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Electromagnetic compatibility solution for oxygen concentrator electronic circuits

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1. Oxygen concentrator industry standards

1.1 Compulsory Certification

FDA (U.S. Food and Drug Administration)

Oxygen concentrators are classified as Class II medical devices under the FDA system.

Regulation number: 21 CFR 868.5655 (applies to medical oxygen generators).

Product codes: CAW (portable oxygen concentrator) and NOU (stationary oxygen concentrator).

Companies must establish: ISO 13485: Manufacturers must establish a quality management system.

NMPA (China) certification.

Passed the GB/T 42061-2022 (equivalent to ISO 13485) system assessment and received on-site inspection by the National Medical Products Administration.

YY/T 0298-1998 "General Technical Specifications for Medical Molecular Sieve Oxygen Concentrators."

1.2 International Industry Standards

01

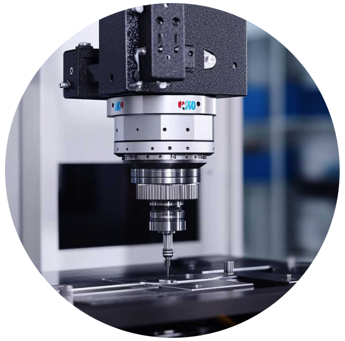
Key international standards for oxygen concentrators include ISO 8359, "Medical oxygen concentrators — Safety requirements." This standard specifies safety requirements for medical oxygen concentrators, covering aspects such as design, manufacturing, and performance to ensure their safe and stable operation in medical environments.
ISO 80601-2-67:2020, "Medical electrical equipment — Part 2-67: Basic safety and essential performance of oxygen concentrators."
IEC 60601-1, "General safety requirements for medical electrical equipment," covers fundamental requirements for electrical safety, mechanical safety, and radiation protection.

02

The American standard F1464-93 has clear regulations on the performance indicators of oxygen concentrators. For example, under continuous working conditions, the change of oxygen concentration at rated flow must be within ±3%, and the average oxygen flow fluctuation must be within ±10%, ensuring the oxygen production effect of the oxygen concentrator is stable and reliable.

1.3 Domestic Industry Standards

YY/T 0298-1998 "General Technical Specification for Medical Molecular Sieve Oxygen Generators"



GB 8982-2009 "Medical and Aviation Breathing Oxygen"

GB 9706.1-2020 "Medical Electrical Equipment - Part 1: General Requirements for Basic Safety and Essential Performance"

YY 0505-2012 "Medical Electrical Equipment - Part 1-2: General Safety Requirements - Collateral Standard: Electromagnetic Compatibility - Requirements and Tests"

GB/T 191-2008 "Picture Marking for Packaging, Storage, and Transportation"

2. EMC test related requirements

2.1 Radiated emission test

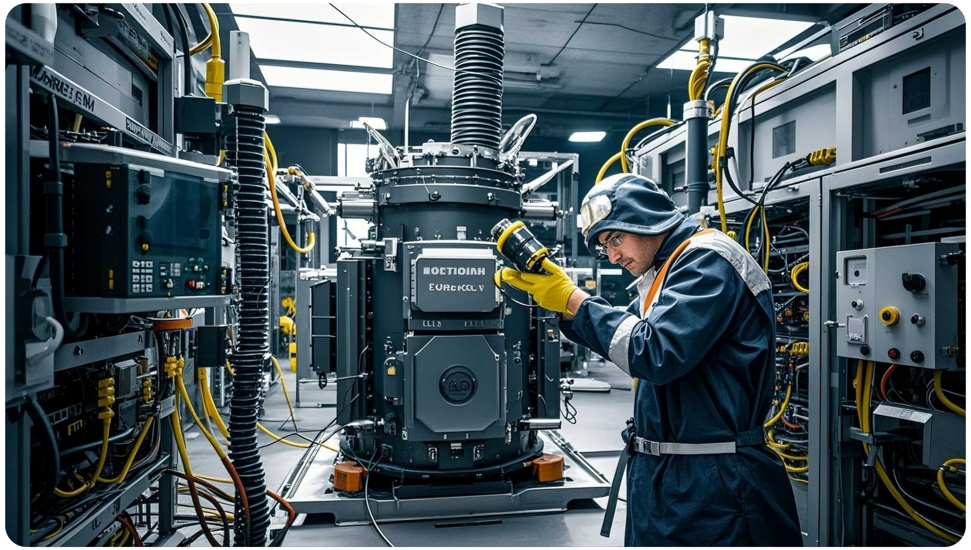
Emission Requirements

Control electromagnetic interference generated by the device to prevent it from affecting other equipment:

Conducted Emissions (CE): Interference conducted through power lines (EN 55011 or EN 55032)

Radiated Emissions (RE): Electromagnetic waves radiated into space (EN 55011 or EN 55032)

Harmonic Current (EN 61000-3-2) and Voltage Fluctuations (EN 61000-3-3)



2.2 Immunity Test

project	Testing requirements	standard
Electrostatic discharge immunity (ESD)	±2 kV (contact discharge) ±4 kV (air discharge)	EN 61000-4-2
RF radiation immunity	3 V/m (80 MHz–2.7 GHz, simulating wireless device interference)	EN 61000-4-3
Electrical fast transient/burst (EFT/B)	±2 kV (power lines)	EN 61000-4-4
Surge immunity (Surge)	±1 kV (line to line) ±2 kV (line to ground)	EN 61000-4-5
Conducted RF immunity	3 V（0.15–80 MHz）	EN 61000-4-6
Special medical environment requirements	**Test at a higher immunity level (e.g. radiated immunity may require 10 V/m)**	

3. Pain points of EMC industry in oxygen concentrators

3.1 Pain Points in EMC Industry

Pain point classification	Medical oxygen concentrator (EC 60601-1-2)	Home oxygen concentrators (EN 55032/EN 61000-6 series)
1. Insufficient anti-interference ability	Need to withstand highly harsh environments (such as hospital operating room electrosurgeries, high-frequency equipment interference), and prone to abnormal oxygen concentration due to radio frequency interference	Interference from home Wi-Fi, Bluetooth, microwave ovens, etc. may cause the machine to false alarm or shut down.
2. Poor power adaptability	Need to pass stringent surge and voltage sag tests (such as ±2kV surge), but some power modules lack redundancy.	Unstable household power grids (such as voltage fluctuations in rural areas) can easily trigger protection shutdowns, affecting continuous oxygen supply.
3. Interference with wireless functions	When integrating remote monitoring (e.g., 4G/Wi-Fi), it may interfere with vital sign monitoring modules (e.g., SpO_2 sensors)	Low-cost Wi-Fi modules are not EMC-optimized and conflict with home appliance frequency bands (such as 2.4 GHz).
4. Electrostatic discharge (ESD) failure	Metal panels or touch screens are susceptible to ESD interference (for example, static electricity during medical staff operations can cause the system to restart).	Static electricity may damage the control board when the user touches the buttons or interfaces (±8kV air discharge protection is required)
5. Conducted emission exceeds the standard	Motor drive circuits (such as compressors) generate high-frequency noise that can affect sensitive hospital equipment (such as ECG monitors)	Inadequate EMI filtering in low-cost switching power supplies causes conducted emissions on power lines to exceed EN 55032 Class B standards.
6. Mechanical noise and EMI coupling	The vibration of the compressor causes the PCB to resonate, causing the electromagnetic radiation (RE) of the signal line to exceed the standard.	In a compact design, the high-frequency circuit and the motor are too close, causing EMI coupling

3.2 Common Problems in Use

Unstable oxygen concentration

According to relevant standards, the oxygen concentration of oxygen concentrators must be maintained within a certain range. However, in actual use, the oxygen concentration often fluctuates, affecting the effect of oxygen therapy. For example, after working for a long time, the oxygen concentration of some oxygen concentrators will drop and cannot meet the needs of patients.

Excessive noise

As a household device, the loud noise of the oxygen concentrator not only affects the user's mood, but also disturbs the family's life. Especially for sound-sensitive groups, such as the elderly and pregnant women, excessive noise may reduce the effect of oxygen therapy or even have a negative impact.

Short lifespan

The molecular sieve, a core component of an oxygen concentrator, can absorb moisture and become damaged after prolonged operation, reducing oxygen production capacity. Furthermore, the vibrations from the machine's operation can cause continuous collision and wear on components, shortening the concentrator's lifespan.

4. Circuit design solutions for EMC

4.1 Electromagnetic compatibility considerations during the design phase

In the early stages of product design, possible sources of electromagnetic interference should be predicted; by analyzing circuit structure, signal transmission path, etc., potential interference points can be predicted, thereby optimizing circuit design and reducing the generation of electromagnetic interference; the Yinte company team recommends introducing a DFMEA mechanism to enhance product competitiveness.

4.2 Medical shielding measures

Medical oxygen concentrator (highly harsh environment, in accordance with IEC 60601-1-2)

Shielding measures	Key points to consider in the early stages of design	Application Examples
Chassis shielding	Use a full metal chassis (such as aluminum alloy) and use conductive pads (conductive foam/reed) at the joints to ensure continuous conductivity. The opening size is ≤λ/20 (for the highest interference frequency, such as 2.7GHz, the opening is ≤5.5mm)	Prevent the operating room electric knife (high-frequency noise) from radiating into the equipment through gaps
Cable shielding	All external cables (power supply, sensor) use double-shielded cables (braided layer + aluminum foil), with 360° termination of the shield layer. The power cable is equipped with a ferrite ring (to suppress 30MHz-1GHz common mode noise).	Prevent SpO_2 sensor signals from being interfered with by ICU monitor radio frequency
PCB shielding	High-frequency circuits (such as MCU and wireless modules) are partially covered with metal shielding, with ground impedance <10mΩ. Sensitive analog circuits (oxygen concentration detection) and digital circuits are partitioned and laid out.	Prevent Wi-Fi modules (2.4GHz) from interfering with ADC sampling circuits
Filter integration	A π-type filter (differential mode + common-mode rejection) is inserted into the power input, and medical-grade X/Y capacitors (meeting 4kV withstand voltage) are connected in series with a common-mode choke on the motor drive line.	Suppression of conducted emissions from compressor PWM speed regulation EN 55011
Grounding strategy	Single-point grounding (star topology) to avoid ground loops Metal housing and safety ground (PE) low impedance connection (<0.1Ω)	Prevents system reset caused by ground potential floating during ESD discharge (±8kV)
Wireless module isolation	The 4G/5G module is placed in an independent shielded cabin, and the antenna adopts a directional design + SAW filter (to suppress out-of-band noise). The software enables "medical mode" (dynamic adjustment of transmission power)	Prevent remote monitoring signals from interfering with sensitive devices such as pacemakers (needs to meet IEC 60601-1-2 Appendix G)

4.3 Home Shielding Measures

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Low-cost oriented, compliant with EN 55032 Class B

Shielding measures	Key points to consider in the early stages of design	Application Examples
Selective shielding	Only partial shielding (nickel-plated steel sheet) is used for noise sources (such as switching power supplies and motors). Non-full metal chassis. The inner wall of the plastic shell is sprayed with conductive paint (surface resistance <1Ω/sq, square coating is 1cm)	Reduce Wi-Fi (2.4GHz) radiation interference to the control board
Simplified cable handling	The power cord uses a single-layer shielded wire (aluminum foil), and the USB/keyboard cables use twisted-pair cables instead of shielded cables (cost optimization). Magnetic rings are only installed at the outlet of noise sources (such as motor cables).	Avoid microwave oven (2.45GHz) interference through power lines
Economical PCB design	Use a ground plane instead of a shield, and ground critical signal lines. Prioritize ICs with integrated EMC protection (such as MCUs with built-in TVS).	Reducing radiated emissions from DC-DC converters (EN 55032 Class B limits)
Filter simplification	Use a single-stage LC filter (not π type) for the power input, omit the Y capacitor (to avoid leakage current risk) and connect the motor in parallel with the RC absorption circuit (not a common mode choke).	Meeting conducted emission limits while controlling BOM costs
Grounding Compromise	Hybrid grounding (single point at low frequency + multiple points at high frequency), the plastic housing achieves "virtual shielding" through the PCB ground plane	Balancing ESD protection (±4kV contact discharge) and cost
Wireless module selection	Use a pre-FCC/CE certified Wi-Fi module (such as the ESP32) and software-limit the frequency (avoiding crowded channels in the ISM band)	Prevents interference with Bluetooth headsets and smart home devices

4.4 Use of filters

Adding a power filter can reduce the propagation path of electromagnetic interference; the power filter can filter out high-frequency interference signals on the power line, ensuring the purity of the power input to the oxygen concentrator, thereby ensuring the clarity and integrity of the signal.

	characteristic	Medical oxygen concentrator	Home oxygen concentrator
Power input filter	Topology	Multi-stage filtering (π-type or T-type) with common mode (CM) and differential mode (DM) suppression	Single-stage LC filtering, mainly for differential mode suppression
	Device Selection	Medical-grade X/Y capacitors (high voltage resistance, low leakage current) Common-mode chokes (high impedance, wide bandwidth)	Ordinary X capacitors and ceramic capacitors Low-cost ferrite magnetic beads
	Key parameters	Insertion loss ⩾40dB (1MHz-1GHz) Leakage current ⩽100μA	Insertion loss ⩾ 20dB (30MHz-300MHz)
Motor/compressor drive	Filtering measures	A sine wave filter is installed on the three-phase motor. A common-mode choke and RC snubber circuit are connected in series with the PWM output.	Single-phase motor parallel RC snubber circuit simplifies EMI filter
	Suppression Target	Avoid interference with life support equipment (eg, ECG, ventilator)	Meet civil EMI limits
	Filters for medical oxygen concentrators focus on high reliability and full-band suppression, while household products focus more on basic EMC compliance and cost control.		

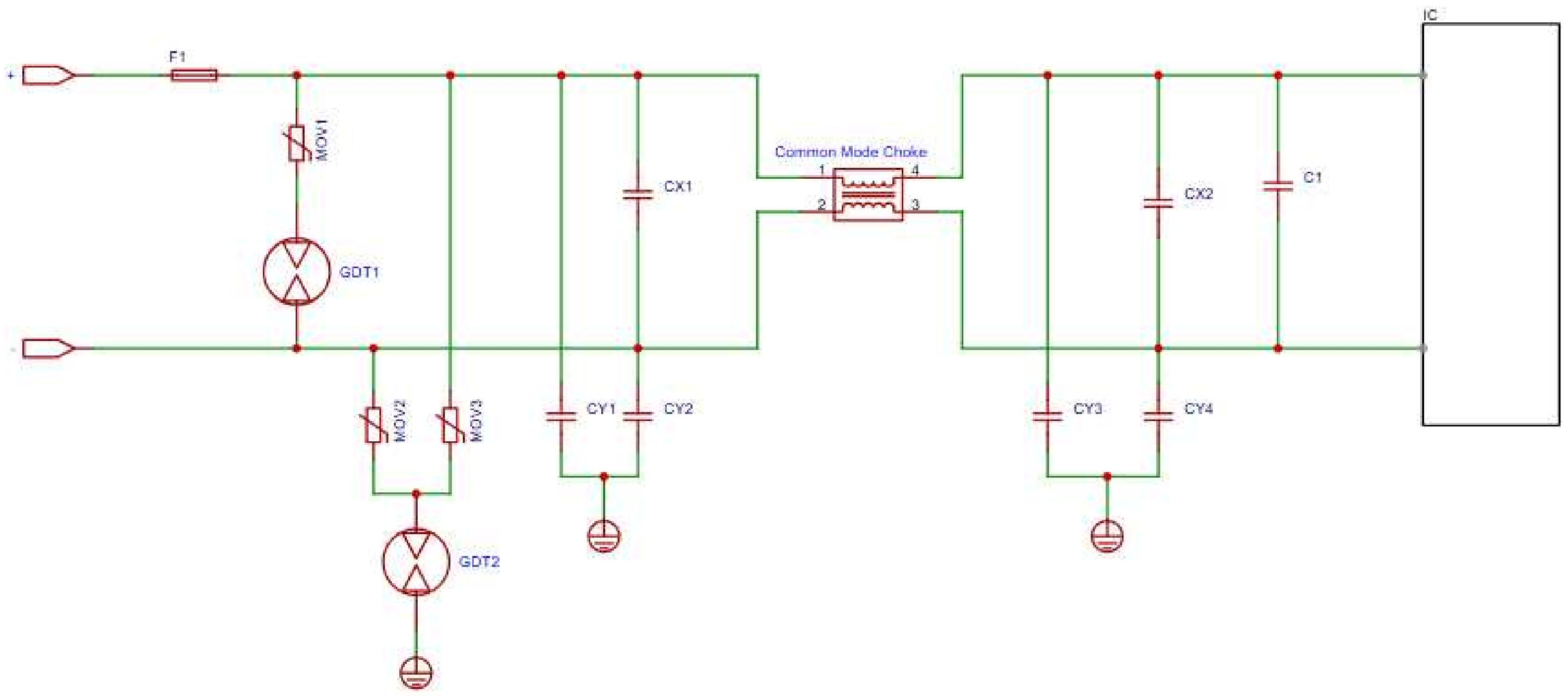
4.5 EMC solutions for cables

Layout elements	Specific measures	Purpose
Partition wiring	Divide the circuit into the noise area (motor, power supply), the sensitive area (oxygen sensor, MCU), and the mixed area (communication module). Keep a distance of ⩾5cm between each area and use metal partitions to isolate them when necessary.	Prevent motor noise from coupling into sensor signal lines (such as SpO_2 analog signals)
Cable classification and routing	High-voltage/high-current lines (such as compressor power): Shortest path + close to the edge of the chassis Low-frequency signal lines (such as temperature sensors): Twisted pair + away from noise sources High-frequency signal lines (such as Wi-Fi antennas): Coaxial cable + independent channel	Reduce crosstalk and radiated emissions (RE)
Shielding and grounding	All external interface cables (power supply, sensor) use double shielded cables (braided layer + aluminum foil), with the shield terminated 360° to the metal chassis. The shield grounding point is a single point grounding (to avoid ground loops).	Suppresses radio frequency interference (such as high-frequency noise from electrosurgical units in operating rooms)
Bundling and fixing	Bundle similar cables in groups with a spacing of ⩾3cm between groups. Use metal cable ducts or conductive cable ties to secure cables, and avoid plastic cable ties (which may accumulate static electricity).	Prevent cable friction and wear caused by vibration (medical equipment must pass mechanical vibration tests)
Via and through-hole design	When cables pass through a metal chassis, use conductive gaskets or EMI filter feedthrough capacitors to seal the holes. Avoid running cables parallel to the edges of the openings (right-angled holes reduce leakage).	Maintain chassis shield integrity (meet 10V/m radiated immunity)

4.6 Optimizing Circuit Design

By reducing the loop area of high-frequency signals, the intensity of electromagnetic waves emitted by them is reduced. By adopting multi-layer circuit board design and reasonable layout of components, the circuit structure is optimized and the anti-interference ability of the circuit is improved.

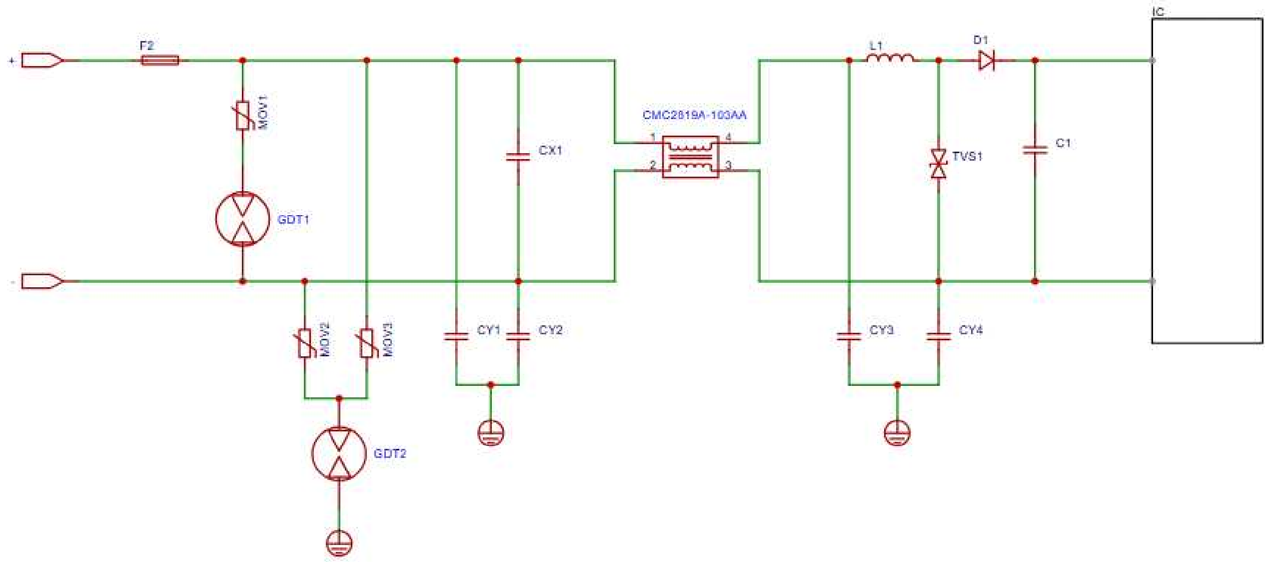
AC power interface: used to connect external 220V AC input



model	Device Type	Use Location	effect	Encapsulation
2R600L	GDT	Power interface	surge, lightning protection (outdoor products, focus on the issue of continuous current)	2RXXXL
14D561K/14D511K	MOV	Power interface	surge, lightning protection	14D
CMZ/CML	EMI common-mode suppressors	Power interface	Common-mode rejection	SMD

4.8 12V/24V Vehicle Power Supply Interface EMC and Reliability Design

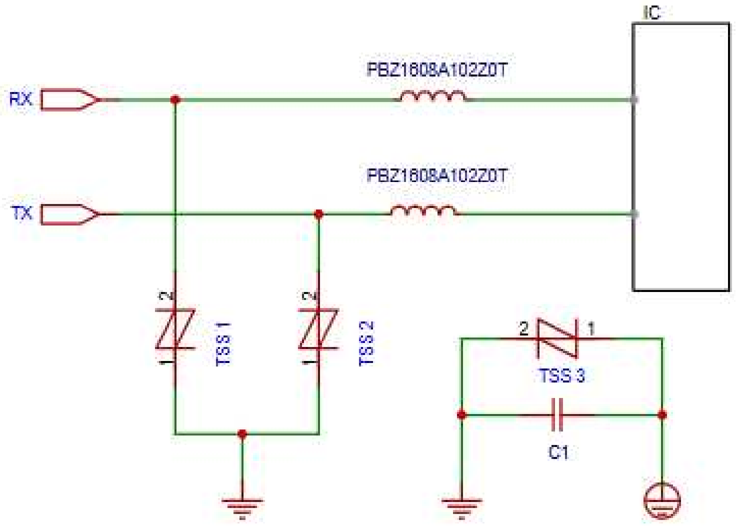
DC power interface: used to connect external 12V/24V vehicle power input



model	Device Type	Use Location	effect	Encapsulation
2R600L	GDT	Power interface	surge, lightning protection (outdoor products, focus on the issue of continuous current)	2RXXXL
14D561K/14D511K	MOV	Power interface	surge, lightning protection	14D
CMZ/CML	EMI common-mode suppressors	Power interface	Common-mode rejection	SMD
SMBJ24CA/SMBJ33CA	TVS	Power interface	surge, load dump	SMB

4.9 RS232 interface EMC and hot-swap reliability design

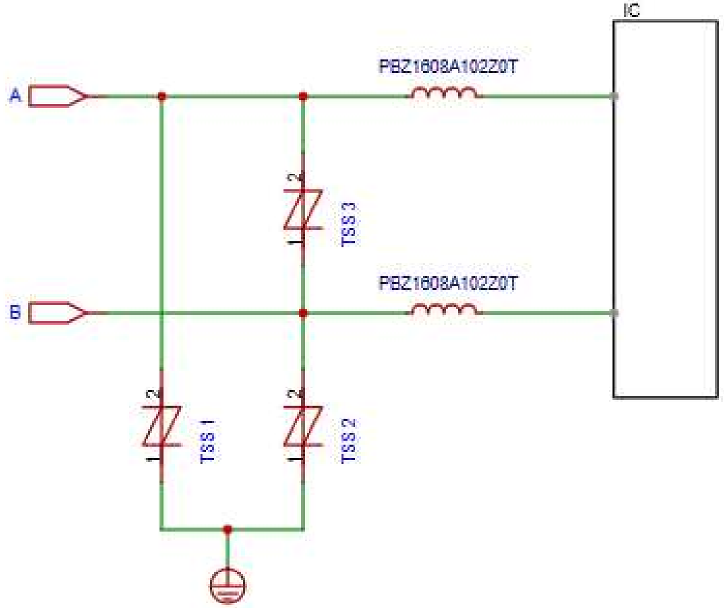
RS232 interface: It is one of the commonly used serial communication interfaces. RS232 is suitable for short-distance device interconnection (such as printers, mice, etc.) and requires a level conversion chip (such as MAX232) to adapt to different logic levels.



model	Device Type	Use Location	effect	Encapsulation
P0220SCL	TSS	RS232 interface	Surge, static electricity	SMB
P3100SCL	TSS	RS232 interface	Lightning strike、Surge, static electricity	SMB
PBZ1608A102Z0T	magnetic beads	RS232 interface	Eliminate high-frequency interference	1608

4.10 RS485 interface EMC and hot-swap reliability design

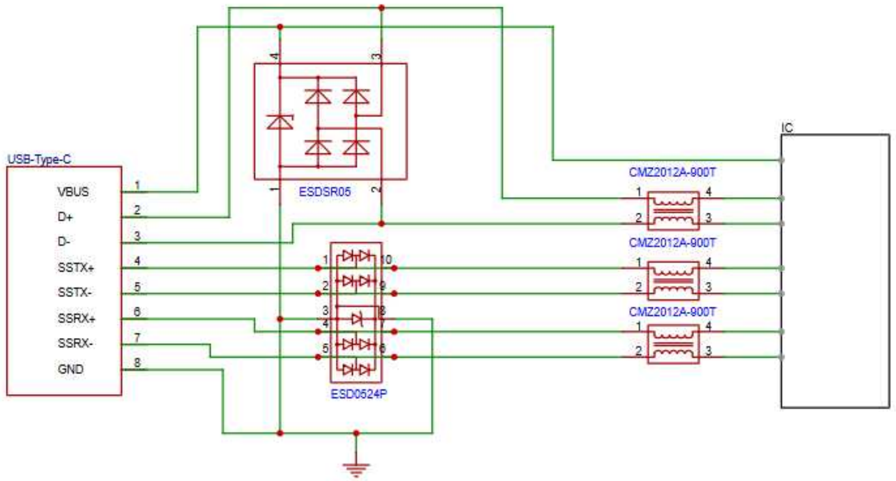
RS485 interface: RS-485 is a serial communication standard that can support multiple devices to communicate through the same serial bus. It is suitable for medium and long distance communication and has good anti-interference ability and data transmission stability.



model	Device Type	Use Location	effect	Encapsulation
P0080SCL	TSS	RS485 interface	Surge, static electricity	SMB
PBZ1608A102Z0T	magnetic beads	RS485 interface	Eliminate high-frequency interference	1608

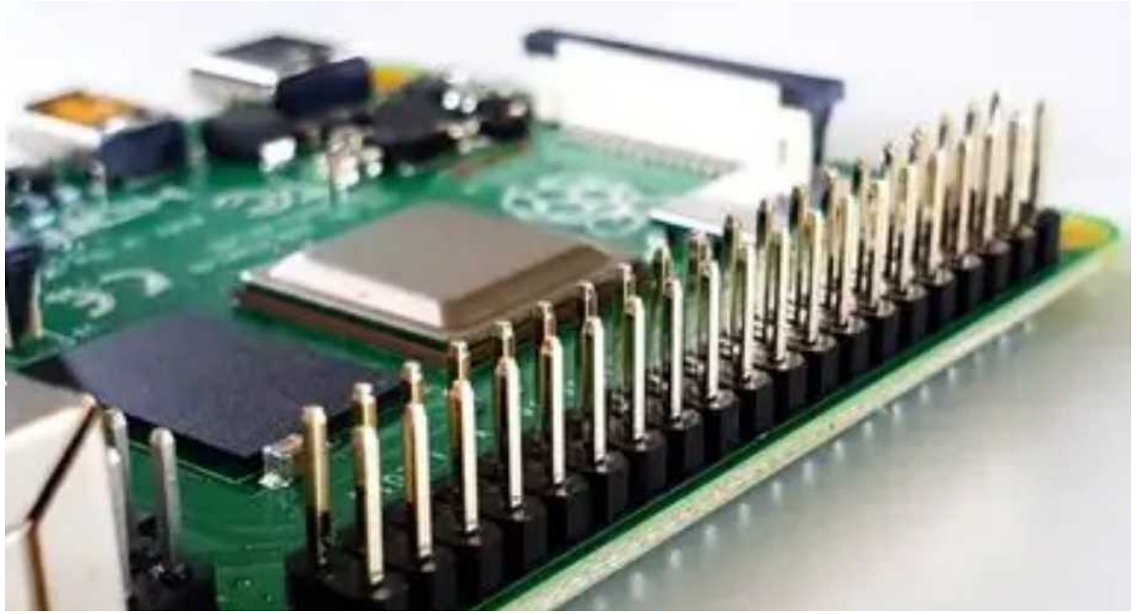
USB-Type-C interface:

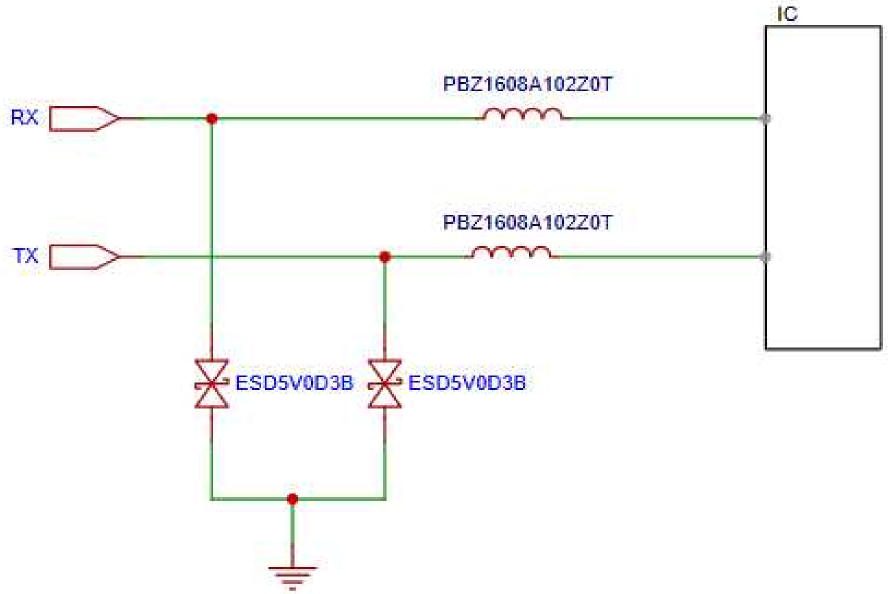
The USB interface boasts high-speed data transmission capabilities and is widely used to connect robots to external storage devices, sensors, and more. Its high-speed data transfer rate can reach 5Gbps, enabling rapid transmission of large amounts of data, such as robot vision image data. Its plug-and-play functionality allows users to easily connect and replace devices, enhancing the convenience of robot use and playing a key role in various robotic applications.



model	Device Type	Use Location	effect	Encapsulation
ESD0524P	ESD	USB interface	Surge, static electricity	DFN2510
ESDSR05	ESD	USB interface	Surge, static electricity	SOT143
CMZ2012A-900T	EMI common-mode suppressors	USB interface	Common-mode rejection	2012

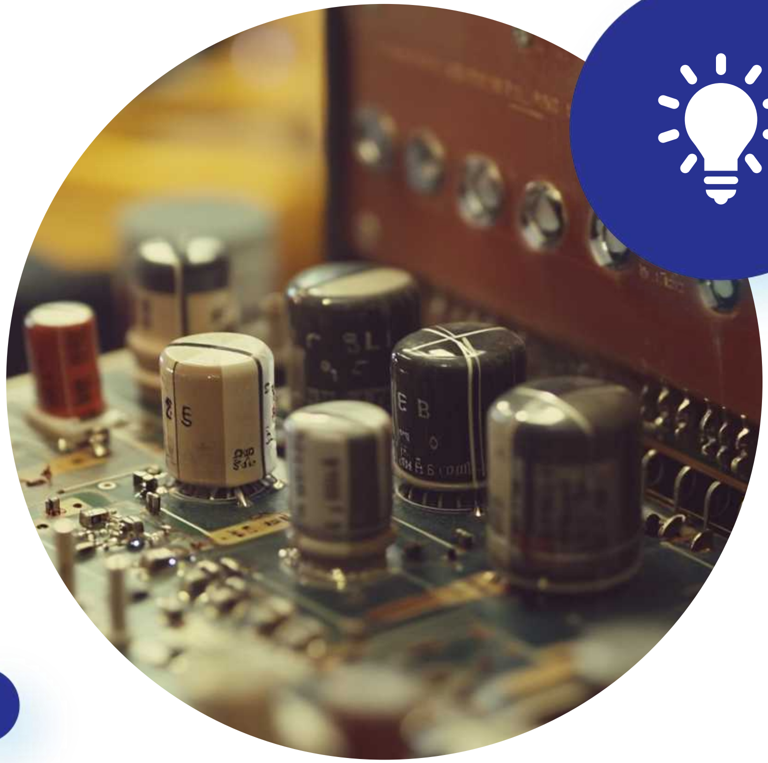
GPIO interface (general purpose input and output): used to connect sensors, actuators and other peripherals, supporting custom programming control





model	Device Type	Use Location	effect	Encapsulation
ESD5V0D3B	ESD	GPIO interface	Surge, static electricity	SOD323
PBZ1608A102Z0T	magnetic beads	GPIO interface	Eliminate high-frequency interference	1608

4.13 Use high-quality components



Select high-quality capacitors, inductors and other components to reduce the electromagnetic interference caused by the components themselves; high-quality components have stable performance and can reduce the generation of electromagnetic interference to a certain extent, and improve the overall electromagnetic compatibility of the oxygen concentrator.

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