April 13, 1943. L. F. CURTIS 2,316,317

FREQUENCY RESPONSIVE NETWORK

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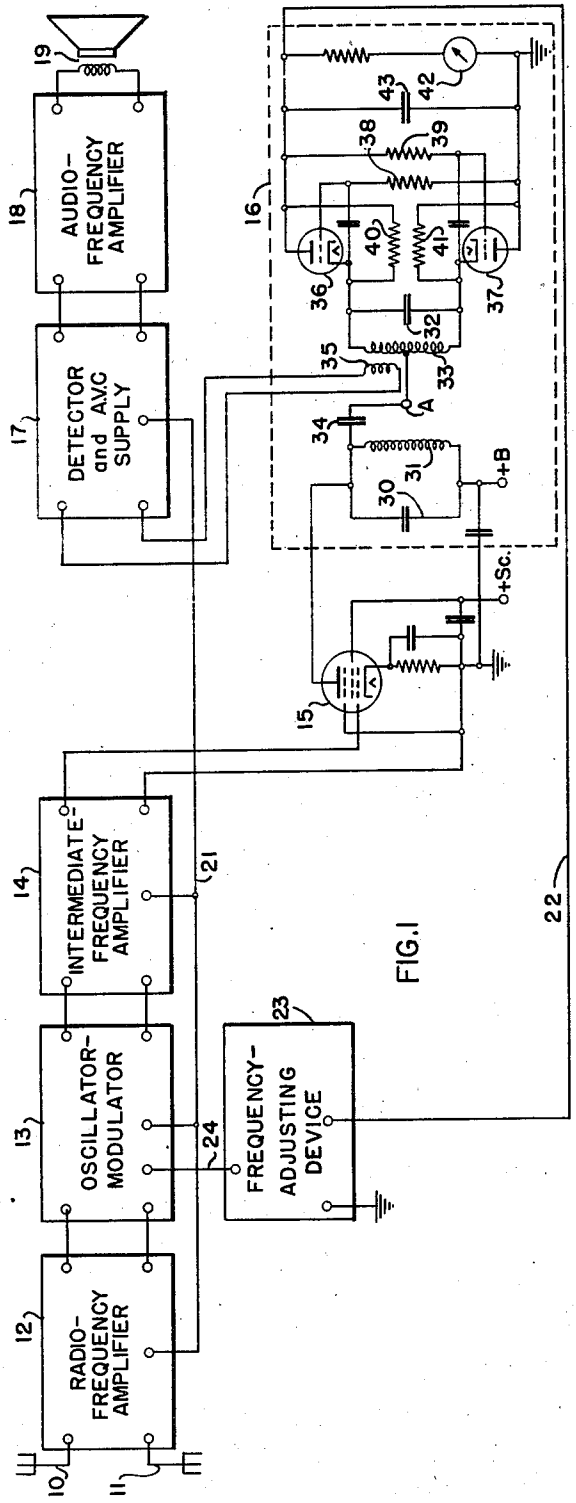



FIG. 1

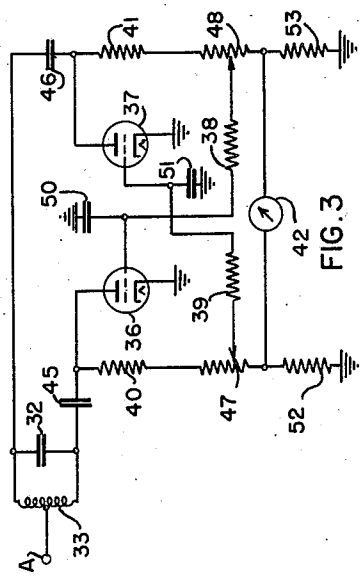



FIG. 3

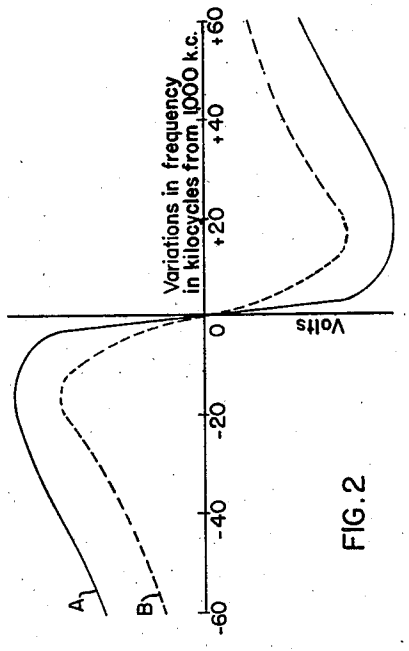



FIG. 2

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## FREQUENCY-RESPONSIVE NETWORK

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8 Claims. (Cl. 250—27)

This invention relates to an improved frequency-responsive network and, more particularly, to such a network adapted to be employed in a control system of a modulated-carrier signal-translating apparatus which has a relatively limited frequency-response range but a relatively high sensitivity over the range for the purpose of obtaining a control effect. As used throughout the specification, the terms "relatively limited frequency-response range" and "limited frequency range" refer to a range of frequencies which is narrow relative to the mean frequency of the range.

One type of frequency-responsive network which has previously been used for such purpose utilizes the principle of rectifying separately the sum and the difference of the voltages existing across the primary and secondary windings of a double-tuned circuit and differentially combining the rectified voltages so obtained to provide a voltage varying in magnitude and polarity with deviation of the frequency of the signal input to the system from its mean value. A disadvantage of such an arrangement is that with usual design of signal-translating and control circuits and at usual signal frequencies, the magnitude of the output of each of the rectifiers varies quite gradually and over a considerable frequency range. Thus, the difference of the rectified voltages also varies gradually with respect to frequency, decreasing the sensitivity of the system, and varies between maximum and minimum values which are relatively remotely separated, permitting the control to extend over adjacent signal channels, effectively blanking them out.

While in certain prior art frequency-responsive networks the sensitivity has been increased, this has been done by decreasing the frequency separation of the maximum and minimum values of the rectified output and also, generally, by reducing the magnitude of the control voltage derived in the network, thus reducing the "pull-in" range of the system, which may be undesirable in certain applications. In a signal-transmitting system comprising automatic frequency control, for example, it is highly desirable that the frequency-discriminating network be capable of providing a very large pull-in effect so that when the oscillator is energized, preparatory to signal transmission, it will be brought to a predetermined operating frequency, even though its initial frequency may be widely at variance therefrom.

It is an object of this invention, therefore, to provide an improved frequency-responsive network which avoids one or more of the disadvantages of the prior-art arrangements and which has an improved sensitivity.

It is a further object of this invention to provide a frequency-responsive network operable over a relatively narrow frequency range having a relatively high sensitivity over the range and producing relatively large control effects.

In accordance with the invention, the frequency-responsive network operable over a given frequency range comprises means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of the range and means for developing from the applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of the range. The network includes a pair of rectifiers, each of which has an output circuit, and means for applying one of the developed voltages to each of the rectifiers. The network further includes means for deriving a delay bias for each rectifier solely from the output circuit of the other and means for deriving from the output circuits of the rectifiers a control voltage which varies in accordance with the frequency of the applied signal. The term "delay bias" as used in the specification is intended to mean an amplitude delay bias.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing, Fig. 1 is a circuit diagram, partly schematic, of a complete superheterodyne receiver including a frequency-responsive network embodying the present invention; Fig. 2 is a graph representing certain operating characteristics of the circuit of Fig. 1; and Fig. 3 is a circuit diagram of a modification of the arrangement of Fig. 1.

Referring to Fig. 1 of the drawing, there is shown a circuit diagram, partially schematic, of a complete modulated-carrier signal receiver of the superheterodyne type embodying the invention. This receiver comprises, in cascade, an antenna-ground circuit 10, 11, a radio-frequency amplifier 12, a frequency changer or oscillator-modulator 13, an intermediate-frequency amplifier 14 which may comprise one or more stages of amplification, a further stage including a vacuum-tube amplifier 15, a frequency-responsive network 16 constructed in accordance with

the invention as will be pointed out more fully hereinafter, a detector and automatic amplification control or A. V. C. supply 17, an audio-frequency amplifier 18 which may comprise any desired number of stages, and a sound reproducer 19. Automatic amplification control is obtained in a well-known manner by a unidirectional bias voltage derived from the A. V. C. supply 17 and applied over conductor 21 to the control electrode of one or more of the tubes included in the radio-frequency amplifier 12, oscillator-modulator 13 and intermediate-frequency amplifier 14. Automatic frequency control is secured in a well-known manner by applying a unidirectional voltage derived from the frequency-responsive network 16, in a manner to be described in detail hereinafter, over a conductor 22 to a frequency-adjusting device 23 which, in turn, is coupled to the oscillator-modulator 13 by way of a conductor 24. All of the components of the superheterodyne receiver with the exception of the frequency-responsive network 16, may be of any suitable conventional construction.

Neglecting for the moment the operation of the frequency-selective network 16, the circuit above described comprises, in general, a conventional superheterodyne receiver including automatic volume control and automatic frequency control systems. The operation of such a receiver is well understood in the art so that a detailed description thereof is unnecessary. In brief, however, a signal intercepted by the antenna-ground circuit 10, 11 is selected and amplified in the radio-frequency amplifier 12 and applied to the oscillator-modulator 13, wherein it is converted into an intermediate-frequency signal. The intermediate-frequency signal is amplified in the intermediate-frequency amplifiers 14 and 15 and is supplied to the detector 17, wherein the audio-frequency signal components and the A. V. C. biasing potential is derived. The audio-frequency signal components, in turn, are applied to the audio-frequency amplifier 18, wherein they are amplified and delivered to the sound reproducer 19 for reproduction. The automatic amplification control bias derived from the A. V. C. supply 17 is effective to control the amplification of one or more of the units 12, 13 and 14 to maintain the signal input to the detector 17 within a relatively narrow range for a wide range of received signal intensities, while the frequency-responsive network 16 is effective to supply an automatic frequency control bias to the frequency-adjusting device 23 to maintain the carrier frequency of the signal input to the detector 17 at a substantially constant value.

Referring now more particularly to the circuit embodying the present invention, for the purpose of developing automatic frequency control bias to govern the tuning of the receiver, the frequency-responsive network comprises means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of the operating range of the network and means for developing from the applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of the range. Specifically, these means comprise a primary tuned circuit including condenser 30 and inductor 31 located in the output circuit of the vacuum tube amplifier 15, a secondary tuned circuit including condenser 32 and center-tapped inductor 33, and a coupling condenser 34 interconnecting the high-potential side of the primary tuned circuit and the mid-tap of the secondary winding 33. The tuned circuits are inductively coupled to one another and are tuned to the normal intermediate frequency of the receiver which corresponds to the mean frequency of the operating range of network 16. An inductor 35 is also inductively coupled to the secondary winding 33 in order to derive the input signal for the detector 17. A pair of triode rectifiers 36 and 37 is included in the network, each of which contains an anode, a cathode and a control electrode, and means are provided for individually applying the aforementioned developed voltages to the rectifiers, no other source of anode potential being employed. To this end the rectifiers are connected to opposite terminals of the secondary tuned circuits, the cathodes of rectifiers 36 and 37 being interconnected through secondary winding 33, which has a relatively low direct current resistance so that the cathodes are maintained at substantially the same unidirectional potential.

The control electrode of each rectifier, in turn, is connected to and maintained at substantially the same unidirectional potential as the anode of the other rectifier, whereby substantially the entire output voltage of each rectifier is applied as a delay bias to the control electrode of the other. Resistors 38 and 39 are included in circuit with the control electrodes of rectifiers 36 and 37, respectively, and, if desired, the control electrode of each rectifier may be by-passed to its cathode through a condenser, as shown, in order to prevent grid rectification. Output circuits which contain no common elements are provided for the rectifiers. The output circuit of rectifier 36 includes a load resistor 40, while that of rectifier 37 includes a load resistor 41.

A control voltage, which varies in accordance with the frequency of the applied signal, is derived from the output circuit of the network which includes load resistors 40 and 41 connected in series by the secondary winding 33 and applied to a tuning indicator or milliammeter 41, bypassed by condenser 43, and included in the output circuit of the network. The control voltage is also applied over conductor 22 to the frequency-adjusting device 23 for the purpose of controlling the tuning of the receiver.

In considering the operation of the circuit just described, it will be seen that it is similar to conventional frequency-responsive networks in that it employs the principle of supplying separately the sum and difference of the voltages developed across the primary and secondary of a double-tuned circuit to the individual ones of a pair of rectifiers for rectification to obtain a voltage varying in magnitude and polarity with the frequency of the applied signal. The circuit differs from conventional frequency-responsive networks, however, in that it supplies as a delay bias to each rectifier a bias derived solely from the output circuit of the other and which, in this embodiment of the invention, is substantially the entire output voltage of the other, which bias is effective to reduce the output of the rectifier to which it is applied substantially to zero at a frequency in the vicinity of the mean frequency of the range. This may be more clearly understood by considering the operation of the network under specific operating conditions.

Assume that the frequency of the applied signal corresponds with the mean frequency of the range. Under this condition it will be seen that both rectifiers are conductive and that equal and opposite voltages appear across their load cir-

cuits so that the control voltage derived from the network is zero. Assume now that the frequency of the applied signal increases to a value above the mean frequency of the range. It will be seen that the output of one of the rectifiers, for example rectifier **36**, increases, while that of the other, rectifier **37**, decreases. Further, the delay bias applied to the control electrode of rectifier **37**, which comprises substantially the entire output voltage of rectifier **36** due to the fact that the cathode and control electrode of rectifier **37** are maintained at substantially the same unidirectional potentials as the cathode and anode, respectively, of rectifier **36**, is effective to reduce the output voltage of the rectifier **37** substantially to zero at a frequency very near the mean frequency of the range. Hence, when the frequency of the applied signal increases beyond this cutoff frequency of rectifier **37**, the control voltage derived from the network is substantially equal to the output voltage of rectifier **36**. Conversely, when the frequency of the applied signal is decreased to some value below but very near the mean frequency of the range, the delay bias derived from rectifier **37** is effective to bias rectifier **36** beyond cutoff, whereby the control voltage derived from the network is substantially equal to the output voltage of rectifier **37**.

The characteristic discriminator S curve of the circuit of Fig. 1 is represented by curve A of Fig. 2, while curve B represents the characteristic discriminator S curve for conventional frequency-responsive networks. The slope of the discriminator characteristic of the circuit of Fig. 1 is seen to be very steep near the mean carrier frequency, as compared with that of conventional frequency-responsive networks, which demonstrates that the frequency-responsive network of the invention is much more sensitive than conventional arrangements. The steepness of this slope and, consequently, the sensitivity of the network, is very great in the vicinity of the mean carrier frequency because the peaks of the characteristic are relatively higher and are relatively closer to the mean frequency of the range than the peaks of the characteristic curve of conventional frequency-responsive networks. This is due to the fact that the delay bias applied to each rectifier is substantially the maximum bias voltage available and is applied to a control electrode so that it has a maximum biasing effect and thereby may reduce the output of the rectifier to which it is applied to zero at a frequency very near the mean frequency of the range. It may also be seen from Fig. 2 that the control voltage derived from the output circuit of the system for the purpose of controlling the tuning of the receiver is considerably greater than that which may be derived from conventional frequency-responsive networks. The peaks of curve A are relatively broad, which shows that a relatively large control effect is derived from the frequency-responsive network of Fig. 1 for relatively large deviations of the frequency of the applied signal from the mean frequency of the range, so that the network has a relatively large pull-in effect.

Thus, it may be seen that the arrangement of Fig. 1 is a very sensitive frequency-responsive network effective to derive a control bias supplied by way of conductor **22** to the frequency-adjusting device to control the tuning of the receiver. Further, the arrangement serves as a very sensitive tuning indicator to indicate the tuning of the receiver circuit.

The following circuit constants were used in obtaining the characteristic curve A and are illustrative of a specific application of the invention:

| | | |
|---|---|---|
| Mean frequency | kilocycles | 1000 |
| Rectifiers **36** and **37** | GT | 6J5 |
| $R_{40}$ and $R_{41}$ | megohms | 1 |
| $R_{38}$ and $R_{39}$ | do | 2.2 |
| Condenser **43** | micro-microfarads | 150 |

A modification of the tuning-indicator circuit of Fig. 1 and embodying this invention is shown in Fig. 3. The circuit of Fig. 3 may readily be employed in the receiver of Fig. 1 by connecting the terminal indicated as A with the corresponding terminal of Fig. 1. The modified form of tuning indicator is similar to that of Fig. 1 and corresponding circuit elements are indicated by identical reference numerals. In Fig. 3 the anodes of rectifiers **36** and **37** are connected to the opposite sides of the secondary tuned circuit by way of coupling condensers **45** and **46**, respectively, while the cathodes of the rectifiers are maintained at the same unidirectional potential. As in the arrangement of Fig. 1, the frequency-responsive network includes output circuits for the rectifiers which contain no common elements and, further, means are provided for deriving a delay bias for each rectifier solely from the output circuit of the other. To this end a voltage-divider resistor **47** is included in the output circuit of rectifier **36** from which a delay bias is derived and applied to the control electrode of rectifier **37** and, in a similar manner, a delay bias derived from a voltage-divider resistor **48** included in the output circuit of rectifier **37** is applied to the control electrode of rectifier **36**. The control electrodes are by-passed to their respective cathodes by way of condensers **50**, **51** to prevent rectification in the grid circuits. Resistors **52** and **53** included in the output circuits of the rectifiers and voltage dividers **47** and **48** comprise the arms of a bridge circuit including a tuning indicator **42**. The bridge circuit is included in the output circuit of the frequency-responsive network and a voltage is derived therefrom which varies in polarity and magnitude in accordance with the frequency of the applied signal and is indicated by the tuning indicator **42** as a representation of the tuning of the receiver.

The operation of the circuit of Fig. 3 will be readily understood from the aforedescribed operation of the circuit of Fig. 1. The delay bias applied to the control electrode of each rectifier in the circuit arrangement of Fig. 3 is derived solely from means included in the output circuit of the other rectifier and comprises a part of the output voltage of the rectifier circuit in which it is derived, whereas in the circuit of Fig. 1 the delay bias applied to each rectifier is substantially equal to the entire output voltage of the other rectifier. Further, since, in the circuit of Fig. 3, the delay bias is derived from a voltage-divider, the magnitude of the delay bias applied to the control electrode of each rectifier may be varied and, accordingly, the sensitivity of the frequency-indicating network may be adjusted as desired.

Although the above-described embodiments disclose the invention as applied to a receiver, it is to be understood that the invention may also be employed in connection with the frequency control of transmitters. When utilized in association with a transmitter, the large pull-in effect of the frequency-responsive network is of particular value in bringing the oscillator to a pre-

determined operating frequency, preparatory to signal-transmission, even though its initial frequency may be widely different therefrom.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers, an output circuit for each of said rectifiers, means for individually applying said voltages to said rectifiers, means for deriving a delay bias for each of said rectifiers solely from the output circuit of the other, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

2. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers, output circuits for said rectifiers having no common elements, means for individually applying said voltages to said rectifiers, means for deriving a delay bias for each of said rectifiers solely from the output circuit of the other rectifier, each of said biases being sufficient to reduce the output of the rectifier to which it is applied to zero at frequency in the vicinity of the mean frequency of said range, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

3. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers each of which has a control electrode, an output circuit for each of said rectifiers, means for individually applying said voltages to said rectifiers, means for deriving a voltage solely from the output circuit of each rectifier, means for applying the voltage derived from the output circuit of each of said rectifiers as a delay bias to the control electrode of the other, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

4. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers, an output circuit for each of said rectifiers, a pair of voltage dividers included individually in said output circiuts, means for individually applying said voltages to said rectifiers, means for deriving a delay bias for each of said rectifiers from the voltage divider included in the output circuit of the other, and means for deriving from the output circuit of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

5. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers, output circuits for said rectifiers having no parts in common, means for individually applying said voltages to said rectifiers, means for applying substantially the entire output voltage of each of said rectifiers as a delay bias to the other, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

6. A frequency-responsive network for operation over a given frequency range comprising, an input circuit, means coupled to said input circuit for deriving a first voltage, means coupled to said input circuit for deriving a second voltage variable in phase with frequency over said range with respect to said first voltage, a pair of rectifiers, output circuits for said rectifiers, means for applying to one of said rectifiers the sum and to the other of said rectifiers the difference of said two voltages, means for deriving a delay bias for each of said rectifiers solely from the output circuit of the other, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

7. A frequency-responsive network for operation over a given frequency range comprising, means for developing from an applied signal a first voltage which decreases in amplitude with frequency in the vicinity of the mean frequency of said range, means for developing from said applied signal a second voltage which increases in amplitude with frequency in the vicinity of the mean frequency of said range, a pair of rectifiers each of which includes an anode, a cathode and a control electrode, said cathodes being maintained at substantially the same unidirectional potential and the control electrode of each rectifier being maintained at substantially the same unidirectional potential as the anode of the other rectifier, means for individually applying said voltages to said rectifiers whereby substantially the entire output of each rectifier is applied as a delay bias to the control electrode of the other rectifier, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

8. A frequency responsive network for operation over a given frequency range comprising, a

pair of coupled tuned circuits resonant at the mean frequency of the range for developing from an applied signal a first voltage and a second voltage variable in phase with frequency over said range with respect to said first voltage, a pair of rectifiers, output circuits for said rectifiers, means for applying to one of said rectifiers the sum and to the other of said rectifiers the difference of said two voltages, means for deriving a delay bias for each of said rectifiers solely from the output circuit of the other, and means for deriving from the output circuits of said rectifiers a control voltage which varies in accordance with the frequency of the applied signal.

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