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MULTI-USER SATELLITE COMMUNICATIONS SYSTEM USING AN INNOVATIVE COMPRESSIVE RECEIVER

Edward J. Staples
Amerasia Technology, Incorporated
Westlake Village, CA 91361

ABSTRACT

There is a need for an on-board simultaneous multi-channel demodulation system for a satellite communications system. Studies indicate that Convolve-Multiply-Convolve (CMC) filtering with surface acoustic wave (SAW) dispersive delay lines will eliminate the necessity of on-board satellite channelized filters or complex Fourier transform processors. The reason for choosing the CMC technique is its ability to perform Fourier transformations in a shorter time with less space and power consumption than digital Fourier transform processors.

Each ground terminal in this multi-users communications system is remotely located and operates independently, and hence a method of synchronizing the transmission of these users is presented which utilizes the existing Global Positioning Satellite (GPS) system. Each ground user is equipped with a low cost ground terminal that has a synchronization subsystem attached to it.

The system design of an on-board Multi-channel Receiver and Demodulator utilizes Quadrature Phase Shift Keying (QPSK) as the modulation technique. This technique provides the best figure of merit, i.e. the lowest transmitter power requirement per communication channel.

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INTRODUCTION

On-board satellite receiver/demodulators for multi-channel Frequency Shift Keyed (FSK) transmission require many narrowband filters to isolate each user's channel. When the requirement is for one hundred or more channels the problem becomes physically impossible. Also, since the users are at many different locations a system is required to synchronize the time of transmission of each user. A Convolve-Multiply-Convolve [Ref. 1] technique for simultaneous demodulation and regeneration of the transmitted FSK is under is under investigation. The implementation of this technique would eliminate the necessity of on-board satellite channelized filters. Synchronization is achieved by a processor that establishes the users position and timing with respect to the communications satellite by the use of timing signals broadcast from the Global Positioning Satellite (GPS) [Ref. 2] system as illustrated in Figure 1.

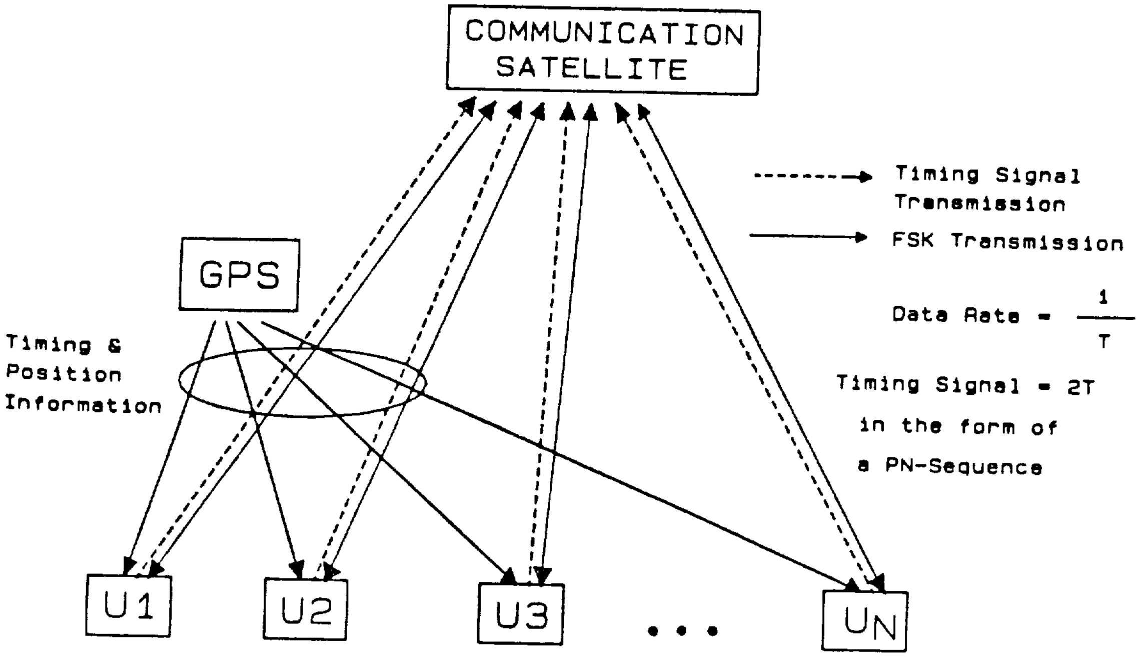


Figure 1- Communication network configuration under study.

Figure 2, illustrates the time/frequency diagram on-board the communications satellite where the timing signal is recovered on the satellite. N users are shown, each employing quarternary FSK (frequency shift keyed) modulation. Therefore, each user is assigned four frequencies within the transponder bandwidth and transmits two of the four at any instant in time. If the data rate of the message is 1/T, T being the bit period, then the dwell time for each pair of frequencies is 2T. In the C-M-C transform configuration a frequency expander is used. The frequency expander has a sweep time of 4T as shown in the figure.

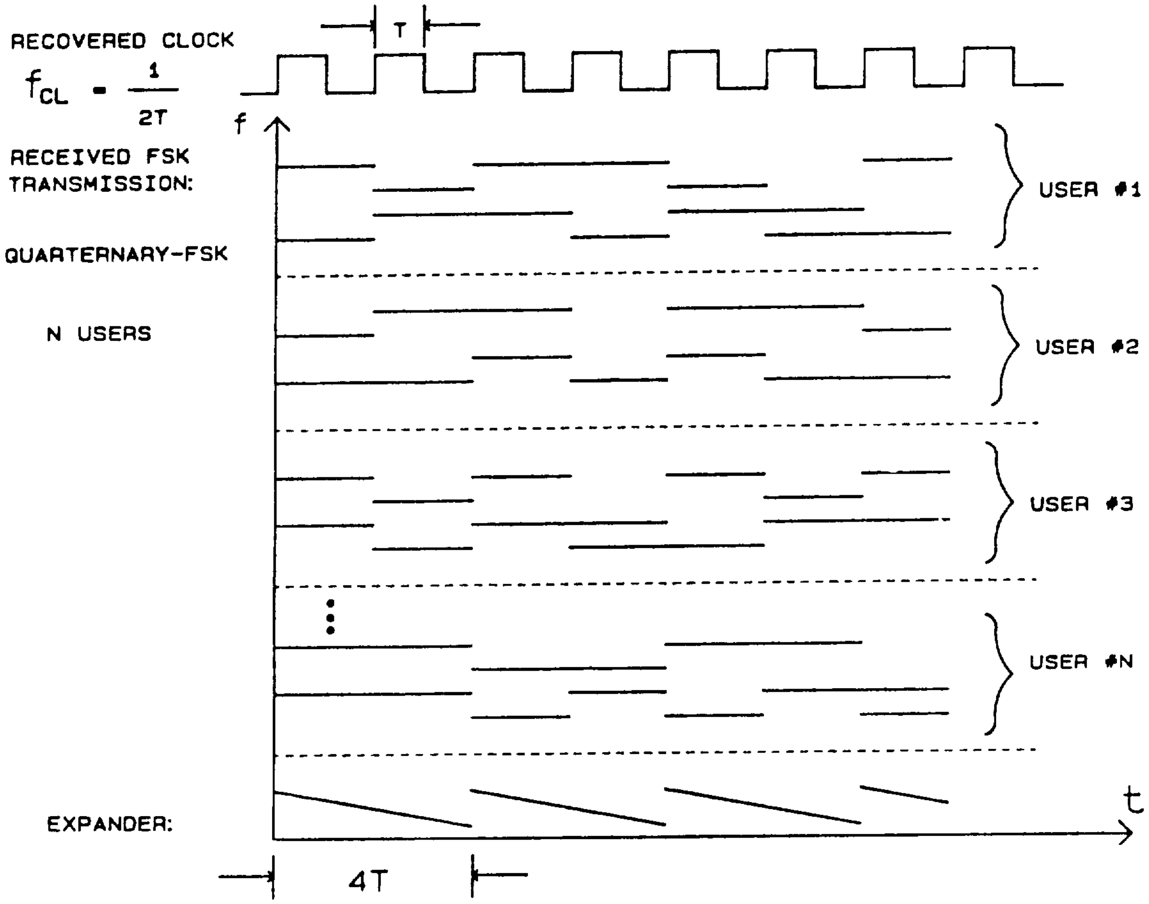


Figure 2- Frequency Time Diagram.

RECEIVER/DEMODULATOR

The basic receiver/demodulator system diagram is shown in Figure 3. The incoming signal is split into two parallel processors. One part is filtered to extract the timing signal. The timing recovery processor outputs three synchronous timing signals, that is, at the FSK symbol rate, data bit rate, and at M times the symbol rate. A timing adjust circuit is incorporated to compensate for any propagation delay difference in the two processors. The second part of the signal is processed by the C-M-C transform processor followed by the decision circuit. The front end of the C-M-C transform processor is a differential delay device (SAW), which has a delay property inversely proportional to the frequency of the input signal. A mixer is used to perform frequency multiplication between the received signal and the expander. This produces pulses corresponding to each incoming frequency. The pulses are aligned in time proportional to each frequency. This process periodically repeats every 2T seconds, and within each 2T interval all the data are time multiplexed to form a composite data stream.

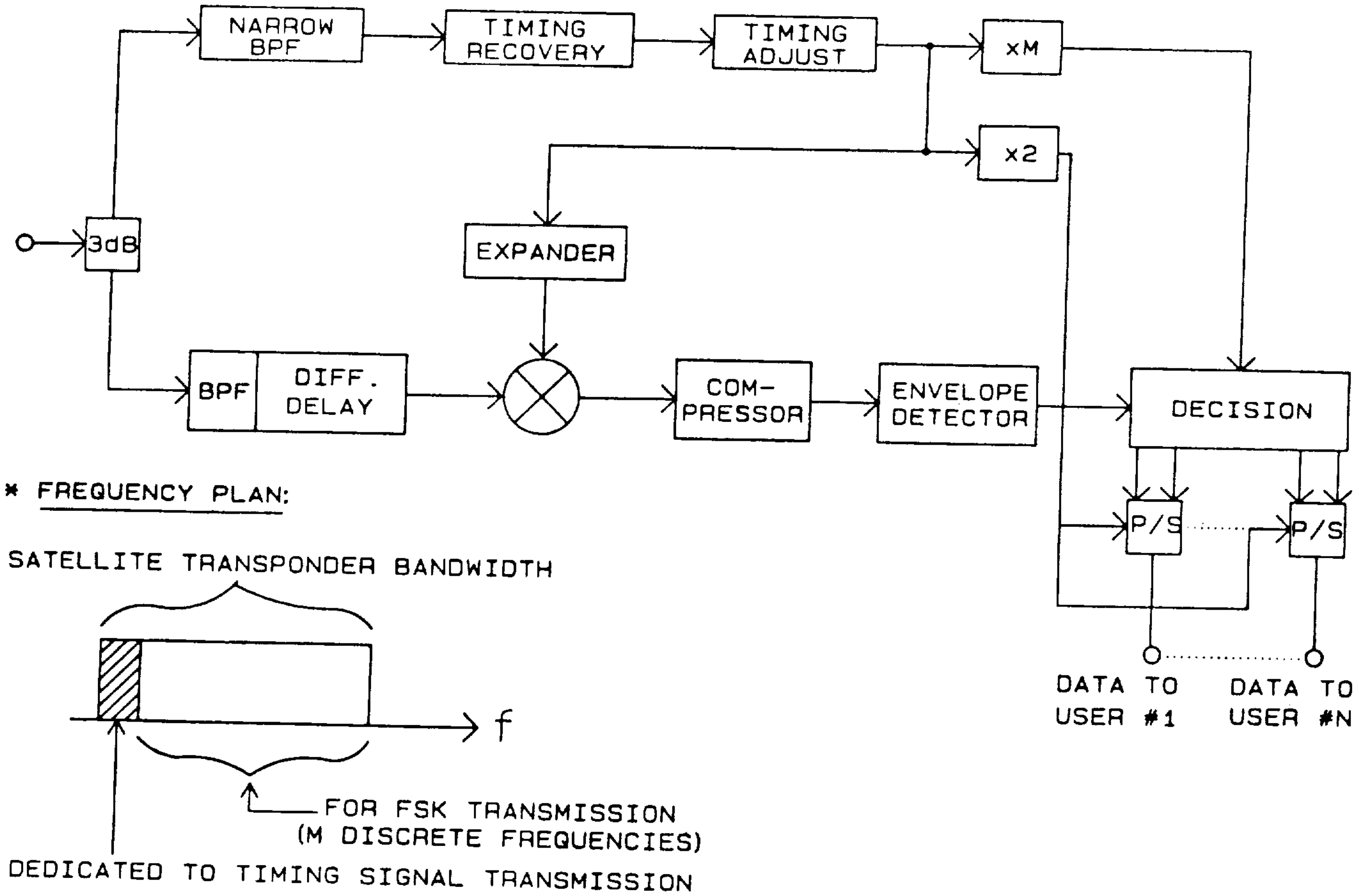


Figure 3-Receiver/Demodulator system.

The system design parameters are as follows:

a. Number of users: 200
b. Type of modulation: Quarternary FSK
c. Frequency separation: 50 KHz
d. Data transmission rate: 50 Kbps
e. Input frequency range: 80 to 120 MHz
f. Number of simultaneous transmission frequencies: 800

The ground based quarternary FSK transmitter transmits the data at the rate of 50 Kbps, hence the data bit period T is equal to 20 microseconds. This data bit stream is split into an "odd" and "even" data stream with a symbol period of 2T=40 microseconds. Each symbol of the "odd" data stream is assigned a frequency, i.e. f1 for "mark" and f2 for "space". Similarly f3 and f4 are assigned to represent a "mark" or "space" respectively. Prior to transmission, the "odd" data stream is delayed by T with respect to the "even" data stream. Consequently, during the transmission of a symbol period there are only 400 frequencies transmitted.

The incoming FSK signals are first processed in a differential delay SAW filter. The SAW device is a dispersive delay line with a delay characteristic such that the high frequency signals are delayed less than the lower frequency signals. It is designed to obtain a "frequency-time delay" transfer function that is linear. In addition, it has also a bandpass characteristic with steep skirts approaching a rectangular shape. The latter is desirable in rejecting out-of-band signals adjacent to the operating frequency band. Following the differential delay unit is a multiplier, which is a frequency mixer. This mixer is driven by a frequency expander that repetitively sweeps its output frequency within a 40 MHz bandwidth over a period of 4T in a downward fashion, hence it is called a down chirp. At the output of the mixer the difference frequency signal is selected as shown in Figure 4. Consequently, the mixer output signal is a series of down chirps corresponding to each received FSK frequency. Each of these down chirps are 40 MHz wide, corresponding to the expander frequency sweep. A linear amplifier restores the level of the down chirps to a convenient level for further processing in the compressor. The compressor is also a SAW device designed to give an up chirp characteristic within a bandwidth of 40 MHz during a period of 2T. If the received signal frequency band and the expander sweep frequency band is B (B=40 MHz), then the time bandwidth products of the differential delay unit and the compressor are equal to 2TB. The transfer characteristic of the compressor is such that for each input down chirp, corresponding to each FSK signal, a frequency impulse is produced in time (within a period of 2T) proportional to the FSK frequency location within the received frequency range. The radio frequency signal of the impulses is proportional to the input signal frequency and is removed by an envelope detector.

CONVOLVE-MULTIPLY-CONVOLVE FSK DEMODULATOR

The differential delay unit and the compressor filter are reflective array filters (sometimes called RACs, reflective array compressors). In this study a surface acoustic wave (SAW) dispersive filter constructed using an innovative single bounce technique and hyperbolically tapered transducers is being considered. The objective is to achieve a large time-bandwidth product (in the order of 3000) and low insertion loss. The insertion loss of the differential delay unit is approximately 35 dB and the compressor filter is projected to have an insertion loss of approximately 10 dB. In addition, the compression filter may contain internal amplitude weighting to improve sidelobe suppression and therefore prevent significant interchannel cross talk.

The single bounce technique for obtaining pulse compression in a SAW filter [Ref. 3] is shown in Figure 4. The transducers are called hyperbolically tapered transducers because each active electrode is a section of a hyperbola. If x is the transverse position across the transducer, then the spacing between electrodes, as well as the wavelength varies as 1/x and the frequency is proportional to x. The surface wave emerges from the transducer as a narrow lobe with a width inversely proportional to the length of the transducer. The width of the acoustic beam is matched to the effective width of the reflective array and this eliminates the geometric mismatch loss. The advantages of the single bounce technique over the conventional two-bounce approach are: (1) lower insertion loss, (2) wider bandwidth, and lower manufacturing cost.

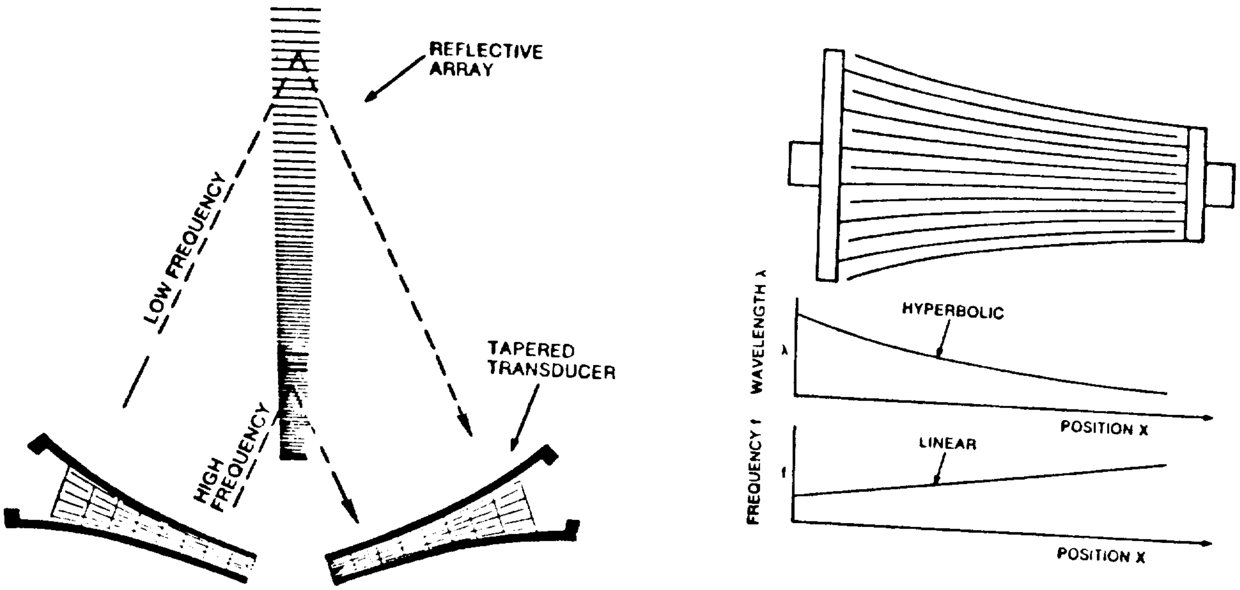


Figure 4- Single Bounce Dispersive SAW filter.

OPTIMUM MODULATION TECHNIQUES

A quarternary FSK modulation technique does not optimally use the available frequency bandwidth. Several other digital modulation techniques have been considered using an uplink performance criterion of $1x10^{-6}$ bit error rate (BER). The techniques considered were multi-tone FSK (up to 16), M-ary PSK (up to 16), quadrature amplitude modulation(4-QAM and 16-QAM), and quadrature partial response (QPR) modulation.

In comparing the Power/Channel requirements of all the modulation techniques, it was concluded that the optimum modulation technique is either QPSK or QPR. However, the equipment complexity of the QPSK system is relatively less than the QPR system. Therefore, QPSK modulation is the best choice for this application. In addition, it is desirable to operate the ground segment power amplifier at one dB compression, due to power efficiency considerations. To this effect, offset QPSK (OQPSK) provides the best solution, because a filtered OQPSK waveform when subjected to amplitude nonlinearity does not result in significant spectrum broadening as in the case of regular QPSK and/or MSK.

MULTICHANNEL OQPSK RECEIVER/DEMODULATOR

In this system, each user is assigned a carrier frequency. Assuming a data transmission rate of 64 Kbps per channel, the frequency carriers are separated by 64 KHz. As in the case of the multi-tone FSK system, all users' signals have to be in synchronism and timing signals transmitted with each transmission. This system will allow 625 channels occupy the entire 40 MHz satellite transponder bandwidth. Optimum detection is achieved by coherent demodulation. A differential coherent demodulation technique eliminates the need for carrier recovery and tracking circuits, thus reducing size and power requirements.

Each user transmitter operates on a preassigned carrier frequency, as shown in Figure 7. The data is initially split into odd and even data streams. The odd data stream consists of the odd bits of the original data, while the even data stream are the even bits. Note that the odd and even data streams are automatically offset by one data bit period relative to each other. If the input data bit period is T_b then the odd and even data symbol period is $T=2T_b$. Subsequently, each data stream is randomized, differentially encoded, and filtered (raised cosine), prior to quadrature modulation.

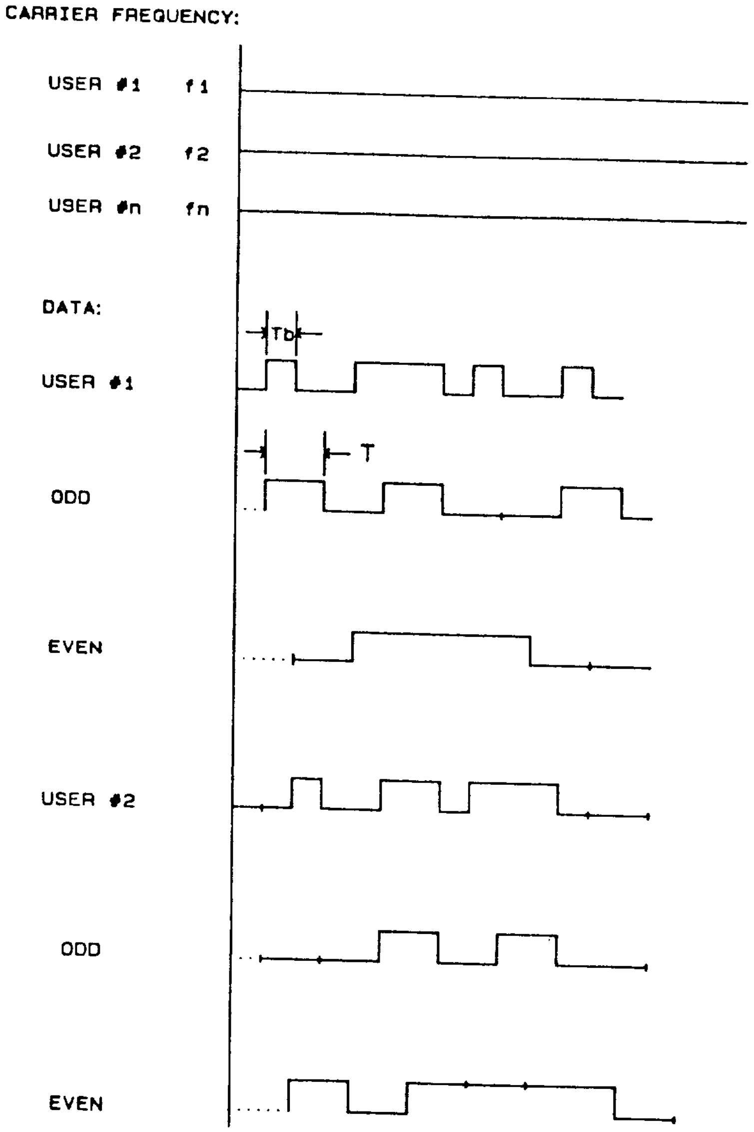
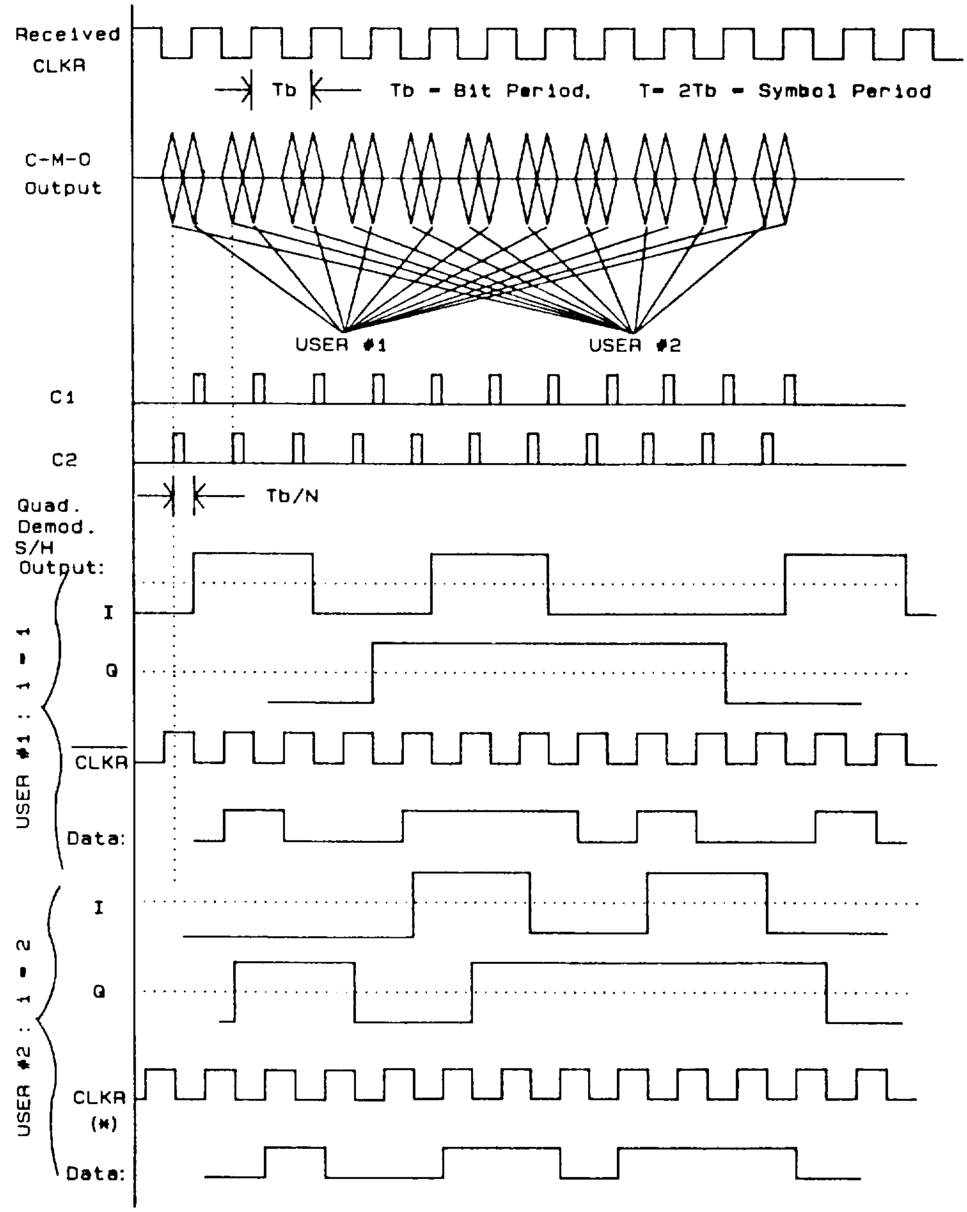


Figure 5- OQPSK Transmission

OQPSK DEMODULATOR/DETECTOR

The step by step process of demodulation and detection of the received OQPSK signal is depicted in Figure 8. The timing recovery process is identical to the process described for the FSK system. Signals received from various ground users are simultaneously transformed into pulses, corresponding to each user, by the C-M-C transformer. These pulses are spaced in time proportional to the user frequency. Each impulse, corresponding to each user periodically occurs every T_b second. Under each pulse is a radio frequency proportional to the input user frequency. The QPSK symbols imbedded in these pulses are related to the amplitude and phase of each received signal.



@ Notes:

1/ (*): CLKR delayed by:

$$Tb \times \frac{N - (i - 1)}{N}$$

2/ i= User Number 1, 2, ..., N.

Figure 6- OQPSK Demodulation and Detection

CONCLUSION

From the study performed during the Phase-I program, it is concluded that the Convolve-Multiply-Convolve (CMC) chirp transformer allows for simultaneous demodulation of multichannel communications signals and is practically realizable. The large time-bandwidth product achievable (up to 3000) with low power and small size is the key advantage of using a CMC chirp transformer based upon SAW dispersive delay lines.

A multichannel digital communications system with an on-board satellite Multichannel Receiver/Demodulator with network synchronization provided by the Global Positioning Satellite system is proposed. The design of a quadrature frequency shift keyed system has been presented. It was found that, from the viewpoint of ground station power requirement associated with the allowable number of communication channels, quadrature phase shift keyed (QPSK) modulation offers the best performance. It is possible to compensate for the performance degradation imposed by temperature variations upon the SAW based CMC chirp transformer using an innovative circuit technique.

A complete QPSK system has been designed for the on-board Multichannel Receiver/Demodulator based upon chirp transformation techniques using SAW dispersive delay lines. The proposed system design also allows expansion for channel multiplexing and switching. It is recommended that a feasibility model of the Multichannel Receiver Demodulator for demonstration and proof of concept be constructed and tested.

The proposed system would expand the practical use and capabilities of satellite communication systems to the industrial, educational, scientific and health institutions. It would allow low cost ground terminals to link hotels, corporations, and other institutions that are not co-located. Similarly, it would allow universities, and research laboratories (scientific as well as medical), to exchange scientific information in an efficient manner. A direct benefit to NASA would be to link its research facilities by satellite, hence providing an efficient mechanism for better coordination.

LIST OF REFERENCES

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2 James J. Spilker Jr., Digital Communications by Satellite, Prentice Hall.

3. L.P. Solie, "A New Low-Loss, Single Bounce, Reflective Array Filter Using Hyperbolically Tapered Transducers," Proceedings 1986 Ultrasonics Symposium.