United States Patent [19]
Ross

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[45] **Apr. 17, 1973**

[54] TRANSMISSION AND RECEPTION SYSTEM FOR GENERATING AND RECEIVING BASE-BAND DURATION PULSE SIGNALS WITHOUT DISTORTION FOR SHORT BASE-BAND PULSE COMMUNICATION SYSTEM

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[73] Assignee: **Sperry Rand Corporation,** New York, N.Y.

[22] Filed: **Mar. 12, 1971**

[21] Appl. No.: **123,533**

[52] **U.S. Cl.** ....**325/38 R,** 325/105, 325/141, 325/129, 325/130, 325/325, 325/373, 325/386, 328/59, 329/104, 329/161, 329/162, 343/820, 343/822, 343/908

[51] **Int. Cl.** **H04b 1/00**

[58] **Field of Search** ....325/27, 38 R, 43, 325/105–107, 129, 130, 141, 325, 375, 377, 386; 328/59, 66–68, 78; 329/103, 126, 161, 162, 104; 333/12, 13, 19, 32, 34; 343/701, 753, 773, 778, 786, 822, 850, 852, 904–906, 908, 912–914, 739

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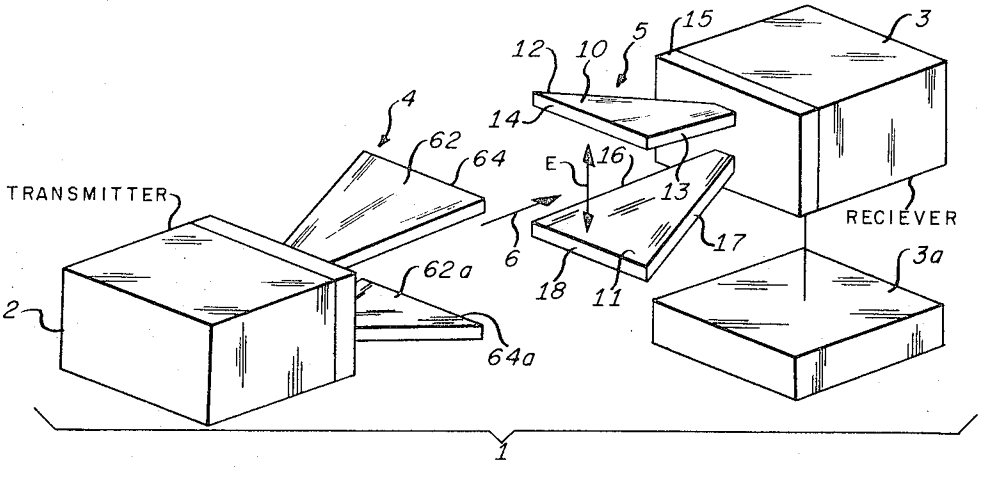
Primary Examiner—Albert J. Mayer
Attorney—S. C. Yeaton

[57] ABSTRACT

An electromagnetic signal communication system utilizing short base-band pulse signals of sub-nanosecond duration employs dispersionless, broad band antenna transmission line elements for generating and preserving the character of the short base-band pulses in respective transmitter and receiver subsystems.

8 Claims, 22 Drawing Figures



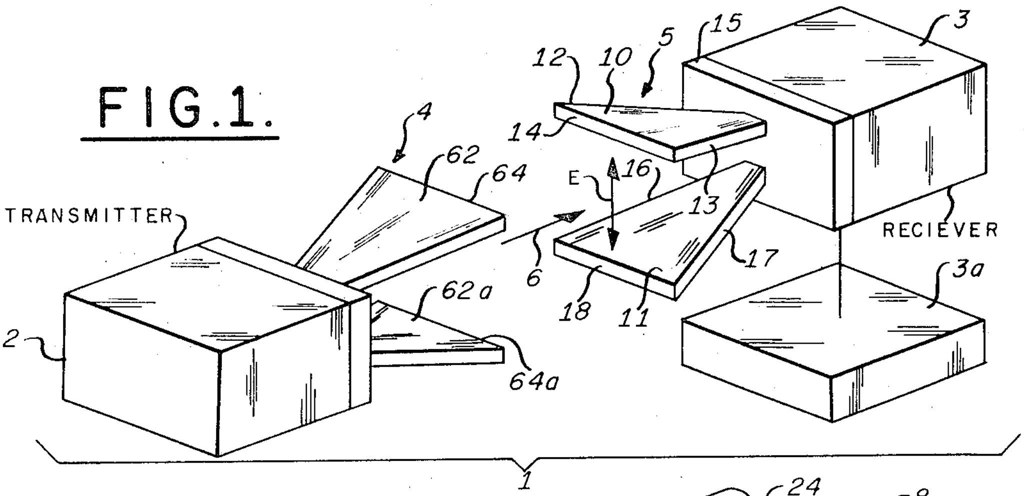


FIG. 1.

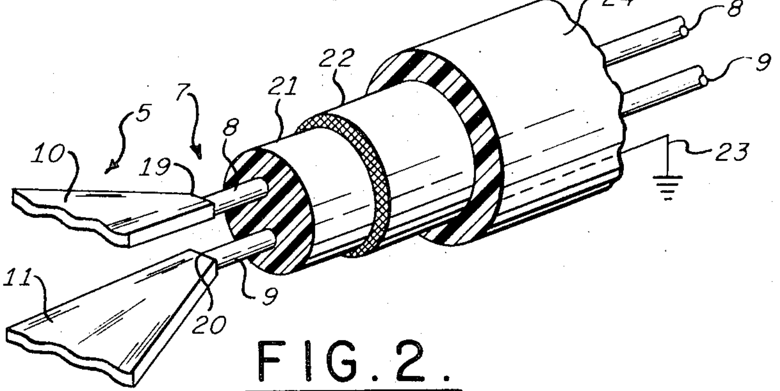


FIG. 2.

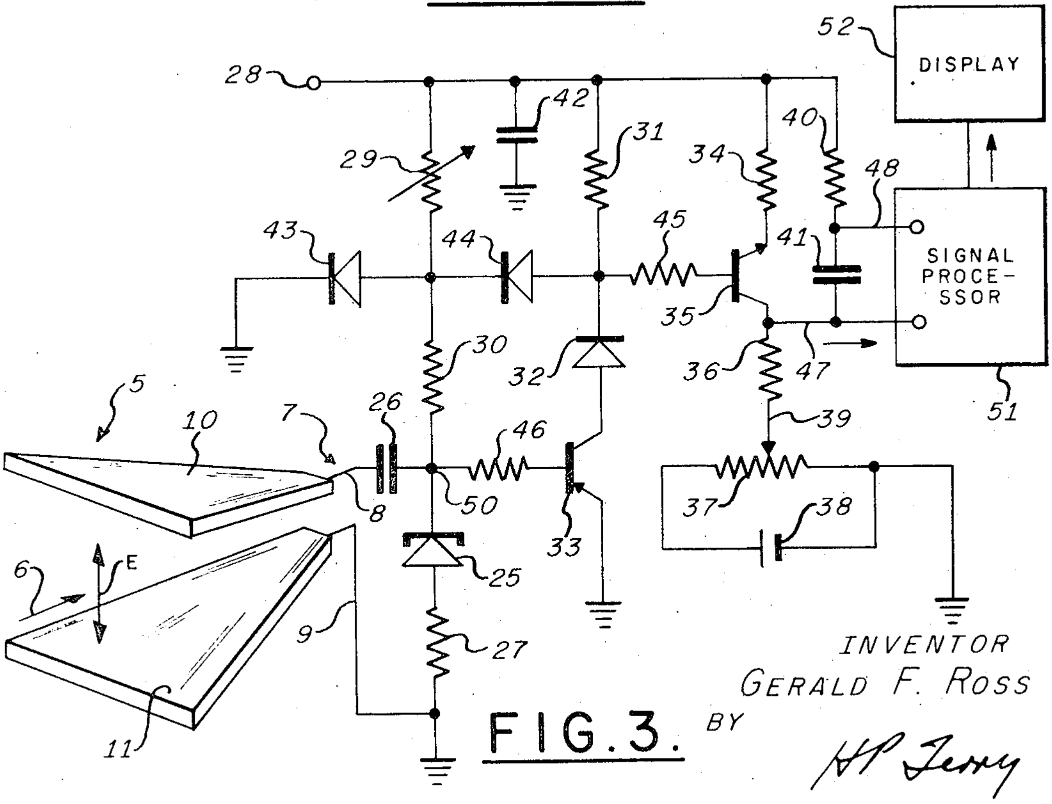


FIG. 3.

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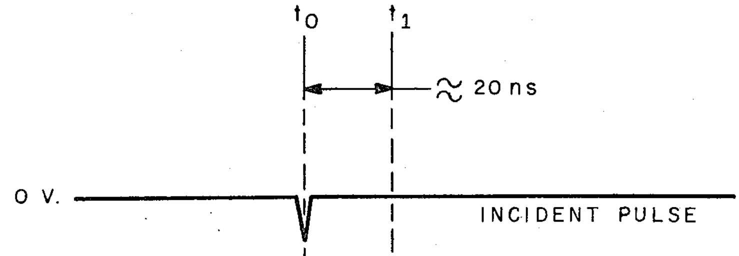

FIG. 4a.

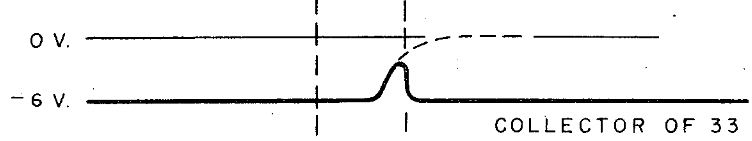

FIG. 4b.

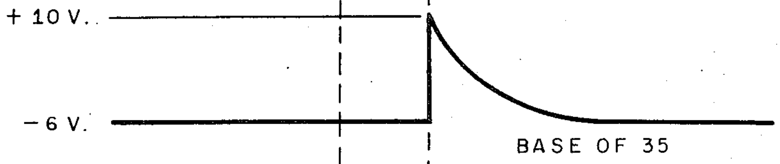

FIG. 4c.

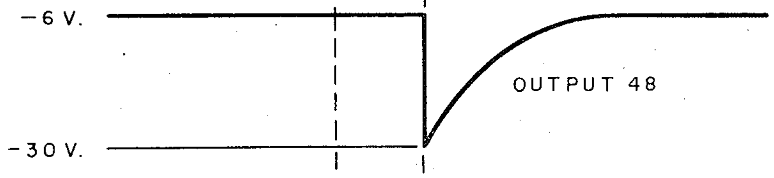

FIG. 4d.

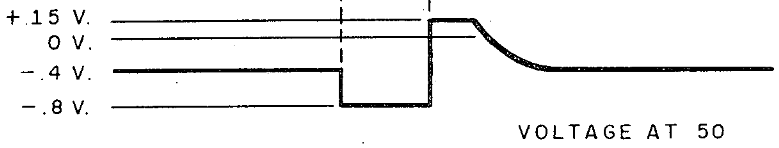

FIG. 4e.

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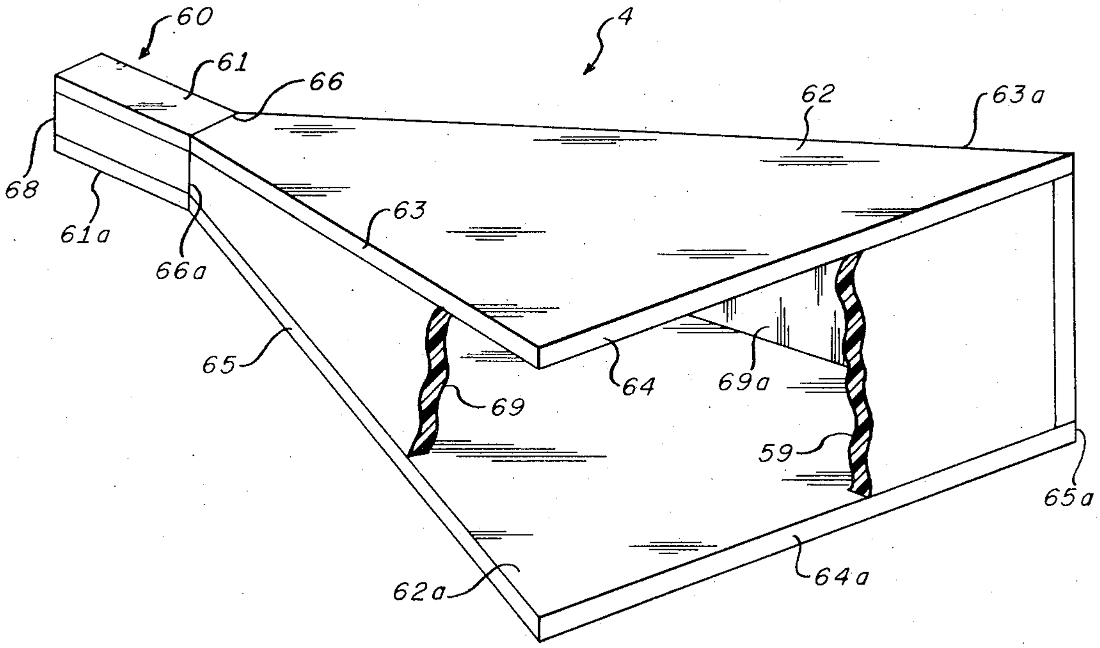

FIG. 5.

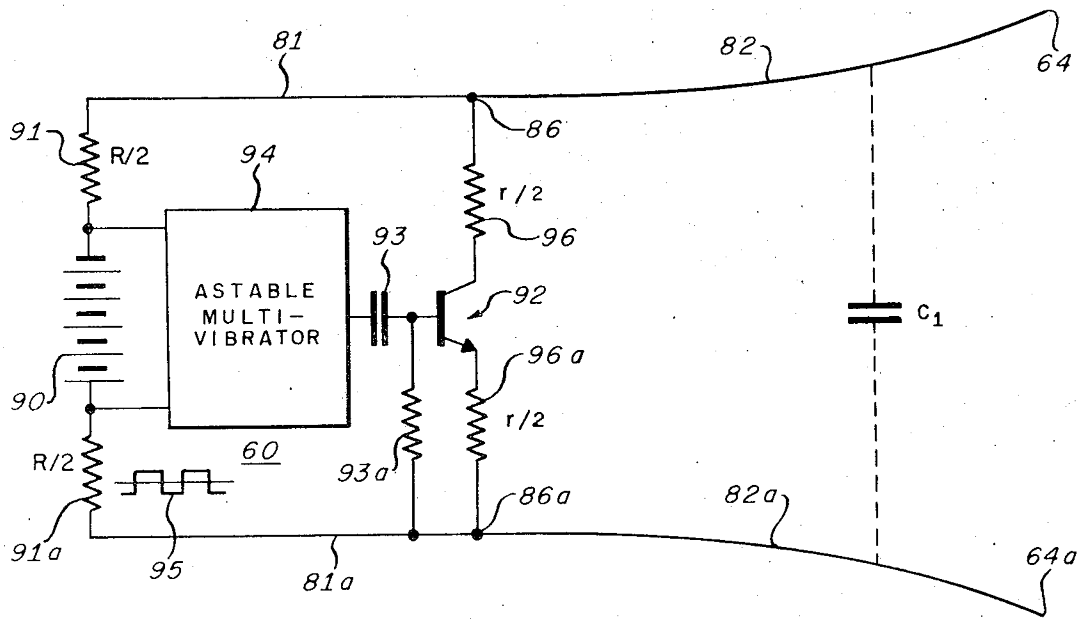

FIG. 6.

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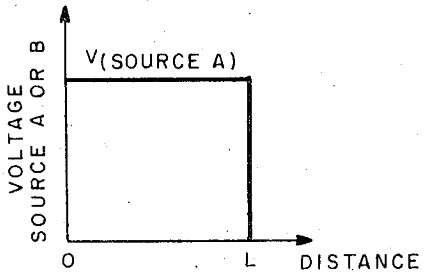

FIG. 7a.

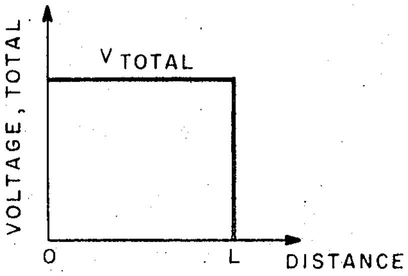

FIG. 7b.

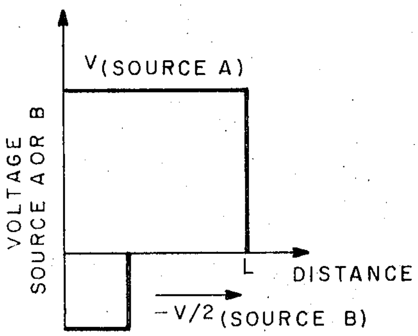

FIG. 8a.

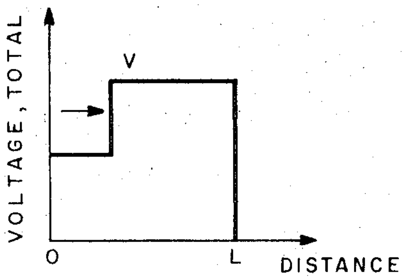

FIG. 8b.

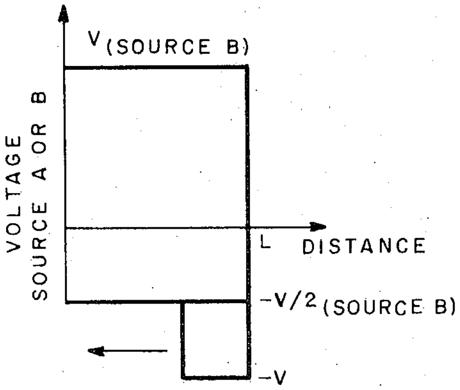

FIG. 9a.

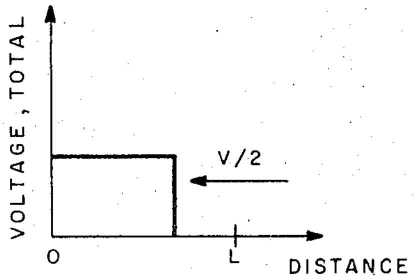

FIG. 9b.

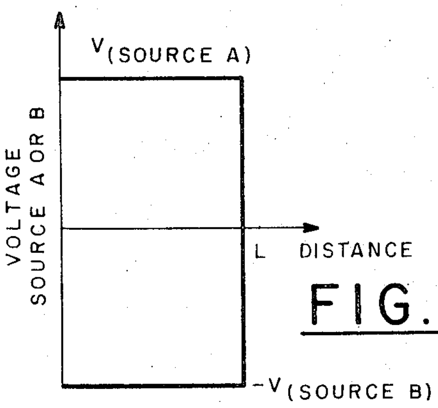

FIG. 10a.

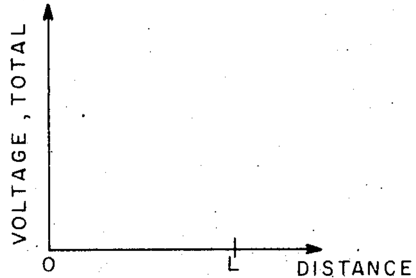

FIG. 10b.

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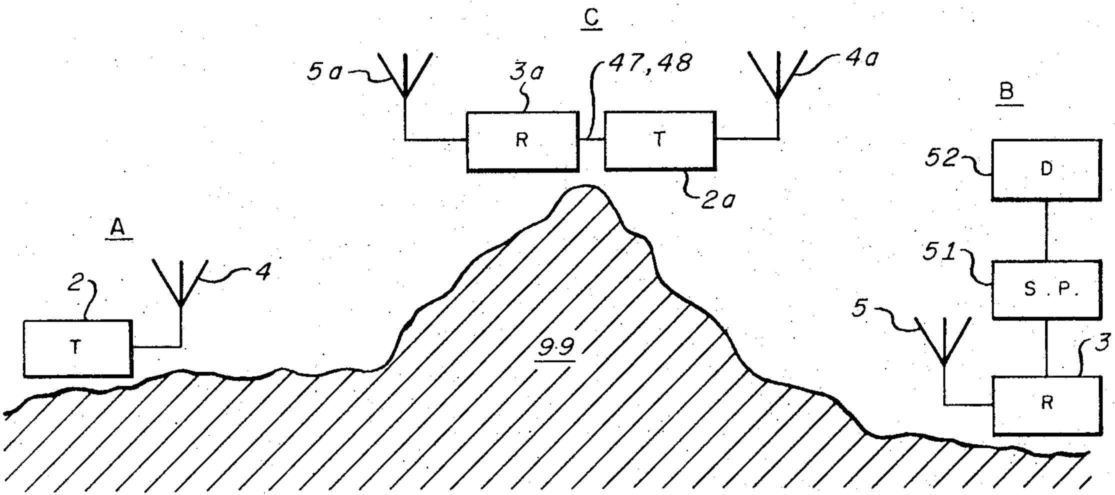

FIG. 11.

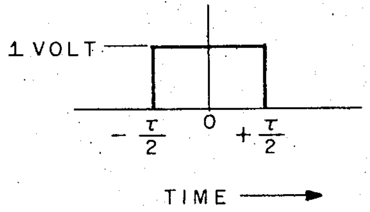

FIG. 12.

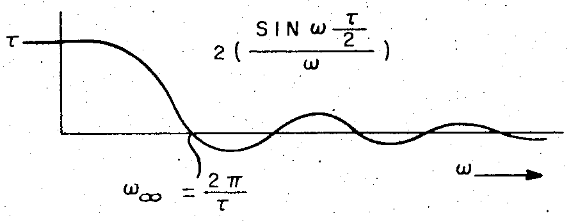

FIG. 13.

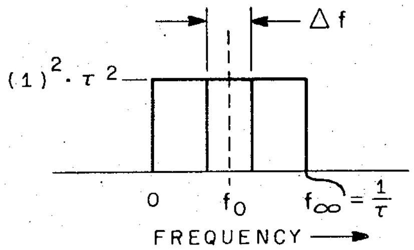

FIG. 14.

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TRANSMISSION AND RECEPTION SYSTEM FOR GENERATING AND RECEIVING BASE-BAND DURATION PULSE SIGNALS WITHOUT DISTORTION FOR SHORT BASE-BAND COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention pertains to the transmission, reception, detection, and use of very short, base-band electromagnetic pulses and more particularly relates to means for the transmission and reception of such base-band pulses of sub-nanosecond duration.

2. Description of the Prior Art

Electromagnetic radio signal communications systems available in the prior art each require for operation a particular frequency band of particular width in the total frequency spectrum. As types of radio communication systems have increased and their applications have become varied and wide spread, the allocation of frequency bands so that new transmitters do not overlap in frequency the wave bands allotted to other communication systems becomes increasingly difficult. Radio frequency interference in the receiver corresponding to transmitters in the same and in remote wave bands has increased the need and cost for providing shielding and other special design features, for example, in ordinary types of broadcast receivers. Even radiation of local oscillator energy must be carefully controlled.

Any spurious radiation, above the extremely low power levels regarded as permissible, adversely affects conventional radio reception. On the other hand, if the competing radiation level is very low and it itself is employed for communication purposes, it is useful only over extremely short ranges and, even then, may be seriously disabled in the presence of other legal transmissions or by ambient electrical noise signals. There is not known in the prior art a radio energy communication system which may be successfully operated with substantial distances between the transmitter and receiver thereof in a wave band already allotted to other receivers in the same geographical vicinity. More particularly, there is not known in the prior art a radio energy communication system of the just described type which can operate at very low or legal power levels without it itself being the victim of interference. Furthermore, there is not known in the prior art a radio energy communication system such as described in the foregoing and also capable of transmission and reception of signals having an extremely wide frequency spectrum without interfering with the transmission of ordinary communication signals.

SUMMARY OF THE INVENTION

The invention pertains to radio pulse communication systems of a novel kind so constructed and arranged so as to afford intelligence communication without interference with conventional types of radio communication and, in turn, being substantially unaffected in normal operation by the radiations of other communication systems or by ambient electrical noise signals.

The transmitter appropriate for employment in the novel communication system utilizes a non-dispersive transmission line system for generation of very short base-band or sub-nanosecond pulses of electromagnetic energy and for their radiation into space, cyclic energy storage on the transmission line and alternate cyclic energy radiation therefrom being employed. The transmission line functions as a non-dispersive radiator radiating the sub-nanosecond impulses with substantially no distortion. Such base-band pulses have an extremely wide energy spectrum; while the total energy content of any given transmitted base-band pulse may be considerable, the few spectral lines falling within the relatively narrow pass band of a conventional receiver will have no effect thereon.

The pulse receiver suitable for detecting such short base-band electromagnetic pulses also employs a dispersionless, broad band transmission line antenna, with a circuit cooperating with a biased semiconductor detector element located within the antenna transmission line for instantaneously detecting substantially the total energy of the base-band pulse and for supplying a corresponding output suitable for application in conventional utilization circuits. The novel receiver antenna system supplies substantially the total energy of each undistorted received base-band pulse directly to the receiver detector; thus, the receiver is adapted to operate successfully with pulse signals having a very wide spectral extent. Further, it may operate with base-band pulse signals having spectral components each of such low individual energy content as to escape detection by conventional narrow band receivers. The total energy in each base-band pulse can, however, be relatively larger than the level of noise or other interfering pulses or signals in the vicinity of the novel receiver. Thus, by appropriately adjusting the output level of the transmitter and the sensitivity or threshold of the receiver detector, base-line communication signals not affecting other receivers are readily received and detected by the novel receiver without it, in turn, being affected in substantial degree by other radio energy transmissions.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of the novel base-band pulse communication system.

FIG. **2** is a perspective view, partly in cross section, of a portion of the receiver of FIG. **1**.

FIG. **3** is a circuit diagram showing circuit components of the receiver of FIG. **1** and their interconnections.

FIGS. **4***a*, **4***b*, **4***c*, **4***d*, and **4***e* are graphs of wave forms useful in explaining the operation of the receiver circuit of FIG. **3**.

FIG. **5** is a perspective view, partly in cross section, of the transmitter of FIG. **1**.

FIG. **6** is a circuit diagram showing circuit components of the transmitter of FIG. **5** and of their interconnections.

FIGS. **7***a*, **7***b*, **8***a*, **8***b*, **9***a*, **9***b*, **10***a*, and **10***b* are graphs of wave forms useful in explaining the operation of the transmitter of FIGS. **5** and **6**.

FIG. **11** is an elevation view of a modification of the communication system of FIG. **1**.

FIGS. **12**, **13**, and **14** are graphs useful in explaining the operation of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. 1 illustrates a short base-band or sub-nanosecond pulse communication system 1 employing an impulse or short base-band pulse transmitter 2 having an antenna 4 operating in conjunction with an impulse or short base-band receiver 3 having an antenna 5.

Short base-band transmitter 2 may be of the general type disclosed by G.F.Ross and D.Lamensdorf in the U.S. patent application Ser. No. 46,079, for a "Balanced Radiation System", filed June 15, 1970, issued Apr. 25, 1972 as U.S. Pat. No. 3,659,203, and assigned to the Sperry Rand Corporation. The Ross, Lamensdorf device, for instance, employs an antenna similar to antenna 4 including an electrically smooth, constant impedance, transmission line system for propagating TEM mode electromagnetic waves. The transmission line system is employed within the transmitter for the cooperative cyclic storage of energy on the transmission line and for its cyclic release by propagation along the transmission line for radiation at the aperture end of an antenna section of the transmission line formed as a flared or tapered directive antenna line antenna 4. Thus, cooperative use is made of the transmission line system for signal generation by cyclically charging the transmission line at a first rate of charging and also for signal radiation into space by discharge of the line in a time much shorter than that required for charging. Discharge of the transmission line causes a voltage wave to travel toward the open end or radiating aperture of the antenna structure. The process operates to produce, by differentiation, a sharp impulse or base-band pulse of sub-nanosecond duration that is radiated into space. The Ross, Lamensdorf antenna has, like the present antenna 4, a wide instantaneous band width, so that it may radiate very sharp impulse-like signals of sub-nanosecond duration, either of positive or negative excursion, with substantially no distortion. Further, antennas 4 and 5 may have wide patterns of transmission and reception or may readily be provided with a focusing characteristic such that energy radiated or received in a predetermined direction is maximized. A particular system for use as transmitter 2 and antenna 4 will be discussed in connection with FIGS. 5 to 10.

The transmitter 2 and its associated antenna 4 of the communication system 1 are designed to radiate a short base-band pulse or pulses which may arrive directly or otherwise at the base-band pulse receiver antenna 5 to be detected by receiver 3. Receiver 3 is a base-band or sub-nanosecond pulse receiver for receiving and detecting such a very short base-band electromagnetic pulse or pulses, and for supplying an output useful for operating utilization equipment 3*a* such a display. The receiver system 3 employs a substantially dispersionless, very wide band transmission line antenna system 5, which may cover a large or small angular region in space, cooperating directly with a specially arranged detector located within the transmission line for detecting the total energy of the base-band pulse. As will be explained with reference to FIGS. 2 and 3, a cooperating circuit coupled to the detector device supplies a corresponding output signal suitable for application in conventional utilization circuits and also recycles the receiver system 3 to make it ready for the receipt of a succeeding short base-band pulse. Since the total energy of the base-band pulse is instantaneously supplied by the dispersionless antenna system 5 to the detector device, the receiver 3 may operate with pulse signals having spectral components the amplitudes of which are all incapable of detection by conventional relatively narrow band receivers. One base-band receiver having suitable characteristics for use as receiver 3 in the novel communication system is disclosed in the K.W.Robbins U.S. patent application Ser. No. 123,720 for a "Short Baseband Pulse Receiver," filed concurrently with the present patent application on Mar. 12, 1971, issued May 9, 1972 as U.S. Pat. No. 3,662,316 and also assigned to the Sperry Rand Corporation.

As will be explained, the novel short base-band pulse communication system 1 of the present invention has unique qualities permitting its use to convey intelligence through space from one location to another along an arbitrarily selectable path in a manner which causes substantially no interference with ordinary radio transmissions. As will also become apparent, while the novel communication system 1 may be adjusted to operate at very low peak and average power densities, it is substantially immune to the presence of random electromagnetic noise or to the presence of conventional broadcast signals of usual levels.

As is seen in FIGS. 1, 2, and 3, one receiver antenna 5 suitable for use in the invention comprises a structure having mirror image symmetry about a median plane at right angles to the direction of the vector of the electric field E propagating into the antenna, for instance, in the direction indicated by arrow 6. The same is true of the cooperating transmission line 7 (FIG. 2) which comprises parallel wire transmission line conductors 8 and 9; conductors 8 and 9 are spaced wire conductors constructed of a material capable of conducting high frequency currents with substantially no ohmic loss. Furthermore, conductors 8 and 9 are so constructed and arranged as to support TEM mode propagation of high frequency energy, with the major portion of the electric field lying between conductors 8 and 9. It will be understood by those skilled in the art that the term TEM mode of wave propagation is that commonly used in the high frequency literature to specify a conventional mode of electromagnetic energy propagation. In the TEM or transverse electromagnetic mode, both the electric and magnetic field components of the wave are everywhere transverse to the direction of wave propagation. This is in contrast to the character of certain other types of conventional electromagnetic waves, such as the transverse electric (TE) and transverse magnetic (TM) waves. The TE and TM modes are dispersive modes, while the TEM mode employed in the present invention is desirably nondispersive, the velocity of propagation in the TEM mode being a constant rather than varying with frequency.

The TEM receiver antenna 5 further consists of a pair of flared, flat, electrically conducting planar members 10 and 11. Members 10 and 11 are, for example, generally triangular in shape, member 10 being bounded by flared edges 12 and 13 and a frontal aperture edge 14. Similarly, member 11 is bounded by flaring edges 16 and 17 and a frontal aperture edge 18. Frontal aperture edges 14 and 18 may be straight or arcuate. Each of triangular members **10** and **11** is slightly truncated at its apex, the truncations **19** and **20** being so constructed and arranged that conductor **8** is smoothly joined without overlap at truncation **19** to antenna member **10**. Likewise, conductor **9** is smoothly joined without overlap at truncation **20** to antenna member **11**. It is to be understood that the respective junctions at truncations **19** and **20** are formed using available techniques for minimizing any impedance discontinuity corresponding to the junctions.

It is also to be understood that the flared members **10** and **11** of antenna **5** are constructed of material highly conductive for high frequency currents and may be supported within an apertured sheet **15** of low loss dielectric material forming a portion of the receiver casing. It is further apparent that the interior volume of antenna **5** may be filled with an air foamed dielectric material exhibiting low dielectric loss in the presence of high frequency fields, such material acting to support conductor **10** in fixed relation to conductor **11**. Alternatively, the conductive elements of antenna **5** may be fixed in spaced relation by dielectric spacers which cooperate in forming enclosing walls for the configuration, thereby protecting the interior conducting surfaces of antenna **5** from the effects of precipitation and corrosion.

As noted, the planar collector elements **10** and **11** of receiver antenna **5** are coupled in impedance matched relation to the two wire transmission line **7**, seen in more detail in FIG. **2**. Transmission line **7** is arranged to have the same impedance as the transmission line comprising antenna elements **10** and **11**. Transmission line **7** may have its parallel wire conductors **8** and **9** molded into a dielectric enclosing element **21** for the purpose of accurately determining the separation of conductors **8** and **9** so that transmission line **7** has a constant impedance along its length. Dielectric element **21** may be surrounded, in turn, by a braided or other conductive shield **22** which may be grounded at a convenient location, as by lead **23**. Shield **22** may, in turn, be surrounded by a protective plastic cover element **24** of the well known type. The two-wire transmission line **7** is thus readily attached to the active input element **25** of receiver **2**, as will be discussed in connection with FIG. **3**. Generally the length of transmission line **7** between antenna **5** and active element **25** will be short.

A cooperating antenna **5** and transmission line **7** system of the form shown in FIGS. **2** and **3** is a preferred antenna, in part, because desired TEM mode propagation therein is readily established. The TEM propagation mode is preferred, since it is the substantially non-dispersive propagation mode and its use therefore minimizes distortion of the propagating subnanosecond pulse signal to be received. The simple dual transmission line structure also permits construction of the antenna-transmission line configuration with minimum impedance discontinuities. Furthermore, it is a property of the symmetric type of transmission line forming antenna **5** that its characteristic impedance is a function of b/h, where b is the width dimension of the major surfaces of conductors **10** and **11** and h is the distance between inner faces of the conductors **10** and **11**. For example, the ratio b/h is kept constant in the instance of the antenna **5** transmission line **10**, **11** because the ratio of b to h is held constant.

According to the invention, the receiver-antenna **5** is made compatible with transmission line **7** by holding the value of the ratio b/h constant within antenna **5**. In other words, if the ratio b/h is kept constant along the direction of propagation **6** in antenna **5**, the characteristic impedance of antenna **5** will be constant along its length and may thus be readily made equal to that of transmission line **7**. By maintaining a continuously constant characteristic impedance and TEM propagation along the structure including antenna **5** and line **7**, frequency sensitive reflections are prevented therein and frequency dispersion is eliminated. The received subnanosecond impulse therefore flows through antenna **5** into transmission line **7** without substantial reflection and without substantial degradation of its shape or amplitude. Since the full energy or amplitude of a low-level subnanosecond base-band pulse is thus delivered to the receiver detector **25** by the antenna-transmission line system, it is seen that the receiver **3** can be sensitive to extremely short low-level base-band pulses having an extremely wide spectral content, any component of which would be incapable of detection using conventional wide pulse reception techniques. In addition, it will be clear to those skilled in the art that suitable types of non-dispersive base-band antennas having different receptivity patterns may be substituted for the illustrated antenna. For example, the omniazimuthal antenna disclosed in the G.F.Ross U.S. patent application Ser. No. 832,337 for a "Time Limited Impulse Response Antenna," filed June 11, 1969, issued June 22, 1971 as U.S. Pat. No. 3,587,107, and assigned to the Sperry Rand Corporation, may be so employed.

Any subnanosecond pulse collected by antenna **5** is passed with substantially no degradation within two wire transmission line **7** to the active detector element **25**, which is preferably a tunnel diode or other high speed diode adapted to serve as an impulse or base-band pulse detector. A suitable detector or diode **25** has a negative resistance current-voltage characteristic such that, under proper bias, the diode response to the arrival of impulse emissions from transmitter configuration **4** is to move abruptly into its region of instability, causing it to become less conductive. While other semiconductor diodes may be used, a suitable diode is the germanium 1N3717 tunnel diode.

Diode **25** is coupled to conductor **8** through a small capacitor **26** and through resistor **27** to ground and also to conductor **9** of transmission line **7**. Resistor **27** serves a potential level setting function, enabling tunnel diode **25** to drive silicon transistor **33**, and aids in providing a proper impedance match to line **7** so that reflections are avoided. Capacitor **26** also acts as a coupling capacitor, preventing damage to the receiver if the input is accidentally shorted. An appropriate bias source (not shown) for diode **25** is connected to terminal **28** for providing current flow through adjustable resistor **29** and level setting resistor **30** to diode **25**.

A second series circuit connected to bias terminal **28** comprises resistor **31**, diode **32**, which may be a conventional 1N914 diode, and transistor **33**, which may be a conventional 2N3638 transistor. A third series circuit connected to bias terminal **28** comprises resistor **34**, avalanche transistor **35**, which may be a selected conventional 2N706 transistor, and resistor **36**. Resistor **36** is connected to a tap **39** of a voltage source comprising potentiometer **37** and battery **38**. A fourth series circuit connected to bias terminal **28** comprises resistor **40** and capacitor **41**. Capacitor **42**, also connected to terminal **28**, forms an alternating current ground connection.

Diode **43** is coupled between ground and the junction between resistors **29** and **30**. The latter junction is connected through diode **44** to the junction between resistor **31** and diode **32**. Diodes **43** and **44**, like diode **32**, may be conventional 1N914 diodes. The junction common to resistor **31** and diode **32** is connected to the base of transistor **35** through resistor **45**. The junction **50** between capacitor **26** and tunnel diode **25** is connected through resistor **46** to the base of transistor **33**. The junction between the collector of transistor **35** and resistor **36** is coupled to one side of capacitor **41** by lead **47**, which also serves as an ungrounded output lead for the circuit. A second ungrounded output lead **48** is coupled at the junction between resistor **40** and capacitor **41**.

While other combinations of parameters may be used in practicing the invention, representative values of such circuit values include the following:

Resistor	
27	82 ohms
29	1 K ohms
30	390 ohms
31	2.2 K ohms
34	22 ohms
36	270 K ohms
40	56 ohms
45	330 ohms
46	390 ohms
Capacitor	
26	100 picofarads
41	680 picofarads
42	1 microfarad

For the above values, the power source represented by battery **38** and potentiometer **37** may be adjusted to supply about +150 volts at tap **39**. Also, a −6 volt bias source may be coupled to bias terminal **28**.

In operation, tunnel diode **25** is biased very near to its break down point by manual adjustment of resistor **29**. For example, in the instance of a representative 1N3713 germanium tunnel diode, somewhat less than **10** milliamperes is required to bias diode **25** near its break down point. In this situation, the voltage levels seen by transistor **33** are not sufficient to cause it to conduct and it remains quiescent. Diodes **32**, **43**, and **44** also remain non-conductive. The avalanche transistor **35** therefore does not have any forward bias. Its collector potential, by virtue of the setting of the tap **39** of potentiometer **37**, is such that it cannot break into spurious saw tooth oscillations. Avalanche transistor **35** is therefore also in its quiescent state and the receiver is ready for the receipt of an input short base-band pulse.

Such a short base-band pulse, preserved in shape and amplitude by antenna **5** and transmission line **7**, may be, for example, 0.5 nanoseconds in duration and may produce an instantaneous voltage pulse across tunnel diode **25**, for example, of −0.1 volts peak. Such a signal is illustrated in FIG. **4***a*, but exaggerated in duration for clarity of illustration. Tunnel diode **25** instantly switches from its quiescent low voltage, positive resistance state through its unstable negative resistance state to its high voltage, positive resistance state. Upon this event, voltage and current relations in the remainder of the circuit are transiently disturbed. Transistor 33 becomes forward biased by virtue of the presence of resistor **46** and the circuit including diode **32**, resistor **31**, and transistor **33** conducts current after a time delay inherent in transistor **33** and diode **32**, thereby causing the positive going signal of FIG. 4*c* to travel through resistor **45** to the base of avalanche transistor **35**. The wave of FIG. **4***c* begins sharply, for the specific circuit described in the foregoing, also substantially 20 nanoseconds after time t_0, which time corresponds to the time of the peak value of the short base-band pulse of FIG. **4***a*, and then begins to experience decay.

The positive wave of FIG. **4***c*, on the order of +10 volts, at the base of avalanche transistor **35** causes the series diodes **43** and **44** to draw current heavily through resistor **45**. The potential at terminal **50** of tunnel diode **25** abruptly changes, resetting tunnel diode **25** and reversing its state. After a time shown in FIG. **4***e*, it returns to its normal or quiescent state. Conduction through diode **32** fails, thus protecting the collector of transistor **33** from experiencing excessive positive bias.

The circuit continues to move toward its original quiescent state. Capacitor **41** discharges, mainly through the circuit path including resistor **34**, resistor **40**, and the avalanche transistor **35**, at an exponential rate of decay in dependence upon the time constant of that discharge circuit. On the other hand, capacitor **41** recharges much more slowly through resistor **36**.

As noted previously, useful output signals comprising relatively long duration pulses appear on output leads **47** and **48**; these have the general character shown in FIG. **4***d*, and appear simultaneously. The pulse on lead **47** has a substantially −100 volt peak value from the −6 volt level and a 63 percent of peak amplitude duration *d* of substantially 200 nanoseconds. The pulse appearing on lead **48** has a substantially 30 volt peak value from the −6 volt level and a 63 percent peak amplitude duration of substantially 200 nanoseconds. The delay *e* of the sharp rise of the output pulses in FIG. **4***b* is again substantially 20 nanoseconds behind the peak at t_0 of the received short-base pulse of FIG. **4***a*.

The output signals found on leads **47**, **48** may be coupled to any desired utilization apparatus **51**, **52** of the type which functions in a normal manner upon receipt of pulses of conventional or non-short-base-band duration normally manipulated by ordinary pulse handling circuits. Although the actual utilization apparatus is not a necessary part of the present invention, it will be seen by those skilled in the art that it may take any of a variety of forms. For example, a single subnanosecond base-band pulse received by antenna **5** may be considered to be an intelligence transmission and the consequent output appearing on output leads **47** and **48** may be placed directly on a conventional cathode ray tube display **52** of the type, for instance, in which the sweep of the indicator along one coordinate is triggered by the pulse to be displayed, the pulse itself, after slight delay, being used to sweep the cathode ray beam along a second coordinate. Signal processor **51** and display **52** may alternatively, for example, count the number of subnanosecond pulses received by processor **51** in an arbitrary time period or in a particular pulse burst and then indicate the total count on a conventional numeric display **52**. A train of subnanosecond pulses collected by antenna **5** may have a modulation, such as carried by pulse interval modulation, which may readily be demodulated in a conventional way by processor **51** and either displayed on indicator **52** or, if the demodulated signal is an audio signal, used to operate a loud speaker or other audio instrument in a conventional manner.

It is seen that the receiver of FIGS. **1**, **2**, and **3** is a wide band or wide open detector device, a receiver which will respond to any signal level in excess of the bias level which might be dictated by the characteristics of a particular tunnel diode **25**. The amplitude of the received impulse or base-band pulse at the receiving antenna **5** may be, for example, about 200 millivolts in a typical operating circumstance, a value several orders of magnitude greater than the signals present in an urban environment due to conventional radiation sources, such interfering signals normally being at a microvolt level. Accordingly, although the novel receiver of FIG. **3** essentially accepts all signals over a very wide pass band, it is substantially immune to interference from conventional radiation sources, including electrical noise signals such as internal combustion engine ignition noise.

The transmitter-antenna configuration **2**, **4** shown in FIG. **1** may be, for instance, capable of transmitting a regular train or a burst of extremely short duration, low amplitude impulses. In one typical situation, these impulselike signals have time durations of substantially 200 picoseconds and an impulse repetition frequency in the order of 10 kilohertz. However, the upper bound on the average power transmitted into all of space may be less than one microwatt. The spectrum of the transmitted signal is spread over an extremely wide band width, typically 100 megahertz to 10 gigahertz. Accordingly, the power radiated in any typical narrow communication band is far below the thermal noise threshold of a typical receiver operating in that band. The transmitted impulse is therefore incapable of interfering with the operation of standard radio communication equipment, while being remarkably adapted for use with the receiver of the present invention.

For generating the short base-band pulses required for use in the present invention, the transmitter apparatus illustrated in FIGS. **1**, **5**, and **6** may be employed. Referring particularly to FIGS. **1** and **5**, the antenna **4** is a structure which may be generally similar to antenna **5** used with receiver **3**. Antenna **4** comprises a structure, for example, having mirror image symmetry about a median plane at right angles to the direction of the vector **6** of the electric field E propagating within the antenna. The same is true of the cooperating transmission line **60** which comprises parallel plate or slab transmission line conductors **61** and **61***a* of similar shape. Conductors **61** and **61***a* are spaced planar conductors constructed of a material capable of conducting high frequency currents with substantially no ohmic loss. Further, conductors **61** and **61***a* are so constructed and arranged as to support TEM mode propagation of high frequency energy, with the major portion of the electric field lying between conductors **61** and **61***a* and with the electric field E substantially perpendicular to the major interior surfaces thereof.

The TEM transmitter antenna **4** further consists of a pair of flared, flat electrically conducting planar members **62** and **62***a*. Members **62** and **62***a* are, for example, generally triangular in shape, member **62** being bounded by flared edges **63** and **63***a* and a frontal aperture edge **64**. Similarly, member **62***a* is bounded by flaring edges **65** and **65***a* and a frontal apertured edge **64***a*. Edges **64** and **64***a* may be straight or arcuate. Each of triangular members **62** and **62***a* is slightly truncated at its apex, the truncation being so constructed and arranged that conductor **61** is smoothly joined without overlap at junction **66** to antenna member **62**. Likewise, conductor **61***a* is smoothly joined without overlap at junction **66***a* to antenna member **62***a*. It is to be understood that the respective junctions **66** and **66***a* are formed using known techniques for minimizing any impedance discontinuity.

It is also to be understood that the flared members **62** and **62***a* of antenna **4** are constructed of material highly conductive to high frequency currents. It is further apparent that the interior volume of antenna **4** may be filled with a a dielectric material exhibiting low loss in the presence of high frequency fields. The interior of transmission line **60** may be similarly filled with dielectric material, such material acting to support conductor **61** in fixed relation with respect to conductor **61***a* and, likewise, the flared antenna member **62** relative to flared member **62***a*. Alternatively, the conductive elements of transmission line **60** and antenna **4** may be fixed in spaced relation by dielectric spacers which cooperate in forming enclosing walls for the configuration, protecting the interior conducting surfaces of the antenna-transmitter configuration from the effects of precipitation and corrosion. For example, thin vertical walls **68** and **68***a* of low loss dielectric sheet material may be used in conjunction with transmission line conductors **61** and **61***a*. Side walls for separating the planar elements **62** and **62***a* may take the form of triangular low loss dielectric wall elements **69** and **69***a*; such side walls, in cooperation with a thin front of radome wall **59** of low loss dielectric material, lend mechanical strength to the antenna configuration **4** and aid in protecting the interior thereof. It will be understood that the planar elements **62** and **62***a* forming the antenna aperture may be exponentially tapered alternative to being lineally tapered.

A form such as that of the transmission line **60** and the transmitter-antenna **4** such as illustrated in FIG. **5** is preferred, in part, because TEM mode propagation therein is readily established. The TEM propagation mode is again preferred, since it is the substantially non-dispersive propagation mode and its use therefore minimizes distortion of the propagating base-band pulse signal to be transmitted by it. The simple, balanced transmission line structure permits construction of the configuration **4** with minimum impedance discontinuities. Furthermore, it is a property of the symmetric type of transmission line of the antenna **4**-transmitter **2** configuration that its characteristic impedance is a function of b/h, where b is the width dimension of the major surfaces of conductors **62** and **62***a* and h is the distance between the inner faces of the conductors **32** and **32***a*. As in the instance of antenna **5**, the ratio b/h is kept constant in the transmission line **60** because both b and h are constant.

According to the invention, the transmitter antenna **4** is made compatible with transmission line **60** by using the same value of the ratio *b*/*h* for both elements. The characteristic impedance of transmitter antenna **4** will thus be constant along its length and may readily be made equal to that of transmission line **60**. By maintaining a continuously constant characteristic impedance along the structure including transmission line **60** and antenna **4**, frequency sensitive reflections are prevented therein. It has been elected, for the sake of simplicity of explanation, to show in FIG. **5** triangular flaring planar configurations for elements **62** and **62***a*. It should be evident, however, that other configurations may readily be realized which maintain a constant characteristic impedance according to the above rule, and that such configurations may also be used within the scope of the present invention.

The system for exciting the transmitter antenna **4** of FIG. **5** has compatible properties therewith, such as being balanced in nature and as avoiding the complicating deficiencies of an interface balun or of other transition elements. The system of FIG. **6** achieves such objectives and, in addition, makes beneficial use of the balanced dual element configuration of transmitter antenna **4** as part of the charging line for the base-band pulse excitation generator. It will be understood that certain liberties have been taken in the drawing of FIG. **6** better to explain the structure and operation of the device disclosed therein. For example, it is seen that FIG. **6** is intended schematically to indicate conductor elements **62** and **62***a* of FIG. **5** as respective single wire transmission lines **82** and **82***a* having the same effective electrical characteristics as elements **62** and **62***a* of FIG. **5** and the same radiating characteristic. As a further example, junctions **66** and **66***a* in FIG. **5** are represented by junctions **86** and **86***a* in FIG. **6**. The symbols **61** and **61***a* in FIG. **5** are represented in FIG. **6** by symbols **81** and **81***a* and identify the opposed conductors of transmission line **60**. Dimensions in FIG. **6** are exaggerated, such as the spacing h between conductors **81** and **81***a* of line **60**, as a matter of convenience.

At the left end of line **60**, conductors **81** and **81***a* are joined by a series circuit comprising battery **90** coupled between charging resistors **91** and **91***a* each having a resistance value of R/2 ohms. At the end of line **60** adjacent junctions **86** and **86***a*, the conductors **81** and **81***a* are joined by a series circuit comprising an electrically actuatable switch **92**, which may take the form of an avalanche transistor or other transistor switch; thus, transistor **92** is coupled across battery **90** through resistors **91**, **91***a*, **96** and **96***a*. Also coupled across battery **90** is an astable multivibrator **94** which is connected through capacitor **93** to the base of transistor **92** for the purpose of controlling the state of conduction of transistor **92**. Resistors **96** and **96***a* each have a resistance value of *r*/2 ohms, where *r* is equal to the characteristic impedance of line **60**(and of the transmission line comprising elements **82** and **82***a*). Transistor **92** is also provided with a base-to-ground resistor **93***a*.

A stable multivibrator or pulse generator **94** may produce a regular bipolar wave train such as wave **95**, of a predetermined pulse repetition frequency for actuation of transistor switch **92**. In operation, it will be observed that transistor switch **92** is first held non-conducting by pulse generator **94** for a time sufficient for the entire structure including the conductors of line **60** and conductors **82** and **82***a* to become charged to a potential difference V equal to that supplied by battery **90** as if charging an effective capacitor C_1. On the next cycle of wave **95**, transistor switch **92** is rendered conducting, forming a conducting circuit path through resistors **96** and **96***a*. The effect is that of putting a second or effective source B in series with the first source A or battery **90**, but reversed in polarity relative to the polarity of the first source A.

FIGS. **7***a*, **8***a*, **9***a*, and **10***a* show the positive voltage V, contributed by the source A or battery **90**, as a positive constant voltage at successive intervals in the operating cycle. The same set of figures shows the progress of the negative wave due to the second or effective source B at the same successive intervals. For example, FIG. **7***a* shows the situation at the instant transistor or switch **92** is rendered conductive; note that the wave due to the effective second source B has not started to flow.

In FIG. **8**a, however, the negative wave of voltage −V/2 from the effective second source B has begun to flow toward the aperture of transmitter antenna **4**. Upon reaching the aperture ends **64**, **64***a* of conductors **82** and **82***a* of FIG. **6**, and upon being reflected, the situation is depicted in FIG. **9***a*. It is seen that when the −V2 wave reaches the respective aperture ends **64**, **64***a* of antenna conductors **82** and **82***a*, it is reflected and begins to flow back toward junctions **86**, **86***a*. The total contribution of the second or effective source B, beginning at the instant of reversal, is now −V volts. It will be seen that the total potential due to the real and the effective sources A and B between conductors **82** and **82***a* at the aperture ends **64**, **64***a* of the antenna at the instant of reversal suddenly drops from +V volts to zero; this instant of time is one of primary interest in the operation of the transmitter antenna **4**. The wave due to the effective source B continues to travel back toward junctions **86**, **86***a* until the antenna conductors **82**, **82***a* which have served as part of the charging line for the system, are substantially completely discharged if the value of *r* is the characteristic impedance of the line comprising conductors **82**, **82***a*. The charging cycle is then reestablished when pulse generator **94** again renders switch **92** conductive. The system may be repeatedly recycled.

It will be readily appreciated that the total potential difference seen across the frontal aperture edges **64**, **64***a* of the antenna, for the same successive instants of time as described above, may be illustrated as in the respective FIGS. **7***a*, **8***b*, **9***b*, and **10***b*. It is seen that the potential across the antenna aperture due to the real source **90** (or A) is progressively eaten away by the travel of the wave due to the second or effective source B as started toward the aperture **64**, **64***a* when switch **92** is conductive and is then reflected at the aperture whereupon radiation occurs, ultimately to effect substantial discharge of the line formed by conductors **82** and **82***a*, the wave having returned to be absorbed in the resistances **96**,**96***a*.

As noted previously, it is the instant of reflection of the wave of the effective source B at the distance L along conductors **82** and **82***a* (the aperture of transmitter antenna 4) that is of prime interest. Because of the finite characteristic impedance r of the transmitter-antenna system, the leading edge of the $-V/2$ wave launched into the aperture or mouth **64**, **64**a of the antenna, which is in effect an open circuit, reverses in direction of flow while maintaining its previous polarity. Radiation into space of an impulse or base-band signal proportional to (dV/dt) must occur at this instant of time. No further radiation can obtain until after switch **92** is recycled by pulse generator **94** and conductors **82** and **82**a are recharged from battery **90**. As noted above, if the resistance r of the sum of resistors **96** and **96**a is made equal to the characteristic impedance of the transmission line system **62**, **62**a, the reflected wave front finally terminates in resistors **96**, **96**a and the potential difference across the entire line drops to substantially zero. It then begins to recharge to approximately rv/R volts, recharging requiring $2rC_t$ seconds.

The base-band pulse receiver **3**, as has been seen, may be employed in the novel communication system to receive intelligence communications in a variety of ways, such as by receiving a single subnanosecond base-band pulse from transmitter **2**, then generating an output pulse of duration for example, of the order of 100 nanoseconds, and displaying same on a conventional indicator **52** of FIG. **3**. In this instance, transmitter **2** of FIG. **6** may be, for example, operated by manually closing a switch corresponding to transistor switch **92**, at the same time disconnecting battery **90** at one of its terminals so that transmission line **60** cannot recharge. Equivalent electronic operation may be readily visualized.

More sophisticated arrangements for conveying intelligence messages from transmitter **2** to receiver **3** are readily apparent to those skilled in the art. For example, multivibrator **94** of FIG. **6**, or other known types of pulse generators for forming a square wave pulse train similar to wave **95**, may readily be adjusted to cause transmitter **2** and antenna **4** to radiate an intelligence transmission, for instance, comprised of a train of 100 base-line pulses. Such a train, if detected by receiver **3**, may be, as previously observed, conveyed to a conventional counter circuit for counting the 100, 100 nanosecond duration pulses, the total count being displayed on a numeric display **52**. Well known pulse generators, useful in addition to multivibrator **94** for the purpose, may have their pulse repetition rates readily changed in a conventional manner from one frequency to another manually or by electrical command signals. Conventional pulse frequency demodulation circuits present in processor **51** may then be employed to process pulse frequency modulated 100 nanosecond pulses to yield a display of frequency as a message on indicator **52**. Similarly, pulse interval modulation in transmitter **2** and cooperative demodulation in receiver **3** may be employed for conveying intelligence messages. It will be understood by those skilled in the art that a variety of ways is available in the prior art for impressing intelligence on the carrier-less base-band pulses of transmitter **2**, and for abstracting that intelligence at receiver **3** by well established demodulation techniques operating on the relatively long pulses generated in receiver **3**.

The versatility of application of the novel communication system is further illustrated by reference to FIG. **11**, which figure represents a relay communication system for sending messages from a transmitter station A to a receiver station B, where, for example, an obstacle in the form of a mountain range **99** is interposed between stations A and B. Transmitter station A utilizes a transmitter **2** and transmitter antenna **4** which may be like elements **2** and **4** of FIG. **1**. Similarly, receiver station B utilizes a receiver antenna **5** and a receiver **3** which may be like those of FIG. **1**.

At station C, located at the top of the mountain or other obstacle **99**, is located a repeater system composed of a receiver **3**a with an antenna **5**a feeding signals for retransmission to a transmitter **2**a having an associated antenna **4**a. It will be understood that the base-band pulse receiver **3**a is similar to the base-band pulse receiver system **3** of FIGS. **1** and **3** and that the base-band transmitter **2**a is similar to that of FIGS. **5** and **6**. It is evident that the wave forms of FIGS. **4**b and **4**c output on leads **47** and **48** of FIG. **3** may be used directly to control a known square wave pulse generator or shaping circuit for producing an output similar to that of pulse generator **94** of FIG. **6**, thus producing the wave form **95** required for operation of transmitter **2**a and for the consequent reception of base-band pulses by receiver **3** at station B. At station B, the output of receiver **3** may be employed in signal processing circuit **51** and display or other utilization apparatus **52**, as discussed in connection with FIG. **3**.

The novel communication system of the several figures is characterized by a base-band pulse generator capable of generating pulses of subnanosecond duration for carrier-less communication and generally considered, in the time domain, to be triangular in shape. Typically, the base line durations of such triangular base-band pulses have values of several hundred picoseconds. Such pulses have, in the frequency domain, an extremely wide energy spectrum, running substantially from direct current to infinity, though with oscillating and diminishing amplitude. While the total energy content of the transmitted base-band pulse may be considerable, the few spectral lines falling within the pass band of a conventional receiver will have no effect thereon. On the other hand, the receiver of the present invention operates with an input system having no dispersive elements and no resonant circuits and is thus, in effect, wide open to receive all of the energy of substantially all spectral lines of each incoming base-band pulse. With the exception that there is present a need for time to generate at the output of the base-band receiver a pulse of energy content and of duration suitable for operation of the conventional pulse utilization circuits **51**, **52**, there is no dependence in the novel receiver's operation on the past history or future reception of transmissions i.e., each received base-band pulse is handled as a distinctly separate event, there being no frequency dispersive circuits and no resonant circuits requiring a carrier transmission and generally requiring many cycles of carrier input signal before sufficient energy is built up in the receiver for an output to be produced.

The theory of operation of the novel communication system will readily be understood by those skilled in the art from the foregoing discussion. However, the following simple analysis of the invention may be offered as one of several possible analyses which might alternatively be selected to explain operation of the short base-band pulse communication system. It will be understood that there is no limitation solely to use of the following analysis since other analyses might equally well be employed. The purpose of the selected analysis is to interrelate time and frequency domain dimensions in dealing with the carrierless short base-band signals employed in the present invention and, in turn, to relate such parameters to the noise level in a conventional narrow band pulse receiver and its characteristic interference level.

Certain assumptions will be made in order to make the analysis simple. First, a rectangular rather than a strictly triangular, base band pulse will be considered of the form:

$$r(t)=1 \qquad t \leq (\tau/2)$$

$$p(t)=0 \qquad t > (\tau/2) \qquad (1)$$

as illustrated in FIG. **12**. As previously noted, the duration of the normalized one volt amplitude pulse measured at the base of FIG. **12** may be several hundred picoseconds. The pulse described by FIG. **12** has, in the frequency domain, an amplitude spectrum (volts/radian) as described in FIG. **13**, where the first zero crossing in the amplitude spectrum occurs at

$$f_\infty = 1/\tau \qquad (2)$$

If each amplitude of the curve of FIG. **13** is squared, the energy spectrum of the pulse signal is obtained. By integration of the squared function from zero frequency (d.c.) to $f_\infty = 1/\tau$, it is seen that 90 percent of the energy is concentrated in the region thus defined.

Introducing a second approximation by using Parsevall's theorem, the spectral energy density function is approximately given by FIG. **14**. The power spectrum density function can be found simply by dividing each ordinate in FIG. **14** by τ.

Assume that the conventional narrow band receiver with which interference is to be avoided has a pass band centered at frequency f_0 and a band width Δf. Then, the amount of peak signal power in the band Δf due to the incident rectangular pulse of FIG. **12** is given by:

$$\mathrm{P}_{peak} = (1)^2 \cdot \tau \cdot \Delta f \qquad (3)$$

or, if the pulse of FIG. **14** has an amplitude of V volts:

$$P_{peak} = V^2 \cdot \tau \cdot \Delta f \qquad (4)$$

The average power depends upon the duty cycle or the pulse duration and the pulse repetition frequency. Average power is given by:

$$\bar{P} = V^2 \cdot \tau \cdot \Delta f \cdot \tau / \bar{T} \qquad (5)$$

where $\bar{T}$ is the time between pulses. Thus

$$\bar{P} = (V^2 \cdot \tau^2 \cdot \Delta f)/\bar{T} \qquad (6)$$

The power within the band of an ideal narrow band receiver due to thermal noise is given by:

$$P_n = K \cdot T \cdot \Delta f \qquad (7)$$

where K is Bolzman's constant and T is temperature in degrees Kelvin. For a non-ideal receiver:

$$P_n = NF \cdot K \cdot T \cdot \Delta f \qquad (8)$$

where NF is the noise figure of the receiver.

What is of interest is the condition for which the potentially interfering pulse signal is equal to the noise signal; this condition is called the minimum discernible signal interference situation. This is now readily found by equating expressions (5) and (8):

$$(V^2 \cdot \tau^2 \cdot \Delta f)/\bar{T} = NF \cdot K \cdot T \cdot \Delta f \qquad (9)$$

or:

$$V = (1/\tau) \sqrt{NF \cdot K \cdot T \cdot \bar{T}} \qquad (10)$$

Equation (10) shows clearly that, as the pulse width τ gets smaller, the pulse signal voltage V must get correspondingly larger to maintain the same interference level. By way of example, assume:

$\tau = 200 \times 10^{-12}$ seconds
$\bar{T} = 10^{-4}$ seconds
$T = 293°$ Kelvin
$K = 1.38 \times 10^{-16}$, and
$NF = 10$.

Putting these values in equation (10) yields a value of V equal to 30 volts. Thus, under the assumed circumstances, a 30 volt subnanosecond pulse placed across the input terminals of the conventional narrow band receiver will just suffice to produce a minimum discernible interfering signal at the receiver detector.

It is seen that the invention is an impulse or base-band radio communication system particularly adapted for using low-total-energy-level transmitted impulses having a spectral content spread over a very wide band so as to make no significant contribution to the background electrical noise level and thus operating well below levels interfering with government controlled radio transmissions. The transmitter of the novel system is adapted to excite a cooperating base-band receiver of such a unique nature that the latter is substantially unaffected by ambient noise or ordinary pulse transmissions. Since the transmitter may operate with very low energy consumption, power supply cost and size are minimized. Furthermore, with such low power operation, inexpensive components may find long life use throughout the transmitter. The receiver is similarly categorized, both the receiver and transmitter element being of very simple nature and otherwise inexpensive of installation, maintenance, and operation, adapting readily to cooperative use with conventional intelligence input and output equipment.

While the invention has been described in its preferred embodiments, it is to be understood that the words which have been used are words of description rather than of limitation and that changes within the purview of the appended claims may be made without departing from the true scope and spirit of the invention in its broader aspects.

I claim:

1. The combination comprising:

transmitter means for transmitting a base-band signal,

receiver means having substantially non-dispersive TEM-mode transmission line means for receiving said base-band signal,

pulse forming detector means directly responsive to said substantially non-dispersive TEM-mode transmission line means for producing an output signal of substantially greater duration than said base-band signal, and

utilization means responsive to said greater duration output signal.

2. Apparatus as described in claim **1** wherein said transmitter means includes means for transmitting without distortion, a subnanosecond duration electromagnetic pulse having a base-band frequency range spectral line content, the energy in any selected one of said spectral lines being below the ambient noise level at said receiver means.

3. Apparatus as described in claim **2** wherein said pulse forming detector means responsive to said substantially non-dispersive TEM-mode transmission line means comprises semiconductor diode means having first and second states and coupled in energy exchanging relation with said substantially non-dispersive TEM-mode transmission line means.

4. Apparatus as described in claim **3** wherein said pulse forming detector means responsive to said substantially non-dispersive TEM-mode transmission line means comprises:

first circuit means biasing said semiconductor diode means in said first state for permitting said semiconductor diode means to change from its said first to its said second state instantaneously upon arrival at said semiconductor diode means of said subnanosecond duration electromagnetic pulse in substantially undistorted form,

second circuit means coupled to said first circuit means for producing said greater duration output signal, and

third circuit means utilizing a version of said extended duration output signal for returning said semiconductor diode means to its said first state.

5. Apparatus as described in claim **2** wherein said pulse forming detector means is biased to respond substantially instantaneously upon receipt by said receiver means of a base-band signal whose amplitude exceeds a predetermined amplitude for producing said greater duration output signal.

6. Communication means comprising:

transmitter means for transmitting a train of subnanosecond duration base-band electromagnetic pulses,

receiver means having substantially non-dispersive TEM-mode transmission line means for receiving said train of subnanosecond duration base-band electromagnetic pulses,

pulse forming detector means directly responsive to said substantially non-dispersive transmission line means for producing an output train of non-overlapping pulses each of greater duration than each of said subnanosecond duration electromagnetic pulses, and

utilization means responsive to said output pulse train.

7. Apparatus as described in claim **6** wherein said utilization means responsive to said output pulse train includes means for abstracting intelligence signals from said output pulse train.

8. Apparatus as described in claim **7** including display means for displaying said abstracted intelligence signals.

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