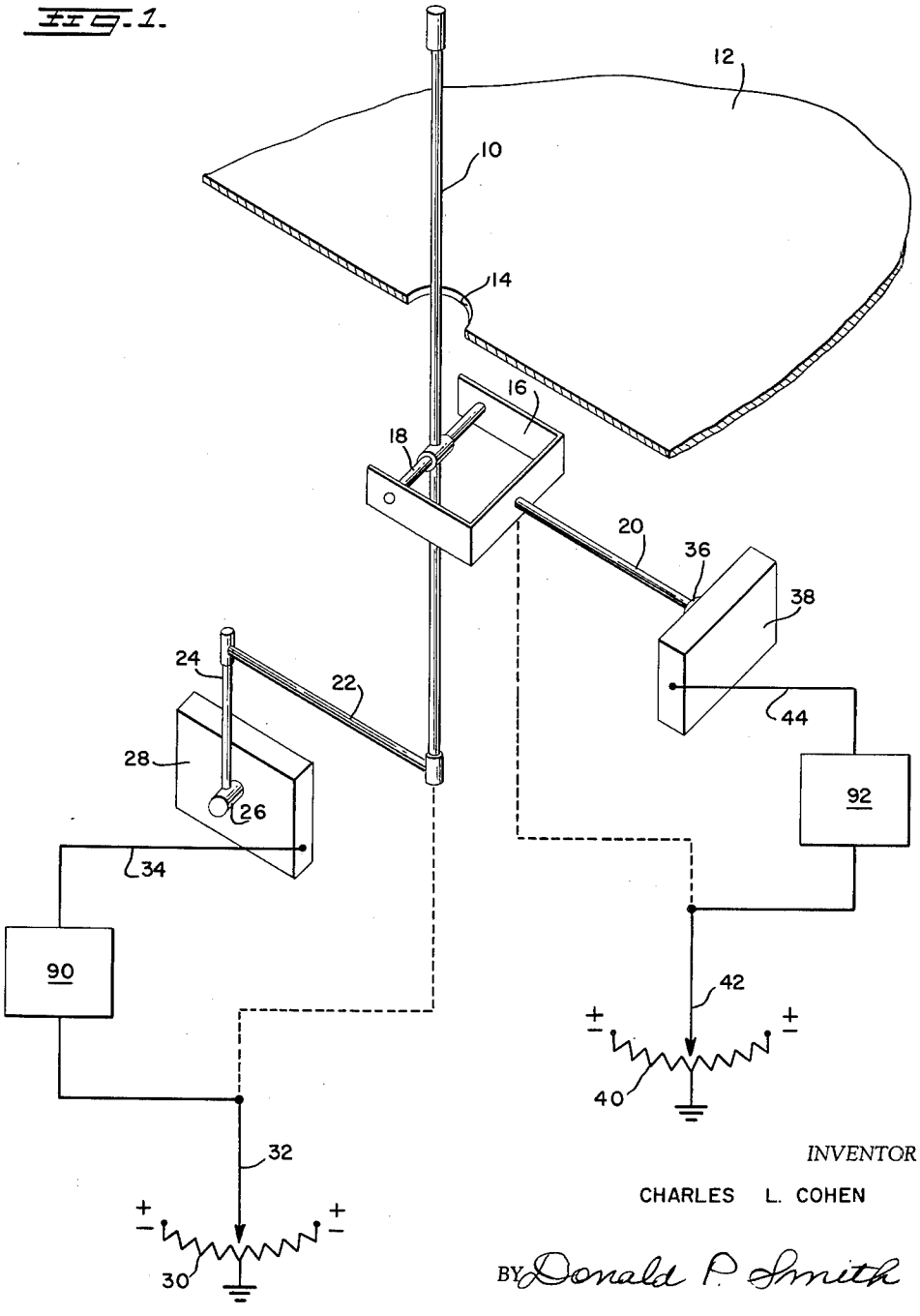
May 1, 1962 C. L. COHEN 3,031,775

FLIGHT SIMULATOR

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Fig. 1.



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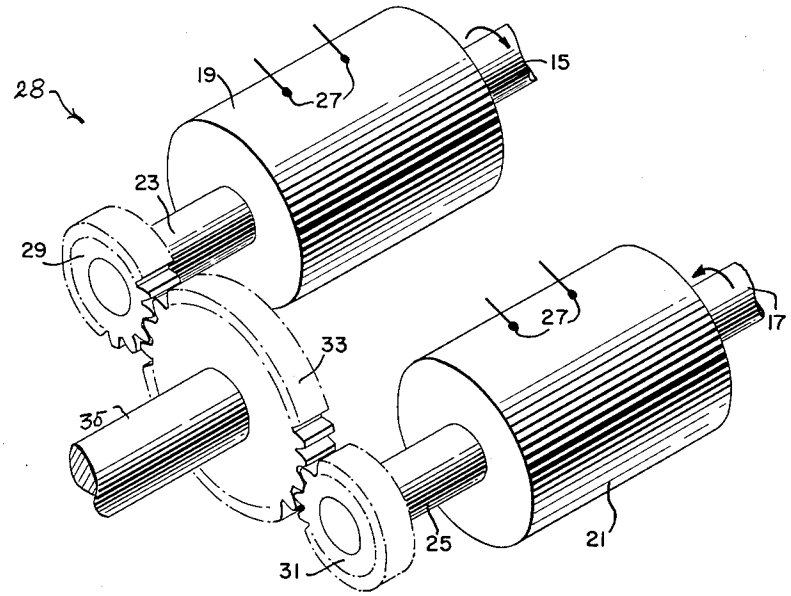


FIG. 4.

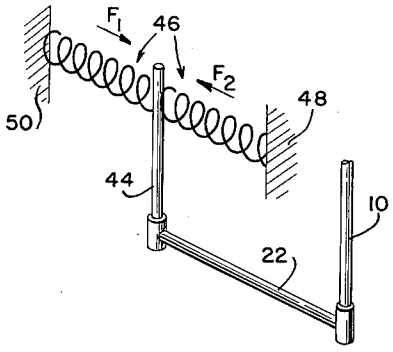
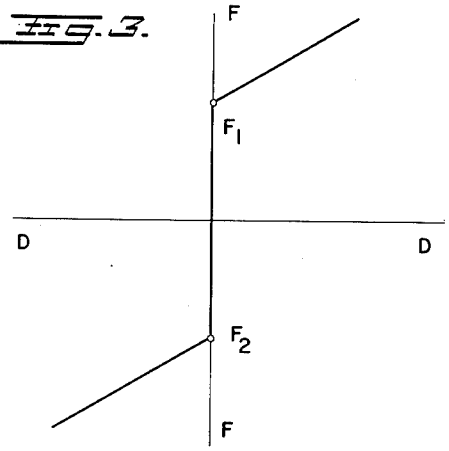


FIG. 2.

FIG. 3.



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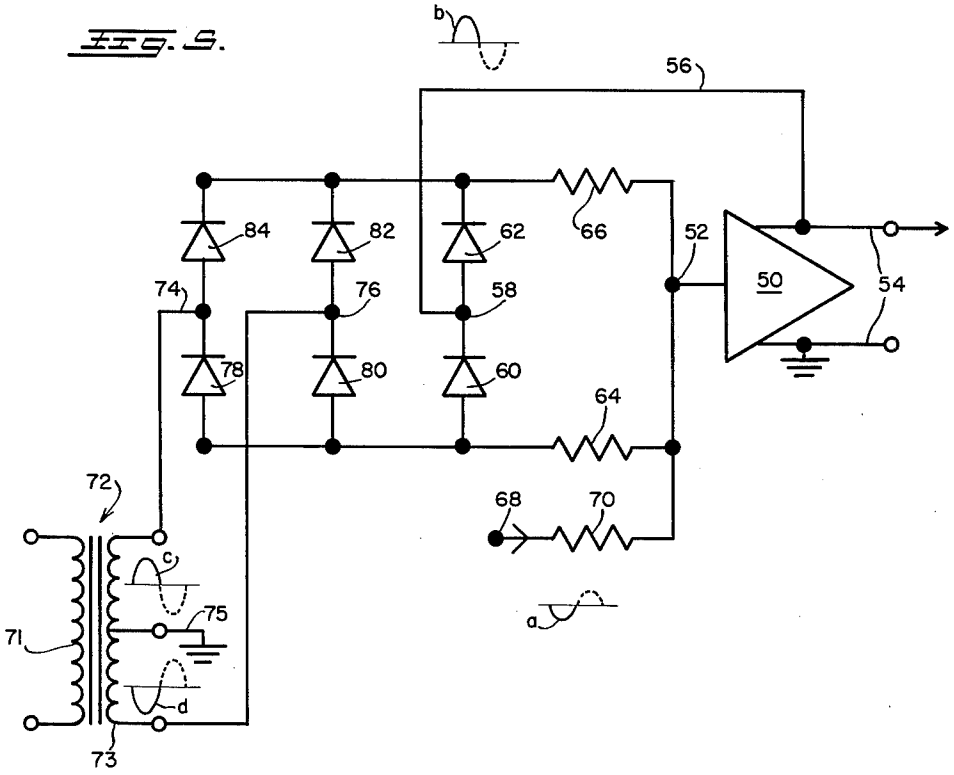
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Fig. 5.



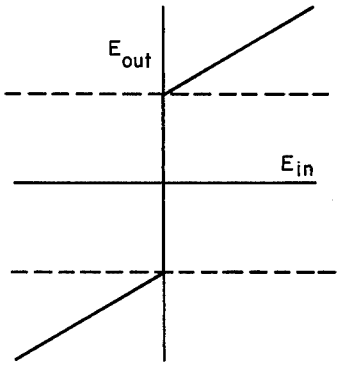


Fig. 6.

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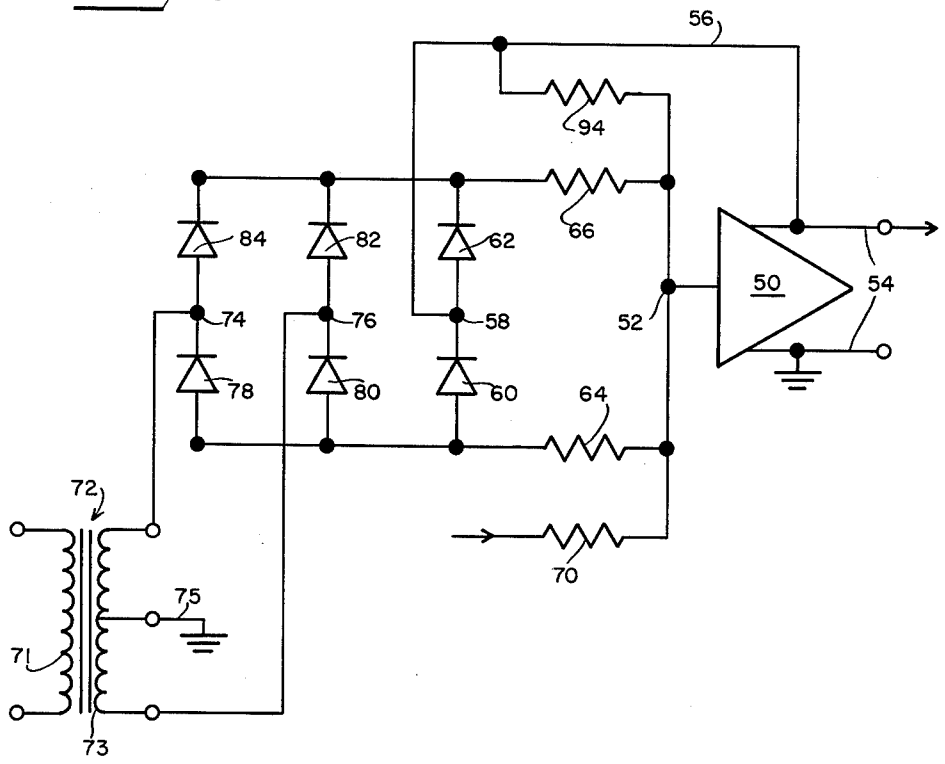
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FLIGHT SIMULATOR

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Fig. 7.



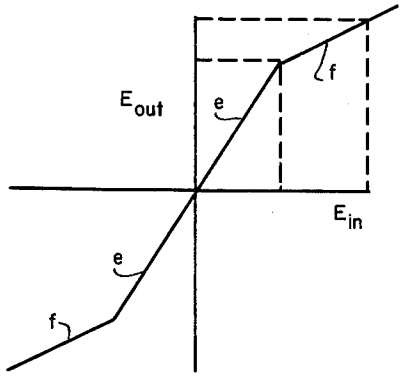


Fig. 8.

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3,031,775

FLIGHT SIMULATOR

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Filed Nov. 4, 1957, Ser. No. 694,376
7 Claims. (Cl. 35—12)

This invention relates to a flight training simulator and more particularly to an organization for representing the operation of the controls of an aircraft.

Modern aircraft design frequently requires that the stick control member be connected to control an hydraulic servo motor instead of being connected directly to the ailerons and elevators, thus eliminating the realistic feel of the elevator and aileron's reaction when the plane is in flight. In order to give the pilot the impression of this force reaction against his control stick a bungee provides an arrangement representative of the forces normally encountered in flight. An example of this type of construction is the F86 Sabre which is a military craft and has the control stick connected to the servo motor to transmit an initiating force through mechanical amplifiers to move the rudder and aileron assemblies whereby the course of the ship is actually controlled. The servo system and associated mechanical amplifiers insulate the control stick from the control member that is moving in the air stream and the pilot does not receive any resisting force to his thrust upon the stick. A spring-type bungee has been used on the craft to give the feel of resistance and consists of two pre-loaded compression springs mounted with their longitudinal axis aligned and respectively urging against opposite sides of a part of the control member. For further details of this organization see the patent to Chenery et al. 2,678,177. Since there is a degree of preload on the stick in neutral position the transition between static and kinetic friction is not encountered, but the amount of force to be exerted varies linearly with the displacement once the preloading of the spring is overcome and the stick starts to move. As will later be more fully pointed out a structure and circuit to simulate this preloading resistance and the subsequent linear force-motion relationship is revealed herein.

A principal object of the invention is to provide in a flight trainer a simulated control member which has the realistic feel of the aircraft in flight.

Another object of the invention is to provide an improved control loading means for simulated aircraft during a training cycle.

A further object of the invention is to provide an organization to provide non-linear forces to react against a control member during motion thereof.

A still further object of the invention is to simulate a preloaded bungee.

A yet further object of the invention is to provide a flight computing means for preloading simulated aircraft controls to represent flight conditions.

A yet still further object of the invention is to provide an electronic function generating circuit which receives a linear input and delivers a non-linear output.

Referring now to the drawings wherein like or corresponding parts are designated by corresponding reference characters:

FIGURE 1 is a perspective view partly in section and partly broken away illustrating a mechanical arrangement of a simulated aircraft control.

FIGURE 2 is a schematic representation of a spring loaded bungee.

FIGURE 3 is a curve showing the relationship between force and displacement for the bungee of FIGURE 2.

FIGURE 4 is a fragmentary perspective view showing a torque member.

FIGURE 5 is a schematic wiring diagram of a circuit used in the simulation of forces.

FIGURE 6 is a curve showing the R.M.S. relationship between input signals and output signals for the circuit of FIGURE 5.

FIGURE 7 is a schematic wiring diagram of a modification of the circuit of FIGURE 5; and,

FIGURE 8 is a curve showing the R.M.S. relationship between input and output for the diagram of FIGURE 7.

A typical simulated training station for a student is shown in FIGURE 1 wherein the stick control is indicated by reference character **10** and is mounted for movement in a conventional manner on a platform **12**. As is usual the trainee's seat (not shown) is disposed adjacent the stick **10** and an aperture **14** is formed in the platform **12** to permit free movement of stick **10** in any direction. The stick **10** combines the usual elevator and aileron control function and is mounted for universal movement by means of a rockable yoke **16** which carries a rod **18** on which the stick is rotatably mounted for forward and after movement simulating the elevator control motion. The yoke is connected to a shaft **20** which is supported by bearings (not shown) so that the stick is also free to move laterally thereby simulating the aileron control. Stick **10** is secured at one end thereof to shaft **22** which is in turn connected to rod **24** leading to crank **26** supported in torque member **28** to load the stick. A potentiometer having a resistance winding **30** grounded at the midpoint has a wiper **32** mechanically connected to the end of stick **10** as indicated by the dotted line there shown and is electrically connected to torque member **28** by circuit **34** which includes amplifier circuitry **90** to be later described.

A fragmentary detail of a typical torque member to load the stick is shown in FIGURE 4 wherein shafts **15** and **17** are driven in opposite directions from a conventional motor and gear train (not shown). Electromagnetic clutches **19** and **21** each having the usual relatively rotatable members have one respective member connected to be driven from shafts **15** and **17** and the other member connected to drive shafts **23** and **25** when energy is applied to their coils through terminals **27**. The clutches may be either the eddy current or the magnetic fluid type, both of which are well known in the art. Spur gears **29** and **31** mesh with pinion **33** having shaft **35** connected thereto which is joined to cranks **26** and **36** of FIGURE 1. Normally there is zero energy input to the clutch pair and pinion **33** does not move. Energy fed to either clutch will result in a resultant torque being transmitted to the gear **33** and its shaft. A polarity sensitive gate such as a diode pair is provided to pass energy of selected polarity to the proper clutch to provide torque in a predetermined direction. As will later be more fully pointed out a circuit having a "jump" function for a characteristic is connected to the clutch pair to give a large input upon initial signal and subsequent linear relationship.

Referring again to FIGURE 1, shaft **20** is secured to crank **36** rotatably supported in torque member **38** of construction similar to member **28** and a potentiometer having a resistance winding **40** is energized by an A.C. voltage and has its center grounded to be engaged by wiper **42** mechanically connected to yoke **16**. Circuit **44** including amplifier circuitry **92** connects between the wiper **42** and torque member **38**.

It is desired to simulate the reaction to the pilot of a bungee system like that shown in FIGURE 2. Here the control stick **10** is mounted in the same manner as the stick of FIGURE 1 and is shown partly broken away. Shaft **22** is connected to the lower extremity of the stick

and terminates in an upturned portion 44. A pair of springs 46 respectively urge against opposite sides of end 44 and are retained between bulkheads 48 and 50 by any conventional means. The springs are respectively precompressed or preloaded to a degree whereby force applied by the pilot to the stick 10 must overcome the initial preloading of the spring before any movement may be imparted to it. It is well to consider the spring system as comprising two forces F_1 and F_2 mutually opposed one to another and embracing member 44 between them. A spring retainer (not shown) is fixed at the stick's neutral position to prevent forward excursion of the springs beyond such position when the stick is moved by the trainee.

FIGURE 3 illustrates the relationship between force (F) and displacement (D) of the bungee of FIGURE 2. Here an increment of force F_1 must be exerted upon stick 10 before any displacement at all is obtained and thereafter the force displacement relationship is entirely linear because of spring reaction and the same is true in the negative sense wherein a force F_2 must be imposed upon the stick before the stick is displaced and thereafter the relationship is linear. This is the force characteristic that the circuit now to be described simulates. Although FIGURE 3 graphically pictures a force-displacement relationship to be simulated by the circuitry, it should be understood that any non-linear physical relationship between two parameters can be simulated by the same circuitry with a suitable transducer.

Referring now to FIGURE 5, reference character 50 indicates an amplifier which is of the inverting impedance transforming type and has an input terminal 52 and output terminals 54. A feedback connection 56 is provided between the output and the junction 58 between a diode pair 60 and 62. This feedback network includes a resistor pair 64 and 66 having identical resistance values connected to input terminal 52. The input of the amplifier is received at terminal 68 and has input resistor 70 connected thereto having the other end thereof connected to input terminal 52. A transformer 72 has its primary 71 energized from a source of reference voltage of the same frequency and phase relationship as the input signals to be applied to input terminal 68 and has its secondary 73 grounded at the center point 75 and the terminals thereof connected at junctions 74 and 76 to a diode bridge comprising diodes 78, 80, 82 and 84. Resistors 64, 66 and 70 together with the input impedance of amplifier 50, existing between point 52 and ground, provide a conventional summing network for producing between point 52 and ground a voltage which is substantially proportional to the sum of the voltages applied to resistors 64, 66 and 70.

Before the operation of the above described circuit is explained the essential characteristics of the diode and the inverting feedback amplifier may be briefly reviewed. A diode may be considered as a resistance element whose resistivity is unsymmetrical with respect to the polarity or sense of the applied voltage. In an ideal diode the resistivities are zero and infinity for respective forward and backward applied voltages. In practice however the forward resistivity never quite equals zero and the back resistivity seldom goes beyond several thousand megohms. The feedback amplifier here used is an inverting impedance transforming A.C. amplifier the net overall gain of which, as is known, is determined by the ratio of the total feedback resistance to the input resistance.

With the transformer primary 71 energized by, for example, a sinusoidal varying waveform of frequency and phase identical to the amplifier input signals then the center grounded secondary produces two waveforms, as shown, of opposite phase which appear at junction 74 and 76 of the diode bridge and only positive half cycles reach resistor 66 and negative half cycles reach resistor 64 because of the polarities of the diodes as there connected. During the interval wherein a positive half cycle is impressed on diode pair 84 and 78 and hence is conducted to resistor 66 a negative half cycle is simultaneously produced by the lower half of the grounded transformer secondary and is conducted to diode pair 82 and 80 and is impressed across resistor 64. The resultant voltage at the input junction 52 of the amplifier 50 arriving via resistors 66 and 64 is zero since the phase of positive and negative half cycles cause the voltages to cancel each other. Therefore if transformer 72 be considered the only source of signal input, amplifier 50 receives no effective input because of the balancing feature and delivers no output. Diodes 60 and 62 of course also have impressed thereon the positive and negative voltages derived from the transformer and the diode bridge. With such voltages applied thereto the diodes cannot pass energy entering at their junction point 58 unless the voltage there impressed is of sufficient amplitude to exceed the back biasing voltage from the transformer and bridge maintained as a standard of reference.

When, as later will be apparent, A.C. voltage from the amplifier output 54 is impressed via feedback connection 56 to the junction 58 and does exceed in amplitude the voltage from either of the bridge connected diode pairs which reflect the transformer reference voltage, then diode 60 or 62 will instantaneously prevent one or the other bridge diodes from passing its voltage by back biasing the same depending on the instantaneous sense of the voltage impressed on junction 58. The diode which is not affected by the amplifier output voltage continues to pass the transformer voltage from one secondary half. This voltage has a phase in opposition to that impressed at the diode junction 58 but it will now have a magnitude lower than the amplifier output voltage and therefore the difference between amplifier feedback voltage and transformer voltage is the resultant voltage impressed upon resistors 66 and 64, one receiving the positive half cycle and the other negative half cycle and being of unequal amplitudes. The amplifier thus finds a path for the conduction of feedback to its input, and since the gain of the amplifier is proportional to the ratio of feedback resistance to the input resistance, as soon as the feedback resistance becomes a finite value the amplifier gain drops thus giving the characteristic curve shown in FIGURE 6.

The operation of the circuit of FIGURE 5 will now be explained in terms of a waveform. Assuming that a signal of small amplitude and negative polarity, *a*, is impressed upon resistor 70, the amplifier 50, then, will invert the polarity and amplify the signal at its maximum gain level because the amplitude of the reference voltage from transformer 72 effectively back-biases diode 62 and the feedback path has an infinite resistance. Since the voltage of signal frequency and phase relationship is impressed upon transformer 72 the waveforms there shown (*c* and *d*) will be used to illustrate the interaction between the feedback energy and the bridge reference energy. If we assume the small signal, *a*, applied to input resistor 70, then a larger signal occurs at output terminal 54 and is fed back through connection 56. The positive half cycle attempting to pass through diode 62 will be back biased by the positive half cycle, *c*, appearing at the upper half of transformer secondary, and the negative half cycle will be biased back in its turn through diode 60 by the transformer secondary. If then the input signal is small as compared with the amplitude of reference voltage from transformer 72 then instantaneously the energy level appearing at terminal 58 will be back biased by the values passing through junctions 74 and 76. Thus no feedback resistance exists in the amplifier circuit and the gain for small input values is as high as the amplifier design permits. As the input voltage to terminal 68 increases the feedback increases as previously explained by the output signal appearing at 58 overcoming the reference voltage at diode pair 60 and 62 and the gain drops. Thus the "jump" characteristic relationship for R.M.S. voltages as shown in FIGURE 6 is obtained. This is

identical with the characteristic of preloaded spring assembly shown in FIGURE 2 and having the characteristic curve shown in FIGURE 3.

Referring now to FIGURE 1 it will be seen that when the pilot moves stick **10** in a forward or reverse direction he moves the wiper **32** across potentiometer **30** thereby first impressing small signals upon the amplifier circuit shown generally by reference character **90** which is connected in a manner shown in FIGURE 5. The output signals from the amplifier circuit are connected to torque device **28** which as previously explained becomes unbalanced and produces torque to resist the thrust of the trainee. Upon the trainee overcoming this torque and moving the stick further along the potentiometer winding the input signals become larger and the amplifier gain automatically drops and the resistance to the trainee follows a straight line relationship. It will be seen that in the neutral position of the stick where the input is extremely small the gain of the amplifier is high and the torque device **28** is thereby energized in a preloaded sense so that the trainee feels a resistance on the stick which must be overcome before it is moved, in the same manner that the resistance of spring **46** must be overcome before the stick **10** can be moved.

In a similar manner shaft **20** connected to yoke **16** could in the aircraft have a pair of torsion springs surrounding the same to act as a bungee whereby lateral motion of the stick encounters an initial force, such force being the preloading of the spring. In the simulator, the wiper **42** is constrained to move along potentiometer winding **40** upon sidewise motion of the stick and signals from the wiper are connected through amplifier **92** and connection **44** to torque device **38** which is similar in all respects to torque device **28**. Here again initial motion from neutral position derives a small signal which passes from amplifier **92** to torque device **38** and receives maximum amplifier gain which tends to resist the initial motion of the stick, but upon overcoming the torque the amplifier gain drops to thereby impart a voltage to torque device **38** which follows a straight line relationship as shown in FIGURE 3.

A modification of the circuit of FIGURE 5 is illustrated in FIGURE 7 wherein like reference characters designate corresponding parts. Here the variation from the showing of FIGURE 5 is the addition of a feedback resistor designated by reference character **94**. Derived signals, impressed on input resistor **70** appear at the input **52** of an impedance transforming amplifier **50**, and signals of a constant magnitude and corresponding frequency and phase relationship are impressed upon transformer **72**. When input signals at **70** are small as compared with the amplitude of the reference energy applied to transformer **72**, then the only feedback path around amplifier **50** is resistor **94** and this resistor may be selected to provide any overall amplifier gain, perhaps one slightly above unity. Feedback voltage from the output of amplifier **50** appearing at junction **58** between diodes **60** and **62** cannot pass through resistors **64** and **66** if the magnitude of the feedback signal is less than the magnitude of the reference voltage drawn from transformer **72** and the preliminary characteristic is shown as *e*. Upon the impressing of a signal to resistor **70** which results in an output of a greater magnitude than the reference voltage from transformer **72** then the back biasing previously described can no longer prevail and diode **60** and **62** will respectively pass the negative and positive portions of the energy as they occur in time thereby placing resistor **94** in parallel with whichever of the resistor pairs **64** and **66** may be instantaneously conducting, whereby the feedback loop of the amplifier now has a lower resistance and the amplifier gain is reduced as shown in portion *f* of the curve of FIGURE 8. FIGURE 8 shows this characteristic which illustrates how the amplifier gain is reduced as a function of input signal. Obviously the circuit of FIGURE 7 could be substituted in the simulator structure of FIGURE 1 if a characteristic stick resistance of the type shown in FIGURE 8 were desired.

It will be understood that the amplifier circuits here illustrated are of general utility in other and different combinations than in the preferred combination revealed in FIGURE 1, they are useful in generating functions which are non-linear and may be applied in any computer combination wherein derived signals beyond a predetermined magnitude are to experience differentials in the gain of an amplifier.

The form of the invention herein shown and described is to be taken as a preferred example of the same and various changes may be resorted to without departing from the spirit of the invention and the scope of the subjoined claims.

What is claimed is:

1. A function generating circuit for use in a stationary trainer or the like comprising an amplifier having an input and an output, a resistor connected to the amplifier input to receive A.C. signals of varying magnitude, a feedback network for said amplifier, the gain of the amplifier being a function of the ratio of the total feedback resistance to input resistance, said network comprising a pair of resistors connected at one end of each resistor to the amplifier input and a diode pair connected in series between the other ends of the resistors, the junction between the diode pair connected to the amplifier output, a diode bridge, a source of A.C. voltage of constant magnitude and of the same frequency and phase as the input signals connected to two of the bridge terminals, the other terminals connected to the diode pair to bias the said diode pair to a non-conducting state for values of input signals which produce output voltages smaller than the reference voltage whereby values of input signals which produce output voltages larger than the reference voltage permits conduction through the diode pair and the said resistors to thereby reduce the total feedback resistance and lower the amplifier gain.

2. A function generating circuit for use in a stationary trainer or the like comprising an amplifier having an input and an output, a resistor connected to the amplifier input, means to connect derived A.C. signals of varying magnitude and representative of a variable to the resistor, a feedback network connected to said amplifier, the amplifier gain being a function of the ratio of the total feedback resistance to the input resistance, said network comprising a pair of resistors connected at one end of each resistor to the amplifier input and a diode pair connected between the other ends of the resistors, the junction between the diode pair connected to the amplifier output, a diode bridge, a source of A.C. voltage of constant magnitude and of the same frequency and phase as the input signals connected to two of the bridge terminals, the other terminals connected to the extremities of the diode pair to bias the same to a non-conductive state for values of input signals below a predetermined magnitude whereby input signals exceeding such magnitude produce output voltages to permit conduction through the diode pair and associated resistors to reduce the feedback resistance and lower the amplifier gain.

3. A circuit for simulating a physical relationship between parameters comprising a feedback amplifier having an input resistor, the amplifier gain being a function of the ratio of the feedback resistance to the input resistance, means to connect derived A.C. signals having magnitudes varying in accordance with one of said parameters to the input resistor, a source of A.C. reference voltage of the same phase and frequency as said derived signals, and a feedback circuit including means connected to the reference voltage source and to the amplifier output to reduce the feedback resistance and thereby the amplifier gain when the input signal exceeds a predetermined magnitude in either direction, the said last recited means comprising a pair of diodes having a common junction,

a resistor connected between each diode and the amplifier input and means connecting the diode junction to the amplifier output.

4. A circuit for generating a non-linear function comprising in combination a feedback amplifier having an input resistor, the gain of said amplifier being a function of the ratio of the feedback resistance to the input resistance, means to derive A.C. signals varying in magnitude in accordance with a variable of said function and to connect said signal to the input resistor, a source of reference voltage of the same frequency and phase as the derived signals, a diode bridge connected to the said source and a second circuit connected to the bridge and to the amplifier input and output terminals to reduce the feedback resistance and thereby reduce the amplifier gain when the input signals exceed a predetermined magnitude from the reference voltage, the said second circuit comprising a pair of diodes having a common junction connected in series across two bridge terminals, a resistor pair connecting the diode pair extremities and the amplifier input and means connecting the diode pair junction to the amplifier output.

5. The invention as set forth in claim 4 wherein the said second circuit includes a third resistor connected between the amplifier output and input and providing the value of feedback resistance when the derived signals are smaller than the reference voltage, the said resistor pair being connected with the said third resistor to reduce the effective feedback resistance when the derived signals exceed the reference voltage.

6. A circuit comprising in combination a feedback amplifier having an input resistor, the gain of said amplifier being a function of the ratio of the feedback resistance to the input resistance, means to derive A.C. signals of variable magnitude and to supply said signals to the input resistor, a source of A.C. reference voltage of the same frequency and phase as the derived signals,

a diode bridge connected to the said source, and a second circuit connected to the bridge and to the amplifier to reduce the feedback resistance and thereby the amplifier gain when the input signals exceed a predetermined magnitude from the reference voltage.

7. The invention as set forth in claim 6 wherein the said circuit comprises a pair of diodes connected in series across the bridge, a resistor pair connecting the series diode pair extremities to the amplifier input, and means connecting the diode pair junction to the amplifier output.

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