Nov. 10, 1970 G. E. MINNICH ET AL 3,538,624

AIRCRAFT SIMULATION

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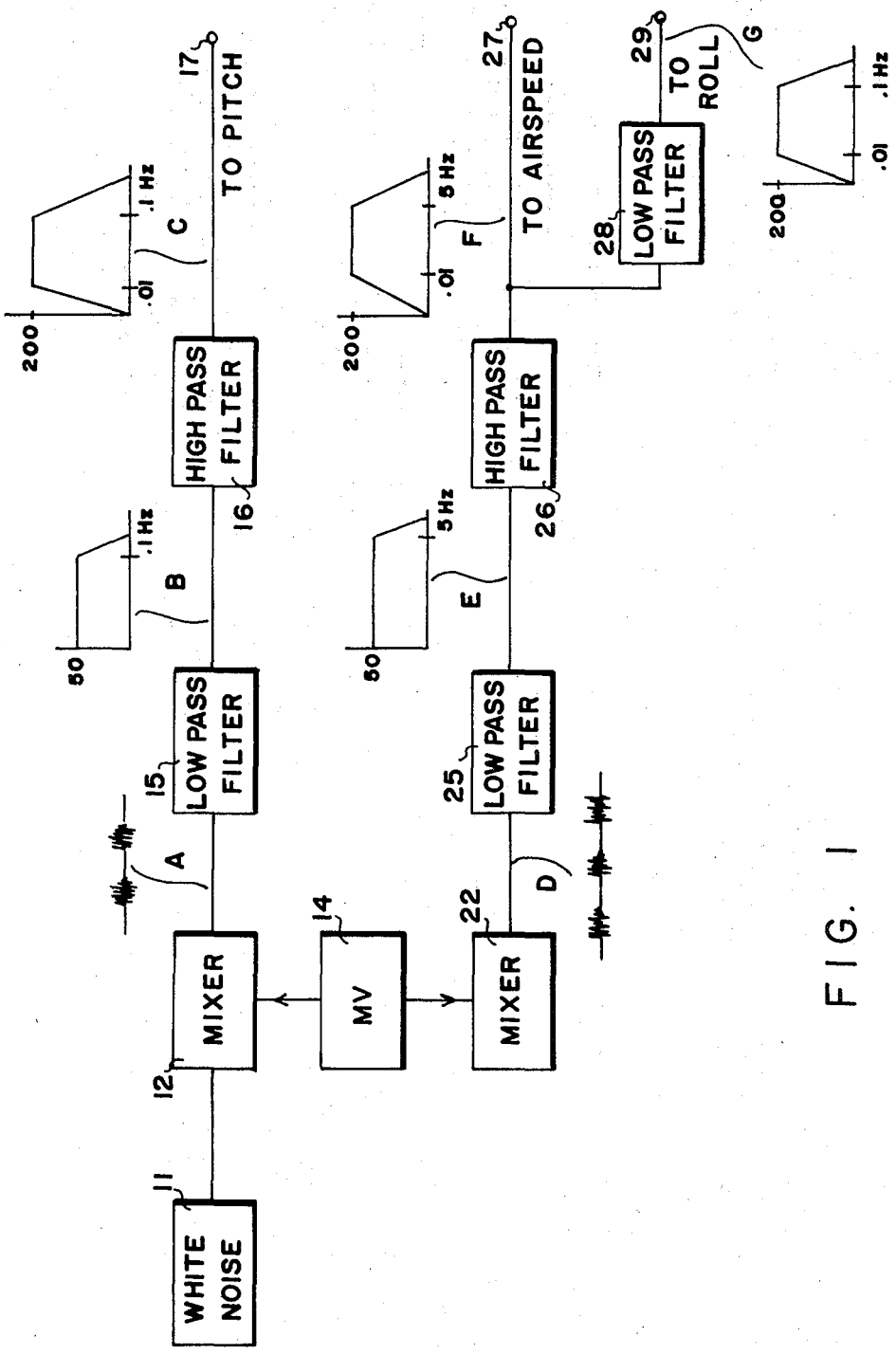

FIG. 1

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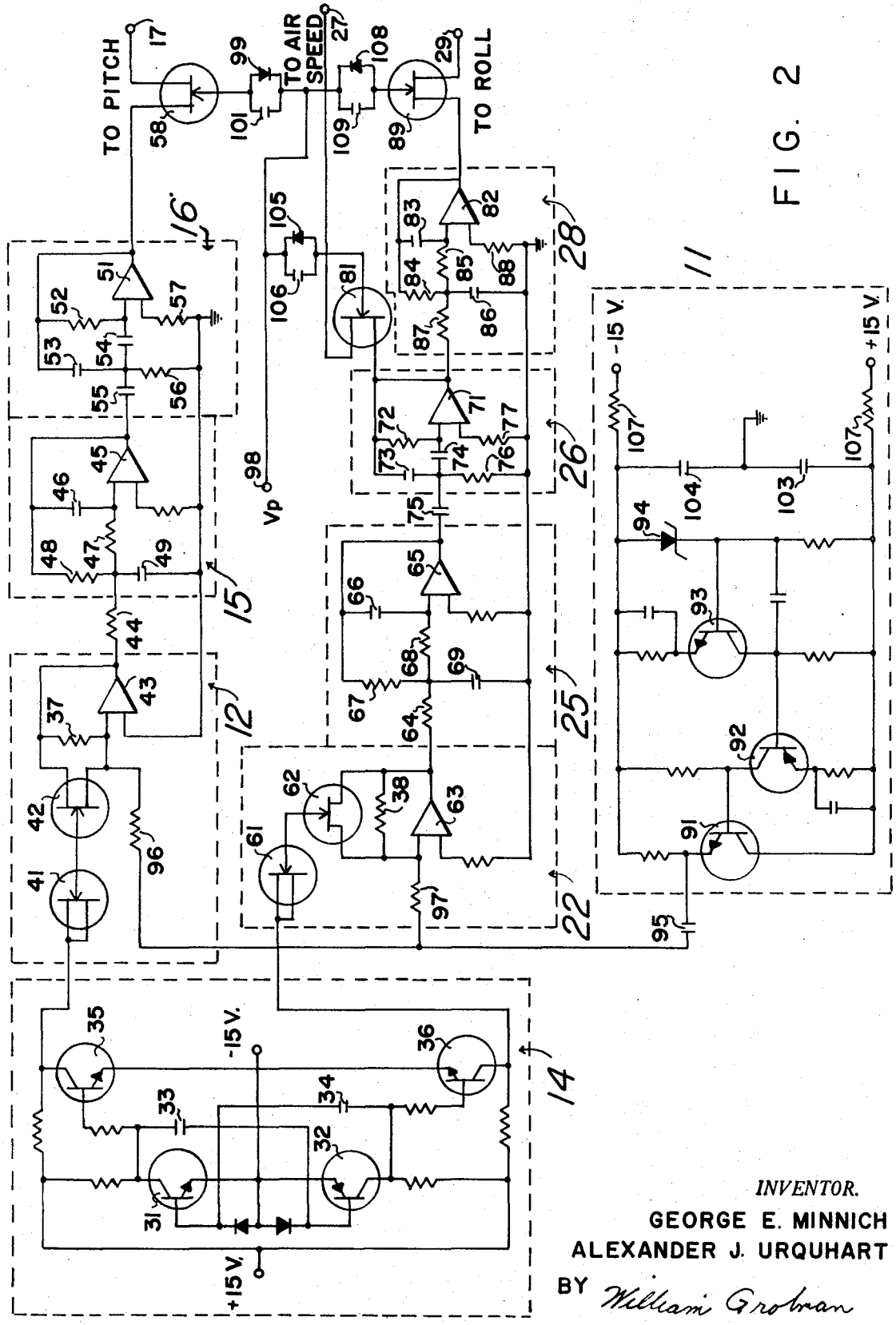

FIG. 2

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AIRCRAFT SIMULATION

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U.S. Cl. 35—12 7 Claims

ABSTRACT OF THE DISCLOSURE

In fixed-base cockpit trainers for simulating the flight characteristics of aircraft, the pitch and roll accelerations are often simulated to produce in the mind of the trainee the impressions he would receive in the actual aircraft. One form of these motions is produced by what is known as "rough air." The effect of rough air is to buffet the trainee in the cockpit. This effect can be introduced by the instructor, if there is one, or automatically by programming it into the training course. One device for producing the effects of rough air is described in this invention. The scheme devised herein is for use in solid state electronic analog computer systems and includes two channels of transmission through the system. A white noise source is multiplexed into the two channels by means of a free-running multivibrator. Since the energy content of low frequency (below 5 Hz.) random noise is very low, a multiplexing system is employed. The effect of the multiplexing is to mix the output of the multivibrator with the random noise and produce useable noise in the low frequency range. Active filters in each channel filter out all but the low frequency components, the difference components, which are passed-on to the pitch and roll computer sections. In those computer sections, the input signals from the rough air generator are used as inputs to affect the computations of the pitch and the roll. In addition, a slightly higher frequency signal is bled off to control the airspeed indicator to duplicate the effect of rough air on the pitot tube in the aircraft.

This invention relates to simulators for duplicating the characteristics of aircraft in flight and, more particularly, to the effects of rough air on grounded base training cockpits.

For the realistic training of future pilots, the fidelity of operation of the system should include as many actual characteristics of an aircraft in flight as possible. One of the flight characteristics is that produced when an aircraft encounters turbulenece in the atmosphere. Unless a pilot is trained to overcome the effects of turbulence, he can rapidly get into trouble in rough air. The duplication of the effects of turbulence in a fixed-base cockpit trainer can assume any of several forms depending upon the type of trainer. In the older Link trainers which were moved by a pneumatic or vacuum system turbulence could be introduced by the rapid movement of a control valve. In later systems which utilize hydraulically driven motion systems, and which included digital computers to compute or calculate the electrical analogs of the flight characteristics, rough air was often produced as a computer program. The digital computer would, in effect, produce a random variation which was then transmitted further to

control the hydraulic motion system. More recent developments have been small, general-purpose aviation trainers which use electrically driven motion systems and solid state analog computers. In the analog computers, the flight equations for the particular type of aircraft being simulated are continually being computed and the electrical results of those computations are fed to the motor control systems to produce the desired effects in pitch and roll. This invention introduces a new means for developing electrical signals to be used in the computations of such an analog computer.

It is an object of this invention to provide a new and improved system for duplicating the effects of aircraft flight characteristics on a fixed-base cockpit trainer.

It is another object of this invention to provide a new and improved system for modifying the operation of a fixed-base cockpit trainer.

It is a further object of this invention to provide a system for randomly modifying the operation of a vehicle motion system.

It is still another object of this invention to provide a new and improved rough air generator for use with vehicle simulators having motion systems.

Other objects and advantages of this invention will become more apparent as the following description proceeds which description should be considered together with the accompanying drawings in which:

FIG. 1 is a block diagram of a generator in accordance with this invention; and

FIG. 2 is a schematic wiring diagram of the system of FIG. 1.

Referring now to the drawings in detail and more particularly to FIG. 1, the reference character **11** designates a source of white noise. The output from the white noise source **11** feeds the inputs to two separate channels. The first channel comprises a mixer **12** the output of which is applied to the input of a low pass filter **15** which then feeds a high pass filter **16**. The output of the high pass filter **16** is applied to an output terminal **17** which can be connected to one input of a computer which computes the pitch equations. The second channel comprises a mixer **22** whose output is applied to the input of a low pass filter **25** which feeds a high pass filter **26**. The output of a high pass filter **26** is simultaneously applied to an output terminal **27** which can be connected to an airspeed indicator and to an input of another low pass filter **28** whose output feeds a terminal **29** which can be connected to a roll input of the computer. A free-running multivibrator **14** has two outputs, one of which feeds the mixer **12** and the other of which feeds the mixer **22**.

The white noise source **11** generates random electrical signals of a wire band of frequencies. Although the output of the source **11** is applied simultaneously to the inputs to the two mixers **22** and **12**, the multivibrator **14**, in effect, duplexes the output from the white noise source **11** and renders one of the two mixers **12** and **22** operative during each half-cycle of its output. The multivibrator **14** can operate at any convenient frequency within the useable noise spectrum, and its signals are mixed in the mixers **12** and **22** with the random signals from the source **11**. The low pass filters **15** and **25** receive the outputs of the mixers **12** and **22**, respectively, and pass only those signals which have frequencies below the cutoff frequency of the filter. Since the amount of energy contained in the low frequency components of white noise is very low in com-

parison to the energy contained in the higher frequency signals, the white noise is mixed with the output of the multivibrator **14**. The two low pass filters **15** and **25** are, in effect, difference filters and pass only those signals which have frequencies which are the difference between the frequency of the multivibrator **14** and the signals from the source **11**. Thus, the signals which are passed through the low pass filters **15** and **25** are of substantially higher energy content than are the original low frequency signals generated by the source **11**.

Since rough air, or turbulence in the atmosphere, occurs at relatively low frequencies and since its effects upon a relatively slow moving aircraft (below 100 miles per hour, for example) are superimposed upon the motion of the aircraft itself, the result upon the aircraft occurs at very low frequencies. For example, modifications to the pitch and the roll of an aircraft in flight usually take place at frequencies of one cycle per second or less. For this reason, the low pass filter **15** has a shoulder or roll-off portion at 0.1 cycle per second. The output of the low pass filter **15** is applied to a "high pass" filter **16** which passes only those signals having a frequency higher than 0.01 cycle per second. Thus, the final output signals applied to the terminal **17** are random signals which lie between 0.01 and 0.1 cycle per second. When this random effect is applied to that portion of the computer which calculates the pitch equations for the aircraft, it modifies the pitch in a random manner at frequencies which lie between 0.01 and 0.1 cycle per second.

In addition to the effect upon pitch and roll of an aircraft in flight, air turbulence also affects the operation of the pitot tube which senses air speed. Because the pitot tube extends outwardly from the aircraft itself, the turbulence effects are at a slightly higher frequency than the effects on the pitch and roll of the aircraft. Therefore, the low pass filter **25** in the second channel has a cutoff shoulder at about 5 cycles per second. The information applied to the low pass filter **25** is essentially the same as the information applied to the low pass filter **15**, but its output is at a higher frequency and the noise variations are completely independent. When the output of the low pass filter **25** is applied to the low pass filter **26**, which has a cutoff shoulder at 0.01 cycle per second, the output of the filter **26** applied to the output terminal **27** is a series of random variations which occur at frequencies lying between 0.01 and 5 cycles per second. The output terminal **27** can be connected to the airspeed indicator, through an amplifier if desirable, so that the indications of the airspeed indicator are modified by the random signals.

The output of the high pass filter **26** is also applied to the input of a second low pass filter **28**. This low pass filter **28** can be identical with the low pass filter **15**. The effect of the filter **28** is to narrow the pass band of frequencies to the range between 0.01 and 0.1 cycle per second. This information is applied to the output terminal **29** to be fed to the computer portion which computes the roll equations for the aircraft. In this manner, the effect upon roll is modulated by the output of the filter **28**.

At each portion of the system shown in block form in FIG. 1 is a curve which gives an indication of the operation of the system at that point. The curves A, B, C, D, E, F and G are supplied for explanatory purposes only. Thus, considering the top channel, the output of the mixer **12** is shown as a series of bursts of oscillations at random frequencies with dead spaces in between. The curve D at the output of the mixer **22** should be essentially identical to the curve A except that the bursts of D occur at the gaps of A. Since the noise is being mixed in the two channels at different intervals, the two channels are independent of each other. The curve B shows the general effect of the low pass filter which passes, at a reasonably constant amplitude, signals below 0.1 cycle per second and whose output begins to rapidly fall off at that frequency. After passing through the high pass filter **16**, the curve C shows that the signals shown in curve B now fall off rapidly at both ends, below 0.01 cycle and above 0.1 cycle per second.

FIG. 2 illustrates the system of FIG. 1 in more detail. Each portion of FIG. 1 is shown in FIG. 2 within dashed lines with the same reference numerals used in FIG. 1. Thus, the white noise source **11** is shown comprising transistors **91**, **92** and **93** and a Zener diode **94**. The Zener diode **94** is literally the source of white noise, and its noise generation is applied to the base electrode of the transistor **93**. The output of the transistor **93** is applied to the transistor **92** which amplifies it and applied the amplified output to the transistor **91** for further amplification. Power is supplied to the white noise source **11** from a source of 15 volts direct current through load resistors **107** and across filter capacitors **103** and **104**. The various capacitors and resistors connected to the transistors **91**, **92** and **93** are load and coupling impedances. The output of the white noise source **11** ranges in frequency from about 50 cycles per second to 10,000 cycles per second. This is applied through a coupling capacitor **95** to the inputs of the two mixers **12** and **22**. The mixer **12** comprises an operational amplifier **43** which has one side grounded and its other side connected through a resistor **96** to the coupling capacitor **95**. In addition, the input to the operational amplifier **43** is connected to the drain electrode of a field effect transistor **42**. The source electrode of the FET **42** is connected in the feedback path of the operational amplifier **43**, and its gate electrode is connected to the gate electrode of a field effect transistor **41**. The source and drain electrodes of the transistor **41** are connected together and to one output of the multivibrator **14**. Thus, the mixer **12**, which comprises the operational amplifier **43** and the two FETs **41** and **42**, has applied through a resistor **96** the output of the white source generator **11** and through the FET **41** the output of one side of a multivibrator **14**.

The multivibrator **14** comprises a pair of transistors **31** and **32**. The base electrode of the transistor **31** is connected to the collector electrode of the transistor **32** through a capacitor **34**, and the base electrode of the transistor **32** is connected to the collector electrode of the transistor **31** through a capacitor **33**. Thus, together with the resistors which form the time constants and determine the frequency of the multivibrator, the transistors **31** and **32** are cross-connected to provide a free-running oscillator. The output from the transistor **31** is applied through a transistor **35** and the output from the transistor **32** is applied through a transistor **36**. Energy is supplied to the multivibrator **14** from a source of 15 volts direct current which could be the same source that supplies the white noise source **11**. The operation of the multivibrator **14** is that of a standard multivibrator which is old and well-known and need not be described in detail here. However, since it is important to the operation of the circuit, it must be mentioned that when the transistor **35** is conductive, the transistor **36** is nonconductive so that the output applied to one of the mixers **12** and **22** is high while the output applied to the other mixer is low. In the operation of the mixer **12**, the FET **41** serves as a voltage variable capacitor which passes the square wave output from the multivibrator **14** to the gate electrode of the FET **42**. When FET **42** is turned on, the low source-to-drain impedance of that FET short-circuits the feedback impedance **37** of the amplifier **43**. This interrups the passage of the white noise applied by the resistor **96** through the amplifier **43**. In a sense, this chops the white noise from the source **11**.

The mixer **22** of the second channel is similarly constructed and operates in the same manner as the mixer **12**. The mixer **22** comprises an operational amplifier **63** having a feedback resistor **38**. A FET **62** has its source and drain electrodes connected across the resistor **38** and its gate electrode connected to the gate electrode of a

field effect transistor **61** whose source and drain electrodes are connected together and to the output of the transistor **36** in the multivibrator **14**. The output of the white noise source **11** is applied to the input of the operational amplifier **63** through a resistor **97**. When the output from the transistor **36** is applied through the FET **61**, which operates as a voltage variable capacitor, to the gate electrode of the FET **62**, that FET is turned on and effectively short circuits the resistor **38**. Thus, the output of the operational amplifier **63** is interrupted for each half-cycle output of the multivibrator **14**. The two mixers **12** and **22** chop the white noise source on alternate half-cycles.

The filters used in the system of FIG. 2 are, for convenience, active filters. The filter **15** comprises an operational amplifier **45** having a feedback path which includes a capacitor **46**, a resistor **48** connected in parallel therewith and a resistor **47** between the two. The output from the mixer **12** is applied through a resistor **44** to the junction of the resistors **47** and **48**, which junction is connected to ground through a capacitor **94**. As the signals applied to the input of the filter **15** vary in frequency, the operational characteristics of the amplifier **45** are varied due to the time constants provided by the capacitors **46** and **49** and the resistors **47** and **48**. Thus, the filter **15** can be arranged to pass at a fairly constant or fixed amplitude signals which are below a desired frequency, in this case 0.1 cycle per second.

The filter **16** is a high pass filter which comprises an operational amplifier **51** having a feedback path which includes a resistor **52** and a capacitor **53**. A capacitor **54** is connected in the input to the amplifier **51** with one side connected to one side of the capacitor **53**, and a resistor **56** has one end connected to the junction of the capacitors **53** and **54** and its other end grounded. Energy is coupled from the output of the filter **15** to the input of the filter **16** through a capacitor **55**. Again, the operational characteristics of the amplifier **51** are varied with the variations in input signal frequency due to the time constants proivded by the resistors **52** and **56** and capacitors **53** and **54**. Filter **16** is a high pass filter and its resistors and capacitors are selected to pass signals above a minimum frequency of 0.01 cycle per second. The low pass filter **25**, the high pass filter **26**, and the low pass filter **28** are similar in construction and operation to the low pass filter **15** and the high pass filter **16**. For this reason, their construction and operation will not be discussed in detail herein.

An airspeed voltage is applied to an input terminal **98** and is applied through a combination of a diode **99** and a capacitor **101** to the gate electrode of a field effect transistor **58**. The output of the filter **16** is applied to the source electrode of the FET **58** and the output terminal **17** is connected to the drain electrode. Thus, the signal which is applied to the output terminal **17** for application to the pitch portion of the computer is a combination of the airspeed voltage and the output from the filter **16**. The airspeed voltage is also applied through a parallel combination of a diode **105** and a capacitor **106** to the gate electrode of a field effect transistor **81**. The source electrode of that FET is connected to the output of the filter **26** which is a high pass filter and passes relatively high frequency signals. The drain electrode of FET **81** is connected to the output terminal **27** which is connected to the airspeed indicator. In this way, the output signals applied to the airspeed indicator are those having the higher frequency random noise applied thereon. The airspeed voltage is also applied through the combination of a diode **108** and a capacitor **109** to the gate electrode of a FET **89**. The source electrode of FET **89** is connected to the output of the low pass filter **28** and its drain electrode is connected to the output terminal **29** which is, in turn, connected to the roll input of the computer. Thus, the roll input portion of the computer has applied to it the airspeed voltage with the random low frequency random noise superimposed thereon. The field effect transistors **81**, **89** and **58** effectively multiply the pitch and roll rough air signals by the airspeed signal so that there are no rough air effect when the airspeed is zero.

The above specification has described a new and improved system for generating rough air signals for use in training devices having motion systems. The apparatus illustrated and described is simple, yet effective and is particularly useful in those vehicle training systems which incorporate solid state analog computers. The random signals which formerly have a low energy content are converted into low frequency signals having a higher energy content by means of an appropriate mixer and the frequency characteristics of the rough air signals are determined by appropriately designed active filters. The overall system as shown and described comprises a new inexpensive but very effective apparatus to accomplish what has been an expensive operation in the past. It is realized that the above description may indicate to others skilled in the art additional ways in which the apparatus of this system may be used without departing from its principles. It is, therefore, intended that this invention be limited only by the scope of the appended claims.

What is claimed is:

1. In a fixed-base aircraft simulator which includes at least means for simulating the effects of aircraft speed, pitch and roll and which also includes electrical means for controlling the simulation of aircraft speed, pitch and roll in response to information from the trainee, the simulated aircraft operation and the simulated environment, apparatus for producing signals to simulate the effects of rough air; said apparatus comprising a noise generator; a first channel and a second channel; a source of alternating signals; first means in said first channel for mixing the output of said noise generator and a first half of the output from said source of alternating signals; second means in said second channel for mixing the output from said noise generator and the other half of the output from said source of alternating signals; first filter means in said first channel for passing a first select band of signal frequencies; second filter means in said second channel for passing a second select band of signal frequencies; and means for applying the outputs of said first and second channels to pitch and roll inputs of said electrical control means so that the output signals from said first and second channels affect the pitch and roll outputs from said control means.

2. The simulator defined in claim **1** where said first filter means in said first channel comprises a first low pass filter and a first high pass filter in series to provide a narrow band having a first high frequency cutoff point.

3. The simulator defined in claim **1** wherein said second filter means in said second channel comprises a second low pass filter, a second high pass filter and a third low pass filter in series to provide a narrow pass band having a first high frequency cutoff point.

4. The simulator defined in claim **2** wherein said second filter means in said second channel comprises a second low pass filter, a second high pass filter and a third low pass filter in series to provide a narrow pass band having said first high frequency cutoff point.

5. The simulator defined in claim **3** further including means connected to the output of said second high pass filter for supplying signals having a second high frequency cutoff point to an airspeed input of said electrical control means to affect the airspeed simulation, said second cutoff point being at a higher frequency than said first cutoff point.

6. The simulator defined in claim **4** further including means connected to the output of said second high pass filter for supplying signals having a second high frequency cutoff point to an airspeed input of said electrical control

means to affect the airspeed simulation, said second cut-off point being at a higher frequency than said first cut-off point.

7. The simulator defined in any one of claims 1, 2, 3, 4, 5 or 6 further including a first multiplier interposed in the output from said first channel, a second multiplier interposed in the output from said second channel, and means for applying a signal representative of simulated airspeed applied to said first and second multipliers so that no outputs appear from said first and second channels when the simulated airspeed is zero.

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