CHAPTER 1 INTRODUCTION

The 20th century saw many developments in the field of electronics because of basically two reasons

1. The development of transistors, which forms the basics of everything that is electronics.
2. The development of IC, which helped in the fabrication of fast, compact & sophisticated electronic circuits.

In the 21st century we are going to see some radical changes in the approach towards electronics. These are :

1. The replacement of semiconducting devices with superconducting devices.
2. The use of new classical theories in physics like the relative physics & quantum mechanics to explain various phenomenon, application & working of electronic devices.

The first step to integrate the previously separate branches, electronics &super conductivity was done by the scientist called Brian Josephson by the invention of the JJ in the year 1962 for which he received the Nobel prize in the year 1973.

The analysis of the device is impossible using classical theories of physics. The device has immense potential & numerous applications in almost all fields of applied electronics.

CHAPTER 2 THE JOSEPHSON JUNCTION

The **Josephson junction** (JJ) is basically an insulator sandwitched between the two semiconductor layers. Hence the device is also called as a SIS (Superconductor-Insulator-superconductor). A tunneling phenomenon called Josephson tunneling takes place through the insulator when the thickness of the insulator is very thin (less than 1.5 nm) and the insulator turns into a superconductor due to the tunneling of charge carriers from the 1st to the 2nd super conductor; through the insulator.

The basic block diagram is as follows.

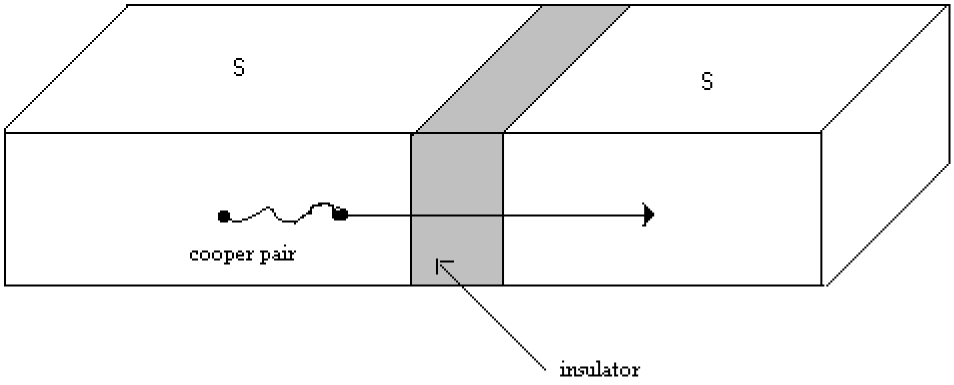


figure :1

To explain the working of the device we need to analyze the principles of superconductivity & the principles of tunneling. The superconductivity is explained in terms of BCS theory & tunneling in terms of the uncertainity principle.

2.1 SUPERCONDUCTIVITY

It is a remarkable property in which there is a complete loss of resistivity in a metal or alloy, usually at temperature close to the absolute zero & this property was discovered by Kammerlingh Onnes. As perfect conductors, superconductors will carry current without resistance loss, i.e, the current applied will persist forever without any loss of power. These materials are also perfect diamagnetic & magnet placed above the super conductor will levitate under its own magnetic field.

Low temperature superconductors exhibit property at temperature near-250°C. LBCO &certain alloys of La & Ba shows this property near 35k, $RBa_2Cu_3O_7$, $Bi_2Sr_2ca_2Cu_3O_{10}$ can show the property near 90k. Thallium based & mercury based cuprates can show superconductivity at 134k. Progress in the development of high temperature superconductivity & particular cuprate based superconductors has made significant advances. Some organic compounds have lately been developed as Superconductors.

2.2 SPIN CLASSIFICATION

One essential parameter for classification of particles is their "spin" or intrinsic angular momentum. Half-integer spin like fermions are constrained by the Pauli exclusion principle whereas integer spin like bosons are not. The electron is a fermion with electron spin 1/2.

The spin classification of particles determines the nature of the energy distribution in a collection of the particles. Particles of integer spin obey Bose-Einstein statistics, whereas those of half-integer spin behave according to Fermi-Dirac statistics.

Fermions : Fermions are particles which have half-integer spin and therefore are constrained by the Pauli exclusion principle. Fermions incude electrons, protons, neutrons. The wavefunction which describes a collection of fermions must be antisymmetric with respect to the exchange of identical particles.

The fact that electrons are fermions is foundational to the buildup of the periodic table of the elements since there can be only one electron for each state in an atom (only one electron for each possible set of quantum numbers). The fermion nature of electrons also governs the behavior of electrons in a metal where at low temperatures all the low energy states are filled up to a level called the Fermi energy. This filling of states is described by Fermi-Dirac statistics.

Bosons : Bosons are particles which have integer spin and which therefore are not constrained by the Pauli exclusion principle like the half-integer spin fermions. The energy distribution of bosons is described by Bose-Einstein statistics. The wavefunction which describes a collection of bosons must be symmetric with respect to the exchange of identical particles, while the wavefunction for a collection of fermions is antisymmetric.

At low temperatures, bosons can behave very differently than fermions because an unlimited number of them can collect into the same energy state. The collection into a single state is called condensation, or Bose-Einstein condensation. It is responsible for the phenomenon of superfluidity in liquid helium. Coupled particles can also act effectively as bosons. In the BCS Theory of superconductivity, coupled pairs of electrons act like bosons and condense into a state which demonstrates zero electrical resistance.

2.3 BCS THEORY OF SUPERCONDUCTIVITY

Three scientists John Bardeen, Leon Cooper & John Schrieffer formulated the BCS theory. The theory explains superconductivity at temperature very close to absolute zero. At these low temperatures the thermal agitation energy available to the electron is very less. In such a case they are much in the influence of +vely charged lattice. The lattice vibrations forces the electron to pair up that means the net interaction between two electrons become attractive rather than repulsive. These pairs of electrons are called Cooper pairs.

Formation Of A Cooper Pair

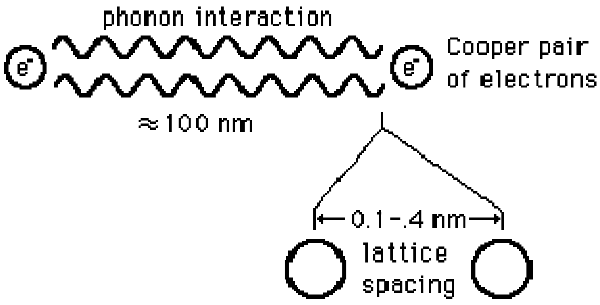


figure :2

The packets of sound wave energy called phonons act as moderator in this process. Phonons are always present in the lattice. When an electron pass by the +vely charged lattice, the lattice distorts leading to the emission of phonons and forms a trough of +vely charged particles around the electron. Before the lattice springs back to the normal position another electron is drawn into the trough. The force exerted by the phonons overcome the electron natural repulsion & keep the electron together. It is through this process that the electrons that must repel each other attract each other. Thus there is an electron –lattice-electron or bound pair interaction for a cooper pair. Since electron moves faster than ion the electrons in the pair will be widely separated. The distance between the electrons in the pair (coherence length) is about 1000 A^o (lattice spacing is about 1 A^o) . The cooper pairs are coherent as they pass through lattice in unison.. When one of the electrons that make up the cooper pair passes close to an ion, the attraction between the +ve ion & -ve electron cause a vibration to pass from one ion to another until electron of the pair absorbs the phonon. It is this exchange of phonon that keeps the cooper pair together**.**

Electron Lattice Interaction

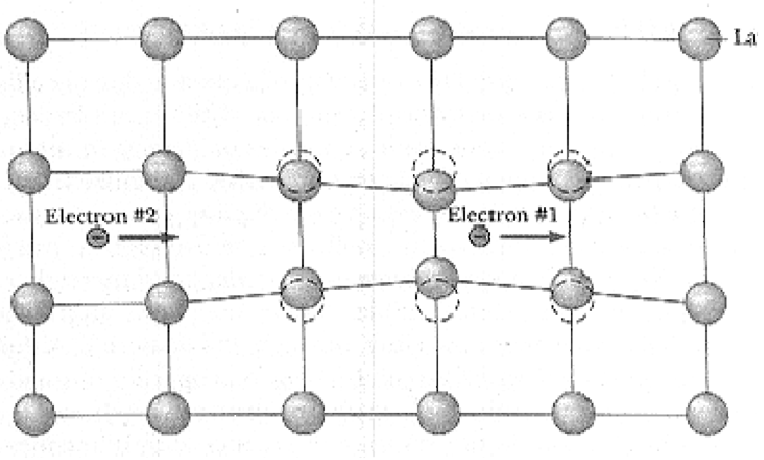


figure :3

The cooper pair has twice the charge of electron. Electrons are fermions which obey the Fermi-Dirac statistics and Pauli's exclusion principle-which allows only one electron to exist in one quantum state. Cooper pair are quasi Bosons unlike electron which are fermions. Cooper pair obeys the Bose-Einstein relationships and are allowed to be in the same quantum state. Electrons have a spin of ½, but bosons have spin of 1.

In contrast to the normal metal in which each individual electron has its own wave function, in a superconductor all cooper pairs are described by a single wave function.

$$\boldsymbol{\Psi (\gamma) = [n_S (\gamma)]^{1/2} \exp [i\varphi (\gamma)]}$$

where $n_S(\gamma)$ can be considered as the number of superconducting cooper pairs. With the discovery of BCS ground state wave function, the fundamental reasons for the remarkable properties became clear.

The BCS model was selected to include the residual attraction between the electron (more accurately quasi particles) of opposite spins and momenta close to the Fermi surface (within the cutoff energy). The BCS ground state was taken to be a coherent state, for which the number of pairs in any given region is not well defined but compromise a system whose order parameter has well defined phase. The function, Φ (γ)

is the relative coordinate wave function of a pair in real space-the same for all pairs. Thus within the pairing approximation, all the pairs are in the same state in the ground state wave function. The function, Ψ (γ) is spherically symmetric(S wave symmetry)

Bosons can be seen to have more of wave nature than particle nature, compiled with the fact that at very low temperature the cooper pairs fall into very low energy levels and an energy gap is formed , the cooper pair can flow through the lattice without any interaction with the lattice & hence no resistivity. Resistivity is formed by the interaction of the moving electron with lattice in normal conductors. Since there is no interaction, there is no resistivity & hence superconductivity.

2.4 OBSERVABLE EFFECTS IN SUPERCONDUCTORS

The important observable effects in superconductors are:-

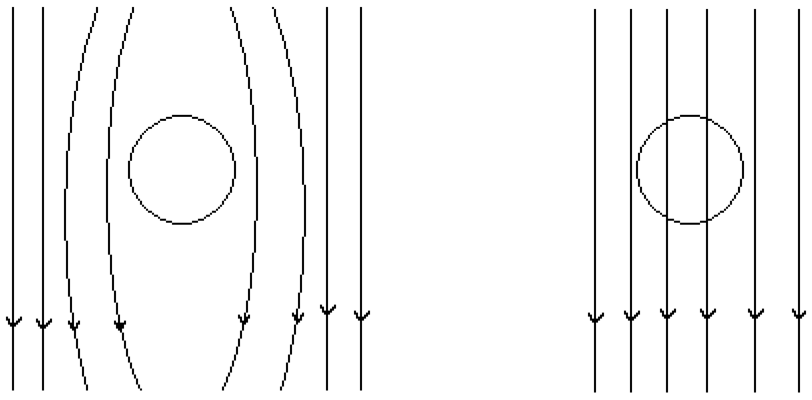
1. Zero resistance at temperatures below the critical temperature. This causes no power loss in the device.
2. Messiner – Oschenfield effect: there is complete expulsion of magnetic field from the interior of the Superconductor. The magnetic inductance becomes zero when it is cooled below Tc in a week magnetic field Hc, above which superconductivity disappears. This field is temperature dependent. The expulsion of magnetic flux causes source magnetic energy. So long as this cost is less than the consideration energy gained by going from the normal to the superconductivity becomes too large, the cost in magnetic energy will outweigh the gain in consideration energy, and the superconduction will become partially or totally normal.
3. Flux quantization: Magnetic flux is classically considered as continuous but quantum mechanically it is quantized and exists only as an integral multiple of the basic quanta of magnetic flux called fluxon.
4. Another important notable effect is that both Ohm’s law and Kirchowfs law of current and voltage are invalidated in superconducting states. There are other laws, which govern the voltage- current relationships.

2.5 TYPES OF SUPERCONDUCTORS

The superconductors are divided into two types: the type1 and the type2 superconductors.

Type1: Blow a critical field called Hc, which increases as the temperature decreases above Tc, the magnetic flux is excluded from the interior of the material, which is said to be perfectly diamagnetic. If applied field increases above Hc, it ceases to be a superconductor and the flux penetrates it completely.

TYPE I



H<Hc H>Hc

figure : 5

Type 2: For type 2 super conductors there are two critical fields Hc1 and Hc2. If the applied field is less than the critical field Hc1, the superconductor completely excludes the field from the interior, just as type 1. At just above Hc1, flux starts to penetrate the material through microscopic filaments called fluxoids or vorticers. Each fluxoid consists of a normal core in which the magnetic field is largely surrounded by a superconducting region in which a persistent current flows which maintains the field in the core. The total magnetic flux in each fluxoid is exactly equal to the integral multiple of fluxon. As the field is further increased and increases above Hc2 the field starts penetrating the material completely and the material ceases to be a superconductor.

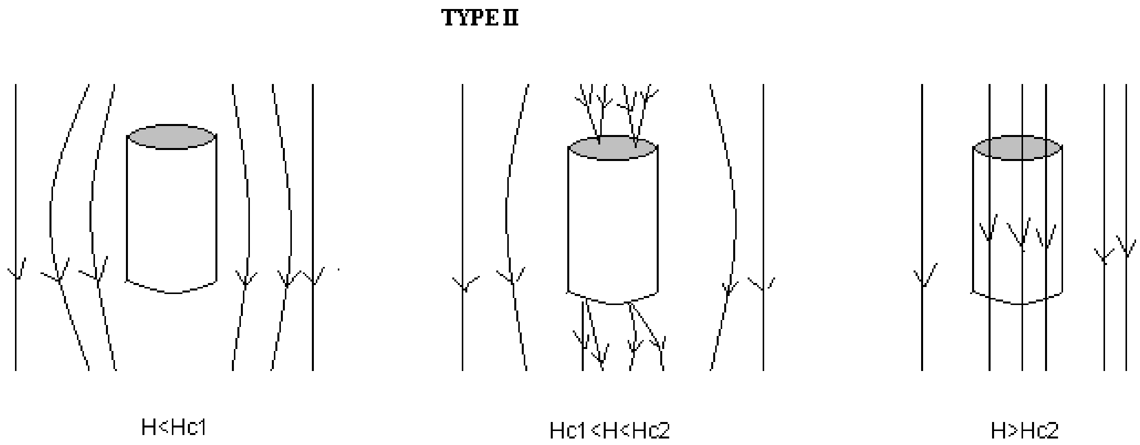


figure : 6

2.6 TUNNELING PRINCIPLE

Tunneling is purely a neoclassical theory. It is based on the Heisenberg's uncertainty principle. It can be inferred from the principle that we cannot be absolutely certain or uncertain about the happening of an event. That is the probability of happening of the event can neither be 1 or 0. It should be somewhere in between. Previously an orbit was defined as the place where you find an electron but now we define it as the place where there is maximum probability to find an electron.

Consider that the probability to find the electron is 99.99%, and then the probability to find it outside its orbit which is its most preferred state of energy is .01 %, that is .0001. This means that if we take a collection of 10000 electrons we have the probability to find one electron outside its most preferred state of energy. The expectation increases as the number of electrons considered increases. The expectation is given by the equation: xf(x) where x denotes the number of items considered and f(x) is the probability density function. Hence if we take a collection of 10^8 electrons we can expect

10^4 electrons outside its most preferred state of energy. These electrons have traveled outside their most preferred state against the laws of classical physics. Hence it can be seen that electrons can cross energy barriers without them having the energy to cross the barrier. This is the principle of tunneling.

In a Josephson Junction we have the difference that instead of electrons we have quasiparticle, the cooper pair tunneling from the first superconductor to the second through the insulator region which poses an energy barrier to the flow of cooper pairs. If the barrier is sufficiently thin we cannot say with certainity that the particle exist only on one side. However the wave function amplitude for the particle is reduced by the barrier so that we can reduce the wave function on the right hand side to the point that negligible tunneling occurs.

The tunneling principle has been previously used to explain the working of some semiconducting devices like the tunnel diodes.

CHAPTER 3 JOSEPHSON EFFECTS

There are two Josephson effects:

1. DC Josephson Effect
2. AC Josephson Effect

3.1 DC JOSEPHSON EFFECT

According to Brian Josephson, if two superconductors are separated by a sufficiently thin layer of insulator (10 A thick), weak superconducting currents can tunnel through the potential barrier without any applied voltage, that is, the resistance is zero. In a given superconductor, the pairs are represented by

$$\Psi = \Psi_0 e^{i\phi}$$

where Φ is the phase and is the same for every pair. They are said to be "phase coherent"

The supercurrent through the barrier is related to the phase difference on the left and right sides of the junction. If the superconductor on the left has phase Φ_1 and that on the right has phase Φ_2, Josephson showed

$$I_s = I_{max} \sin(\phi_2 - \phi_1) = I_{max} \sin \delta$$

This current is called the DC Josephson current and I_{max} is the maximum current across the junction under zero voltage conditions ,also called as the critical current (I_{C}). The critical current is the current above which superconductivity ceases to exist. The tunneling of cooper pairs back and forth through the JJ weakly couple the two superconducting condensates and reduce the total energy of the system. The Josephson coupling energy is given by

$$\mathbf{E\ (\partial) = -Ej\ cos\partial}$$

To understand this phenomenon, consider two separate superconductors, each described by its wave function. These wave functions are not related.

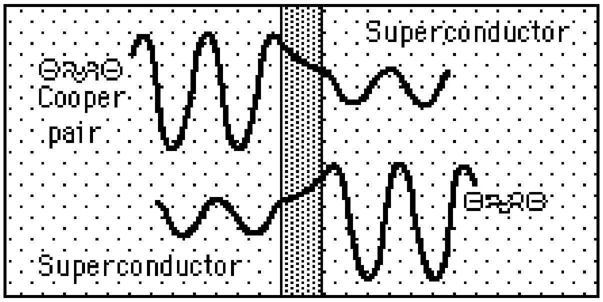


figure : 7

If we now couple these two superconductors, their wave functions become locked together and phase coherence extends through both of them. A phase difference can exist between both the S which means that a superconducting current can flow.

Consider two identical superconducting electrodes, A and B separated by a thin insulating barrier. For sufficiently weak Superconductor the cooper pairs will tunnel through the barrier and the JJ will behave like a superconductor. There is no voltage drop across the barrier. At zero voltage the current that passes through the junction will depend upon the phase difference ($\Phi_A - \Phi_B$) of the macroscopic wave function.

If the injected current I_g through the junction is higher than the critical value Ic, the junction becomes resistive and there occurs a voltage drop V across the junction. One can therefore define a characteristic voltage drop V, across the junction. Theoretical considerations give $V_t = \Pi\ \Delta/2e$ where Δ is the energy gap.

When some external voltage is applied it causes the phase difference between the order parameters to increase. This causes increase in the DC Josephson current. It can be seen that the rate of change of phase difference is directly proportional to the applied voltage.

VI Characteristics

The VI characteristics (to be specific, IV characteristics can be explained on the basis of the explanation for the DC Josephson effect. It can be seen that when the current is below Ic, there is no voltage drop. As the current increases just above Ic, the voltage drop is $\Pi \Delta/2e$.

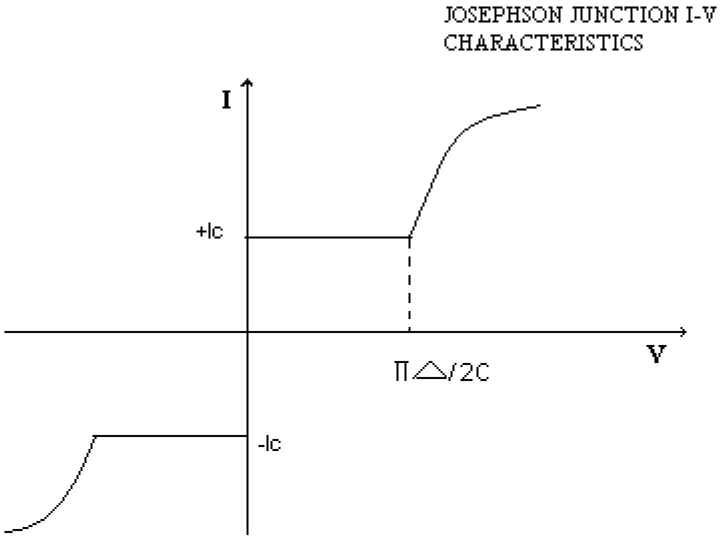


figure: 8

As the current is further increased the voltage rises somewhat nonlinearly with current in a small region. The nonlinear increase can be attributed to the fact that there is nonlinear variation of junction resistance in this region because of non linear variation in number of tunneling cooper pairs.

3.2 AC JOSEPHSON EFFECT

Josephson predicted that when a finite voltage V is applied across the junction there will be a flow of current. Solution to Schrödinger's equation gives the expression for current as,

$$I = Ic \sin [\partial (0) + [(2eV/h) t]$$

This shows that current oscillates with frequency ω_j=2eV/h where V is the applied voltage, h is the constant; e is the basic electronic charge. If V is a constant then the phase difference can be given by the equation $\partial=\partial$ (0) + ωj t. Then d∂/dt = ω_j. That is the ratio of change of phase difference is directly proportional to the applied voltage.

This is a very important relationship because it can be seen that a sinusoidal voltage of frequency ω is produced across the junction, which is directly proportional to the applied dc voltage. Hence a JJ is seen to act as a voltage controlled insulator (**VCO**)

The frequency produced is 484 MHz per µV of applied dc voltage. Hence it is very easy to produce frequencies in the range of 1THz. This is an important application of the device.

CHAPTER 4 APPLICATIONS OF JOSEPHSON JUNCTION

4.1 HIGH FREQUENCY DETECTOR

If a dc bias voltage and a microwave signal of frequency ω are applied to the junction simultaneously, a form of mode locking will occur when the frequency ω is equal to the oscillation frequency ω_j. As a result steps of constant size at voltages Vn=nhw/2e will be formed. The voltage step is given by Vs = hw/2e .These constant voltage steps are called sapphire steps and these can be observed in the VI characteristics of the device as follows.

VI characteristics

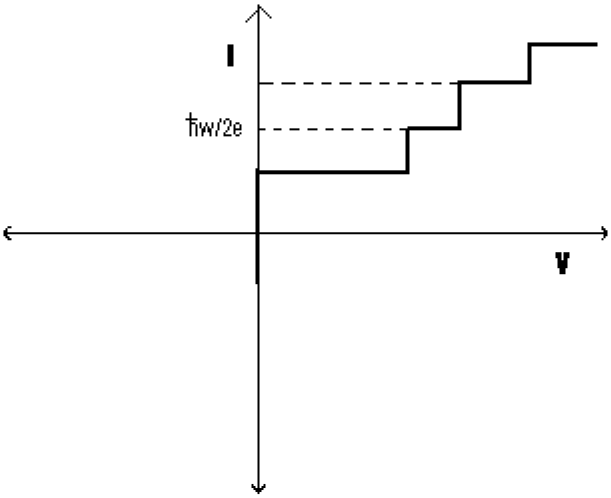


figure : 9

This phenomenon helps JJ to be used as a high frequency detector. To detect a particular frequency, JJ should be tuned by applying a variable voltage and sapphire steps are observed at the output. By measuring its step size, we can directly measure the frequency of the external applied high frequency. This is much improved over the conventional high frequency detectors, which use narrow band pass filters. The narrow band pass filter cannot achieve perfect cutoff. In case of JJ the mode locking occurs only for that particular frequency and they are very much accurate and also work at much higher frequencies.

4.2 VOLTAGE STANDARD

One of the best known applications of JJs is that of a voltage standard. It is based on the AC Josephson effect. The formation of sapphire steps has already been noted. When a DC voltage is applied to a Josephson junction, an oscillation of frequency

$$f_{\text{Josephson}} = \frac{2e\ \Delta V}{h}$$

occurs at the junction. Since this relationship of voltage to frequency involves only fundamental constants and since frequency can be measured with extreme accuracy, the Josephson junction has become the standard voltage measurement.It is independent of the junction material or other properties of the junction. Josephson junction standards can yield voltages with accuracies of one part in 10^10. since the frequency can be measured with very high precision , one can transfer the precision to the voltage. The frequency standard is based on the cesium atomic clock. Since voltage can be directly represented in terms of frequency, the cesium standard can also be employed for the voltage. JJ voltage standard is three or four orders better than the western cell standard.

The Standard Volt

The standard volt is now defined in terms of a Josephson junction oscillator. For one microvolt applied to the junction the frequency is

$$f_{\mathrm{Josephson}} = 483.6\ \mathrm{MHz}$$

Therefore the **standard volt** is now defined as the voltage required to produce a frequency of 483,597.9 GHz.

4.3 SQUID

The SQUID, **Superconducting Quantum Interference Device** consists of two superconductors separated by thin insulating layers to form two parallel Josephson junctions.It is extremely sensitive to the total amount of magnetic field that penetrates the area of the loop –the voltage that you measure across the device is very strongly correlated to the total magnetic field around the loop. The great sensitivity of the SQUID devices is associated with measuring changes in magnetic field associated with one flux quantum.

SQUID

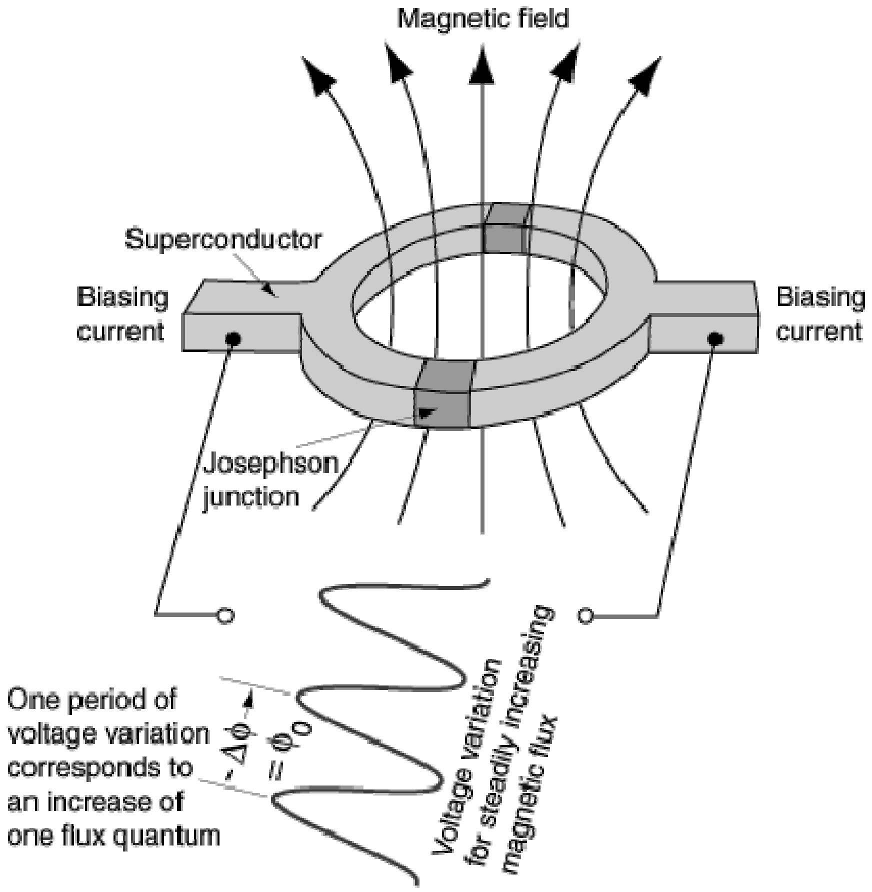


figure :10

One of the discoveries associated with Josephson junctions was that flux is quantized in units

$$\Phi_0 = \frac{2\pi\hbar}{2e} \cong 2.0678 x 10^{-15} tesla \cdot m^2$$

If a constant biasing current is maintained in the SQUID device, the measured voltage oscillates with the changes in phase at the two junctions, which depends upon the change in the magnetic flux. Counting the oscillations allows you to evaluate the flux change which has occurred.

SQUIDs are being used for research in a variety of areas. Since the brain operates electrically, one can, by sensing the magnetic fields created by neurological currents, monitor the activity of the brain or the heart. You can also use a SQUID magnetometer for geological research, detecting remnants of past geophysical changes of the earth's field in rocks.

Similarly, changes in the ambient magnetic field are created by submarines passing below the surface of the ocean and the US navy is very interested in SQUIDs for submarine detection. SQUIDs are also of considerable use in the Research Laboratory in specially designed voltmeters, in magnetometers and susceptometers and in scanning SQUID microscopes .In this last instrument, a squid is scanned across the surface of a sample, and changes in the magnetism at the surface of the sample produce an image.

A **SQUID voltmeter** is basically a magnetometer .The voltage, which needs to be measured, is passed through a conductor and the current produces a magnetic field, which can be detected by the SQUID magnetometer. A meter can be directly calibrated in terms of voltage. These are high sensitivity voltmeters and can measure in the range of Pico volts.

4.4 JOSEPHSON DEVICES

Devices based upon the characteristics of a Josephson junction are valuable in high speed circuits. Josephson junctions can be designed to switch in times of a few picoseconds. Their low power dissipation makes them useful in high-density computer circuits where resistive heating limits the applicability of conventional switches.

4.5 RAPID SINGLE FLUX QUANTUM LOGIC

The fastest integrated circuits in the world today are unique for their technology as well as for their speed. They are made with a super conducting material, niobium rather than a compound semiconductor. Their exotic technology is based on

Josephson junction devices and the transmission of single quanta of magnetic flux along superconductor interconnects. A new logic family that promises huge improvements on circuit speed and has the potential to replace the existing TTL and CMOS logic is the RSFQ.This logic draws on an intrinsic property of these devices, namely that within a closed section of superconductor material, magnetic flux can exist only in discrete or quantized amounts. These are multiples of the magnetic flux quantum Φ_0 ,which is equal to h/2e or $2.07*10^{-15}$ wb.

. In RSFQ circuits, it is not a static voltage level, but the presence or absence of quantized magnetic flux (fluxons) that represents 1 or 0 respectively . The basic RSFQ structure is a superconducting ring that contains one Josephson junction plus a resistive shunt outside it .Rather than use the escaping flux directly, RSFQ relies on the fact that the movement of a fluxon into or out of this loop induces a very short voltage pulse across the junction. If the Josephson junction were a square, 1 µm on a side, this voltage pulse would be about 1 ps long and 2 mV in amplitude. The SFQ pulses become briefer and taller as the junctions dwindle in size, but the voltage-time product of the pulse (which is equal to the quantum of magnetic flux passing through the junction) always remains the same: 2mV-ps, which is equal to 2 $x10^{-15}$ weber. The energy consumed each time an SFQ pulse passes through a junction is just the circulating current of about 100 µA times the amount of flux $*_0$ or about 2 x 10^{-19} joule, which is very small.

The voltage pulses can be transmitted ballistically to other gates over either microstrip transmission lines or active Josephson transmission lines, the latter so-called because they contain extra Josephson junctions as repeaters of the pulse, providing delays for timing synchronization. Naturally, all interconnects are superconducting and therefore lossless, at least at dc, and the losses remain low, compared to metals at room temperature, up to clock frequencies of about 750 GHz.

To transfer the pulses as bits of information, a clock provides a steady stream of timing pulses (one for each clock cycle), such that the presence of a data pulse within the clock cycle denotes a logic 1, while the absence of the pulse denotes a logic 0.

Combinations of Josephson junctions can then be interconnected to achieve SFQ pulse fan-in and fan-out and create a variety of logic structures.

The basic RSFQ structure is a superconducting ring which contains one JJ plus a resistive shunt outside it**.** Any binary function can be constructed from three types of RSFQ building blocks. The transfer block, a Josephson junction [indicated by an X] plus a 6-pH inductor [left], moves pulses from one device to another. The storage loop, a junction and an inductor of about 12 pH, stores pulses in a persistent current loop, Ip [middle]. The decision-making pair, which consists of junctions of two different sizes [right], determines whether or not to send a pulse to the next device. Any binary function can be constructed from these elements.

RSFQ Building Blocks

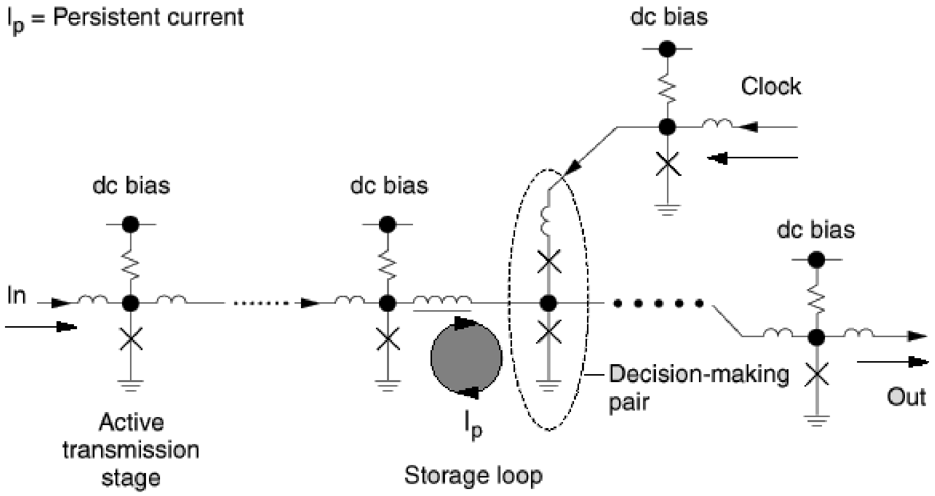


figure :11

The operation of an RSFQ reset-set flip flop gate is a simple example .If a set pulse arrives, J1 transmits it into the quantizing inductance loop, where it becomes trapped as a circulating current--the 1 state. This current biases J3, so that when a clock/reset pulse arrives at the gate, it causes J3 to transmit the stored fluxon to the output, thus resetting the flip-flop to the 0 state. Alternatively, if no set pulse input has occurred during the clock period and a clock/reset pulse arrives, the unbiased J3 cannot transmit the pulse and J2 is forced to let the fluxon escape the circuit. Result: no pulse at the output.

RSFQ Reset Set FlipFlop

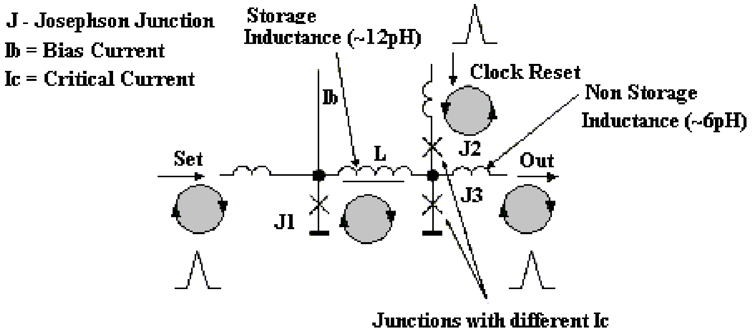


Figure :12

The first RSFQ products will probably leverage superconductor superiority in performing high-speed and high-accuracy analog-to-digital conversion. Given adequate resources, the next few years are likely to see the first superconductor digital RF modules for both wireless communications base stations and high-performance instrumentation. Other potential applications include petaflops computing platforms and high-throughput and high-density network switches. In short, thanks to two key features--speed conjoined to low power and analog-to-digital quantum accuracy--RSFQ circuits should extend digital power and flexibility directly into the RF and microwave domains.

Such applications are now practical because the linewidths of Josephson junction devices are shrinking to about 1 µm--down from 2-3 µm--pushing the performance of these very large-scale integration (VLSI) ICs well past anything their semiconductor counterparts can do. Meanwhile, the development of powerful, small, closed-cycle refrigerators makes it practical to integrate room temperature semiconductor systems with cryogenic superconductor systems. Hybrid systems of this kind will allow RSFQ to undertake the fastest tasks, with semiconductors (possibly chilled) performing functions that need large-scale integration, lower speed, and the interface to room temperature.

4.6 JOSEPHSON JUNCTION QUANTUM COMPUTER

A superconducting qubit (or quantum bit), which consists of a micrometer, sized loop with three or four Josephson Junctions, has two persistent currents of opposite direction as its two states. Since Kirchoff's current law is not valid in superconducting states such coexistence of states can easily be achieved. The states of the qubits, manipulated with magnetic fields and measured with a SQUID, can be brought into quantum coherence to perform quantum computing. Classical bits can also be obtained from these superconducting loops by increasing its critical current making it possible to base processor array architecture on this qubits (quantum bits used in a classical way). Such a classical computer might also serve as pre and post processor.

4.7 DIELECTRIC BASE TRANSISTOR

The original concept of Dielectric Base Transistor is based on resonant tunneling from a superconducting emitter to a superconducting collector.

Dielectric Base Transistor

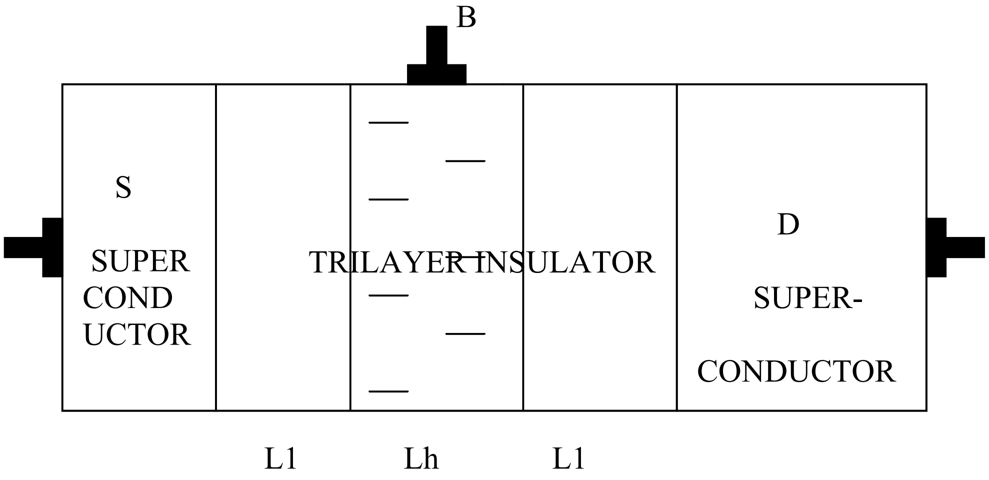


Figure :13

The charge carriers tunnel resonantly through a dielectric barrier that contains defect states of well-defined energy. This barrier is a trilayer, consisting of defect containing, high permittivity insulator Lh having a high dielectric constant sandwiched between two dielectric layers L1, having a lower dielectric constant. Because Lh transmits an electric field well, a voltage can shift the energetic position of the defect levels applied to the base electrode connected to the edge of Lh. The device is highly precise transistor, as Ice depends on the precise energy of the resonant states, and thus on V_B .The variation of the energy states is brought about by the applied voltage, which causes the tunneling current flowing from drain (D) to source (S) to charge. Hence, depending on the base voltage the drain to source current varies and this produces amplification.

Switching times of the order of 0.5psec or less can be obtained. The device is highly sensitive and very high voltage and current gain can be achieved.

4.8 JOSEPHSON JUNCTION X RAY SPECTROMETER

Superconducting X ray spectrometer are being developed to exploit the small binding energy in order to measure the energy of X ray photons with great precision. In a JJ X ray spectrometer, X ray photons are absorbed in the superconductor resulting in non -equilibrium distribution of quasi particles and photons. The number of quasi particles produced is directly proportional to the number of photons absorbed, i.e. the X ray energy. When the superconductor is cooled far below the critical temperature the cooper pair tunneling is suppressed by a magnetic field. The current flowing through the insulator is directly proportional to these photo injected quasi particles .

The device is of very small dimension 0.1mm by 0.1 mm to reduce capacitance and hence the noise. To ensure high quality the thickness is of the order of 300nm thick. The device is fabricated using trilayer process.The junction is patterned in a sinusoidal shape. This helps in reducing the magnetic field needed to suppress the dc Josephson current.

When the X rays are absorbed in to the superconductor a cloud of quasi particles are formed which diffuses in to the insulator and becomes trapped. This trapping concentrates quasi particles near the barrier and increases the tunneling rate and therefore magnitude of X ray induced current. By placing Aluminium trapping layers on both sides of the barrier we increase the duration of the current pulse.

When an X ray is absorbed into one of the insulating films the photoquasiparticles will typically reach one of the superconducting layers before stopping, thereby spreading the initial cloud of quasiparticles into both the insulators and the superconductor. A detector at the output can be directly calibrated in terms of X-ray energy.

CHAPTER 5

DAZZLING TALENTS

The second-generation technology has striking attributes.

Firstly, its performance is scalable. There are no known physical barriers to decreasing size by a factor of 10 and thus increasing speed by a factor of 10, using lithography to move from today's 3-µm linewidth to 0.3 µm. Work is ongoing at the State University of New York (SUNY) at Stony Brook, to explore how far it can get by scaling simple gates to the 0.25-µm linewidths of today's semiconductor processes. In fact, data rates of more than 750 Gb/s have already been experimentally demonstrated for RSFQ toggle flip-flops having gates of this size .

Secondly, accuracy at such blinding speeds is another built-in feature of Josephson junctions. The ac Josephson effect allows the frequency of output bits (fluxons) to be inferred from a simple measurement of voltage, where each microvolt corresponds to a data rate of 483.5 Mb/s. In fact, this correspondence has been certified to 3 parts per billion by the U.S. National Institute of Standards and Technology (NIST), in Boulder, Colo. So accurate is this technique that it was adopted in 1990 as the official

Système Internationale (SI) definition of the volt in standards laboratories around the world. Digital RSFQ circuits in 1.5-µm and 0.8-µm processes have been tested at Hypres with the unambiguous results that the measured voltage is indeed a product of digital operations, and that the output data rate scales as expected--doubling with each halving of linewidth and appropriate adjustment of other circuit elements. Further support comes from theoretical studies in the United States and abroad that match well with the experimental data.

Thirdly, there's circuit density. Because Josephson devices and their superconducting interconnects dissipate hardly any power, they can be very densely packed without overheating. For instance, RSFQ circuits made with minimum Josephson junctions 0.3 µm on a side and running at clock frequencies of 250 GHz could pack individual devices as close as 1 µm, herding some 100 000 devices onto a 0.5-cm^2 chip dissipating less than 0.25 W.

More important still, signals propagate virtually without dispersion. This fact, plus the pipelined architecture made possible by superconducting passive and active interconnects, removes a key obstacle to semiconductor circuits increasing clock speeds by scaling: the significant delay associated with on-chip interconnects, as identified in the 2000 Semiconductor Industry Association's International Technology Roadmap for Semiconductors.

CHAPTER 6 JOSEPHSON JUNCTION MANUFACTURING

Today's Josephson circuits are fabricated with a process technology that is reliable, reproducible and rugged. The superconductor is made of niobium (Nb) or sometimes niobium nitride. A tunnel barrier of aluminium oxide creates a sandwiched type barrier. Such junctions are very stable and can survive long.

The niobium electrodes are deposited either by vacuum evaporation or by sputtering. The critical step is the oxidation of the Nb electrode and the formation of a thin aluminium oxide tunnel barrier. However we can obtain very uniform insulating barriers using plasma oxidation. The latest process for the development of Josephson junction is called the trilayer process. Instead of depositing and then patterning each layer of the Josephson junction separately the whole wafer is completely covered with three layers of films; first layer of Nb, then a barrier of aluminium oxide and then a final layer of Nb. Such junction shows no degradation with multiple cooling cycles to 5k and can be stored infinitely at the room temperature.

Fabrication of Josephson Junction

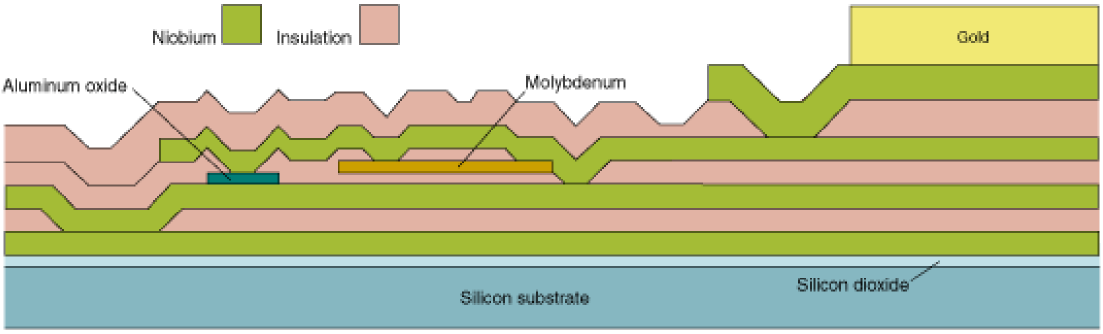


figure :14

Initially the photo-resist is applied to a substrate, which is then exposed to a light through a suitable mask .The resist is removed from the exposed areas by the developer. Subsequently we deposit the metal electrode. The resist and the metal on top of it are removed by chemical etching leaving the patterned top base electrode. In the next step one produces a resist pattern with openings for the top electrode and carries out plasma oxidation of the oxide barrier. Finally the top metal is deposited and by stripping of the resist one obtains the desired top electrode pattern of the completed junction. For industrial production and patterning of the control lines over the junction, one requires several additional processing steps like the deposition and patterning of the control lines over the junctions. Present technology enables one to fabric several tens of thousands of working junctions of a chip.

CHAPTER 7 CONCLUSION AND FUTURE SCOPE

In the coming years, Josephson junction will see immense application in the fields of electronics & applied physics. Once high temperature super conductors are developed &they become cost effective even at room temperature, Josephson junctions might almost completely replace conventional electronic system.

Up to now Josephson junctions were made with a fixed gap that, being unadjustable, limited control of the tunneling current. Research is being done to fabricate junctions whose gap can be adjusted. Researches at Bell Laboratory has demonstrated several junctions made of super conducting organic materials in which gap width can be varied. The radical changes being brought about by the Josephson junction will reach the common man in the years to come.