitably amplified and filtered to create quite pleasant musical tones. Despite the attractive principle of the beat-frequency oscillator, its applications in the field of electronic music were fairly limited, precisely because of the difficulty involved in preventing various parasitic phenomena from having an effect on the high-frequency oscillators. For this reason, the "Theremin" has virtually no successors.

(1) Both books were published by the *Société des Editions Radio.*

Electronic beat-frequency oscillators can give rise to both monophonic and polyphonic instruments. In the latter case, the number of oscillators used must, in theory, be at least the same as the number of notes to be produced. In reality, certain tricks enable the number of oscillators to be reduced. Moreover, an amplifier stage must be inserted between each oscillator and the mixer tube. Its primary role is to separate the different oscillators from one another, in order to avoid harmful interactions. All of the tubes are kept warm, but the anode voltage is only applied to those playing a given note.

The Present and Future of Electronic Music

The applications of electronic music have already become very important. To repair the devastation caused in the recent war, which did not spare churches, a number of destroyed bell towers were replaced cheaply with electronic bells. This contributed to the approval of automation and the punctuality typical of clockwork mechanisms.

Considering the question of music itself, we notice that certain electronic instruments, such as the "Ondioline" or the "Ondes-Martenot," have become an integral part of orchestras or are even being used as solo instruments.

Prominent composers have written works that are particularly well-suited to the new possibilities these instruments offer.

However, it seems that electronic music is still in its infancy and that it will experience tremendous growth, the extent of which is, at present, difficult to predict.

The invention of the transistor will undoubtedly modify the structure of future polyphonic musical devices that could, without their price or size becoming excessive, include a large number of individual oscillators using semi-conductor triodes.

On the other hand, studying the shape of the oscillations in depth as well as the application of appropriate filters, will surely allow the desired timbres to be obtained. The practical application of frequency modulation processes will enable the richness of the "vibrato" to vary, by adjusting repetition frequency and the frequency deviation amplitude, as needed. For that matter, it is possible that "electronic memory" devices may play a useful role in the production of sounds, particularly where polyphonic instruments are concerned.

As we await these future developments, anyone blessed with a love of both technology and music could, thanks to the detailed instructions provided by Georges **Jenny**, build, for his own enjoyment (and it will be thoroughly enjoyable), a musical instrument offering an extraordinarily wide range of possibilities; that is to say, the Ondioline.

The Origins of the Ondioline

This instrument was created in 1942, when Georges **Jenny**, a law student at the time, found himself forced to complete a long stay at the Saint-Hilaire-du-Touvay sanatorium, in Isère.

In theory, there was nothing to suggest he was destined to become the inventor of such an instrument. However, a lover of music who has, on one hand, a lot of free time and, on the other, a very well-organized mind, won't sit idle. Through study and patience, Georges **Jenny** succeeded in assembling a few devices that took the grand prize in the Foire de Paris (Paris Fair)'s inventions competition. From that point on, with the help of the **Centre National de la Recherche Scientifique** (National Center for Scientific Research) he secured patents worldwide and, after his complete recovery, in 1947 threw himself into the development of hand-crafted "Ondiolines."

He took satisfaction in having music-loving customers from around the world. On these lists can be found the names of Prince RAINIER of Monaco, the Emperor of Abyssinia, Edith PIAF, the priest of Saint-Maxime, Mr. Ennemond TRILLAT (Director of the Lyon Conservatory), the director of the Conservatory of Algiers, as well as the King of Denmark, where the instruments neighbored those belonging to Charles TRENET, the Prince of HOHENZOLLERN, Mick MICHEYL, Madeleine SOLOGNE, etc.

Overworked by his business, in 1952, Georges **Jenny** contracted poliomyelitis. It took great willpower to continue his work while again waiting to recover. Once more, he proved incredibly strong of character. Today, hardly a trace of this disease remains; at most he may be seen leaning slightly on a cane.

Recently, he can be found sowing a love of music in those around him by teaching children the simple use of the "Ondioline" and thereby proving that the instrument he created is also a fantastic educational tool. Now, without taking up any more of our patient reader's time, we shall yield the page to the well-named... Georges **Jenny**.

(Translator's note: "Well-named" because in French "Jenny" is a homonym of "génie", the word for genius)

E. A.

The design and development of the Ondioline was described in several articles written by Georges Jenny and published in various issues of "Toute la Radio," most of which are, incidentally, out of print.

To meet the demand of those who would like to have this complete set of papers written by the Ondioline's inventor, we are reproducing them, in the following sections, in the form of a revised edition complete with a previously unseen appendix describing a device that allows the "coupled octaves" effect to be obtained.

THE ONDIOLINE

By **Georges JENNY**

Design and Construction

Introduction to Electronic Lutherie

"Electronic lutherie," or the making of instruments that produce music not by mechanical acoustic sources (as in a violin or saxophone) but electronic sources (circuits oscillating at audible frequencies), officially began in 1915 in the form of the first patent by American Lee De Forest, *the famous father of the vacuum tube.*

Since then, hundreds of researchers around the world have attacked the problem of how to create harmonious sounds that rival those emitted by orchestral instruments played by expert hands.

Traditional instrument making falls into two broad categories: polyphonic instruments (organ, harmonium, piano) and "super-expressive" but monophonic instruments (violin, flute, clarinet, trumpet and other solo orchestral instruments). Similarly, there are two families of electronic instruments manufactured: electronic organs and monophonic instruments. The making of the latter—a practice referred to as electronic lutherie—is what will be discussed below.

The first and principal researchers in electronic lutherie in France were Hugoniot *(1920),* Givelet, Bertrand, Martenot *and* Péchadre, *along with many others. The author of the following paper, the inventor of the Ondioline, was introduced to electronic music long after these pioneers. He was thus able to build on all of the research conducted by his predecessors. Due to the limited technical capabilities of their time, an era of tinny gramophone speakers and unstable oscillators, some ideas were not feasible; over time, though, they became possible. These excellent ideas resulted in patents (including the one by De Forest and others) that eventually fell into the public domain, thus no royalties were paid—far from that!—to their inventors. The twenty-year legal patent term had flown by. We have patents ourselves that are already fifteen years old...*

Now seems like the right time to take stock of developments in electronic music. The first part of this paper focuses on introducing a few concepts relevant to both musicians and radio operators, though the two sometimes speak very different languages. We will try to provide clear definitions of the required qualities and purposes of certain essential mechanisms in monophonic electronic musical instruments.

The second part of this paper describes in detail the various modules that make up the Ondioline, one of the latest such instruments. It is then up to readers, whether for themselves or for a musician friend, to connect their high-fidelity stereo system to an electronic musical instrument and add their own features, which of course can be revised, corrected and supplemented as desired.

Though certain parts of the instrument such as the expressive keyboard and particular timbre-selecting circuits are practically impossible for amateurs to build correctly from scratch, professional and home technicians will be able to build certain special sub-assemblies, do the wiring and adjustments, and connect everything correctly to a high-quality, low-frequency amplifier. All any would-be luthiers need is a good schematic to work from and a knowledgeable musician friend or a sharp ear of their own to discern good notes from bad.

One interesting consideration is that amateurs may be the ones to help electronic music come into its own, as they did with shortwave radio, since there is still much to invent and experiment with in this field.

We are happy to offer guidance and facilitate collaboration between any amateurs interested in electronic lutherie.

G. J.

CHAPTER ONE

Speaking the Same Language

Several of the chapters in these pages will be dedicated to describing a new musical instrument. The descriptions cover both the electronics behind the instrument and the *construction of the instrument* itself. It seems beneficial and even essential to spend the first chapter restating and establishing some fundamental definitions of terms that will serve to bridge the two subjects.

Musicians and radio operators may both refer to the definitions at their leisure so that they may speak the same language. We hope that by doing so, we will avoid or eliminate misunderstandings that might otherwise occur.

Here we address radio operators: Operators have within them the heart of a musician, making them, in our opinion, the perfect reader. Thus, we ask a small sacrifice from them: to be patient until we get to the schematics of oscillators, timbre-selectors and frequency converters so familiar to them, while we make a fairly long foray—for which we apologize in advance—into a field that has been poorly defined until now. By doing so, we will gradually converge on a specific vocabulary that, once established, will help us better understand each other when we finally begin discussing how to replicate the sound of an oboe, guitar or other instrument electronically.

First misunderstanding

"You see!" comes the disdainful cry from our friend *Stradi-Invarius*, a die-hard of the old Renaissance lutherie. "With your electronic music, you hope to imitate (badly, undoubtedly) an oboe or a guitar. How horrible!"

Do we respond? Do we try to explain to him that if we call a certain voice an oboe and a specific transient a guitar, it is the fault of his (*Stradi-Invarius*') ancestors, who gave the same name to the machine that makes the sound as to its *product*, that is, the sound emitted. Painters, who are more evolved than musicians on the matter, have always had a practically continuous range of colors and know various ways to mix a particular light blue or a specific dark red. They call a cat a cat...

But until now, musicians have had only one discrete range of timbres (colors) and furthermore have had only one tool (i.e., one musical instrument) to produce a specific, defined timbre and thus—let us repeat, for it is very important to remember—they have given the resulting sound the same name as the instrument used to create it.

The question is complicated by the fact that, over the centuries, the ear has come to associate the timbre and transients represented by, for example, a violin, with all its specific qualities and flaws. The ear is then confused by electronics, which can combine or break up timbres and transients as desired, while traditional orchestral instruments naturally cannot.

With this caveat, let us return to our suggested parallel between music and painting. Let us say that the oboe represents the color green, a nod to nature-lovers, but also avoiding giving it a number that might indicate, for example, its harmonic or formant content.

In a traditional orchestra, the oboe's sound color is obtained by blowing into a pipe while blocking specific holes in a specific way. To obtain a neighbouring sound color—that of an oboe d'amore, for example—you, my friend *Stradi-Invarius*, must visit the conservatory museum and remove an oboe d'amore from its display case, then relearn with your ten fingers how to block the differently arranged holes.

I would do one better than you then, dear *Stradi-Invarius*, if I were able to replicate the sound of an ordinary oboe (shamrock green, say) simply by playing on a keyboard, and the sound of an oboe d'amore (emerald green, for our purposes ...) by playing the same fingering on the same keyboard... Readers who understand electronics already know that all we need to do is modify the value of a capacitor by a few picofarads to obtain such a slight variation in sound color...

Thanks to electronics, lutherie can now remedy one of the biggest disadvantages inescapable by mechanical acoustic instruments: the need for each instrument to have its own fingering, requiring musicians to learn to play each one differently, to the extent that, in many cases, only one timbre (thus only one instrument) has been preserved, while instruments with related but uniquely different timbres have been relegated to museums... Such has been the case with oboes, saxophones, violins and cellos, all of which have close relatives, each with a different key layout for the same range. That is why the oboe d'amore, viola da gamba and many other instruments are now found only in museums.

You, my dear *Stradi-Invarius*, may object, retorting that the sound, the biting attack of an oboe, cannot be replicated precisely using electronics.

But why insist on comparing? Unless, of course, the ear—an ear free of all prejudice—finds it displeasing. What is more, my dear Invarius, I do not claim that my timbre selectors, transient controllers, or my loudspeakers have, in just a few years, attained the perfection reached by your oboe after many centuries. Give me—or rather, give us, since more and more researchers are joining this brand-new field—just five or ten years and you will see...

Electronic lutherie is still nascent, but given the new resources at its disposal and the rigid limitations of pure acoustics, limitations that the science of electronics is helping to bend, I wager that musical instruments of the same artistic value as the most marvelous products of the past will arise from fruitful collaborations between electronics technicians and musicians who appreciate beauty.

Let us acknowledge that, one day, it seems logical we may even attain artistically superior results.

TABLE I

COMPARISON OF THE VOCABULARIES OF MUSICIANS AND RADIO OPERATORS

Suggested symbol	Corresponding electroacoustic definition	Equivalent in the musician's vocabulary	Suggested terminology valid for both musicians and radio operators
F*m*	(Periodic) frequency modulation	Vibrato	Vibrato
Fv_{ap}	Aperiodic variation in frequency	Glissando, portamento, appoggiatura	Glissando
A*m*	(Periodic) amplitude modulation	Tremolo	Tremolo
Av_{ap}	Aperiodic variation in amplitude, divided into:		
Av_{ap} 1	Rapid variation (less than 1/10 sec.) in amplitude: transients	Attack (terminology varies by instrument)	Method of attack or form of transient sound
Av_{ap} 2	Slow variations in amplitude	Volume	Volume
F_m	Modulating frequency	"Quality" of vibrato, which can be "narrow" or "wide"	Vibrato speed
ΔF	Variation in frequency around the average frequency F when changing the frequency of a sound: frequency excursion	"Quality" of vibrato, which can vary in range	Vibrato amplitude
ΔF/F	Rate of frequency excursion		

"Dead" sounds

A "fixed" sound is traditionally defined by four traits (1):

Suggested symbols (2)

1) Pitch or frequency .... F
2) Intensity .... A
3) Timbre .... H
4) Length .... D

A "fixed" sound is a "snapshot" of a sound during which time none of the three elements above (pitch, amplitude or timbre) varies.

In reality, no sound of this type makes sense to the ear, since any sound played over time must have a start and a finish. This start and finish assume a variation "A" (the amplitude), the shift from silence to the fixed amplitude "A", and back to silence. Note that the closest sound to this theoretical fixed sound is one with a brutal attack played on an electric organ by pressing a key while engaging the expression pedal to stop the sound in its path, ceasing any tremolo or vibrato.

Musically speaking, such a sound may fairly be described by musicians as "dead" or "soulless." Indeed, the brutal, nearly instantaneous shift from silence (or "zero" amplitude) to a fixed amplitude "A" and vice versa unpleasantly influences the esthetic value of the sound played.

We have conducted several convincing experiments on this matter. We played three or four preselected, very different timbres, well-defined by an oscilloscope, for professional musicians, composers and orchestra conductors.

We played the timbres multiple times in the same order, changing only the method of attack or the decay of the sound. Listeners were asked to describe in writing the quality of the timbres they heard. They described rigorously identical timbres in very different ways depending on (i) the shell (the transient) by which the timbres shifted from "zero" intensity to a fixed intensity "*x*", or (ii) the shape with which the timbres decayed. When we added different vibratos or tremolos to the attacks, even the hardiest musician became completely lost, because the notion of pure timbre (harmonic content) weakened considerably when confronted by factors that our listeners had often thought of as secondary (attacks and frequency changes).

If we want to be thorough, we cannot fail to include a description of how our "fixed" sound comes into being and how it decays—in short, the entire lifespan of transients, which has been thoroughly neglected in the study of music until now.

"Lively" sounds

In addition to the factors that characterize "dead" sounds, there are factors relevant to the entire duration of a note.

We must try to draw up a table of factors that play a part in the most complete definition possible of a sound, of a "sound object." A sound is an oscillation at an audible frequency and, like any oscillation,

(1) If we wish to be rigorous, electroacoustic techniques require us to add to the three traditional factors—sound pitch, intensity or amplitude, and timbre—the consideration of phase (P) for the phase shift between fundamental and harmonics. Musicians cannot clearly define this interval in esthetic terms, though they can hear it.

(2) We purposely do not use the lowercase f to stand for frequency, for in music it is universally used to indicate volume: f = forte and ff = fortissimo.

may vary in periodicity or aperiodicity, frequency, amplitude, waveform or harmonic content.

In short, any music played on any orchestral instrument, no matter how refined or perfected, can be translated at any time from its musical characteristics using a formula in which F, A and H vary (3).

The combinations of F and A over time T will be represented by specific symbols, which will be very useful to us and which correspond to known elements in music.

Indeed, let us recall that our primary goal in this preliminary study is to establish a potential common language between radio operators and musical artists, whether professionals or amateurs. In the first two columns of table I, we attempt to scientifically define an observed musical phenomenon. In the third column, we include the all-too-often vague language used by musicians to designate the phenomenon. Finally, in the fourth column, we offer provisional definitions acceptable to both sides. Note that we have avoided using the word "tone," a source of unfortunate confusion, as it is sometimes used to mean strength and other times used to designate the quality of the timbre of one violin or violinist compared to another.

This first table attempts to include all elementary methods for combining F and A. For the sake of simplicity, we have excluded H (timbre, and thus harmonic content) and P (phase shift between fundamental and harmonics). We also excluded them because in monophonic sounds, as we saw above, combinations of F and A are, by far, the most common means of expression in the language of music.

Old friends

Our readers will give a passing salute to the old amplitude modulation (the tremolo of the theater organ) and its adopted symbol A*m*, and will admire violinists who, for two thousand years, like Mr. Jourdain with his prose—that is to say, unthinkingly—have been modulating frequency (F*m*). However, when confronted with the qualitative definition of F*m* used by violinists ("narrow" and "wide" vibrato), they will undoubtedly join us in suggesting the expressions "vibrato speed" and "vibrato amplitude" (as suggested in the "compromise" column).

Though we cannot and do not wish to quantify everything (to "detract from the art," as our friend *Stradi-Invarius* would say), we will see later how these few definitions and even these formulas will help us in designing and constructing an electronic musical instrument.

There is not much to say about the glissando, or Fv_{ap} (aperiodic variation in frequency), other than that whether it is ugly or beautiful appears to boil down to this: its careful combination with the other variables, $Av_{ap}1$ and $Av_{ap}2$. The vibrato's beauty lies in the musician's artistry, of course, but experiments with young musicians have shown us that enlightened players using these technical considerations progress much faster, even on a real violin, than students whose teachers have not explained what logically happens from a mechanical and acoustic point of view when players move their fingers in a certain way on the strings.

Volume of transients

Regarding Av_{ap}, or aperiodic variation in amplitude, we felt it necessary to subdivide the phenomenon into $Av_{ap}1$ and $Av_{ap}2$.

$Av_{ap}1$ is the extremely fast, very significant variation in amplitude that can describe a note's method of attack. In electroacoustic music, it goes by the familiar name of transient.

$Av_{ap}2$ is a slow variation.

Comparing the two to each other sows confusion for several reasons:

1) The ear does not react the same way to slow and fast variations in amplitude. For variations noticeable to the ear (i.e., of at least two to three decibels), when the variation is produced slowly, the ear perceives it quantitatively, and the perception is classified as a variation in volume (*p* to *f*, or *piano to forte*) by musicians (fig. 1 *a*).

If, however, the variation is very fast, the ear perceives it qualitatively (4) as the attack—the hammer strike of a violinist's bow or the "tu" of the saxophonist's tongue.

Furthermore, an examination of the phenomenon using an oscilloscope shows that the amplitude variation of $Av_{ap}1$ is not simple as in $Av_{ap}2$ but nearly always complex (fig. 1*b*).

2) The second reason we have distinguished between fast and slow variations in amplitude is because in certain mechanical acoustic instruments, $Av_{ap}1$ and $Av_{ap}2$ are controlled or affected by different mechanisms.

In the example of the saxophone (a very expressive instrument), the tongue affects $Av_{ap}1$ more so than the breath does. Air pressure provided by the lungs affects volume, and therefore in this instrument, it is the pectoral and abdominal muscles that control $Av_{ap}2$.

For the violin, on the other hand, $Av_{ap}1$ and $Av_{ap}2$ are controlled by the bow (through combined variations in the pressure and speed of the bow on the string). In this instrument, $Av_{ap}1$ can be further modified by changing the speed and pressure by which the bow suddenly comes into contact with the string (spiccato, staccato, etc.), creating subtle methods of expression unique to the instrument and one of the secrets to its "soul."

(3) We will only examine monophonic sounds here (single sounds that vary over time) and not harmonies, which fall under the science of chords.

(4) The same quantitative and qualitative phenomena of perception are observed when listening to sound and infrasound. Below a certain frequency (several periods per second), the ear hears countable pulses, a quantitative perception. Above a certain frequency, the ear hears a note from a range named by musicians, for example, A3—a qualitative perception. But the ear cannot "count" the number of vibrations. To be able to say that an A is made up of 435 vibrations per second requires special equipment. In the former case, there is a perception of rhythm, and in the second a perception of sound.

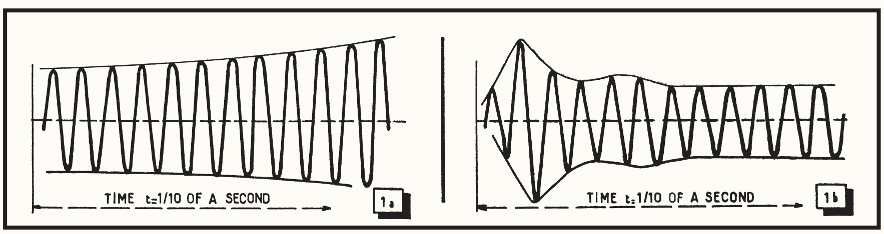


Fig. 1. — *Variations in a sound's amplitude affect the ear differently depending on their speed. A slow variation* (1a) *is perceived quantitatively and called volume. A fast variation— tonguing by a saxophonist, for example—* (1b) *is perceived qualitatively, and the phenomenon is called a transient.*

TABLE II

COMPARISON OF VARIOUS INSTRUMENTS TO THE ONDIOLINE

	Violin	**Saxophone**	**Organ**	**Human voice**	**Ondioline**
I. — **Primary source of energy**	Muscles	Muscles	Electricity	Muscles	Electricity
II. — **Transformation of energy** up to the point of usage, and final method for producing oscillations at an audible frequency	Drawing a bow along a string, thus transforming a continuous movement (bow) into a movement alternating at an audible frequency (vibrating string).	Pneumatic: Air flow causing a reed coupled to a tube to oscillate.	Pneumatic (compressor that keeps pressure in a reservoir constant): air pressure acting on a reed or mouthpiece connected to a tube.	Pneumatic, acting on the player's vocal cords (flapping reeds).	Transforming continuous voltage into an oscillation at an audible frequency.
III. — **Fv_{ap}** Ways to **affect frequency**, mechanisms that control the action when the player plays	Vary the position of the fingers along the string.	Valves block openings placed along the body (tube) of the instrument, manipulated by the player's fingers. Pressure of the lips on the reed: variations in breath pressure.	None while playing. (One tube is needed for each frequency.)	Muscle tension exerted on the vocal cords.	Variation in certain electrical sizes (of resistors, capacitors) in the oscillator's circuits.
Methods available to the player to vary **frequency** (**Fv_{ap}**)	Continuous if desired (glissando) or discrete.	Continuous (to a point) and discrete.	None	Continuous and discrete.	Continuous (only in certain models) and discrete (using the keyboard).
Range of frequency	4 octaves	2 1/2 octaves	—	About 2 octaves	5 to 8 octaves, depending on the model
IV. — **$Av_{ap}1$** Ways to **affect the attack** (transients)	Very fine and varied using the bow (by varying pressure and speed on the string).	Very fine (using the breath, lips and tongue).	Very limited (all or nothing).	Extremely fine and varied, using **consonants**.	Varies widely (using an expressive keyboard with playable keys and a system of preset attacks).
V. — **$Av_{ap}2$** Ways to **affect volume**	Very fine, using the bow. However, **pianissimo** is difficult and limited by a lower bound.	Fairly fine, but **piano** and **forte** are limited by the risk of octavation.	Very limited (only by closing shades, which muffle the sound).	Very fine.	Very fine (a knee lever or switches operate a potentiometer).
VI. — **Holding a long note**	Limited by the length of the bow.	Limited by breathing capacity.	Unlimited.	Limited by breathing capacity.	Unlimited.
VII. — **Fm and Am** Ways to **affect vibrato** and **tremolo**	Vibrato can be finely controlled.	Fm and Am seem to blur and are undoubtedly difficult for the player to separate.	Impossible with a single tube.	Vibratos and tremolos are closely intertwined (by design or poor... education?)	Fm and Am can be separated as desired and finely controlled.
VIII. — **Change in timbre** as volume changes	Natural phenomenon caused by distortion of all instruments at high volumes.				Can be maintained.
IX. — **H** (harmonics and formants) Ways to **affect timbre** while playing	Varies little but very finely depending on the distance between the bow and the bridge, the string played and the pressure of the finger on the string, the angle of the bow on the string, the part of the bow used (middle, tip, frog) and the degree of pressure and speed.	Varies quite widely: action has been poorly defined until now (lips, tongue, etc.).	Does not change.	Marvelously subtle and varied using vowels. Continuous and discrete variations both possible by instantly varying the size of the mouth's natural resonators.	Very subtle and varied. Theoretically infinite by changing the electrical sizes of the filters.

Once table I has been assimilated and accepted by our readers (and their musician friends, with whom they can converse at leisure—a conversation that may become animated), we can move on to table II, a comparison between various mechanical acoustic musical instruments (violin, saxophone, organ, human voice) and the *Ondioline*, an electroacoustic instrument.

When read vertically (from top to bottom, column by column), table II reveals how musical instruments may, in a certain light, be considered machines invented by humans in order to "manufacture" sounds. Like any machine, they assume a source of energy, mechanisms (motor, relays) for transforming the energy, and mechanisms for control and manipulation to allow the player to alter at any time the qualities of the sound emitted by the machine.

Comments on table II

I. — In an instrument like the violin, the human is the source of energy, the machine's primary motor, as well as the driver and controller of the machine.

In the *Ondioline*, the energy is not provided by the players, it is only shaped by them. We will see the consequences (advantages and disadvantages) of this later.

II *a*. — Transforming the energy up to the point of application: Here we see the inevitable "relays" between the player and the mechanism that produces the sound. In the violin, for example, by coating the bow with rosin and drawing it along a taut string, a relatively slow, continuous movement is transformed into an alternating movement at an audible frequency. This observation is important, because it reminds musicians that they can influence the production of sound only indirectly. In short, among the living organisms that produce musical sounds, only flies and mosquitoes directly generate sound at an audible frequency, by using tremendous muscle action to flap their wings hundreds of times per second.

II *b*. — Producing oscillations at an audible frequency: In musical instruments invented prior to the electronic era, oscillations are produced by vibrating a solid object (string, reed, skin, etc.) or a more-delicate medium, such as a column of air (as in the flute). In electronic musical instruments, the vibrated object is even more delicate: It is the flow of electrons that must be vibrated in rhythm. But we know that the natural limits that explain and define vibration (oscillations with multiple degrees of freedom, forced oscillations, resonance phenomena, etc.) are the same for a taut string as for a tuned circuit.

Logically, electronic oscillations should be able to be manipulated, so to speak, more finely than oscillations in cruder materials. And experience bears this out. But the problem lies in choosing the right ways to act on and control oscillations. The entire art of lutherie revolves around this, whether or not the luthier is also an electrician. Paragraphs III, IV, etc. of the table outline the methods used by luthiers to achieve these results depending on the instrument in question. These remarks simultaneously reveal the advantages and the difficulties that can be encountered, advantages and difficulties that are inherent to mechanical acoustic and electroacoustic instruments.

In this short paper, we should not get carried away with detailed analyses, comments or comparisons of each instrument's qualities and flaws. Readers will do so themselves in reading each column as they read each paragraph. They would do well to refer to the table frequently later, when we study proposed solutions offered by electronics.

To conclude this first chapter

In summary, in melodic (or monophonic) music, solo playing requires a certain level of expression that each musical instrument renders in its own way, with varying degrees of success.

It could be said that melody is like the expression of a thought and, what is more, that it unwinds like a thought. Monophonic musical instruments, as a whole, represent potential mechanisms for expressing such thoughts. Therefore, in our opinion, it would not be an exaggeration to speak of *instrument phonetics*. Our table is an attempt to define, somewhat crudely, the branches of this phonetics, branches which it would be beneficial to describe further and elaborate upon, though this is not the purpose of this paper.

Among the musical instruments in the table, we have purposely included the human throat. Compared to other instruments, it seems from an expressive point of view to be the king of all instruments. With its variable attacks (consonants) and finely controlled timbres that can shift in an instant (vowels), it far surpasses any string or wind instrument in the orchestra. We will see later how electronic music can match it in some ways and surpass it in others, as voices are rather limited in range (barely two octaves), volume and nimbleness.

But then comes the even more difficult matter of controlling so many parameters simultaneously: volume, attack, vibrato, glissando and variable continuous and discrete timbres. Two hands and two feet can move quickly! But after that?

In any case, we are fully prepared to undertake a study of the many parts of an electronic musical instrument and its various modes of expression. For example, we will see that although the hurdy-gurdy (an instrument with keys and a rotating handle) is in the same family as the violin (the string family), their instrument phonetics are as dissimilar as the Papuan language is from the language of Gœthe. Our readers will come to understand that, in the world of electronic lutherie, there are hurdy-gurdies and there are violins, and they can aspire to build either one.

We will now examine how it is possible, electronically, to find satisfactory solutions to these problems.

CHAPTER TWO

An Initial Look at the Ondioline Schematic

We have just seen the qualities of expression that can be expected from a monophonic instrument, whether electronic or acoustic, and how each traditional orchestral instrument creates these qualities in its own way.

Our conclusion is as follows: The more means of expression a musical instrument gives its players, and the more subtle those means, the more "evolved" the instrument is. Put another way, it is not the language that counts, but the richness of the vocabulary available to the composer and player.

We have grouped and summarized the means of expression available on various musical instruments in the table on page 11. This table allows us to assess the degree of "evolution" of a given musical instrument.

But let us never forget that a musical instrument, even a Stradivarius, is only a device; soul and creative intelligence come from the player.

Now we shall set aside the expressive side of things (the potential effect on the sound produced) and consider how the sound itself is made, from the moment oscillations are generated at an audible frequency to the instant sound floats into the surrounding air and arrives at our ears.

The table in figure 2 depicts the four primary links in the chain:

A — Production of oscillations at an audible frequency;

B — Modification of their form;

C — Amplification;

D — Diffusion into the air.

Some of these links are clearly familiar to us at low frequencies. But instead of high-fidelity sound systems, we should speak here of controlled high-infidelity.

The table reveals that within the oscillation formation process, there are interesting and encouraging analogies among monophonic musical instruments.

To produce a given timbre, resonant circuits B unique to an instrument remain constantly tuned to the same frequency, or to the same band of frequencies, regardless of the oscillation frequency emitted by oscillator A, whose frequency varies across the musical scale.

Oscillator A produces a specific note; in other words, it controls the pitch of the sound. The resonant circuit or circuits B control the timbre.

For now, we assume that they (the circuits B) always stay in tune, which is true only for the violin and saxophone. The size of the body or of the tube/bell ensemble are fixed by design. However, as we have seen, for the human voice

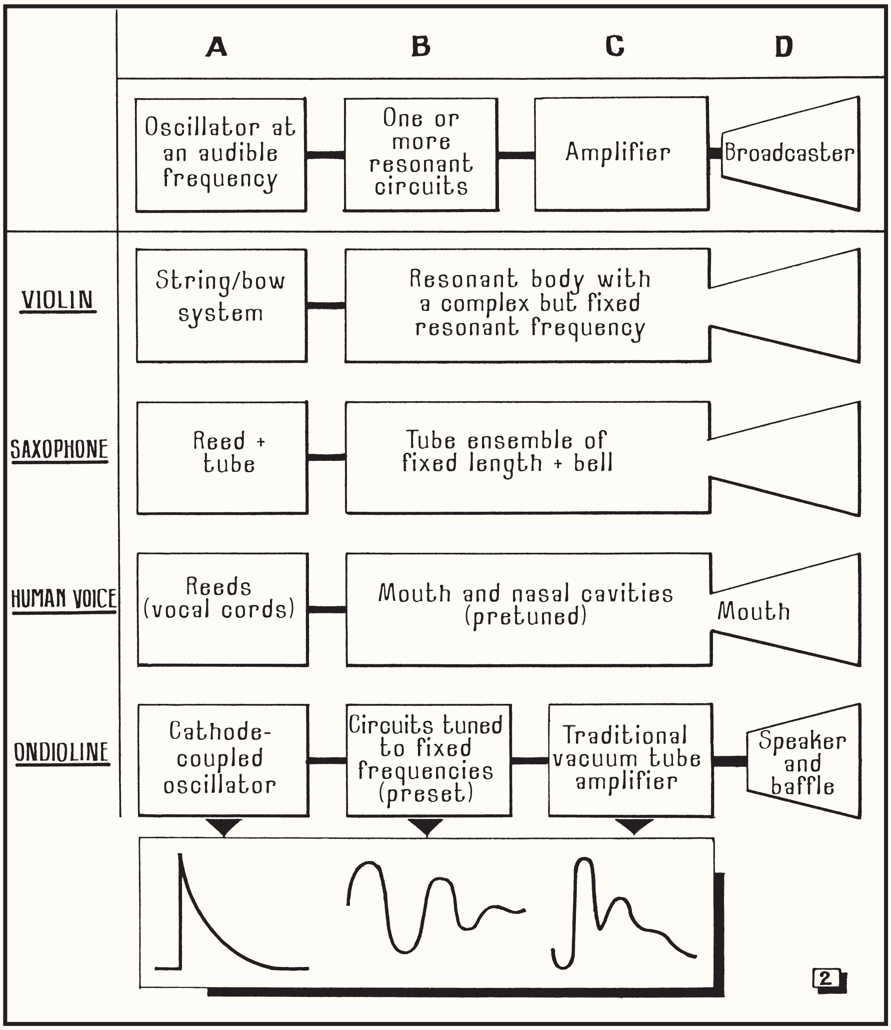


Fig. 2. — *The process of forming a given timbre is the same for multiple musical instruments and even for the human voice.*

and for the *Ondioline*, circuits B can be untuned as desired (hence the highly noticeable variation in timbre). Let us suppose here that circuits B are pretuned and fixed and will not change during an oscillographic examination of the phenomena. We admit that the frequency emitted by A does vary, as it naturally does when playing, depending on how the musician fingers the instrument.

What happens then? First, let us note that the instrument can only be played correctly under these conditions (the variable frequency generator A exciting one or more invariably tuned circuits B) *if oscillation A is a relaxation* oscillation or similar to one in form. This is true for all monophonic orchestral instruments, whether string or wind, as well as for the human voice (1).

This relaxation oscillation is what the ear hears as determining the pitch of the note (for example, for the A3 to which an orchestra tunes, this relaxation oscillation has a frequency of 435 Hz).

However, the frequency unique to resonator B, a frequency adopted by pulse A, is a damped fixed-frequency wave and is what the ear perceives as an instrument's unique timbre. Or at least that is the case according to formant theory, which is clearly borne out by electronic musical instruments built according to the principles of the *Ondioline*. This formant theory is true not only for the human voice (vowel theory) but for all solo instruments in the orchestra.

Some examples

In reality, the aural impression of timbre (as the "voice" of a continuous sound) is the result of the combination along a sound spectrum of; a pulse A, its harmonic content (all harmonic orders), and various formants (sequences of damped waves of fixed frequencies x, y, z, etc.) generated by the pulses and then blended or modulated by them.

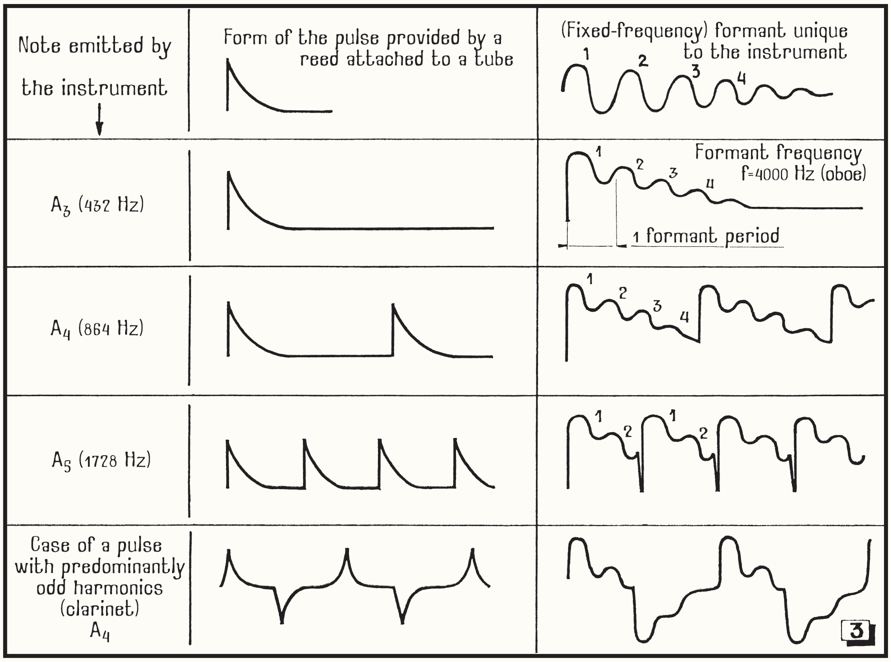


Fig. 3. — *Oscillograms taken at different points (A and B) in the chains of figure 2. The first three rows are for an oboe and the fourth is for a clarinet.*

Figure 3 shows us an example of what happens in the case of the oboe (first three rows) and then in the case of the clarinet, whose formant frequencies are largely similar but whose excitation waves take on very different forms.

The oboe's fixed-frequency resonating body, made up of a tube connected to a bell, is excited by a pulse provided by a reed (2). Note that for an excitation frequency of 432 or 864 Hz, the formant has the time to dampen completely before being continued by the next pulse. Obviously, this process is not the same for pulses of frequencies greater than 1000 Hz. The formant's resonant oscillation is interrupted by being continued before it can decay through damping.

Nevertheless, the timbre of the oboe remains distinctive to the ear, regardless of the register in which the player plays, whether high or low. This proves that it is, in fact, the formant's frequency that dominates the general impression of the timbre. Indeed, if the formant's resonant frequency is changed (when the timbre of the oboe is replicated electronically) without changing the form of the excitatory pulse, the timbre is quickly changed.

In reality we find multiple resonant frequencies for the formant-generating cavity or cavities—hence an oscillographic waveform that is often much more complex than those diagrammed in figure 3. But what is important to remember for now is the coexistence in any instrumental or vocal sound (in addition, naturally, to the fundamental sound) of:

(1) However, in a polyphonic instrument like the organ, the problems are different: Each pipe is excited by a single frequency, and its form may be tuned to best resonate with this excitation frequency. In other words, an organ pipe can easily emit a sinusoidal wave into the surrounding air (which is approximately what happens when playing the bourdon or flute). However, a monophonic orchestral instrument will rarely emit a quasi-sinusoidal wave, and even then only for certain notes in the scale.

(2) In wind instruments, the tube actually plays two roles: When combined with a reed, the tube and reed work together to determine the frequency (by blocking or unblocking holes arranged along the tube). Alternatively, we know that depending on whether the tube is cut as a cylinder or a cone (closed at one end), it emits a series of even or odd harmonics. When combined with a bell, the tube can be considered to generate formants, or sequences of damped fixed-frequency waves, whatever the excitation frequency. These problems have not been studied sufficiently to date. All of the classical specialized works in the last ten years or so have come up with diverging theories. But comparisons of oscillograms taken from oboes, clarinets and violins with those taken from electronic instruments described below have been too striking (and the aural impressions perceived too similar) for formant theory to be discarded. From this perspective, the development of electronic lutherie will be a giant leap forward in the functional study of musical instruments in general.

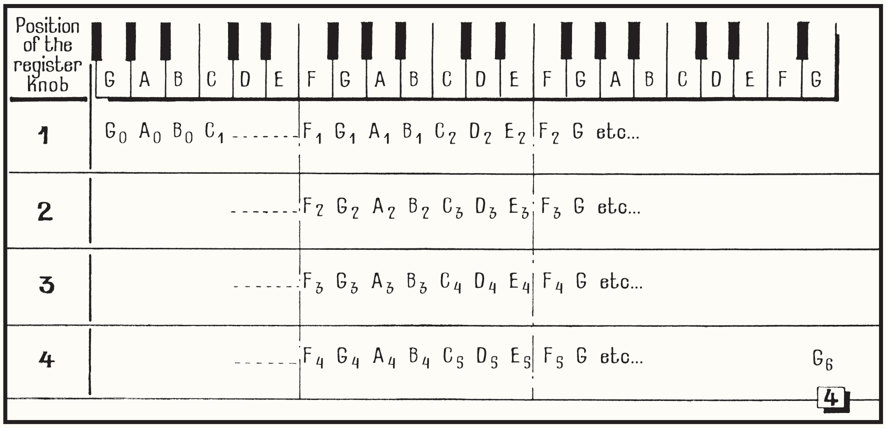


Fig. 4. — *Depending on the position of the "register knob," the first key F on the keyboard is F_1, F_2, F_3 or F_4 on the musical scale.*

1) Harmonics (generally contained in the excitatory pulse, or strengthened by that pulse's combination with an open or closed tube);

2) Formants, which have no direct arithmetic relationship with the fundamental or its harmonics, and whose frequency does not vary as the fundamental varies.

The form of the excitatory pulse strongly influences the timbre. This is easily understood by the way a resonant circuit reacts to excitations of varying sharpness or duration. Likewise, the damping of resonant circuits or the cavities of acoustic instruments affects the form of the final waveform, which is detectable using an oscilloscope at the end of the chain (this amount of damping is called the "quality factor" or "Q factor").

If, furthermore, the excitation wave A is not a positive or negative pulse but both successively, as in the case of a clarinet (whose excitation wave consists mostly of odd harmonics), the resulting waveform (fig. 3, last row) will be very different, and the aural impression will also be highly distinctive.

Musicians will be tempted to exclaim, "It really does sound like a woodwind instrument!" (wooden flute, clarinet). This is pure association between the aural and the visual—a wooden tube equals the sound of a clarinet—but has no real meaning, for metal and plastic clarinets have been made with barely a change to their sound.

In figure 2, we have reproduced the four links A, B, C and D separately. But in mechanical acoustic instruments, the mechanisms B, C and D are often grouped together. For example, the resonating body of a violin is a cavity and thus a generator and resonator of formants. It is also an amplifier for the waves generated by the strings (if the body were eliminated, not only would the timbre be modified, but the volume of the sound would be lowered considerably). The body also consists of a top and a back, connected to the top by a soundpost (3). The body serves as a speaker, transmitting mechanical vibrations to the air by the same rules as those for matching impedances. The same can be said for the tube/bell ensemble of a saxophone or trumpet...

Thus, only in an electroacoustic musical instrument is it possible and useful to clearly distinguish between the four links. However, we will see later that this separation of functions, even in electroacoustic instruments, is not entirely perfect and may not always be desirable. This explains the occasional, highly esthetically interesting results produced by second-rate speakers and equipment. Even so, it all depends on what happens exactly in these instances. But let us not get ahead of ourselves...

Back to the electronics

Readers who have followed us thus far in our introduction, whether patiently or not, will be rewarded for their effort. At the very least, there will be no lingering questions of the type "How do you ensure that the timbre of your electronic instrument is a faithful replica, no matter which note is played?" and "What complicated mechanism is used to keep your timbre circuits in tune with your frequency generator when the generator shifts from low to high?" etc.

The answer, as we have seen, is as follows: There is no complicated mechanism...

All we have done is studied what happens in good-old mechanical acoustic instruments from past centuries and reproduced the same, or approximately the same, phenomena in an electroacoustic instrument. Some researchers have erred by beginning with a heterodyne sound and attempting to make a musical instrument out of it. But just as nature abhors a vacuum, the ear abhors simple sounds. We will see later that a lack of attack, bite and brilliance in the attack are other potential pitfalls. For these two reasons, the first electronic musical instruments closely resembled a musical saw or warning siren...

That is why this preliminary study, this "meditation" on existing instruments is, in our opinion, indispensable. We have, in essence, led the reader along the same path we ourselves took before arriving at conclusions acceptable to musicians. This allows those who both love and build electronic instruments to see what should not be done and, in all modesty and sincerity, what remains to be done in this exciting field!

Link A: the oscillator

Now we will provide some electronic solutions to the problems posed in the tables above.

The first problem mentioned is that of selecting an appropriate oscillator.

Our ideal oscillator (electronic, of course) should cover the entire range of audible frequencies, from 30 Hz to 10 kHz, or about eight octaves. But a keyboard with such a range (let us assume we will use a piano keyboard, which is easy to play and, above all, commonplace) would measure 1.3 m long... For that reason, we must choose an oscillator that allows *transposition*. In actuality, the *Ondioline's* keyboard is fixed at three octaves, and a knob that transposes notes from one octave to another allows the keyboard to cover the six or seven most commonly played octaves on the musical scale (however, nothing prevents the oscillator from going even higher or lower than this).

Next, our oscillator must be able to emit two types of tones: simple tones (preferably negative) and

(3) The soundpost is a short, small-gauge rod that in a violin transmits vibrations from the top to the back.

waveforms that alternate (positive/negative) by period.

The oscillator's frequency must also be suitably stable. And finally, it must allow the instrument to be tuned easily using a simple technique that takes into account the transposition of octaves, which also must remain precise regardless of the note to which the instrument is tuned.

The small table in figure 4 illustrates the last problem more clearly: By engaging a knob (called the "register knob" on the *Ondioline*), the player should be able to play, for example, middle C on the three-octave keyboard and hear a C2 when the register knob is in position 1, or play the same key and hear a C immediately above that (C3) when the register knob is in position 2, and so on.

In addition, by turning the general tuning knob (actually a potentiometer with continuous frequency variation), it must be possible to shift the frequency upwards or downwards by a quarter step, half step, whole step or more, so that if, for example, we play a middle C, where we would have heard a middle C before, we hear instead a B or perhaps a C♯ or a D. This should be true regardless of the position of the register knob. If we use the general tuning knob to shift middle C to, for example, play a D in the first register, then we should hear a D2 in the second register with the same key, and a D3 in the third register, and so on.

This was the preliminary data that led us to choose and patent, after some modifications for this specific application (4), the cathode-coupled multivibrator, the primary schematic of which appears in figure 5*a*.

Once modified according to the general schematic in figure 5*b*, by dividing resistor string R_{g2} into as many resistors as there are keys on the keyboard (3 octaves = 36 notes), the oscillator allows frequency to vary discretely, from half step to half step.

Resistor R_5, with a value of 6,900 Ω, corresponds to the highest note, while resistor R_{40}, at 53,588 Ω, corresponds to the lowest note.

When pressed, each key on the keyboard grounds its corresponding resistor, thereby limiting to a determined value the resistance of string R_{g2}, which is made up of a chain of resistors in series. The oscillation frequency is the value calculated thusly:

$$f = \frac{1}{R_{g2}.C}$$

The influence of the cathode resistor (at several thousand ohms) and of the anode resistor R_{a1} at 20 kΩ is effectively negligible in this formula compared to the resistance of string R_{g2}, which varies from 100 kΩ (the highest note on the keyboard) to nearly 1 MΩ (the lowest note).

However, some distributed parasitic capacitance is generated at capacitor C that connects anode 1 to grid 2 and controls transposition from one octave to the next. This capacitance cannot be eliminated completely, despite precautions that we will describe later when providing tips on assembly. The distributed capacitance resulting from the keyboard and essential shielding must be corrected for, when octaves are transposed using the register knob. If there were no parasitic capacitance, the octaves would be transposed simply by doubling the capacitance of C between anode 1 and grid 2 when you want to divide the frequency by two. The necessary corrections are made by adding a second controller disc to the register knob. The disc removes the short circuit of additional grid resistors R_{v4}, R_{v3}, R_{v2} and R_{v1} as capacitors C_{v3}, C_{v2} and C_{v1} are added to C_{v4} (the highest register), each lowering the frequency of the oscillator by one octave. C_{v4}, C_{v3}, etc. and R_{v4}, R_{v3}, etc. are adjustable to allow the instrument to be tuned correctly after manufacture.

Finally, the general tuning knob tunes the instrument upwards or downwards as desired at any time, obviously without having to alter the register-adjusting resistors and capacitors ($R_{v1, 2, 3}$ and $C_{v1, 2, 3, 4}$), which are set permanently during manufacture. Our corrected oscillator is very easy to handle, as it emits a stable frequency and

(4) French patent no. 974,201 of March 17, 1941, issued in the United States under serial no. 750,000 (patent no. US2562429A).

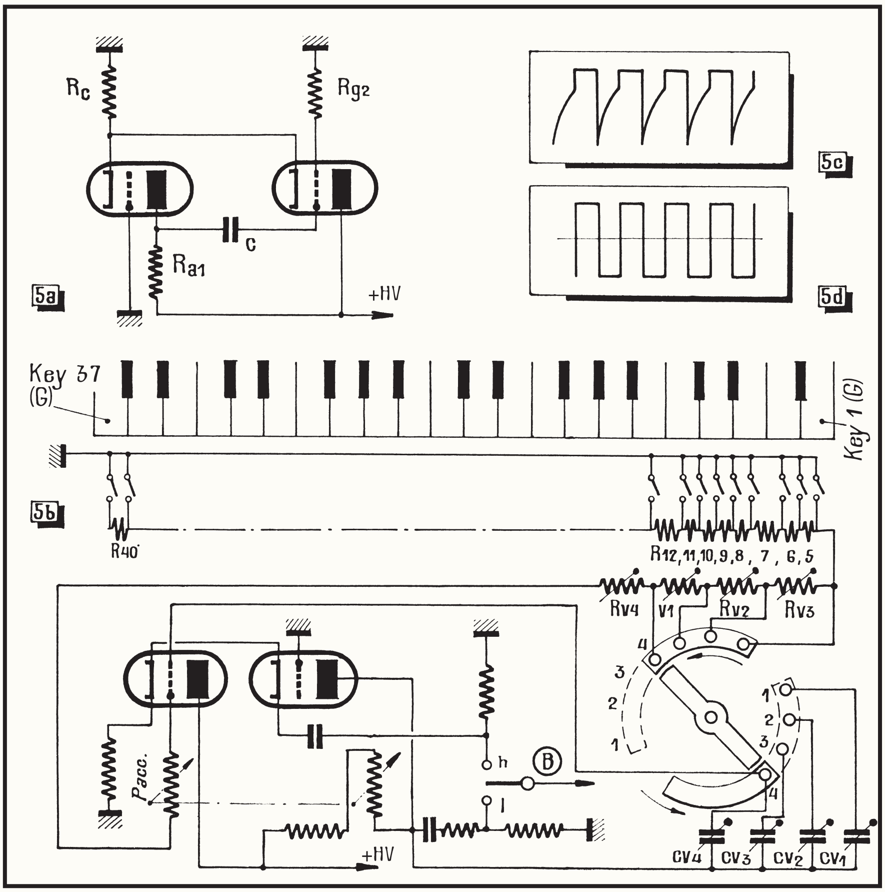


Fig. 5. — *The Ondioline oscillator is derived from the cathode-coupled oscillator* (5a) *and modified according to the schematic* (5b) *to transpose octaves without disruption. Fig.* 5c *depicts an oscillogram of signals produced at the common connection between the cathodes. Fig.* 5d *shows the form of the signals produced at the anode of the right vacuum tube in schematic* 5b.

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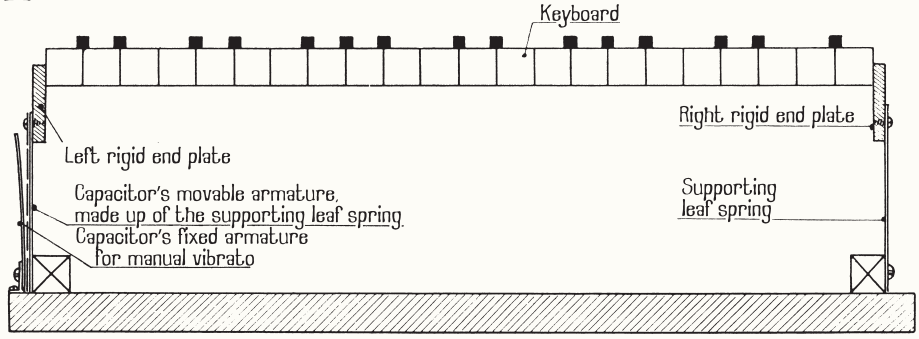

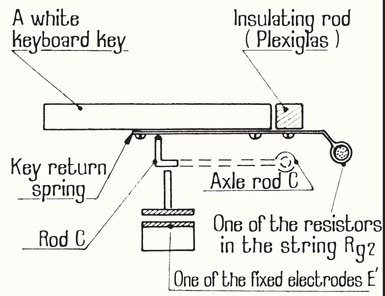

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Fig. 6. — *The playing hand can produce light horizontal oscillations on the keyboard, which is mounted on supporting leaf springs. The oscillations translate into variations in frequency (vibrato) via a capacitor whose armature is made up of one of the leaf springs.*

Fig. 7. — *When any key is pressed, a horizontal bar is lowered, closing the chain* R_{g2} *and simultaneously pressing the movable palette P on the progressive attack controller, which gives the sound an intensity proportional to the pressure on the key.*

a sufficiently constant amplitude from the top to the bottom of the musical scale. Usable signals are produced as desired at two points, B_h or B_l (at the cathode or the anode), depending on whether negative pulse or rectangular signals (fig. 5*c* and 5*d*) are desired. Both wave forms are easy to transform by bypassing or clipping (or both) before applying them to formant-generating circuits.

For the first part of the assembly, let us look at the actions available to the player while playing.

DISCRETE ACTION ON FREQUENCY ($Fv_{ap}1$) (5).

This action is produced by playing a key on the keyboard and moving the register knob at the same time. (Keyboard size: 3 octaves; total range covered by the instrument: 6 octaves, or 7–8 octaves, depending on the number of additional positions of the register knob).

VIBRATO

On the *Ondioline*, vibrato can be produced in one of two ways: manually or automatically.

Manual vibrato.— The *Ondioline's* keyboard was specially designed to be much lighter than that of the harmonium, piano or even of a simple portable reed organ. The goal was to make the keyboard so light that it could be suspended on a spring and *moved horizontally* when played. In this way, it would become possible to produce on a keyboard the same effect as produced by violinists when they oscillate their fingers from front to back and vice versa on a string—in other words, to play vibrato, or a periodic variation in frequency (6).

The design accommodates the transposition of octaves, which allows us to reduce the physical keyboard from seven to only three octaves, further reducing the inertia of the ensemble.

The *Ondioline's* keyboard (fig. 6) is suspended from rigid end plates on two leaf springs carefully calibrated to allow the ensemble to effortlessly oscillate horizontally with practically no inertia for the player's hand. In the player's horizontal back-and-forth movement, the keyboard compresses and releases a variable dielectric mica capacitor, one of whose (movable) armatures is made up of the keyboard's left supporting leaf spring. This capacitor is connected in parallel to the capacitor C_{v4} in figure 5*b*. But when constructed in this way, the capacitor has a greater effect in the higher registers (when only C_{v4} is in series) than in lower registers (when C_{v3}, C_{v2} and C_{v1} are connected in parallel to it). In practice, this flaw is corrected by a third disc (controlled by the register knob at the same time as the two other discs), which in positions 2, 3, and 4 introduces a small capacitor in series with the vibrato capacitor that mitigates the effect. (In order to keep the schematic clear, these mitigating capacitors and the third disc that controls them are not shown. They will be shown in the general schematic on page 21.)

Manual vibrato, when tightly controlled and used correctly by the player, can produce very refined effects much better than those produced by automatic vibrato. Furthermore, by agitating the keyboard left or right while playing, it is possible to produce the difference between a sharp note or a flat note. We intend to return to these considerations in another chapter when we examine how to properly manage all of these features offered by the *Ondioline* to the player.

Automatic vibrato.— We will provide instructions for constructing a unit that plays automatic vibrato once we have described the schematic for preamplification tubes, when we can demonstrate the possible tremolo effects at the same time (Am in table I).

ATTACK ($Av_{ap}1$ in table I)

If we were to connect the B_h (or B_l) outputs in the diagram of figure 5*b* to the input of an amplifier, when any key on the keyboard were depressed or released, there would be a horrible clacking noise, a highly unpleasant, distinctive banging caused by the closing or opening of the circuit of string R_{g2}. Even if the clack were eliminated, the note would still shift instantaneously from silence to maximum sound and vice versa, which the ear dislikes and for which it justly criticizes overly simplistic electronic musical instruments.

There are several possible solutions. Since we are discussing the *Ondioline*, we will only describe the solution adopted here.

(5) See table I, page 9, for explanation of this terminology.

(6) The idea for the oscillating keyboard dates back to Maurice Martenot (French patent no. 666,807 of 1928).

Underneath all of the keyboard keys, we have placed a long, very light, very rigid rod. This rod C features joints around axles attached to the right and left end plates generally supporting the keyboard (fig. 7 and 8). When any key on the keyboard is pressed, the rod is lowered parallel to itself, similar to a spacebar on a typewriter. Regardless of the key depressed, the mechanism compresses a variable resistor (or more precisely, a resistance-capacitance assembly that we will describe later in detail) called a "progressive attack controller" in the drawings (fig. 7 and 8). The rod C is metal and serves to ground the resistors R_5, R_6, R_7, etc. in the resistor string R_{g2}.

Figure 7 shows how the keyboard is actually built. Black and white keys are assembled on a *Plexiglas* rod using their respective leaf springs (phosphor bronze springs). Each key's leaf spring serves as both a return spring and a contact electrode for the key. Hence the need to carefully insulate each key from the others and from the ground: A loss of value here, even of several megohms, affects all resistors in R_{g2} in parallel and causes the instrument to fall out of tune.

The 36 tuning resistors R_5 to R_{40} are film resistors with preset values stabilized and calibrated at 0.5% (7). They are assembled in series behind the Plexiglas rod and connect each phosphor bronze leaf to its neighboring leaf.

On the upper keyboard (arranged facing the player in playing position), resistor R_5 is to the right (high end), and resistor R_{40} is to the left, ending at the leaf spring for the lowest G note.

The contact rod C is made of a light, very rigid alloy (*duralinox*), since it must have as little inertia as possible. Two return springs (not shown in the drawing) return it to its resting position against the leaf springs for the keys. The contact between the key's leaf spring and the general contact rod C is not metal to metal. To prevent parasitic noise (the nemesis of musical instruments), the upper part of the general contact rod C is covered with thick felt. The felt is covered with a flexible braid woven of silver thread, which is in turn carefully connected electrically to the contact rod, which is connected to ground.

This flexible braid is called an "officer braid" in military lingo. The braid conducts electricity perfectly and permits contact without crackling. Nevertheless, despite its original purpose, we have seen no notable improvements in the *Ondioline's* cavalry trumpet timbre since we began using it...

Producing the progressive attack

Let us now take a look at the entire mechanical and electronic ensemble to see how the progressive attack occurs.

The signal available at point B_h (fig. 5 and 8) is applied to the grid of the vacuum tube (6J5 or half-12AU7), both to be amplified and damped so as to eliminate the portion of the base formant signal in the drawing. This result is easily produced by giving the triode's loading resistance a very high value (0.5 MΩ or even 1 MΩ) and by reducing the cathode to zero or nearly-zero polarization. We then get a pulse of the type shown in the first few rows of figure 3.

However, if we desire a signal with predominantly odd harmonics (fig. 3, bottom row), all we have to do is lower the switch B on the timbre unit, and the signal available at point B_l will become thus. This signal is produced by combining the capacitor and the resistors located between the 12AU7 oscillator tube anode and point B_l, and bypassing the rectangular signal produced at the anode. In this case, the (half-12AU7) vacuum tube, attacked by a weakened signal (the role of the 5 MΩ-to-10 MΩ resistor in figure 9), will not clip our signal.

Either of the signals, as desired, is sent to the input of the progressive attack controller. The controller is carefully shielded and contains a movable metal palette P and two fixed electrodes coated with a relatively flexible, semiconductive mineral substance, E and E'. The two electrodes are also separated by a grounded metal barrier to prevent any direct capacitive radiation between E and E'.

The controller attaches underneath the keyboard, and the movable palette P is mechanically connected to the general contact rod C. When the player presses a key on the keyboard, the leaf for that key, which is connected to the resistor string R_{g2}, makes contact with the metal general contact rod C (which is grounded). The oscillator is then no longer disabled and oscillates at the prescribed frequency.

The oscillation measured at B (for example, at B_h if the B switch is raised) is amplified and clipped and arrives at the attack controller input on electrode E. It affects electrode E' only in terms of capacitance (palette P is metal but insulated from the general contact rod C and furthermore is entirely enclosed with E and E' inside the shielded case within the progressive attack controller).

The signal available at point E' is therefore extremely weak. As palette P nears electrodes E and E', the two (air) capacitors connected in series formed by EP and PE' increase in value, as does the signal available at E'. When P makes contact with E and E', the phenomenon becomes more complicated, since stacked on EP+PE' are two resistors (in series with EP+PE') whose value was previously infinite, but which is lowered to several megohms at the end of the compression, and the signal available at E' is at its maximum. This signal attacks the grid of the following pentode and then the formant circuits of the timbre switches.

As complicated as this mechanism may seem, it was adopted (8) after hundreds of trials of every

(7) The value of resistor R_5 is 6,900 Ω. The resistor for the octave below, R_{17}, should be 6,900 x 2, or 13,800 Ω. But in reality it should be changed to 13,600 Ω because of the capacitance distributed as a result of the parasitic capacitor formed by the keyboard as a whole (between the assembly formed by the contact leaves and resistors, and the assembly formed by the shields and ground). Therefore, the theoretical formula for calculating the value of each resistor, $R = \sqrt[12]{2}$, must be corrected for. In practice, during manufacture it has been shown to be better to use fixed resistors with a definite calculation (numbered 5 to 40 on the diagram) and high degree of precision (0.5%). If, instead of resistors, we adopted potentiometers assembled as variable resistors, we would have to tune the instrument note by note, and if the other elements (R_{v1}, R_{v2}, R_{v3}, R_{v4}, C_{v1}, C_{v2}, etc.), R_c (the cathode resistor), R_{a1} and the tube itself contained flaws, we would end up with values from R_5 to R_{40} that were different from the norm. We would observe phenomena such as the following: The instrument would be **in tune** in one register but **out of tune** in another! This phenomenon would generally be caused by "leaks" in some mechanism of the oscillator ensemble. But which one would be at fault? The tube? The C_Vs? Potentiometers poorly insulated from the ground? Hence the need to use well-understood components: a 12AU7 oscillator tube, preferably one specially selected; tuning resistors R_5 to R_{40}, whose precision and quality are well-known; and very well-insulated C_{v1}, C_{v2}, C_{v3} and C_{v4} (ceramic capacitors, which are disastrous in low-frequency oscillators, should be avoided at all costs because of their significant losses).

(8) **Georges Jenny:** Perfecting Electronic Musical Instruments. French patents nos. 947,024 and 1,090,491.

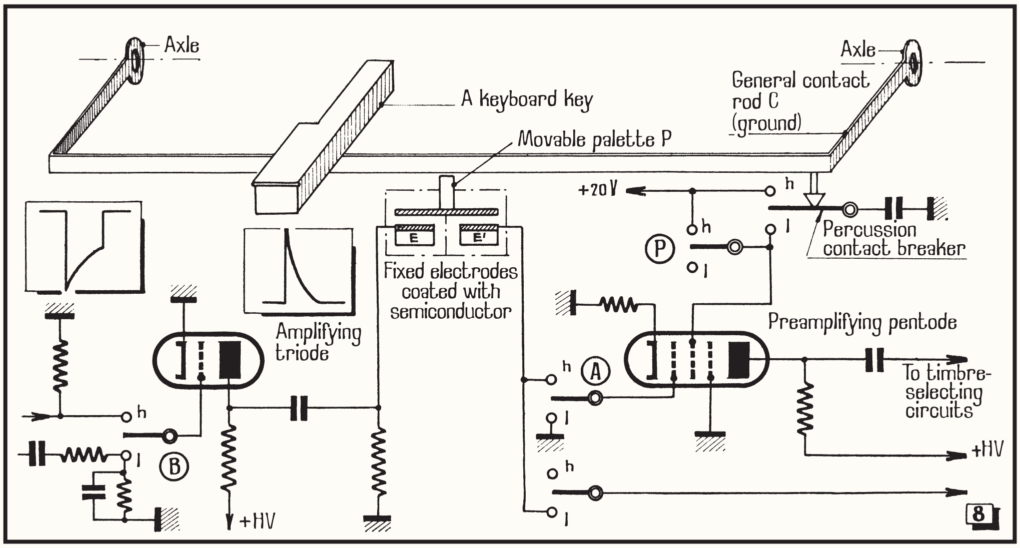

Fig. 8. — *Detail of circuits in the progressive attack controller, and circuits that create the percussion effect. This part of the schematic appears between the oscillator and the timbre circuits, which will be described later.*

kind because of two problems: first, the issue of transmitting a signal with a certain amplitude distortion, as happens in mechanical acoustic instruments during certain attacks (bowing by violinists or tonguing by saxophonists; see paragraphs IV and VIII of table II on page 11). And second, given that each depression and release of any keyboard key produces a corresponding movement of the progressive attack controller, the controller must be able to tolerate thousands of manipulations (or even *millions*, after a year of use) of varying degrees of roughness. Players must be able to strike it as they would a piano keyboard. What variable resistor or potentiometric device, even a wirewound one (which would be cumbersome), could stand up to such treatment?

Finally, considering the place where such a device *must* be inserted—that is, *before* the resonant circuits and amplifiers—the slightest crackle is amplified... Therefore, compressed graphite powder, flat potentiometers, etc. cannot be used.

But we will see in a later examination that there are other methods. For now, let us remain with this one, which has proved itself on the *Ondioline* and which for ten years has successfully worked in multiple instruments played for many hours each day. We should also note that the semiconductor used can easily be replaced if necessary.

The size of the electrodes, the flexibility of the ensemble and the quality of the semiconductor are all critical for the satisfactory result of a slight overvoltage on E when a key is struck vigorously—hence the unusual form of the transients $Av_{ap}1$, providing a sound quite similar to that made by a bow or tongue. When the player presses a key gradually, the sound emitted is not sudden and is played with a gradual progression satisfying to the ear.

The same can be said for the release: It becomes possible to play legato, semilegato, détaché and staccato. But this requires the careful use of certain parameters, or an "*Ondioline* method," at which we have not yet arrived.

Other methods of attack: plucked string sounds (guitar, harpsichord, etc.)

The progressive attack controller is sufficient in most cases—for example, to reproduce attacks made by bowed or wind instruments. Another mechanism was added to reproduce the sound of a plucked string. A "percussion reverser" switch is located under the contact rod C and controlled by it.

When no key is pressed, the rod is raised and at rest, as is the percussion reverser. The 0.5 µF capacitor is thus charged by high voltage. When any key on the keyboard is pressed, the general contact rod C is lowered, and the oscillation passes through the attack controller, leaves it and attacks the preamplifying pentode grid. But if the switch P is lowered, no oscillation appears on the plate, since the pentode grid is not yet powered. When the keyboard key arrives at the end of its path, the percussion reverser switches from the "resting" position to the "working" position, and the 0.5 µF capacitor discharges through the pentode grid. An oscillation appears instantly on the pentode plate but decays immediately following the same curve by which the 0.5 µF capacitor is discharged. The resulting effect sounds in every way like a plucked string (much more than the sound of a string struck by a hammer). Fast and slow discharges of the capacitor evoke strings that are long or short, tight or loose. Of course, all of this can be made adjustable by modifying the value of the high voltage, the capacitance C, the cathode resistor, etc. (9).

On the *Ondioline*, it is the switch P—whether connecting the grid directly to the high voltage or not—that activates or deactivates the percussion reverser under the keyboard.

NOTE: On the *Ondioline*, all of the timbre control switches are grouped into an 18-switch unit located on the upper portion of the instrument, under the keyboard (see photographs). The switches are labeled, from left to right, A, B, C, D, E, F, G, H, I, J, K, L, M, P, V_1, V_2 and W. We have already seen how to use switch B (which affects the form of the excitatory pulse) and switch P (plucked string sound). We will now examine the use of V_1, V_2 and W (automatic vibrato).

(9) **Georges Jenny:** French patent no. 895,822 of June 24, 1943.

CHAPTER THREE

The Complete Schematic

Before setting aside *excitation circuits* to talk about *resonant circuits*, which generate *formants*, we will describe how *automatic vibrato and tremolo* are produced, as we have already examined manual vibrato earlier.

Vibratos

A very low frequency oscillator (3 Hz to 10 Hz) emits an oscillation that, while not sinusoidal, correctly modulates our oscillator to an audible frequency, resulting in an automatic vibrato whose speed is modifiable using two adjustable potentiometers, P_v and P_w, located on the rear part of the upper chassis and adjusted during the refinement phase. The potentiometers are made parallel by switch W, resulting in one vibrato speed that is somewhat slow and another faster one. By convention, we have chosen a raised W to represent the slower speed.

Switches V_1 and V_2 control the *amplitude* of the vibrato, meaning the frequency's level of deviation. They simply use resistors of varying values connected in series to link a modulating tube to a modulated tube. The resistors are adjustable, are made up of potentiometers P_{v1} and P_{v2} and are also located on the rear part of the upper chassis.

At the resistors' output, the pattern of the voltage emitted by the vibrato tube is uneven. The filter, which is composed of a 1 MΩ resistor and a 100 nF capacitor, smooths the edges of the pulses before applying them to the cathodes of the primary 12AU7 oscillator tube. This is how the frequency of the voltage produced in this phase is modulated slightly.

Tremolos

If we lower switch D, the very low frequency pulses from the vibrato generator are directed toward the grid of the 6BA6 pentode. Since the pentode is part of the amplifying chain for the signal coming from the audible-frequency oscillator, the outgoing voltage is divided into the rhythm of the pulses. This results in a mandolin or banjo sound, as long as the oscillation rhythm is accelerated by the vibrato tube, an effect easily obtained by further reducing the value of the tube's grid resistor, a connection made automatically by certain "resting" contacts of V_1 and V_2.

Intermediary effects—true tremolos similar to those of the bandoneon—can be produced by filtering the vibrato signal before applying it to the amplifying pentode grid.

To be thorough, we note that a metal string stretched in front of the *Ondioline* keyboard, above a bar also made of metal, plays banjo, guitar and mandolin sounds that are less automatic and more human. The player plays as usual with the right hand and with the left hand taps the string at various speeds, establishing contact between the metal string and bar in that rhythm. This contact acts as a switch at the terminals of point M. Point M, as we know, plays percussive sounds. The same sound can be obtained in time with the fingers on the string, resulting in the highly realistic sound of not only a guitar or banjo, but castanets or a tom-tom as well.

But to properly understand how this seemingly magical operation is possible, we must first discuss the third part of the *Ondioline*, the resonators, which are given the same name as the parts found in acoustic speakers and which play the same role in both string and wind instruments.

Resonant circuits

At this point in our Ariadne's thread, we could almost assuredly leave any readers who might be interested in constructing an *Ondioline* to manage on their own. After sorting through a batch of old iron core conductors, 500 pF to 200 nF capacitors and providentially poorly labeled resistors, they may soon write to us saying they have discovered new timbres much better than those they may have heard from *Ondiolines* in the past during film intermissions or at a Jean Nohain show. And that may be true! Here is where the unassigned letters A, C, E, F, G, H, etc. will combine to form creative combinations that will stick in amateur musicians' minds alongside SNCF, RATP, CQFD and other well-known abbreviations.

If we wanted to use all the possible nuances of the sound palette, the alphabet would not be long enough to label all the switches that would be required. For that reason, we will only provide a starting point: a complete schematic of the timbre-control mechanism used in *Ondiolines* currently being manufactured. Experience shows us that the quality of the amplifier and speaker used at the end of the sound system strongly influence the result. Therefore, the value of the coil, or at least of the tuning capacitor, should be modified without hesitation to achieve a sufficiently convincing—or simply a sufficiently pleasant—timbre.

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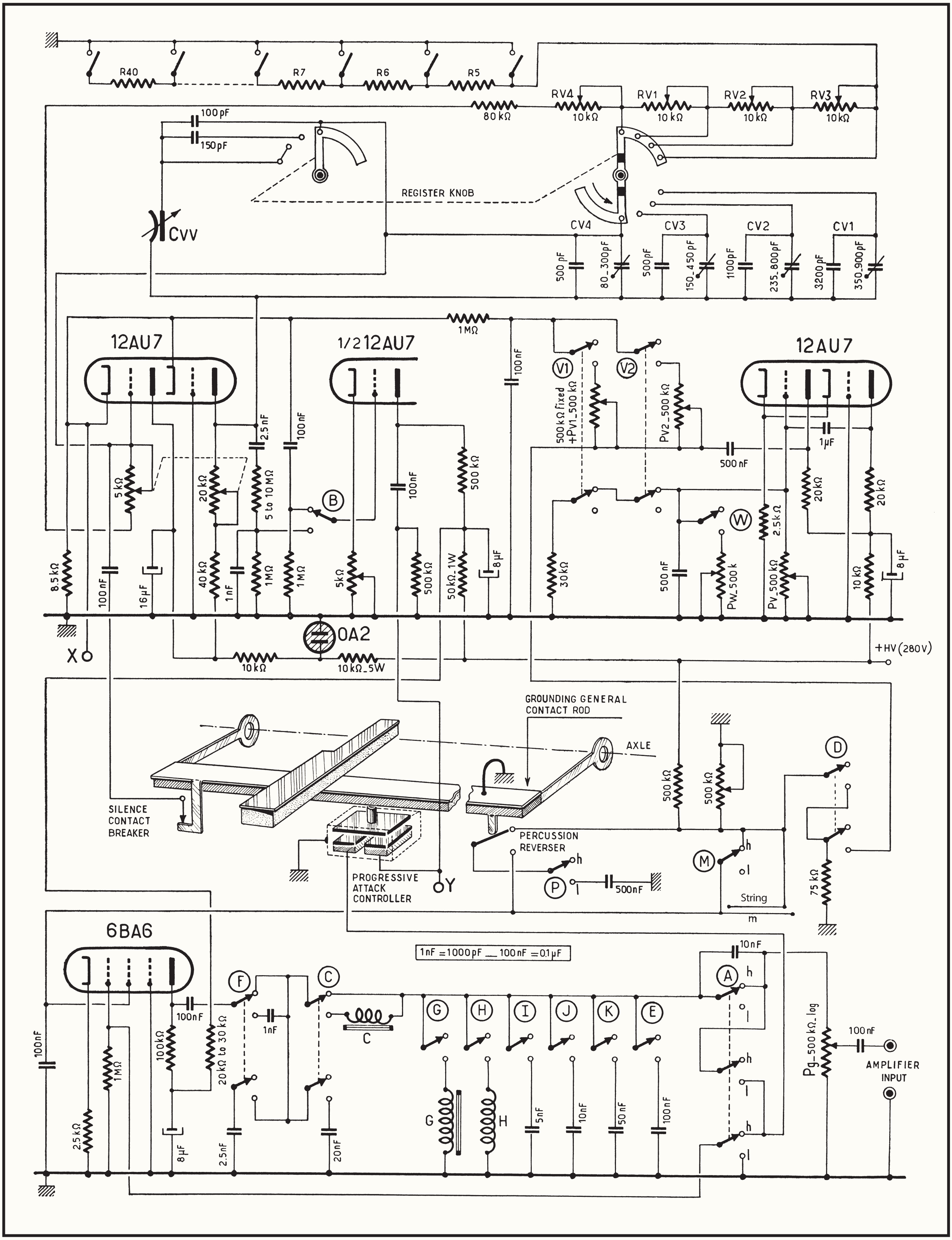
Fig. 9 (opposite page). — *Complete schematic of the upper module of the Ondioline (the lower module is made up of the power amplifier). The resistors R_5 to R_{40} normally provided with the keyboard are film type with a precision of* 0.5% *of threshold values equal to* 6,900 *and* 53,588 Ω. *Coils C, G and H are special parts that—like the progressive attack controller, the high-value adjustable capacitors and other special parts—are available on demand from the organisation "La Musique Electronique." The text provides information on the characteristics of the knee lever P_g. The resistance of all other potentiometers is linear. The terminals x and y are points of attachment arranged with the intent of allowing improvements later.*


R40
R7
R6
R5
RV4
RV1
RV2
RV3
80 kΩ
10 kΩ
100 pF
150 pF
REGISTER KNOB
CVV
CV4
CV3
CV2
CV1
500 pF
80_300pF
500pF
150_450 pF
1100pF
235_800pF
3200pF
350_900pF
12AU7
1/2 12AU7
12AU7
1MΩ
100nF
V1
V2
500 kΩ fixed +Pv1_500 kΩ
Pv2_500 kΩ
1μF
500 nF
2.5 nF
5 to 10 MΩ
5 kΩ
20 kΩ
500 kΩ
B
W
8.5 kΩ
100 nF
16μF
40 kΩ
1nF
1MΩ
5kΩ
50kΩ_1W
8μF
30 kΩ
Pw_500 k
2.5 kΩ
Pv_500 kΩ
10 kΩ
OA2
10 kΩ_5W
X
+HV (280V)
GROUNDING GENERAL CONTACT ROD
AXLE
SILENCE CONTACT BREAKER
PROGRESSIVE ATTACK CONTROLLER
PERCUSSION REVERSER
Y
P
500nF
h
l
M
String
m
D
75 kΩ
6BA6
1nF = 1000pF __ 100 nF = 0.1μF
10nF
F
C
A
G
H
I
J
K
E
100kΩ
20kΩ to 30 kΩ
2.5 kΩ
8μF
2.5nF
20nF
5nF
50nF
Pg_500 kΩ_log
AMPLIFIER INPUT

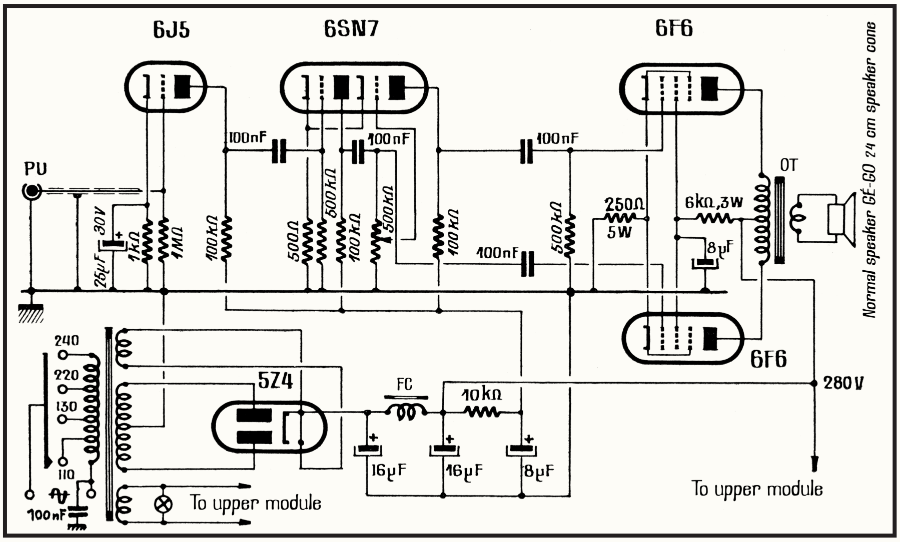


Fig. 10. — *This is the Ondioline's standard amplifier, the design of which is quite old. It is entirely possible to use your own amplifier, and it is likely that excellent results can be obtained using your high-fidelity systems. A bit of trial and error will undoubtedly be necessary to find the values for the parts in the upper module (schematic on page* 21*) necessary to produce each timbre.*

We have seen that switch B modifies the form of the excitation signal. The same is true for switch F, which when placed before the resonant circuits modifies the pattern of the signal by inserting a low-value capacitor. Switch C produces a different effect: Using a low-pass filter, it blunts the pulse before applying it to the resonators themselves, which are made up of coils G and H and capacitors I, J, K and E, which tune them to a determined frequency. It goes without saying that damping resonant circuits to a certain value using the same self-induction would provide different results depending on the section of iron used, the size of the air gap and the section of wire. Without changing the coil, it is still possible to play with the damping by connecting a resistor in parallel.

For certain instruments, like the oboe, it is better for the damping to be small, though it can and even should be fairly large for brass instruments. The violin timbre is produced by lowering switches A and F instead of by using filters.

We stress here that the volume of the baffle and the characteristics of the materials used have an enormous effect on the resulting timbre. This is especially true for the violin. The sound of a muted violin can be produced by inserting coil H but using a 10 nF capacitor in series (a quite critical value).

A detailed analysis of each timbre and an explanation of why each circuit was chosen would turn this monograph into a small encyclopedia and would be useless for anyone who does not have some experience with it themselves.

General schematic

Now that we have discussed the principal elements of the schematic, we can consider it freely, focusing only on the parts not yet described in order to explain their role and to provide some practical tips on constructing them.

EXPRESSION WITH THE KNEE LEVER.

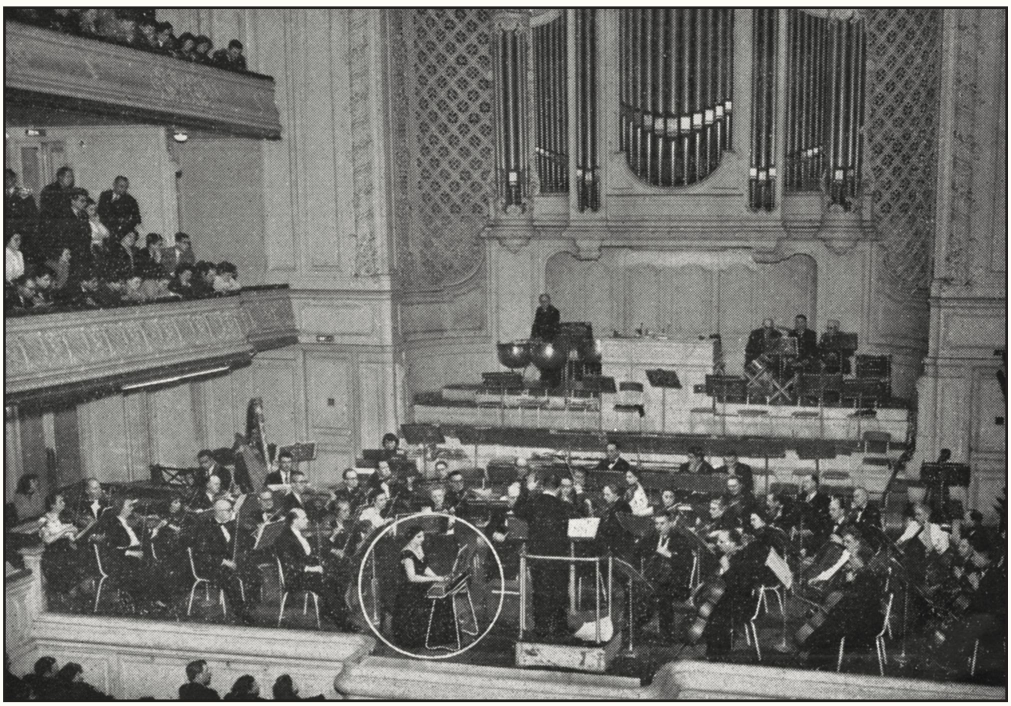
In the *Ondioline*, the right hand normally plays the keyboard, chooses the notes, plays vibrato by laterally moving the entire keyboard, and is partially responsible for determining the method of attack and the intensity of the playing, since the amplitude of the signal sent to the output amplifier is proportional to the pressure of the finger on the key.

At the same time, the amplitude can be tempered by a potentiometer P_g, which is connected to the output terminals on the upper chassis of the *Ondioline*, before the shielded wire running to the amplifier.

In order for the potentiometer to be operated easily by the left hand or the knee, it is controlled by a metal rod called the *knee lever*, which transmits its movement through a notched section and a gearwheel. The potentiometer is moved along its full path by rotating the knee lever 90°.

In practice, the sounds of a bow stroke or of tonguing unique to the instrument whose voice the player seeks to replicate are produced by carefully combining two techniques: the progressive or sudden action of a finger on a key, and the movement of the knee lever by a knee or by the left hand. We cannot go into detail here about mu-

Salle Gaveau, Geneviève Robert, RTF soloist, ondiolinist accompanied by a large symphony orchestra, "Taj Mahal," concerto by Darius Cittanova, written specially for Ondioline and orchestra.



sical playing techniques, but we strongly advise would-be *Ondioline*-builders to seek out written lessons for the instrument (1).

The potentiometer P_g must be a special model, as it has an extremely difficult job. An ordinary model will last no longer than a few days, and as irritating as it is, we must admit that we have searched in vain among French-made models for one that is robust enough. For our mass manufacturing, we have resorted to importing parts, such as the *Allen Bradley* model (distributed by *Rocke International*) and the *Vitrohm* model (by *Ets Frankel*, with delivery times that vary widely).

SILENCE CONTACT BREAKER. In the general schematic, under the left portion of the grounding contact rod, in addition to the progressive attack controller and the percussion reverser, we see another contact that acts as a simple contact breaker. We have called this the "silence contact breaker". Its role is as follows: When at rest, the general contact rod is pressed against all the key springs, and the oscillator renders the frequency of the highest note on the keyboard (G). Although the attack controller's movable electrode is not depressed, the capacitance between the fixed electrodes is non-zero, and a fraction of the signal arrives at the potentiometer P_g. If the potentiometer is not "resting," the speaker will reproduce the signal, which, though very weak, is bothersome. That is why the general contact rod, when at rest, uses the silence contact breaker to short-circuit the oscillator. The oscillator is enabled once the player presses any key on the keyboard, even lightly.

SWITCH A.—Switch A "skips" the preamplifying 6BA6 pentode placed after the progressive attack controller when the player wishes to eliminate the distortion (whether desired or not) introduced by the pentode.

OTHER SWITCHES.— For informational purposes, at right is a list of some of the timbres that can be played on an *Ondioline*, and the switches that should be lowered to play them. Readers will notice that the switches L and M are missing in both the schematic and the list, though they appear in some photographs. These switches were intended for future additions. They are included in the professional *Ondioline* model, but we did not want to overly complicate the general schematic or this brief description. The *Ondioline* currently being described is the model used by Radiodiffusion Française, Radio Luxembourg (Radio Théâtre and Radio Circus) and some music conservatories, including those in Lyon and Dakar.

TABLE III — LIST OF TIMBRES

Timbre	Lower these switches	Register
Violin	AF or AFI	3
Muted violin	AFH or AFHV$_2$W	4
Cello	AF or AFI or AFV$_1$	1
Alto saxophone	CGJ or CGIJ	3
Tenor saxophone	CGK or GJ	2
Jazz trumpet	GIJ	3
Cavalry trumpet	FGIJ	3
Oboe	FHIJ or FHK	3
Brass hunting horn	EGK or CGKV$_2$ or GCE	2
French horn	CK	2
Bassoon	CGK or EGK	1
Flute	GJ or BGIJ	3 or 4
Bugle	CGJ	1 or 2
Recorder	GJ or GI	4
Mandolin	DFH or DH	3 or 4
Mandolin with string	FHM or HM	3 or 4
Banjo	DFGIJ	3
Banjo with string	FGIJM	3
Bagpipes (by holding the note an octave lower)	FG or FGHI	3
	BCEV$_2$W or ABCIV$_2$W or	1 or 2
	BCHKV$_2$W or BCEHV$_2$W or	3
Theater organ	BHKV$_2$W or FGHV$_2$W or	2 or 3
	BGHIJV$_2$W or GIJV$_2$W or	2 or 3
	BV$_2$W or BEHV$_2$W	2 or 3
Clarinet	B or BGI	2 or 3
Bandoneon	A or M	3
Flamenco guitar	FGHP	1 or 2
Soft guitar	CGIP	1 or 2
Hawaiian guitar	GIPV$_2$W	2 or 3
Harpsichord	FGHP or HP	3
Zither	FGIPV$_1$	3
Castanets (by tapping on the string and without using the keyboard)	FGP	
Bongos (same method as above, by alternating the E)	BCEFGIJKP	
Trombone	CJF or BGIJK	2
Contrabass bugle (helicon)	BCE	1
Double bass	ABCEF	1

VERY IMPORTANT NOTE: Playing the Ondioline correctly, especially the attacks (in other words, mastering the expressive keyboard), requires at least one or two months of study by the player, in addition to any prior knowledge (of the piano or another instrument).

This technique is acquired through special, essential exercises. Ondioline players who fail to understand the need to develop certain reflexes through daily, extremely simple exercises will only be able to coax theater organ or electronic music sounds out of the instrument, which pale in comparison to the refinement and variety of expressions possible with the Ondioline. When used properly, the Ondioline merits the trust and interest expressed in it in writing by masters such as Arthur Honegger, Landowsky, Delannoy, Darius Milhaud, Georges Auric, J. Kosma, Jean Marion, Guy Bernard de La Pierre, Jean Ledrut, José Padillat, Jean-Jacques Grunenwald, Henry Sauguet and Philippe Parès.

Oscillograms

It would be interesting to compare oscillograms of primary or-

(1) **Beginner's Handbook for Ondiolinists.** By **G. Jenny**. This handbook contains very simple exercises for amateurs and will be "illustrated" with a microgroove record that demonstrates the instrument's expressive and timbral possibilities. (Publisher: **Forgotten Futures**)

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The Ondioline can be played solo, as it offers a wide selection of timbres, including the violin, mandolin, flute and oboe. This young virtuoso goes so far as to accompany herself on the piano.

★

chestral instruments or of the human voice to oscillograms of some of the timbres of the *Ondioline*. This should be done by comparing waveforms observed on the display of a harmonic analyzer, like the *Pimonof* system used at the Central Telecommunications Laboratory. Through the hard work of Messrs. *Pimonof and Chavasse*, directors of the *National Telecommunications Study Center*, this work has already begun. We hope to be able to add to it one day and possibly even publish the results in a more thorough paper than this one.

Patents

Some parts of the *Ondioline* (the transposing oscillator and its tuning mechanism, the percussion mechanism, the progressive attack keyboard) are patented and therefore cannot be reproduced for commercial purposes. *However, we are happy to authorize individual constructors to draw inspiration from them, exclusively for their own personal use.* But we beg any would-be constructors *not to slavishly copy the exterior appearance of the Ondioline*, which is a patented model, in order to avoid any potential confusion between amateur-built models and commercial ones.

With the exception of these restrictions, we believe we can strongly pique the interest of *Ondioline*-playing technicians by noting that all special parts, including the keyboard, and any missing stock parts can be found in stores. (2) Using these parts, anyone is free to construct their own invention, changing the appearance of the instrument or the arrangement of certain expression mechanisms or controls as desired. New timbres and original methods of expression can be tried.

We are happy to spread the love of electronic music that we feel so strongly ourselves. We are sure that electronic music will follow the same path as broadcasting and radio did in their early days; in other words, intelligent amateurs will spur on the field, which will eventually grow into a full-fledged industry. Conducting numerous experiments and sharing results will inevitably help accelerate progress, here and elsewhere.

Anyone with the time and inclination should not hesitate to construct an electronic musical instrument themselves. As long as they have a good ear or a musician friend to help them at the beginning, they, too, can experience the delight of having constructed their own musical instrument and the personal joy of playing music.

The *Ondioline* is used in both popular music and by some classical ensembles. There is even an *Ondioline* trio, the Trio d'Ondes de Paris, composed of Ms. *Geneviève Robert* and Messrs. *Cittanova* and *Mérer*, who perform on Radiodiffusion France, playing modern works written specially for electronic music as well as very old works: *Bach, Vivaldi*, etc... Indeed, that is one of the exciting aspects of electronic lutherie: the ability to resurrect old, nearly abandoned timbres in modern times. Even if the recreated sounds are slightly different from the way the instruments would have sounded at the time, no one can call it sacrilege, since *Bach* is played today on violins, flutes and trumpets that differ noticeably from instruments of his era. Or we need simply cite the tuning A, which at 435 Hz today has risen considerably over the past few centuries. *Bach's* "Suite in D", for example, is more than a whole step higher than its original key. If *Bach* were alive today, he would not recognize his own works!

Let us conclude by observing that there is already a club for fans of electronic music, the *Friends of Electronic Music Association*, whose mission is to promote the development of this new branch of art. Anyone who is interested is invited to join the club. (3) This is a way for local and even regional like minds to discuss the subject, and to contribute to the progress we mentioned above.

All that remains now is for us to provide some tips on the actual construction of the instrument, and instruction on how to refine it.

(2) **Ondioline Establishments**, 190 Faubourg Saint-Denis, Paris (10th). Tel. BOT. 74-03.

(3) For more information, write to **Georges Jenny**, Chemin du Paradis, near Bar-sur-Loup (A.- M.). Include a stamp for the reply.

CHAPTER FOUR

Tips on Assembly

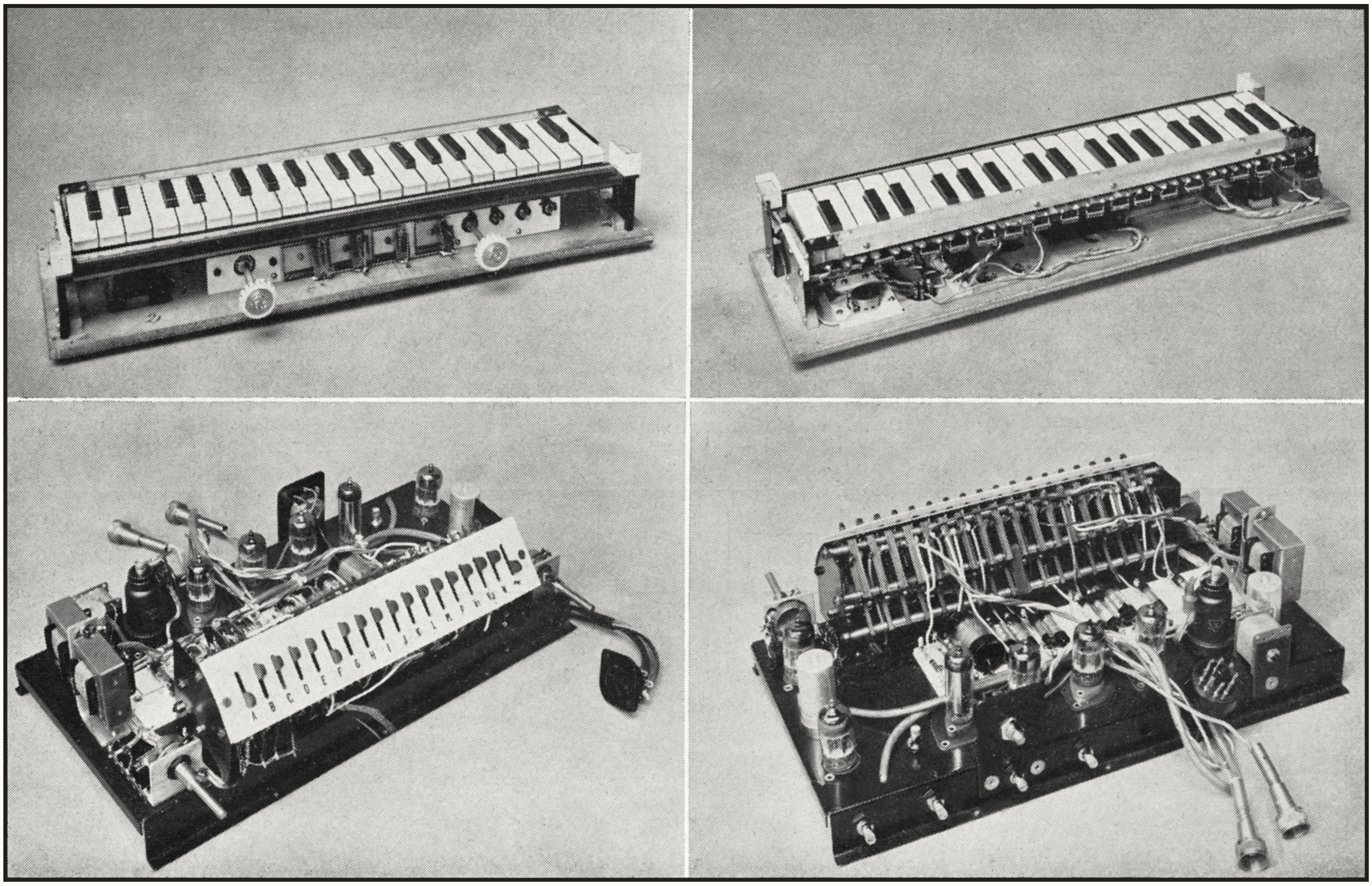
General precautions

Before describing how to build the *Ondioline* (assembly, wiring, refinement), we must first touch on some general principles that should be kept in mind during construction.

The important things to heed are the quality of the insulation and the placement of the mechanisms, which must be arranged in a way that reduces parasitic capacitance as much as possible in the oscillation circuits, so that there is next to no induction between certain stages, and nearly no interaction between certain circuits.

Circuits of the 12AU7 tube, the audible-frequency oscillator, should be particularly well insulated. Even the slightest loss or leak at low frequency or in continuous current will have a catastrophic effect here (ceramic capacitors, in particular, should be avoided, as they are not always satisfactory at low frequency): The instrument will be out of tune on the low end of the keyboard and will be unevenly tuned depending on the register. For the 12AU7 tube, use a high-frequency, Bakelite noval base. Use mica as the dielectric for backup capacitors, similar to the adjustable tuning capacitors C_{v1}, C_{v2}, C_{v3} and C_{v4}.

Use Plexiglas for the plank supporting the 36 tuning resistors; avoid certain Bakelite ones, even the ones labeled “high-frequency.” Any resistor below 5,000 MΩ inserted between grid 1 and plate 2 of the first 12AU7, or between plate 2 and the ground, will cause the instrument to fall out of tune, especially the lower notes. And excessive parasitic capacitance between grid 1 and the ground will narrow the tuning of the higher notes. The purpose of the adjustable resistors R_{v1}, R_{v2}, R_{v3} and R_{v4} is to remedy this latter flaw. But excessive parasitic capacitance cannot be corrected. That is why a shielded wire cannot be used in



Top: The Ondioline keyboard. The two knobs control transposition and tuning. In the rear view, we see the Plexiglas plank that supports the key springs and, soldered between the row of leaves, the resistors that make up the chain R_{g2}. Bottom: Front and rear views of the electronic module showing the timbre and special effects switches. Details on the arrangement of the mechanisms, assembly, wiring and tuning of the Ondioline are provided later in this paper.

these parts of the *Ondioline*. Even the coaxial cable has too much capacitance. The only circuits that should be shielded are the ones we list below.

This first 12AU7 tube should be selected carefully; choose types with properties similar to those prescribed by the manufacturer, especially in regards to internal resistance and insulation between electrodes.

The panel supporting the tuning and transposition parts (C_{v1}, C_{v2}, C_{v3} and C_{v4}; R_{v1}, R_{v2}, R_{v3} and R_{v4}; the dual tuning potentiometer, the register knob's three-disc switch) should be cut into high-quality insulation—Plexiglas, for example. The register knob's disc switch should also be perfectly insulated from the contact points. We recommend silicone-coated steatite insulation by Chambaut. The silence contact breaker circuit, similarly, must be perfectly insulated.

With the exception of these precautions, arrange the oscillator circuit mechanisms however is most logical from a functional perspective. Do not attempt to reduce the values of the power supply's decoupling capacitors, even if the values sometimes appear to be unnecessarily high.

Modules of the Ondioline

For the sake of convenience, in the description, we will designate the keyboard module by the letter A; the electronic module, including the oscillators, preamplifying circuits and timbre switches, by the letter B; and the amplifier by the letter C. Any comments regarding the amplifier are pointless; all we will say is that it is entirely possible to replace it with any good push-pull amplifier, of which *Toute la Radio* has published a good many diagrams. However, avoid correction circuits and feedback circuits (1).

The keyboard module

Module A is the most difficult for amateurs to build. Extremely advanced amateurs may attempt it; if they do, adjustment and refinement will be a simple matter of thought and logic.

We have been hesitant to write a complete set of refinement instructions aimed at general amateur builders, as such instructions would take up many pages of this manual. In all honesty, we think it best if the company we have entrusted with the selling of *Ondioline* parts assembled and refined this highly delicate unit.

However, we will describe the unit briefly. The module consists of the keyboard itself, with tuning resistors for each note and a general contact rod. The keyboard is mounted on supporting leaf springs that allow it to oscillate horizontally, as we saw in previous pages. Under the rod are percussion contacts, silence contacts and the progressive attack controller.

Openings located under the connector board supporting the keyboard unit grant users access to adjustment screws for each part. However, they should only have to access the screws occasionally, since the screws should have been adjusted permanently by the manufacturer to fit a standard B chassis. The manual vibrato capacitor located to the left of the keyboard is also permanently adjusted.

In front of the keyboard is stretched a metal string used to play banjo, tom-tom and castanet sounds, among others. Under the black Bakelite board supporting the string are the tuning and transposing mechanisms mounted on an insulating plate. When facing the keyboard, we see, from left to right: the register knob; the four adjustable pretuning capacitors C_{v1}, C_{v2}, C_{v3} and C_{v4}; the general tuning knob; and the three corrective potentiometers for the high notes, R_{v1}, R_{v2} and R_{v3}. The only axles that protrude are those for the register knob and for the general tuning knob.

All connections run to the back

(1) *Editor's note:* You may disagree with the author here. The role of a booster amplifier is, in principle, to transform low voltage from previous stages into strong current while changing its form as little as possible. However, it is highly likely that the booster amplifier, the output transformer, the speaker and the body of commercial *Ondiolines* play a major role in the quality of timbre produced. That is why we must warn readers who wish to use an existing amplifier that they may need to experiment with the values of certain elements responsible for timbres. Under these conditions, we recommend keeping the feedback loop of the booster amplifier. This can only improve the fidelity of sounds reproduced, given the well-understood action of feedback on the damping of the movable coil. But it might be necessary to create a stage outside of the feedback loop but between the *Ondioline* and the amplifier. Distortions that seem necessary to be able to reproduce certain timbres would appear in this stage. As you can see, technicians wishing to explore this question have plenty to experiment with!

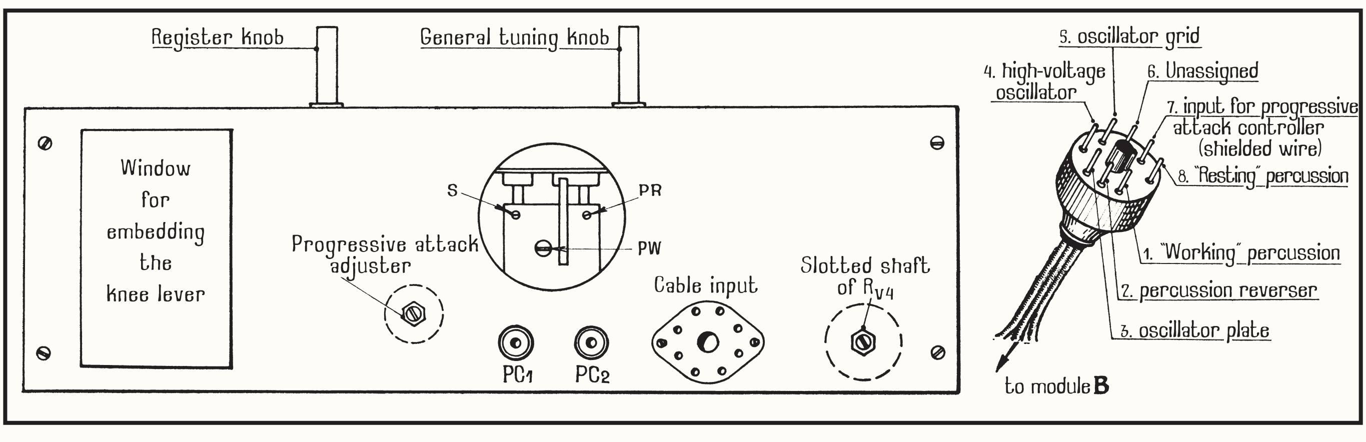


Fig. 11. — *View of module A, the keyboard module, from underneath. Legend: PC_1: Coaxial output jack for the progressive attack controller; PC_2: Coaxial jack for input to the knee lever potentiometer; S: Adjustment screw for the silence contact breaker; PR: "Resting" percussion contact adjustment screw; PW: "Working" percussion contact adjustment screw. On the right, wires from module B (the electronic module) are distributed by the octal socket, which connects to the base of module A.*

of the keyboard unit, ending at a plug attachment system composed of two male coaxial plugs and one 8-pin molded Bakelite base. Additional mechanisms connect to module B. You should ensure that the 8-pin socket is of high quality (molded melamine formaldehyde from the original manufacturer), since grid and plate connections from the oscillator attach to it.

Module A is wired in such a way as to prevent any signals leaking from the progressive attack controller. Leaks may be tolerated upstream of the controller; that is fortunate, since an increase in parasitic capacitance should be avoided at all costs at the oscillator stage. After leaving the progressive attack controller, the signal does not return to the keyboard module unless it is to the knee lever potentiometer, provided the builder has chosen to install the potentiometer in module A, an optional step. The potentiometer input is connected to a coaxial jack. The knee lever input circuits, the potentiometer itself and the output to the pickup portion of the low-frequency amplifier should be properly insulated using continuous shielding.

The electronic module

Here, amateur builders have great latitude in how they arrange the mechanisms, and which parts they choose to use, including the tubes (except for the oscillator tube, which must be a 12AU7).

In general, it is best to place module B as close as possible to the keyboard module to prevent parasitic induction and capacitance along the grid and plate wires of the 12AU7. A length of 30 cm each is acceptable for the wires between the tube base and the octal socket connecting to the keyboard. The tubes and switches in the B chassis can be rearranged as permitted by the wire length and if upstream and downstream mechanisms are kept electrically separated from the progressive attack controller.

How should the timbre switches be arranged? In the current arrangement, they run in alphabetical order from left to right. Over the last ten years, some have been added, removed and swapped, which is why their placement on the instrument differs from the placement that seems logical given the schematic. Constructors are slaves to the past, as composers and musicians resist the use of new names, which would require all music to be rewritten and new habits to be learned. Of course, this placement is not required for beginner constructors, who have an opportunity to act independently and use their imagination. Proper precautions should be taken planning the placement of additional switches from the start, for nothing is more exciting than searching for new timbres.

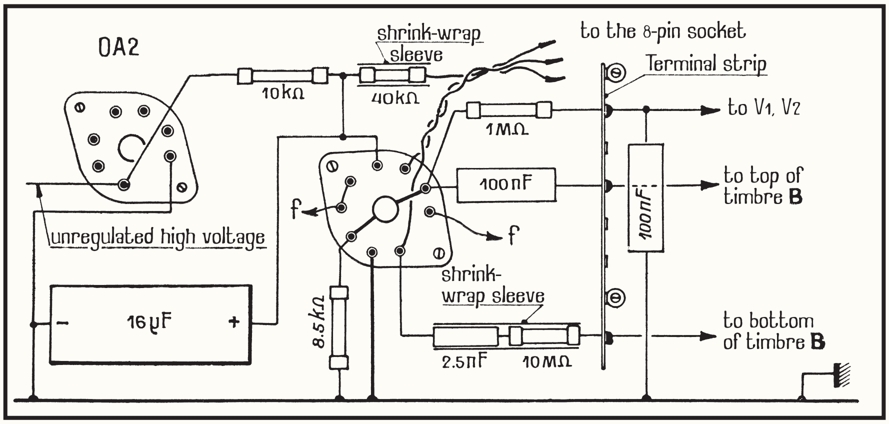


Fig. 12. — *The author recommends following this wiring plan for the audible-frequency oscillator section. Connections are sensitive to low-frequency leaks and losses at the terminal strip, which is not always perfectly insulated, or is only insulated after high-value resistors.*

Let us recall the logic behind our codification: As we have seen, switches A, B, C and F determine the form of the excitation signal before it attacks the formant-generating circuits. Consequently, any new switch that activates a mechanism modifying the form of the signal before it is applied to formant circuits G, H, I, J, K or E should be indexed using a code derived from the letters A, B, C and F—for example, A_1, A_2, etc. for A-type pulses; B_2, B_3, etc. for nearly rectangular signals; C_1, C_2, etc. for sinusoidal excitation signals, and so on. The same conventions apply to formants: Additional coils can be activated by keys G_1 and G_2 or H_1 and H_2, depending on the sound. Switches for additional capacitors will be named with the letters I, J, K and E. By adopting this standard used in commercial instruments, however imperfect, you will make it easier for other ondiolinists to understand the instrument you build.

Now let us discuss the oscillator portion of our module B. We believe it useful to repeat the schematic of the recommended wiring. By following this plan, readers will avoid tuning and transposing surprises later. Note that the connections (well-insulated, flexible wire) for grid 1 and plate 2 run directly to the octal socket without touching the terminal strip, a potential source of leaks. A 2.5 nF paper or mica capacitor and a 10 MΩ resistor also leave from plate 2 and are soldered end to end under a shrink-wrap sleeve. It should be noted that the timbre B decoupling elements are not shown in the drawing.

A brief aside regarding the authentic switch A. If you have difficulty procuring the two-direction, three-loop switch required for this portion, divide it into two or three parts with individual controls. This results in additional combinations.

Another comment about possible places to procure timbre switches: For financial reasons (high price) and ethical reasons (homemade *Ondiolines* may resemble commercial *Ondiolines* too closely), the organization *La Musique Électronique* cannot sell the switches currently used in commercial models separately. But the parts required do not need to be special ones. The most difficult step will be finding parts with a good, clean contact that are not noisy. That said, any good-quality, two-direction radio-type switch will serve perfectly, as will push-button keyboards that are so popular right now, if they are modified as needed to make them as quiet as possible. Another solution consists of using separate discs in traditional rotary switches and adding a small lever to them that is interdependent with the rotor in the disc design. You can then attach all of the discs using cross-braced, threaded rods.

Finally, we should mention the small *Jeanrenaud* switch, simple, robust and inexpensive, as well as a model found at “Pigeon

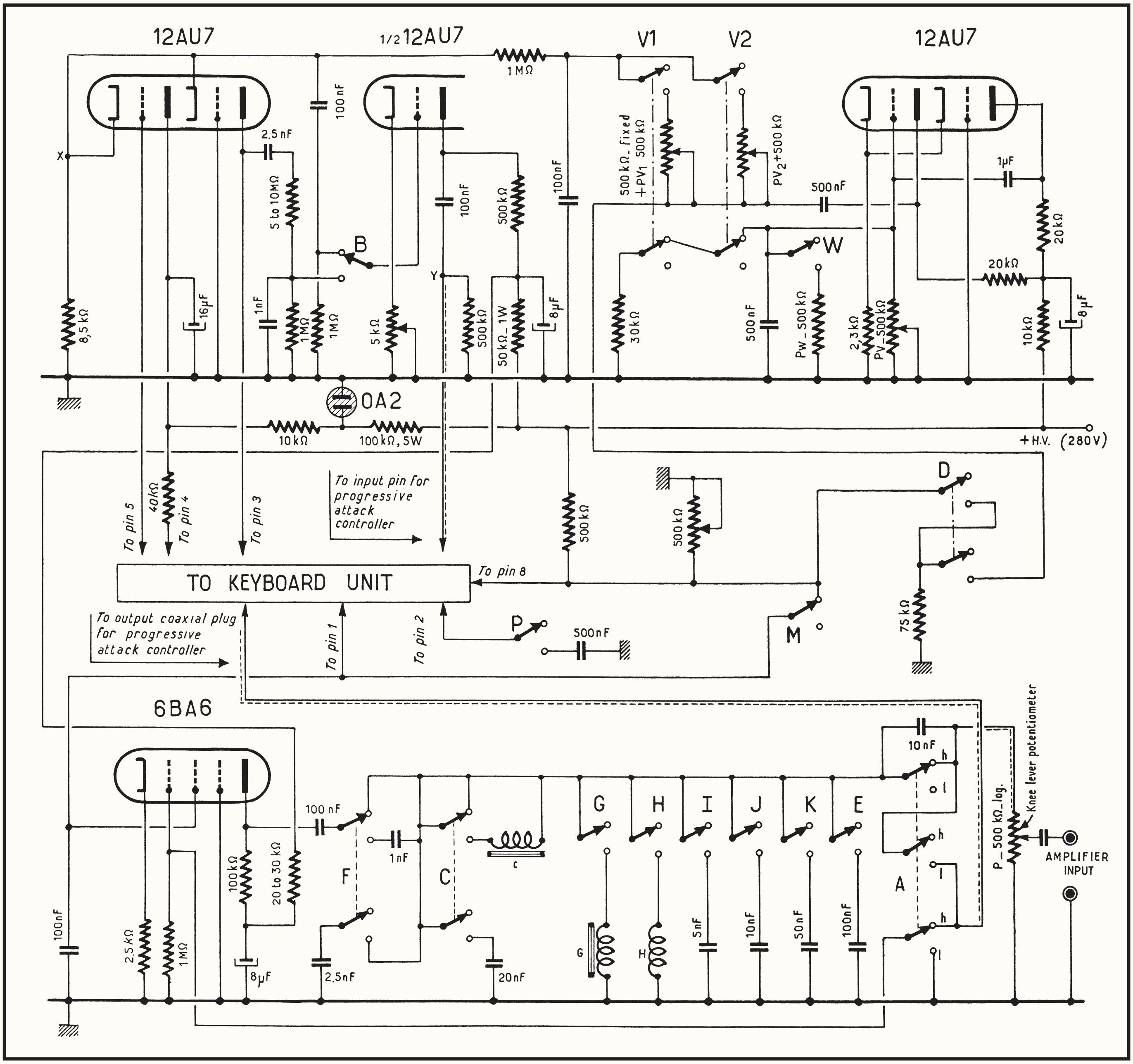


Fig. 13. — COMPLETE SCHEMATIC OF MODULE B

Voyageur", which probably came from *Becuwe's* and has the advantage of having a lever already attached. Since their movement is too abrupt, it would be good to take a pair of needle nose pliers and curve the leaf spring slightly to make the movement very gentle.

Wiring for the switches

Only wires leading to A switches, and those running to or from the knee lever potentiometer should be shielded. Connections running from the audible-frequency 12AU7 oscillator cathode to the half-12AU7 grid using switch B should be as short as possible and should, under no circumstances, lie less than 3 cm away from connections running to A, C and the other timbres F and E. But it is impossible to shield the cathode-to-grid connection, since the slight capacitance introduced would alter the quality of the transposition.

If possible, it would be good to shield the timbre B switch using two small pieces of simple foil to protect it from static from switches A and C.

The placement of coils C, G and H is not critical. Of course, the best arrangement, if possible, would be to place them near their respective switches. However, if you are planning to use a separate power supply for module B, be sure to account for the 50 Hz ripple coming from the power transformer, which when concentrated by windings and coils C, G and H could drastically alter the sounds produced by the *Ondioline*

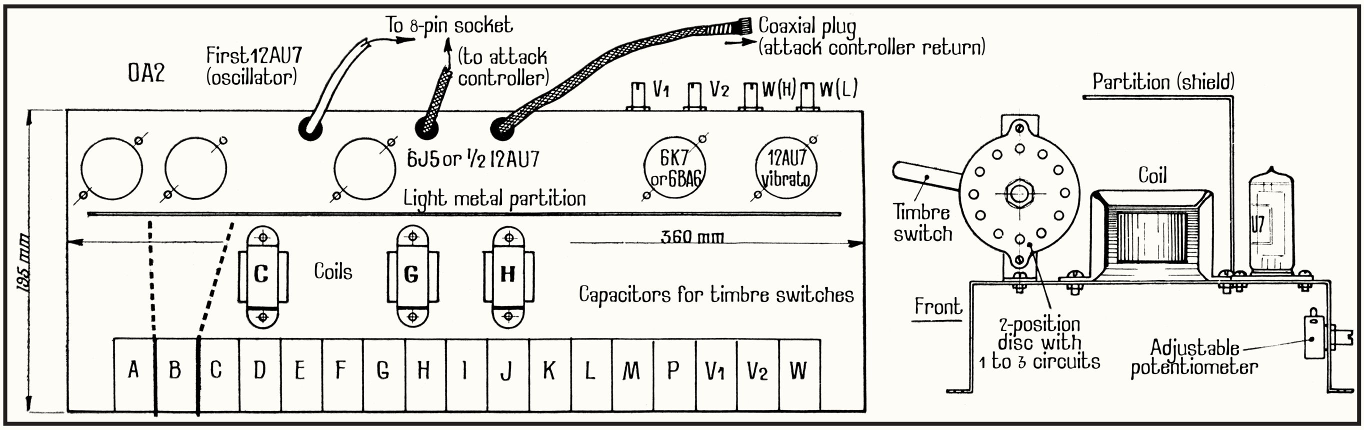


Fig. 14. — *Layout of module B with connections to module A (keyboard module) marked in words/with an octal socket (*7 *of whose pins are used) and a PCL coaxial plug for the progressive attack controller output. The second coaxial plug for module A, shown only in figure* 11 *and not here, connects the shielded input of the knee lever potentiometer to the low-frequency amplifier. The potentiometer's output runs through a shielded cord with banana plugs.*

or even incorporate them in the form of an unpleasant hum. It is better to distance the transformer coils and experiment to find the best way to orient them. If you are having trouble, shield the coil connections and, if necessary, the coils themselves.

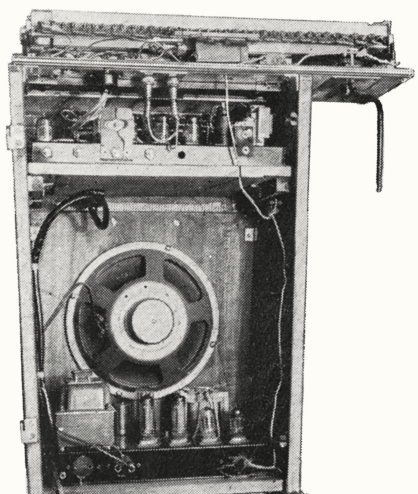
Tubes

We reiterate that it is best to use a 12AU7 for the audible-frequency oscillator tube. The vibrato oscillator tube could be a 6SN7 if you do not have any noval or miniature tubes at hand. The half-12AU7 connector tube can be replaced with a half-6SN7 or 6J5 tube. The 6BA6 may be called a 6SK7 or even a 6J7. The 0A2 voltage regulator tube is not essential; we only began using them recently in commercial *Ondiolines*. Tuning will be slightly less stable, but it will still be better than the tuning stability of a violin and can always be corrected using the general tuning knob. In short, the 0A2 should be used if that part is exposed to rapid voltage changes.

The arrangement of mechanisms in module B

Figure 14 depicts an example of a fairly logical arrangement of parts in the B chassis. This arrangement takes into consideration both the current state of the *Ondioline* and possible future refinements.

The 12AU7 audible-frequency oscillator tube base was placed nearly opposite the timbre B control. That way, connections running to it do not interfere with C, F, G, etc. connections. The return of the grid from the half-12AU7 tube will reach the tube without the partitioning that would be required to prevent radiation from reaching C. The return of the progressive attack controller coming from the keyboard should end at timbre A and would be made of a shielded wire directly from the female coaxial plug to A—naturally, with no interconnecting terminal strip along the way. From there, the shielded wire runs to the 6J7 or 6BA6 grid. From the 6J7 plate, shielded wire returns to timbre F. After that, regular wire can be used for other timbre circuits, since shielding is not necessary.



Rear view of an industrially produced Ondioline.

A simple light partition made of foil, for example, at the height of the highest mechanism (the switch or the 6J7) will provide the protection from static necessary between the timbre and flexible wire running through the octal socket to module A. This partitioning may also prove useful if more circuits are added later.

The tubes are lined up along the rear so as to be easily accessible simply by opening a back panel on the instrument. For the same reason, the potentiometers that control vibrato should be placed in the rear recess of the chassis (fig. 14, right).

Vibrato capacitors and resistors may be placed under the chassis, near the corresponding 12AU7 tube. The length of the connections to V_1, V_2 and W is unimportant, as is the length of the wires running to M, P and D.

Switch L is currently unassigned. If switches are added, it is best to place them as follows:

1) Between C and D (modifies excitation signals)

2) Between D and E (modifies mandolin rhythm)

3) After G and H (add more coils)

4) After K (add more capacitors and resistors)

5) After M and P (modifies the guitar voice: attacks are gentler, decay is longer or shorter, etc.)

But is it reasonable for us to speak of additional timbres when the *Ondioline* already plays all timbres?

Let us stop here then. We believe that success is assured for amateur constructors, especially after they have read the next and final chapter, on refinement.

CHAPTER FIVE

Refinement

Verifying voltage

On page 21, we provided the general schematic of the *Ondioline*. Depending on the power supply used, fairly substantial variations in the average voltages listed below (given only for informational purposes) are tolerable.

After activating the 0A2 tube, the high voltage should be around 150 V. (Obviously, the tube should be turned on.) If this is not the case, check that the voltage upstream of the 10 kΩ, 5 W resistor is greater than 185 V when the 0A2 regulator tube is removed. This resistor limits current in the tube to no more than 30 mA. Do not give in to the temptation to remove the other 10 kΩ resistor placed downstream of the 0A2 tube, as this could trigger relaxation oscillations between the tube and the 16 μF capacitor.

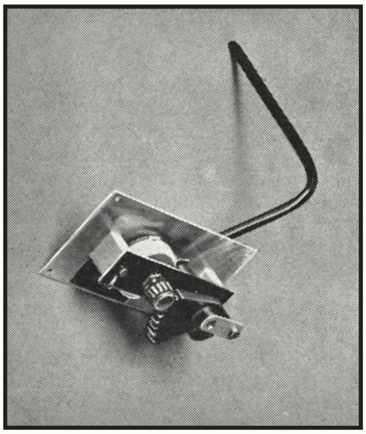
The cathode voltage of the 12AU7 tube varies from 10 to 15 V, depending on whether the tube oscillates. The cathode voltage of the 6K7 (or 6BA6) tube is measured with M and P selectors raised. The same goes for the grid voltage, which is modified by adjusting the 500 kΩ variable branch of the bridge that powers the grid. If P is lowered, the bridge no longer flows, and the voltage will rise to about 40 V.

Dynamic control step-by-step

Refining the *Ondioline* requires the use of both the ear and an electronic voltmeter, supplemented, if possible, by an oscilloscope. Listen as you check visually, but listen without paying too much attention to what you hear at the start.

We will use the electronic voltmeter to measure the low-frequency voltage at various points. First, check the 6J5 (or half-12AU7) grid: Place the register knob at the highest register (IV) and the general tuning knob at the center point, and raise all of the timbre switches. Play middle C on the keyboard. You should get a reading of about 5 V. Lower switch B: The voltage should fall to about 0.2 V. If this voltage is too low, lower the resistance from 10 MΩ to 7 MΩ, or even 5 MΩ, but no less. Ensure that the polarization voltage of the 6J5 is optimal.

Those with an oscilloscope can perform further refinements as follows: observe the waveform at the triode plate or, equivalently, after the 100 nF capacitor for the connector between the 6J5 plate and the progressive attack controller input. The waveform you see with B raised should be free of bossage (fig. 15*a* and 15*b*).



Knee lever potentiometer control

Otherwise, all timbres will be imbued with a distinctive “hollow” sound. String timbres, in particular, all use the tube, regardless of the formant circuits introduced later, so this is a very important matter. The waveform obtained with B lowered is less critical (fig. 15*c* and 15*d*).

On the 6J5 plate, we will measure a voltage of about 21 V with B lifted and 2.5 V with B lowered.

Next, connect the tube voltmeter to the place where the female coaxial plug connects the progressive attack controller output to the B chassis (so the 6J7 circuits, formant circuits and knee lever circuits are disconnected). We can then verify separately the relationship between the voltage at the beginning and end of the progressive attack controller’s depression. Since module A comes fully wired and adjusted by the manufacturer, all that needs to be done is to verify that the adjustments are correct.

To do this, play middle C on the keyboard in register IV, pressing the key all the way down. With B raised, the electronic voltmeter should read about 2.5 V. Gradually release the C key to about 2 mm from its resting position. The voltage should be at least 6 times lower than the maximum voltage, or about 0.4 effective volts. Maximum voltages can vary from one *Ondioline* to another, but the ratio should always be at least 1/6 (1/10 is sometimes observed, which is acceptable). A ratio that is too low will result in poor expressive playing. The cause may be a maladjusted progressive attack controller; hence the utility of verifying the circuit as explained above.

When the key is fully released, the silence contact breaker takes over, and all alternating voltage disappears, both at the input and the output of the progressive attack controller. If alternating voltage persists, adjust the silence contact breaker. To do so, release the key fully and then slowly unscrew the small adjustment screw marked S in figure 11 of the previous chapter. If, on the other hand, the minimum voltage only appears when the key is depressed 2 or 3 mm, that means the screw is too loose. We should mention that this distance is measured at the front edge of the white key.

If you need to adjust the progressive attack controller, use the adjustment nut provided (see figure 11 in the previous chapter). Tightening the nut raises the lower part of the controller and thus the semiconductor wafer in relation to the movable palette, which might be necessary to do after several months of use if the controller has sunken slightly. When at rest, the movable palette should not touch the wafers, but it may come very close—for example, 1 mm—with no problem. If the controller is too low, attacks may be weak or may “knock.” Refrain as much as possible from fiddling with the controller adjuster for no reason. And after any adjustment, make sure to check that the minimum-to-maximum ratio is still 1/6 or higher.

Once you have verified the attack controller, reconnect the female coaxial plug to module B, then connect the electronic voltmeter or oscilloscope to the input of the knee lever potentiometer. Check that the minimum-to-maximum ratio of this new point is still correct. If not, there is a parasitic induction somewhere between the upstream and downstream of the controller.

Find out where it is coming from: an unshielded or poorly shielded wire, inductions between timbres B and A or between B and C, etc. This induction must be eliminated or the attack will make a fuzzy “meowing” sound, and the ear will hear a distinctive timbre variation as a key is gradually depressed.

Before continuing, let us use the electronic voltmeter to check some alternating voltages with the timbre switches still raised: 1.5 V for the 6K7 or 6BA6 pentode grid and 13 V for the anode, or the knee lever potentiometer input. On the oscilloscope (fig. 16*b*), the waveform will naturally be a reverse of the grid waveform, but larger and with no major distortion evident.

Tuning

Before we move on to formant, percussion and automatic vibrato circuits, now is the perfect time to refine the tuning. Otherwise, waveforms observed may appear differently for the same instruments and coils.

Here is where technicians should be backed up by a musician, or work with friends who dabbled in violin or guitar in their youth and who thus know what a half step, a third, a fifth and an octave are. Readers of this manual might even form partnerships like the one in the fable of the blind man and the lame man: “Single young radio technician seeks local female musician to build an *Ondioline* together. Smart, serious applicants only!”

But, let us reiterate, the refinement process is less complicated than tuning the four strings of a violin a fifth apart from each other. Furthermore, the keyboard module comes already tested and tuned on a standard B chassis. All an amateur builder needs to do is make a few small adjustments to perfect the tuning.

First, check that the general tuning knob (fig. 17) causes a total shift of three half steps (for a middle note on the keyboard, for example). If it does not, slightly lower or raise the value of the 40 kΩ resistor inserted under the shrink-wrap sleeve (fig. 12 of the previous chapter) between the oscillator’s high-voltage output and the connection to the octal socket. By raising the resistance, the range of the tuning is lowered, and vice versa. Any range smaller than three half steps can make it difficult to instantly tune the instrument to a note when playing with an orchestra, accordion or piano that is tuned sharp or flat. On the other hand, a greater range is not recommended, as the alternating voltage distributed to the cathode (with B raised) is lessened if the anode’s load resistance, which the 40 kΩ resistor is part of, is lowered too much. The 6J5 would affect clipping as well as general accuracy.

After making any necessary corrections to the resistance, set the general tuning knob to the center point. The following step consists of making necessary adjustments from potentiometers R_{v4} to R_{v1}, which as we recall correct for the inevitable parasitic capacitance between the grid and the ground of the oscillator tube. Depending which way the knob is turned, the potentiometers musically shorten or lengthen the distance between the last (highest) two Gs on the keyboard. The procedure is as follows:

Set the register knob to position IV. Alternately play the two right-most Gs on the keyboard. Do not check whether they are in tune absolutely; rather, verify whether they are an octave apart. To do so, turn the potentiometer R_{v4} in either direction, as necessary. Once you are satisfied, switch to register III and, this time using the potentiometer R_{v3}, tune the two right-most Gs on the keyboard until they are an octave apart. Continue in register II, making adjustments using R_{v2}, and then in register I, using R_{v1}.

Tuning to a single note

For this step, readers must have a reference note. One solution would be to run to the nearest musical instrument seller, purchase a standard *Ondioline* (1) and tune your homemade *Ondioline* to it.

Another solution: At the same store, purchase a pitch pipe (2) that plays a 435 Hz A, which will work just as well! We should also mention that Paris-area telephone customers can simply lift their receivers and listen. PTT broadcasts a tempered-scale G day and night for free.

(1) Retail price: 191,750 francs.

(2) Retail price: about 70 francs.

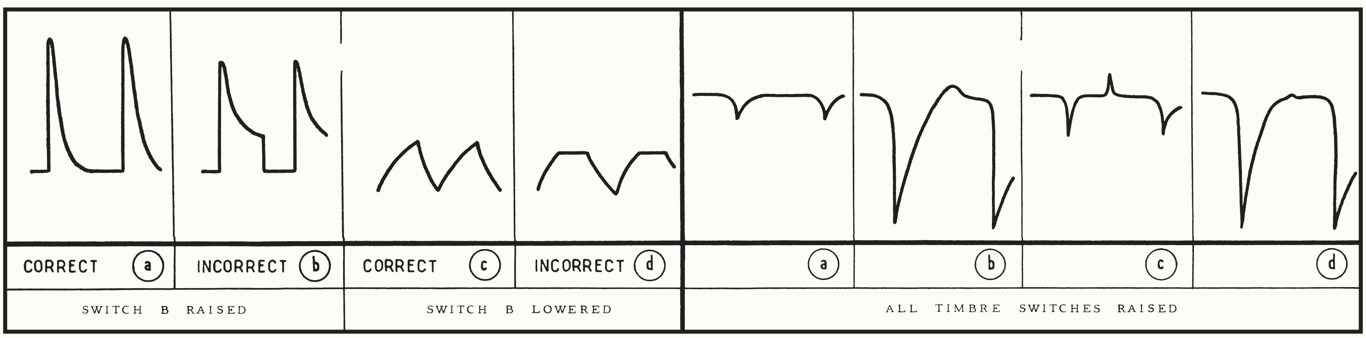


Fig. 15. — By carefully adjusting the resistance of the cathode in the connecting triode 6J5 *or half-*12AU7*, you should obtain the “correct” waveform for the anode, meaning it should be deliberately lower when the timbre switch B is raised. And when B is lowered, the wave applied to the triode grid is much weaker and should be undeformed, or nearly so, on its anode.*

Fig. 16. — High oscillograms on the knee lever input when testing the progressive attack controller. A correct instrument produces waveform (a) when the key is very slightly depressed and (b) when it is fully depressed. Waveforms (c) and (d) are the waveforms for an Ondioline with maximum parasitic induction between the progressive attack controller’s upstream and downstream, respectively.

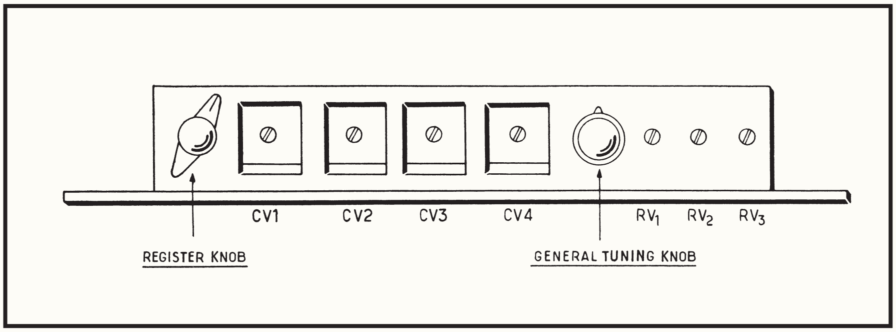


Fig. 17. — *Placement of main control mechanisms and their adjustment. The potentiometer R_{v4} can be accessed from the rear of the instrument, under the board supporting the keyboard. (See Fig. 11, page 26)*

Once you have done this, set the register knob to position IV. Check that the general tuning knob is set to the center position. Play an A on the keyboard (if using a pitch pipe) or a G (if using PTT). Choose an A or G in the central left part of the keyboard for this. Then make any necessary refinements, this time adjusting only capacitors C_{v4} to C_{v1}, whose role is to uniformly raise or lower all the notes on the keyboard at the same time.

To do this: While in register IV, using a screwdriver with an insulated handle, turn the flathead screw of C_{v4} to tune to the reference pitch. The *Ondioline* should play a G4 or A4; do not tune to the reference pitch itself, but to an octave above it. Repeat in register III, adjusting the C_{v3}, then do the same in register II and register I , adjusting C_{v2} and C_{v1} respectively. If the range of variation of one of the C_vs is insufficient, check whether the cause is one of the other circuits in module B (a poorly calibrated 40 kΩ resistor, incorrectly regulated voltage, etc.). Since module A is pretuned by the manufacturer, there should only be a slight difference, of no more than a quarter step, when assembling modules A and B.

In all cases—and this should be obvious for anyone who has examined the tuning circuit schematic carefully—any adjustment, whether from C_{v1} to C_{v4} or R_{v1} to R_{v4}, should always be performed starting in the highest register (register IV).

We should note that when refining module A, the values of the backup fixed capacitors have been chosen to allow enough of a range that the instrument can, in subsequent tuning sessions, be tuned a half step upwards or downwards, if necessary, by adjusting the appropriate C_vs. Do not add or remove any portion of the fixed backup values without verifying the oscillator's other circuits. When replacing capacitors, be sure to use only very high-quality parts (for example, *Stéafix* M 1500 capacitors). Also, make sure that you have verified the 12AU7 oscillator tube used (a red mark is painted on the glass of each tube provided after calibration on a B chassis in the laboratory).

After this initial adjustment, musicians with a discerning ear will be tempted to further refine general tuning by repeating the calibration process once or twice more, adjusting R_{v4}–C_{v4}, R_{v3}–C_{v3}, etc., somewhat the way *paddings* and *trimmers* of frequency converters are adjusted.

Adjusting timbres

Without an oscilloscope, the ear is obviously the only judge. We can lend it a hand by providing the average alternating voltages that should be measured using the electronic voltmeter at the knee lever input. The table on page 31 shows the normal waveforms when certain timbre switches are lowered. The measurements are taken with the knee lever potentiometer first at zero, then progressively engaged, while the ear listens and the eye watches the waveform on the oscilloscope. You will often notice that a large difference in sound may not appear to differ at all on the display, and that sometimes a considerable difference on the oscilloscope may not be incorrect at all and may even seem correct to the ear. This will come as a comfort to those who prefer to construct an *Ondioline* without an oscilloscope...

Adjusting the percussion

Since the percussion reverser is adjusted at the same time as the other mechanisms in module A, in principle it should not need to be adjusted again. However, here are the adjustment standards. The three stages are: 1. Charging the capacitor with high voltage; 2. Dead time, when the capacitor has disconnected from the load circuit and is not yet connected to the discharge circuit; 3. Discharge of the capacitor through the grid circuit. These three stages should take place starting only the instant the key is depressed halfway. That way, it is not necessary to release a key all the way before pressing another. The note need only be released about halfway before the plucking sound occurs on the next note. If the electrode/reverser were to touch the "resting" and "working" contacts at the same time, an unpleasant clacking sound would be made. That is why the three stages are necessary.

Verification is performed by sight or using a buzzer. Note that if you touch the central screw PW (fig. 11 in the previous chapter), which controls the position of the percussion contact, the sole unit of insulating material supporting both the silence contact breaker and the percussion reverser will be raised or lowered. Thus, it may be necessary to adjust the silence screw S slightly.

If the "plucked string" attack is not entirely satisfactory, you may need to adjust the voltage emitted by the grid's power supply bridge. Try a different pentode as well. Check the 0.5 μF capacitor. And you may need to correct the accuracy and duration of the sound decay after percussion (resistors in series with the 0.5 μF capacitor in the grid or in the high voltage, additional capacitors on the grid's 0.1 μF capacitor, etc.).

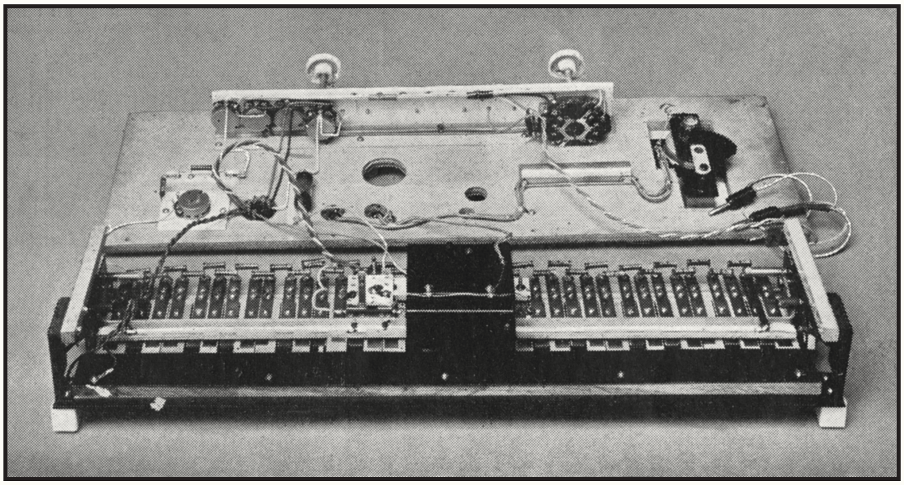
Refining the automatic vibrato

Connect an electronic or analog 0-300 V continuous-reading voltmeter between plate 1 of the vibrato tube and the ground. Leave switches V_1, V_2 and W raised for now. Turn potentiometer P_v (this is the potentiometer that controls the speed of the slowest vibrato). For a given position of P_v, the needle of the voltmeter will oscillate rapidly in time with the pulses emitted by the vibrato tube. This demonstrates that this circuit is assembled correctly.

Next, lower V_1 and V_2 in order to slow the rhythm. This adjustment is impossible as long as the 30 kΩ resistors remain in parallel on P_v by way of the raised switches V_1

and V_2. Lower switch W and roughly adjust the speed. With W raised, the beat should be about 5 Hz; with W lowered, it should be 7 to 8 Hz.

Do not linger on this visual adjustment, which can be distorted by the internal resistance of the voltmeter. Disconnect the device and listen to the vibrato. First, lower V_1 and adjust P_{v1} until you hear a frequency change that is quite subtle in depth. Then lower V_2 and leave P_{v2} in such a position that the resulting frequency change is greater. Working with more precision this time, readjust the speeds, using P_v (switch W up) and P_w (switch W down).



Module A (the keyboard module of the Ondioline) from underneath. The dark shielding in the center protects the progressive attack controller.

Mandolin

Lower switch D and an appropriate timbre such as FH. Because V_1 and V_2 remain raised, the 30 kΩ resistor connected in parallel to P_v of the vibrato tube changes the pulse to the same value as the rapid back-and-forth picking of a mandolin-player. This resistor can always be replaced by a 50 kΩ or 100 kΩ potentiometer, making this special effect adjustable.

Manual vibrato

We will conclude with adjustments to the manual vibrato, which are the most delicate to perform, as the changes must not be too great nor too small. Neither should the resulting change in frequency be too small or too large, which would cause quavering. When sold attached to the keyboard module, the manual vibrato has already been adjusted and verified, so we beg users not to touch it unless absolutely necessary and only if, after serious experimentation, the user decides to increase or decrease its sensitivity for reasons of personal taste. In that case, adjust the value of the fixed capacitors connected in series to the vibrato Cvv. However, any changes to the value of these capacitors must also be corrected for by slightly adjusting the tuning capacitors C_{v1} to C_{v4}, since the vibrato capacitors are connected to them in parallel.

Additional verifications

First, we must root out any remaining parasitic induction.

1. Undesirable induction between the grid circuit and the plate circuit of the pentode: With all timbre switches raised and in register IV, play middle C on the keyboard, depressing the key fully. Measure the voltage at grid 1—for example, about 1.5 V. Remove the pentode and measure the alternating voltage at the knee lever input. It should read zero or less than about 15 mV. If not, connections upstream and downstream of the pentode may be too close or insufficiently shielded.

2. Return the pentode to its base and lower switch P. Play the C key again. With all timbres raised except P, after the percussion effect, the alternating voltage at the pentode plate or at the knee lever input should lessen and tend toward zero. If there is significant residual alternating voltage—greater than 15 mV, say—it may be caused by insufficient high-voltage decoupling, a leak in the grid's decoupling paper capacitor (10 nF) or an excessive capacitor value.

3. Finally, between the input circuit and the output circuit of the potentiometer P_g, check that the wires are individually shielded, up to 1 mm if possible, from the input terminals on the potentiometer. If not, a very low parasitic capacitance (but not insignificant for some timbres) may occur permanently between the potentiometer input and its midpoint. For certain timbre combinations, you will hear a very clear difference depending on how far the knee lever is engaged. The sound will be shriller at its beginning than at its end.

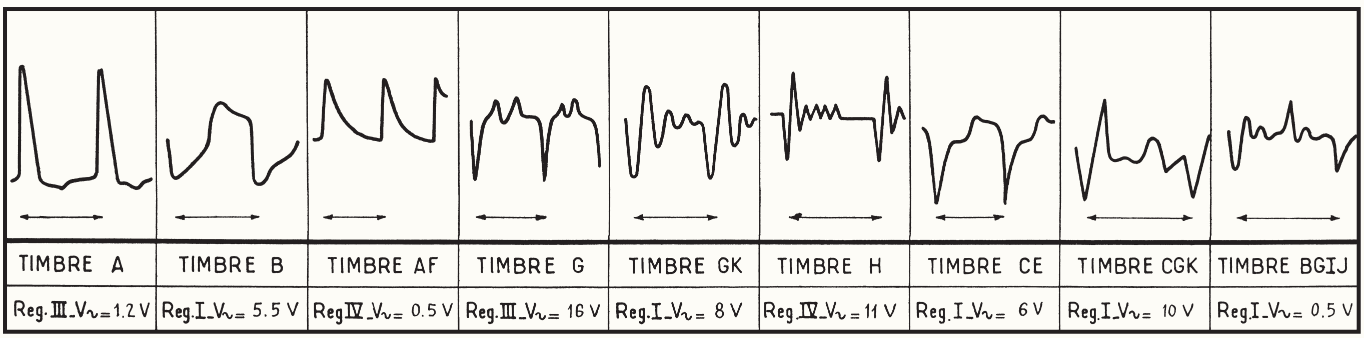


Fig. 18. — *Oscillograms taken at the knee lever input for middle C on the keyboard when the specified switches are lowered. The arrows indicate the period of the fundamental. The voltages are average values from peak to peak.*

Parasitic humming

If humming occurs, check the high-voltage filter. If that is not the cause, check whether the humming is coming from the filament circuit. To do this, disconnect the filament circuit for a few seconds while leaving the high voltage connected. If the humming stops, try changing the side the filament grounding is on, or try a more traditional approach using an improvised midpoint made with a "loto" potentiometer of several hundred ohms. Adjust by ear until the humming disappears.

In some cases, you may notice a change in the frequency of the instrument's notes. Check the high-voltage filter again. If it is not the cause, experiment to find the best orientation for coils C, G and H. In the event of an issue, increase the distance from the power supply transformer to module B.

The two problems mentioned above may be caused not by magnetism but by static (due, for example, to the absence of a grid in the power supply transformer). In this case, it is simpler to use the solution used in commercial *Ondiolines*: a 100 nF capacitor between one of the inputs of the transformer's primary and the chassis ground (do not place a capacitor at each end of the primary, as they will cancel each other out). If the sector features a grounded neutral, determine the correct connection direction for the plug. Finally, a drastic but effective solution is to eliminate the decoupling and use a simple ground.

Refining the ondiolinist

Since humans, unlike futuristic robots in science fiction magazines, do not have adjustment screws protruding from various points of their nervous system, refining the ondiolinist is a thornier matter...

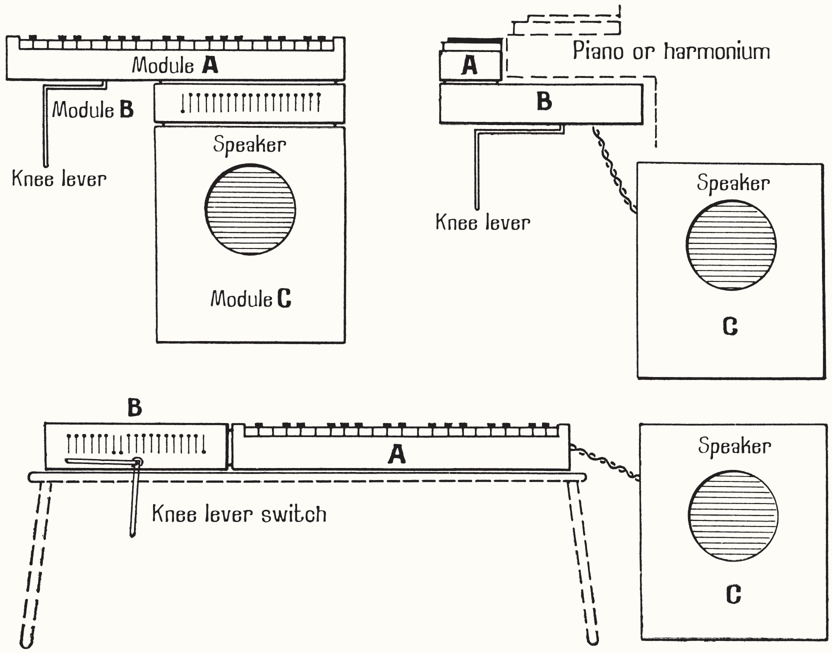


Fig. 19. — *Suggestions for arranging the various modules of the Ondioline. You can even create combinations that include a record player, tape recorder, radio, television, bar or bookcase!*

The best thing for readers to do is carefully reread the first two chapters on how musical instruments work in general (September and November). Since we cannot provide an introductory music lesson here, we recommend that beginners refer to the method mentioned previously (3) and perhaps even explore one of the very logical methods out there today to learn to read music quickly and play in tempo. (4)

And to conclude, let us repeat the secret to success: half an hour of practice per day, especially in the first two months. This is enough to give players a good start and will allow them to soon play correctly.

We will be happy if, with the help of all those interested, we have helped generate interest in electronic lutherie, a hobby and precious source of "active artistic leisure" which, if sociologists are to be believed, will occupy the majority of people's lives in the year 2000.

(3) Beginner's Handbook for Ondiolinists (Publisher: **Forgotten Futures**)

(4) **Pleyel** method for children, **Leyat** method, **Thiberge** method, etc.

APPENDIX

Playing "Coupled Octaves"

Ondiolines from 1956 include an important feature called "coupled octaves" or "sub-octaves".

Through the familiar process of frequency division, it is possible to build an instrument that uses the oscillator of the *Ondioline* as a master oscillator, dividing the frequency in two (sub-octave I), and whose divisions can also be divided in two (sub-octave II)

This results in an A3, A2, A1, etc. being played simultaneously; the mix of which can be adjusted as desired. Producing this result is a delicate matter, however, if the frequency is always to be divisible regardless of the master frequency (as is the case for a musical instrument such as the *Ondioline*).

We recommend that readers who wish to add this feature to their *Ondioline* refer to the (very useful) book by J. P. Oehmichen, *Electronic Circuits*. Once they are familiar with how the Eccles-Jordan works (see pages 37 et seq. of the book), they may begin construction, for which we provide a complete schematic below.

Here is some information that will save them some trial and error.

First, build the *Ondioline* described in the previous pages and play it for some time before attempting to add features. This is an important piece of advice: If octave-multiplying circuits function incorrectly, they can disturb the normal functioning of the master oscillator. Couplings with feedback between stages, power supply or induction may cause the instrument or transpositions to fall out of tune or alter the timbres of the normal *Ondioline*.

Synchronization voltages

Synchronization voltage is measured at point X indicated in the gen-

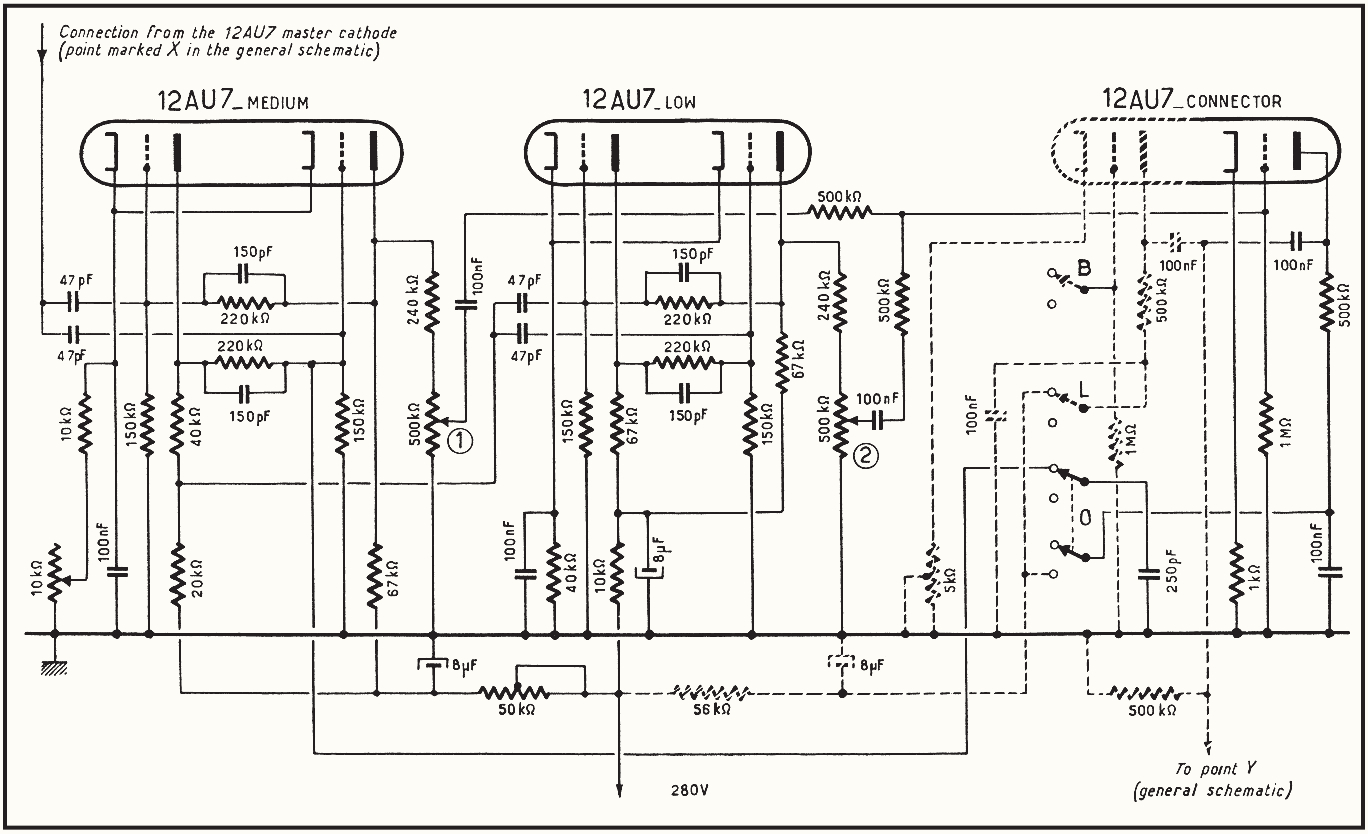


Fig. 20. — *Diagram of the octave-multiplier circuit. Points X (input) and Y (output) correspond to those indicated on the general schematic of the Ondioline. The half-*12*AU*7 *drawn in dashed lines is the one marked half-*12*AU*7 *on the general schematic. It is repeated here to help orient the reader. It also includes the correction that should be made to the circuit as compared to the general schematic: the ability to cut off high-voltage power to the first half-*12*AU*7 *using the timbre switch L.*

1. *Introduction potentiometers for the mezzo voice (medium)*
2. *Introduction potentiometers for the contralto voice (low)*

eral schematic. It is therefore negative, and sufficiently steep to trigger the Eccles-Jordan directly without pre-amplification.

Multiplication

The 10 kΩ potentiometer inserted in the cathode of the first Eccles-Jordan helps find the optimal point of operation so that multiplication can occur correctly for any note and any register of the *Ondioline*.

Grid resistors should have a value of within 5% of the maximum. The same goes for the anode resistors. Sub-miniature resistors (*Transco*) or small resistors (*Vitrohm*) are preferred, as they allow wires to run directly to the tube bases, avoiding the use of terminal strips, which require excessively long connections (otherwise, parasitic capacitance will cause a loss of synchronization for certain frequency bands). Finally, the dual triodes (12AU7) used should contain two sufficiently similar triode elements, which is rarely the case.

If multiplication is unstable along the musical scale, check the dual triode; use 12AU7 tubes selected specifically for this purpose. If this does not work, another solution consists of applying preamplified voltage to the synchronization. In this case, it will be necessary to take the synchronization signal not at the cathode but at the anode of the 12AU7 master oscillator tube (using a very low capacity mica capacitor, so as not to affect the instrument's tuning). Once amplified by a 12AU7 triode element, the voltage will be much higher than the voltage available on the master oscillator cathode, making synchronization more reliable. We reiterate that this additional triode is not necessary (in fact, it does not come in commercial *Ondiolines* with coupled octave capabilities). But it can help amateurs refine their instruments more easily and achieve correct frequency multiplication along the musical scale.

Mixing

A resistance (of about 240,000 ohms) is connected between the anode of each Eccles-Jordan and a metering potentiometer. The 240 kΩ resistance should leave directly from the tube's noval base (to prevent feedback and radiation between stages). The radiation is lessened after the 240 kΩ. However, shield the connection between the 240 kΩ resistor and the metering potentiometer if necessary. Also, shield the 0.1 μF connecting capacitor (or place it near the potentiometer, in any case). Use shielded wires up to the half-12AU7 mixer. Do the same for the connection from the 0.1 μF capacitor to the plate, which carries the sub-octave signals to point Y.

Two switches are provided so that the sub-octaves can be used for musical purposes. Switch L (left unassigned on the *Ondioline* described earlier) shuts off high-voltage power to the half-12AU7 amplifier tube from the master oscillator (in the "normal" *Ondioline*). That way, when the L switch is lowered, signals from the master oscillator no longer reach point Y. Only sub-octave signals can pass, and their perfect waveform produces new combinations of timbres (sounds rich with odd harmonics).

Another switch, which we will call O (for coupled octaves) cuts high-voltage power from the second part of the 12AU7 mixer, thus preventing sub-octave signals from reaching point Y, even if the metering potentiometer or potentiometers for the sub-octaves are open.

Comments

In commercially produced 1956– style *Ondiolines*, switch O is replaced with a switch M, and switch P is wired in such a way that when lowered it produces the same sound as lowering both M and P in previous models. Amateurs may choose to adopt this simplification; however, the disadvantage of it is that it eliminates the ability to use switch M alone (without P) for the guitar and mandolin with the string. But the string remains usable as before, with MP, to produce the sound of the banjo, castanets, etc...

Original French edition:
Editions Radio, Paris, 1957.

English edition:
Forgotten Futures, New York, 2017.

English translation: ITC Global Translations

Layout and design: Mike Buffington

Technical consultant: Stephen Masucci

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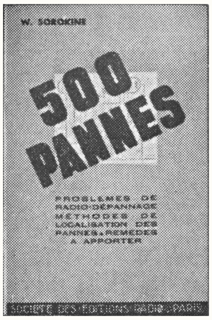

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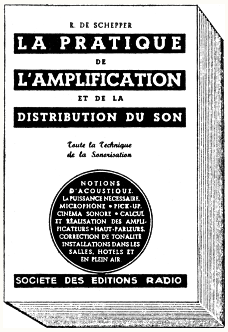

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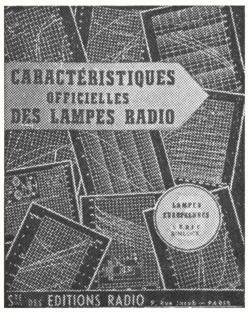

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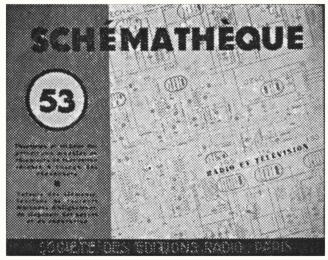

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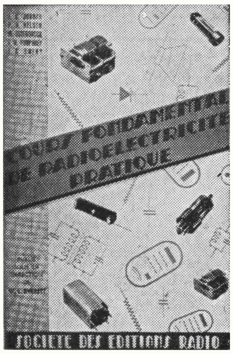

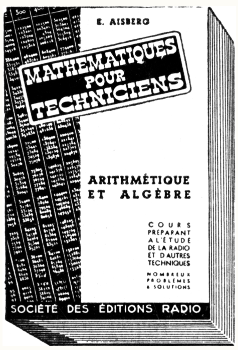

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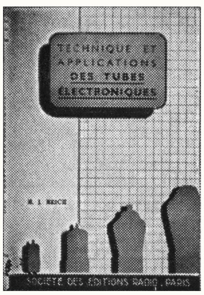

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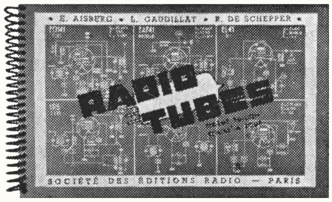

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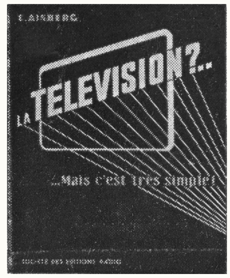

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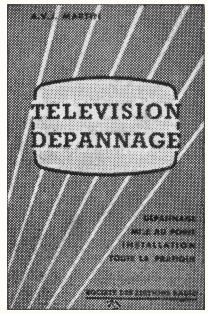

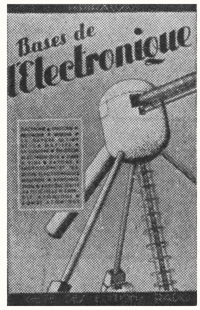

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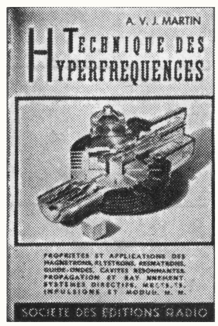

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