May 5, 1942. G. A. RANDALL ET AL 2,281,996

SUBMARINE CABLE AMPLIFYING SYSTEM

Filed June 5, 1940 2 Sheets-Sheet 1

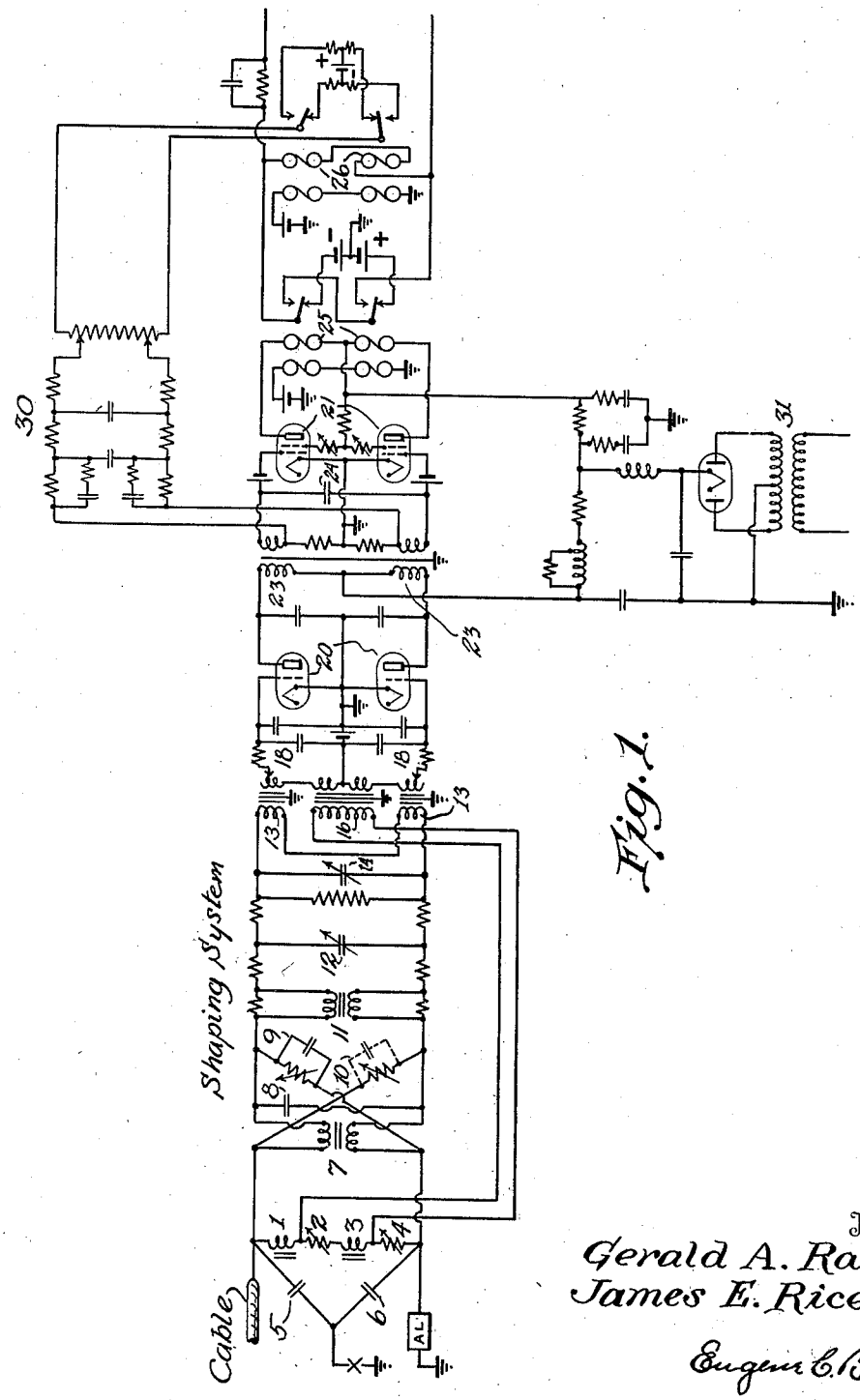

Fig. 1.

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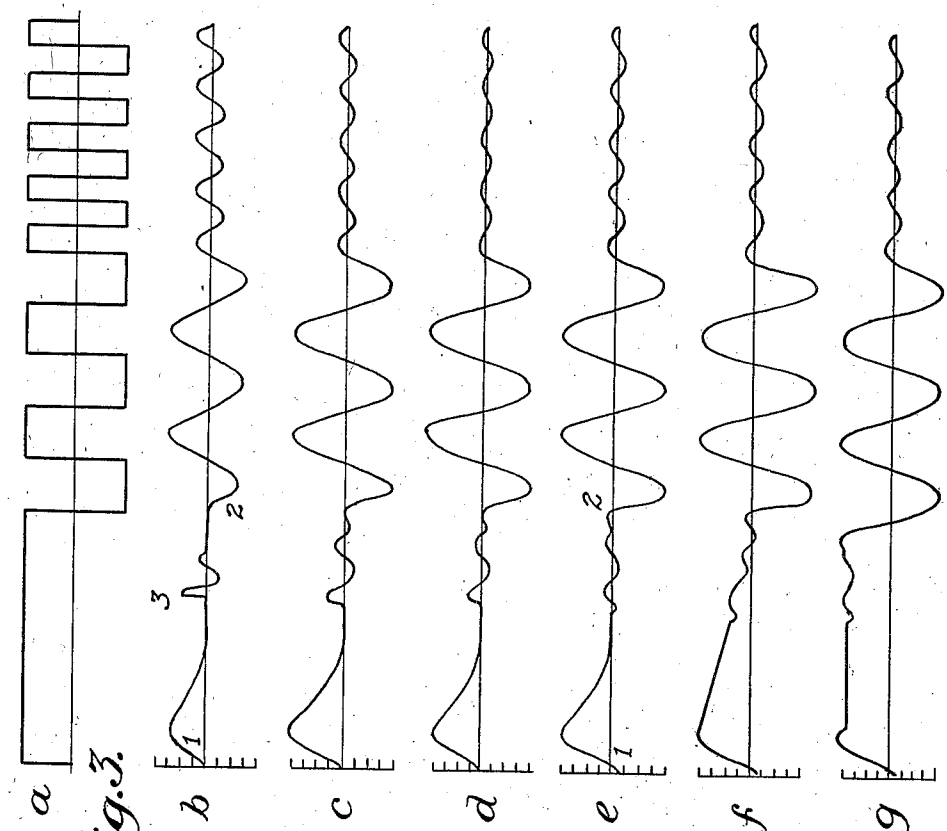

Fig. 3.

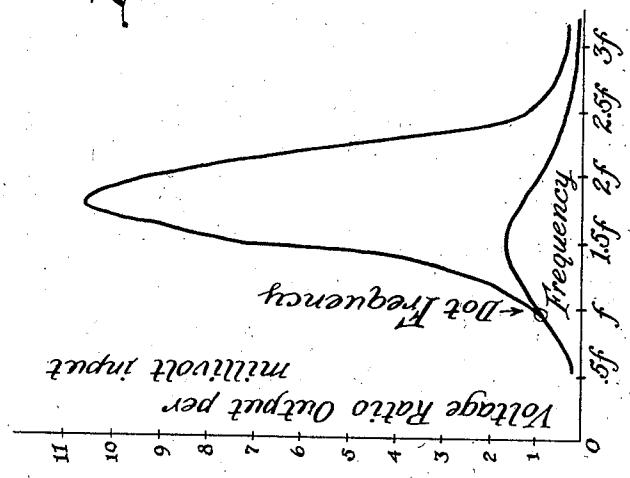

Fig. 2.

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SUBMARINE CABLE AMPLIFYING SYSTEM

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Application June 5, 1940, Serial No. 338,990

13 Claims. (Cl. 178—63)

This invention relates to submarine, cable telegraph systems, and particularly to the shaping and amplifying of the distorted and attenuated current waves of the signals received over submarine cables.

It is well known that telegraphic or other signals transmitted over long conductors of high capacity, such as submarine cables, are subject to serious distortion and attenuation which greatly interferes with proper reception and the faithful reproduction of the original signal waves.

In the design of receiving systems for submarine cable signals, it is necessary to provide signal shaping elements which will so operate upon the respective amplitudes of the various frequency components comprising the received signal as to restore them to their original proportions. It is also necessary to have these various frequency components properly displaced with respect to each other. When these two operations are properly performed, the resulting signal sufficiently approaches the original signal that it may be satisfactorily identified by mechanical receiving apparatus or by receiving operators. In practice it is customary to generate locally a portion of the signal and to introduce it in proper relation to the shaped preliminary portion of the signal as received over the cable. These two parts in combination provide a substantial duplicate of the original transmitted signal.

A further essential feature of submarine cable receiving systems is the provision of agencies designed to eliminate interference which may be picked up in the cable and in the receiving system itself. These agencies should cooperate with the associated elements of the system to provide a frequency characteristic which will accommodate the essential components of the signal but will provide a high degree of suppression adjacent to this range.

One of the objects of the invention disclosed herein is to meet the above described requirements to a much higher degree and with a simplicity of apparatus and ease of adjustment unattained in previous systems. A particular object of the invention is to concentrate the shaping and interference-eliminating elements into a single and relatively small group immediately adjacent to the cable and preceding the amplifier. A further object is to provide a shaping system wherein all of the elements thereof possess an inherent selectivity to signal frequencies and thus combine to produce extraordinary discrimination against high frequency interference. Other objects will be evident from the following description when considered in connection with the accompanying drawings, in which:

Figure 1 is a diagrammatic illustration of a circuit arrangement embodying the invention.

Figure 2 illustrates by curves showing relay milliamperes per millivolt input, a comparison of the frequency characteristic of the system disclosed herein with other systems commonly used in similar cable receivers; and

Figure 3 illustrates by a group of oscillograph curves, the effect of the respective elements of the shaping system upon the current waves of the received signals.

The shaping system

The general features of the receiving system are disclosed in Figure 1. The cable, which may be arranged for duplex working, terminates in a magnetic shunt comprising inductive and resistance elements **1—2—3—4**. This shunt is divided into two parts, designed to separate the lower and higher frequency components of the incoming signals, which together tune with the block condensers **5** and **6** at a frequency of 1.0 to 1.6 *f*, when *f* is the dot signaling frequency. This combination is of relatively low impedance and while the elements may be arranged symmetrically, it has been found unnecessary in the present case.

The next element of the shaping system is a low pass filter section, comprising the inductance **7**, the condenser **8**, and the two diagonal paths **9** and **10**. This section possesses phase shifting properties by virtue of the two paths **9** and **10**, which by-pass the higher frequency components through the phase adjusting condensers and resistances. The two by-pass arms need not be identical. It will be observed that this network is in effect a Wheatstone bridge.

The next element of the shaping system is another low pass filter network comprising the inductance **11** and condenser **12** and this is followed by the primary coils of the input transformer **13**, which is tuned to a frequency approximately of 1.5 *f*, by means of a condenser **14**.

On the secondary side of the input transformer, there may be provided a highly damped resistance-capacity network **18**, for the purpose of eliminating high frequency interference due to duplex operation or other causes. The shaping system is, in general, suitably damped by means of appropriate resistances and it is understood that all of the elements may be adjusted to provide in combination the optimum overall

performance. As shown in Fig. 1 the entire shaping system is connected across the cable terminal duplex bridge. In general this arrangement is satisfactory although it is necessary to maintain in the shaping system a high degree of symmetry with respect to ground. Should this condition prove difficult to maintain, an isolating transformer can be inserted between the magnetic shunt and the first element of the shaping network.

All of the shaping procedure just described applies only to the relatively higher range of frequencies. The lower frequencies are by-passed directly to the amplifier input transformer primary **16**, and while shaping elements could be introduced here if desired, the magnetic shunt and the step up of the input transformer in combination, provide sufficient adjustment of the phase and amplitude of these components with respect to the higher frequency components. In being thus by-passed the low frequency components are freed from adverse effects which might occur in the shaping system, and the shaping system itself through limitation to very narrow range of frequencies is rendered all the more efficient. A transformer ratio of approximately 1:13 for the transformer **13**, and 1:2.7 for the transformer **16** has been found suitable.

The curves illustrated in Fig. 2 show relay milliamperes per millivolt input and indicate in the lower curve, the frequency characteristic of the present shaping system and in the upper curve the corresponding characteristic commonly formed in other cable receivers. The upper curve indicates the very large amount of energy in the neighborhood of 1.5 *f* to 2.5 *f*, which it is ordinarily necessary to receive in order to produce the necessary degree of signal legibility. Such a high degree of selectivity in this region renders the cable receiver very susceptible to the interference which abounds here. Further, the system is somewhat unstable and susceptible to shock excitation, particularly that due to residual duplex unbalance or "jar."

Due to the improved facility with which the signal components may be recombined, it is only necessary in the present cable shaping system to receive the essential components in the magnitude indicated by the lower curve. This relatively smaller amount of tuning and greater damping permits a very great amount of improvement on the older system in the matter of interference elimination and in reduced susceptibility to "jar." This latter type of disturbance is subject to a reduction of approximately 50 percent.

The amplifier system

The amplifier is of the balanced or push-pull type and in the present case consists of a triode stage of tubes **20**, followed by a stage employing relatively high power beam type tubes **21**. Additional stages may be added if desired. The coupling transformers are designed to possess very high inductance so that they will faithfully reproduce the very low frequencies here involved. It is necessary to provide shields between primary and secondary windings of the input transformers, although it is not necessary to employ extraordinary shielding measures. The higher frequency input transformer **13** is tuned by means of condenser **14** to a frequency of 1.0 to 1.6 *f*, preferably about 1.5 *f*. Ordinarily the interstage transformer **23** is untuned, although a small condenser **24** may shunt the secondary for the purpose of eliminating interference. The final stage of the amplifier works into dot and dash relays **25** or other system of relays, preferably of a high impedance type. These relays in turn control a pair of shaping relays **26**, whose contacts are arranged to transmit a low frequency holding or sustaining pulse through the shaping system **30** to the input of the final amplifier stage. A particular form of network has been shown at **30** but this network may vary in numerous respects as is well understood by persons skilled in this art.

Plate potentials are supplied for the two stages from a commercial alternating current power source **31**, after rectification and special filtering. A high degree of matching is required for the associated tubes in the push-pull stages. Aside from the initial selection of tubes this matching may be perfected by the inclusion of series resistances in the plate circuits or by adjustment of screen grid potentials.

A transformer coupled amplifier as illustrated is preferred in many cases. It possesses the advantage of simplicity and a minimum number of elements, which is in turn reflected in simplified operating procedure and freedom from apparatus troubles. Such an amplifier possesses also the advantage that longitudinal interference currents cancel out magnetically at each stage. Resistance coupled amplifiers have also been used successfully in connection with this shaping system.

Operation of signal shaping system

For the purpose of indicating graphically the effect of the several shaping elements of the shaping system upon the form of the received signal waves, we have illustrated in Fig. 3, by means of a group of curves *a* to *g*, the influence exerted by each element as shown by oscillograms secured at the output of the amplifier as the various elements were added successively to the shaping system.

The signals are in the ordinary multiplex code and were sent at a speed well in excess of the limiting speed of the cable, so that single pulses are virtually suppressed before reaching the receiver. As illustrated in Curve *a* the group of transmitted signals represents in succession a single long pulse, a series of pulses two elements long, and a series of pulses one element long.

Curve *b* represents such a series of signals as they appear at the output of the amplifier when the shaping elements, including the low frequency transformer **16**, are all removed with the exception of the condensers of the duplex bridge and the magnetic shunt **1**, **2**, **3**, **4**. It will be noted that the two units signals are three units in amplitude according to the scale at the left, the single pulses are rather prominent, the initial rise of signal from the zero line, at points **1** and **2**, is rounded and slow, and a pulse of interference indicated at **3** is rather sharp in shape and of considerable amplitude. Such interference of course may occur at any place in the series of signals and frequently will cause serious mutilation. It may be produced by various causes, notably by an imperfect duplex balance or by lightning or static disturbances.

In Curve *c* the amplifier input transformer **13** has been tuned through adjustment of the condenser **14**. This tuning is in the neighborhood of 1.6 *f*, and thus serves to emphasize the longer pulses while suppressing the short pulses and interference. It will be noted that the double pulses have been increased in amplitude to 4 units, while the singles and the interference have

been reduced. The transient disturbance now shows a number of oscillations of small magnitude at approximately the natural frequency of the tuned transformer.

In Curve *d* the interference suppressing network **11**, **12**, has been added to further suppress the higher frequencies comprised in the single pulses and the interference. The shape and amplitude of the longer pulses has not been impaired.

In Curve *e* the bridge-type shaping network **7**, **8**, **9**, **10** has been added. This network primarily provides a desired phase shift in the signal components to produce an "underthrow" in the signal at the points **1** and **2**. In effect, this underthrow delays slightly the initiation of the signal rise which, however, then occurs with greater rapidity to produce a steeper curve. A sharply rising wave front obtained in this manner is less susceptible to interference. This network at the same time increases the amplitudes of certain frequency components useful in the ultimate signal shape. An unavoidable result of this is a slight increase in the interference and single pulses, although these remain at a level very low as compared with the signal amplitude.

In Curve *f* the low frequency transformer **16**, has been connected in circuit to provide a lengthening or hold-up of the long pulses. This change produces no further effect on the signal shape.

Curve *g* illustrates the form of the final signal after connection of the feedback correction through the network **30** for the purpose of maintaining the signal current through the length of the long pulses.

As indicated in Fig. 2 higher frequency interference is substantially suppressed, while the zero wander is perfectly corrected by means of the feedback arrangement.

Some of the outstanding features of this invention which will be appreciated by engineers and those familiar with the difficulties encountered in the reception of signals over submarine cables, are:

1. All the elements of the shaping system possess an inherent selectivity to the signal frequencies and thus combine to produce extraordinary discrimination against high frequency interference. The entire shaping system is of relatively low impedance and is thus but slightly subject to the pickup of interference. At the same time, signal energy is conserved so that excessive amplifier gain with the attendant interference troubles are avoided.

2. The cable terminates in a low-impedance shaping element which serves to effectively isolate the cable from the receiving system so that the receiving system may be adjusted independently of the electrical constants of the cable and without disturbance to duplex balance.

3. The sections comprising the shaping system are of a type chosen to operate in immediate association with each other and as a consequence may be grouped together and directly connected without the interposition of vacuum tube stages.

4. The frequency components of the signal are divided into lower and upper ranges, which are shaped separately and then applied via separate transformers to the common amplifier. By a choice of different turn ratios in these two transformers, considerable flexibility in proportioning the amplitudes is achieved. Particular advantage resides in the unique relation between these two turn ratios.

5. The improved shaping procedure makes only a relatively narrow range of frequencies necessary. By restricting these to the lower range, high frequency interference is enormously reduced.

We have illustrated a particular circuit arrangement for the purpose of clearly disclosing the essential features of the invention, but it will be evident to engineers that modifications may be made therein with the scope of the disclosure herein.

We claim:

1. The method of shaping a submarine cable telegraph signal, which comprises separating the frequency components of the received signal waves into lower and upper ranges, shaping said frequency ranges separately without amplification, eliminating high frequency interference from the upper range frequencies, and separately impressing the frequencies of both ranges upon a common amplifier with simultaneous differentiation of the voltage ratios of said upper and lower ranges.

2. The method of shaping a submarine cable telegraph signal, which comprises separating the components of the received signal waves into two frequency ranges without amplification, shifting the phase relation of the higher frequency components, eliminating disturbing effects of high frequency interference, and combining the components of the higher range with those of the lower range with simultaneous amplification in the ratio of not less than 4 to 1 respectively, to produce a resultant signal simulating the original transmitted signal.

3. The method of shaping a submarine cable telegraph signal, which comprises separating the components of the received signal waves into two frequency ranges, initially shaping the higher frequency components without amplification, eliminating therefrom disturbing effects of high frequency interference, combining the resulting higher range components with the components of the lower range with simultaneous amplification of the components of both frequency ranges in substantially the ratio of not less than 4 to 1, and supplying locally a holding current component in proper phase relation to sustain the amplitude of the signal wave through the operating period.

4. The combination with a submarine telegraph cable, of a duplex bridge terminal arrangement therefor, a magnetic shunt connected across said bridge having one portion adapted to function with the higher frequency components of the received signals and another portion in series with said first portion adapted to function with the lower frequency components, a phase-shafting network connected to receive and reshape said higher frequency components, a common amplifier, and transformers arranged to separately apply said higher and lower frequencies to said common amplifier.

5. The combination with a submarine telegraph cable, of a duplex bridge terminal arrangement therefor, a magnetic shunt connected across said bridge, said combination being tuned at a frequency of from 1.0 to 1.6 of the unit dot signaling frequency, said magnetic shunt being divided into two portions connected in series designed to separate the lower and higher frequency signal components respectively, of the received signals.

6. The combination with a submarine telegraph cable, of a duplex bridge terminal arrangement therefor, a magnetic shunt connected across

said bridge, said bridge and shunt being tuned at a frequency of from 1.0 to 1.6 of the unit dot signaling frequency, said shunt being divided into two portions designed to separate the lower and higher frequency components respectively, of the received signals, an amplifying device, separate transformers having their secondary windings connected to said amplifying device, a shaping circuit having a phase shifting network connected to the higher frequency portion of said magnetic shunt and to the primary of one of said transformers, and a circuit by-passing the lower frequency components from said magnetic shunt to the primary of another of said transformers.

7. In a combination as set forth in claim 6, said transformers for the higher and lower components having amplification factors in the ratio of not less than 4 to 1.

8. The combination with a submarine telegraph cable, of a duplex bridge terminal arrangement therefor, a magnetic shunt connected across said bridge, said combination being tuned with the block condensers of the bridge at a frequency of from 1.0 to 1.6 of the unit dot signaling frequency, said shunt being divided into two portions designed to separate the lower and higher frequency components respectively, of the received signals, an amplifying device, separate transformers having their secondary windings connected to said amplifying device, a circuit connected to said higher frequency portion of the magnetic shunt and to the primary of one of said transformers, said circuit having a plurality of sections, one section being provided with a phase shifting network functioning to reshape said higher frequency components and another section being provided with a low filter network functioning to suppress the higher frequencies comprised in the single pulses and in any interference, and a circuit connected to said lower frequency portion of the magnetic shunt and to the primary winding of another of said transformers.

9. In a combination, as set forth in claim 8, means for tuning the secondaries of said transformers in combination to approximately 1.6 times the unit dot signaling frequency.

10. A signaling shaping system for a submarine cable comprising in series an inductive shunt, two low pass filter sections, one arranged to have phase shifting properties, and a tuned circuit.

11. In a submarine cable receiving system a plurality of shaping networks connected in series, the network nearest to the cable having a low impedance with respect to the cable, and the succeeding networks having impedances of increasing order.

12. A signal shaping system comprising two parallel resonant circuits connected by a series of low pass sections, certain of said sections having phase shifting properties.

13. A signal shaping system comprising a plurality of networks connected in series and arranged to pass a range of frequencies, all of said networks having high attenuation above said range and certain of said networks possessing phase shifting properties.

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