RECEPTION PERFORMANCE OF FLEXIBLE WIRELESS SYSTEM RECEIVING MULTI-SIGNALS SIMULTANEOUSLY

Hiroyuki SHIBA (NTT, Yokosuka-shi, Kanagawa, Japan, shiba.hiroyuki@lab.ntt.co.jp);
Takayuki YAMADA (NTT, Yokosuka-shi, Kanagawa, Japan);
Takana KAHO (NTT, Yokosuka-shi, Kanagawa, Japan);
Yo YAMAGUCHI (NTT, Yokosuka-shi, Kanagawa, Japan);and
Kazuhiro UEHARA (NTT, Yokosuka-shi, Kanagawa, Japan)

ABSTRACT

A great variety of wireless systems are currently being used to provide diverse and sophisticated information and communication services. New wireless systems are being standardized for later implementation. We have proposed a new flexible wireless system (FWS) supporting a wide variety of wireless systems. This system processes all received radio waves with software on the network. Since FWS receives multiple signals simultaneously, the widening of received signal power and conflicts with received signals have become major problems. To solve them, we propose a new multi-band, multi-signal receiver and a multi-band, multi-signal auto gain control (AGC) method. We also propose a signal separation method based on the features of received radio wave data. We used computer simulation and the prototype to show the effectiveness of these proposed technologies for multi-band, multi-signal reception.

1. INTRODUCTION

A great variety of wireless systems are currently being used to provide diverse and sophisticated information and communication services. New wireless systems are being standardized for later implementation. However, the increased diversity and the number of wireless systems cause problems such as inter-system interference, a lack of suitable base station installation locations, and an increase in capital expenditure (CAPEX) and operating expenditure (OPEX) for telecommunications carriers. Moreover, in the future these problems will certainly become more severe since wireless systems need to support an enormous number of wireless terminals.

In light of this background, we previously proposed a flexible wireless system (FWS) using software defined radio technology and cognitive radio technology [1]. The system is a unified wireless platform that supports a wide variety of wireless systems. Its main feature is that it stores all received radio waves in a network and processes them with software. Thus, as opposed to conventional wireless systems, the waves do not need to be processed at a base station.

The major difference in the signal power level and the interference between received signals becomes serious problems due to the need to simultaneously support the reception of multi-band, multi-signals in FWS. To solve these problems, we propose a new multi-band, multi-signal receiver and a multi-band, multi-signal auto gain control (AGC) method. We also propose a signal separation method based on the features of the received radio wave data. We develop a prototype of the receiver and use computer simulation and the prototype to show the effectiveness of these technologies for multi-band, multi-signal reception.

The rest of the paper is organized as follows. Section 2 describes the FWS in detail. Section 3 proposes a multi-band, multi-signal receiver, a multi-band, multi-signal AGC method, and a signal separation method. Section 4 describes the multi-band multi-signal receiver prototype and how we used it and computer simulation to evaluate the proposed methods. Section 5 concludes the paper with a brief summary of the main points.

2. FLEXIBLE WIRELESS SYSTEM

Figure 1 shows a conceptual diagram of our new system [1]. It is composed of flexible access points and a protocol-free signal processing part. Both parts are connected via an access network, i.e., an optical fiber network. Each flexible access point consists of a broadband antenna, a broadband RF circuit, and an AD/DA converter. The system can send and receive the radio waves of a wide variety of wireless systems regardless of the frequency band. The protocol-free signal processing part is attached to the network and processes the signal data in software. This architecture allows us to flexibly and quickly support a new wireless protocol because the wireless protocols are processed in software. As a similar concept, radio on fiber (ROF) has been used for service area expansion [2]-[5]. References [6] and [7] reported an optical feeder transmitter and receiver type base station in which antenna equipment is connected to modulation and demodulation equipment by an optical fiber network. The “Fiber optic networks for distributed and extendible heterogeneous radio architectures” (FUTON) project, one of the projects funded under the seventh framework program (FP) of the European Union (EU), has proposed the development of a hybrid fiber radio infrastructure transparently connecting remote antenna units to a central unit where joint processing can be performed. The object of the FUTON project [8] is to achieve broadband wireless transmission and inter-cell interference cancellation for fourth generation (4G) systems. The main difference between these research works and our study is that our proposed system supports transmission and reception in a wide variety of systems simultaneously.

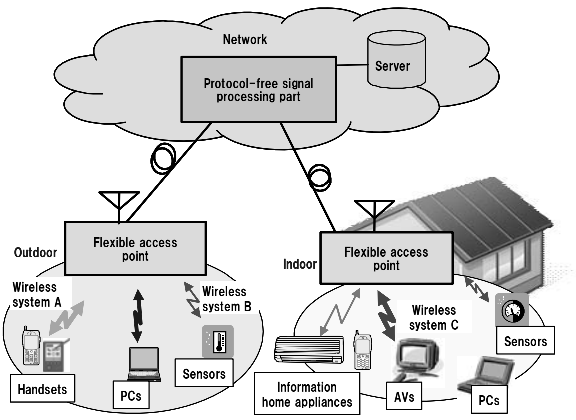

Fig. 1 Conceptual diagram of system

3. MULTI-BAND, MULTI-SIGNAL RECEPTION

3.1 Multi-band, multi-signal receiver

Figure 2 shows two typical architectures to achieve a multi-band receiver [9]. In the figure, (a) shows an architecture in which single band receivers are placed in parallel, and (b) shows one composed of a broadband antenna and a broadband low noise amplifier (LNA). These architectures convert broadband radio waves to digital signals directly. The former, however, has a problem in that it necessitates an increase in the number of components. The latter requires an analog-to-digital (AD) converter with a sampling frequency of several GHz. It also requires high resolution to support the wide dynamic range of radio signals. As a result, these architectures suffer from the problem of an increase in the processing load due to the huge data volume incurred by digitization. To solve this problem, we propose a multi-band receiver that can receive multiple signals simultaneously. Figure 3 shows the receiver’s conceptual configuration. Its mixer configuration is very different from that of a conventional mixer. It can receive multiple signals at multiple bands simultaneously by inputting multiple local oscillators to a mixer circuit in parallel. This causes the conversion gain at the mixer part to deteriorate, but our receiver can reduce deterioration of the receiver’s noise figure (NF) by increasing the gain in the front-end LNA. To expand the receiver’s dynamic range, our receiver has variable gain amplifiers for each frequency band and variable attenuators to control the power level of LO signals. The proposed receiver keeps the LO signal power level constant to maintain the mixer linearity by controlling the relative power level between LO signals. This enables us to achieve a high dynamic range receiver that can support the major difference between the power level of received signals, which is about 100 dB, by controlling a variable gain amplifier and the input signal power level of a mixer at each frequency band.

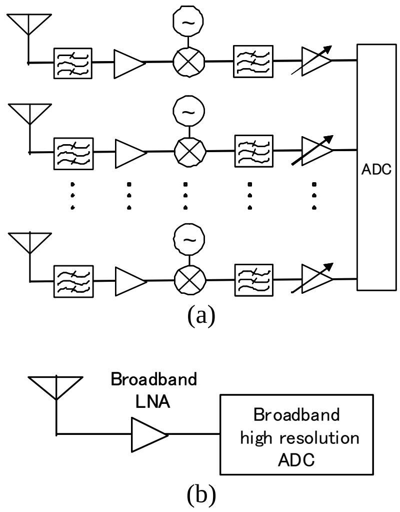

Fig.2 Multi-band, multi-signal receiver

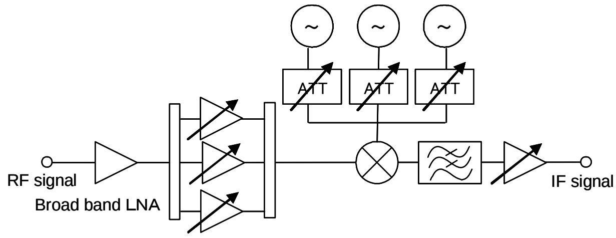

Fig.3 Proposed multi-band, multi-signal receiver

3.2 Multi-band, multi-signal AGC method

An AGC method for software-defined radio has been reported in [10], but no AGC method for multi-band, multi-signals has yet been reported to our knowledge. We thus propose a multi-band, multi-signal AGC method that adjusts all IF band signals together after controlling the IF signal power level to equalize the power level of IF band signals that were down-converted from RF signals in each frequency band.

We carried out our method after performing the AD conversion shown in Fig.4. Figure 5 shows a flowchart of the method. The method works in collaboration with the multi-band, multi-signal receiver described in 3.1. It first analyzes the frequency of received signals and estimates the power level with respect to each frequency band that was predetermined by the receiver. After it sets the reference power level based on the received signal's power level at each frequency band, it determines the controlling value at each frequency band based on the reference power level. Next, it determines a controlling value of a variable gain amplifier to adjust the power level of all IF band signals together. Finally, it transmits the controlling values to the receiver, which then sets them.

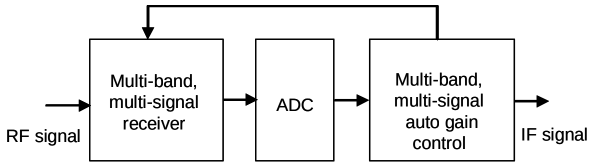

Fig. 4 Configuration of our multi-band, multi-signal AGC

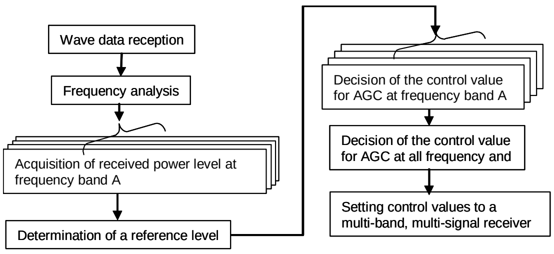

Fig. 5 Flowchart of our multi-band, multi-signal AGC method

3.3 Signal separation method

Since FWS receives multiple signals at multiple bands simultaneously, if the receiver uses a conventional band pass filter (BPF) and a filter bank [11][12], the receiving performance will be degraded. To solve this problem, we propose a signal separation method that separates the received multiple signals simultaneously. Our method analyzes the frequency of received radio signals and separates each signal based on an amplitude value and the phase value of received radio waves. Figure 6 shows our method in a simplified manner, whereby a received radio wave overlaps a radio signal S1 with a center frequency f_1 and a radio signal S2 with a center frequency f_2. The proposed method separates the S1 and S2 using complex data of fl and f2 and center frequency f1 and f2, which are known information.

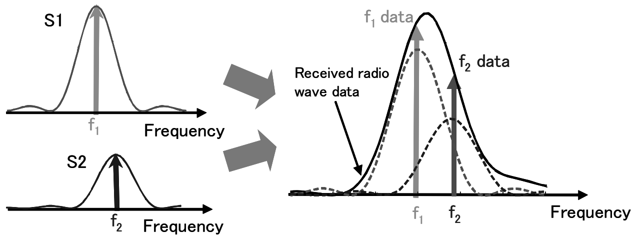

Fig. 6 Two radio waves overlapping received radio wave

The following shows the procedure of our method. The radio signals are defined as $y_k(t)$ with a center frequency *k* (*k*=1～K). The received signal overlapping multiple signals is indicated in Equation (1).

$$y(t)=\sum_{k=1}^{K} y_k(t)+n(t) \tag{1}$$

$$y_k(t)=h_k(t)a_k(t)e^{j(\omega_k t+\phi_k(t))} \tag{2}$$

where $a_k(t)$ and $\phi_k(t)$ are the amplitude and phase elements of the *k*-th signal in time *t*, $h_k(t)$ is the impulse response, *n*(*t*) is the noise element.

Short time Fourier transformation (STFT) of the received signal is computed with the window function w(t) and as a result, the complex element Y(ω_k, τ) at center frequency *k* (*k*=1～K) and time τ is derived.

$$Y(\omega,\tau)=\int_{-\infty}^{\infty} w(t-\tau)\,y(t)\,e^{-j\omega t}dt$$
$$\approx \int_{-\infty}^{\infty} w(t-\tau)\left\{\sum_{k=1}^{K} h_k(t)\,a_k(t)\,e^{-j(\omega-\omega_k)t}e^{j\phi_k(t)}\right\}dt \tag{3}$$

If the noise factor is neglected, Equation (3) becomes as follows.

$$Y(\omega,\tau)\approx\sum_{k=1}^{K} A_{k,\tau}e^{j\Phi_{k,\tau}}\int_{-\infty}^{\infty} w(t-\tau)e^{-j(\omega-\omega_k)t}dt \tag{4}$$

where $A_{k,\tau}$ and $\Phi_{k,\tau}$ are constant amplitude and phase components of the k-th signal in clipping with the short time window, and $A_{k,\tau}$ and $\Phi_{k,\tau}$ are the averaged amplitude and phase fluctuation caused by $h_k(t)$. Here, we assume that the center frequencies are obtained from a prior information source such as a network database, or as a result of signal detection. The amplitude and phase values at the center frequencies of overlapped signals are extracted from the spectrum of received wave data.

$$\begin{bmatrix} Y(\omega_1,\tau) \\ \vdots \\ Y(\omega_K,\tau) \end{bmatrix} \approx \begin{bmatrix} \sum_{k=1}^{K}\int_{-\infty}^{\infty} w(t-\tau)\,y_k(t)\,e^{-jw_1 t}dt \\ \vdots \\ \sum_{k=1}^{K}\int_{-\infty}^{\infty} w(t-\tau)\,y_k(t)\,e^{-jw_K t}dt \end{bmatrix}$$
$$=\begin{bmatrix} \int_{-\infty}^{\infty} w(t-\tau)dt & \cdots & \int_{-\infty}^{\infty} w(t-\tau)e^{-j(\omega_1-\omega_K)t}dt \\ \vdots & \ddots & \vdots \\ \int_{-\infty}^{\infty} w(t-\tau)e^{-j(\omega_K-\omega_1)t}dt & \cdots & \int_{-\infty}^{\infty} w(t-\tau)dt \end{bmatrix}\begin{bmatrix} A_{1,\tau}e^{j\Phi_{1,\tau}} \\ \vdots \\ A_{K,\tau}e^{j\Phi_{K,\tau}} \end{bmatrix} \tag{5}$$

Therefore, the amplitude value and phase rotation value of each center frequency are derived from equation (6).

$$\begin{bmatrix} A_{1,k}e^{j\Phi_{1,\tau}} \\ \vdots \\ A_{k,\tau}e^{j\Phi_{K,\tau}} \end{bmatrix} = \begin{bmatrix} \int_{-\infty}^{\infty} w(t-\tau)dt & \cdots & \int_{-\infty}^{\infty} w(t-\tau)e^{-j(\omega_1-\omega_K)^t}dt \\ \vdots & \ddots & \vdots \\ \int_{-\infty}^{\infty} w(t-\tau)e^{-j(\omega_K-\omega_1)^t}dt & \cdots & \int_{-\infty}^{\infty} w(t-\tau)dt \end{bmatrix}^{-1} \begin{bmatrix} Y(\omega_1,\tau) \\ \vdots \\ Y(\omega_{k},\tau) \end{bmatrix} \quad (6)$$

Finally, radio signals of each center frequency expressed in Equation (7) are reconstructed by using $A_{k,\tau}e^{j\Phi k,\tau}$. Thus, the proposed method separates the received multi-band, multi-signals.

$$y'_k(t) = \sum_{\tau} A_{k,\tau} w(t-\tau) e^{-j\omega_k t + \Phi_{k,\tau}} \quad (7)$$

4. PERFORMANCE EVALUATION

4.1 Multi-band, multi-signal receiver

We developed a prototype of the proposed receiver to ascertain its practicality and evaluate its performance. Figure 7 shows the prototype's overview and Fig. 8 shows its configuration. It can support four bands, i.e., the 280 and 300 MHz bands and the 2.4 and 3.5 GHz bands. AGC is performed at three parts, i.e., the multi-band filter, the multi-band mixer, and the VGA parts. We designed our prototype to execute 100-dB AGC in the first and second parts.

Fig. 7 Overview of proposed receiver prototype

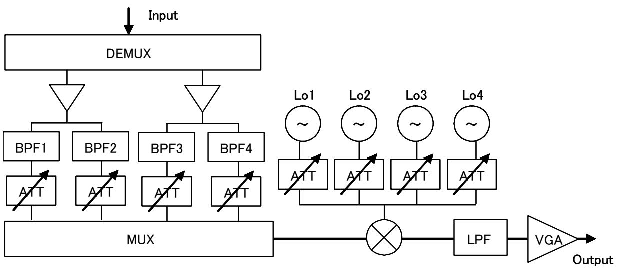

Fig. 8 Configuration of proposed receiver prototype

We evaluated the receiver's performance to confirm its practicality. We first confirmed that it makes it possible to control the 100 dB power level in the first and second parts. Next, we evaluated the linearity of the prototype's mixer part. Figure 9 shows the experimental model. In the figure, the LO2 signal's power level in the 2.4 GHz band is fixed and that of the LO1 signal in the 300 MHz band is varied by changing a variable attenuator. Figure 10 shows the input output measurement characteristic of our prototype's mixer part when the variable attenuator of the 300 MHz band was set to 0, 20, and 40 dB, respectively. We confirmed that the high linearity of its mixer was maintained even if the power level of an LO signal of 300 MHz band was attenuated.

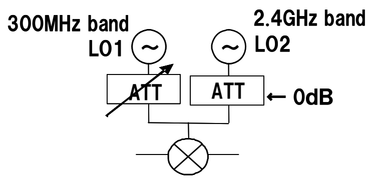

Fig. 9 Multi-band level control mixer

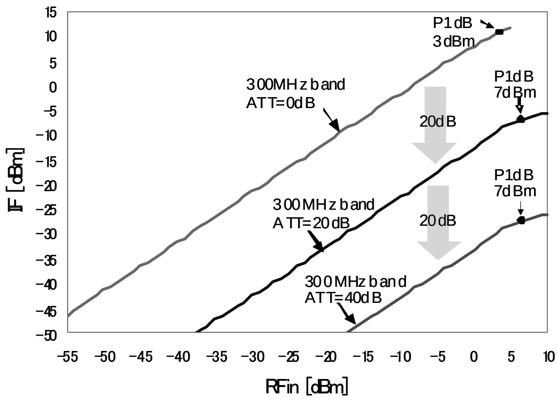

Fig. 10 Input output measurement characteristic of multi-band level control mixer

4.2 Multi-band, multi-signal AGC method

We evaluated the receiver's performance by using a prototype with two radio signals that differed in frequency band and signal power level. The two radio signals input to the prototype were continuous wave (CW) signals at the 315 MHz and 2416 MHz bands. The power level difference between the two signals was 30 dB. The input signals were first down-converted to 4 MHz and 6 MHz as shown in Fig. 11. Our proposed AGC analyzed the frequency after AD conversion. In this experiment, frequency analysis results indicated that the input signal's power level in the 300 MHz band should be increased by 30 dB. After determining this, it transmitted the control value to the prototype. Figure 12 shows the IF band signal after executing AGC. From Figs. 11 and 12, we confirmed that the performances of the proposed AGC method and the prototype were consistent with the designed intention. The time taken for AGC was one second because the proposed method used the Fast Fourier transform (FFT) method to analyze the frequency.

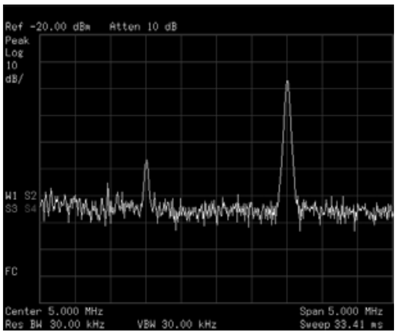

Fig.11 Before executing AGC

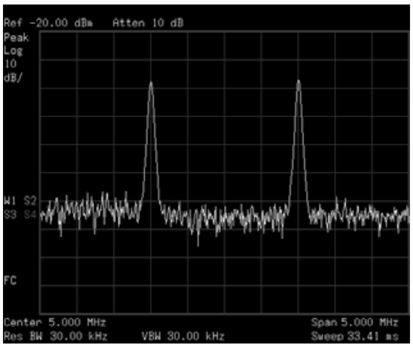

Fig.12 After executing AGC

4.3 Signal separation method

We used computer simulation to evaluate our method's separation performance. Table 1 shows the simulation conditions used. In this evaluation, the two radio signals S1 and S2 overlapped and their respective power levels were P1 and P2. We defined S1 as a desired signal and S2 as an interference signal. Signal to interference ratio (SIR) means the power level ratio obtained when overlapping a desired signal and an interference signal. Figure 13 shows the bit error rate (BER) performance obtained with the proposed method. When the P1/P2 ratio is –3 dB and the BER is 10^{-3}, our method improves SIR by 5 dB for the BPSK and by 3.5 dB for the QPSK signals, as the results shown in Fig. 13 indicate. Furthermore, better BER performance is obtained when the P1/P2 ratio is –3 dB than when it is 0 dB because the interval between the center frequency of S1 and S2 grows wider between the former and latter cases. This shows that the proposed method is more effective for wider center frequency intervals between two signals. Next, we evaluated the signal separation method with the prototype. In this evaluation, two radio frequency identification (RFID) tags transmit data at the same time (Signal 1: 313.025 MHz channel, FSK, 19.2 kbps. Signal 2: 313.025 MHz channel, FSK, 2.4 kbps). Table 2 shows the experimental conditions we used. Figure 14 shows the relationship between carrier-to-noise ratio (CNR) and packet success rate. Since the two overlapped signals are separated by the proposed method, it becomes possible to demodulate the received signals with almost the same performance as that obtained for single signal reception. We also found that our method was able to improve the packet success rate in the case of single signal reception. Because our method restores signals based on a featured amount of radio wave data, it can eliminate noise.

Table 1 Simulation conditions

Symbol rate	20 kbaud
Sampling rate	20 Msps
FFT points	8192
Band pass filter	Root raised cosine filter
Window function	Raised cosine window (window size: 500 samples)
Center frequency	1 MHz
SNR	20 dB

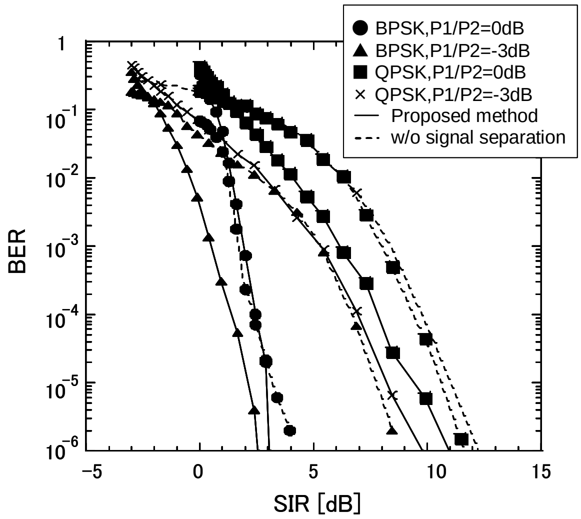

Fig. 13 SIR vs. BER

Table 2 Experimental conditions

Packet length	208 bits
Modulation	FSK
Bit rate	19.2 kbps, 2.4 kbps
Center frequency	313.025 MHz
Frequency separation	±105 kHz (19.2 kbps), ±60 kHz (2.4 kbps)
FFT points	8192
Window function	Rectangular window (window size: 512 samples)

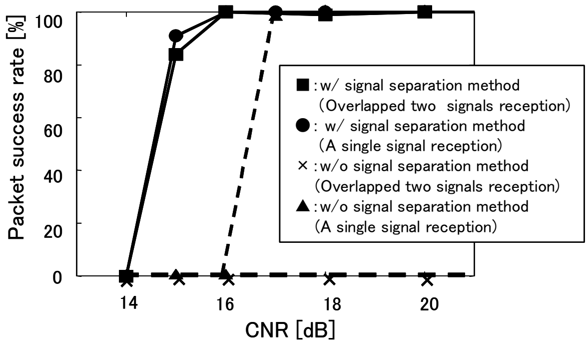

Fig. 14 Packet success rate vs. CNR

(Signal 1:f=313.025MHz, FSK, 19.2kbps, Signal 2:f=313.025,FSK, 2.4kbps)

5. CONCLUSION

We proposed a multi-band, multi-signal receiver, a multi-band, multi-signal auto gain control (AGC) method, and a signal separation method. Together, these comprise multi-band, multi-signal reception technology that represents an important innovation in the struggle to achieve flexible wireless systems. The receiver has a multi-band level control mixer configuration that achieves a high dynamic range. By using our proposed AGC method, it can deal with major power level differences between received signals (i.e., as much as 100 dB) and adjust such differences to an equivalent power level. We used a prototype to confirm the operational validity of our AGC method. We also used the prototype and computer simulation to show the effectiveness of our proposed separation method. It was found that this method can separate overlapping signals and is particularly useful when overlapping signal frequency intervals become wider.

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