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(54) IMPROVEMENTS IN OR RELATING TO COMPRESSION OR EXPANSION OF AUDIO FREQUENCY SIGNALS

(71) We LICENTIA PATENT-VERWALTUNGS-GESELLSCHAFT MIT BESCHRANKTER HAFTUNG, a company organised under the laws of Germany of Theodor-Stern-Kai 1, 6 Frankfurt/Main 70, Germany, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:

The present invention relates to circuits for dynamic compression or expansion of audio frequency signals and is especially, though not exclusively related to improvement of the signal to noise ratio of recording systems by such means

In relation to the reproduction of audio-frequency signals over a noise introducing transmission path, such as a magnetic wire or tape, it is known to improve the signal to noise ratio by compressing the signals prior to transmission and expanding them after reception (the so-called Componder system).

However known systems for achieving this do not readily fulfil all the requirements for such a system which are: low and economical expenditure, characteristics for compression and expansion which correspond to each other, good ability to reproduce the require values in different examples of the apparatus (for example in a production series) and the ability to extend the principle of the system as regards choice of the degree of expansion and compression. Compression and expansion systems hitherto known require a relatively high expenditure for high quality or else, with low expenditure, they do not sufficiently meet the above mentioned requirements. This is especially true of apparatus for domestic use.

It is an object of the present invention to provide an improved expansion and compression system

According to the invention there is provided a circuit for automatic compression

or expansion of the dynamic range of an audio frequency signal comprising a first signal path, including control means for varying the transmission of said path to said signal, and a further signal path, branched from the first path at the input or the output of said circuit, including control voltage generator means for driving a control voltage from said signal and second control means for varying the transmission of said further path wherein the control voltage is applied to each of said control means so that the transmission of said second path is varied in a sense counter to the amplitude of said signal.

In order that the invention may be clearly understood and readily carried into effect practical examples thereof will now be explained with reference to the accompanying drawings of which,

Figure 1 is a block circuit diagram of the circuit for achieving a compression,

Figure 2 is a block circuit diagram of the circuit for achieving an expansion,

Figure 3 shows characteristics of the circuit for achieving an expansion,

Figure 4 is another block circuit diagram of the circuit for achieving a compression,

Figures 5 and 6 each show another block circuit diagram of the circuit for achieving an expansion,

Figure 7 shows a practical example of the block circuit diagram of Figure 1,

Figure 8 shows a practical example for a compression with subdivision of the frequency range,

Figure 9 shows a practical example for an expansion with subdivision of the frequency range,

Figures 10 to 13 show practical examples of an improved voltage generator.

Referring now to Figure 1, it is intended to convert input signals U_1 of a given dynamic range at an input terminal 1 into signals U_2 which can be taken off at an

output terminal 2 and which have a narrower dynamic range. For the purpose described a control means in the form of an amplifier 3, the amplification of which is controllable, is arranged in the useful signal path between the terminals 1 and 2. The amplifier 3 has a control input 4 via which its amplification is controllable by means of a direct control voltage for the purpose of varying the degree of transmission.

For obtaining the direct control a branch path is provided with a further control means, being an amplifier 7, an input of which is connected to the output of the amplifier 3. The output of the amplifier 7 feeds a control voltage generator 5 which serves to generate at the point Q a direct voltage dependent on the amplitude of its alternating input voltage. It is applied as a control voltage to control inputs 4 and 6 of the amplifiers 3 and 7.

The circuit described narrows the dynamic range of the useful signal, since with increasing output voltage of the amplifier 3 an increasing direct control voltage appears at the output of the control voltage generator 5, which regulates the amplification of the amplifier 3 in a reducing sense. Furthermore, in accordance with the invention the amplification of the amplifier 7 is also regulated in a reducing sense, so that in the branch path regulation takes place which substantially linearises the regulating characteristic of the compression circuit in Figure 1. The control voltage is therefore a regulating voltage in Figure 1. This effect will be described below with reference to Figure 3.

In Figure 2 is illustrated the use of the circuit of the invention for the expansion of alternating voltage signals. For expansion circuits the corresponding voltages will be given in brackets. Such a circuit serves e.g. to expand the signals compressed from U_1 to U_2 by means of the circuit illustrated in Figure 1, in such manner that output signals (U_3) again have the same dynamic range as the input signals U_1 in the circuit in Figure 1.

The expansion circuit in Figure 2 includes a controllable amplifier 8 between an input terminal 10 and an output terminal 11. A branch path, the input of which is in this case connected to an input of the amplifier 8, in the useful signal path, instead of to its output, includes the controllable amplifier 7 already described with reference to Figure 1. A control input 9 of the amplifier 8, as well as the control input 6 of the amplifier 7, are fed from the output Q of the control voltage generator 5. Because of the expansion required the amplifier 8 is so designed that the slope of its control characteristic is of opposite sign to the slope of the control characteristic of the amplifier 3, whilst the

amplifier 7 in Figure 2 is identical to the amplifier 7 in Figure 1 and is similarly regulated. If the input voltage (U_1) rises and therewith the value of the direct control voltage at the control inputs 9 and 6 rises, this has the effect that the amplification of the amplifier 8 is increased, whilst the amplification of the amplifier 7 is reduced. This may also be effected by locating between the control voltage generator 5 and one of two otherwise similarly designed amplifiers for 7 and 8 a phase reversing circuit for the direct control voltage. Similarly designed amplifier may also be used when the amplification is determined in each case by a negative feedback voltage divider (such as that described hereinafter in relation to Figure 7). The same direct control voltage for the two amplifiers then controls in known manner (German Offenlegungsschrift 2 218 823) via the one voltage divider resistor during compression and the other voltage divider resistor during expansion.

In Figure 3 a level diagram is conventionally illustrated. The useful signals U_1 to be acted upon during compression are located on the abscissa between -75 dB (assumed threshold of the source noise) and the nominal level of 0 dB. The absolute value of the input voltage rises on the abscissa from left to right up to the nominal level. The output level U_2 for compression or the input level (U_2) for expansion are located between -45 dB and 0 dB on the ordinate or abscissa respectively. The absolute value of the output voltage rises on the ordinate from bottom to top up to the nominal level. With exact expansion the output signals (U_3) are likewise located between the said values of -75 dB and 0 dB.

The curve 12 of the dependence of the output level U_2 on U_1 represents the characteristic of the compression circuit in Figure 1. Between -75 dB and -60 dB for U_1 there is constant amplification of 30 dB (45° slope of the characteristic 12), so that with the maximum amplification of the amplifiers 3 and 7 in Figure 1 assumed to be equal there is an amplification at the point P of 60 dB relative to the point 1. Only for an input level U_1 of -60 dB (at the change of direction of the characteristic 12) which, owing to the amplification of 60 dB, corresponds to a level of $U_2 = 0$ dB at the point P, does the regulating action (compression) commence in the example illustrated, since in that case the threshold of the control voltage generator (5 in Figure 1) is exceeded. From the value $U_1 = -60$ dB onwards the amplification decreases continuously, and for an input level of 0 dB it has the value 0 dB, viz. unity amplification. Above 0 dB the curve 12 continues with unity amplification value, i.e. it forms

a continuation of the broken straight line 15, for unity amplification. It will be appreciated that the dynamic range of -75 dB to 0 dB of the input signals U_1 is reduced to a range of -45 dB to 0 dB of the output signals U_2 . The curve 13 for U_4 gives the course of the voltage U_4 at the point P. It extends horizontally between -60 dB and 0 dB if the above-mentioned control voltage generator is used (examples will be shown in more detail in Figures 10 to 13). In contrast, when using a conventional control voltage generator with diode rectification the characteristic gradually rises since the alternating voltage at the point P in Figure 1 rises somewhat with increasing signal voltage owing to the regulating operation in the branch path. This characteristic is curved, and its curvature depends on the tolerance of the diodes. This curvature is transmitted in a weakened form to the characteristics 12 and 14, which correspondingly impairs their linearity.

In the case described expansion also takes corresponding to the compression. The characteristic necessary for this is provided with the reference numeral 14. In this case the input signals (U_2) in Figure 3 (abscissa) are between -45 dB (compressed threshold of the noise) and 0 dB, the change of amplification commencing at the change of direction of the characteristic 14, at -30 dB. From these input levels again comes the original dynamic range -75 dB to 0 dB via the characteristic 14 of the expansion circuit. The curve 13 for (U_4) again gives the course of the voltage (U_4 at the point P. As regards the characteristic, there applies what has been said in the preceding paragraph.

The essential advantage of the invention is that the middle section of the characteristics 12 and 14 respectively, which determines the regulation, is practically linear in consequence of the counter regulation in accordance with the invention. The linear form means that the characteristics agree with one another, even in different apparatus. For a single apparatus it is in itself immaterial which course the characteristic has, so long as the courses for compression and expansion correspond to one another. The difficulties occur if the characteristics are also to be the same in production apparatus. In this case a linear characteristic has the advantage of being easily and well reproduced. The conventional tolerances of the components employed have no appreciable influence on the linearity of the characteristics when using the invention.

Figure 4 shows a further practical example of the circuit according to the invention for the case of compression. In comparison with Figure 1 a further amplifier 17 is included. The effective characteristic has a different

course according to whether terminal 16 or 18 is selected as the output terminal. The circuit therefore has a reversible characteristic.

In order to enable the signals compressed in accordance with Figure 4 to be expanded again in a simple manner, the circuit illustrated in Figure 5 is suitable if in Figure 4 the terminal 18 serves as output terminal. In comparison with Figure 2 an amplifier 19 is included.

If in the circuit of Figure 4 the terminal 16 is selected as the output terminal, there serves as the expansion circuit the circuit illustrated in Figure 6 in which an additional amplifier 20 is necessary in the branch path.

Figure 7 shows a practical example of the compression circuit of Figure 1. As amplifier in the useful signal path there is used a differential amplifier 3, an inverting input 27 of which is connected via a resistor 26 to the input terminal 1 and a non-inverting input 28 of which is connected to a reference voltage. The differential amplifier 3 is therefore connected up as an inverting amplifier. The amplification of the differential amplifier 3 is determined by the negative feedback path to a feedback voltage divider 24, 26. The resistor 24 is controllable at its control input 21. The amplifier 7 in Figure 1 is formed in Figure 7 by the inverting amplifier 7, the amplification of this amplifier 7 being determined by a resistor 23 with a control input 22 in the feedback path. The resistors 23 together with a resistor 25 forms a negative feedback voltage divider.

In the practical examples of the circuit according to the invention so far described there is always uniform compression and expansion over the whole of the frequency range to be transmitted. However, it is sometimes desirable to subdivide the frequency range of the compression or expansion circuit, as known, into a plurality of partial ranges in each of which the effect takes place independently of the other partial ranges. In this way the so-called "breathing" noise is removed, which occurs owing to the dynamic regulation of useful signals of low frequencies (e.g. a drum roll).

A corresponding development of the circuit for a compression circuit is illustrated in Figure 8. The amplification of the amplifier 3 is controllable by controlling a negative feedback path including a voltage divider 31, 30. This feedback path also includes a frequency dependent network 29.

In a second negative feedback path including a voltage divider 34, 30, there is a second frequency dependent network 36. From the junction of the frequency dependent network 29, which is designed as a filter, and the resistor 31 there is fed via a resistor 130

32 a branch path which includes a controllable amplifier 7 and a control voltage generator 5. The amplification of the amplifier 7 is controlled via a controllable negative feedback resistor 33.

The negative feedback path which includes the frequency dependent network 36, also formed as a filter, is designed to correspond to the negative feedback path that includes the filter 29. The controllable resistor 34 is controlled from a further control voltage generator 38, which is designed like the control voltage generator 5. The control voltage generator 38 for its part is controlled by an amplifier 39 the amplification of which is controllable via a controllable negative feedback resistor 35. A resistor 37 forms with the resistor 35 a negative feedback voltage divider.

The amplification of the amplifier 3 is thus regulated in the frequency ranges determined by the filters 29 and 36, substantially independently of one another. The filters 29 and 36 are in the present case so designed that one filter favours the passage of the low and middle frequencies and the other filter favours the high frequencies.

Subdivision of the frequency range to be transmitted into a plurality of partial ranges is likewise shown by the expansion circuit in Figure 9, in which expansion takes place only in the upper part of the frequency range determined by the filter 29. For this purpose a controllable negative feedback path 41, 40 is included in series with the filter 29. The parts 32, 7, 5, 33 serve for control, as in the compression circuit in Figure 8. In series with the filter 36 for the lower part of the frequency range is included a fixed negative feedback path 41, 42. This circuit, which is simplified compared with the circuit in Figure 8, suffices for lower standards of quality such as are required e.g. in cheap tape cassette apparatus.

In itself, the described subdivision of the frequency range can be taken as far as desired. This is merely a question of the acceptable expenditure. As regards the characteristics diagram in Figure 3, subdivision into a plurality of frequency ranges has the effect that the characteristics indeed have different courses (position of the change of direction, steepness), but that the individual sections of the characteristics are again substantially linear.

For the controllable resistors described in the negative feedback paths the source-drain paths of field effect transistors are suitable and advantageous. Furthermore, if two controllable resistors are to be controlled in the same manner, say the resistors 23 and 24 in Figure 7 or 33 and 40 in Figure 9, then advantageously dual field effect transistors are suitable (e.g. type E 420 of the Siliconix company).

There now follows a description of four practical examples of the advantageous control voltage generator already referred to, the effect of which is that the regulating voltage characteristic for compression (14 in Figure 3) and the corresponding characteristic for expansion (12 in Figure 3, which have already been made linear by the invention, necessarily also have the same slope for different examples of the apparatus. Furthermore, it also ensures that there is a distinct change of direction at the transition from the lower part of the characteristic to the middle part (regulating range), so that this transition is easily reproducible.

This improved control voltage generator includes, as in known diode rectifiers, a condenser which is charged and discharged. However, whereas in the diode rectifier the condenser is charged by the peaks of the half oscillations of the useful signal, in the improved control voltage generator charging is effected from the source of operating voltage. The useful signals have only a controlling effect on the charging (or discharging) in that upon a threshold value being exceeded they close an electronic switch in the charging circuit (or discharging circuit). The time constant of the charging (or discharging) operation can be made extremely short, in contrast to the known rectifier, so that the control action (in the case of compression a regulating action) is initiated instantly (or the order of the duration of a half oscillation of the useful signal) and thereby again depresses the amplitude of the useful signal to below the said threshold value. The switch therefore opens, and charging (or discharging) takes place with a longer time constant (longer, so that no distortions occur). The operation described takes place periodically, since after the opening of the switch the amplitude of the useful signal, in fact the next half oscillation, again lies at the threshold value. The control voltage generated is limited either by the charging of the condenser to the full operating voltage (Figure 10) or by the complete discharging of the condenser (Figures 11 to 13). At this value of the control voltage the characteristics 12 and 14 in Figure 3 meet the straight line 15 (e.g. at the zero point in Figure 3 or below it).

Figure 10 applies to the case referred to of charging, and Figures 11 to 13 apply to the other case of discharging via the switch, referred to above in the brackets. In all four Figures there is illustrated a switch for the control voltage generator 5 (also 38 in Figure 8) having an input terminal P and an output terminal Q.

In Figure 10 the switch, indicated by reference numeral 43 becomes closed upon a threshold value of the useful signal, fed to the point P, being exceeded, so that a

condenser 44 is almost immediately charged from a source of operating voltage U_B via a resistor 46, with a very short time constant determined by a resistor 45 and the components 44 and 46. The threshold value may be determined by the switch itself e.g. by the base-emitter path of a transistor, or by a pre-connected means such as an amplifier. On the condenser there therefore appears a control voltage, which is taken off at the point Q. It slowly falls due to charging of the condenser via the resistor 45, so that the amplitude of the useful signal at the point P rises correspondingly and again exceeds the threshold value and thereby initiates a new operation. It will be appreciated that such a control voltage generator in the regulating circuit included in the branch path in Figure 1 or 2 (for regulation of the amplifier 7) has a very rapid regulating action when there is a rise of amplitude at 3. This advantage is important, but such a control voltage generator also has the second important advantage that at its input P there is an absolutely constant alternating voltage U_1 during compression or (U_1) during expansion, which has the same meaning as the horizontally extending part of the curve 13 in Figure 3. This ensures that the characteristics 12 and 14 have a slope in their middle part which is constant from one apparatus to another and which is affected only to an unimportant extent by the tolerance of components of normal magnitude. The characteristics 12 and 14 in Figure 3 have, with the simplifying proviso that the amplifiers 3 and 7 in Figure 1 or 8 and in Figure 2 are similar, a predetermined angle relative to the broken straight line 15, which applies to amplification of 0 dB, hence to unity amplification.

Preceding the switch 43 there is included a half-wave rectifier, or a full-wave rectifier 47 if the switch 43 is to respond to both directions of the applied alternating voltage. The real resistor 46 in Figure 10 (and correspondingly the resistor 45 in Figure 11) does not need to be an ohmic resistance but may be formed in known manner (e.g. as in deflection circuits of television receivers) as a current source that supplies a substantially constant current.

In Figure 11 there is illustrated a circuit for the other case already referred to, that after closing of the switch 43 upon a threshold value being exceeded the condenser 44 which was previously charged from the operating voltage U_B via the resistors 45 an 46 is very rapidly discharged through the small resistor 46.

In Figure 12 is illustrated a practical example on the principle of Figure 11. Here, there is used as switch a transistor 43 the base of which is controlled by the useful signal voltage reduced by a voltage

divider 48, 49. The transistor becomes conducting upon its pass voltage of say 0.7 V being exceeded, and in this way determines the said threshold value. The tolerance of the pass voltage is extremely small, so that the slope of the characteristics 12 and 14, even under high demands, is sufficiently constant from one example of the apparatus to another. At the same time it acts as a rectifier, since only the one direction of the applied alternating voltage can open the transistor. If an electronic switch does not have this property a rectifier may be preceded it, but it is not essential. The resistor 46 is represented by the internal resistance of the transistor, which may if necessary be increased by an additional resistance.

In Figure 13 there is illustrated another possible way of taking into account the positive and negative directions of the useful signal voltage. Here, each direction has its own associated electronic switch. The left-hand switch 43 for the positive half oscillations is designed as in Figure 12; a right-hand switch 51 with its associated components is similarly designed and is controlled by the negative half oscillations of the useful signal via a phase reversing circuit 50, shown as an inverting amplifier.

In the invention the dynamic compression or expansion is performed in the undivided part of the first signal path and, in one example in the dynamic compression, small amplitudes of the signal are enlarged relative to the large amplitudes by limiting the control action of the control means in that path to a predetermined level.

If desired, the responses of the amplifier in the signal path and the amplifier in the feedback path to the control voltage, for either expansion or compression, may be arranged to differ only by a constant factor.

WHAT WE CLAIM IS:—

1. A circuit for automatic compression or expansion of the dynamic range of an audio frequency signal comprising a first signal path, including control means for varying the transmission of said path to said signal and a further signal path, branched from the first path at the input or the output of said circuit, including control voltage generator means for deriving a control voltage from said signal and second control means for varying the transmission of said further path wherein the control voltage is applied to each of said control means so that the transmission of said second path is varied in a sense counter to the amplitude of said signal.

2. A circuit according to claim 1 wherein the first control means is arranged to respond to the control voltage to vary the transmission of the first path in the same or



condenser 44 is almost immediately charged from a source of operating voltage U_B via a resistor 46, with a very short time constant determined by a resistor 45 and the components 44 and 46. The threshold value may be determined by the switch itself e.g. by the base-emitter path of a transistor, or by a pre-connected means such as an amplifier. On the condenser there therefore appears a control voltage, which is taken off at the point Q. It slowly falls due to charging of the condenser via the resistor 45, so that the amplitude of the useful signal at the point P rises correspondingly and again exceeds the threshold value and thereby initiates a new operation. It will be appreciated that such a control voltage generator in the regulating circuit included in the branch path in Figure 1 or 2 (for regulation of the amplifier 7) has a very rapid regulating action when there is a rise of amplitude at 3. This advantage is important, but such a control voltage generator also has the second important advantage that at its input P there is an absolutely constant alternating voltage U_1 during compression or (U_1) during expansion, which has the same meaning as the horizontally extending part of the curve 13 in Figure 3. This ensures that the characteristics 12 and 14 have a slope in their middle part which is constant from one apparatus to another and which is affected only to an unimportant extent by the tolerance of components of normal magnitude. The characteristics 12 and 14 in Figure 3 have, with the simplifying proviso that the amplifiers 3 and 7 in Figure 1 or 8 and in Figure 2 are similar, a predetermined angle relative to the broken straight line 15, which applies to amplification of 0 dB, hence to unity amplification.

Preceding the switch 43 there is included a half-wave rectifier, or a full-wave rectifier 47 if the switch 43 is to respond to both directions of the applied alternating voltage. The real resistor 46 in Figure 10 (and correspondingly the resistor 45 in Figure 11) does not need to be an ohmic resistance but may be formed in known manner (e.g. as in deflection circuits of television receivers) as a current source that supplies a substantially constant current.

In Figure 11 there is illustrated a circuit for the other case already referred to, that after closing of the switch 43 upon a threshold value being exceeded the condenser 44 which was previously charged from the operating voltage U_B via the resistors 45 and 46 is very rapidly discharged through the small resistor 46.

In Figure 12 is illustrated a practical example on the principle of Figure 11. Here, there is used as switch a transistor 43 the base of which is controlled by the useful signal voltage reduced by a voltage

divider 48, 49. The transistor becomes conducting upon its pass voltage of say 0.7 V being exceeded, and in this way determines the said threshold value. The tolerance of the pass voltage is extremely small, so that the slope of the characteristics 12 and 14, even under high demands, is sufficiently constant from one example of the apparatus to another. At the same time it acts as a rectifier, since only the one direction of the applied alternating voltage can open the transistor. If an electronic switch does not have this property a rectifier may be preceded it, but it is not essential. The resistor 46 is represented by the internal resistance of the transistor, which may if necessary be increased by an additional resistance.

In Figure 13 there is illustrated another possible way of taking into account the positive and negative directions of the useful signal voltage. Here, each direction has its own associated electronic switch. The left-hand switch 43 for the positive half oscillations is designed as in Figure 12; a right-hand switch 51 with its associated components is similarly designed and is controlled by the negative half oscillations of the useful signal via a phase reversing circuit 50, shown as an inverting amplifier.

In the invention the dynamic compression or expansion is performed in the undivided part of the first signal path and, in one example in the dynamic compression, small amplitudes of the signal are enlarged relative to the large amplitudes by limiting the control action of the control means in that path to a predetermined level.

If desired, the responses of the amplifier in the signal path and the amplifier in the feedback path to the control voltage, for either expansion or compression, may be arranged to differ only by a constant factor.

WHAT WE CLAIM IS:—

1. A circuit for automatic compression or expansion of the dynamic range of an audio frequency signal comprising a first signal path, including control means for varying the transmission of said path to said signal and a further signal path, branched from the first path at the input or the output of said circuit, including control voltage generator means for deriving a control voltage from said signal and second control means for varying the transmission of said further path wherein the control voltage is applied to each of said control means so that the transmission of said second path is varied in a sense counter to the amplitude of said signal.

2. A circuit according to claim 1 wherein the first control means is arranged to respond to the control voltage to vary the transmission of the first path in the same or

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complementary manner for compression or expansion respectively.

3. A circuit according to either of the preceding claims wherein each of said control means includes a field-effect transistor and said transistors are provided as a dual field effect transistor.

4. A circuit according to claim 1 wherein the responses of the first control means and the second control means to the control voltage for either expansion or compression are arranged to differ only by a constant factor.

5. A circuit according to any of the preceding claims wherein the control voltage generator is arranged so that, in the event of the input signal to the generator exceeding a threshold level, it generates a control voltage which, independently of that input signal, rises or falls from a predetermined value until the amplification in the branch path has been so reduced that the said input signal falls below the threshold and thereafter falls or rises to the predetermined level.

6. A circuit according to claim 5 wherein the control voltage generator includes a

condenser and an electronic switch capable of charging or discharging said condenser wherein said switch is arranged to be responsive to the said input signal and to become conducting when said threshold value is exceeded and wherein said charging or discharging is effected by an operating voltage via a resistance.

7. A circuit according to claim 1 wherein in the dynamic compression the control voltage or the control action of the control means in the first path is limited to a predetermined value.

8. A circuit including filter means for dividing the audio signal into components having different frequency ranges and including at least one circuit according to any of the preceding claims operating on at least one of said components independently of the other components.

9. A circuit for automatic compression or expansion of the dynamic range of an audio frequency signal substantially as herein described with reference to the accompanying drawings.

Chartered Patent Agent.

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