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Spread Spectrum for Consumer Communications
—— Applications of Spread Spectrum Communications in Japan ——

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SUMMARY The recent progress in communication devices has reduced the cost of spread spectrum systems that have been mainly used in the military field, enabling the possibility of using spread spectrum systems for nonmilitary use. Nonmilitary communication networks are classified into two categories: public communication networks and consumer communication networks. At the present, the public communication network share is much larger than that of the consumer communication networks. Both of them will increase; however, the consumer communication network share will be comparable to the public one. The progress of consumer communications is due to inexpensiveness (without charge), user privacy, free design from regulations and advantages of local and small zone communications. To overcome fading, power restrictions, interference and interception is very important for its progress. One of the key technologies of consumer communications is the spread spectrum. Consumer communication networks are characterized by user possession of the network itself in addition to the possession of personal terminals. From the viewpoint of analogy between communication networks and transportation networks, "from public to individual" seems to be today's trend. Several spread spectrum applications for consumer communications in Japan have been introduced as follows: a home security system using power line communication as a wire spread spectrum communication system; a data carrier, a radio remote control, low-power radio systems and a clock rate modulation system as radio spread spectrum communication systems. In addition SAW device applications and digital signal processing applications are introduced.

1. Introduction

Spread spectrum (SS) communication systems have many applications mainly in military communications, because of its antijamming and anti-interception properties. However, there have been few nonmilitary applications, because the spread spectrum systems were thought to be too expensive for nonmilitary uses. Today, the progress of communication devices reduces the cost of the systems and enables us the possibility of nonmilitary applications.

Nonmilitary communication networks can be classified into two kinds: public communication networks and consumer communication networks*, both of which are very promising. Figure 1 shows today's share of nonmilitary communication networks; the public communication network share is much larger than that of the consumer communication networks. Figure 2 shows predictions for the future share; the total number of both kinds will become much greater than that of today, and consumer communication networks will be comparable to public communication networks. The progress of consumer communications is due to the inexpensiveness (without charge), user privacy, free design from regulations and advantages for local and small zone communications. Consumer communications will be most fruitful in future communications as mentioned above. However, several problems must be overcome, not only problems of hardware

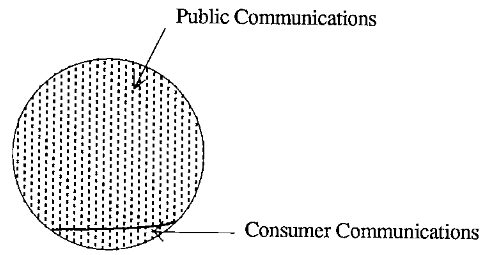

Fig. 1 Today's share.

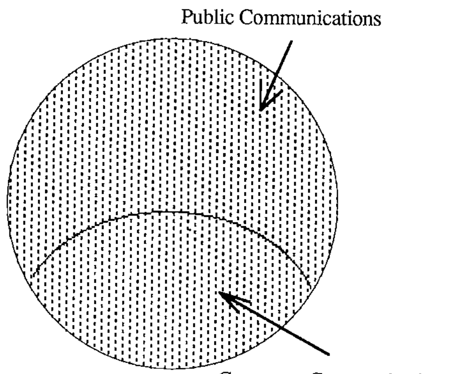

Fig. 2 Future share.

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* LAN, WLAN, indoor communications, cordless telephones, communications for robots, remote control, data carrier, home communications, office communications, factory communications etc.

but also those of transmission lines, because consumer communications are hampered by poor transmission lines with fading, restrictions of low power transmission, interference and interception in their networks. If we demand good transmission lines, instead of poor ones, we will encounter economic restrictions and severe output power restrictions especially in radio consumer communication networks. Therefore, we must find a method to compensate poor transmission lines to overcome these problems in consumer communication networks.

The key technology to overcome the above problems is the spread spectrum, which is suitable for poor transmission lines with multipath fading, interference and interception. Many researchers are interested in spread spectrum communication technology as one of the key technologies for consumer communications in Japan. This paper presents the growing applications of spread spectrum communications in consumer communications.

2. Consumer† Communications

Communication networks have long been mainly public or military, and have never been owned by consumers; therefore, users have had to share these networks because communication equipment has been so expensive that consumers could not possess their own communication networks. Hovever, due to today's progressing equipment technology, it is now possible for consumers to possess their own communication networks. We can find a good analogy between communication networks and transportation networks. Railway networks appeared at the first stage in the history of transportation in this century, while the transportation network of cars owned by consumers

† Consumers usually mean people who consume energy, services and goods. However, we may add the meaning of consumers being people who consume information.

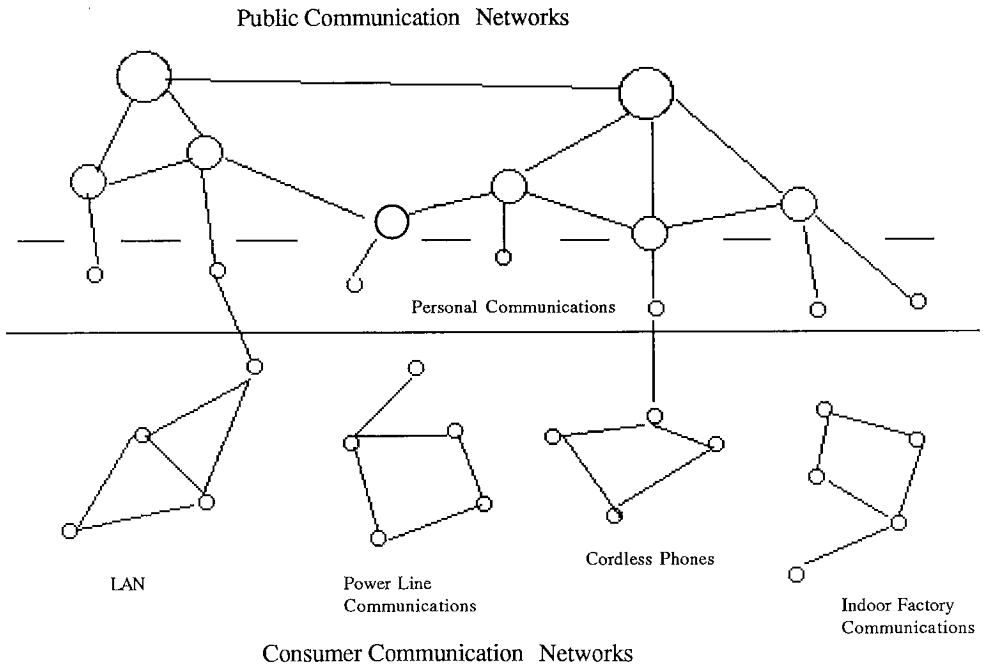


Fig. 3 Public communication networks and consumer communication networks.

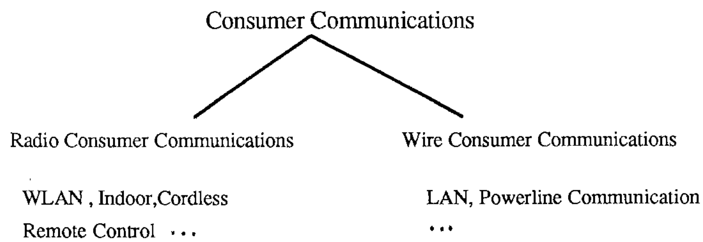


Fig. 4 Classification of consumer communications.

appeared at the second stage. The trend "from the public to the individual" seems to hold true in communication networks as well.

Figure 3 shows the relationship between consumer communication networks and public communication networks, where personal communication networks are a part of the public communication networks. The final goal of the personal communications is that all users possess their own personal terminals in public communication networks. On the contrary, consumer communication networks are not public, but are owned and used by consumers. Public communication networks are designed usually in top-down style; however, the design of consumer communication networks is done in bottom-up style. Such a bottom-up style will bring much competition into the communications industries.

Consumer communications are classified into two parts, wire consumer communications and radio consumer communications, as shown in Fig. 4. Examples of wire consumer communications are LAN and power line communications; those of radio consumer communications are cordless telephones, indoor radio communications and remote control systems. Since spread spectrum technology is a key to consumer communications, we will show several applications of spread spectrum communications in consumer communications in Japan.

3. Spread Spectrum Applications in Consumer Communications

3. 1 Wire Spread Spectrum Communications

We show here a power line communication as a successful application of the spread spectrum.

If we look for a reliable communication method for consumer communications, we would find that wire communications are the most reliable. However, the most reliable method is also the most expensive one because of the cost of cable construction. Power lines which supply electrical power to transceivers can be used as transmission lines between the transceivers without any extra cable construction. However, they have their problems in communication performance, i. e., the fluctuations of the frequency characteristics due to the load changes and the heavy noises generated by motors, regulators and so on. The problems are similar to those in fading channels in mobile communications.

The spread spectrum has been adopted to overcome the above problems in such power lines. The first proposal to adopt the SS method was put forward by NEC in 1983. The power line is utilized as the home bus connected with the terminals, as shown in Fig. 5. NEC Home Electronics Co., Ltd. has developed the spread spectrum home communication system whose specifications are shown in Table 1. Figure 6 shows the bit error performance[(1)-(3)].

One of the most difficult problems is the synchronization of a spreading code in power line communications whose channel fluctuation often makes the system asynchronous. Such instability is decreased by an improved DLL[(4)].

Power line transmission suffers severe bandwidth limitation, where the spreading gain must be reduced in order to increase the bit rates in the limited bandwidth transmission. A parallel spread spectrum communication system was proposed as an effective method to increase the bit rates without large reduction of the spreading gain[(5)]. Figure 7 shows the block diagram and the autocorrelation function of the parallel spread spectrum system.

A code division multiple access method for power line transmission which uses cancellers to cancel the mutual interference between the transmitted spread spectrum signals is proposed[(6)]. Figure 8 shows the system block diagram and Fig. 9 shows the performance comparison of both systems with and without cancellers.

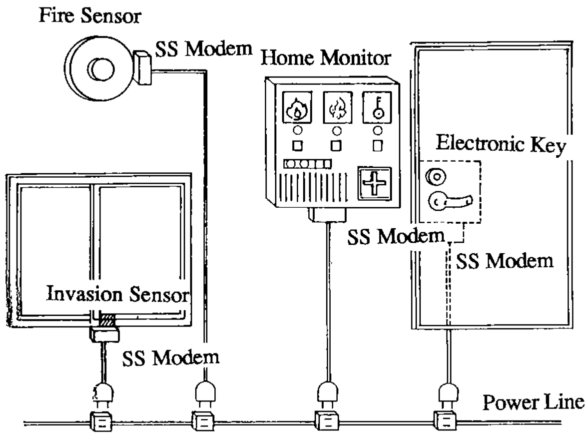


Fig. 5 Home security system using spread spectrum power line communication.

Table 1 SS home bus system.

Term	Specification
Modlation	DS/SS
Processing Gain	31
Freq. Band	10kHz~ 450kHz
Code	Bi-Phase
Bit Rate	960kbs
Aquisition Time	Max 13 msec

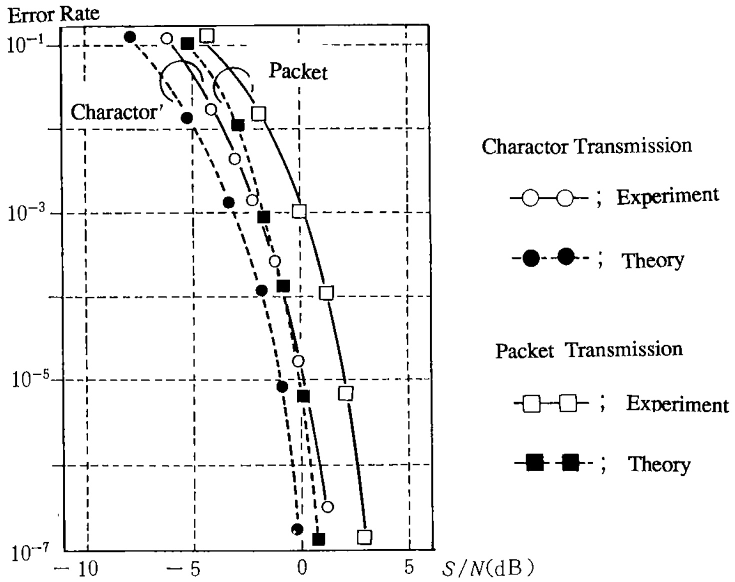
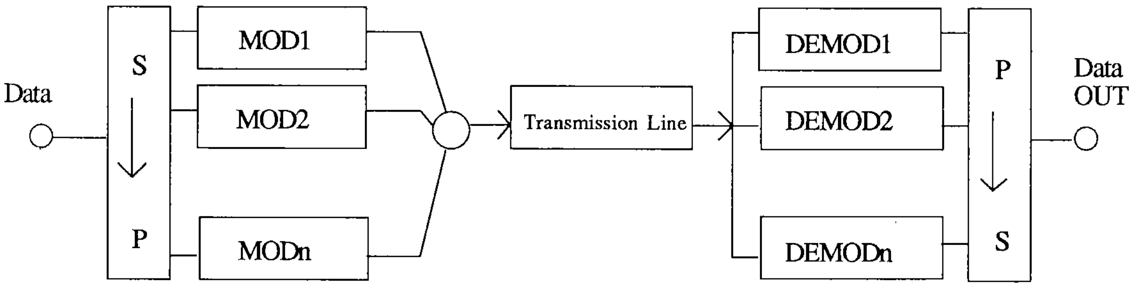
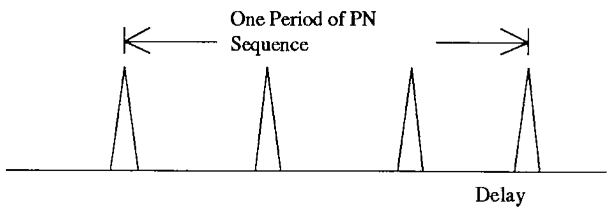


Fig. 6 Error rate in SS power line transmission.



(a) Parallel Spread Spectrum System



(b) Autocorrelation Function of Parallel Spread Spectrum System.

Fig. 7 Parallel spread spectrum communication system.

3.2 Radio Spread Spectrum Communications

The most elegant applications of the spread spectrum method are in radio communications, which are used in the presence of multipath, interference, interception and so on. We show here four examples: a data carrier, a radio control system, low-power radio systems and a clock rate modulation system.

3.2.1 Data Carrier[7]

Figure 10 shows the block diagram of a data carrier system which is mainly used in factories where manufactured objects must be automatically identified. The data carrier system usually consists of a controller unit, a read/write (R/W) head unit and a data carrier unit (tag) ; the controller and the R/W unit are fixed and the data carrier unit is mobile because the

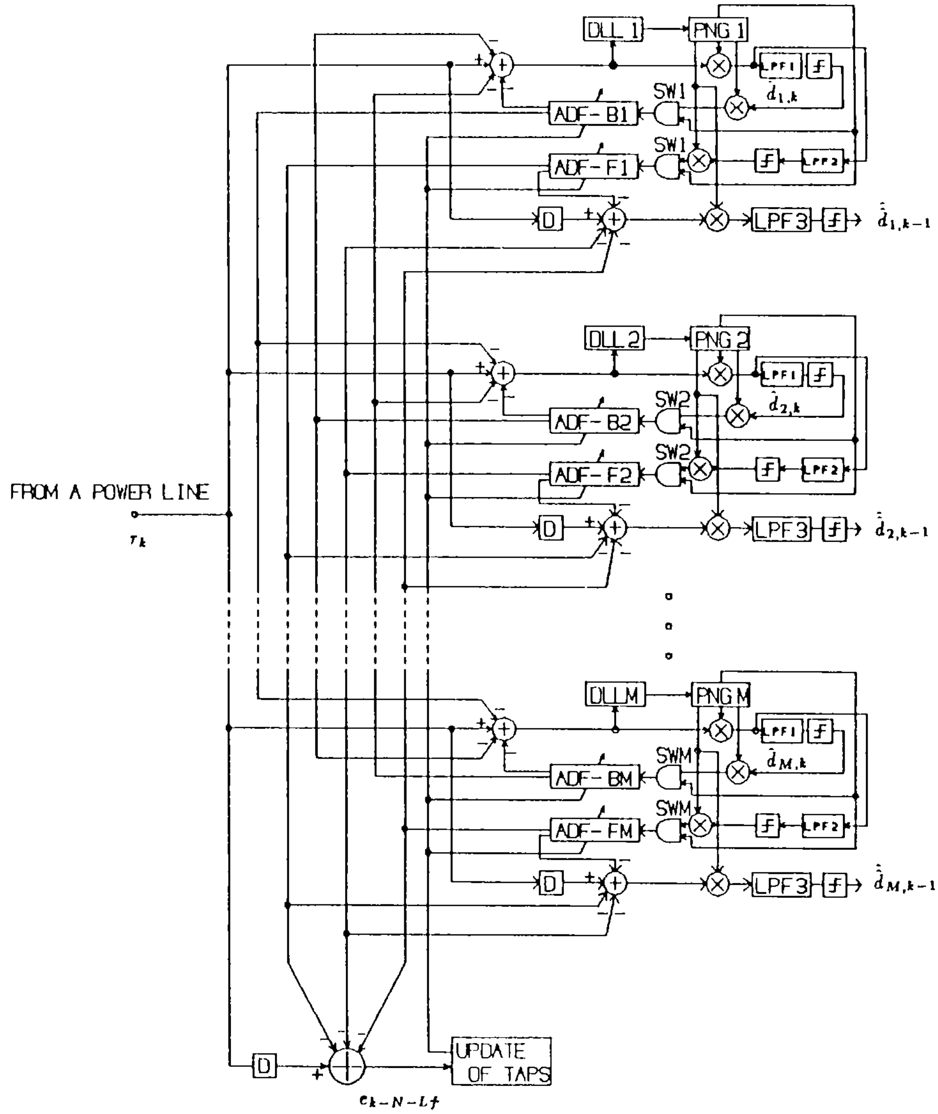


Fig. 8 The receiver with cancellors in power line transmission.

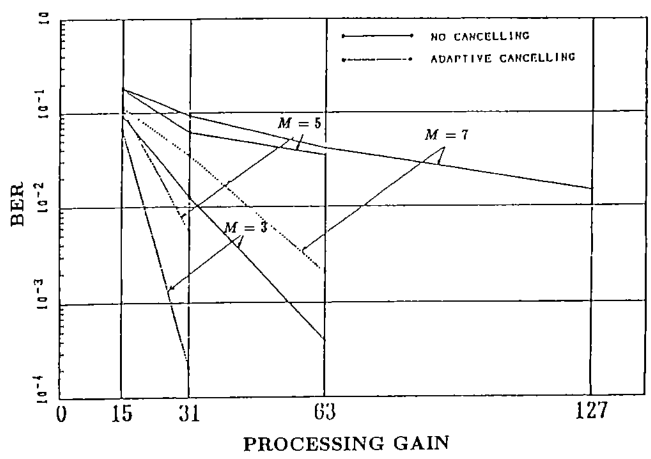


Fig. 9 BER vs. processing gain (M = the number of accessing users).

manufactured objects to which the tag is attached are carried on belt conveyers. The tag needs electrical power for data transmission to the fixed R/W head unit ; the power is supplied by the head unit through the coupling coils as electromagnetic wave power. Therefore, the transmission power is so small that the data transmission is apt to be disturbed by noise such as clock noise generated by processors in the controllers and the R/W units. The spectrum of the clock noise is not white, but a set of line spectra. Spread spectrum modulation is strong against such noise. Figure 11 shows the outside view of the SS data carrier system.

3. 2. 2 Radio Remote Control

Radio remote control systems are widely used in factories, construction sites, offices, homes and so on

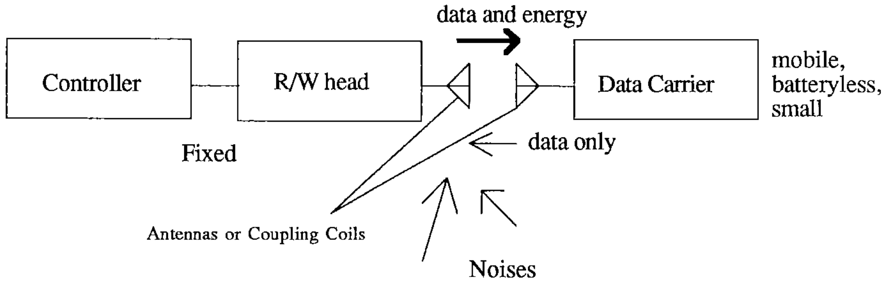


Fig. 10 Data carrier system.

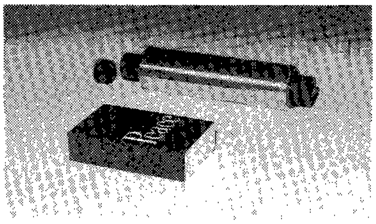


Fig. 11 Photo of SS data carrier system (the big one is R/W head, the small one is data carrier).

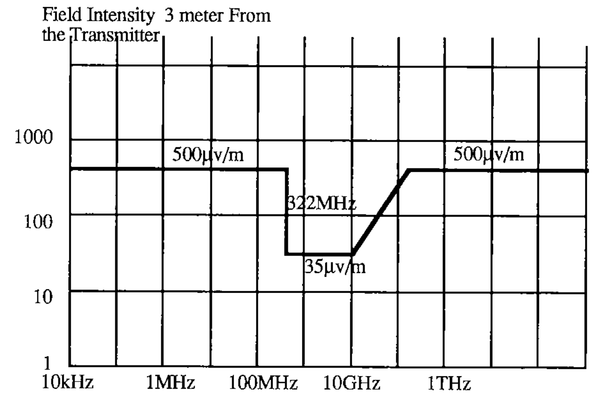


Fig. 12 Field intensity limit for a low power radio station.

Table 2 SS radio remote controller.

Term	Specification
Trans. Power	Low power regulation
FHband width	5MHz
The number of Hopping	15 (RS code)
Hopping Freq.	4.88kHz
DS Processing Gain	32
Modulation	FSK(m=1)
Chip rate	6.4μs/chip
Bit rate	4.88kbps
Error Control	1/2 convolutional code, Viterbi decoding, CRC
DS synch.	64 steps mached filter
FH synch.	DS synch. signal

Table 3 DS/SS low power experiment.

	No.1	No.2
Transmitted centre freq.	250MHz	310MHz
Received centre freq.	310MHz	250MHz
PN code	M-sequence	
Code length	127chips	
Chip rate	14MHz	
Modulation	DS-FSK	
Radio band width	28MHz	
Trans. antenna	1/4λ whip	
Receiv. antenna	1/2λ DP	

for robots, cranes, computers, etc. These systems are required to have high reliability because a data transmission error may cause a serious accident. As mentioned in the previous sections, multipath fading, interference and noise degrade the reliability of the data transmission in the radio remote control systems. A radio control system using a DS/FH (direct sequence/frequency hopping) hybrid technique was proposed, whose specifications are shown in Table 2[8]. DS/FH, Viterbi decoding and the error correction by CRC (cyclic redundancy check) increase the reliability.

3. 2. 3 Low-Power Radio Communications

Bijaku musen setsubi (BMS: low-power radio equipment) is a low power radio station which is not required to be licensed in Japan. It can use any frequency, if it satisfies the following regulation.

The field intensity 3 meters from the BMS must be below the lines shown in Fig. 12. The intensity is

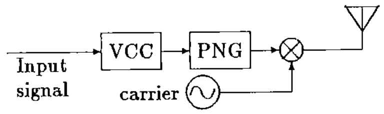


Fig. 13 Block diagram of transmitter in clock rate modulation system.

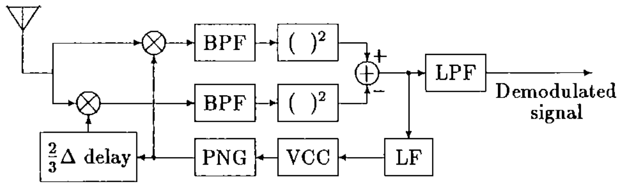


Fig. 14 Block diagram of receiver in clock rate modulation system.

measured by a quasi peak detector with 120 kHz bandwidth for cases below 1000 MHz. It is measured by a peak detector with 1 MHz bandwidth for cases above 1000 MHz.

This definition is advantageous to spread spectrum systems because the limit value of the field intensity is given as the value of 120 kHz or 1 MHz bandwidth and spread spectrum signals usually have bandwidth wider than 120 kHz or 1 MHz.

A group affiliated with Tohoku University and Clarion Co., Ltd. confirmed the above fact through experiments whose specifications are shown in Table 3[(2)]. In comparison with the conventional FM-BMS, SS-BMS has about ten times the communication range.

3.2.4 Clock Rate Modulation System[(9)]

The above-mentioned system is for digital signals, while the clock rate modulation is for analog signals. Of course, it is available for digital signals by using FSK. The system uses 2/3 Δ DLL for good demodulation quality[(10)]. The block diagrams of the transmitter and the receiver are shown in Figs. 13 and 14, respectively. The various performance of the system was evaluated by computer simulations.

4. Saw Device Applications

One of the most difficult problems for spread spectrum communication systems is the synchronization of the local pseudonoise (PN) code to the received PN code at the receivers. The sliding correlation method is the simplest, but it needs long acquisition time. Matched filter methods need very short acquisition time; in addition, the matched filters and the convolvers are available not only for acquisition but also for demodulation. However, they need complicated devices. SAW devices have often been adopted as these devices.

Table 4 SAW matched filter experiment.

Modulation	DS/SS
PN code	127chip Msequence
Chip rate	16Mcps
Centre freq.	144MHz
Bit rate	126kbps

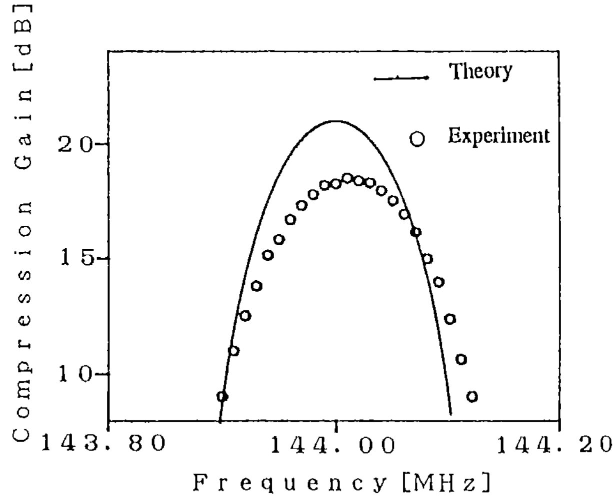


Fig. 15 Effect of frequency offset.

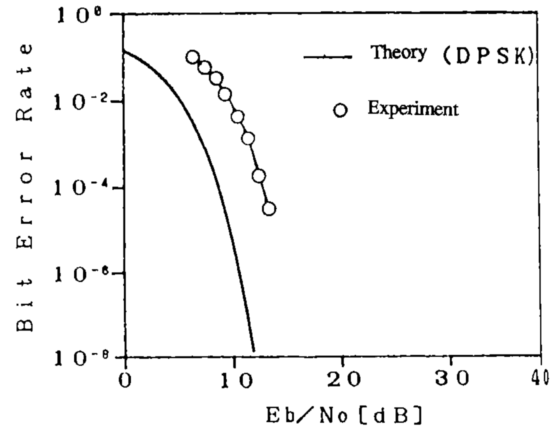


Fig. 16 Bit error rate.

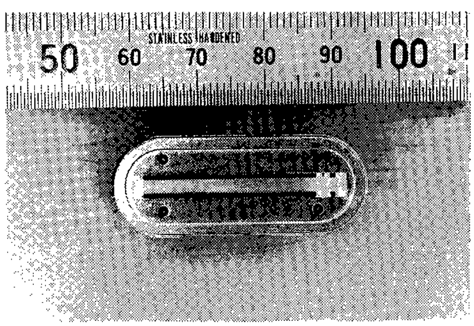


Fig. 17 SAW matched filter.

4. 1 Matched Filter

Reference(11) shows a SAW device matched filter experiment whose specifications are shown in Table 4. Figure 15 shows the performance degradation due to the offset of the carrier frequency. Figure 16 shows BER versus *Eb/No*. Figure 17 shows the matched filter module.

Another topic of the SAW matched filter is the restriction of the data rate. In the case of using only one SAW matched filter in on-off keying or differential phase shift keying, the data rate cannot exceed the sequence rate. To overcome this restriction, the spread spectrum pulse position modulation system was proposed(12).

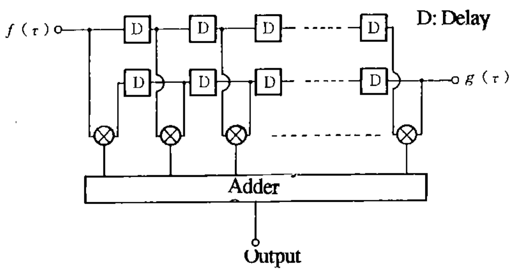


Fig. 18 SAW convolver structure.

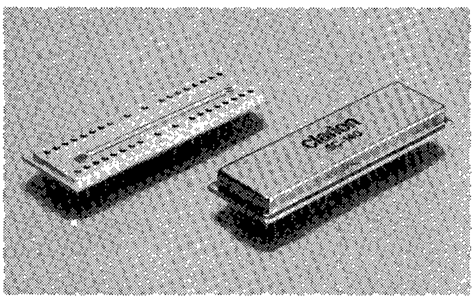


Fig. 19 Exterior of convolver.

Table 5 SAW convolver specifications.

Input 3dB Bandwidth	24MHz
Processing Time	9.0μsec
Time Bandwidth Product	216
Input Centre Freq.	215MHz
Output Centre Freq.	430MHz
Terminal Efficiecy	-50dBm
DC Voltage	+12v, -12v

4. 2 Convolver

Matched filters such as those mentioned above utilize a convolutional effect between the impulse response of the filter and the received pseudonoise (PN) code. However, it is difficult to change one received PN code to another received PN code because the pattern of the impulse response depends on the pattern of the electrodes on the SAW filter.

The structure of a convolver, as shown in Fig. 18, overcomes this problem. We can change one received PN code to another by changing the external reference PN code without any internal structural change. The multipliers in a convolver shown in Fig. 18 which utilize a nonlinear effect in the SAW device are for convolution between the received PN code and the external PN code. The specifications of the spread spectrum convolver are shown in Table 5. Figure 19 shows the exterior view of the convolver(2). Field tests done by Clarion Co., Limited in Los Angeles area of a spread spectrum wireless modem using a SAW convolver were reported(13).

A spread spectrum signal with a polyphase PN code(14) can be easily detected by the convolver(15). The polyphase PN code has less side robe than the biphase PN code. The SAW convolver is available for various systems.

5. Digital Signal Processing Applications

Digital signal processors have been adopted in many communications systems because of the stability, the variability of parameters, the flexibility and the capability of new functions. We show here a demodulation method in spread spectrum communications receivers with new functions which can be done only by digital signal processing. Also, other examples are shown.

5. 1 Spread Spectrum Block Demodulator for Packet SS(16)

Spread spectrum techniques have been applied to packet radio networks for interference resistances, code division multiple access, antifading capability and so

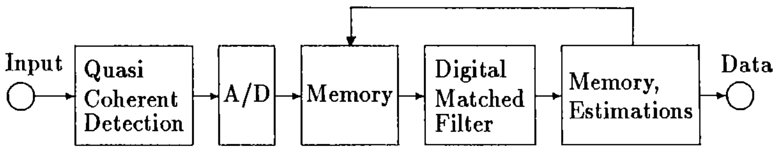


Fig. 20 Spread spectrum block demodulator for packet SS.

on[17]. As mentioned in the previous section, in general, the initial synchronization between the received PN code and the local PN code at the receiver is one of the most difficult problems in SS techniques because it takes a long time. The problem is more serious in packet radio networks. Each SS packet must have a long preamble for initial synchronization, which cannot be used as data and degrades the efficiency of the packet data transmission. Conventional demodulation systems have no solution to the problem because they have no memory function. The SS block demodulator has a memory block to store a quasicoherent-demodulated packet, as shown in Fig. 20. The memorized packet is applied to the digital matched filter (DMF) and then the DMF generates matched pulses at the output. The arctan function detects the frequency and phase offsets (Δf, $\Delta\phi$) of the carrier signal which a matched pulse includes but are not eliminated by the preceeding quasi-coherent demodulator. Thus, both PN code and carrier synchronizations are done and the data are detected. Δf and $\Delta\phi$ are estimated using the least mean squares algorithm and the estimation quality is equal from the packet head to the tail.

On the contrary, the estimation quality is so bad at the packet head in conventional SS demodulators that a preamble part may be required because of its transient pull-in phenomenon.

5.2 Other Examples

We show two other examples of digital signal applications. One is an acquisition system for power line communications using a microprocessor[18]. The system accomplished quick correlation. The other is an application for sonar using real-valued orthogonal pseudonoise sequences[19]. Although this is not a communication system, we must not forget that spread spectrum systems simultaneously accomplish both communication and measurements.

6. Conclusions

Consumer communications will play an important role and one of the key technologies is the spread spectrum method. Several examples of spread spectrum applications for consumer communications in Japan were shown.

"From military to civil" and "from public to individual" will become true simultaneously.

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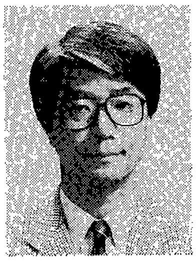

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