Low-Loss Broadband Planar Balun with CPW-to-Slotline Transition for UHF Applications

Young-Pyo Hong · Jong-Gwan Yook

Abstract

This paper presents a low-loss broadband balun that uses a coplanar waveguide-to-slotline field transformation. It operates over a very wide frequency range and is of compact size since it does not depend on a resonant structure. To analyse imbalance, the coplanar wavelength(CPW) input ground is connected to the CPW output ground through various capacitors to introduce common-mode impedances. As the common-mode impedance increased the imbalance became significantly higher at the higher-frequency band compared with the lower-frequency band. The bias-circuit approach is used to improve the operation bandwidth of the lower-frequency band. The measured results show a passband of 200 MHz to 2 GHz, an insertion loss of less than 0.75 dB, and a size of 20×14 mm. The amplitude imbalance is approximately 0.3 dB and the phase imbalance is less than 6° over the entire operational range.
Key words : Balun, Broadband, Coplanar-waveguide, Low loss, Planar.

Ⅰ. Introduction

Balanced circuits have been widely used in RF design because of their immunity to many noise sources, suppression of even-harmonic spurious responses, and improvement of dynamic range. In the design of broadband balanced components, such as dipole antennas, balanced mixers, and push-pull amplifiers, baluns are necessary to produce an accurate 180° phase difference and equal amplitude with minimum insertion loss. Various types of broadband baluns have been reported[1]~[12]. Among them, planar Marchand baluns are one of the most popular because of their ease of implementation and broadband performance. The planar Marchand balun consists of two coupled sectionscomposed of interdigital couplers[1] and three-dimensional broadside couplers[2]. Alternatively, a transmission line surrounded by ferrite can be used for broadband operation with a 1-dB loss[3]. In [4], a coaxial balun is developed by using ferrite material to taper a coaxial coil. Although enhanced coupling techniques improve bandwidth, a bandwidth limitation still exists due to their dependence on transmission-line length[1],[2]. While ferrite material supports low-frequency operation, high-frequency operation with low-loss performance is difficult to achieve.

Recently, the use of transitions between distinct transmission line media involving planar structures is of interest for use in broadband baluns. A broadband balun with asymmetric coplanar-waveguide to coplanar-stripline (CPW-to-CPS) transition was designed in a double-balanced mixer[5]. In [6], an ultra-wideband three-port balun is investigated by using the transition of CPW-to-airgap overlay parallel plates and was used as a broadband class-B push-pull power amplifier in [7]. In this paper, a new CPW-to-slotline broadband transition is presented. Compared with the horizontal(CPW)-to-vertical(air-gap overlay) transition in [6], the horizontal(CPW)-to-horizontal(slotline) transition has the advantage of having ashorter transition length for good amplitude balance. In addition, no extra manufacturing steps are needed airgap overlay and alignment of the overlap is not required, as it is in other transitions. This transition not only provides an impedance transformation of a factor of two between balanced outputs and an unbalanced input, but also performs an unbalanced-to-balanced transformation over a broad frequency band. An estimate of the operational frequency bound(lower and upper) is obtained by considering parasitic ground capacitance, field transformation, and the input impedance of the proposed balun.

Ⅱ. Balun Design

The proposed balun structure is composed of a CPW input, a slotline, and two identical CPW outputs as shown in Fig. 1(a). During operation, the balun exhibits two dominant modesthe CPW mode and the coupled-slotline (CSL) modedue to the parallel conductors. The CPW mode has an electric field with opposite polarities between the two slots while the CSL mode has the same polarities between the two slots. The air-bridge(labelled

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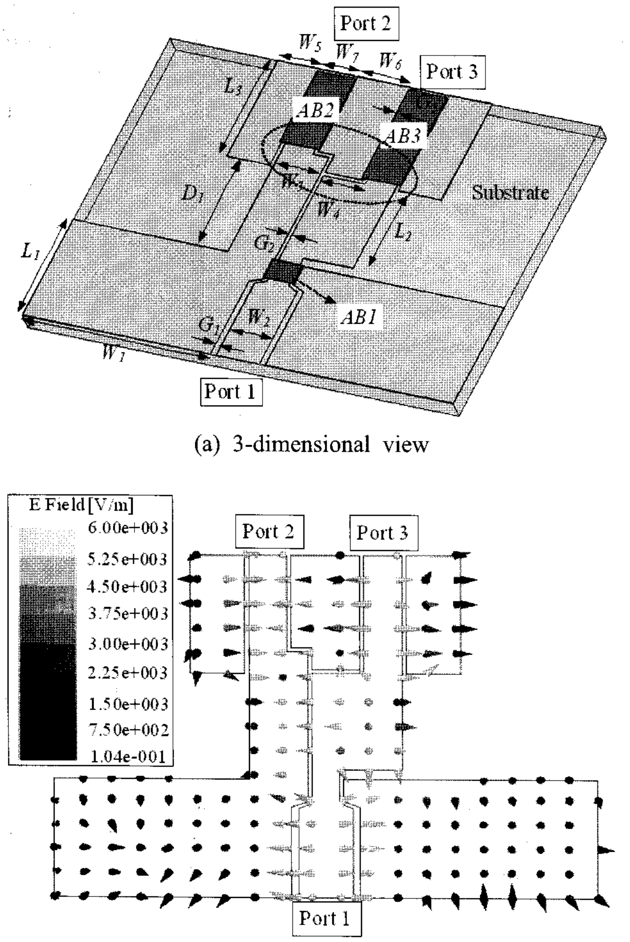


(a) 3-dimensional view

(b) EM simulation results

Fig. 1. Geometry of proposed the balun.

as AB1 in Fig. 1(a)) is placed at the starting point of the mode-conversion section to keep the ground planes at the same potential, thereby eliminating the slotline mode on the CPW line. The air-bridges(AB2 and AB3 in Fig. 1(a)) at the output are used to suppress the unwanted CSL mode and to provide pure CPW-mode operation at the output.

In Fig. 1(b), the electric field distribution on the CPW-slotline-CPW transition is shown to verify the design concept. When the CPW is fed from a coaxial line at the input, an unbalanced signal is launched onto the CPW line. As is well known, the slotline-mode field excites a balanced signal in the CPW. Therefore, the electric length difference between the two CPW outputs is exactly 180° when the middle CPW ground plane behaves as a virtual ground of the two CPW outputs. In addition, the two outputs have 25-Ω impedance at each port, since both are made from the 50-Ω input. The dimension of the middle CPW ground plane is chosen to support a 180° phase difference for broadband operation. The bandwidth of the transition will be limited by the length of both the slotline and the CPW lines at low frequencies, and limited by the appearance of the higher modes at high frequencies.

At low frequencies, phase balance is achieved due to the field transition, so the amplitude balance becomes the key factor in performance. To achieve good amplitude balance, the field transitions on the CPW-slotline (controlled by L_2 in Fig. 1(a)) as well as the slotline-CPW(controlled by L_3 in Fig. 1(a)) are critical for good low-frequency performance. An estimate of the upper frequency bound is obtained when the total electrical length(L_1+L_2+L_3+W_4) is equal to one quarter of the wavelength. Also, the distance between the CPW input and the two CPW outputs(D_1 in Fig. 1(a)) is chosen to minimize parasitic ground capacitance, which deteriorates the phase balance at higher frequencies. Hence, a trade-off between two conditions for the choice of L_2 must be observed: L_2 should be reduced in order to move the upper frequency bound towards higher frequencies and L_2 should be increased to extend the lower frequency bound.

The centre conductor of the CPW input is connected by using a slotline conductor, and then is extended to one of the CPW outputs. Meanwhile, one of the CPW ground planes is connected to the second slotline conductor and then is attached to the other CPW output. As shown in Fig. 1(a), one of the slotline widths is wider than the other because broader strip width reduces conductor loss. The asymmetric structure of the slotline has a minor effect on the electrical performance of the balun, since most of the current shown in Fig. 1(b) is concentrated on the slot. The balun requires no resonant transmission structures to realize a 180° phase difference for the two CPW outputs, and it occupies a small area. Detailed design parameters are summarized in Table 1. The impedance presented to incident signals on the balun from port 2 and 3 corresponds to 50 Ω for the differential mode, and for the common mode the impedance is dependent on the external circuit connections. The common-mode impedance will be very high if the external circuit connected to port 1 does not allow co-

Table 1. Detailed dimensions of the balun.

Parameter	W_1	W_2	W_3	W_4	W_5
Value(mm)	8.7	2	2.1	1.9	2
Parameter	W_6	W_7	G_1	G_2	G_3
Value(mm)	2.4	1.4	0.27	0.2	0.16
Parameter	L_1	L_2	L_3	D_1	
Value(mm)	4.9	4	4.9	4.4	

mmon-mode currents, with an outside current return path to ports 2 and 3. A feature of the present balun design is that the ground sections of the input and output ports cannot be directly connected.

Ⅲ. Simulated and Measured Results

All simulations were performed by using Ansoft's High Frequency Structure Simulator(HFSS)™ for the balun. The measurement was carried out by using an Agilent PNA-X(Model: N5242A) network analyser. *S*-parameters were characterized in a 50-Ω environment, while the two CPW outputs were characterized in a 25-Ω environment. The balun was fabricated on 30-mil *FR-4* substrate with a dielectric constant of 4.4. Fig. 2 shows the simulated and measured return loss, insertion loss, and isolation results of the balun, demonstrating low-loss and broadband characteristics. Measured and simulated results agreed well over the entire operation band except for a small insertion loss difference. Within the entire operational frequency, the measured return loss was better than 10 dB, and the balanced port isolation was better than −6 dB. The low isolation is due tothe fact that the middle CPW ground is shared by two CPW outputs to achieve a balanced signal.

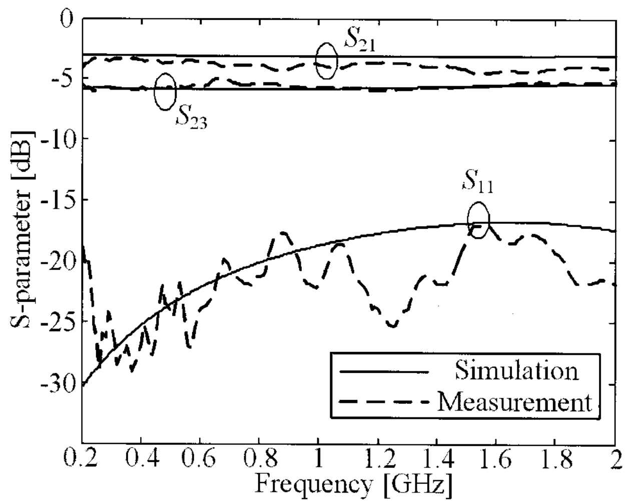


Fig. 2. Simulated and measured *S*-parameters.

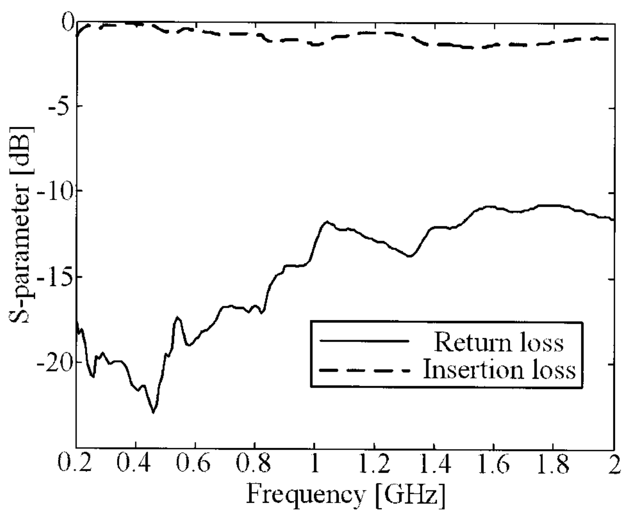


Fig. 3. Measured return loss and insertion loss of the back-to-back configuration.

Fig. 3 shows the measured performance of the back-to-back configuration of the balun, revealing a return loss of more than 10 dB and insertion losses of less than 1.5 dB(0.75 dB for a single balun) from 200 MHz to 2 GHz. Compared with the measured insertion loss from Fig. 2, there was a maximum of 0.7 dB difference of insertion loss, which can be explained by CPW-to-CSL mode conversion or vice versa, which is generated by the asymmetry of the two CPW outputs(the dotted circle region in Fig. 1a). Also, another asymmetry may occur at the CPW input, since the balun is attached to a coaxial line without a coax-to-CPW transition.

The amplitude imbalance was less than 0.3 dB throughout the bandwidth. The phase imbalance(deviation from 180°) was less than 6° over the entire operational frequency range, as shown Fig. 4. Since there is no rigorous prediction available for the optimum dimensions(D_1 and W_5 in Fig. 1(a)) of the CPW outputs ground, both the amplitude and the phase balance versus the differing CPW output ground width(W_5) and distance (D_1) between the CPW input ground and the CPW output ground are shown in Fig. 5. As the width of the CPW output ground(W_5) increased the phase imbalance became higher due to undesired parasitic ground capacitance between the CPW input and the CPW output. It

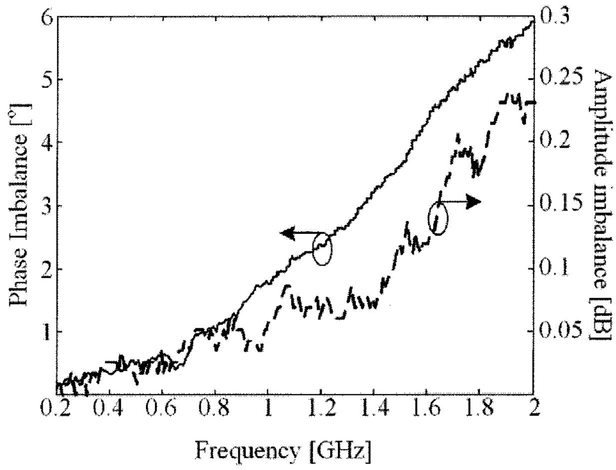


Fig. 4. Measured amplitude and phase mismatch.

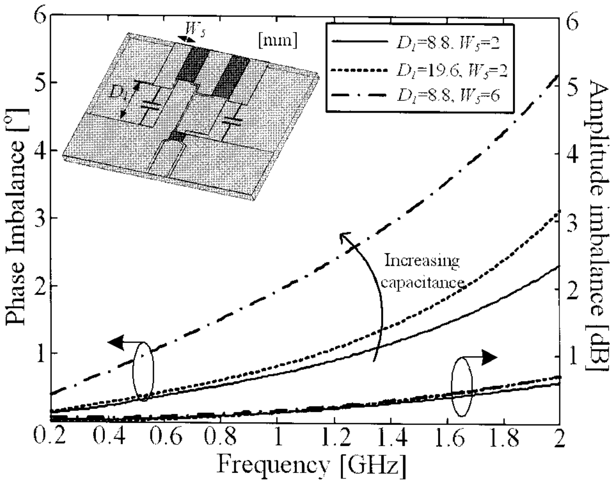
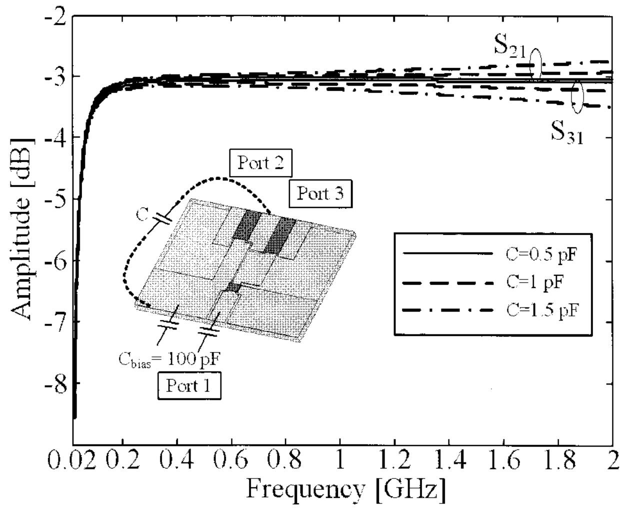


Fig. 5. Simulation of the effect of parasitic capacitance(between the CPW input ground and the CPW output ground) on the amplitude and the phase balance.

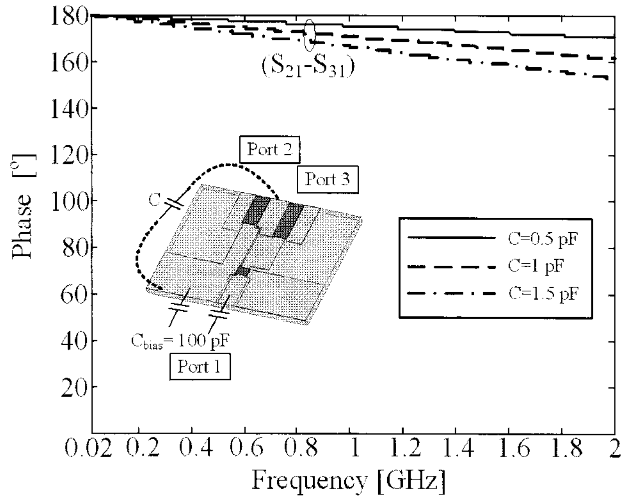
has been found that a larger distance(D_1) between the CPW input ground and the CPW output ground only slightly improves phase balance. Furthermore, minor variation in the amplitude balance with respect to different dimensions was observed. The optimised amplitude/phase balance was achieved when D_1 was roughly one-third of $\lambda_g/4$ while W_5 was the same as W_2(centre-conductor width of the 50-Ω CPW input).

Fig. 6 shows the imbalance results when the CPW input ground is connected to the CPW output ground through various capacitors to introduce common-mode impedances. As the capacitance increased due to the introduction of common-mode impedance, the imbalance became higher at higher frequencies. To study the usage of the proposed balun for low-frequency operation(below 200 MHz), the new design approach is introduced. As shown in Fig. 7, we believe that the most elegant solution to the low-frequency ground connection problem is simply to isolate the differential amplifier's ground from the system ground(i.e., the source and load grounds). This solution is utilized in [7], where the output ground was left floating.

If a floating ground is not desirable, another approach is to bias the output common of the balun to a known voltage, as shown in Fig. 7. The connection betweenthe input single-ended common(labelled ICOM in Fig. 7, which is the same CPW input ground shown in Fig. 1(a)) the differential output common(labelled as an OCOM in Fig. 7, which is the same CPW output ground shown in Fig. 1(a)) broken by the V_{DD} inductor and bypass capacitor. Both the V_{DD} inductor and the capacitor would naturally be present as part of any RF-biasing circuit. In other words, no new components are introduced. It is evident from Fig. 7 that the input common and the output



(a) Amplitude



(b) Phase

Fig. 6. Simulated results after the introduction of common-mode impedance.

common are isolated at both high and low frequencies, preventing a large ground loop that could lead to radiation. Also, for the CPW input excitation, capacitive coupling should be utilised to realise DC isolation between the CPW input and the CPW output. Both the AC and the DC signal flows, with relative voltage values for the proposed balun as well as the differential amplifier, are shown in Fig. 7.

The photograph of the prototype balun and the back-to-back configuration are shown in Fig. 8. Table 2 shows a measured performance comparison of previous systems with this work[3],[4],[8]~[10]. The phase-matched balun of [10] tends to exhibit very high insertion loss due to its broadband inverter design, which has disadvantages in high-efficiency applications. The proposed balun shows that the CPW-to-slotline transition significantly improves

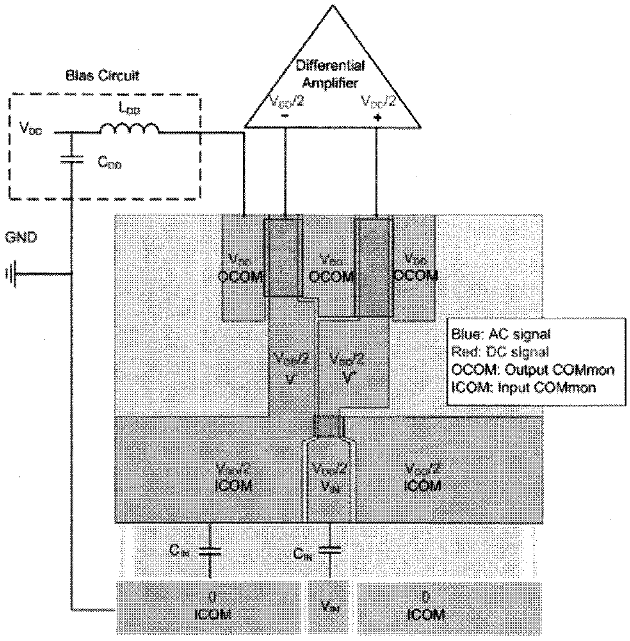
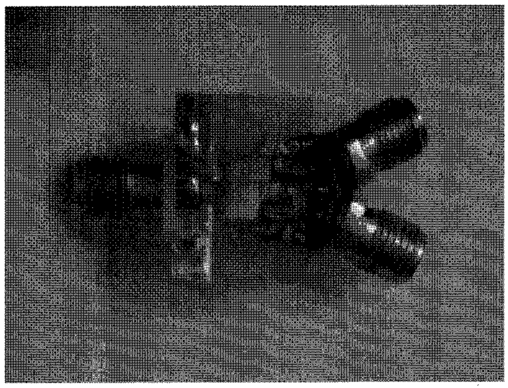
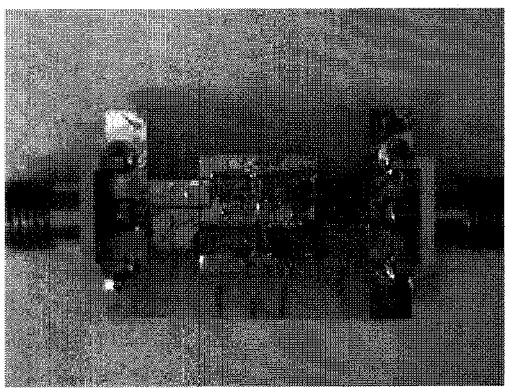


Fig. 7. Balun withbias circuit for low-frequency(less than 200 MHz) application.



(a) Proposed



(b) Back-to-back

Fig. 8. Photographs of the fabricated balun(size: 20×14 mm).

insertion loss, and it becomes a strong candidate for broadband UHF applications while retaining good features, including multi-octave bandwidth, excellent amplitude/phase imbalance, and compact size.

Ⅳ. Conclusions

A new broadband planar balun has been presented. The proposed balun is realized by using a CPW-to-slotline transition, which is capable of an operating range from 200 MHz to 2 GHz. Imbalance effects while the CPW input ground is connected to the CPW output ground through various capacitors to introduce common-mode impedances were measured. As the common-mode impedance increased the imbalance became significantly higher at the higherfrequency band compared with the lower frequency band. Also, the bias-circuit approach is used to improve operation bandwidth near the lower frequency bound. A prototype has been designed, EM simulated, and measured. Good agreement between simulationsand measurements has been achieved. The results show that the proposed planar balun has a low insertion loss over a multi-octave bandwidth. The measured amplitude and phase imbalances between the two CPW outputs are within 0.3 dB and 6°, respectively, over the entire operating frequency band. The structure requires no resonant transmission structures and occupies a small

Table 2. Comparison between this and previous work.

Ref.	Topology	Bandwidth [GHz]	Insertion loss Max. [dB]	Isolation Typ. [dB]	Amp. imbalance Max. [dB]	Phase imbalance Max. [°]	Size [mm^2]
[3]	Coaxial ferrite-loaded	0.005～2.5	0.9	?	0.4	?	?
[4]	Coaxial ferrite-loaded	DC～26.5	4	?	?	?	13×6
[8]	Power divider-phase shifter	1.7～3.3	0.8	<−15	0.3	5	70×50
[9]	CPW multi-stage power divider	0.8～3.3	0.8	<−12	0.5	6	?
[10]	Proprietary inverter design	0.004～6.5	4.3	?	0.3	2	38×44
This work	CPW-slotline transition	0.2～2	0.75	<−6	0.3	6	20×14

circuit area, thus allowing it to be easily integrated into a variety of circuit designs including mixers, multipliers, and push-pull amplifiers. Further work will focus on achieving high isolation between the CPW input ground and the CPW output ground, and an improved transition between the CPW and the 50-Ω coaxial connector.

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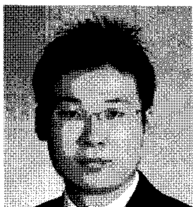

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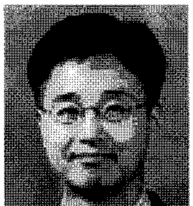

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