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Design and Develop Wireless System Using Frequency Hopping Spread Spectrum

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***Abstract*—Rapid advances in information technology and telecommunications, specifically the wireless and mobile communication have the potential of supporting an array of advanced services for healthcare. Concomitant advances in communications and medical technology have let to increasing deployment of telemedicine systems and services around the world. Wireless data services and systems represent a rapidly growing and increasingly important segment of the communications. It is becoming increasingly diverse and fragmented, that one can identify a few mainstreams which relate directly to users' requirement for data services. The use of wireless LANs in a hospital provide doctors and nurses with rapid accesses to patient data, including various laboratory reports. The system designed in this paper work at 2.4GHz using frequency hopping spread spectrum for wireless LAN between two systems**

Index Terms— ACK (Acknowledgment), frequency hopping spread spectrum, spread spectrum, Wireless LAN

I. INTRODUCTION

The purpose of implementing information technologies is to reengineer processes, so that care is delivered more cost effectively and efficiently, not to reengineer people to do things differently as required by the information system.

Satellite systems have the advantage of worldwide coverage and offer a variety of data transfer speeds, even though satellite links have the disadvantage of high operating cost. A few analog radio telemedicine systems were developed for the support of aircraft and ships in isolated areas.

Infrared waves cannot penetrate walls or structures, so direct line of sight is required between transmitter and receiver. Range is limited to approximately 30 feet per sensor, so multiple sensors are required. The infrared content of ambient light can interfere with IR radiation and, if extensive, can overload the receiver photodiode and drive it beyond its operating point. Three sources of ambient light are daylight, incandescent illumination, and fluorescent lamps, all of which potentially interfere with IR communications. Fluorescent light is the common method of lighting in office environments and poses the most serious problem for IR communications.

At higher frequencies, signal transmission through walls is more difficult. This feature is advantageous in wireless LAN applications where confinement of the signal within a room or building is a desirable privacy feature. Also, at higher frequencies the relationship between cell boundaries and the physical layout of the building is more easily determined, facilitating the planning of wireless LAN cell assignments within the building.

The term wireless refers to telecommunication technology, in which the radio waves [1], infrared waves and microwaves, instead of cables or wires, are used to carry a signal to connect communication devices. Wireless technology is rapidly evolving, and is playing an ever-increasing role in the lives of people throughout the world [1].

A. Wireless Technologies

Telemedicine, as a concept, was introduced about 30 years ago, when telephone and fax machines were the first telecommunication means used. In recent years, several telemedicine applications have been successfully implemented over wired communication technologies like POTS (Plain Old Telephone System) and ISDN (Integrated Services Digital Network). However, nowadays, modem means of wireless telecommunication, such as the GSM (Group Special Mobile -Global System for Mobile Communications), GPRS (General Packet Radio Service), and the forthcoming UMTS (Universal Mobile Telecommunications Systems) mobile telephony standards, as well as satellite communications, allow the operation of wireless telemedicine systems, freeing the medical personnel and/or the subject monitored from being bound to fixed locations [2]-[4].

GSM is a system currently in use, and is the second-generation (2G) of mobile-communication networks. When it is in the standard mode of operation, it provides data-transfer speeds of up to 9.6 kbps [5], which is the current maximum rate of GSM. The available bandwidth of GSM is not sufficient for still images and ECG data of the patient.

The greatest obstacle to achieving wireless multimegabit data communication rates is the lack of a suitable frequency band for reliable high-speed communication. The existing ISM bands [6] assigned for multiple-user applications are suitable for Wireless Local Area Network (wireless LAN), but they are restricted to spread-spectrum technology [7].

Wireless LAN [8] is a flexible data-communications system, implemented as an extension to or as an alternative for a wired LAN. Using radio frequency technology, wireless LANs transmit and receive data over the air, minimizing the need for wired connections. Thus, wireless LANs combine data connectivity with user mobility. They are becoming very

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popular in a number of vertical markets, including healthcare, retail, manufacturing, warehousing, and academia.

The industries have profited from the productivity gains of using hand-held terminals and notebook computers to transmit real-time information to centralized hosts for processing. Today, wireless LANs are becoming more widely recognized as a general-purpose connectivity alternative for a broad range of applications. This technology will penetrate the health sector in the near future. In patient monitoring applications, the most important feature is reliability so that contact is maintained with patients at all times. Bandwidth, flexibility, expandability, ease of implementation and cost are important, but secondary considerations. Some of these are interrelated such as the installation must have sufficient bandwidth to support patient monitoring needs in order to be reliable.

II. SPREAD SPECTRUM TECHNOLOGIES

Spread Spectrum modulation techniques are defined as being those techniques in which the bandwidth of the transmitted signal is much greater than the bandwidth of the original message, and the bandwidth of the transmitted signal is determined by the message to be transmitted and by an additional signal known as the Spreading Code. Spread spectrum technology was first used during the World War II by the military, who experimented with spread spectrum because it offered low interference and much-needed security. There are two methods for performing the spreading: frequency hopping and direct sequencing. This paper uses frequency hopping spread spectrum for wireless LAN because of the following reasons.

- Frequency hopping is one of the variants of spread spectrum technique which enables coexistence of multiple networks (or other devices) in the same area.
- Federal Communication Commission (FCC) recognizes Frequency Hopping as one of the techniques withstanding “fairness” requirements for unlicensed operation in the ISM bands.
- Frequency Hopping is resistant to multipath fading through the inherent frequency diversity mechanism.

A. Frequency hopping spread spectrum (FHSS)

Frequency hopping is a radio transmission technique where the signal is divided into multiple parts and then sent across the air in random pattern of jumping or “hopping,” frequencies. When transmitting data, these “multiple parts” are data packets. The hopping pattern can be from several times per second to several thousand times per second.

Frequency hopping is the easiest spread spectrum modulation to use. Any radio with a digitally controlled frequency synthesizer can, theoretically, be converted to a frequency hopping radio. This conversion requires the addition of a pseudo noise (PN) code generator to select the frequencies for transmission or reception. Most hopping systems use uniform frequency hopping over a band of frequencies. This is not absolutely necessary, if both the transmitter and receiver of the system know in advance what frequencies are to be skipped. Thus a frequency hopper in two meters could be made that skipped over commonly used repeater frequency pairs. A frequency hopped system can use analog or digital carrier modulation and can be designed using conventional narrow band radio techniques. De-hopping in the receiver is done by a synchronized pseudo noise code generator that drives the receiver's local oscillator frequency synthesizer. FHSS splits the available frequency band into a series of small sub channels. A transmitter hops from sub channel to sub channel, transmitting short bursts of data on each channel for a predefined period, referred to as dwell time (the amount of time spent on each hop). The hopping sequence is obviously synchronized between transmitter and receiver to enable communications to occur. FCC regulations define the size of the frequency band, the number of channels that can be used, and the dwell time and power level of the transmitter. In the frequency hopping spread spectrum a narrowband signal move or hops from one frequency to another using a pseudorandom sequence to control hopping. This results in a signal’s lingering at a predefined frequency for a short period of time, which limits the possibility of interference from another signal source generating radiated power at a specific hop frequency. The basic frequency hopping system is shown in Fig. 1[9].

The FHSS subsystem produces a spreading effect of pseudo randomly hopping the RF carrier frequency over the available RF frequencies $f_1 \ldots f_N$ where N could be several thousand or more. If Δf is the frequency separation between adjacent discrete frequencies and N is the number of available RF frequency choices, that is, channels, then the processing gain of an FHSS system is

$$\mathrm{Gp} = \frac{\text{RF bandwidth}}{\text{message bandwidth}} = \frac{N.\Delta f}{\Delta f} = N \qquad (1)$$

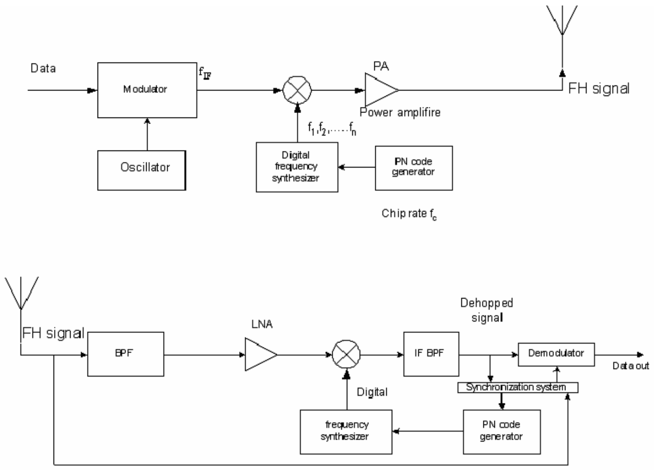


Fig. 1: General form of frequency-hopping system: (a) transmitter and (b) receiver

The transmitted hopped frequencies are generated by a digital frequency synthesizer, which is controlled by serial or parallel “words”, each containing m binary digits. These m-bit words produce one of $M = 2^m$ frequencies for each separate word or symbol combination of the digits. The number of radio frequencies available for a frequency hopper is frequently $M = 2^m$ where m=2, 3….. although not all of these are necessarily used in a particular application. The instantaneous change of transmitted discrete RF frequencies is attained at the chip rate $f_{c,}$ frequently specified in chips/second (c/s), kilochips/ (kc/s) or megachips/second (Mc/s). The baseband data rate is f_b (kb/s). Frequency hopping spread spectrum systems are categorized into

- Slow frequency hopping (SFH)
- Fast frequency hopping (FFH)
- Intermediate (rate) frequency hopping (IFH)

B. Slow frequency hopping (SFH)

In an SFH spread system the hop rate f_H (chip rate) is less than the baseband message bit rate $f_{b.}$ Thus two or more (in several implementations, more than 1000) baseband bits are transmitted at the same frequency before hopping to the next RF frequency. The hop duration, $T_{H,}$ is related to the bit duration T_b by

$$T_H = kT_b \quad \text{for} \quad k = 1, 2, 3\ldots.. \quad \text{and} \quad f_c = f_H = 1/T_H \tag{2}$$

C. Fast frequency hopping (FFH)

In an FFH spread spectrum system the frequency chipping rate, f_c, (chipping rate is the same as hopping rate) is greater than the baseband data rate f_b. In this case one message bit T_b is transmitted by two or more frequency hopped RF signals. The hope duration or chip duration ($T_H = T_c$), is defined by

$$T_c = T_H = \frac{1}{k} T_b \quad \text{for} \quad k = 1, 2, 3\ldots.. \quad \text{and} \quad f_c = f_H = 1/T_c \tag{3}$$

III. DESIGNING A WIRELESS SYSTEM

A. Methodology

As discussed in the introduction of this chapter, we came to the conclusion to design a portable, safe and reliable system which can send medical data wirelessly. **C** and **Matlab** programming language was used to implement the desired application.

Medical data transfer application is implemented on frequency hopping protocol with PC with two serial ports interfacing the serial ports on two EVBOARDS (nRF24E1). Data has been transferred at a 1000 Kbps. The range of each radio is approximately 10m, but can be extended to 100m with an optional amplifier. Block diagram of the proposed system is shown in Fig 2. The medical device which usually sends the data to PC or monitor in order to display the results is connected through wires which is cumbersome while in mobility. In order to get rid of such huge and bulky setup, EVBOARD is used in this project which is connected to medical device in noisy environment through serial port using UART. The EVBOARD is programmed like that ,once it will receive the data, it will send the data accompanied by PN code automatically through wirelessly to the concern area where EVBOARD after receiving the data send it to PC through serial communication. The designed system is automatic and friendly no need of human intervention.

B. Protocol Description

The frequency hopping code hops between 64 channels (channel 2 to channel 65) pseudo-randomly distributed in a 256-bytes constant table embedded in the code. The 64 channels are shown in Fig 3.

C. Hopping Functions

Each time the transmitter sends a packet on a channel it starts waiting for an acknowledge packet (ACK) on the same channel. If the ACK is received within a predefined time-out (3ms in this system) the transmitter selects the next channel in the hopping table and sends the next packet on the newly selected channel. If an ACK is not received within the time-out period the packet is re-transmitted on the same channel. If this does not result in a valid ACK the transmitter hops to the next channel and repeats the procedure above. This process is repeated until an ACK is received or a time-out (3 seconds) is reached and if the time-out is reached the function returns with an error. A float chart for a transmitter is shown in Fig. 4.

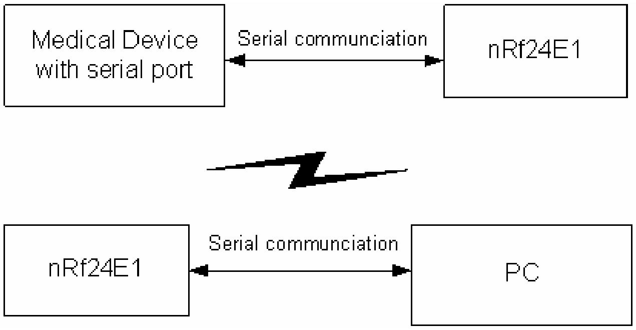


Fig. 2: Block diagram of the system

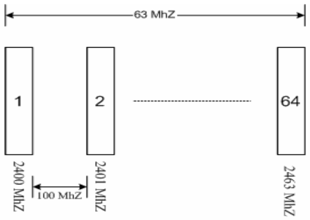


Fig. 3: Allocation of Channels

The functionality on the receiver mirrors that of the transmitter. The flowchart for receiver is shown in Fig.5. Each time a packet is received, an ACK is sent before changing to the next channel in the hopping table.

Frequency hopping is a safe way to avoid communication failure due to total jamming of a traffic channel. The units in a frequency hopping system change channels after a predefined channel table and in a time synchronous manner.

Generating a global clock based on each unit's distributed clock gives a reference for the time synchronization. This will look much the same as dynamic channel assignment; a channel's change will be initiated each time a packet is transmitted. A frequency hopping protocol must also run a flow control like acknowledgment to ensure that all the information gets through.

Frequency hopping is most used by systems operating with very high output power that the frequency regulation demands the use of it. In addition to the address and CRC, each packet consists of 0-25 bytes of data and one byte of control information as shown in Fig. 6.

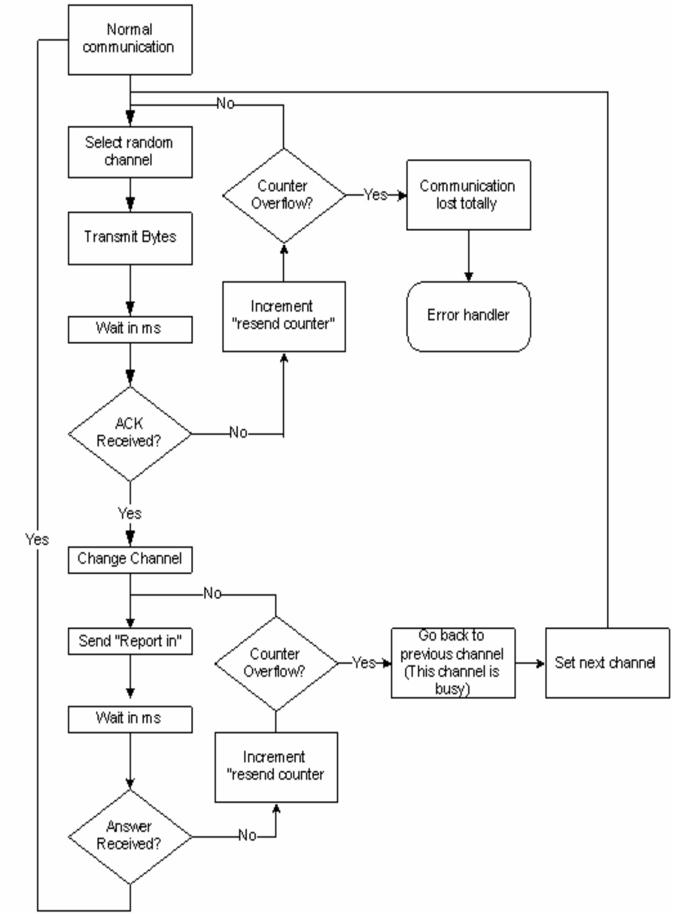


Fig.4: Flowchart of packets transmission

At present there are two types of messages defined: data message (type=0001b) and ACK (type=0010b). The ACK has 0 bytes message data in this application. The sequence bits contain a four-bit counter which increments after each packet is sent, is used by the receiver to keep track of which packet has been received.

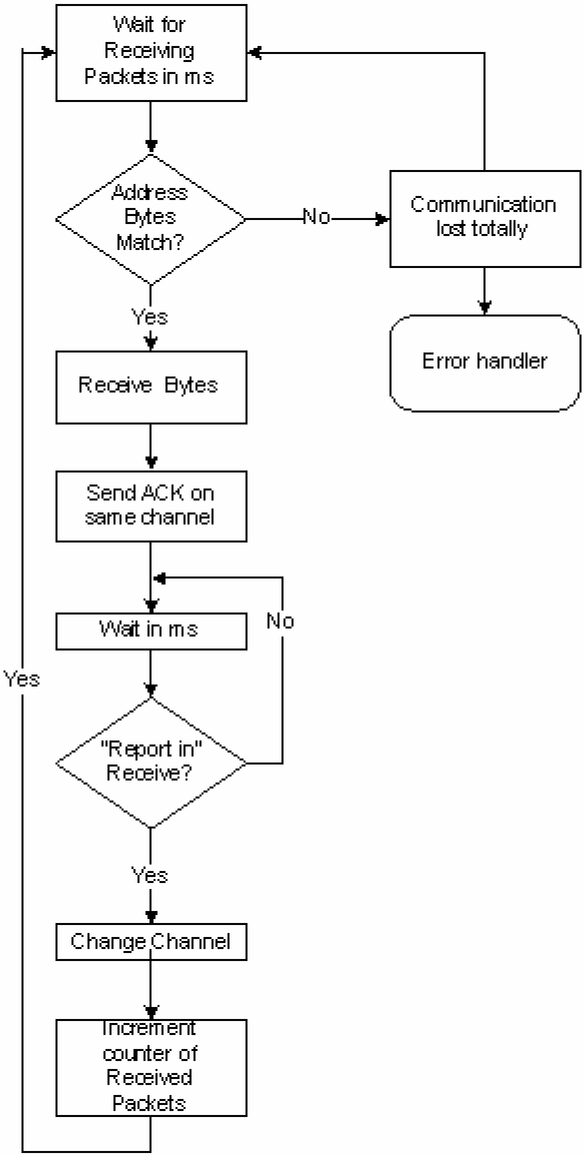
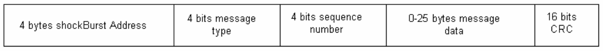


Fig. 5: Flowchart of packets reception



4 bytes shockBurst Address	4 bits message type	4 bits sequence number	0-25 bytes message data	16 bits CRC

Fig. 6: Data packet

IV. USE OF A UART (UNIVERSAL ASYNCHRONOUS RECEIVER TRANSMITTER)

To implement software routines to transfer data from one microcontroller to another via nRF24E1 we use UART. Packet format of the UART is shown in Fig. 7.

(1) Preamble

A packet has to begin with a preamble. The preamble has two tasks:
1: Stabilize the receiver.
2: Synchronize a receiving UART if used.

(2) Address

The address in the packet is used by the receiver to identify a packet. It can be a system address or a device address. In the case of a system address, the device address will be part of the payload. The length of the address depends on how many devices the system has contains. Normally 1 to 2 bytes are enough as address field.

(3) Payload

The golden rule in the payload bytes is to keep the packet as short as possible because this will give the packet greater chance to survive through the link.

(4) Checksum

The checksum is used to validate the packet. This is calculated from the address and payload bytes. Normally one byte with checksum is enough. A typical checksum routine is the Cyclic Redundant Check (CRC) routine.

When there are no transmitters present, a receiving nRF24E1 device will demodulate noise. This noise will be handled by the receiving UART. The receiving UART might be in the middle of sampling a byte when the first byte in the preamble arrives. Detecting the start bit is crucial to read the rest of the byte correctly. Therefore preamble must be able to synchronize the UART so that when the first address byte arrives, the UART will detect the start bit correctly. The UART TXD is connected to the nRF24E1 DIN pin, and UART RXD is connected to the nRF24E1 DOUT pin. The flowchart in Fig. 8 shows how to send a data packet via hardware UART. In most microcontrollers with hardware implemented UART, an interrupt is send to the MCU each time a complete byte is received. This routine must be run each time the UART has received a whole byte. The flowchart for UART reception is shown in Fig. 9.

Fig. 7: Packet format

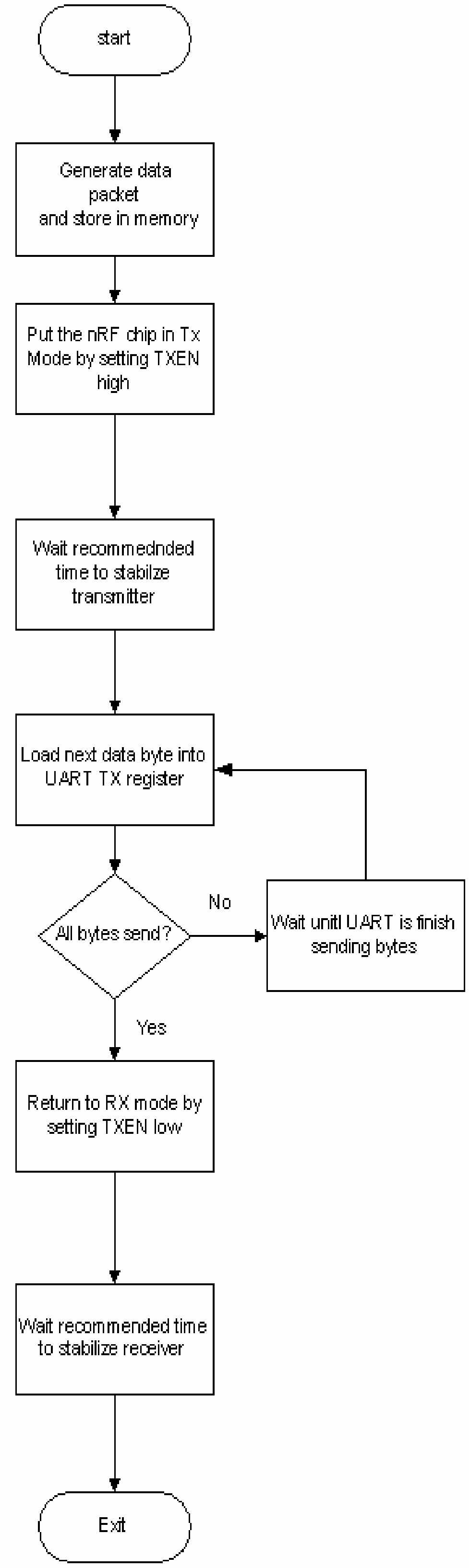


Fig.8: Flowchart for UART transmission

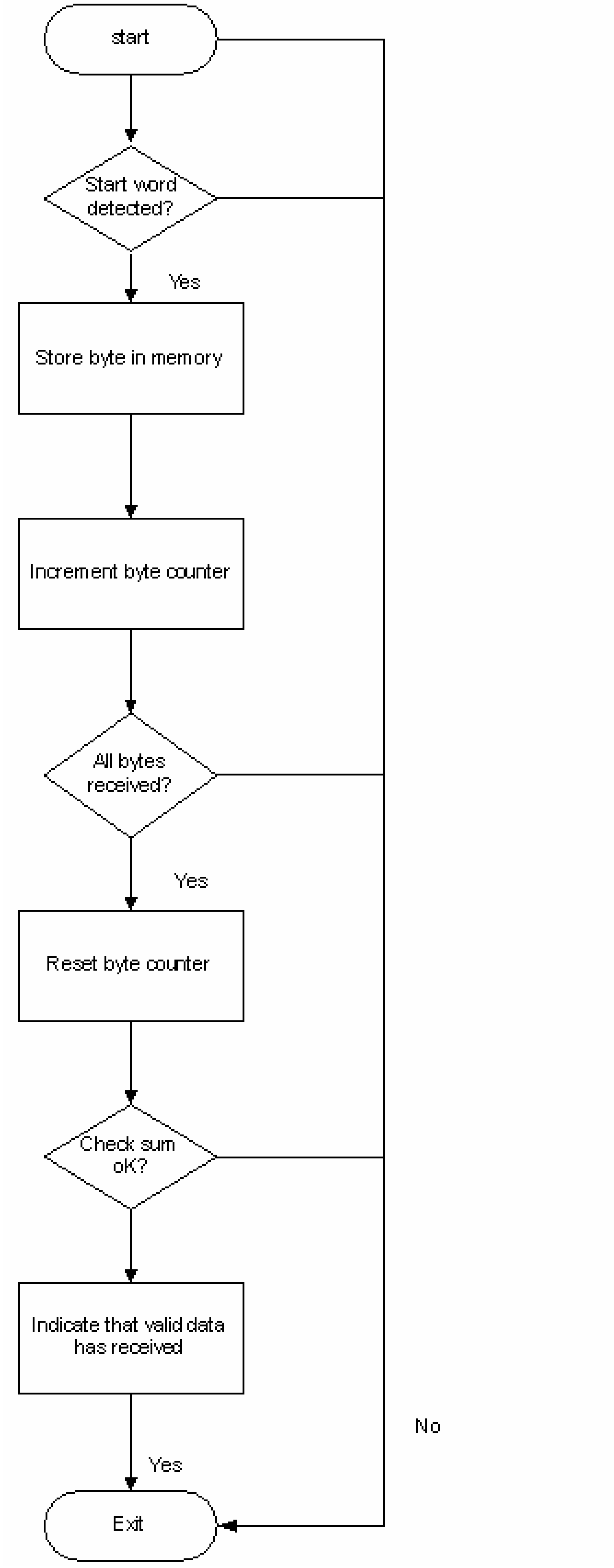


Fig. 9: Flowchart for UART reception

V. RESULTS AND DISCUSSION

A spectrum measurement tool, called a *spectrum analyzer*, was used to measure the power levels emitted by the nRF24E1 transceiver as shown in Fig. 10. The instrument scans the ISM range of frequencies to record the frequency and power level of the signals emitted from the transceiver. When successive frequency sweeps are performed, each trace element on the spectrum analyzer's display is updated with the maximum signal level detected as shown in Fig. 11.

The update spectrum data is compared with that of last time for each point of the X-axis, and the larger one is retained and displayed. Thus, the analyzer works like an integrator that compares the present detected power level with the previously recorded power level at a frequency. If the present power level is higher than the previous value, the display is updated with the higher value. This is called Maximum-Hold, and is a display function used to portray maximum values for any detector over a measured period.

The spectrum analyzer continuously performs sweeps in the ISM band. The center frequency for the sweeps is chosen to be 2400MHz. Since the default number of points per sweep is 401, there are 400 points representing the bandwidth between the first and last frequency of interest.

At the end of a few sweeps over a time period, the analyzer's display is showing the maximum signal level at each frequency that occurred at some point in time. Actually it rarely emits peak power levels on all frequencies continuously.

Adjacent channel power (ACP) measurement is as shown in Fig.12 with - 0.46dB and -31.35dB for upper and lower ACP respectively. The main channel power measurement is -65.03dBm which combined with channel spacing, main channel bandwidth specified the range of integration used in calculating the power in the center reference channel. Changing main channel bandwidth automatically changes adjacent channel bandwidth and channel spacing to the same value as shown in Fig.12.

Fig.13 is depicting the channel power measurement with -127.02dBm/Hz density and 2.00MHz integration bandwidth. This measures the sum of the power in the zone specified by the zone center and zone width. In other words it is possible to measure the total power in the specified frequency band.

It is possible to measure the occupied frequency bandwidth as the bandwidth of the point that is lower by X (dB) than the peak level or as the bandwidth of the point of Y (%) of the total power. The occupied bandwidth is 2.926MHz with 99% bandwidth power as shown in Fig. 14. Fig. 15 to17 represent the emission bandwidths which allow to specify the measurement span over which to search for the peak level and X dB level transition points of the signal.

In order to clearly see the spectral impulse signals on the display, the resolution bandwidth and video bandwidth were both set properly. A tradeoff is involved in setting the value of these bandwidths. Resolution bandwidth (RBW) is the minimum bandwidth over which two signals can be separated on the display and still be seen. Increasing the RBW will allow more of the weaker power emissions in the band to be seen, but this will also increase the noise floor power.

Choosing a narrower video bandwidth will filter more noise than a wider bandwidth. On the display, the rise time of the low-pass filter is inversely proportional to the bandwidth by the equation (Ziemer *et. al* (1998))

$$\tau_r = \frac{0.35}{BW} \tag{4}$$

However, (4) shows that decreasing this bandwidth slows down the analyzer's sweep time.

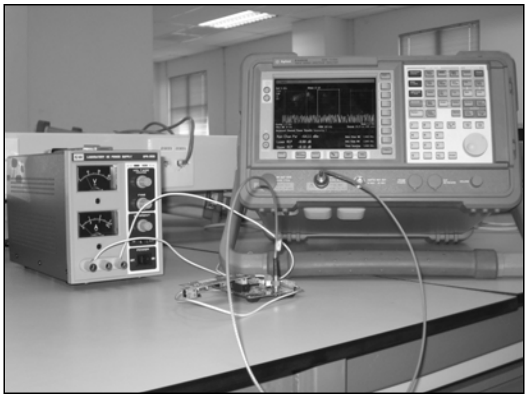
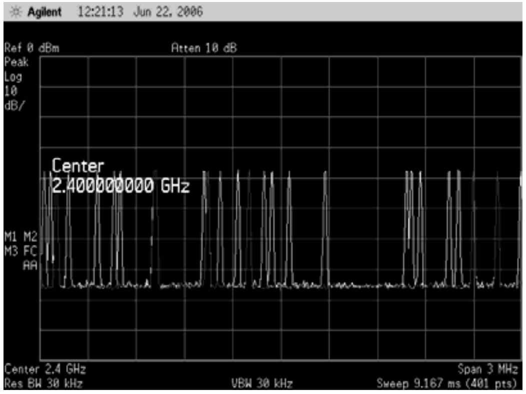


Fig. 10: *Spectrum analyzer*, use to measure the power levels emitted by the nRF24E1 transceiver



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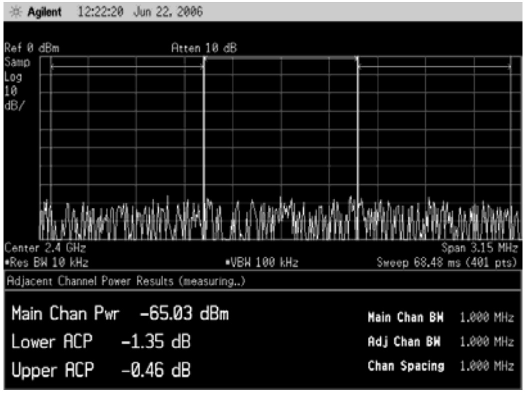
Agilent   12:21:13  Jun 22, 2006

Ref 0 dBm              Atten 10 dB
Peak
Log
10
dB/
        Center
        2.400000000 GHz

M1 M2
M3 FC
   AA

Center 2.4 GHz                                    Span 3 MHz
Res BW 30 kHz           VBW 30 kHz     Sweep 9.167 ms (401 pts)
```

Fig. 11: Maximum-Hold of frequency sweeps



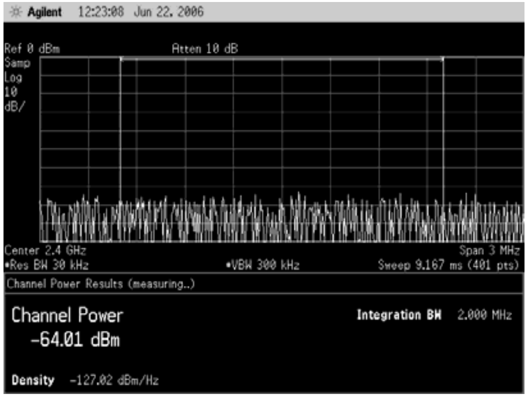
```
Agilent   12:22:20  Jun 22, 2006

Ref 0 dBm              Atten 10 dB
Samp
Log
10
dB/

Center 2.4 GHz                                 Span 3.15 MHz
•Res BW 10 kHz         •VBW 100 kHz    Sweep 68.48 ms (401 pts)
Adjacent Channel Power Results (measuring..)

Main Chan Pwr   -65.03 dBm             Main Chan BW   1.000 MHz
Lower ACP    -1.35 dB                  Adj Chan BW    1.000 MHz
Upper ACP    -0.46 dB                  Chan Spacing   1.000 MHz
```

Fig. 12: Adjacent channel power (ACP) measurement



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Agilent   12:23:08  Jun 22, 2006

Ref 0 dBm              Atten 10 dB
Samp
Log
10
dB/

Center 2.4 GHz                                    Span 3 MHz
•Res BW 30 kHz         •VBW 300 kHz    Sweep 9.167 ms (401 pts)
Channel Power Results (measuring..)

Channel Power                          Integration BW   2.000 MHz
  -64.01 dBm

Density   -127.02 dBm/Hz
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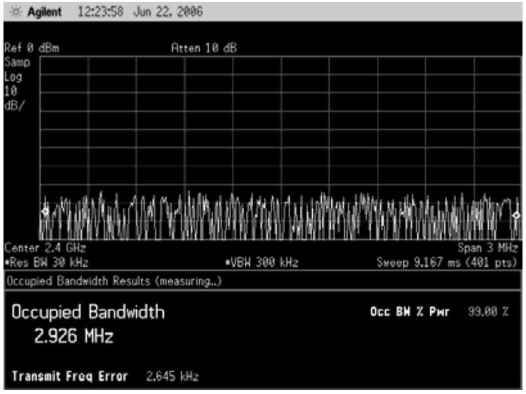
Fig. 13: Channel power -64.01dBm with -127.02dBm/Hz density



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Agilent   12:23:58  Jun 22, 2006

Ref 0 dBm              Atten 10 dB
Samp
Log
10
dB/

Center 2.4 GHz                                    Span 3 MHz
•Res BW 30 kHz         •VBW 300 kHz    Sweep 9.167 ms (401 pts)
Occupied Bandwidth Results (measuring..)

Occupied Bandwidth                     Occ BW % Pwr   99.00 %
  2.926 MHz

Transmit Freq Error   2.645 kHz
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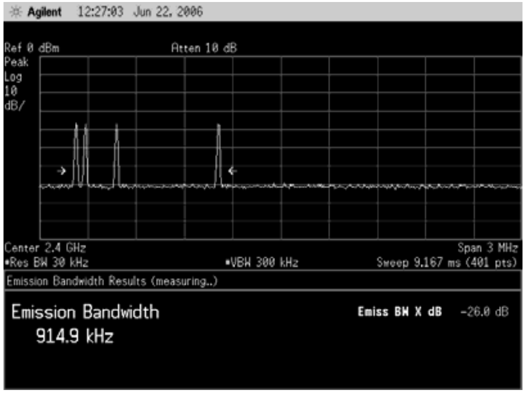
Fig. 14: Occupied bandwidth 2.926MHz



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Agilent   12:27:03  Jun 22, 2006

Ref 0 dBm              Atten 10 dB
Peak
Log
10
dB/

Center 2.4 GHz                                    Span 3 MHz
•Res BW 30 kHz         •VBW 300 kHz    Sweep 9.167 ms (401 pts)
Emission Bandwidth Results (measuring..)

Emission Bandwidth                     Emiss BW X dB   -26.0 dB
  914.9 kHz
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Fig. 15: Emission Bandwidth 914.9 kHz

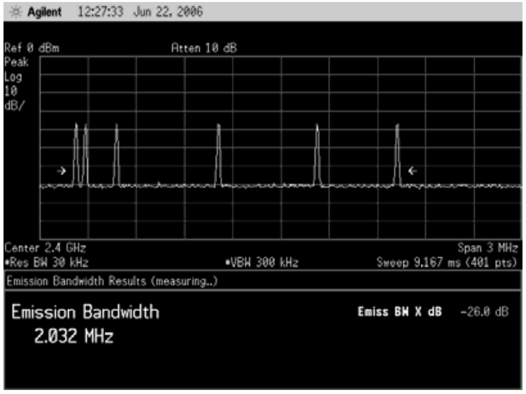

Fig. 16: Emission Bandwidth 2.032MHz

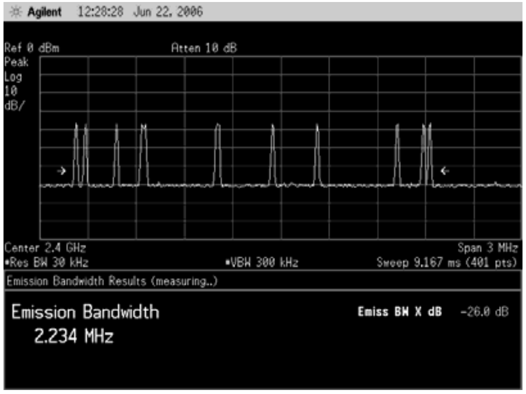

Fig. 17: Emission Bandwidth 2.234MHz

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