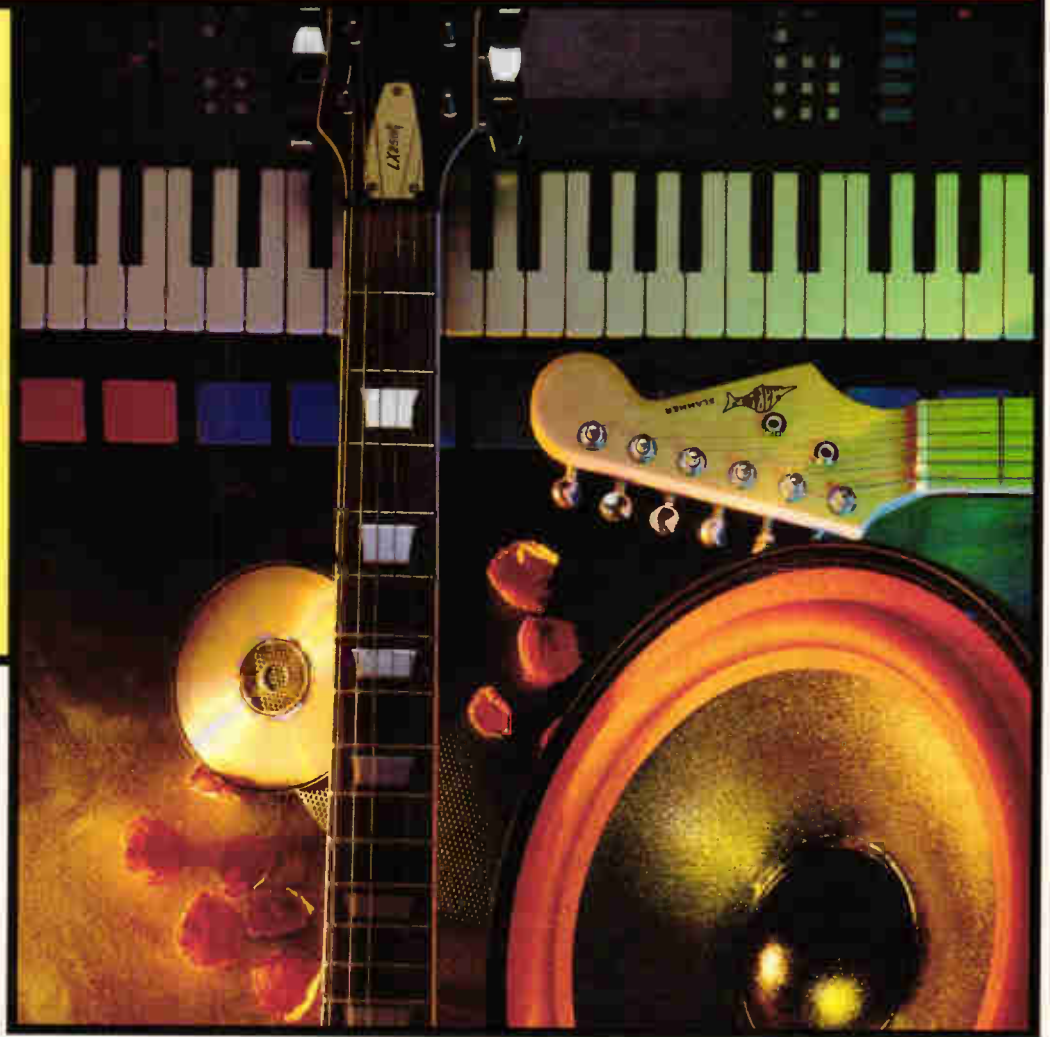


# Electronics in music

From the  
Theremin to the  
electric guitar:  
**Richard Brice**  
looks at  
instruments  
that involve  
electronics and  
discusses their  
uses in modern  
music.



**T**he invention of the microphone, the loudspeaker and the electronic valve amplifier, brought about a revolution in the art of music making. For several centuries preceding our own, a firm distinction may be made between large-scale music making and music for intimate entertainment; or chamber music.

The ability to amplify instruments and solo voices meant that for the first time 'chamber-music' could become a large-scale musical activity. As I researched and wrote the book 'Music Engineering,' I became convinced that the cultural revolution of rock-and-roll – and later rock music – is as much about how the music is made as it is about its sociological and musicological roots.

For the first time in history, and due solely to the progress in electronics, the world-view of a few young men – in those days it was just men – could capture the hearts and minds of hundreds, thousands of young people. And with the intervention of radio, the numbers increased to millions. Little wonder it is then that the establishment has always had an uneasy relationship with rock music!

Technologically a stone's-throw from the early microphones is that icon of rock-and-roll rebellion, the electric guitar. From Scotty Moore's chiming lead guitar on the early

Elvis records to Hendrix's angst-ridden, tortured performances, no other instrument characterises the octane-charged sound of rock-and-roll better than the electric guitar.

So it is with this symbolic, and seminal musical voice that we begin our look at electric instruments.

## Electric guitars

A modern electric guitar is illustrated in Fig. 1. The earliest electric guitars were created by attaching a contact microphone to the top sound-board of a conventional acoustic guitar, the resulting signal being fed to an external amplifier.

The modern electric guitar was born with the invention of the electro-magnetic pick-up and a typical arrangement is illustrated, diagrammatically, in Fig. 2. In principle, all electric guitar pick-ups are formed this way; with a coil wound on a permanent bar-magnet former.

The magnet is arranged so that it points with one pole towards the string and with the opposing pole, away from the string. As the string is excited by the player, and moves in close proximity to the magnetic circuit, the flux in the circuit is disturbed and hence a small electric current is induced in the coil.

Early pick-ups used a single magnet for all the strings but

later models used separate magnets, or separate pole pieces at different heights relative to the strings. This allowed compensation for the different sensitivity of the pick-up in relation to each of the guitar's six open strings.

**Pick-up problems**

Guitar pick-up coils contain very many – often several thousand – turns of fine-gauge wire and are thus very sensitive to minute string movements. Unfortunately, this also renders them very sensitive to electromagnetic interference. They are especially sensitive to induced hum due to magnetic fields emanating from the large transformers that find their way into the power supplies of guitar amplifiers.

To counter this, Gibson introduced the Humbucker pick-up. This comprises two magnets and two coils wound electrically in series but arranged in magnetic opposition, Fig. 3. The vibrating string will, of course, create a similar signal in both these coils, and these will add due to the series connection. But an external field will induce a signal of opposite phase in either coil. These fields will cancel due to the series connection.

Most guitars are fitted with a number of pick-ups and furnished with a selector switch to allow players to choose their favoured sound. Pick-ups nearest the bridge tend to sound more 'trebly' and bright. Those nearest the fingerboard have a more 'bassy' sound.

Because players like to have a local control over amplification level and tone-colour, all guitars provide volume and tone controls on the guitar itself. The pick-ups themselves have a relatively high output impedance, so it is necessary that they work into a very high impedance source. For this reason, most guitar volume potentiometers are very high value; perhaps 250 or 500kΩ.

Similarly, tone control circuits operate at very high impedance. As you may have already guessed, because of this, the action of the guitar cable itself – as well as the amplifier input impedance – all have a marked effect on the overall sound of an electric guitar set-up. This situation has helped fuel the enormous mythology which surrounds electric guitars, pick-ups and their associated amplifiers.

The circuit schematic for the internal circuitry of the famous Fender Stratocaster guitar is drawn in Fig. 4.

**Hammond and Compton organs**

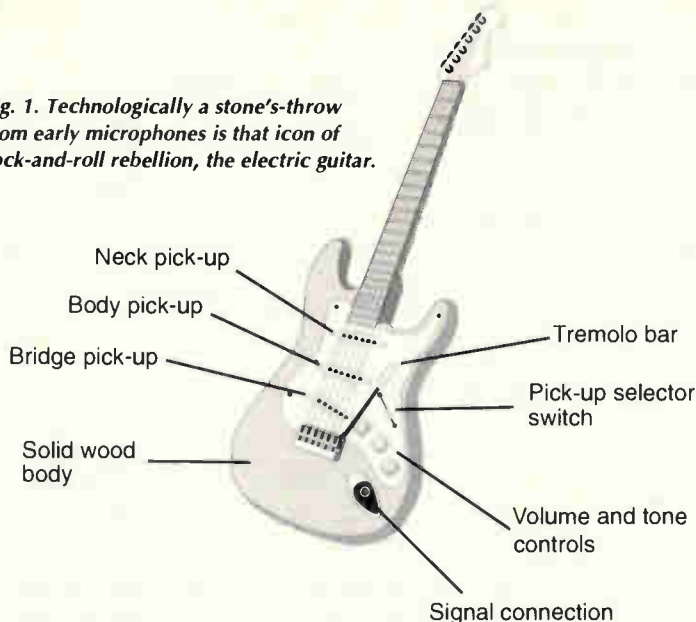
At first, electronic organs sought only to emulate the tone of the acoustic organ – a feat which is now so well accomplished that only experts can tell if the organ in a church is electronic or the acoustic original.

But it wasn't long before the designers of these electronic instruments began experimenting with harmonic combinations. The increased flexibility of electronic coupling relative to the traditional mechanical coupling made such experimentation easy. Just such an ambition led to the development of the classic Hammond B3 organ.

The B3, Fig. 5, was developed before solid state electronics became widely available. Its designers wisely forewent the use of electronic oscillators to produce the fundamental sine tones. Instead they opted for an electro-mechanical scheme whereby rotating discs with shaped edges influenced the magnetic field of electromagnets wound near the edge of the disc. The principle, illustrated in Fig. 6, is thus a variable reluctance electro-mechanical oscillator and is pretty well unique.

Other manufacturers displayed equal lateral thinking. Compton used rotary tone generators too, but these operated by means of a variable capacitance technique. Identical electromechanical components were used for each note of the scale, the different pitches being achieved by the choice of pulley ratio used to drive the tone generators from a common mechanical drive.

*Fig. 1. Technologically a stone's-throw from early microphones is that icon of rock-and-roll rebellion, the electric guitar.*



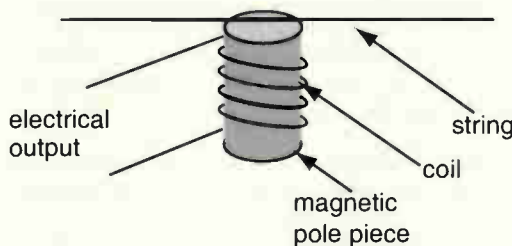
Hammond's ambitions went far beyond that of reproducing a pipe organ sound. Instead the company aimed at recreating the sounds of other instruments. Hammond's additive synthesis technique involved analysing real instrumental sounds – using a Fourier analyser. These sounds were recreated by selecting and adding sine waves generated from the continuous oscillator 'bank'.

Fascinatingly, it is fair to say that Hammond almost totally failed to achieve what it set out to do with the Hammond organ – that is, to simulate the sounds of other instruments. But they did create a 'classic' sound in its own right.

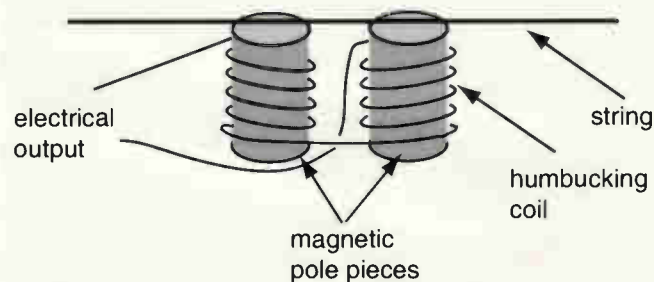
**Theremin**

One of the earliest electronic instruments, from around 1920, is the Theremin. This is a monophonic melodic instrument originally developed in Russia by Leon Theremin.<sup>2</sup>

The Theremin player does not touch the instrument and



*Fig. 2. Electro-magnetic guitar pick-up involves a coil wound on a permanent bar-magnet former. One pole points towards the string. As the string moves, flux is disturbed and a small electric current is induced in the coil.*



*Fig. 3. Since guitar pick-up coils contain sometimes thousands of turns, they are sensitive to electromagnetic interference. This arrangement cancels unwanted fields.*

Fig. 4. Internal circuitry of the famous Fender Stratocaster guitar. Note the high impedances involved.

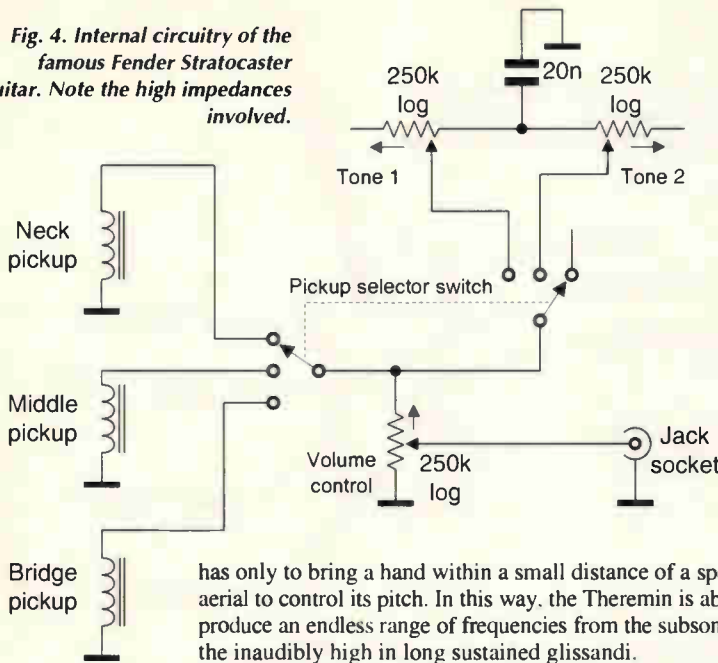


Fig. 5. Developed before solid-state electronics, Hammond's B3 organ has no oscillators. It uses electromechanics instead.

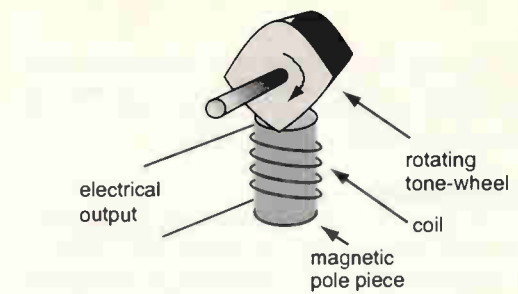


Fig. 6. The Hammond B3 incorporates many rotating cams whose lobes influence a magnetic field.

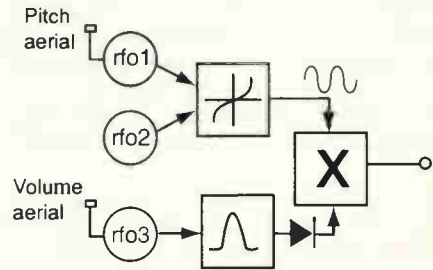


Fig. 7. The Theremin contains three rf generators. Oscillators 1 and 2 are pre-tuned to exactly the same frequency. The third oscillator varies output amplitude.

has only to bring a hand within a small distance of a special aerial to control its pitch. In this way, the Theremin is able to produce an endless range of frequencies from the subsonic to the inaudibly high in long sustained glissandi.

Despite being very difficult to play, the Theremin has achieved limited artistic success. It may be heard in several orchestral pieces and has been used on many film and early tv soundtracks. Furthermore the Theremin remains the emblem of experimental electronic music. It enjoys this status because it is one of the very few instruments designed in historical memory to employ a truly novel playing technique.

The operation of the Theremin is illustrated in schematic form in Fig. 7. Notice that the instrument contains three radio frequency generators operating in the hundreds of kilohertz region. Radio-frequency oscillators 1 and 2 are pre-tuned to exactly the same frequency.

Clearly, the resulting output from the non-linear circuit, i.e. the rf mixer, will be the sum and difference signal; the sum is subsequently filtered, leaving the difference signal alone to be passed on to the following amplifier stage.

Oscillator 1 differs from oscillator 2 with the addition of the extra tuning capacitance, across the main resonant circuit, formed by the metal aerial and its interaction with ground. The player has only to bring a hand within a small distance of the aerial for there to be a change in oscillation frequency and a resultant audible tone issuing from the process of multiplication.

The nearer the player gets to the plate, the more depressed the oscillation frequency of oscillator 1 and the higher the resultant pitch of the Theremin's audio frequency output.

The expressive potential of such a system is inevitably limited, hence the addition of the third oscillator and its asso-

ciated circuitry. This third rf circuit produces a tuneable output, once again variable by means of the interaction of the player's anatomy in proximity to another metal aerial or wand.

But this oscillator does not interact with another oscillator, instead its output is fed to a resonant circuit, tuned to the lower end of the variable oscillator's range. As the player approaches the aerial, the generated frequency drops and the output across the resonant filter rises. Suitably rectified, this signal becomes a control voltage which is employed to alter the gain of the final audio stage.

The complete instrument thus has the ability to change pitch and volume and thereby produce articulate musical phrases. It is generally played with two hands; one to adjust the pitch, the other to adjust the intensity.

### Electric pianos

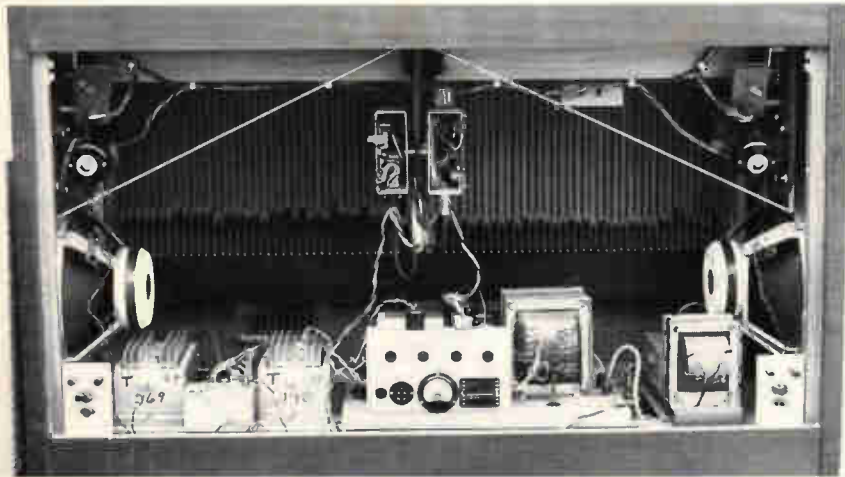
The most famous electric piano is, without doubt, the Fender Rhodes. This – and its many imitators – is actually more of an electronic Glockenspiel, or Vibraphone, than an electronic piano because the sound producing mechanism is formed from struck metal bars. The hammers striking the bars are actuated via a conventional keyboard mechanism.

Fender's Rhodes Piano dates from the early forties when Harold Rhodes, an American serviceman, built a 'baby Piano' in which metal rods were struck directly by the wooden keys themselves. It was an immediate success with the servicemen, for whom it was built to entertain, and hundreds were constructed.

Later on, an adaptation of the electric guitar type pickup was added so that the piano could be amplified. It was this unit that attracted the attention of guitar maker Leo Fender and thus the Fender Rhodes, as we know it today, was born.

The operation of a Rhodes is simple. The wooden key activates a hammer via a cam. When the key is depressed, the dampers are lifted above the sounding bars which are struck by the hammer. This bar, known as a tine, vibrates and disturbs the magnetic circuit formed by the permanent magnet within the pickup. The movement is thereby transduced into an electric current.





**Fig. 9. Inside a Mellotron. This instrument operated by means of a length of tape with recordings of real instruments on it. When a key was pressed, the length of tape was drawn over a playback head until it was exhausted.**

In the sixties, Chamberlin hired a salesman who, frustrated by the inventor's inability to resolve various technical problems, took the idea to Bradmatic Ltd in England, who supplied tape heads for the Mellotron. He suggested they production engineer a new model of the Mellotron and this they duly did.

Unfortunately the salesman failed to tell Bradmatic that the concept wasn't his and, similarly, omitted to inform Chamberlin about the new 'arrangement'!

After much acrimony, in 1966, Chamberlin agreed to sell the technology to the Bradleys who renamed their company Bradmatic to Streetly Electronics and commenced production of the mature Mellotron keyboard.

Chamberlin continued on a parallel development path with a series of instruments known simply as the Chamberlin. But it was the Bradleys' new Mellotron keyboard that attracted the attention of British bands who were searching for new

additions to their tonal palette. Amongst them were The Beatles, The Rolling Stones and The Kinks.

In 1966, John Lennon composed a small phrase which McCartney played on the Mellotron; it was the beginning of Strawberry Fields Forever. This four-bar phrase alone, forming as it does the opening of one of the most innovative records of all time, guarantees the Mellotron a place in the annals of sonic history.

The interior of a sixties Mellotron is illustrated in Fig. 9 in which the individual pieces of tape are clearly visible.

### Tape-bow Violin

Akin to the Mellotron is the Tape-bow Violin, the invention of Laurie Anderson who was born in 1948 in Chicago Illinois.

Anderson studied sculpture at Columbia University and engaged in various performance artworks while at college. After qualifying, she remained in New York where she met Philip Glass.

During work with a number of electronic musicians, Anderson designed the Tape-bow Violin; an instrument with magnetic tape instead of a bow, and a playback head instead of strings. The musical 'sample' recorded on the bow could be made to play by drawing the bow across the tape head as in conventional violin technique.

The invention's power lies in that variations in bowing can bring about very flexible sample manipulation. ■

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3. Coates, B, Melbourne Music Centre Web Pages. 1997.
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## Music Engineering

### The Electronics of Playing and Recording

Written by Richard Brice, published by Newnes

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