It's H.O.T. Understanding the Horizontal Output Transistor

It's one of the most commonly replaced semiconductors in monitors. I would probably not be going out too far on a limb to say that it is the most common semiconductor failure in monitors. From my personal experience, I know this to be true, anyway. At a recent slot tech training class at Table Mountain Casino we went through more than a dozen of them!

By way of review, let's take another quick peek at the horizontal deflection circuit. To be specific, let's concentrate on the horizontal output circuit since that's where the horizontal output transistor does its thing. In fact, in this case, we don't even need to consider the horizontal deflection coils in the deflection yoke or their associated collection of capacitors and inductors. Let's just look at the relationship between the B+ power supply, the flyback transformer and the horizontal output transistor itself.

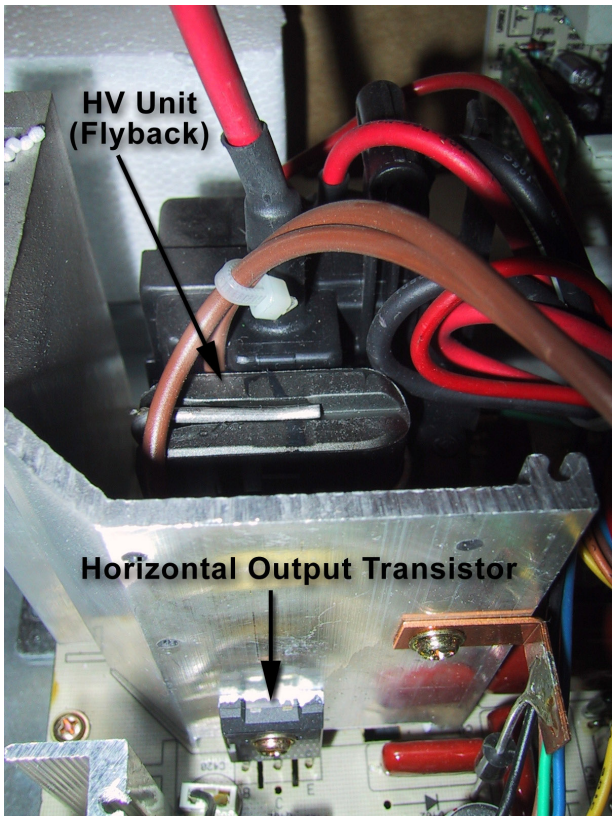
The switched-mode power supply (SMPS) creates the B+. This power supply will vary between manufacturers and models but is generally somewhere in the range of +77 VDC to +136 VDC.

The B+ is connected to one end of the primary winding of the flyback transformer. The other end on the flyback's primary winding is connected to the collector of the horizontal output transistor. It's easy to identify the horizontal output transistor in any monitor. It is always the largest transistor, closest to the flyback transformer. In a modern monitor, this is typically a TO-218 package, sometimes referred to as a TO-3P ("P" for "plastic") package as well.

The horizontal output transistor is always an NPN transistor. The emitter of the horizontal output transistor is always grounded. The horizontal output transistor is simply a "ground switch," a topic that we have covered previously here in Slot Tech Magazine.

When the horizontal output transistor is turned on, the B+ current flows from the power supply, through the primary winding of the flyback transformer, through the horizontal output transistor (from collector to emitter) to ground. This builds up a nice big magnetic field in the flyback. When the transistor is turned off, the magnetic field surrounding the flyback transformer collapses. As the magnetic field expands and collapses, electric current is forced to flow through the secondary windings, creating all of the voltages that the flyback is supposed to create: the EHT, the focus voltage, the screen voltage and, in many cases, the CRT heater voltage as well. See the January 2002 issue of Slot Tech Magazine (available online at slot-tech.com) if you need to learn more about flyback derived power supplies.

The collector current flowing through the horizontal output transistor is the single highest current flow in the entire monitor. It's the James Brown of the monitor, the



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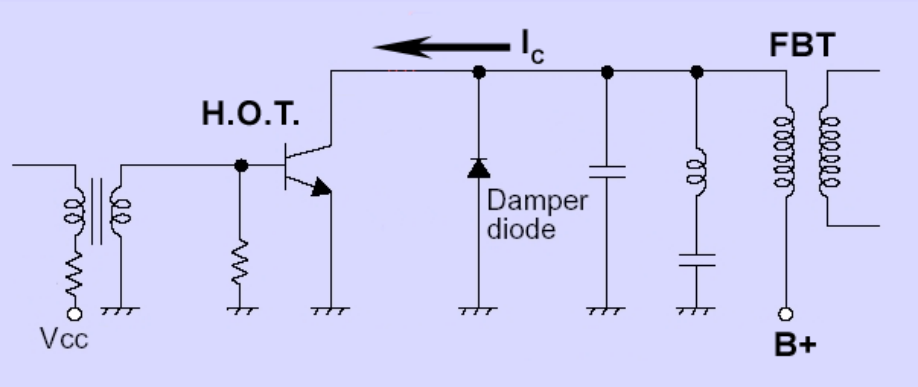
hardest-working transistor in show business. When the horizontal output transistor fails, it almost always goes in a big way. Not with a shower of sparks, flame and smoke but with a dead short between the collector and the emitter. Not too surprising of course, since that's where all the current is flowing. It doesn't look bad when it fails. It's just shorted.



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So, What's Up With All the Different Part Numbers?

If all horizontal output transistors in all monitors are all more-or-less the same shape and size and they're all connected the same way and all performing the same function and all doing the same thing, why is it that there are so many different part numbers for the darned things? Every time you look at a new make or model of monitor, there's a different part number for the horizontal output transistor.

Well, first of all, there are hundreds, thousands of transistors that can be interchanged with one another and will function properly. In a way, it's kind of like the battery in your car. It doesn't matter what brand of battery you use but Delco and Diehard batteries will have different part numbers, regardless of the fact that their specifications might be identical or nearly so.

Consider too the fact that, although your vehicle might call for a battery that can provide 400 amps, if you replace it with a 450 amp battery, you're cool, right? You may never use the extra 50 amp capacity but it's not hurting anything either. As long as the size of the battery (the "package") is the same, it fits and it works.

	V_{CBO} = 1500 V			V_{CBO} = 1700 V			V_{CBO} = 2000 V		
Package	TO-3P(H)IS		TO-3P(LH)	TO-3P(H)IS		TO-3P(LH)	TO-3P(H)IS		TO-3P(LH)
Pc max	40 to 75 W		180 to 220 W	40 to 75 W		180 to 220 W	40 to 75W		180 to 220 W
** $I_{C(sat)}$	Built-in damper	Not built-in damper	Not built-in damper	Built-in damper	Not built-in damper	Not built-in damper	Built-in damper	Not built-in damper	Not built-in damper
3 A	2SD2599			2SD2550					
3.5 A	2SD2586								
4 A	2SD2499	2SD2498		2SD2551					
4.5 A	S2055N	S2000N							
5 A	2SD2539 2SC5339								
5.5 A				2SD2638					
6 A	2SC5280 2SD2559	2SC5386 2SD2500		2SC5716 2SD2553					
7 A		2SC5404							
8 A	* S3H58	2SC5387 2SC5855					* S3H60		
11 A		2SC5411 2SC5856	2SC5421			2SC5422		* 2SC5997	
12 A				* S3G18	2SC5588	2SC5590			2SC5748
14 A		2SC5587 * S3G90	2SC5589			2SC5446			
15 A			2SC5445						
17 A		2SC5717	2SC5695		2SC5857	2SC5858			2SC5612
18 A						2SC5859			
22 A						2SC5570			

It's kind of the same way with horizontal output transistors. It's really just a matter of specifications and, in the case of horizontal output transistors, there are four or five that you need to consider when selecting a replacement device.

Specifications

I_c - Collector Current This is the maximum current (measured in amperes) that can be controlled by the transistor. Naturally, large transistors can handle more current that small transistors, just as thick wire can handle more current than thin wire. The largest size transistor we commonly use in games is the TO-218 package.

V_{CEO} or BV_{CEO} - Collector-to-Emitter Voltage This is the maximum voltage that the transistor can handle as measured between the collector and the emitter when the base lead is open (not connected.) This is when the transistor is completely turned off and must block the current from flowing between the collector and emitter of the transistor.

V_{CBO} or BV_{CBO}- Collector-to-Base Voltage This is the maximum voltage that the transistor can handle as measured between the collector and the base when the emitter lead is open. This is a measurement of the "strength" of the collector-to-base junction when it is reverse-biased. That is to say, it's an indication of how much voltage the transistor can withstand when the collector is at a very high positive voltage with respect to the base.

h_{FE} - Current Gain or "Beta" This is an indication of the transistor's ability to amplify an incoming signal. The higher the gain, the less current it takes to drive the transistor. For example, a transistor with a gain factor of 100 will require just 1/100 amp of base current for 1 amp of collector current.

We can lump most transistors into three general categories. Low gain transistors have a gain of up to 250. Medium gain transistors have a gain of 250-750. High gain transistors are those with a gain factor of more than 750. Admittedly, these figures are somewhat arbitrary. All horizontal output transistors are low gain transistors.

Substituting horizontal output transistors is a lot like substituting diodes. You can make the substitution as long as the replacement transistor is the same polarity (NPN or PNP) and has the same or higher voltage rating and current rating. However, you should try to match the gain rating of the transistor as best you can. Substitute only low gain transistors for low gain transistors, mediums for mediums and highs for highs. This is not actually too difficult. As long as you're in the ballpark you should be okay.

But there is another, very important consideration when selecting a replacement horizontal output transistor and that is the frequency response or "speed" of the transistor. This parameter is also known as the "switching time" of the transistor.

As monitor and computer technology has progressed, the horizontal frequency of monitors has increased markedly. Take a look at the chart below and you can see the dramatic increase in horizontal frequency.

Resolution	H(kHz)
640 x 400	31.47
640 x 480	31.47
640 x 480	37.50
640 x 480	43.28
800 x 600	35.13
800 x 600	46.87
800 x 600	53.68
1024 x 768	48.34
1024 x 768	60.00
1024 x 768	68.68
1280 x 1024	63.96
1280 x 1024	79.96
1280 x 1024	91.12
1600 x 1200	75.00
1600 x 1200	87.50

For around forty years, we have been looking at standard, NTSC monitors. That's a 525 line, interlaced raster picture, with 480 visible lines on the screen. At a leisurely 63 microseconds per horizontal line (including the horizontal retrace time) we're looking at a horizontal frequency of just 15,734 Hz. Because NTSC is so slow, the interlaced raster scheme requires us to lay down two alternating fields of just 240 lines each.

NTSC is okay for watching a low-resolution television program but if we want to display slick-looking computer graphics (and we do want to display slick-looking computer graphics) we're going

to need more lines and the way to accomplish that is to speed up the horizontal deflection circuit. If we double the horizontal frequency, we can put twice as many lines on the screen in the same amount of time. We can dump that crappy, interlaced scan and go for a 480 line, progressive-scan picture that we now refer to as "VGA" resolution or 640 X 480. The numbers refer to a picture that is 640 pixels wide by 480 lines tall, corresponding to the 4:3 aspect ratio of the CRT itself. The horizontal frequency is now doubled to 31,468 Hz or approximately 31.47 kHz.

Naturally, this means that the horizontal output tran-

① 2SC Series

Part Number	Maximum Ratings			** pack -age	*** Di	h_{FE}			$V_{CE(sat)}$ Max(V)			Switching Time (Typ.)				Gene-ration
	V_{CBO} (V)	I_C (A)	P_C (W)			Min (–)	Max (–)	@5 V / I_C (A)		@$I_{C(sat)}$ (A)	@ I_B (A)	t_{stg} (us)	t_f (us)	@ f_H (kHz)	@ I_{CP} (A)	
2SC5280	1500	8	50	H	✔	4	8.5	6	5	6	1.5	4	0.2	31.5	6	4th
2SC5339	1500	7	50	H	✔	4	8	5	5	5	1.25	4	0.2	31.5	5	4th
2SC5386	1500	8	50	H		4.3	7.5	6	3	6	1.5	2.5	0.15	64	5	4th
2SC5387	1500	10	50	H		4.3	7.8	8	3	8	2	2.5	0.15	64	6	4th
2SC5404	1500	9	50	H		4	8	7	3	7	1.75	2.5	0.15	64	5.5	4th
2SC5411	1500	14	60	H		4	8	11	3	11	2.75	2.5	0.15	64	8.5	4th
2SC5421	1500	15	180	LH		4	8	11	3	11	2.75	2.5	0.15	64	8.5	4th
2SC5422	1700	15	200	LH		4.5	8.5	11	3	11	2.75	2.5	0.15	64	8	4th
2SC5445	1500	20	200	LH		4.5	8.5	15	3	15	3.75	2	0.1	100	8	4th
2SC5446	1700	18	200	LH		4	8	14	3	14	3.5	2.1	0.1	100	7	4th
2SC5570	1700	28	220	LH		4.5	7.5	22	3	22	5.5	1.4	0.1	130	8	4th
2SC5587	1500	17	75	H		5	8	14	3	14	3.5	1.8	0.1	100	7.5	4th
2SC5588	1700	15	75	H		4.8	8	12	3	12	3	1.8	0.1	100	6.5	4th
2SC5589	1500	18	200	LH		5	8	14	3	14	3.5	1.8	0.1	100	7.5	4th
2SC5590	1700	16	200	LH		4.8	8	12	3	12	3	1.8	0.1	100	6.5	4th
2SC5612	2000	22	220	LH		4.8	9	17	3	17	4.25	4	0.15	32	8	4th
2SC5695	1500	22	200	LH		4.5	8.5	17	3	17	3.75	1.6	0.1	100	8	*5th*
2SC5716	1700	8	55	H	✔	3.8	9	6	5	6	1.5	3.5	0.2	32	5.5	4th
2SC5717	1500	21	75	H		4.5	8.5	17	3	17	3.75	1.6	0.1	100	8	*5th*
2SC5748	2000	16	210	LH		4.8	7.5	12	3	12	3	4	0.15	32	8	*5th*
2SC5855	1500	10	50	H		4.3	6.7	8	3	8	2	2.3	0.1	80	5.5	*5th*
2SC5856	1500	14	55	H		4.5	7.8	11	3	11	2.75	1.8	0.1	100	6.5	*5th*
2SC5857	1700	21	75	H		5	7.5	17	1.5	17	4.25	3.5	0.1	45	8	*5th*
2SC5858	1700	22	200	LH		5	7.5	17	1.5	17	4.25	3.5	0.1	45	8	*5th*
2SC5859	1700	23	210	LH		4.5	8	18	3	18	4.5	1.8	0.1	100	7.5	*5th*
* S3G18	1700	(16)	75	H	✔	(4)	(8)	(12)	(3)	(12)	(3)	(3.5)	(0.1)	(45)	(8)	*5th*
*2SC5997	2000	(14)	75	H		(5)	(7.2)	(11)	(1.5)	(11)	(2.75)	(5)	(0.12)	(32)	(6)	*5th*
* S3G90	1500	(18)	60	H		(5)	(8)	(14)	(3)	(14)	(3.5)	(1.8)	(0.1)	(100)	(7.5)	*5th*
* S3H58	1500	(10)	50	H	✔	(4.5)	(7.5)	(8)	(3)	(8)	(2)	(3.5)	(0.2)	(45)	(6)	*5th*
* S3H60	2000	(10)	60	H	✔	(4.5)	(7.5)	(8)	(3)	(8)	(2)	(3.5)	(0.2)	(45)	(6)	*5th*

② 2SD Series

Part Number	Maximum Ratings			** pack -age	Built-in damper diode : ✔	h_{FE}			$V_{CE(sat)}$ Max(V)			Switching Time (Typ.)				Gene-ration
	V_{CBO} (V)	I_C (A)	P_C (W)			Min (–)	Max (–)	@5 V / I_C (A)		@$I_{C(sat)}$ (A)	@ I_B (A)	t_{stg} (us)	t_f (us)	@ f_H (kHz)	@ I_{CP} (A)	
2SD2498	1500	6	50	H		5	9	4	5	4	0.8	7	0.4	15.75	4	3rd
2SD2499	1500	6	50	H	✔	5	9	4	5	4	0.8	7.5	0.3	15.75	4	3rd
2SD2500	1500	10	50	H		4	8	6	3	6	1.5	8	0.35	15.75	6	3rd
2SD2539	1500	7	50	H	✔	5	9	5	5	5	1	6	0.3	15.75	5	3rd
2SD2550	1700	4	50	H	✔	8	22	1	8	3	0.8	7.5	0.3	15.75	3	3rd
2SD2551	1700	5	50	H	✔	5	10	4	5	4	0.8	7.5	0.5	15.75	4	3rd
2SD2553	1700	8	50	H	✔	5	9	6	5	6	1.2	9	0.3	15.75	6	3rd
2SD2559	1500	8	50	H	✔	5	9	6	5	6	1.2	6	0.4	15.75	6	4th
2SD2586	1500	5	50	H	✔	4.4	8.5	3.5	5	3.5	0.8	7.5	0.3	15.75	3.5	4th
2SD2599	1500	3.5	40	H	✔	8	25	0.5	8	3	0.8	7.5	0.5	15.75	3	4th
2SD2638	1700	7	50	H	✔	4.5	7.5	5.5	5	5.5	1.2	7	0.4	15.75	5.5	4th

sistor will have to switch on and off twice as fast. If the horizontal output transistor is not able to change state fast enough, the entire horizontal output circuit will become terribly inefficient. The transistor will generate huge amounts of heat and fail after just a few minutes, hours or days of operation.

It's really a heart-breaker as well because you locate the bad horizontal output transistor and replace it in just 10-15 minutes, you fire-up the monitor and it works great! You get all excited that you've fixed the monitor and you're looking forward to savoring your triumph with a cup of coffee and a smoke when . . . Pfffft! The monitor goes dead and you hear the tell-tale sign of a bad horizontal output transistor - the SMPS begins its subtle ticking or chirping sound - and you know that that cup of Joe is just gonna have to wait.

Other resolutions require even higher horizontal frequencies. In some monitors (we don't use them in gaming . . . yet!) the horizontal frequency approaches 100 kHz.

The point is that when you're obtaining a replacement component, you need to pay attention not only to the three specifications mentioned previously (voltage, current and gain) but to the frequency response of the

JIS Part Numbers

2SA - PNP transistor for High Frequency Application
2SB - PNP transistor for Low Frequency Application
2SC - NPN transistor for High Frequency Application
2SD - NPN transistor for Low Frequency Application
2SK - N Channel Field Effect Transistor

●Video Display Monitor Horizontal-Deflection-Output Transistors (VCBO = 1500 V series)

Intended Uses for Horizontal-Deflection-Output Transistors Screen size <Icp> & maximum horizontal frequency <fH(max)>													Package / Recommended Alternative Product (for reference)				Maximum Ratings	
15 inch ICP = 4.5 A: ● ▲ ICP = 5.0 A: ○ △		17 inch ICP = 5.5 A: ● ICP = 6.0 A: ○		19 inch ICP = 6.5 A: ● ICP = 7.0 A: ○			21 inch ICP = 7.5 A: ● ICP = 8.0 A: ○						TO-3P(H)IS		TO-3P(LH)		IC	PC
fH@(max)													Damper diode		Damper diode		(A)	(W)
54 kHz	69 kHz	69 kHz	82 kHz	96 kHz	82 kHz	96 kHz	107 kHz	120 kHz	96 kHz	107 kHz	120 kHz	135 kHz	Built-in	Not Built-in	Built-in	Not Built-in		
▲													2SC5339				7	50
	○													2SC5386			8	50
▲													2SC5280				8	50
	○	●												2SC5404			9	50
	○	○	●											*2SC5855*			10	50
	○	○	●											2SC5387			10	50
				○	○	●								2SC5411			14	60
				○	○	●	●							*2SC5856*			14	55
				○	○	○	●	●	●							2SC5421	15	180
								○	○	●				2SC5587			17	75
							○	○	●	●				* *S3G90*			18	60
																2SC5589	18	200
											○	●				2SC5445	20	200
										○	●			*2SC5717*			21	75
											○	●				*2SC5695*	22	200

●Video Display Monitor Horizontal-Deflection-Output Transistors (VCBO = 1700 V series)

△													2SC5716				8	50
				○	○	●								2SC5588			15	75
				○	○	○	●									2SC5590	16	200
							○	●								2SC5446	18	200
							○	●						*2SC5857*			21	75
								○	●							*2SC5858*	22	200
									○	●						*2SC5859*	23	210
											○	○				2SC5570	28	220

transistor as well. Here is where a little bit of knowledge about the JIS part numbering system can help you out.

JIS

JIS stands for "Japan Industrial Standard" and it's a standard part numbering scheme for semiconductors used worldwide. It's really pretty clever because unlike the American system (called "JEDEC" for Joint Electron Device Engineering Council) a JIS part number actually tells you something about the specifications of the device.

As it is in the JEDEC system, the first number indicates the number of PN junctions in the device. Diodes, for example, have only a single PN junction. A typical JEDEC part number is something like 1N4004. A typical JIS diode might be something like 1S1234.

Transistors have two PN junctions, so their part numbers begin with "2." But here is where the standards split. JIS follows with the letter "S" while JEDEC uses "N" but what's neat is that JIS part numbers are then split into four groups: A, B, C and D. As and Bs are PNP transistors while Cs and Ds are NPN so, unlike JEDEC part numbers that don't tell you anything at all about the component's specifications, you can tell from the part number whether it's an NPN or a PNP transistor. Since the horizontal output transistor is always an NPN transistor, its part number will be 2SC or 2SD.

Not only can you tell its polarity, you can also tell if it's a low frequency part or a high frequency part. As and Cs are high frequency transistors while Bs and Ds are low frequency transistors.

Armed with this bit of knowledge, I can make some informed decisions about substitutions when it comes to horizontal output transistors. First of all, I can completely forget about any transistor that's 2SA or 2SB. They're PNP. I can also forget about replacing any 2SC with a 2SD. If the design engineer felt that it was important to install a 2SC then I'm not going to second-guess him.

Generally speaking, you can use a 2SC to replace a 2SD. A high-speed transistor can switch be used to switch at a slower speed without problems, just not the other way around.

But Wait . . . There's More

Before you go charging off to order a slew of horizontal output transistors, there are a couple of other things to look at. Actually, you can't really look at them at all because they're inside the transistor package. Your horizontal output transistor might include a built-in diode called the "damper diode." All horizontal output transistors in all monitors require a damper diode. In some cases, the damper diode is a separate component but in many cases, the damper diode is built-in to the transistor. The damper diode is critical. Without it, the horizontal output transistor will last about 15 seconds before shorting. If the transistor that came out has a built-in damper diode, the replacement component must have one as well.

Many horizontal output transistors also will contain an internal resistor, connected between the base and the emitter. A typical value for this resistor is 40-50 ohms. Like the diode, this resistor serves as a damper. Generally speaking, damping is not necessary in this circuit, as the output impedance of the secondary winding of the horizontal drive transistor is very low (it's just a handful of turns of wire). If the distance between the horizontal drive transformer and the horizontal output transistor is sufficiently great, some ringing can occur. If so, the resistor will damp the ringing. If you didn't understand all that, don't sweat it. If the original transistor had an internal resistor, I suppose the replacement should as well. I can't say that I've experimented in this regard.

This internal resistor is the reason that many horizontal output transistors do not test properly, even when they're perfectly good and tested out of circuit. They often seem to have a short between base and emitter due to the low value of this resistor. When testing the horizontal output transistor, don't bother with the base-to-emitter junction. When the horizontal output transistor is bad, it will almost always have an emitter-to-collector short circuit.

Of course, it's nice to be able to consult a data sheet whenever possible. Toshiba makes a great selection of horizontal output transistors. A selection guide (with specifications) is included in this article.

I suppose that one of the points to realize here is that you do not have to order different replacement horizontal output transistors for each of the different makes and models of monitors you have in the casino. Look around the shop and see what you already have. Maybe it will work. Generally speaking, there's no risk in trying what you have on hand (you're already replacing a shorted transistor, remember?) but you can greatly increase your chances of finding a proper replacement if you follow these simple guidelines.

Naturally, if you can obtain an exact replacement you should do so. Most cities have at least one electronic component retailer who carries a series of universal replacement components that can be used as substitutes. The most popular is the NTE line of replacement components. NTE publishes an extensive cross-reference catalog that will allow you to make substitutions as quickly as locating a word in the dictionary. You simply look up the original part number of the component you want to replace and the index will tell you which substitute to use. These "Master Replacement Guides" are usually available from your local electronics retailer. If you can't find one, you can solve your semiconductor replacement woes easily with just a few mouse-clicks and keystrokes at www.nteinc.com.

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