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Spectral Signature based Chipless RFID Tag using Coupled Bunch Resonators

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ABSTRACT

Multiresonator based spectral signature chipless RFID tag using a novel idea of coupled bunch resonators is presented in this paper. Increasing the surface encoding capacity is an important factor in the development of spectral signature based chipless RFID tag. The amplitude and/or group delay of the spectral signature are utilized for the chipless tag application. The multi-resonator circuit provides a 1: 1 correspondence of data bits. The experimental results for various bit combinations show the potentials of the proposed chipless tag.

Key words: Chipless RFID tag, spectral signature tag, coupled bunch resonator, ultra-wideband monopole antenna

INTRODUCTION

Radio Frequency Identification (RFID) is a technology used for remotely identifying any object without any direct line of sight requirements [1]. The need for greater reading range has put RFID technology as one of the leading data capturing technique widely used in asset tracking, logistics, equipment/personnel tracking in hospitals and many other similar applications. The RFID system consists of two main elements, the RFID tag and the RFID reader. The tags are typically chip-based, and generally contain silicon chips and antennas. The RFID tag encodes the data and the RFID reader decodes the encoded data from the tags. Based on the method the tags are powered, the tags can be classified as active tags, having an internal power source, and passive tags, without an internal power source. RFID systems are being developed with passive tags that do not contain silicon chips and these tags are known as chipless tags. Chipless RFID tags are now gaining importance over barcodes due to benefits of low cost, absence of power source, no line of sight requirements etc

The chipless RFID can be classified into three main categories such as Time Domain Reflectometry (TDR) based chipless tags, Amplitude/Phase backscatter modulation based chipless tags and Spectral signature based chipless tags. Time Domain Reflectometry (TDR) based chipless tags are interrogated by sending a signal from the reader in the form of a pulse and observing the echoes of the pulse sent by the tag. In Amplitude/Phase backscatter modulation based chipless RFID tags, data encoding is performed by varying the amplitude or the phase of backscattered signal based on the loading of the chipless tag. In Spectral signature based chipless tags unique ID is encoded as the spectral signature, which is created by a set of planar microwave resonators [2]. Capacitively tuned dipoles for RFID barcode was first reported by Jalaly and Robertson in [3]. Fully printable chipless RFID tags using multiresonators are reported in [4-7]. Slot-loaded dual-polarized chipless radio frequency identification tag is presented in [8]. Depolarized tag with dual L resonators and 45deg tilted shorted dipoles is reported in [9].

This paper discusses the design and development of a spectral signature based chipless RFID tag using coupled bunch resonators. The paper discusses briefly about evolution of coupled bunch resonator and the data encoding technique. Here bistatic detection method is used to decode the tag identity. In this approach the system is implemented using coupled bunch resonators and cross-polarized ultra-wideband (UWB) monopole antennas. The complete tag system and its measured characteristics are discussed in detail.

MULTIRESONATOR DESIGN

Coupled Hair Pin Resonator

The resonators must be compact, fully planar and narrow bandwidth (high Q-factor) for printable chipless tag applications. Parallel coupled line resonator as shown in Fig.1 consists of a conducting strip placed near to a microstrip transmission line which acts as a half wave resonator. The disadvantages of coupled line resonator are large physical dimension, and less energy coupling between transmission line and resonator. Due to this reason it is not a good candidate for chipless tag applications. In order to overcome this problem, line resonator is modified to a hairpin resonator. These resonators are simple and compact structures especially suited for microstrip filters and Transversed Electromagnetic Waves (TEM) printed circuit realization.

The geometry of coupled hair pin resonator shown in Fig. 2(a). Hair pin resonator of length 34mm, thickness 0.2mm and coupling gap 0.35mm that exhibits resonance at 2.6828 GHz due to electric field fringing. The transmission characteristics of coupled Hair pin resonator is shown in Fig. 2(b) which act as a band stop filter with good insertion loss. The open ended $\lambda g/2$ hairpin resonator acts as a parallel RLC circuit which produces high impedance to transmission line at its resonance as shown in Fig. 2(c). The design equation of hair pin resonator is

$$Li = (a + b + c) \approx \lambda g/2 \qquad (1)$$

Where λg is the guide wavelength ($\lambda g \approx \lambda/\sqrt{\varepsilon_{eff}}$), Li is the length of the stub; ε_{eff} is the effective permittivity of the substrate.

Fig.3 shows surface current distribution of the hairpin resonator. From the figure it is obvious that hair pin resonator is a half wavelength resonator. Resonator absorbs electromagnetic energy from transmission line at its resonance. Consequently, the system act as a band notch filter propagation of energy from port 1 to port 2 of transmission line is blocked. Variation in electrical length of coupled symmetric hairpin resonator causes change in resonant frequency as shown in Fig. 4(a). This property is utilized for implementing multiresonator circuit.

Asymmetric hairpin resonator is used to increase the coupling between the transmission line and resonator as shown in Fig. 4(b). The width variation in arms of the resonator causes asymmetry in structure. Even physical length is kept constant at 34mm the resonant frequency is shifted due to the variation in electrical resonator as depicted in Fig. 4(c).

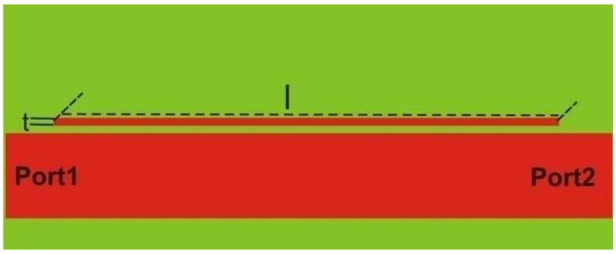
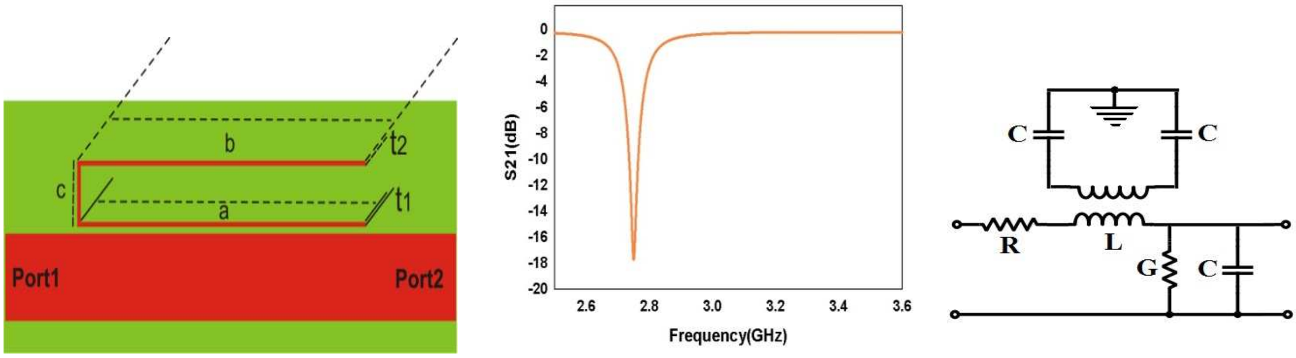


Fig. 1 Microstrip coupled line resonator (l=34mm,t=0.2mm,gap=0.35mm, ε_r=3.7, h=1.6mm)



(a) **(b)** **(c)**

Fig. 2(a) Coupled hair pin resonator (a = b=16mm; c=2mm, t1 = t2 =0.2mm) (b) Simulated insertion loss (c) Equivalent circuit of coupled hair pin resonator

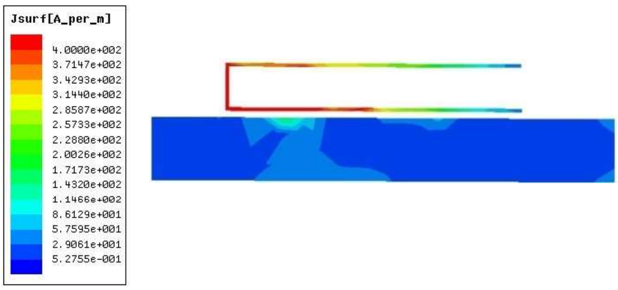


Fig.3 Surface current distribution at resonance at 2.74 GHz

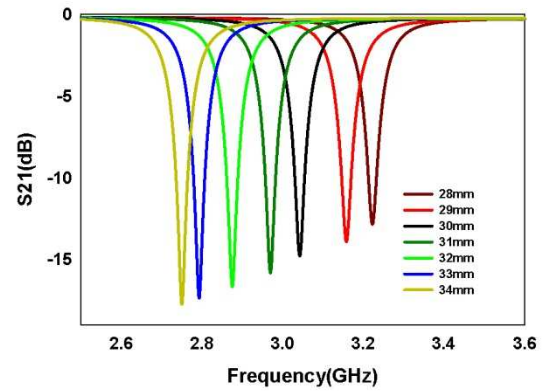


Fig. 4(a) Effect of the variation in total length of hairpin line resonator (a + b + c)

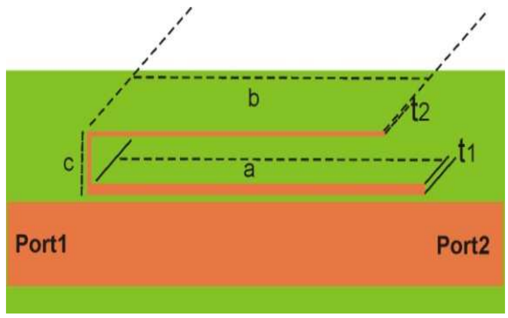


Fig. 4(b) Geometry of asymmetric hairpin resonator (a≠ b; t_1≠ t_2), (L_i = a +b + c = 34mm)

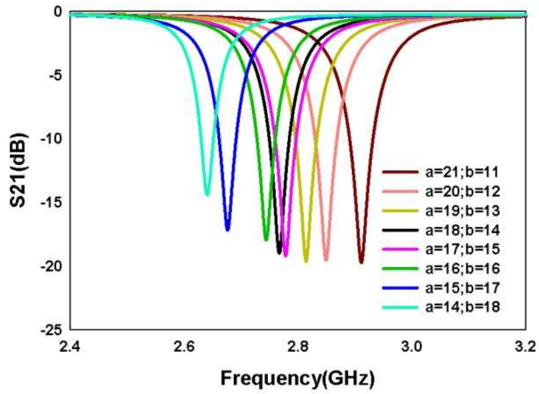


Fig. 4(c) Effect of length and width variation in the asymmetric hairpin resonator (a≠ b; t_1≠ t_2, L_i = a +b + c = 34mm, c=2 mm)

Fig. 5(a) shows the geometry of the proposed coupled bunch resonator for chipless tag. Novelty of the proposed tag is encoding a large number of bits within a small area. Coupled hair pin resonator is modified to form a bunch resonator. One arm of hair pin resonators is common to all resonators and the manifold structure also folded. Here frequency can be independently controlled by varying the length of the corresponding section Li (i=1, 2, 3…8). Here two bunch resonators of four resonances are used for 8–bit data encoding. The multiresonator circuit is printed on a substrate of relative permittivity εr =3.7, loss tangent, δ=0.003 and height, h=1.6mm.

The transmission characteristics of bunch coupled resonator are shown in Fig. 5(b). The resonant frequencies are 2.6784GHz, 2.744GHz, 2.8552GHz, 2.9576GHz, 3.0416GHz, 3.1506GHz, 3.21GHz, and 3.3348GHz. The frequency difference between higher band notch frequency and lower band notch frequency is 656.4 MHz i.e., eight resonant frequencies within this range. Each band notch has very low 3dB bandwidth and Fractional bandwidth (FBW) which is very helpful to accurate design of multiresonator. The resonant frequencies, bandwidth and FBW are shown in Table.1. The resonant frequency of each resonator can be calculated easily by using the expression

$$\lambda g/2 \approx L_i = (a + b + c) \quad (2)$$

Where $\lambda g = \lambda/\sqrt{\varepsilon eff}$; $\varepsilon eff \approx 2.65$, $\varepsilon r=3.7$

The surface current distribution on each resonator at its resonant frequency is shown in Fig. 5(c). Each resonator is excited when its length is approximately equal to $\lambda_g/2$. The current distribution minimum at both ends and maximum at center of the resonator, that means apparent half wavelength variation of surface current at resonance. The mutual coupling between resonators is very low, so the performance of each resonator is not affected by adjacent resonators.

Table -1 Bandwidth, Fractional and Bandwidth at Different Resonances

Length of resonator (mm)	Resonant frequency (GHz)	Bandwidth (MHz	FBW
34.15	2.6784	31.4716	0.01175
34	2.744	31.256	0.011391
32.35	2.8552	29.4948	0.01033
32	2.9576	29.0424	0.00982
30.5	3.0416	27.4584	0.009028
30.2	3.1506	27.0494	0.008585
28.55	3.21	25.34	0.007894
28	3.3348	24.6652	0.007396

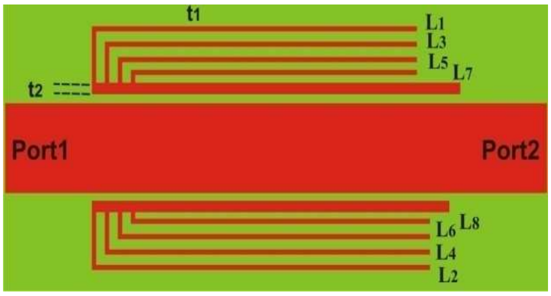


Fig. 5(a) Layout of the proposed 8 bit multi-resonator circuit (L_1= 34.15mm, L_2= 34mm, L_3= 32.35, L_4= 32mm, L_5= 30.5 mm, L_6= 30.2 mm, L_7= 28.55 mm, L_8= 28 mm, t_1 = 0.2 mm, t_2 = 0.2 mm, ε_r=3.7, height=1.6mm, loss tangent 0.003)

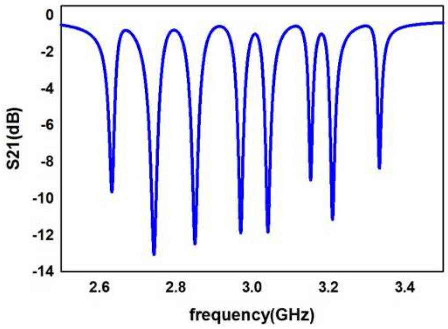


Fig. 5(b) Simulated insertion loss of 8- bit coupled bunch resonator based band stop filter

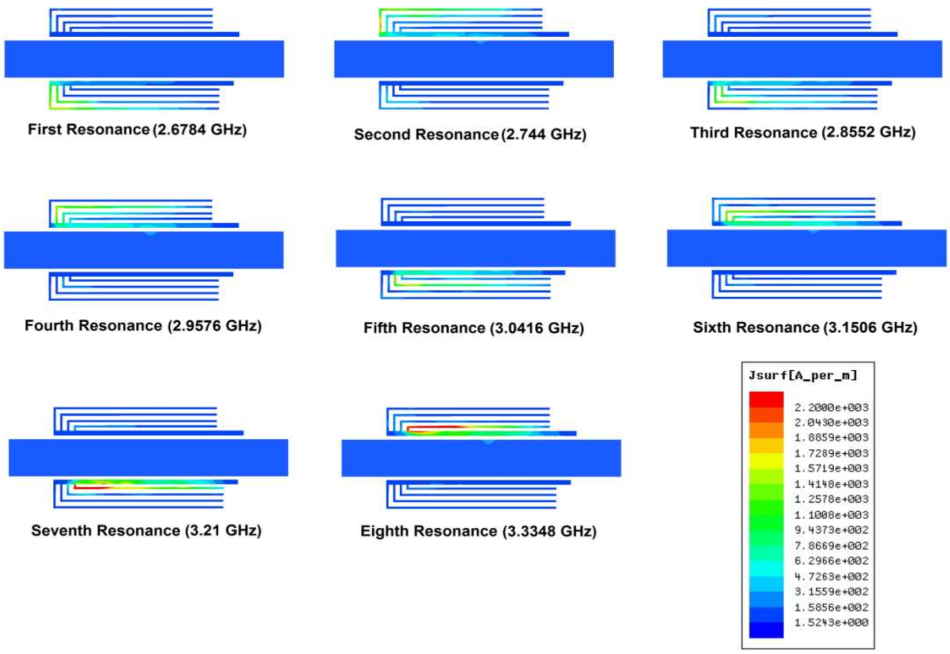


Fig.5(c) Surface current distribution at resonance

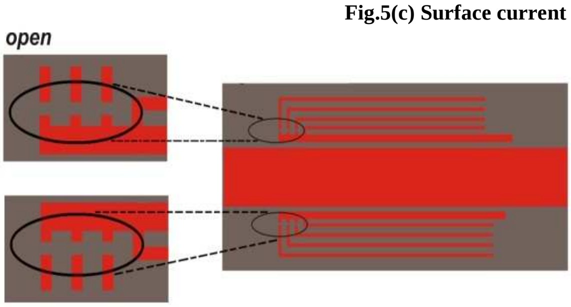


Fig. 6(a) Data encoding technique

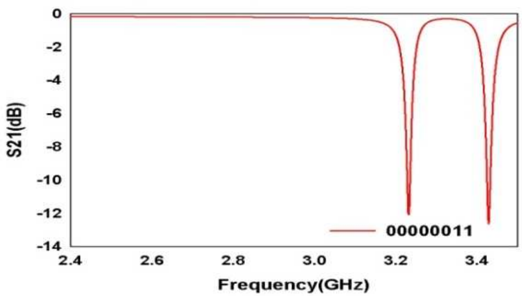


Fig. 6(b) Tag with identity 00000011

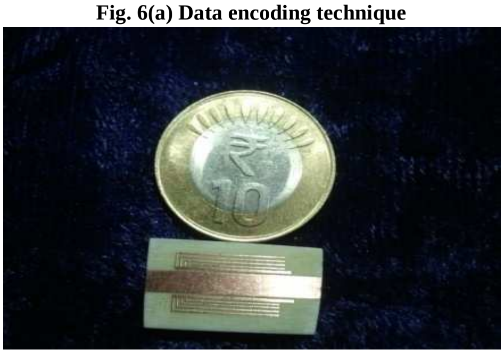


Fig. 7 Photograph of proposed bit multi-resonator circuit

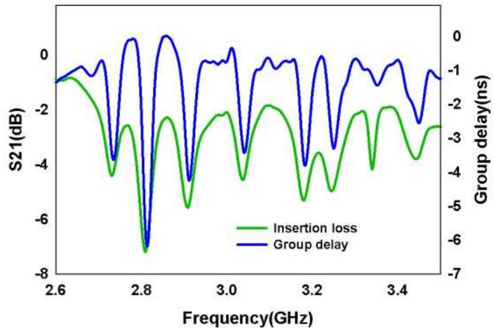


Fig.8 Measured Insertion loss and Group delay of bunch multiresonator

Data Encoding Technique

Each bit is usually associated with the presence or absence of a resonant peak at a predetermined frequency in the spectrum. The presence of resonance is used to encode logic 1 and the absence of resonance is used to encode logic 0. In order to avoid a particular resonance from predetermined spectrum to form a unique spectral signature, open the corresponding resonator near the common section of bunch resonator as shown in Fig. 6(a). Consequently, the effect will be same as the absence of that resonator. The absence of a specific resonator will result in a retransmitted signal with minimum attenuation at that particular frequency. i.e., electrically band notch filter will be disappeared from the tag thus, encoding the data into spectrum. The transmission characteristics of multiresonator for the bit combinations 0000 0011 is shown in Fig. 6(b).

Experimental Results

The prototype is fabricated on substrate of dielectric constant 3.7 and loss tangent 0.003. The photograph of prototype is shown in Fig.7. The transmission characteristics of multiresonating circuit are measured using DUT method by using PNA E 8362B analyzer.

For bistatic measurement technique, the transmitting and receiving antennas are to be connected to the multi resonators to realize a chipless tag. As the ranges of multi resonance is from 2.73GHz to 3.45GHz as shown in Fig.8, antennas operating in this frequency range are required. The measured return loss of microstrip fed disc loaded monopole antenna is shown in Fig. 9. Orthogonally polarized UWB circular disc monopole antennas are employed for transmission and reception purpose which avoid mutual interaction between them. The bistatic measurement set up is shown in Fig.10.

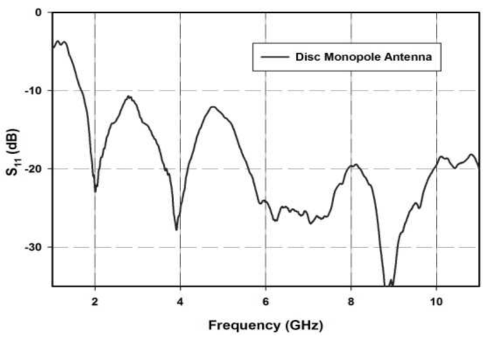


Fig.(9) Measured return loss of microstrip fed disc loaded monopole antenna

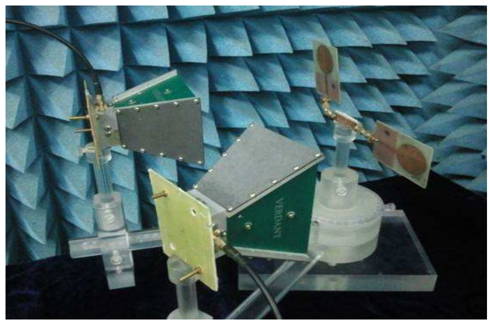
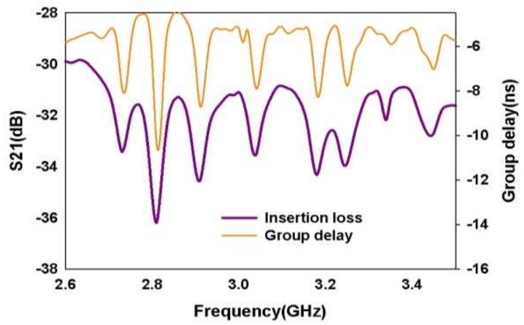
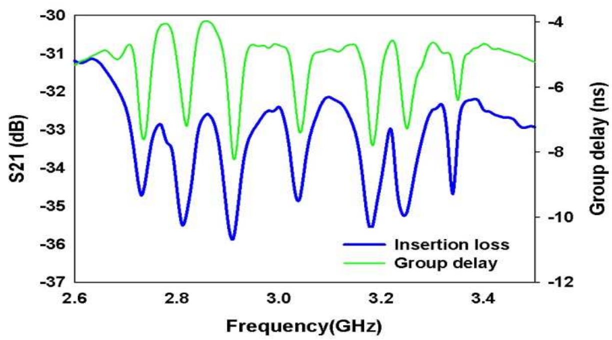


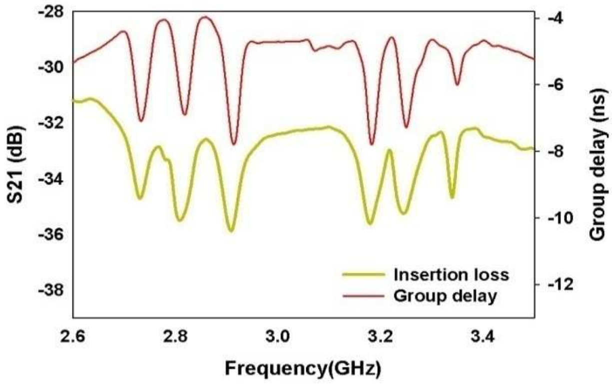
Fig. (10) Bistatic measurement set up



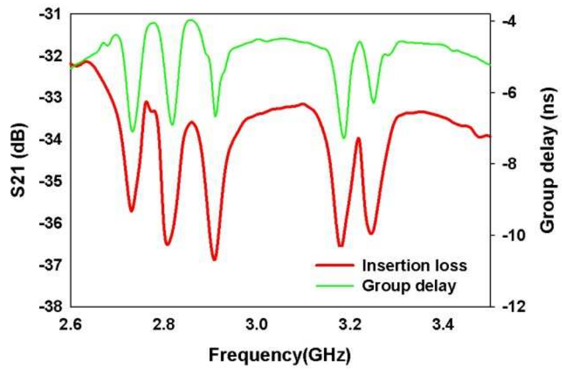
(a)1111 1111



(b)1111 1110



(c) 1110 1110



(d) 1110 1100

Fig.11 Different tag response of bunch multiresonator based tag

CONCLUSION

Coupled bunch resonator for spectral signature based chipless tag application is presented here. Data encoding is possible by varying the each resonator length. Orthogonally polarized UWB circular disc monopole antennas are employed for transmission and reception purpose which avoid mutual interaction between them. Multi resonator characteristics and field trials are carried out which validated by both simulation studies and experimental results.

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