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Nadkarni

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[54] **CONTINUOUS UP/DOWN SPECTRUM SCALING OF SIGNALS**

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[52] **U.S. Cl.** **324/76.35**; 324/77.11; 333/140; 333/159; 368/200

[58] **Field of Search** 324/76.12, 77.11, 324/76.29, 76.35, 76.49; 333/140, 147, 149, 154, 159; 368/200

[56] **References Cited**

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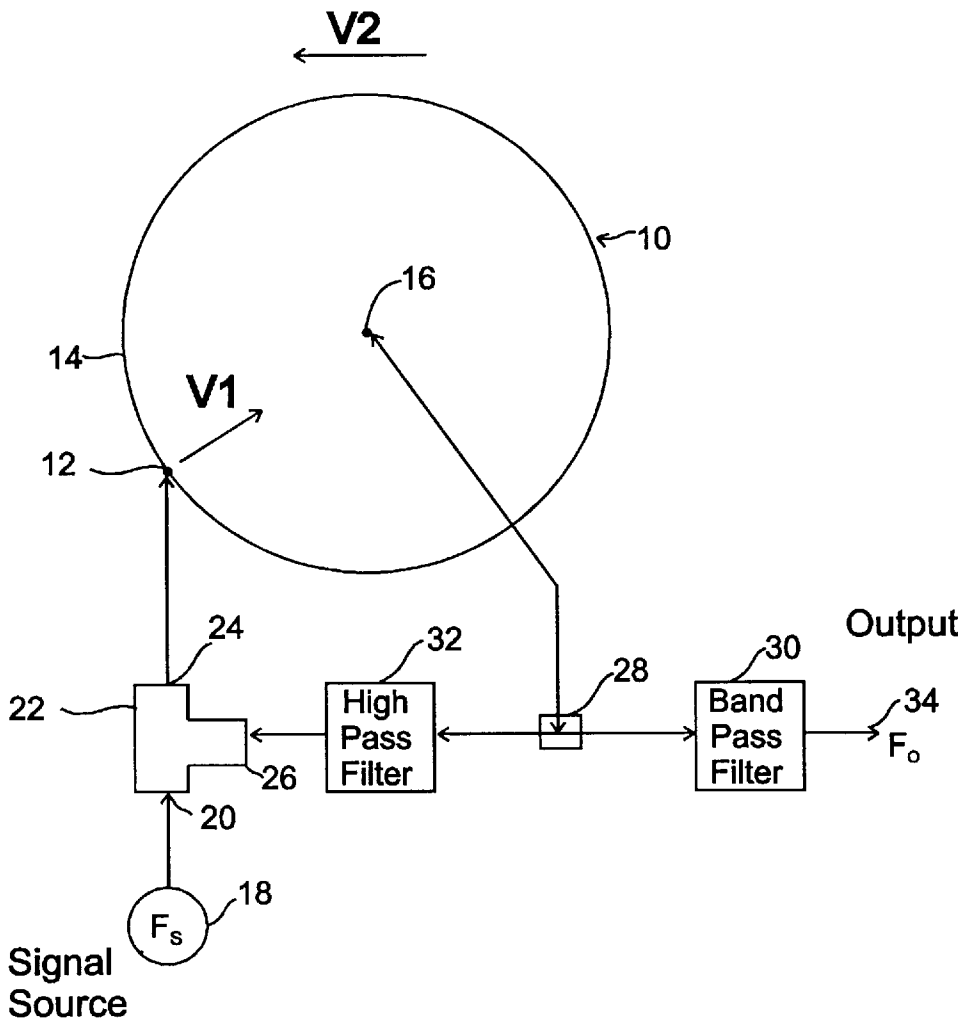|			
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Primary Examiner—Glenn W. Brown
Attorney, Agent, or Firm—Sidley & Austin

[57] **ABSTRACT**

A rotating transmission line for use in spectrum up-scaling or down-scaling of signals. The rotating medium is characterized by different velocity gradients, whereby when a signal propagates in such medium, the signal undergoes a Doppler effect as it propagates through the moving medium.
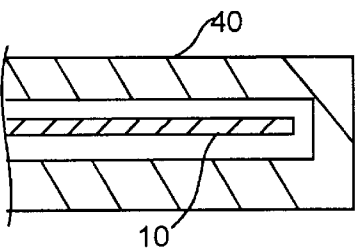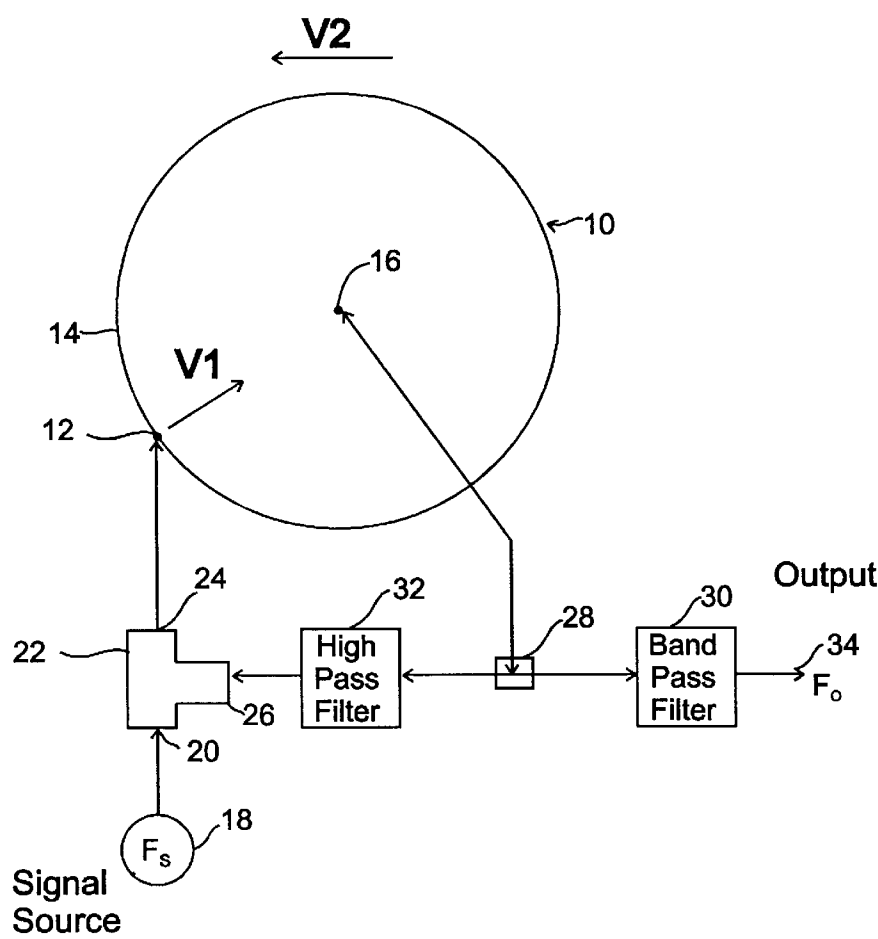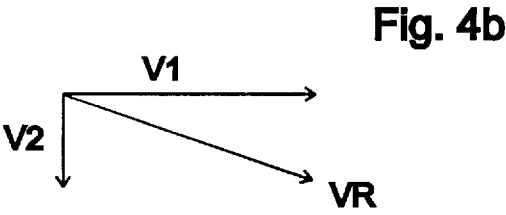
12 Claims, 3 Drawing Sheets

40

10

Fig. 2

Fig. 1

V2

10

16

14

V1

12

24

22

High Pass Filter 32

28

Band Pass Filter 30

Output

34

F_o

26

20

F_s 18

Signal Source

Output
RL

54

V1

12

Rg

52

F_s

Input

50

16

10

Fig. 3

V2

Fig. 4a

10

V1
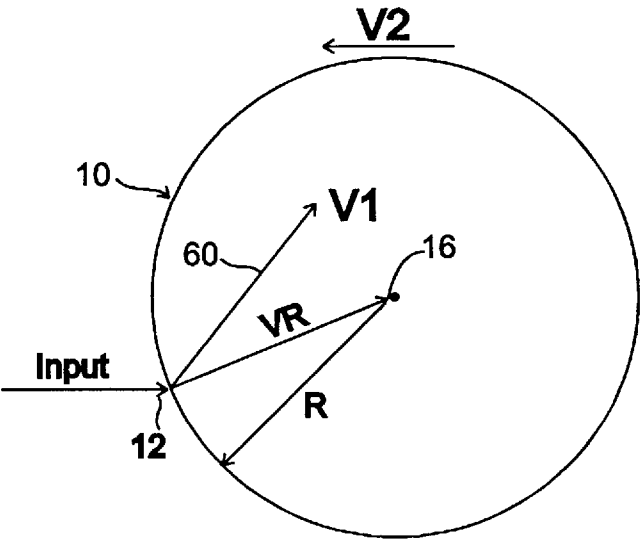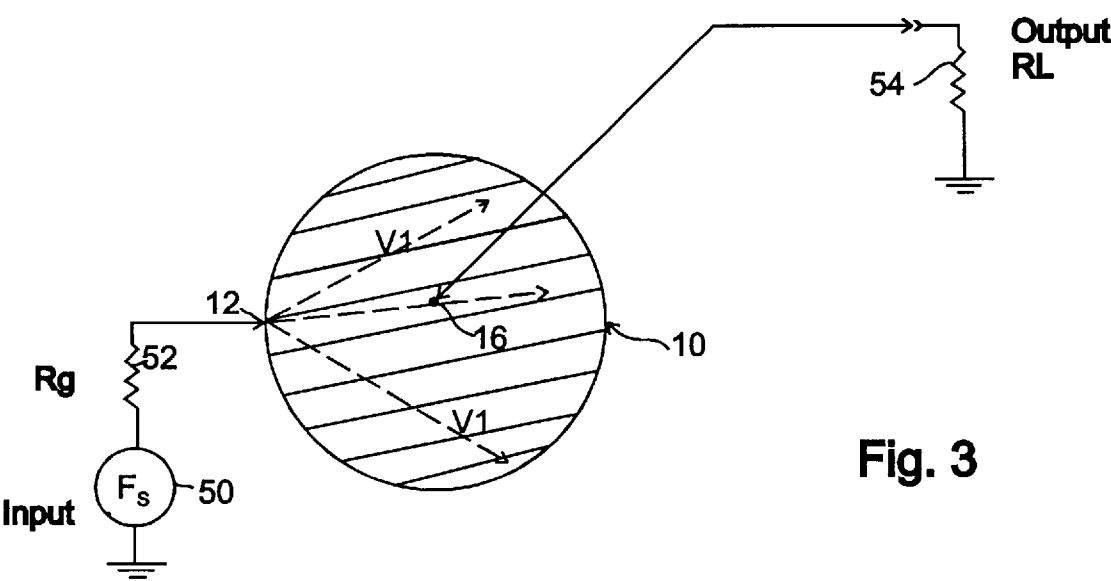
60

16

VR

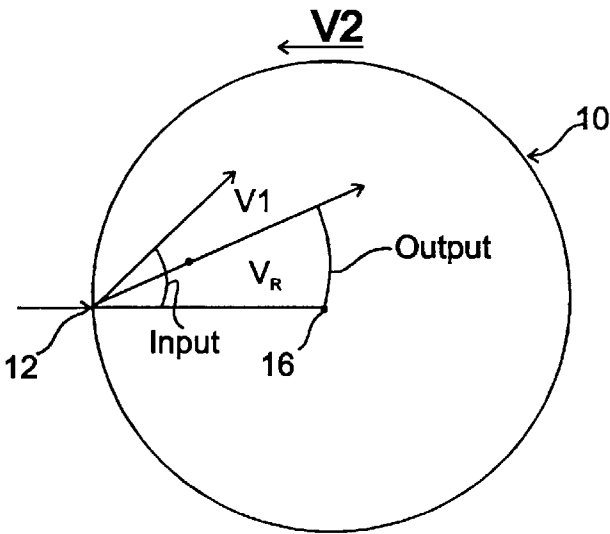Input

R
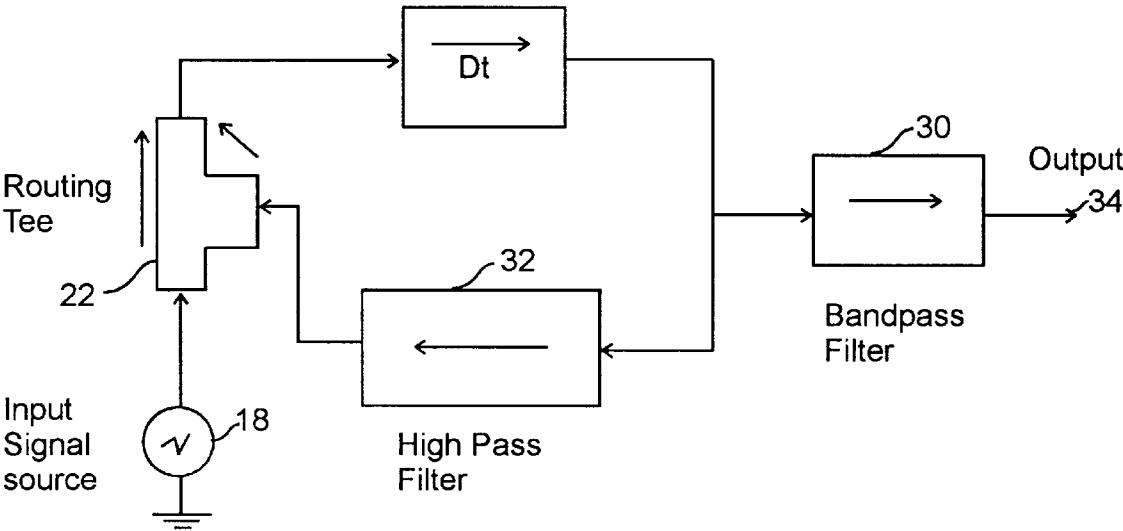
12

Fig. 4b

V1

V2

VR

Fig. 5

Fig. 6

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CONTINUOUS UP/DOWN SPECTRUM SCALING OF SIGNALS

TECHNICAL FIELD OF THE INVENTION

The present invention relates in general to equipment for the spectrum up-scaling or down-scaling of signals, and more particularly relates to methods and apparatus for accomplishing the continuous spectrum scaling of signals.

BACKGROUND OF THE INVENTION

When a signal undergoes a Fourier transformation, it is expressed in terms of a set of harmonically related phasors which can be graphically represented by the spectrum. Each harmonic of the spectrum has a specific amplitude, phase and frequency. Scaling in frequency of the spectrum corresponds to the inverse scaling in time of the signal. A common illustration is the effect on the frequency content that results when an audio tape is recorded at one speed and played back at a different speed. If the playback speed is higher than the recording speed, then the frequency is scaled up, which corresponds to compression in time, and vice versa. In practice, this inverse relationship between time and frequency may be valuable for several situations in the field of electrical systems. For instance, high speed single shot events are difficult to capture and record numerically using present day analog-to-digital converters. By down-scaling all of the frequencies of the spectrum, the signal can be stretched in time and then recorded in numerical form using conventional technology.

The technique of spectrum scaling is well known in signal processing and conditioning systems. It is understood that the techniques rely on the scaling of the Fourier transform relationship which is difficult to implement in real time for high speed signals due to the large computational time involved in the fast Fourier transform algorithms. An example of a noncontinuous technique for up/down spectrum scaling of signals is described in U.S. Pat. No. 5,481,182 by Nadkarni et al. In such patent, the up or down conversion of frequencies is achieved using the Doppler effect. As signals propagate over a transmission line having multiple delays, samples of the signal are obtained at each delay point, and the samples are utilized to reconstruct the original source signal without losing any characteristics. While such digital technique is well adapted for capturing single event signals, a need exists for a new apparatus and technique which provides for a continuous up or down scaling of the frequencies of input signals. Another need exists for a technique for spectrum scaling of signals while achieving very low loss in the conversion process.

SUMMARY OF THE INVENTION

In accordance with the principles and concepts of the invention, disclosed is a moving transmission line that provides for the continuous spectrum scaling of signals.

In accordance with the preferred embodiment of the invention, a rotating transmission line comprises a disc rotatable at a given speed. The rotating disc is electrically shielded so that electromagnetic energy is not radiated from the disc. Moreover, the rotating transmission line is provided with an input contact to the disc for inputting signals from a source, and an output contact. For up-scaling of frequencies, the output contact is located preferably at the center of the disc, and the input contact is displaced a given radius from the center of the rotating disc.

The output contact of the rotating disc is coupled to two circuits, one being a very narrow bandpass filter for selecting

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the output frequency desired to be achieved from the spectrum scaling process. The output contact is also coupled through a highpass filter and to a coupling circuit or routing device. Both the signal from the source as well as the signal output from the highpass filter are independently coupled back to the input contact of the rotating transmission line. The highpass filter functions to eliminate those lower frequencies which are not desired to be recirculated from the output contact back to the input rotating transmission line.

The spectrum scaling is achieved by virtue of the gradient of the rotational or angular velocity of the disc in conjunction with the propagation velocity of the electrical wave as it is input to the disc. As can be appreciated, the radial velocity of the disc is greatest at the circumference and is the least near the center of the disc, whereas the propagation velocity of the wave through the disc medium remains relatively constant.

The down-scaling of frequencies can be achieved with the invention so that, for example, by inputting a continuous 1 KHz electrical signal to the system, a continuous 10 Hz signal can be obtained at the output, with relatively insignificant losses in the system.

In accordance with another embodiment of the invention, the Doppler effect can be also utilized in conjunction with a moving medium to provide a spectrum scaling of sound or audio signals.

BRIEF DESCRIPTION OF THE DRAWINGS

Further features and advantages will become apparent from the following and more particular description of the preferred embodiment of the invention, as illustrated in the accompanying drawings in which like reference characters generally refer to the same parts, elements or functions through the views, and in which:

FIG. 1 diagrammatically illustrates the basic components of the rotating transmission line according to the preferred embodiment of the invention;

FIG. 2 illustrates a partial cross-sectional view of the rotating transmission line showing the electromagnetic shielding thereof;

FIG. 3 illustrates in simplified form the vector components of an electrical wave as it propagates from the input to the rotating disc;

FIGS. 4a and 4b illustrate the vector components of the wave velocity, including the radial velocity and the resultant velocity;

FIG. 5 diagrammatically illustrates the vector components of a wave in order for it to reach the output contact at the center of the disc; and

FIG. 6 illustrates the functional blocks of the rotating transmission line according to the preferred embodiment, with the rotating disc diagrammatically shown in equation form.

DETAILED DESCRIPTION

FIG. 1 illustrates a diagram of the rotating transmission line according to the preferred embodiment of the invention. The rotating transmission structure includes a conductive disc 10 that is preferably rotated at a constant speed. The disc 10 can be rotated by motors and feedback circuits such as well known in the field for driving hard disc drives, and the like. When employed to provide spectrum up-scaling of frequencies, a broad band electrical contact 12 is provided at a location spaced from the center of the disc 10. Preferably, although not necessarily, the broad band input contact 12 is

located at the peripheral edge **14** of the disc. In like manner, a broad band output contact **16** is placed at or near the center of the disc **10**. As will be described more thoroughly below, the aspect of the wave velocity of a signal provided at the input contact **12** together with the different radial velocities at different disc radii, enables the signals reaching the output contact **16** at the center of the disc **10** to undergo a Doppler effect. The Doppler effect is the most pronounced at higher radial velocities, and becomes smaller as the electrical wave approaches the center of the disc **10**.

In providing spectrum up-scaling of signals, electrical signals are coupled to an input **18** of the system and to a first input **20** of a routing device **22**. From the routing circuit output **24**, the source signals are coupled to the input contact **12**. The routing device **22** includes a second input **26** for receiving recirculating signals. Electrical signals provided at the first input **20** and the second input **26** of the routing circuit **22** are not mixed or otherwise heterodyned in the routing device **22**, but rather are carried as separate and independent signals to the routing circuit output **24**. The routing device is thus a linear circuit, such as either a "Y" connected transmission line, a dual amplifier circuit with a single output having an overall gain of unity, or other similar linear circuits and devices. Source electrical signals and recirculation or feedback signals coupled via the routing device **22** to the input contact **12** undergo a Doppler effect. In practice, the routing device can be eliminated, whereby the source signals are coupled to a first input contact to the rotating disc **10**, and the feedback signals are coupled to an adjacent second input contact. Those electrical waves that reach the central output contact **16** are removed from the rotating disc and coupled to an electrical junction **28**. An output bandpass filter **30** and a highpass filter **32** have respective inputs coupled to the junction **28**. The bandpass filter **30** preferably has an extremely narrow bandpass at a frequency desired to be achieved at the rotating transmission line system output **34**. For example, if a 1 MHZ signal is provided at the source input **18** and after undergoing the Doppler effect, a 100 Hz signal is provided at the transmission line system output **34**, the bandpass filter would be designed to narrowly pass the 100 Hz signal. Bandpass filters of many designs and types are suitable for providing such function.

The highpass filter **32** may also be of conventional design for passing frequencies above a cutoff point, and blocking the passage of signals with frequencies therebelow. The highpass filter **32** is preferably of the type having a very sharp cutoff frequency, in the example, at about 100 Hz. Thus, while frequencies below 100 Hz are blocked by the highpass filter, all frequencies above such cutoff frequency are passed and coupled to the second input **26** of the routing device **22**. These highpass frequencies are allowed to be input to the rotating disc **10** and recirculated to undergo further or additional Doppler effects. Power losses to the rotating transmission line are minimized by blocking and eliminating the recirculation of low frequencies. As can be appreciated, the bandpass filter **30** and the highpass filter **32** are designed to have particular characteristics to achieve the spectrum up-scaling of desired signals. Indeed, the filters **30** and **32** can be variable or programmable to achieve different up-scaling characteristics.

With reference now to FIG. **2**, there is shown a partial cross-sectional view of the rotating disc structure. The disc **10** is entirely housed within a conductive shield **40** to prevent radiation of electromagnetic signals from the conductive disc **10**. As such, the rotating disc **10** functions as a transmission line, rather than an antenna. The conductive

shield **40** may be typically connected to a circuit common potential, such as ground. Moreover, the conductive shield **40** does not contact the rotating disc **10**. The dielectric medium that electrically isolates the conductive disc **10** from the conductive shield **40** is preferably air. Hence, the rotating disc **10** and shield **40** electrically function similar to a transmission line, such as the coaxial type. Reference is now made to FIGS. **3–5** where there is illustrated the spectrum scaling of signals employing the rotating transmission line. As noted above, there is a continuous spectrum scaling of signals as long as a source signal is input to the system. Moreover, based on a given spectrum scaling factor, signals will be recirculated a number of times to undergo successive Doppler effects before reaching the center frequency of the bandpass filter **30**. As such, there is an inherent time delay that is a function of the scaling factor between the input of a source signal and the output of the desired spectrum scaled signal. With such a system, one can obtain highly accurate conversions of signal frequencies. The radial dimensions of the disc **10**, the rotating speed and the frequency characteristics of the filters determine in a large part the operational frequency of the rotating transmission line. Accordingly, very low frequencies up to microwave frequencies, and higher, can be accommodated by the invention.

With reference now to FIG. **3**, there is shown in simplified form the rotating disc **10**. A signal source **50** is coupled via a source impedance **52** to the broadband input contact **12** of the system. Because the disc **10** is spinning, the input contact **12** injects the source signals continuously around the periphery of the disc **10**. Injection source frequency is then transmitted outwardly into the conductive disc **10**. As the disc **10** continues to rotate, some frequency wave vectors find their way to the disc center, the other frequency vectors do not. Output frequencies finding a path to the disc center are coupled via the broadband output contact **16** to a load resistance **54**. The output of the system is taken across the load resistance **54**.

An electrical wave applied to the rotating disc **10** at the input contact **12** is transmitted outwardly into the conductive disc **10** in a uniform manner, with the wave fronts being of equal radii with respect to the point of input. The vectors V_1 illustrate the transmission of the signal in the disc **10** in all directions. Assuming the disc dimensions are small as compared to the periodicity of the input signal, there is only a single mode of transmission. For the following analysis, the traveling wave velocity of the electrical signal is represented by V_1, the radial velocity of the disc at given points is V_2 and the radius of the disc is R. If the disc **10** were stationary, the only movement would be the propagation of the electrical waves and no Doppler effect would occur. However, in accordance with an important feature of the invention, the disc **10** rotates to thereby allow the electrical waves to propagate on a moving medium, thus resulting in a Doppler effect. As will be set forth below, the Doppler effect can either be additive or subtractive with regard to the original source wave to produce the up and down spectrum scaling of signals.

As can be appreciated from the foregoing, an electrical wave that is initiated at the input contact **12** and has a vector component directed to the center, does not reach the center of the disc **10** as it travels a distance R. Rather, because of the rotational movement of the disc, the wave is deflected in an off-center direction. With regard to FIG. **4a**, there is shown the spinning disc **10** that is rotating in a counterclockwise direction, with a velocity V_2 at a radius R from the center of the disc **10**. In order for a wave front to propagate from the input contact **12** and reach the center output contact

16, a vector portion thereof must be directed as shown by the vector **60**. With the vector component V_1 which represents the electrical wave velocity, and the vector V_2 which represents the radial velocity of the disc, the resultant velocity vector V_r is shown in FIG. **4***b*. The resultant vector V_r is that which reaches the center output contact **16** and undergoes the Doppler effect. The electrical waveform carried on the rotating disc undergoes the Doppler effect due to the velocity gradient of V_2 based on disc radius. As can be appreciated, the linear velocity at any point on the disc is $V=\omega r$, where ω is the angular velocity at a given radius from the center of the disc. The linear velocity of the rotating disc is greatest at its peripheral edge and decreases toward the center of the disc **10**.

FIG. **5** is another illustration of the vector components of the wave velocity V_1, the radial disc velocity V_2, and the resultant velocity V_R. The angle I (Input) is the phase angle between the radius R of the disc **10** and the wave velocity vector component V_1. The angle O (Output) represents the resultant vector V_R with respect to the radius R. It is the resultant vector V_R that must exist with respect to the signal wave front in order for such wave portion to reach the center of the disc **10** and be output by the output contact **16**. The mathematical expression for the spectral output signature is set forth as follows:

$$F_0 = F_s((V_1 - V_2) + V_1)^x,$$

where F_s is the signal input and x is a scaling factor.

It can be appreciated that the Doppler effect can be either additive or subtractive to thereby provide up-scaling or down-scaling of source signals F_s.

As noted above, in view that the disc **10** is rotating in the direction of V_2 shown in FIG. **5**, the wave front vector must point in a partially opposite direction with respect to V_2 in order to reach the center of the disc **10**, where the output contact **16** is positioned. It should be understood that the output contact **10** need not necessarily be at the center of the disc **10**, whereupon the angle of the vector V_R would be different. The first tangential vector at the point of contact for this wave vector is expressed as $V_1 \sin i(1) - V_2$, and the second radial vector is $V_1 \cos i(1)$. In this case, the Doppler effect is V_R/V_1, and the angle of V_R with respect to the radius R is:

$$(i(2)) = \operatorname{Tan}^{-1}((V_1 \sin i(1) - V_2)/(V_1 \cos i(1)).$$

The Doppler effect is thus equal to:

$$V_R/V_1 = ((V_1 \sin i(1) - V_2)^2 + (V_1 \cos i(1))^2)^{0.5}/V_1$$

As noted above, the disc velocity V_2 becomes smaller as the disc radius becomes smaller and thus the Doppler effect becomes smaller as the wave travels from the peripheral edge of the disc **10** toward the center of the disc **10**. As noted above, $V_2 = \omega r$, where ω is the angular velocity of the disc **10** and r is the radius at any point on the disc with respect to the center contact **16**.

Since i(n) commences at i(1) and drops to zero as r goes from R to zero, i(1)/R is a constant by first approximation. In view of the foregoing, i(1)/R=k1, and by similar approximation, $(V_1 - V_R))/R = k2$, then the Doppler effect at any radius r is:

$$D_r = \omega k2[r^2(n) \cdot \sin (k1 \cdot r(n)) - r^2(n-1) \cdot \sin (k1 \cdot r(n-1))]$$

as r goes from O to R for different values of n.

The overall effective Doppler is thus the integral of D_r from r=0 to r=R, divided by R. In other words, the effective

Doppler is:

$$D_t = \int_O^R \frac{D_r}{R}$$

The effective Doppler D_t is for one signal wave which is expected to reach the output contact **16** at the center of the disc **16**. The signal wave vectors that have directions and corresponding angles which cause them to miss the output contact are lost. This will occur for a certain range of magnitudes of the disc velocity V_2. It should be noted that if the input contact **12** is connected at the center of the disc, and the output contact **16** is coupled to the disc at a radius r, the Doppler effect will be additive, namely, $(V_1 + V_2)/V_1$.

If the signal transmission and contact losses are negligible, the spectrum scaling factor D_t will have certain losses associated with it, as only some of the wave vectors will reach the center, output contact **16**. If these losses are negligible, a continuous spectrum scaling will be achieved.

The signal output of the system can be expressed as $F_{out} = F_s(D_t)^x$, where x is determined by the functionality of the bandpass filter **30** and the highpass filter **32**. If, for example, the scaling factor D_t is 0.01, and the rotating transmission line is configured for spectrum down-scaling, this means that if a 1 MHZ signal is the signal source **18** (FIG. **1**) and coupled to the input contact **12** via the routing device **22**, the first frequency coupled to the output contact **16** will be a 10 KHz frequency signal. If, in the example, the bandpass filter **30** has a 100 Hz center frequency, there will be no output signal at this time. Hence, the 10 KHz signal will pass through the highpass filter **32** and be also coupled together with the source signal **18** to the input contact **12** via the routing device **22**. In the second circulation of the signals, they undergo further Doppler effects, whereupon the 10 KHz frequency is further divided by the scaling factor 0.01, whereby a 100 Hz signal appears at the output contact **16**. In this event, the 100 Hz signal is passed by the bandpass filter **30** and an output down-scaled frequency then appears. In addition, the 100 Hz signal is blocked by the highpass filter **32** so that it is not thereafter recirculated to undergo further Doppler effects and/or signal losses. By blocking these lower frequencies, they are prevented from undergoing unnecessary Doppler effects. In this example, it is also noted that a time delay is involved during which the Doppler effects cause the signal to be up-scaled or down-scaled so that they reach the frequency of the bandpass filter **30**. It is noted that the inputs and outputs of the rotating transmission line are reversible to thereby achieve either spectrum up-scaling or down-scaling. It is also noted that those skilled in the art may find that other types of filters can be used to achieve different effects. Indeed, the highpass filter may be dispensed with if power losses are not a concern.

FIG. **6** illustrates a functional diagram of the principals and concepts of the invention. Here, the mechanical portion of the rotating transmission line is shown as a mathematical function, having a spectrum scaling factor D_r. Thus, the mechanical portion of the rotating transmission line may indeed be constructed as an electrical equivalent. Those skilled in the art may desire to carry out the invention utilizing a magnetic field that varies in strength based on radius to thereby cause electrons to undergo a Doppler effect when moving in radial paths. Thus, the electrons will undergo a Doppler effect without involving mechanically moving parts of the system.

Although the present invention has been described above with a certain degree of particularity, it is understood that the

present disclosure has been made by way of example, whereupon changes in detail or structure may be made without departing from the sprit and scope of the invention, as defined by the appended claims.

What is claimed is:

1. A spectrum scaling device, comprising:

a moving medium for carrying signals;

an input device for coupling signals to an input of the moving medium so that the movement of the medium together with the propagation of the signals in the medium allows the signals to undergo a Doppler effect, and

an output device for coupling signals from an output of the moving medium, whereby the frequency coupled at the output of said moving medium is different from the frequency coupled to said input of said moving medium.

2. The spectrum scaling device of claim 1, wherein said moving medium comprises a rotating disc.

3. The spectrum scaling device of claim 1, wherein said signals comprise electrical signals.

4. The spectrum scaling device of claim 2, further including a feedback circuit for recirculating electrical signals from said output device back to said input device.

5. The spectrum scaling device of claim 4, wherein said feedback circuit comprises a highpass filter.

6. The spectrum scaling device of claim 3, further including a bandpass filter for coupling signals from the moving medium output to a system output.

7. A spectrum scaling device, comprising:

a rotating conductive disc;

a first contact and a second contact electrically coupled to said rotating disc; and

a feedback circuit for coupling signals from said second contact back to said first contact.

8. The spectrum scaling device of claim 7, further including a bandpass filter for carrying signals from said second contact.

9. The spectrum scaling device of claim 7, further including a routing device having a first and second input, and an output, said routing device output coupled to said first contact of said rotating disc, a source of signals to be spectrum scaled coupled to said first input, and said feedback circuit coupled to said second input of said routing device.

10. The spectrum scaling of claim 7, wherein said spectrum scaling device is configured for spectrum up-scaling of signals.

11. The spectrum scaling device of claim 7, wherein said spectrum scaling device is configured for spectrum down-scaling.

12. A method of spectrum scaling of signals, comprising the steps of:

coupling signals to a moving medium; and

propagating the signals at different velocities in the moving medium with respect to an output of the moving medium to thereby produce a frequency at the output that is different from a corresponding frequency input to the moving medium.

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