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REPLY TO
ATTN OF: GP

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,550,023

Government or Corporate Employee : California Institute of Technology Pasadena, California 91109

Supplementary Corporate Source (if applicable) : JPL

NASA Patent Case No. : NPO-10198

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:
Yes ☒ No ☐
Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words ". . . with respect to an invention of . . . ."

Elizabeth A. Carter

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Enclosure
Copy of Patent cited above

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FACILITY FORM 602

N71-24806

Dec. 22, 1970 JAMES E. WEBB 3,550,023

ADMINISTRATOR OF THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

REMODULATOR FILTER

Filed April 24, 1968

FIG.1

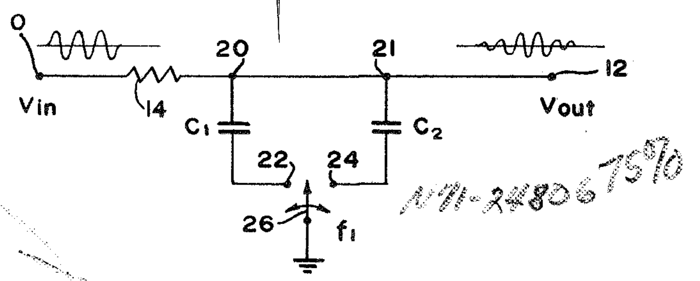


FIG.6

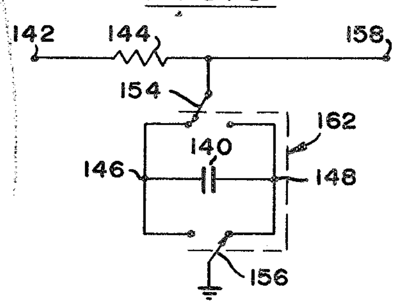


FIG.2

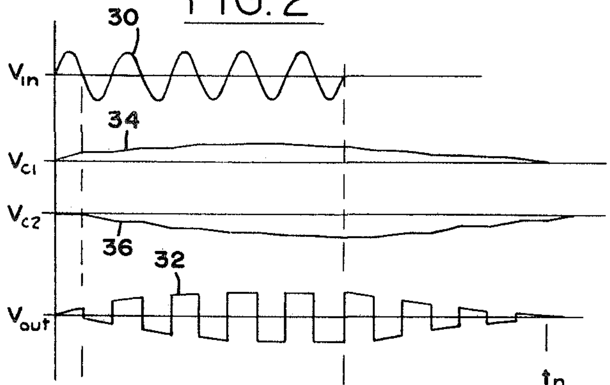


FIG.7

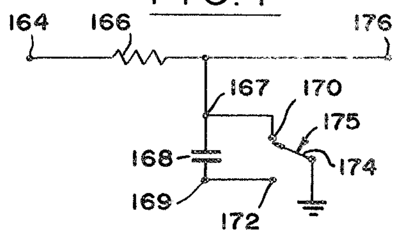


FIG.3

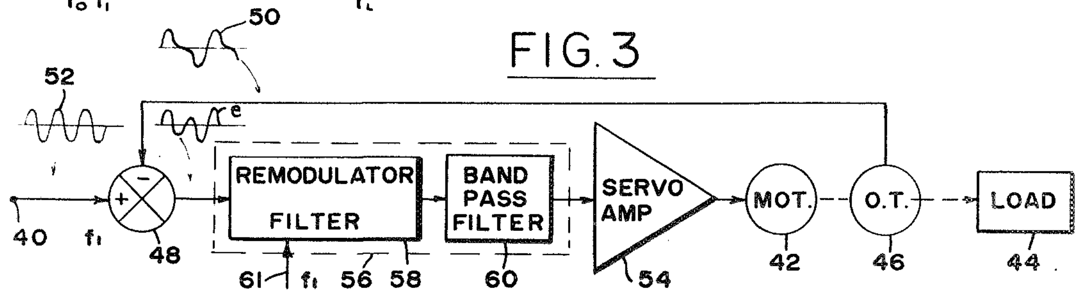


FIG.4

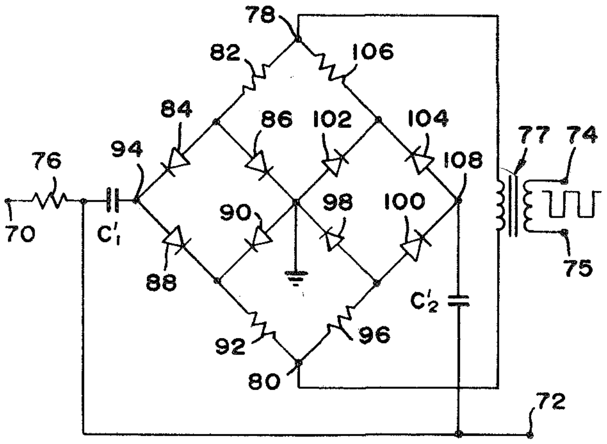
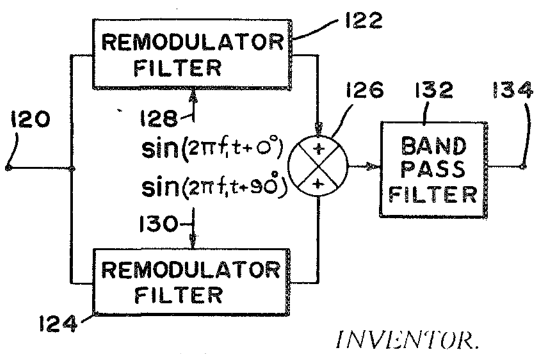


FIG.5



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United States Patent Office

3,550,023
Patented Dec. 22, 1970

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3,550,023
REMODULATOR FILTER

James E. Webb, Administrator of the National Aeronautics and Space Administration, with respect to an invention of Howard C. Vivian, La Canada, Calif.

Filed Apr. 24, 1968, Ser. No. 723,804
Int. Cl. H03b *1/04*
U.S. Cl. 328—165 2 Claims

ABSTRACT OF THE DISCLOSURE

An apparatus is disclosed for filtering an input signal to obtain the components of a particular frequency and phase. The apparatus comprises a pair of capacitors, each having a first side coupled directly to the output and coupled through a common resistor to the input. The apparatus also includes a switch which alternately connects the second side of each capacitor to ground to enable the capacitors to alternately charge toward the input signal level during alternate half cycles of the switch frequency.

ORIGIN OF INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 U.S.C. 2457).

BACKGROUND OF THE INVENTION

(1) Field of the invention

This invention relates to filtering circuits.

(2) Description of the prior art

Many information processing systems require narrow band filtering to limit noise, reject spurious signals or shape the information signal response. Typical filters for these purposes include LC networks, twin-T or parallel-T networks, and phase-locked-loop apparatus. Generally, the use of these filters results in the decrease of an important system performance factor, such as gain, stability, or Q factor.

One method which enables narrow band filtering is disclosed in Pat. 2,909,656, issued Oct. 20, 1959, to M. A. Meyer. It involves the demodulation of the input signal, the filtering of the demodulated signal, and the remodulation of the signal, to obtain or exclude only those components of the original signal of a particular frequency. However, the apparatus required for such processing is at least moderately complex and expensive due to the complexity of the modulating and demodulating processes. Apparatus which simplified these processes would allow this method to be more widely utilized.

In some filtering applications, it is necessary to exclude not only those signal components which differ in frequency from a reference signal, but also those components which differ in phase. For example, in servo and related systems it is important to remove not only the undesired harmonic content from the error signal, but also quadrature components, to avoid saturation and excessive dissipation in other system apparatus. A method for doing this is disclosed in Pat. 3,085,166, issued Apr. 9, 1963, to J. K. Gogia and J. C. Guyeska. It involves demodulating the input signal, filtering the demodulated signal, and remodulating the filtered signal, to obtain only those components of the input signal which are of use in the system. A simpler apparatus which combined the three functions of demodulation, filtering and remodulation in a single circuit would lower the cost and complexity and permit this method to be more widely used.

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OBJECTS AND SUMMARY OF THE INVENTION

One object of the present invention is to provide a synchronous filter capable of operation within a wide band of frequencies including very low frequencies, and which is extremely simple and economical to produce.

Another object is to provide a circuit for performing demodulating, filtering, and remodulating on an input signal to eliminate spurious signal components, which is of very high performance yet of extreme simplicity.

In accordance with the present invention, a narrow band synchronous filtering circuit is provided which comprises a pair of capacitors, each having a first terminal connected to the circuit input through a resistor. The output of the circuit is taken directly from the first capacitor terminals. The circuit includes a switch for alternately connecting the second terminals of the capacitors to ground. The switch is operated at the passband frequency.

The alternate grounding of the capaictors at each half cycle allows one capacitor to charge to the positive excursions of the input while the other charges to the negative excursions of the input, for input components of the passband frequency and which are in phase with the alternations of the switch. Components of other frequencies sometimes add and sometimes subtract from the capacitor charge, while components out of phase by 90° add and subtract the same amount every half-cycle. The net effect of such other components over a period of many cycles is substantially zero.

In certain applications, such as certain servomechanism systems, the frequency and phase of the signal component which it is desired to pass through the filter are known (but not its amplitude). In such cases, the switch can be operated in exact phase relationship to the input signal to be passed, and the output of the simple, two-capacitor filter can be used directly. In other applications, the phase of those input signal components which are of passband frequency is not known. In these applications, two of such two-capacitor circuits are required whose switches operate 90° out of phase with each other. The outputs of the two circuits are added and filtered to eliminate any effects due to the switches being out of phase with the input component of passband frequency.

The novel features of the invention are set forth with particularity in the appended claims. The invention will best be understood from the following description when read in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified circuit diagram of a filtering apparatus constructed in accordance with the invention;

FIG. 2 shows the waveforms of various voltages encountered in the circuit of FIG. 1;

FIG. 3 is a block diagram of a servo system employing the filtering apparatus of the present invention;

FIG. 4 is a more complete circuit diagram of the circuit of FIG. 1;

FIG. 5 is a block diagram of a circuit for enabling filtering when the phase of the input components or center filter frequency is unknown;

FIG. 6 is a simplified circuit diagram of filtering apparatus constructed in accordance with another embodiment of the invention which utilizes only one capacitor; and

FIG. 7 is a simplified circuit diagram of filtering apparatus constructed in accordance with still another embodiment of the invention which utilizes only one capacitor.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 is a simplified circuit diagram of a filtering apparatus in accordance with the invention comprising an input terminal **10**, an output terminal **12**, and a resistance **14** connecting them. The circuit includes a first capacitor C_1 and a second capacitor C_2, each having one terminal **20**, **21** connected to the output **12** and another terminal **22**, **24**. A switch **26** alternately connects one of the capacitor terminals **22** or **24** to a reference potential such as ground. The switch **26** is operated at a frequency f_1 which is equal to the center frequency of the filter.

The operation of the filter circuit of FIG. 1 can be appreciated by considering its response to a sinusoidal input signal at **10** which starts suddenly, and which stops suddenly after a few cycles. It is assumed that the input at **10** is of the same frequency f_1 as the frequency of operation of the switch **26** and is in phase with the operation of the switch. The voltage waveforms for various parts of the circuit of FIG. 1 are shown in FIG. 2. The input voltage is shown at **30**, the output is shown at **32**, the voltage across capacitor C_1 is shown at **34**, and the voltage across capacitor C_2 is shown at **36**.

In the waveforms of FIG. 2, it is assumed that a first cycle of the input voltage **30** begins at the time t_0. At this time, the switch **26** connects the first capacitor C_1 to ground, thereby allowing an increase in the voltage across it. While the capacitor C_1 is connected to ground, its voltage also appears at the output **12**. During the next half cycle, beginning at t_1, the switch connects the second capacitor C_2 to ground, and C_2 acquires a negative voltage, which also appears on the output **12**. On succeeding half cycles, the voltages across the capacitors rise until they reach the average voltage during a half cycle of the input. Upon removal of the input voltage at t_i, the capacitors are alternately discharged exponentially towards zero through the input resistance **14**. After several output cycles without any voltage at the input terminal, a time t_n is reached, after which a negligible output is observed. The time constant of the output envelope is a function of the resistance and capacitance values.

The output voltage **32** is in the nature of a square wave with negligible components of a frequency other than the fundamental frequency and its odd harmonics. Components of a frequency only slightly different than the fundamental frequency do not appear at the output. Thus, if the output signal **32** is passed through a broadband or low pass additional filter of even moderately sharp cutoff above the frequency f_1 (to eliminate odd harmonics) an almost pure sinusoidal output will be obtained. This output of the additional filter will equal the component at the input **10** of the frequency f_1.

FIG. 3 illustrates one application of the filter circuit of FIG. 1. This is as a phase or waveform restorer in an alternating current servomechanism system. FIG. 3 is a block diagram of a typical servomechanism which includes an input terminal **40** whose input signal **52**, after processing, energizes a motor **42** that drives a load **44**. An output transducer **46** connected to the motor shaft generates a signal **50** which is delivered to a summing junction **48**. The summing junction substracts the transducer signal **50** from the input signal **52** and delivers a difference signal e. This difference signal must be amplified by a servoamplifier **54** to drive the motor. As the motor is driven, the transducer output **50** increases. This results in a decrease in the output from the summing circuit **48**, thereby decreasing the input to the motor.

The carrier frequency used for the input signal **52** is the same as the frequency of the excitation signals for the transducer **46**, e.g., the signals that energize the field coils of a synchro generator transducer. Accordingly, the fundamental frequencies of all inputs to the summing circuit **48** are the same. However, due to phase shifts and waveform distortions in the transducer **46**, its output **50** may differ in phase from the input at **40** and may also contain harmonic components, particularly the first harmonic. (Even if the input **40** contains harmonic components, distortion will result in a different proportion of harmonic content in the transducer output **50**.) When subtracted by the summing circuit **48**, the fundamental in-phase content at the output of the summing circuit **48** may be zero, but a large quadrature and harmonic signal will remain that overloads the servoamplifier **54** and causes excessive heating of the motor.

A filter system **56**, which includes a remodulator filter **58** whose output is passed through a bandpass filter **60** is used to filter the output of the summing circuit. This filter system extracts the fundamental in-phase component of signals and provides a controlled phase and waveform to the servoamplifier **54**. The switch of the remodulator filter **58** is driven by a signal f_1 at switch input **61**, which is at the same frequency and phase as the signal **52** at the circuit input **40**. The bandpass filter **60** can be of a moderate bandwidth which can prevent the passage of the third and higher harmonics of the filtering frequency. A simple LC circuit can be used for this purpose. It should be noted that, since the remodulator filter operates by filtering the information content of the input signal, a lag in response is produced which must be considered in the design of the servomechanism loop.

FIG. 4 shows an embodiment of a remodulator filter circuit of the type shown in FIG. 1. The input waveform to be filtered is received at input terminal **70**, while the output is delivered at output terminal **72**. The switch input which governs the frequency and phase of filtering is received at the control inputs **74** and **75** and passed through a transformer **77**. The switch signal may be a square wave, whose fundamental frequency is the center of the passband, and whose instants of voltage change represent the zero crossings of the signals having a phase which will allow them to pass through the filtering circuit without reduction.

Input signals to be filtered, which are received at **70**, pass through a resistance **76** corresponding to the resistance **14** in FIG. 1. These signals are processed by capacitors C_1' and C_2' corresponding to the capacitors C_1 and C_2 of FIG. 1. The eight diode arrangement serves the function of the switch **26** of FIG. 1. When the input at **74** is positive with respect to terminal **75**, so that the terminal **78** is positive while the terminal **80** is negative, currents flow through resistor **82**, the four diodes **84**, **86**, **88**, and **90**, and resistor **92**. The terminal **94** is then essentially grounded, so that capacitor C_1' begins to charge. When the input at **74** becomes negative, the terminal **80** is positive while terminal **78** is negative, and currents flow through resistor **96**, diodes **98**, **100**, **102**, **104** and resistor **106**. Junction **108** is then essentially grounded so capacitor C_2' is charged by the input. Thus, the apparatus operates in the same manner as the switch **26** illustrated diagramatically in FIG. 1. A variety of other switching arrangements can, of course, be used instead of the diode arrangement of FIG. 4.

FIG. 5 illustrates an application of the invention for filtering an input signal of unknown phase by the use of two remodulator filters of the type shown in FIG. 1. The apparatus of FIG. 5 comprises an input terminal **120** for receiving signals to be filtered, a pair of remodulator filters **122** and **124**, and an adder circuit **126** for adding the outputs of the two remodulator filters. Each remodulator filter is of the type shown in FIG. 1, and both have a switch driven at a frequency f_1 which is the only frequency to be passed through the filter.

While both remodulator switches are driven at the same frequency, the switches are operated 90° out of phase with each other. Thus, the switch input **128** to the first remodulator filter may be defined by $\sin(2\pi f_1 t+0°)$, while the switch input **130** to the second remodulator filter may be defined by the function $\sin(2\pi f_1 t+90°)$. In practice, square waves are often used, and the foregoing sine waves would be the fundamental components of such square waves.

The outputs from the two remodulator filters are added together in the adder circuit **126**. The output of the adder circuit is proportional to the component of frequency f_1 at the input **120**, regardless of the phase of that component. For example, the f_1 component at the circuit input **120** may be greatly out of phase with the switching of the first remodulator filter **122**. However, the resulting decrease in output from the first remodulator filter **122** is made up by the increase in output from the second remodulator filter **124**. The sum of the outputs of the two filters, which are switched 90° out of phase with each other, is always proportional to the input at **120**. The output from the adder circuit **126** is in the nature of a square wave of the type shown at **32** in FIG. 2, and can be passed through a broad passband filter **132** which eliminates third and higher harmonics before reaching the output terminal **134**.

The manner of filtering by synchronously charging a capacitor during half cycles of the center frequency can be accomplished in a number of different ways. FIGS. 6 and 7 illustrate filtering apparatus utilizing only one capacitor.

In FIG. 6, a capacitor **140** is utilized which has two terminals **146** and **148**. The two terminals are alternately connected to two switch arms **154** and **156** of a double-pole-double-throw switch **162**. The input **142** to the circuit is connected through a resistor **144** to the switch arm **154**, while the other switch arm **156** is connected to ground. The switch **162** is driven at the center passband frequency f_1. Thus, capacitor terminals **146** and **148** are alternately connected to the output **158** and to ground at every half-cycle. The output of the circuit of FIG. 6 is similar to the output of the circuit of FIG. 1.

FIG. 7 illustrates a half-wave filtering apparatus utilizing one capacitor **168**. The capacitor has two terminals **167** and **169** which are connected to two contacts **170** and **172** of a single-pole-double-throw switch **175**. The capacitor terminal **167** is also connected directly to the circuit output **176**, and through a resistor **166** to the circuit input **164**. The arm **174** of the switch has one side connected to ground, while the other side alternates at a center passband frequency f_1 between the two contacts **170** and **172**. The output of the circuit of FIG. 7 is zero (ground) at alternate half cycles, and is the same as the circuit of FIG.1 during the other half cycles.

Although particular embodiments of the invention have been described and illustrated herein, it is recognized that modifications and variations may readily occur

to those skilled in the art, and, consequently, it is intended that the claims be interpreted to cover such modifications and equivalents.

What is claimed is:

1. Bandpass filtering apparatus responsive to an input signal for passing signal components of a selected frequency, comprising:
first capacitance means;
first charging means for repeatedly charging said first capacitance means towards the level of said input signal during periods spaced at said selected frequency;
first output means coupled to said first capacitance means for carrying a signal proportional to the voltage across said first capacitance means;
second capacitance means;
second means for repeatedly charging said second capacitance means towards said input signal during periods spaced at said selected frequency, but phase delayed by 90° of said frequency with respect to the periods of said first charging means;
second output terminal means coupled to said second capacitance means for carrying a signal proportional to the voltage across said second capacitance means; and
adder means coupled to said first output means and second output terminal means for generating a signal proportional to their sum.

2. Filtering apparatus as defined in claim 1 including:
additional filter means coupled to said output means for filtering out only signals of a frequency approximately equal to and greater than the third harmonic of said selected frequency.

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STANLEY T. KRAWCZEWICZ, Primary Examiner

U.S. Cl. X.R.

307—233, 240, 246, 257, 317; 328—127, 138; 329—50