Yamaha Professional Audio Products

EMX512SC Powered Mixer

Circuit explanation of

Switch-mode Power Supply (SMPS) and Class-H power amplifier

1. Introduction

The EMX512SC is the most powerful of the three models in the recently released Yamaha EMX Powered Mixer range. Its "brick" styling is similar to familiar models such as the EMX68S, EMX88S and others. However, whilst these and many other current Yamaha models use "EEEngine" circuitry *(Reference 1)* to reduce thermal dissipation in their power amplifiers, the EMX512SC uses a simpler and more cost-effective switched-rail configuration rated at 500W continuous per channel into 4-ohms, or 1000W continuous into a bridged 8-ohm load. Yamaha calls it a "Class-H" design, a similar circuit having been used as far back as the '80s in the Yamaha B6 Stereo Main Amplifier *(Reference 2)*.. Similarly, the switch-mode power supply (SMPS) used in the EMX512SC is a very simplified version of the one used in the PC9500N Professional Power Amplifier *(References 3 & 4)*.

For convenience, please refer to the EMX512SC Circuit Diagrams that are included with this technical explanation.

2. SMPS Circuit description

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference L3

The 240VAC IEC input jack and filter components are mounted on the rear-panel OUT circuit board. From here, flying leads connect the AC to the PS circuit board, on which the rest of the power supply circuitry is located.

Relay RY401 provides a "soft-start" function. It is initially unenergised and its contacts are open when power is first applied, so the incoming 240VAC reaches the bridge rectifier D401 via mains fuse F401 and two series-connected 6.8-ohm 5W resistors R418 and R424. These limit the peak current into the (initially) discharged electrolytic capacitors C409 and C410. After the SMPS starts up and the regulated +/-15V rails are present, RY401's coil is energised, and its contacts short out R418 and R424 to provide full power capability.

Using the negative terminals of C410 as a reference, the voltage at the positive terminal of C409 is about 340V DC (A-spec model). The 100Kohm resistors R408 and R409 maintain a "half supply" of 170V DC.

Previous SMPS designs (EMX5000, PC9500, BBT500H, etc) used a small sub-transformer to provide a low-voltage supply to the switching regulator IC. This design does away with the need for a transformer by initially deriving the required low-voltage supply directly from the 240VAC, then, when the SMPS has started up, from a low-voltage winding on the switching transformer.

In detail, transistors Q414 and Q415 form a simple series regulator that reduces the main 340V supply to a level that the +15V regulator IC403 can tolerate - around 33V. Diode D429 and capacitor C435 provide a very lightly filtered DC voltage, which is fed via resistors R438, R439, R446 and R447 to the gate of Q414, forward-biasing it until the voltage at its emitter rises to around 33V. At this point, zener diode D418 conducts to turn on Q415. As a result, Q414's gate voltage drops, which reduces Q415's conduction, and so on. This linear feedback action between Q414 and Q415 maintains the required voltage at IC403's input.

With a supply now available to the switching-regulator IC401, the SMPS starts up to generate the secondary supplies. The AC voltage from one of the secondary windings is full-wave rectified by D414, D415 and C423 to provide an alternative supply to IC403. Additionally, R444 and D419 permanently turn on Q415, effectively "taking over" from the job initially done by Q414.

Switching regulator

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference L8

An oscillator contained within the SG3525AN PWM Control Circuit IC401 is the source of all switching activity in the SMPS. This device is normally used in switching-regulator applications where feedback to the device (usually by an opto-coupler or transformer) modulates its waveform pulse-width to regulate the output voltage. In this application however, no feedback is used, and both the frequency and pulse-width of the output waveform are fixed.

A sawtooth waveform is generated across C406 by repetitively charging it with a constant-current, the value of which is set by resistor R404, and rapidly discharging it through resistor R407. As a result, a rectangular waveform appears at pin 11 (A-output) and pin 14 (B-output) of IC401. The operating frequency is approximately 70 KHz. During normal operation, other than during the "dead time", either A or B is high (+15V) but not together. The "dead time" is determined by the value of R407 and is that short period of time during normal switching operation when neither A nor B is high. The dead time is necessary to avoid the momentary short circuit across the high-voltage supply that would otherwise occur in the SMPS's half-bridge output stage during the switchover between A and B.

A high logic level at IC401's SHUTDOWN pin 10 disables oscillation (and consequently, the generation of all SMPS secondary supply rails). This pin is held low during normal operation.

Transformer drivers

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference K3

The pulses from IC401's A and B outputs are fed to the inputs of IC402, an L6385 High/Low Driver. This IC provides voltage level-shifting and current drive to the half-bridge switching transistors Q406 and Q407, which are Insulated Gate Bipolar Transistors (IGBTs). An IGBT can be regarded as a combination of a MOSFET and a bipolar transistor and is used here because its on-resistance is much lower than that of the more commonly used MOSFET device.

One end of the primary winding of the high-frequency, switching transformer T104 is connected via capacitors C411 and C412 to the 170V "half supply" mentioned earlier. The other end of T401's primary winding is alternately switched to either 0V or 340VDC by Q406/Q407. The voltages induced in T401's secondary windings are rectified and filtered in conventional fashion to provide all of the required supply rails for the mixer. Note that there is no actual regulation of secondary voltages by optical or transformer feedback to IC401.

Overcurrent protection

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference J8

Fusible resistors protect against short-circuits or faults that draw excessive currents from any of the low-voltage secondary windings. A power amplifier failure or shorted loudspeaker output that draws excessive current from any of the multiple, high-voltage supply rails will activate the SMPS's overcurrent protection circuit consisting of transistors Q401, Q403, Q404 and Q405, to effectively switch off the entire power supply.

Under normal conditions, resistor R410 forward-biases Q401, keeping its collector low, which allows IC401 to produce switching pulses. When an overload occurs, the current reflected into T401's primary winding from the high secondary winding current develops a voltage across resistors R426/R427 that switches on Q405. This in turn switches on Q403, which switches off Q401. This allows R405/R406 to pull the SHUTDOWN pin 10 of IC401 high, stopping its oscillator. In addition to turning off Q401, Q403 also switches on Q404 to “latch on” this shutdown state. All secondary supply rails fall to zero, protecting against further damage. The only way to restore switching operation (assuming a temporary overload condition initiated the shutdown) is to turn off the unit's POWER switch, then turn it back on.

A sustained, high secondary current draw whose value is not sufficient to trip the overcurrent protection circuit will tend to increase the dissipation of Q406/Q407, making them run hotter than normal. To protect against excessively high device temperatures, a Positive-Temperature-Coefficient (PTC) thermistor PR401 monitors the temperature of the heatsink upon which Q406 and Q407 are mounted. When cold, PR401's resistance is low and transistor Q402 is off. At a heatsink temperature of around 100degC, PR101's increased resistance will allow Q402 to turn on, and initiate the same shutdown sequence described earlier.

DC voltage protection

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference D10

Due to their high power capability, the EMX512SC's power amplifier output stages are connected directly to the loudspeaker terminals, not, as is common practice, through relay contacts. As this offers no protection to the loudspeakers in the event of a DC voltage appearing at the amplifier outputs, the SMPS itself is called upon to switch off the high-voltage supply rails. When this occurs, it will remain in this condition until the POWER switch is turned OFF, then turned ON again.

The loudspeaker signals are resistively mixed and lowpass filtered to remove their AC content, and fed to the bases of transistors Q411 and Q413. Q413 detects positive DC voltages; Q411 together with Q408 detects negative voltages. When a DC condition is detected, the LED portion of photo-coupler PH401 is illuminated, turning on its transistor portion, and initiating the same latched shutdown action described earlier.

Fan control

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference C10

The EMX5000 incorporates a variable-speed cooling fan that is controlled by transistors Q416 and Q417. Transistor Q417 acts as a variable current-source in conjunction with the PTC thermistor PR102 (mounted on the main amplifier PA circuit board). When the main amplifier heatsink is cold, PR102's resistance is low and Q417 passes little current. The resulting low voltage drop across resistor R451 is buffered by emitter-follower Q416, and the fan turns at a low speed. As the thermistor's resistance rises with increasing temperature, Q417 sources more current, increasing the fan's drive-voltage.

Mute control

EMX512SC/EMX312SC PS & SW Circuit Diagram Grid Reference C8

The conventional loudspeaker protection relay fitted to most amplifiers serves two purposes: 1) disconnecting the speaker when DC voltages are detected at the amplifier's output, and 2) preventing audible turn-on "pops" by delaying the connection of the speaker for a few seconds after power-up, and immediately after power-down. As described earlier, in the EMX512SC, the SMPS itself is called upon to shutdown all power supplies under fault conditions, eliminating the need for a relay. However, power-on/off muting is implemented by electronically disabling the power amplifiers, which will be described in detail later. For now, suffice to know that an *unmuted* condition will exist (amplifiers *enabled*) when the MUTE line of connector CN415 is grounded by transistor Q410's collector.

Normally, Q410 is held on by the rectified AC voltage from one of T401's secondary windings, the components involved being D411, D428, R431, R432 and C422. However, immediately after power-up, capacitor C428 is discharged, which turns on transistor Q412 through R457. This shorts the base of Q410 to ground, turning it off and muting the amplifier. After C428 has charged up, it appears as a DC open-circuit to Q412's base current. Consequently, Q412 switches off, allowing Q410 to turn on and unmute the amplifier.

An over-temperature condition on the amplifier's heatsink will also mute the amplifier. When cold, the PTC thermistor PR101 mounted on the heatsink will have a low resistance, preventing Q412 from turning on through R433 and R436. At around 90degC, PR101's resistance will now have risen to a value that raises the voltage at the junction of R433 and R436 sufficiently to turn Q412 on, Q410 off, and mute the amplifier.

Note that unlike that for the DC and overload protection, the muting action is not latching. When the condition that caused muting ceases (such as the cooling down of an excessively hot heatsink), normal action is restored without having to turn the amplifier off and on again.

3. Class-H Power Amplifier

The EMX512SC's power amplifiers are quite conventional in most aspects. They are each configured in an inverting mode, with a differential-pair input stage, a differential-pair and current-mirror type voltage amplifier stage, and a fully complementary, Triple-Darlington output stage. A detailed analysis of this type of amplifier circuit topology is described in a previous paper (*Reference 5).* Strictly speaking, the output devices themselves are operated in Class-B, with a Class-A idling-current adjustment. The "Class-H" label refers to the use of switched supply-rail voltages to accommodate the requirements of the output signal amplitude. This will be explained in more detail later, after several other aspects of the power amplifier stages are described.

In the following text, all part numbers refer to the A (or left) channel; the operation of the B (or right channel) is identical.

Signal Muting

EMX512SC/EMX312SC PA Circuit Diagram Grid Reference L2

As described earlier, the power amplifiers are directly connected to the loudspeaker terminals, and not via a relay. To provide signal muting, all AC signal-flow through the amplifier is stopped by turning off the constant-current-source transistor Q110, which deprives the differential-pair transistors Q112 and Q116 of their operating current. They both turn off, consequently turning off the entire voltage-amplifier and current-mirror transistors Q122, Q124 and Q118. This leaves the Darlington output-stage “floating” at a zero-volt DC-level.

Note that the muting technique used here is only possible due to the use of a differential voltage-amplifier stage and its current-mirror load. If a single-ended voltage-amplifier stage had been used instead, the amplifier’s DC output would rise to the positive supply rail when muted, because of the “pull-up” effect of either a constant-current source transistor or “bootstrapped” load resistor.

Signal Limiter

a) Signal voltage limiting

EMX512SC/EMX312SC PA Circuit Diagram Grid Reference N2

A signal limiter circuit precedes each power amplifier to attenuate or “limit” the loudspeaker output signal level under certain conditions. Two front-panel LEDs (one for each power amplifier) provide a visual indication that this limiting action is currently being applied to the signal. Limiters first appeared in Yamaha EMX-series mixers with the introduction of the EMX640 model in 1996, and successive models used slightly different versions of the original design *(Reference 6)*.

In a basic limiter, input signal levels below a certain threshold pass through the limiter unaffected. Above the threshold level however, the limiter acts to maintain a constant output level regardless of the input signal level. In the EMX512SC, limiter action is initiated by the onset of clipping in the power amplifier, and the limiter acts to maintain a non-clipped condition with a high-level input signal that would otherwise severely clip the power amplifier.

Op-amp IC101 is configured as a conventional unity-gain inverting stage. In combination with the inverting power amplifier, an overall non-inverting configuration exists from input to output.

Two junction-FETs Q106 and Q163 shunt the input signal applied to IC101s inverting input. Normally, these FETs are kept off (non-conducting) by their gates being tied to -15V through resistor R104 and capacitor C104.

If the power amplifier clips, the consequent imbalance in the collector voltages of the power amplifier’s differential pair will be detected by transistor Q114 (for positive-clipped signals), or Q161 (for negative-clipped signals). In either case, Q104 turns on, which rapidly charges C104 to a maximum level of +0.6V as set by clamping diode D138. The FETS are turned on, and

IC101's output level reduces. Since clipping now no longer exists, Q104 is turned off, allowing C104 to discharge through R104, which restores the original gain and the cycle repeats. This feedback action maintains a non-clipped condition at the power amplifier output.

b) Signal power limiting

EMX512SC/EMX312SC PA Circuit Diagram Grid References J3 & M3

The limiting action just described refers to signal *voltage* limiting, as distinct from signal *power* limiting, which the EMX512SC also provides. What's the difference? The former does not take into account the load connected; given an adequate enough signal level, clipping (and consequent limiting) will occur regardless of load. However, by sensing load *current* at a specified signal voltage, the power dissipated in the load can also be limited.

To do this, transistor Q126 sources a current that is dependant on the voltage drop across resistor R176, which is the emitter resistor for the pre-drive transistor Q153N. The voltage drop across R176 is in turn proportional to the load current drawn on positive half-cycles of the output signal. Q126's collector is connected to the base of transistor Q108 via the wiper of preset-potentiometer VR102. At the power-limiting point, Q108 turns on Q104 to initiate the same limiter action described above.

In operation, VR102 is adjusted so that when a 2.8VRMS, 1 KHz sine wave is applied across pins 4&5 of CN101, a 46.5VRMS output signal is obtained across a connected 4-ohm load. This corresponds to a power output of 540WRMS.

<u>Supply rail switching</u>

EMX512SC/EMX312SC PA Circuit Diagram Grid Reference C3

A conventional Class-B audio amplifier output stage requires a value of power supply voltage sufficient to allow it to deliver its maximum undistorted power output. The power dissipated as heat by the output devices (transistors, MOSFETs, etc) when operating at a high supply voltage, and when they are driving a load (i.e. a loudspeaker), reduces amplifier efficiency.

To reduce the amount of heat generated, the positive and negative supply voltages to the output transistors in the Class-H output stage are each switched between two values, depending on the instantaneous value of the output signal:

+BH (+94volts) or **+BL** (+48volts), and **–BH** (-94volts) or **–BL** (-48volts).

The +BL and –BL supplies are fed directly to the output-transistor collectors via blocking-diodes D135 and D133, and it is these supplies that are used at low-to-medium signal levels. At higher signal levels, the +BH or –BH supplies (depending on signal polarity) are switched through to the transistor collectors by N-channel MOSFETs Q149 and Q150. Each MOSFET is driven by buffer transistors: Q143 and Q144 drive Q149; Q145 and Q146 drive Q150. Note that the same-polarity devices are used in the buffer/MOSFET arrangements for both the positive and negative rails - a sort of quasi-complementary configuration.

The purpose of the circuitry around transistor Q151 is not immediately obvious. To turn on an N-channel MOSFET, its gate terminal must be taken more positive than its source terminal. If the gate-source voltage is too low, the MOSFET will only partially conduct, significantly increasing its own dissipation. Conversely, the device can be damaged by too high a gate-source voltage. Q151 is configured as an “amplified diode” and acts as a regulating zener diode; it maintains the voltage at its collector at about 12V more positive than that at its emitter, or 12V more positive than +BL volts. This is used as the supply voltage for Q143/Q144, ensuring a maximum MOSFET gate-source drive of 12V. Diode D131 and capacitor C143 further ensure that this 12V supply “floats” above whatever rail voltage (+BL or +BH) is present at the output transistor collectors at any given moment. They maintain an adequate gate-source voltage while the MOSFET is switched on. In fact, the voltage at D131’s cathode goes even more positive than +BH volts during this period.

Q151’s output is used by both amplifier channels, as is the corresponding negative-regulated voltage provided by zener diode D101. The lower current requirements of the negative-supply switching control circuitry means that the lower dissipation rating of a single zener diode compared to that of a transistor configured as one (Q151), is adequate in this location.

The comparisons between the output signal level, and the threshold levels that result in the BL-to-BH switching (or vice-versa), are performed by IC102.

In detail, IC102 contains four, high-speed voltage comparators, two of which are used in each channel. Each comparator’s output device is an open-collector NPN transistor, which either switches hard to -15V, or releases to a voltage determined by any external pull-up resistance.

Since both amplifier channels operate identically, only the A (or left) channel component numbers will be used.

The inverting input pin 8 of one comparator section of IC102, and the non-inverting input pin 11 of another, are held at a reference voltage of approximately +1.9V and -1.9V respectively. The amplifier’s output signal is attenuated by resistors R233 and R237 and fed to the remaining inputs (pins 9 & 10) of these same sections. As long as the instantaneous value of the output signal is between approximately +29V and -29V (corresponding to around 50WRMS/8Ohm or 100WRMS/4Ohm), both comparator outputs will be ON at -15V. Beyond these limits, one of the comparator outputs will turn OFF.

For the positive-supply side, with pin14 of IC102 at -15V, transistor Q137 is *on*, which takes the bases of Q143 and Q144 to just below +BL volts, as determined by diode D129. Consequently, Q149 is off, blocking off +BH volts. For the negative-supply side, with pin13 of IC102 at -15V, transistor Q138 is *off*, which takes the bases of Q145 and Q146 to –BH volts. Q150 is off, blocking off –BH volts.

As soon as the output signal exceeds +29V, pin 14 of IC102 will release, and turn off Q137. This allows R237 to turn on Q143, which takes Q149’s gate high relative to its source, turning it on. Consequently, +BH volts will be switched in.

Conversely, when the output signal exceeds -29V on its negative half-cycle, pin 13 of IC102 will release, allowing Q138 to turn on via resistors R259 and R260. The gate of Q150 is turned on via Q145, and -BH volts will be switched in.

Positive feedback through R249 and R251 provides a hysterisis characteristic around the switching point of the comparators, which eliminates any tendency for the devices to oscillate at high frequency.

Reference 1. Yamaha EEEngine and HED. J. Pantalleresco, Service Department - Yamaha Music Australia 19/05/2000

Reference 2. Yamaha Stereo Main Amplifier B6 Service Manual. Document number 004416 Electronic Products Service Department Nippon Gakki Co. Ltd. Japan May 1981

Reference 3. Yamaha Professional Power Amplifiers PC9500N/PC4800N Service Manual. Document number PA011652 Electronic Products Service Department Yamaha Corporation Japan Sept 2002

Reference 4. Yamaha PC9500N Circuit Explanation. J. Pantalleresco, Service Department - Yamaha Music Australia 20/11/2002

Reference 5. Amplifier Servicing Guide. J. Pantalleresco, Service Department - Yamaha Music Australia 28/07/2000

Reference 6. EMX Limiter Circuit Explanation J. Pantalleresco, Service Department - Yamaha Music Australia 22/01/2001

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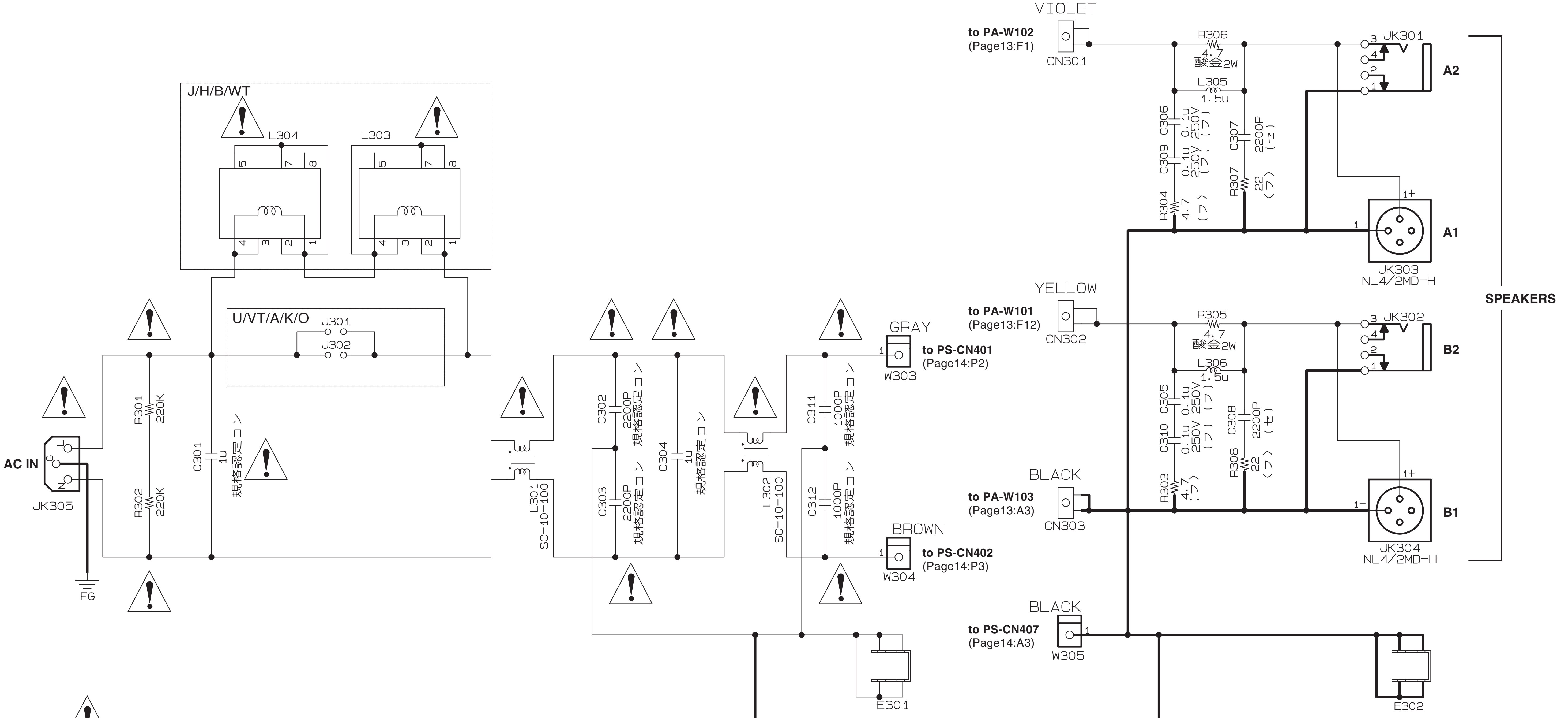
■ OUT CIRCUIT DIAGRAM (EMX512SC/EMX312SC)



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⚠ : Important safety parts
重要安全部品

Parts of each model

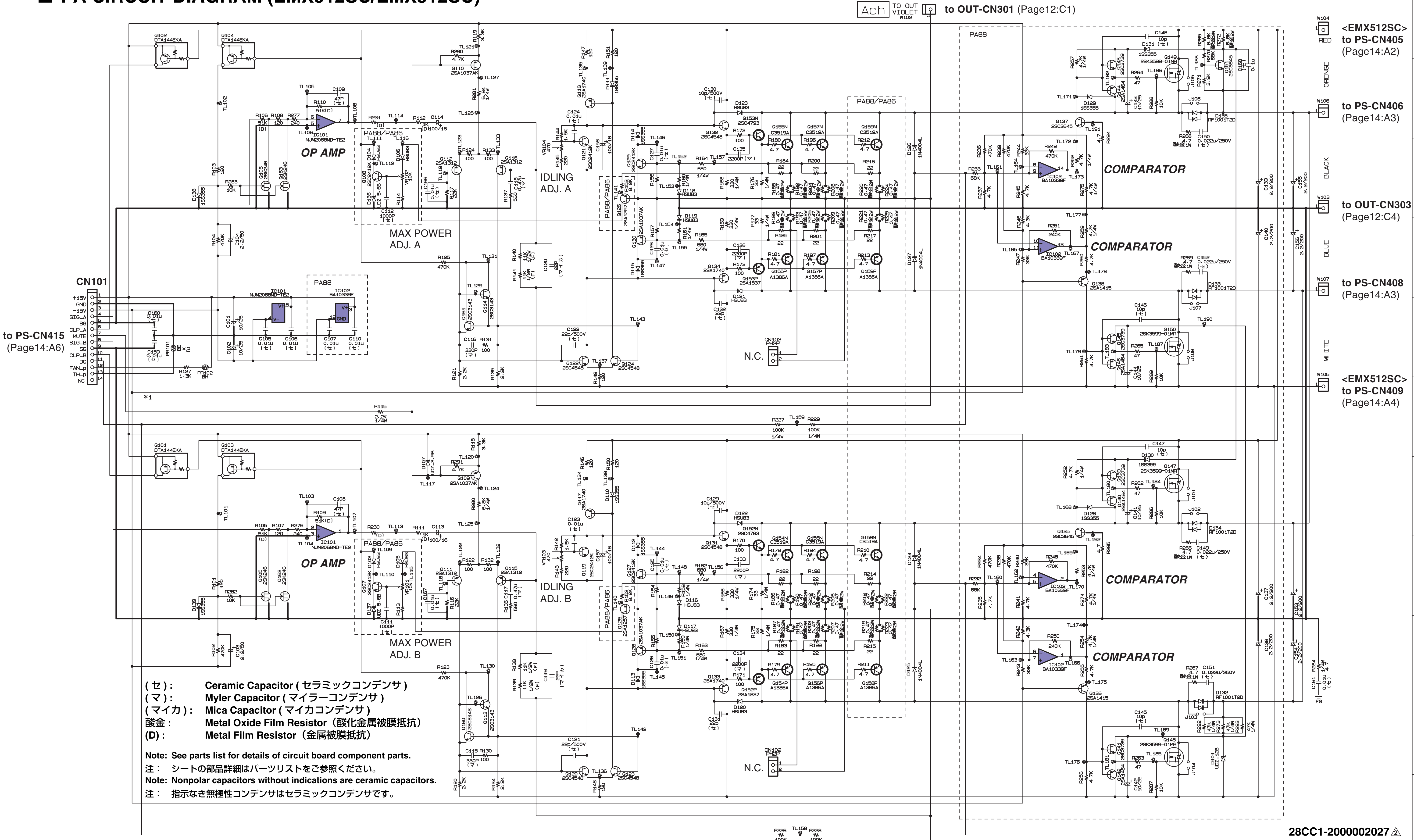
DESTINATION	L303, L304	J301, 302
J	WF514600 or WG090600	×
U/V/A/K/O	×	○
H/B/W	WF514500 or WG090700	×

規格認定コン : Capacitor（規格認定コン）
(セ) : Ceramic Capacitor (セラミックコンデンサ)
酸金 : Metal Oxide Film Resistor（酸化金属被膜抵抗）
(フ) : Flame Proof C. Resistor (不燃化カーボン抵抗)

Note: See parts list for details of circuit board component parts.
注： シートの部品詳細はパーツリストをご参照ください。
Note: Nonpolar capacitors without indications are ceramic capacitors.
注： 指示なき無極性コンデンサはセラミックコンデンサです。

■ OUT CIRCUIT DIAGRAM (EMX512SC/EMX312SC)

■ PA CIRCUIT DIAGRAM (EMX512SC/EMX312SC)



(セ) : Ceramic Capacitor (セラミックコンデンサ)
(マ) : Myler Capacitor (マイラーコンデンサ)
(マイカ) : Mica Capacitor (マイカコンデンサ)
酸金 : Metal Oxide Film Resistor（酸化金属被膜抵抗）
(D) : Metal Film Resistor（金属被膜抵抗）

Note: See parts list for details of circuit board component parts.
注： シートの部品詳細はパーツリストをご参照ください。
Note: Nonpolar capacitors without indications are ceramic capacitors.
注： 指示なき無極性コンデンサはセラミックコンデンサです。

	R154, 155, 156, 157	R158, 159, 160, 161	J101–108	R230, R231	R113, R114
PA88	4.3k	24k	×	200	22k
PA86	–	27k	○	560	30k

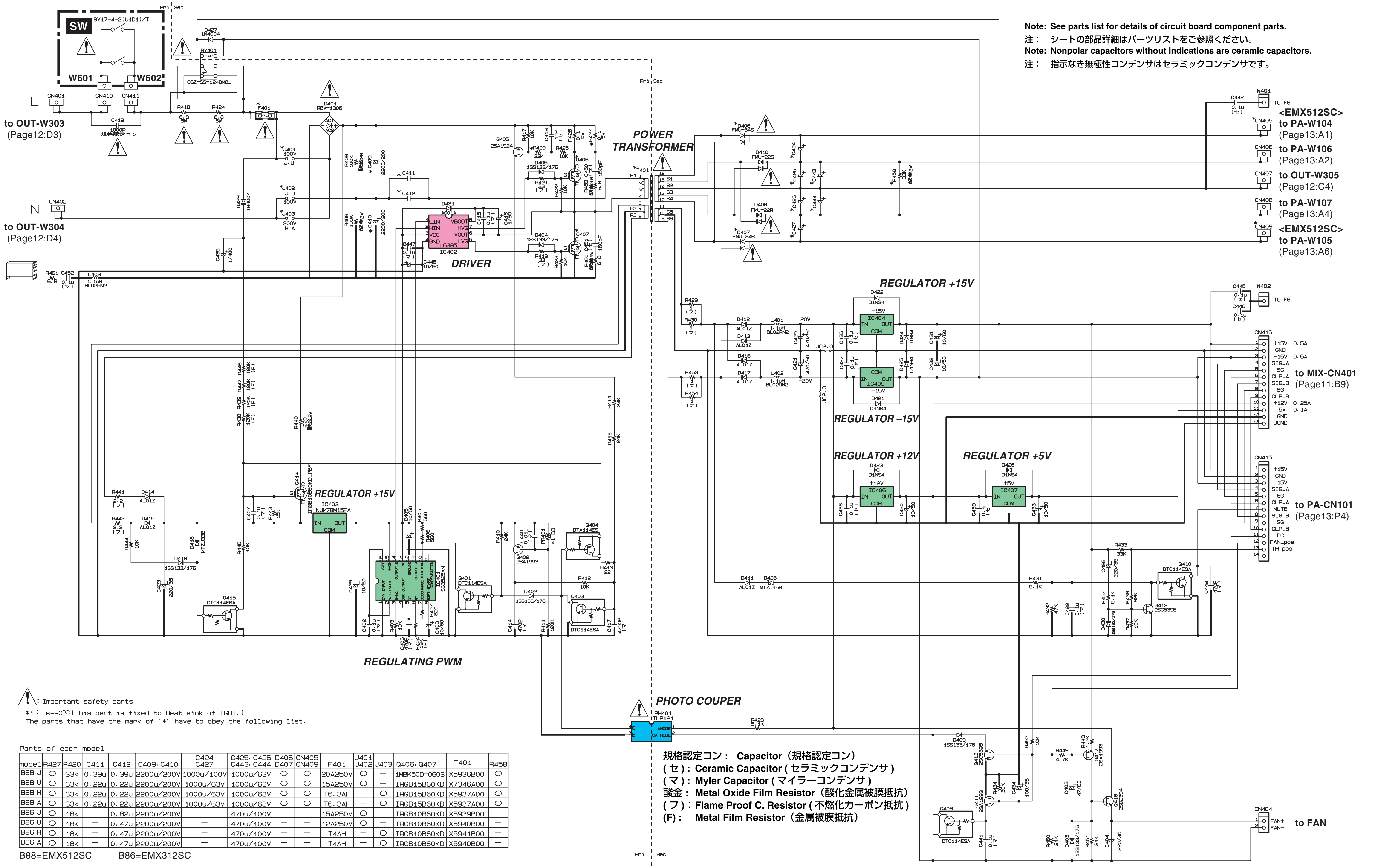
PA88=EMX512SC PA86=EMX312SC

*1: Ts=60°C (This part is fixed to Heat sink.)
*2: Ts=90°C (This part is fixed to Heat sink.)

■ PA CIRCUIT DIAGRAM (EMX512SC/EMX312SC)

■ PS & SW CIRCUIT DIAGRAM (EMX512SC/EMX312SC)

Note: See parts list for details of circuit board component parts.
注：　シートの部品詳細はパーツリストをご参照ください。
Note: Nonpolar capacitors without indications are ceramic capacitors.
注：　指示なき無極性コンデンサはセラミックコンデンサです。



⚠: Important safety parts

*1 : Ts=90°C (This part is fixed to Heat sink of IGBT.)
The parts that have the mark of '*' have to obey the following list.

Parts of each model

model	R427	R420	C411	C412	C409, C410	C424 C427	C425, C426 C443, C444	D406 D407	CN405 CN409	F401	J401 J402	J403	Q406, Q407	T401	R458
B88 J	○	33k	0.39u	0.39u	2200u/200V	1000u/100V	1000u/63V	○	○	20A250V	○	—	1MBK50D-060S	X5936B00	○
B88 U	○	33k	0.22u	0.22u	2200u/200V	1000u/63V	1000u/63V	○	○	15A250V	○	—	IRGB15B60KD	X7346A00	○
B88 H	○	33k	0.22u	0.22u	2200u/200V	1000u/63V	1000u/63V	○	○	T6.3AH	—	○	IRGB15B60KD	X5937A00	○
B88 A	○	33k	0.22u	0.22u	2200u/200V	1000u/63V	1000u/63V	○	○	T6.3AH	—	○	IRGB15B60KD	X5937A00	○
B86 J	○	18k	—	0.82u	2200u/200V	—	470u/100V	—	—	15A250V	○	—	IRGB10B60KD	X5939B00	—
B86 U	○	18k	—	0.47u	2200u/200V	—	470u/100V	—	—	12A250V	○	—	IRGB10B60KD	X5940B00	—
B86 H	○	18k	—	0.47u	2200u/200V	—	470u/100V	—	—	T4AH	—	○	IRGB10B60KD	X5941B00	—
B86 A	○	18k	—	0.47u	2200u/200V	—	470u/100V	—	—	T4AH	—	○	IRGB10B60KD	X5940B00	—

B88=EMX512SC　　B86=EMX312SC

規格認定コン： Capacitor（規格認定コン）
(セ)： Ceramic Capacitor (セラミックコンデンサ)
(マ)： Myler Capacitor (マイラーコンデンサ)
酸金： Metal Oxide Film Resistor（酸化金属被膜抵抗）
(フ)： Flame Proof C. Resistor (不燃化カーボン抵抗)
(F)： Metal Film Resistor（金属被膜抵抗）

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■ PS & SW CIRCUIT DIAGRAM (EMX512SC/EMX312SC)