

Jan. 24, 1950

J. M. HANERT
ELECTRICAL TRANSMISSION SYSTEM
FOR MUSICAL INSTRUMENTS
Filed Dec. 23, 1944

2,495,581

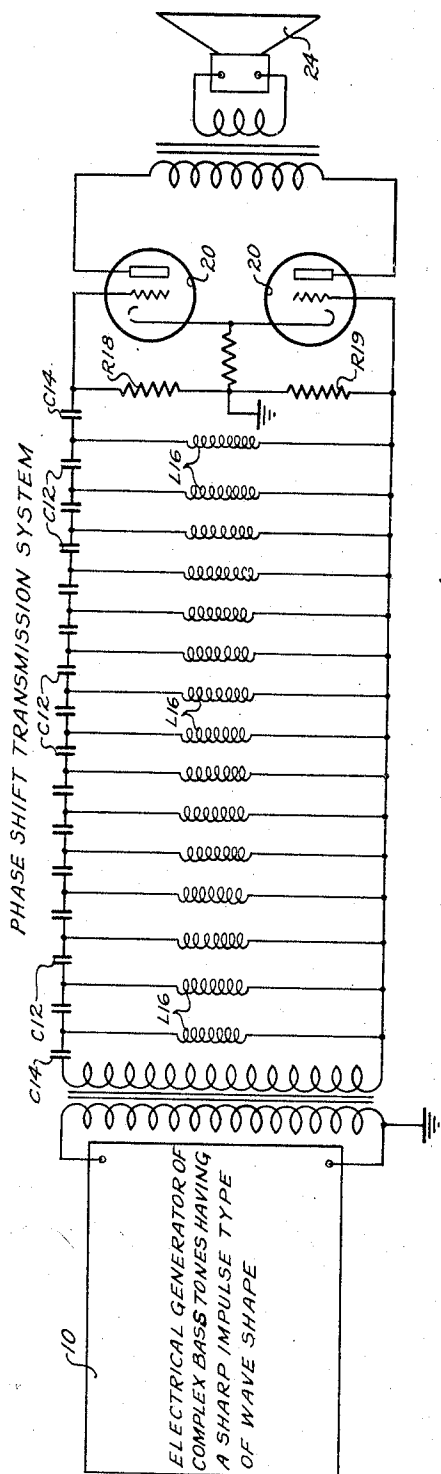
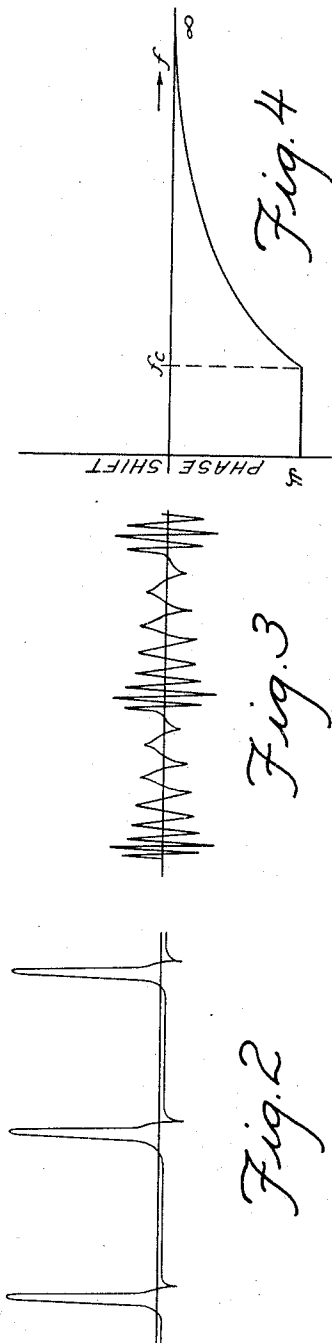


Fig. 1



Inventor
John M. Hanert
By Benjamin F. Hopper
Atty.

UNITED STATES PATENT OFFICE

2,495,581

ELECTRICAL TRANSMISSION SYSTEM FOR
MUSICAL INSTRUMENTSJohn M. Hanert, Park Ridge, Ill., assignor to
Hammond Instrument Company, Chicago, Ill.,
a corporation of Delaware

Application December 23, 1944, Serial No. 569,569

3 Claims. (Cl. 84—1.19)

1

My invention relates generally to electrical musical instruments, and more particularly to a phase distorting transmission system adapted to improve the electrical transmission of complex bass tones in which the tone originates in a wave consisting of sharp impulses.

In many musical instruments, especially in those in which the tone is electrically generated by means of certain types of oscillators, frequency dividers, etc., in which the original tone is picked up electrically from an instrument, such as in an electronic piano, or in which the tone is generated by an electric generator of the rotating or vibrating type, the wave comprises a plurality of equally spaced relatively sharp high amplitude impulses. The transmission of tones having this wave form presents a number of difficulties in the amplifier, in the speaker, and in its effect upon the ears of the listener. This is due to the fact that the high amplitude impulse wave of the bass tones causes distortion in the amplifying system and tends to overload the speaker, causing further distortion, and due to the high instantaneous air pressures produced by such sound, it frequently has a painful or at least unpleasant effect upon the ears of the listener.

At extremely low frequencies, in the range from 16 C. P. S. to 40 C. P. S., which correspond to the frequencies produced by the pipe organ 16 and 32 foot pedal stops, impulse waves of the above mentioned form, while producing tones having the desired series of overtones, nevertheless give the listener the impression that he is hearing a rapid succession of discreet pulses (a "machine gun" effect) rather than a cohesive sustained tone.

Waves of the above described shape represent the resultant of a fundamental and a long series of harmonics in which the fundamental and harmonics are in a special phase relation with respect to each other, that is, the peaks of all of the partials occur at the same instant and add up to produce the high peak of the resultant wave.

It has generally been assumed by experts in the field of music and audition that the quality of a musical tone is independent of the phase relation of the partials of the tone. This is believed to be true for musical tones in the middle and upper registers but it has been found that this assumption is incorrect as applied to complex tones of the low bass range.

It appears that the ear, in hearing a sharp impulse type wave of low frequency, has the ability to resolve the overall repeating frequency into the tone quality of the discreet impulses which make up the wave pattern of the overall

2

repeating frequency. Thus, if the low sub-bass frequency be in the form of repetitive impulses, the ear experiences little difficulty in resolving the effect into a series of easily separable impulses which do not have a pitch in the audio sense but rather are heard as a series of repetitive transient events. Such an auditory analysis is unmusical in that the ear does not readily assign a pitch in the even tempered musical scale to such tone. The effect of this phenomenon is similar to that produced by a rapid-firing machine gun, or other mechanical impulse generator.

It is thus an object of my invention to provide an improved transmission system for electrical musical instruments in which a sharp impulse type of low frequency wave is subjected to violent phase distortion so that the output wave is of entirely different and more complex shape and of considerably lower peak amplitude, while maintaining substantially the same intensity of the harmonics when subsequently translated into sound.

A further object is to provide an audio frequency time delay transmission system in which the delay time is not a constant for all frequencies but rather is longer for the lower frequencies than for the higher frequencies, so that a single input pulse results in a plurality of time-spaced output pulses.

A further object is to provide an audio frequency time delay transmission system which is effective sequentially to transmit the higher and lower order harmonic components of a repetitive bass or sub-bass input pulse so that the peak amplitude of the output wave is materially less than the peak amplitude of the input wave.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figure 1 is a block and schematic wiring diagram of an electrical musical instrument incorporating the transmission system of the invention:

Figure 2 shows a representative wave shape of the output of an electro-mechanical or electronic generator used for the generation of the low bass frequencies in various musical instruments;

Figure 3 shows the wave shape of the output of the transmission system when its input wave is of the shape shown in Fig. 2; and

Figure 4 is a diagram illustrating the phase shift characteristics of one section of the transmission line.

Referring to Fig. 1, the block 10 represents a

bass tone frequency generator, the output of which is a sharp impulse wave. This generator 10 may comprise an oscillator such as shown in Smiley Reissue Patent No. 20,831. Another form which the generator 10 could assume would be electromagnetic or capacity type pickups applied to the strings of a piano or the vibrating reeds of a melodeon or reed organ. A further form which the generator 10 might assume would be a rotary phonic wheel having sharp teeth, provided with a pickup of either the electromagnetic or capacity type. In general, the apparatus necessary for the production of a low bass tone having the desired harmonic analysis, for example, of a rich trombone tone is simple, and may be more economically and reliably produced, if the generated wave consists of a series of uniformly spaced high amplitude impulses, as compared with the apparatus necessary to generate a signal of the same complex harmonic content having its partials out of phase with respect to each other.

In fact, it is found that the sharp impulse type of wave is a unique wave and is the type of wave which is most easily produced mechanically and electrically in musical instrument tone generators. It is therefore of particular importance in the musical instrument art to provide a wave form changing apparatus which is effective to convert the impulse type of wave into a more complex type of wave without, however, substantially altering the number and relative amplitude of the various partials. One form of electrical musical instrument in which the present invention may be employed to advantage is disclosed in my copending application Serial No. 569,568, filed December 23, 1944, now Patent No. 2,468,062, issued April 26, 1949.

The generator, having its output generally of the wave shape shown in Fig. 2, is transformer coupled to a phase distorting transmission line comprising a series of capacitor C12, illustrated as fourteen in number, and a terminal capacitor C14 at each end of the series. The capacitors C12 and C14, together with inductances L16, form a multiple T-section artificial transmission line which terminates in a characteristic impedance comprising a pair of resistors R18, R19. The output end of the artificial line is coupled to a pair of triodes 20, comprising a push-pull power output amplifier which may be of any suitable design. The output circuits of the triodes 20 are transformer coupled to a speaker 24.

The artificial transmission system comprising the series capacitors C12 and C14 and shunt inductances L16 has the inherent characteristic of non-uniform velocity of propagation for different frequencies. High frequencies have a higher velocity of propagation than low frequencies. Therefore, this type of line is particularly well adapted for causing phase distortion to occur without objectionable frequency distortion. Non-objectionable frequency distortion is here used in the sense that, for frequencies above the low cutoff frequency, the frequency response at the end of the line is substantially the same as the frequency response at the beginning of the line. However, the phase of the signal at the end of the line differs from the phase of the signal at the beginning of the line, and the extent of this difference in phase decreases with increased frequencies. Such phase distorting transmission line has a natural low frequency cutoff and the various capacitors and induct-

ances, together with the terminating resistors, may be computed from the following relations:

$$R_{18}=R_{19}=2F_cL_{16}$$

and

$$C_{12}=\frac{1}{2F_cR_{18}}$$

in which $C_{14}=2C_{12}$; F_c is the low frequency cutoff in C. P. S.; L_{16} is the inductance of L16 in henries; and C_{12} the capacity of capacitor C12 in farads.

For a suitable bass transmission line the following constants have been found satisfactory: $L_{16}=7.2$ henries; $C_{12}=0.41$ microfarads; $C_{14}=0.82$ microfarad; $R_{18}=2000$ ohms; and, $F_c=46.3$ C. P. S.

The phase shift characteristic curve for a single section of such transmission line is shown in Fig. 4 and from this figure it is seen that maximum phase shift of 180 electrical degrees per section occurs at the cutoff frequency, which, in the above example, was 46.3 C. P. S. The phase shift produced at higher frequencies will fall off logarithmically to zero phase shift as an asymptote at infinity.

The phase shift per section of the artificial transmission line is thus unequal for the various harmonics of a low frequency complex bass tone, and the extent of deviation decreases progressively for the higher harmonics. The effect of the artificial transmission line is therefore to cause very substantial degrees of phase shift among the various harmonic overtones produced, and the extent of this phase shift may be increased by increasing the number of sections in the transmission line. It has been found that a phase distorting transmission line of fifteen sections is sufficient to produce a very pronounced change in wave shape, such as from the shape of Fig. 2 to the wave shape illustrated in Fig. 3. A shorter phase distorting transmission line, for example, a line of five sections, is adequate substantially to eliminate the "machine gun" effect in low bass frequencies and materially to reduce the peak amplitude of the output signal.

The wave shape of Fig. 3 is seen to cross the axis many times per cycle and therefore the above mentioned "machine gun" effect is obviated, and the ear no longer resolves the tone into its individual impulses, because successive impulses are now at a much higher frequency than that of the fundamental. This is readily observed by noting the large number of times the secondary impulses cross the axis for each wave length of the output wave.

A close inspection of the complex bass tone wave cycle shown in Fig. 3 reveals that it is composed of a series of transients of differing steepness and of increasing duration. A physical interpretation of the phenomenon involved is that the high frequency harmonics of the original pulse (which cause the steepness of its wave front) travel along the phase distorting line very fast, whereas the lower frequency harmonics of the bass tone pulse wave are progressively delayed. Consequently, it can be observed that the lower frequency harmonic components follow the higher frequency harmonic components in time sequence, as observed at the end of the line, to form the very complicated series of pulses shown in Fig. 3. The reduction in peak amplitude of the output signal may be understood by considering that the various harmonic frequencies which make up the original bass tone pulse follow one another in time sequence rather than occurring simultane-

ously and in phase, in which case the individual harmonic frequencies are additive and produce the very high peak wave shape of the impulse signal.

It is also apparent from Fig. 3 that the peak amplitude of the wave is materially less than the peak amplitude of the sharp impulse wave of Fig. 1. This results in less fatigue of the ear and is very beneficial in preventing overloading in the amplifier and speaker system, which latter consideration is of great importance in the production of bass tones, for which relatively powerful amplifiers and speakers must be provided.

While for the sake of simplicity the line is shown as having a pure resistive termination, it will be clear to those skilled in the art that other terminations may be utilized. An "M-derived" terminating section, while more costly, is desirable in that it reduces reflections in the major portion of the band of frequencies passed by the line, particularly when "M" has a value of 0.6.

From the foregoing it will appear that I have provided an improved means and method for coupling an electrical generator, generating complex bass tones having a sharp impulse type wave shape, to the output system of an electrical musical instrument in which the peak amplitude of the signal is materially reduced without causing objectionable frequency distortion. By violently altering the relative phases of the harmonics, the "machine gun" effect is completely eliminated in the transmission of musical bass tones.

While I have shown and described the invention in one of its more simple forms, it will be apparent to those skilled in the art that numerous variations and modifications of the invention may be made without departing from the underlying principles set forth herein. I therefore desire, by the following claims, to include within the scope of the invention, all modifications and variations by which substantially the results of the invention may be obtained through the use of substantially the same or equivalent means.

I claim:

1. For use in an electrical musical instrument having a generator of electrical signal waves of the sharp impulse type corresponding to musical tones of complex quality in the bass and sub-bass pitch ranges, the combination of a phase distort-

ing transmission line for transmitting the signals from the generator, said line comprising a plurality of series connected capacitors and shunt connected inductances of such values as to cause the various partials of the complex bass tone signals to be shifted in phase substantially relative to one another, and an amplifier and electro-acoustic translating means coupled to the output end of said line.

2. The method of improving the tonal character of the bass and sub-bass tones of a musical instrument in which the tones are of high harmonic development and are in the form of an electrical signal wave comprising sharply peaked pulses of high amplitude at the fundamental frequencies of the tones, which comprises relatively shifting the phases of the partials of the electric signal wave to an extent sufficient to reduce their peak amplitudes substantially and to make the wave of a complex shape such that it crosses the zero axis at least four times during each cycle of the fundamental frequency.

3. In a musical instrument having electro-acoustic translating means, the combination of a generator of electrical pulses at the frequency of a bass or sub-bass tone of the musical scale, the output of said generator being in the form of repetitive waves of relatively sharp peaks, a differential phase shifting network coupled to the generator and introducing a substantial differential time delay in the partials composing the pulses produced by said generator, and means for coupling the output of said network to the electro-acoustic translating means.

JOHN M. HANERT.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,007,370	Hopkins -----	July 9, 1935
2,009,229	Hammond -----	July 23, 1935
2,148,478	Kock -----	Feb. 28, 1939
2,217,957	Lewis -----	Oct. 15, 1940
2,231,079	Longo -----	Feb. 11, 1941
2,233,948	Kock -----	Mar. 4, 1941
2,328,282	Kock -----	Aug. 31, 1943