

RECEIVER IMPROVEMENT FOR EXPANDED INFORMATION CAPACITY FOR EXISTING COMMUNICATION TRANSMISSIONS SYSTEMS

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BACKGROUND OF THE INVENTION

This application claims priority to a U.S. Serial No. 60/171,384 filed December 22, 1999, entitled, "Receiver Improvement for Expanded Data Capacity," which is incorporated herein by this reference.

10 Field of the Invention

The present invention relates to communications systems and methods for transmitting additional information via television transmissions and other transmissions. Although the invention applies to a wide range of communication transmissions, this disclosure focuses, although not in a limiting way, largely on the applicability to television.

15 Background

The standard method for over-the-air transmission of television signals in the United States is called NTSC. This is an analog system in which the picture is transmitted in a vestigial sideband modulation format on the visual carrier and the sound component transmitted as frequency modulation on a separate sound carrier. Relatively recent developments in the television industries have focused upon the transmission of High Definition Television (HDTV) that requires a substantial increase in transmitted information and hence greatly expands the required baseband video signal bandwidth. Great progress has been made in the area of digital TV bandwidth compression so that one or more HDTV signals can be conveyed in the standard television bandwidth of 6 MHz. These HDTV developments have, by a combination of techniques, substantially reduced the bandwidth required for fully digital transmission of the video information. Subsequently, it was determined that the same compression techniques can be used to put multiple "Standard Definition Television", SDTV, signals in the same bandwidth. Both of these techniques, HDTV

and SDTV, are generically called Digital Television, DTV. A further move from the original HDTV goal is the allowance by the FCC of data transmission instead of television transmission.

The development of DTV and its acceptance as a future broadcast standard has also led to the requirement for a transition period between broadcasting the present analog TV to that of compressed DTV. Since the transmission of standard analog NTSC will remain for many years before the complete transition to DTV, the availability of a technique allowing simultaneous, non-interfering transmission of digital signals within the same channel as an analog NTSC signal would result in a two (or more) channel capacity increase in the existing broadcast frequency assignments. Alternatively, data transmission can be accommodated in addition to or instead of DTV along with the analog NTSC signal. As more efficient means of bandwidth compression emerge, the transmission of HDTV simultaneously with analog NTSC in the same 6 MHz bandwidth is an attractive possibility.

While the focus of this work has been on NTSC television signals, it applies equally well to any vestigial sideband signal transmission system.

TECHNICAL CONSIDERATIONS

The standard NTSC format allocates 6 MHz of spectrum to the transmission of the combined video and audio signals. The visual carrier is placed 1.25 MHz above the lower band edge and the aural carrier 5.75 MHz above the lower band edge. The visual information is impressed on the visual carrier using a vestigial sideband amplitude modulation (AM) technique so that the frequency components below the visual carrier occupy no more than the 1.25 MHz of the available spectral assignment, while the frequency range allocated to the visual information extends for approximately 4.2 MHz above the visual carrier.

The color information is carried on the color subcarrier of the main visual carrier at approximately 3.58 MHz above the visual carrier (4.83 MHz above the lower band edge). The modulation of the color information is both in-phase and quadrature and contains more lower sideband components than upper.

The aural information is carried on the separate aural carrier at 4.5 MHz above the visual carrier (5.75 MHz above the lower band edge) and is frequency modulated (FM) with a peak deviation of 25 KHz over the range of audio frequencies extending to somewhat above 15 KHz.

5 It should be noted that 1) the amplitude modulation of the visual luminance information is solely an in-phase variation with no quadrature component prior to the vestigial filter while, 2) the aural subcarrier is solely frequency modulated. Subcarriers are sometimes added to the aural carrier but they too are frequency modulated on the main aural carrier. It can be seen then that not all of the information
10 carrying capacity in the 6 MHz analog channel is occupied. There are no quadrature components in the region close to the visual carrier and no amplitude modulation components in the aural carrier region.

Other opportunities exist which make possible the transmission of additional information within the normal TV spectral assignments. One company called
15 WavePhore, Inc. utilizes a signal which puts single sideband phase shift data in the area of approximately 3.9 to 4.2 MHz above the visual carrier (5.15 MHz to 5.45 MHz above the lower band edge) and is capable of transmitting in the order of 500 Kbits / second while causing only minor interference to the analog television signal. This system is covered under U.S. patent(s).

20 Another approach of transmitting data within the NTSC broadcast format has been developed by Digideck, Inc. This technique is called the D-Channel and operates at a reduced level in the lower frequency portion of the video vestigial sideband is capable of transmission of something in the order of 750 Kbits per second with only minor interference to the analog television signal and is covered under U.S.
25 patent(s).

In order to transmit a digitally compressed NTSC signal, a data transmission rate in the order of 1 to 5 megabits per second will be required when employing present day compression techniques. The above mentioned prior art systems are incapable of these high data rates without causing significant and unacceptable
30 interference to the analog NTSC signal.

The Federal Communications Commission (FCC) has authorized the use of the prior art systems for transmitting digital data in analog television systems and invited other inventors to come forth with improved systems for this type of data transmission in Report & Order (R & O), "Digital Data Transmission Within the Video Portion of Television Broadcast Station Transmissions", in MM docket No. 95-42. Consistent with that invitation, the FCC has granted the inventors an experimental license on September 23, 1999 to transmit its signal on Channel 62 in Scottsdale Arizona.

Further background information is found in U.S. Patent application 09/062225 filed April 17, 1998. Still further background information is found in the book: "Modern Cable Television Technology: Video, Voice, and Data Communications" by Walter Ciciora, James Farmer, David Large, published December 1998, Morgan Kaufmann Publishers, (Web Page: <http://www.mkp.com>) 912 pages, ISBN 1-55860-416-2, which is incorporated herein by this reference.

The Need for an Improvement in the Receiver for Expanded Information Capacity for Existing Communication Transmission Systems.

The interference visible on non-ideal television receivers due to data transmission using the invention of U.S. Patent application 09/062225 filed April 17, 1998 are governed by several factors including:

1. The desired coverage area in broadcast applications.
2. The number of data levels.
3. The performance of the data receiver.
4. The injection level of the data signal.
5. The amount of abatement signal applied.
6. The acceptable level of video errors.
7. The acceptable level of data errors.

All of these factors interact. Most importantly, the better the performance of the data receiver, the less data signal injection is required for a given data rate and a given coverage area. This minimizes the visibility of the interference of data

transmission as experienced by non-ideal television receivers. Conversely, other trade-offs can be made. For example, for a given amount of visible interference, a better performing data receiver will allow either greater coverage area or other desirable benefits.

5 While U.S. Patent application 09/062225 filed April 17, 1998 focuses on, but is not necessarily limited to, the double sideband region of the NTSC signal, the present invention facilitates improved performance when going beyond the double sideband region of the NTSC signal. This allows greater data capacity. Increased data capacity is a clear benefit satisfying an important need.

10 There are certain requirements for the filters in the receivers disclosed in U.S. Patent application 09/062,225 filed April 17, 1998. The improvements of the present invention relax the need for higher performance filters in the data receiver of the invention of U.S. Patent application 09/062,225 filed April 17, 1998.

There is always a need for more cost-effective implementation of the data receivers such as in the invention of U.S. Patent application 09/062,225 filed April 17, 1998. Modern mixed signal techniques for designing integrated circuits such as those developed by Microtune Incorporated (<http://www.microtune.com>) and others are especially suitable for cost-effective implementations. The present invention facilitates using those techniques for the implementation of a data receiver for the invention of U.S. Patent application 09/062,225 filed April 17, 1998.

While the focus of this invention is on the data receiver, the invention is applicable to the improved reception of analog television signals as well. The reception of VSB signals for television display involves significant compromises. This invention overcomes many of those compromises.

25 **SUMMARY OF THE INVENTION**

Systems according to U.S. Patent application 09/062,225 filed April 17, 1998 enable transmission of data (including compressed digital video), in the range of several megabits / second by techniques involving amplitude modulation of the aural carrier and quadrature or phase modulation of the visual carrier. Although the discussion of the specification of U.S. Patent application 09/062,225 filed April 17, 1998 and the disclosure of this invention focuses on the NTSC-M television standard,

similar concepts apply to analog television systems including but not limited to the multiple versions of PAL, other versions of NTSC, and SECAM and other vestigial sideband systems and frequency modulation systems.

The present invention improves the television receiver and more specifically the data receiver of the visual portion of the signal of U.S. Patent application 09/062,225 filed April 17, 1998. While the reception of the aural portion of the signal of U.S. Patent application 09/062,225 filed April 17, 1998 is not further discussed here, it remains an important part of the total system according to a preferred embodiment. It is not further discussed here because the present invention does not change its implementations.

The invention of U.S. Patent application 09/062,225 filed April 17, 1998 includes a Compensator Subsystem which adjusts the transmitted data spectrum so that when passed through the Nyquist filter of an existing television receiver, the data spectrum will become symmetrical about the television signal's visual carrier. In the double sideband region of the spectrum after the television receiver's Nyquist filter, the data signal will be in quadrature with the visual signal to the extent that the Compensator Subsystem accurately compensates for the effects of the Nyquist filter. The visual signal will have both in-phase and quadrature components because the television receiver's Nyquist filter has made the visual spectrum unsymmetrical about its carrier. An ideal synchronous detector that is phase locked to the visual carrier in the television receiver will only respond to the in-phase components of the visual signal and will thus ignore the quadrature data signal as well as the quadrature components of the visual signal.

The data receiver of the invention of U.S. Patent application 09/062,225 filed April 17, 1998 should ideally perform in a complementary manner. That is, the data receiver will not have a Nyquist filter. Thus the visual spectrum in the double sideband region will remain symmetrical about its carrier and thus will not have any quadrature components. The data spectrum, however, will have both in-phase and quadrature components due to the action of the Compensator Subsystem in the data transmitter. An ideal synchronous detector that is phase locked to ninety degrees

relative to the visual carrier would respond only to quadrature data components and ignore the visual signal in the double sideband region which is completely in-phase with the visual carrier as well as the in-phase components of the data signal.

There are at least two practical problems in implementing the data receiver.

5 First, the visual signal has quadrature components outside the double sideband region. Consequently, the data signal demodulated by the data detector will be contaminated with the quadrature components of the visual signal. In one approach to minimize this, the quadrature components must be strongly attenuated by a filter to prevent their detection by the data synchronous detector. Ideally, this filtering would eliminate the

10 visual quadrature components. But practical filters will not accomplish this. Such detection of the quadrature components of the visual signal by the data detector would result in "eye closure" of the data signal. As is appreciated by those of ordinary skill in the data detection arts, this will reduce the overall system performance margin and lead to data detection difficulties. This filter must remove as much of the visual

15 quadrature components as possible while not unduly damaging the amplitude or phase of the data components. This is a severe constraint. The invention of U.S. Patent application 09/062,225 filed April 17, 1998 proposes an alternative feedforward approach which has some benefits, but still leaves a need for better techniques. Secondly, if the network transfer function experienced by the data signal or the visual

20 signal has phase and amplitude characteristics that upset the quadrature relationships, further contamination of the data signal by the visual signal and distortion of the detected data signal will result. This reduces the performance of the data receiver and forces undesirable trade-offs in total system outcomes.

The present invention alleviates these problems by synthesizing a double side

25 band signal in such a manner that both the visual signal and the data signal are each symmetrical with respect to their carriers in both amplitude and phase. This allows synchronous detection techniques to be applied to cleanly separate the data signal from the visual signal.

The double sideband synthesis is accomplished by reversing the received

30 spectrum and adding it back to itself. Reversing the received spectrum interchanges

the upper sideband and the lower sideband in a manner that causes the lowest frequency of the lower sideband in the received spectrum to become the highest frequency of the upper sideband in the reversed spectrum. Likewise, the highest frequency of the upper sideband in the received spectrum will become the lowest frequency of the lower sideband in the reversed spectrum. One method of implementing spectrum reversal is presented in the preferred embodiment. Other methods of spectrum reversal can be implanted by those of ordinary skill in these arts.

While the main focus of this invention is the improved recovery of data signals, the invention has benefits for television receiver design even for signals that do not include data. Also, this invention will improve the reception of data signals that are phase modulated onto the visual carrier.

The invention will be described with the aid of the attached figures.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1a is a graph of a television signal spectrum normalized to 0.0 Hz.

FIGURE 1b is a graph of the output of a flat response television receiver.

FIGURE 1c is a graph of an idealized and typical TV receiver response curve.

Figure 2a is a graph of Data & Video Modulator Signals.

Figure 2b is a graph of Data Receiver Signals.

Figure 2c is a graph of television Receiver Signals.

Figure 2d is a block diagram of Data Detection receiver using a Filter. The receiver is subject to "Rude Video" interference.

Figure 3a is a graph of the Data Spectrum subjected to Data RF Tx Filter.

Figure 3b is a graph of the Data Spectrum subjected to TV Receiver's Nyquist Filter. This yields a Q component only (note: in the receiver the spectrum is reversed at IF).

Figure 4a is a block diagram of the Data Demodulator and an optional NTSC demodulator using the present Synthesis of a Double Sideband Signal invention.

Figure 4b is a graph of the NTSC spectrum and the Data Spectrum after the tuner and before Nyquist filter in a conventional television receiver. (The spectra is shown "as is" in the receiver; i.e. opposite to at RF). The two spectra are shown

separately for purposes of illustration. In the actual system, the two spectra are combined in a manner that does not allow them to be viewed separately.

Figure 4c is a graph of the TV Receiver's Nyquist filter characteristic.

Figure 4d is a graph of the NTSC spectrum and the Data Spectrum after the
5 tuner, Nyquist filter, and Precision Phase-Correct Delay.

Figure 4e is a graph of the NTSC spectrum and the Data Spectrum at output of Spectrum Reverser.

Figure 4f is a graph of the NTSC spectrum and the Data Spectrum at output of Summer.

10 Figure 5a block diagram of the Spectrum Reverser.

Figure 5b is a graph of the IF spectrum as seen at IF frequencies (the reverse is seen at RF frequencies.)

Figure 5c is a graph of the spectrum of Figure 5b heterodyned by a cosine wave with $N = 3$ and band pass filtered to select the desired sideband.

15 Figure 5d is a graph of the spectrum of Figure 5c heterodyned by a cosine wave with $N = 3$ $\{(N + 2) = 5\}$ and band pass filtered to select the desired sideband.

Figure 6a is a block diagram of a Precision Phase-Correct Delay Example using exactly the same filters as used in the Spectrum Reverser.

Figure 6b is a graph of the IF spectrum as seen at IF frequencies (the reverse is
20 seen at RF frequencies.)

Figure 6c is a graph of the spectrum of Figure 6b heterodyned by a cosine wave with $M = 3$ and band pass filtered to select the desired sideband.

Figure 6d is a graph of the spectrum of Figure 6c heterodyned by a cosine wave with $M = 5$ and band pass filtered to select the desired sideband.

25 Figure 5e is a block diagram of the Spectrum Reverser Without filters.

Figure 5f is a graph of the IF spectrum as seen at IF frequencies (the reverse is seen at RF frequencies.)

Figure 5g is a graph of the spectrum of Figure 5f heterodyned by a cosine wave with $N = 3$.

30 Figure 5h is a graph of the spectrum of Figure 5g heterodyned by a cosine wave with $N = 3$ $\{(N + 2) = 5\}$.

Figure 6e Precision Phase-Correct Delay Without Filters.

Figure 6f is a graph of the IF spectrum as seen at IF frequencies (the reverse is seen at RF frequencies.)

Figure 6g is a graph of the spectrum of Figure 6f heterodyned by a cosine wave with $M = 5$.

5 Figure 6h is a graph of the spectrum of Figure 6g heterodyned by a cosine wave with $M = 5$.

Figure 6i is a graph of the spectrum resulting from adding the spectra of Figs 5h and 6h.

Figure 6j is a graph of the spectrum of a cosine wave at the IF frequency.

10 Figure 6k is a graph of the spectrum of Figure 6i heterodyned by a cosine wave at the IF frequency and a low pass filter to receive the baseband signal.

Figure 7a is a graph of the television spectrum and the data spectrum at the output of a Nyquist Filter and a Precision Phase-Correct Delay as see at IF (at RF, spectrum is reversed).

15 Figure 7b is a graph of the television spectrum and the data spectrum at the output of the Spectrum Reverser.

Figure 7c is a graph of the sum of the television spectrum and the data spectrum found at the output of Precision Phase-Correct Delay and at the output of the Spectrum Reverser.

20 Figure 8a is a block diagram of the Data Demodulator and an optional NTSC demodulator using the present Double Sideband Synthesis invention but without a Nyquist Filter. This Figure is similar to Figure 4a.

Figure 8b is a graph of the television spectrum and the data spectrum at the output of a Precision Phase-Correct Delay as see at IF (at RF, spectrum is reversed)
25 but without first passing through a Nyquist filter.

Figure 8c is a graph of the television spectrum and the data spectrum at the output of the Spectrum Reverser, but without first passing through a Nyquist filter.

Figure 8d is a graph of the sum of the television spectrum and the data spectrum found at the output of Precision Phase-Correct Delay and at the output of the
30 Spectrum Reverser, but without first passing through a Nyquist filter.

Figure 9a is a graph of the Data Spectrum after the tuner and Precision Phase-Correct Delay but without first passing through a Nyquist filter. Note: This spectrum

has both Q components and I because it is not symmetrical about the carrier. (Spectra shown "as is" in the receiver; i.e. opposite to at RF).

Figure 9b is a graph of the Data Spectrum at output of Spectrum Reverser, but without first passing through a Nyquist filter.

5 Figure 9c is a graph of the Data Spectrum at output of the Summer. This spectrum has only a Q component because it has been made symmetrical about the carrier frequency. The delayed and reversed data spectra prior to summation are shown to illustrate that they add to the summer output spectra.

10 Figure 10a is a block diagram of the Data Demodulator of the receiver using the present Double Sideband Synthesis invention. Note that this figure is identical to Figure 8a.

Figure 10b is a graph of the television spectrum and an expanded bandwidth data spectrum at the output of a Precision Phase-Correct Delay as see at IF (at RF, spectrum is reversed) but without first passing through a Nyquist filter.

15 Figure 10c is a graph of the television spectrum and the expanded bandwidth data spectrum at the output of the Spectrum Reverser, but without first passing through a Nyquist filter.

Figure 10d is a graph of the sum of the television spectrum and the expanded bandwidth data spectrum found at the output of Precision Phase-Correct Delay and at the output of the Spectrum Reverser, but without first passing through a Nyquist filter.

20 Figure 11a is a graph of the amplitude transfer function of the Data RF Tx Filter found at the transmitter.

Figure 11b is a graph of the amplitude transfer function of the NTSC Vestigial Sideband Filter found at the transmitter.

25 Figure 11c is a graph of the amplitude transfer function of the Composite Filtering applied to Data at Transmitter found by combining the amplitude transfer functions of Figure 11a and Figure 11b.

Figure 11d is a graph of an expanded bandwidth Data Spectrum extending to 1.25 MHz and the Composite Filter function of Figure 11c along with the resulting non symmetric Filtered Data Spectrum.

30 Figure 12a is a graph of the application of the present Double Sideband Synthesis invention to receive the expanded bandwidth Data Spectrum of Figure 11d.

The present invention yields perfect reconstruction of the data spectrum between + 0.75 MHz and modest distortion between + 0.75 MHz and +1.25 MHz. This modest distortion could be pre-distorted at the transmitter.

Figure 12b is a graph of the expanded data spectrum after the television receiver's Nyquist Filter. In the television receiver, the expanded bandwidth Data spectrum has been made symmetrical and has been reduced in bandwidth to the double sideband bandwidth of the NTSC signal. The data spectrum is all in quadrature with the visual signal and a Synchronous detector in the television receiver will be blind to this data signal.

DETAILED DESCRIPTION

Reference will now be made in detail to embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers or numbers with the same trailing digits will be used throughout the drawings to refer to the same or like parts.

Figure 1a describes the standard analog NTSC television signal comprising a Video Carrier 102 that is Amplitude Modulated (AM), a Sound Carrier 103 that is Frequency Modulated (FM) and a Color Carrier 105, which is modulated with an in-phase and a quadrature phase components. The lower sideband of the television signal is unattenuated to a frequency 750 KHz below the visual carrier. The signal is severely attenuated at frequencies more than 1.25 MHz below the visual carrier. The signal is rolled off between 750 KHz and 1.25 MHz below the visual carrier in a manner that can be realized with practical filters. This filtering results in a vestige of the lower sideband leading to the term "Vestigial Side Band" (VSB) modulation. The VSB technique was motivated by the desire to provide increased picture resolution while remaining within the allocated 6 MHz frequency band for a television channel. The details of the VSB implementation were governed by practical consideration for the economic realization of the required filters.

Figure 1b illustrates the difficulty this VSB technique causes in the demodulation process. Because the region 104 of Figure 1a between 750 KHz below the visual carrier and 750 KHz above the visual carrier is ordinary double sideband

modulation and the region 106 in Figure 1a between 1.25 above the visual carrier and 4.0 MHz above the visual carrier is single sideband modulation, the demodulated signal will have twice the strength in the baseband frequencies which are less than 750 KHz compared to the signals in the baseband frequencies between 1.25 MHz and 4.0 MHz.

Figure 1c illustrates the solution adopted in analog television receivers to deal with this problem. Before demodulation, the signal is weighted with a filter that is antisymmetric about the visual carrier and results in half strength passed through the filter at the visual carrier frequency 102. This normalizes the strength of the demodulated signal from zero baseband frequency to its highest frequency. This type of filter, with an antisymmetric characteristic, is called a Nyquist filter.

Figure 2a describes the data and video modulator signals at the signal origination point. Figure 2b illustrates the processing of the signals in a data receiver of the invention of U.S. Patent application 09/062225 filed April 17, 1998 while Figure 2c shows the processing of these signals in an ordinary television receiver.

It is important to recognize at this point that a conventional double sideband signal has only in-phase components. It has no quadrature components. Also, a signal which is not a conventional double sideband structure has both in-phase and quadrature components. As a consequence, the visual signal of Figure 1a between 750 KHz below the visual carrier and 750 KHz above the visual carrier is a conventional double sideband signal and has only in-phase components. The signal with frequencies higher than 750 KHz above the visual carrier is not a conventional double sideband signal and thus has both in-phase and quadrature components. This is illustrated in the center section of Figure 2a. The left part of the top section of Figure 2a shows the VSB filter characteristic 202 that converts a conventional double sideband television signal into the VSB signal 204 of the center section of Figure 2a.

The well-known process of synchronous demodulation wherein a signal is multiplied by a cosine wave of the same phase and frequency as the signal's carrier responds only to the in-phase components of the signal. If that same signal were multiplied by a ninety degree phase-shifted cosine wave (which becomes a sine

wave), then only the quadrature components would be demodulated. In this manner, in-phase and quadrature components can be completely separated from each other.

The top section of Figure 2c shows the television receiver's Nyquist filter characteristic 206 and the center section of Figure 2c shows the resulting television signal spectrum 208 after passing through the television receiver's Nyquist filter 206.
5 All portions of this spectrum have in-phase and quadrature components because no portion of this spectrum is symmetric about the carrier.

A more detailed discussion of conventional analog and digital television signals is contained Chapters 2 and 3 in one of the inventor's texts "Modern Cable
10 Television Technology, Video, Voice, and Data Communications", Ciciora, Farmer & Large, 1999 Morgan Kaufmann Publishers, ISBN 1-55860-416-2.

The left portion of the bottom section of Figure 2a shows a data signal 210 double sideband modulated onto a quadrature phase shifted visual carrier 212 and the quadrature phase shifted carrier then completely suppressed. This data signal 210 has
15 only quadrature components; no components of this data signal exist in-phase with the television signal's visual carrier 214. If this signal was to pass through the Nyquist filter 208 of the center section of Figure 2c, its double sideband nature would be destroyed resulting in the creation of components in-phase with the visual carrier 214 of the television signal. These components would become visible as interference on
20 the television screen. This is undesirable and is likely to be unacceptable unless the interference is reduced to such a low level as to become invisible to viewers under normal circumstances. To prevent this difficulty, the data signal is predistorted in a manner such that passage through the receiver's Nyquist filter 206 will convert it back into a conventional double sideband signal 216 with only quadrature components.
25 This signal will then be ignored by the television receiver's synchronous demodulator. This is accomplished with the Data Radio Frequency Transmit Filter 218 (Data RF Tx Filter) with characteristic described in the right hand side of the top segment of Figure 2a. This filter characteristic 218 has the shape of the Nyquist filter used in the receiver 206 but with the frequencies reversed. This causes the transmitted data signal

spectrum 220 to appear as in the bottom section of Figure 2a. That spectrum has both in-phase and quadrature components.

The data demodulation process of the prior art is shown in Figure 2b. Synchronous demodulation is employed to separate the quadrature data signal from the in-phase visual signal. However, the visual signal is conventional double
5 sideband only in the range between 750 KHz below the visual carrier and 750 KHz above the visual carrier. Outside that range, the signal will have components 222 in quadrature which will be demodulated by the data signal synchronous demodulator 224 and will interfere with the detection of data; i.e. the discrimination of the discrete
10 levels of the data signal at baseband after demodulation.

Even if the data demodulation filter 226 has perfect symmetry, the visual signal will have undergone the VSB filtering 202 process at the transmitter on one side of its spectrum but not the other. Consequently, the two sides of the data spectrum are not perfectly symmetrical and therefore a quadrature component has
15 been created. This quadrature component has been called "rude video" 228 because it interferes with the detection of the data signal after demodulation. Since the visual signal 204 is much stronger than the data signal 210, relatively small asymmetries in the composite filter characteristics will result in "rude video" and lead to problems in detecting the data.

20 Note that if the filtering process were to be made completely symmetrical by the use of a reversed VSB filter in the data receiver, the video would have only components that are in-phase with the visual carrier and would not be detected. Since the VSB filter 202 is not precisely specified, there would be some difficulty in choosing a proper reversed VSB filter design. The relative strength of the visual
25 signal relative to the data signal makes the precision of this choice important. Note also that since in the television receiver, the data signal 216 is of much lower strength than the visual signal 208, the degree of precision in matching the transmitting data filter 218 (which ideally is the reverse of the receiver's Nyquist filter 206) is much less critical. The situation further benefits from the fact that the data signal 210 is

uncorrelated to the visual signal 204 and imperfections will appear as noise rather than as some annoying pattern or image.

Figure 3a shows a data double sideband spectrum 302 (of raised cosine shape, chosen for illustrative purposes only and not as a limitation). A data transmit filter characteristic 304 shape is shown (as a linear filter, chosen for illustrative purposes only and not as a limitation). The resulting transmitted data signal 310 has been made unsymmetrical and therefore will have both in-phase and quadrature components.

Figure 3b shows the transmitted data signal 308 passing through the television receiver's Nyquist filter 306 and being converted once again into a symmetrical spectrum shape 312 that will have only spectral components that are in quadrature to the visual signal. Thus a synchronous demodulator in the television receiver will not respond to the data signal. Since the data signal is of much lower strength, any inaccuracies in converting it into a symmetrical spectrum will result in relatively minor interference, not visible under ordinary viewing condition.

Figure 4 shows one embodiment of the principle of the current invention which is called "Data Separation from Video by Synthesis of a Double Sideband Signal" and synchronous demodulation. In Figure 4a, the invention is installed in a device that is to optionally receive television signals. The TV receiver has a Nyquist Filter 406 whose output is split into three paths. One path 402 feeds a mechanism for recovering the carrier signal. A phase locked loop 404 is shown here for illustrative purposes but not as a limitation. The recovered carrier signal is used in a mixer 408 for synchronous demodulation of the visual signal. It is also phase shifted 410 for use in another mixer 412 for synchronous demodulation of the data signal. The second path 414 feeds a Spectrum Reverser block 416. This reverses the entire received spectrum, after the Nyquist filter 406, interchanging high frequencies with low frequencies and low frequencies with high frequencies symmetrically about the visual carrier. The third path 418 feeds a precision phase-correct delay 420 to ensure the correct timing of the otherwise unprocessed signal. The Spectrum Reversed signal and the precision delayed signal are added to form a double sideband signal. Figure 4b shows the received television 422 and data signals 424 prior to Nyquist filtering

426. The television signal 422 is shown as an NTSC signal for illustrative purposes but not as a limitation. The television signal 422 and the data signal 424 are shown as two separate signals for purposes of illustration. Their algebraic sum would be seen on a spectrum analyzer instrument in the frequency domain or an oscilloscope instrument in the time domain. Figure 4c shows the television receiver's Nyquist filter 426. Figure 4d shows the television signal 428 and the data signal 430 after the television receiver's Nyquist filter 426. The data signal 430 has become symmetrical in its frequency range and thus has only quadrature components. The television signal 448 in this same frequency range has become unsymmetrical having both in-phase and quadrature components. Figure 4e shows the output 432, 434 of the Spectrum Reverser 416 that flips the spectrum around the visual carrier frequency 436. Figure 4f shows the sum of the precision delayed spectrum and the reversed spectrum 438, 440. At this point, both the visual signal 438 and the data signal 440 have become double sideband. The visual signal 438 has only in-phase components throughout and the data signal 440 has only quadrature components throughout. The two signals can be completely separated with synchronous demodulation without the need for precision filters. The data path no longer requires a well designed filter to remove quadrature components of the visual signal 438 from the data path. There are no quadrature video components in the video signal 438 in the range of frequencies occupied by the data signal 440 or in the regions of frequencies anywhere near the frequencies occupied by the data signal 440. There is no "rude video" to contend with.

Figure 5 describes an implementation of a Spectrum Reverser 502. The Spectrum Reverser 502 is not the invention itself. It will be appreciated that other methods of implementation of spectrum reversal would also be effective in implementing this invention. Other methods of implementation will be understood by those of ordinary skill in these arts. The first Local Oscillator 504 operates at a frequency N times the receiver's intermediate frequency, IF. Mixer # 1 506 multiplies this oscillator's 504 cosine wave output with the combined video and data signal. Figure 5b shows the combined video and data signal 508. Figure 5c shows the result when N is set equal to 3. This choice is for illustrative purposes only and is not a limitation. The mixer 506 behaves as a doubly balance mixer yielding and output

which is comprised of the sum frequencies and the difference frequencies. The input components are balanced out and do not appear at the output. The local oscillator signal 510 is depicted in Figure 5c as a dashed vector to indicate its location at the input to the mixer 506, but to also indicate that it is not present in the output signal.

5 The sum frequencies 512 which form the upper sideband in Figure 5c are retained with the Band Pass Filter # 1 514 and the lower sideband 516 is rejected by that filter 514. Note that the spectrum 512 is not reversed at this point, but merely shifted to another frequency. Next Local Oscillator 518 # 2 operates at a frequency $(N + 2)$ times the IF frequency. Since N has been set equal to 3, Local Oscillator # 2 518 in

10 this illustration operates at five times the IF frequency. This choice is for illustrative purposes only and is not a limitation. Mixer # 2 520 multiplies this oscillator's cosine wave output with the output of Band Pass Filter # 1 514. Figure 5 d shows output of Mixer # 2 520. The mixer behaves as a doubly balance mixer yielding an output which is comprised of the sum frequencies and the difference frequencies. The input

15 components are balanced out and do not appear at the output. The local oscillator 518 signal is depicted in Figure 5d as a dashed vector 520 to indicate its location at the input to the mixer, but to also indicate that it is not present in the output signal. The sum frequencies that form the upper sideband 522 in Figure 5d are rejected with Band Pass Filter # 2 524 and the lower sideband 526 is passed by that filter. Note that the

20 passed spectrum 526 is now reversed and at the same IF frequency 528 as the original spectrum 508 of Figure 5b. The mixers 506, 520 and especially the BandPass Filters 514, 524 of Figure 5a have propagation times that result in a delay of the signal. This gives rise to the need for the Precision Phase-Correct Delay 420 element of Figure 4a.

Figure 6 describes an implementation of a Precision Phase-Correct Delay. The

25 Precision Phase-Correct Delay is not the invention itself. It will be appreciated that other methods of implementation of a Precision Phase-Correct Delay would also be effective in implementing this invention. Other methods of implementation will be understood by those of ordinary skill in these arts. Comparison of Figure 5a, Figure 5c, and Figure 5d respectively with Figure 6a, Figure 6c, and Figure 6d illustrates that

30 the respective filters 514 and 614, 524 and 624 are identical and the mixers 406 and 606, 420 and 620 are identical. Thus the propagation time through this circuit will be identical to that of the Spectrum Reverser 502 to the precision of the matching of the

components. Optional Phase Adjusters 630, 632 have been added to compensate for mismatches in the implementation. The Local Oscillators 504, 518, 604 operate at different frequencies, but that does not impact the propagation delay through the system. The explanation of Figure 5a through Figure 5d provides an understanding of the operation of Figure 6a through Figure 6d.

It is noted that the information signals in the vestigial sideband portion of the received spectra are correlated with the information signals in the unattenuated other side. As a result, the voltages add when spectrum reversal and addition is done. The noise in these two sidebands is uncorrelated and the noise powers add. This results in an advantageous signal to noise ratio improvement.

Now that the basic principle of the invention has been presented, simplifications will be described.

The filters of Figure 5a and Figure 6a 514, 524, 614, 624 aid in understanding the operation. In the implementation itself, the primary function of the filters is to prevent overloading the mixers 506, 606, 520, 620. Ideal mixers would not require these filters. That is, mixers with sufficient dynamic range would not require these filters. The filters 514, 524, 614, 624 are a source of expense and complexity and delay that can be avoided with adequate mixer design. Figure 5e shows the Spectrum Reverser 502 of Figure 5a, but without the band pass filters 514, 524. Figure 6e shows the Precision Phase-Correct Delay 634 of Figure 6a, but without the band pass filters 614, 624. Spectrum Reverser Figures 5f, 5g, and 5h correspond to and perform the same functions as Figures 5b, 5c, and 5e. In the former set of Figures, the undesired spectra are not filtered out; they are just left in place. Similarly, the Precision Phase-Correct Delay Figures 6f, 6g, and 6h correspond to and perform the same functions as Figures 6b, 6c, and 6e. In the former set of Figures, the undesired spectra are not filtered out; they are just left in place. Figure 5h and Figure 6h describe the input to the Summer 450 of Figure 4a and Figure 6i describes the output of that Summer 450. Note that the shapes of the spectra in these figures is schematic, intending to easily illustrate when spectra are reversed. These are not intended to show actual spectra or even the actual summation of spectra. Figure 6j is the output

of the Phase Shifter 410 of Figure 4a that feeds the Mixer 412 connected to the Data Output. Figure 6k shows the output of that Mixer 412. Note that it is the sum and difference of the IF frequency and the spectra of Figure 6i. If the result is then low pass filtered with a relatively simple low pass filter 652, only the data baseband spectra 654 remains. The low pass filter 652 is simple and inexpensive because the
5 closest interfering spectrum 656 is at twice the IF frequency, some ninety MHz away from the baseband data spectra which consists of less than a few MHz. In fact, normal parasitic reactances will attenuate the higher frequencies. If these higher frequency components were not completely removed, they would only have the effect
10 of slightly closing the eye pattern when the data signal is detected and converted into a digital stream. Depending on the system signal to noise ratio, this may be quite acceptable.

Note that expense, complexity, and delay of any band pass filters 514, 524, 614, 624 has been avoided. This is especially of importance in an integrated circuit
15 implementation where filters are a significant challenge. Even in a discrete realization, filters are a labor intensive and expensive part of the design that will not be missed. The signal to noise ration is significantly improved with this invention. These are just some of the advantages of the innovation of this invention.

Figure 7 shows the spectra in a larger, easy to see form. Figure 7a is the
20 output of the Nyquist Filter 406 and the Precision Phase Correct Delay 420. Figure 7b shows the output of the Spectrum Reverser 416. Figure 7c sums the spectra at the outputs of the Precision Phase-Correct Delay 420 and the Spectrum Reverser 416. Both the television 738 and the data spectra 740 are double sideband after the Summer. The television signal 738 has just in-phase components and the data signal
25 740 has only quadrature components. These components are easily separated with synchronous demodulation techniques.

Figure 8 shows a further simplification in cases where high quality video is not required or where just a data receiver is implemented. In that case, the Nyquist filter 406 is eliminated. There is no Nyquist filter 406 at all. As the Figures show, the
30 result is again a symmetrical double sideband spectrum 838, 840. Both the television

838 and the data spectra 840 are double sideband. The television signal 838 has just in-phase components and the data signal 840 has only quadrature components. These components are easily separated with synchronous demodulation techniques. The television signal 838 is modestly distorted in that it has more strength in its lower
5 frequencies than is expected. This will not be objectionable on a small screen television receiver such as used in portable applications.

In the case where an adaptive equalizer is used to combat multipath in the signal, the increased signal strength in the visual signal will be of advantage when the visual signal is used as a "training signal" for the data. In the special case where the
10 antenna is adjusted by observing the NTSC picture, the adjustment will be aided by the increase signal strength in the range of frequencies occupied by the data.

The elimination of the Nyquist filter 406 saves expense and complexity. This is especially of importance in an integrated circuit implementation where filters are a challenge. The absence of Nyquist filter 406 facilitates implementation with a just a
15 few or even just one integrated circuit.

Figure 9a displays the transmitted data spectrum 924. Figure 9b shows the reversed data spectrum 934. Figure 9c shows the addition of the two spectra 924, 934 yielding a symmetrical spectrum 940 with only quadrature components.

There is a further significant advantage in the implementation of Figure 8
20 compared to the implementation of Figure 4. In Figure 4, the Nyquist Filter 406 attenuates data signal 424 frequencies that are closer to the band edge while simultaneously attenuating the NTSC signal 422. Since the NTSC signal 422 and the data signal 424 are combined, it is not possible to attenuate portions of the NTSC signal 422 and not attenuate portions of the data signal 424 where they both occupy
25 the same frequencies. This attenuation of the data frequencies in the receiver reduces the signal to noise ratio and that lowers the margin of data recover performance. The implementation of Figure 8 avoids this reduction in signal to noise ratio by utilizing the entire received data spectrum rather than rejecting a significant portion of it. In both implementations, the signals in the sidebands are correlated so their voltages add

while the noise is uncorrelated and so the noise powers add. The result is an important improvement in signal to noise ratio.

Figure 10 demonstrates the results of extending the data spectrum beyond the normal double sideband region of the NTSC signal 1060 (which consists of those frequencies between 750 KHz above the visual carrier and 750 KHz below the visual carrier). Figure 11 shows the spectra details. Figure 11a is the Data RF Transmit filter 1118. Note that it severely attenuates the data signal between 750 KHz above the visual carrier and 1.25 MHz above the visual carrier. Figure 11b is the NTSC VSB filter 1102 that strongly attenuates the data (and visual) signal between 750 KHz below the visual carrier and 1.25 MHz below the visual carrier. At frequencies more than 1.25 MHz below the visual carrier, the VSB filter 1102 severely attenuates the data and visual signals. Figure 11c is the composite filter function 1166 of these two filters at the transmitter. Figure 11d repeats this composite filter function 1166, shows a raised cosine data spectra 1168 (for illustrative purposes only and not as a limitation) and the result 1170 of the composite filter function operating on the data spectra 1168. It can be seen that the transmitted data spectra 1170 is highly unsymmetrical. It slumps 1172 between 750 KHz below the visual carrier and 1.25 MHz below the visual carrier. It is severely attenuated between 750 KHz above the visual carrier and 1.25 MHz above the visual carrier. However, the information-carrying bandwidth of this signal extends to 1.25 mHz. This is 50% more bandwidth than the previous implementations discussed.

Figure 12a shows the received data spectra 1270, the same as in Figure 11d. It also shows a spectrum-reversed data spectra 1272 and the sum 1274 of the received 1270 and reversed spectra 1272. For comparison, the original data spectra 1276 is also shown in Figure 12a. Within the NTSC double sideband region, ± 750 kHz around the carrier, the shape of the sum 1274 of the received 1270 and the reversed spectra 1272 is identical to the original data spectrum 1276. It will be noted that there is some minor distortion in the reconstructed data spectra outside of this region. While it is symmetrical and therefore only has quadrature components which can be separated from the video by synchronous demodulation, the spectra slumps in the region between 1.25 MHz below the visual carrier and 750 KHz below the visual

carrier and in the region between 1.25 MHz above the visual carrier and 750 KHz above the visual carrier. This distortion is likely not serious and will result in only a slight closing of the eye pattern of the data. It is noted that this could be compensated with a predistortion at the point of origination and this effect eliminated.

5 Figure 12b displays the data signal 1216 in existing television receivers. The television receiver's Nyquist filter 1206 severely attenuates the data in the region between 750 KHz below the visual carrier and 1.25 MHz below the visual carrier. This causes the data spectra 1216 in the television receiver to become symmetrical and have only quadrature components. It also limits the data spectrum 1216 in the
10 television receiver to the NTSC double sideband region. Synchronous demodulation will separate the desired visual components from the data components 1216. Since the visual signal is much stronger than the data signal 1216, small asymmetries in the data spectra will result in only a small impact on the video. Since the data is uncorrelated with the video the small in-phase contribution only adds a trivial amount
15 of noise to the video. This will not be objectionable under nearly all practical circumstances.

 The foregoing is provided for purposes of disclosure of preferred embodiments of the invention. Modifications, deletions, additions and alternative techniques for creating systems according to the present invention and for carrying out processes
20 according to the present invention may be accomplished without departing from the scope or spirit of the invention.

CLAIMS

What is Claimed is:

1. A process for communicating information via two spectra, said spectra conveying different information modulated onto carriers of the same frequency, said process comprising: (a) in a transmitter, creating said carriers in quadrature with each other and modulating said two spectra onto said carriers, said two spectra combined, said two spectra overlapping over at least some of their frequencies, at least one of said spectra being non-symmetrical about its carrier frequency; and (b) in a receiver, converting said combined signal into a symmetrical spectrum such that one of said spectra is made to be in quadrature with the other of said spectra..
2. A process according to claim 1 in which both spectra are unsymmetrical.
3. A process according to claim 1 in which at least one of the carriers is at least partially suppressed.
4. A process according to claim 2 in which at least one of the carriers is at least partially suppressed.
5. A process according to claim 2 in which one of the spectra is a vestigial sideband television signal and the other spectra is a signal predistorted in a manner which will substantially compensate for a Nyquist filter in a television signal receiving device whereby said other spectra will become essentially symmetrical after said Nyquist filter in said television signal receiving device.
6. A process according to claim 5 in which at least one of the carriers is at least partially suppressed.
7. A receiving system for receiving information on at least one carrier of two carriers that are in quadrature at the same frequency, comprising
 - a. a phase locked loop adapted to be locked to said carrier frequency;

- b. a first mixer coupled to a phase shifter and a summer;
 - c. a phase shifter adapted to ensure the correct phase for synchronous detection of said information and coupled to the phase locked loop;
 - d. a summer coupled to a spectrum reverser and a precision phase-correct delay;
 - e. a precision phase-correct delay coupled to a signal source; and
 - f. a spectrum reverser coupled to a signal source.
8. The receiving system of claim 7 further comprising a second mixer coupled to the phase locked loop and a summer.
9. The receiving system of claim 7 further comprising a television receiver Nyquist filter at the inputs of the precision phase-correct delay and the spectrum reverser..
10. The receiving system of claim 9 further comprising a second mixer coupled to the phase locked loop and a summer.
11. The receiving system of claim 7 further comprising a spectrum reverser comprising
- a. A second spectrum reverser mixer coupled to a second local oscillator and a first spectrum reverser mixer;
 - b. A second local oscillator adapted to be locked to $(N + 2)$ times the frequency of said phase locked loop;
 - c. A first spectrum reverser mixer coupled to a first local oscillator and said signal source; and
 - d. A first local oscillator adapted to be locked to N times the frequency of said phase locked loop.
12. The receiving system of Claim 11 further comprising
- a. A second band pass filter coupled to said second spectrum reverser mixer and passing the lower sideband of its output; and
 - b. A first band pass filter coupled to said second spectrum reverser mixer and said first spectrum reverser mixer and passing the upper sideband of the output of the first spectrum reverser mixer.

13. The receiving system of claim 7 further comprising a precision phase-correct delay comprising:
- a. A second precision phase-correct delay mixer coupled to a local oscillator and a first precision phase-correct delay mixer;
 - b. A first precision phase-correct delay mixer coupled to a local oscillator and said signal source; and
 - c. A local oscillator adapted to be locked to M times the frequency of said phase locked loop.
14. The receiving system of Claim 13 further comprising:
- a. A second band pass filter coupled to said second precision phase-correct delay mixer and passing the lower sideband of its output; and
 - b. A first band pass filter coupled to said second precision phase-correct delay mixer and said first precision phase-correct delay mixer and passing the lower sideband of the output of the first precision phase-correct delay mixer.
15. The receiving system of Claim 14 further comprising:
- a. A second phase adjuster coupled to said second band pass filter; and
 - b. A first phase adjuster coupled to said second precision phase-correct mixer and said local oscillator.