Facsimile Theory

The information presented here is specifically for Canon Facsimile but most of the theory can be applied to any brand.

The facsimile or fax machine was first invented back in 1842 by a Scottish electrical engineer named Alexander Bain. This was about five years after Morse invented the telegraph.

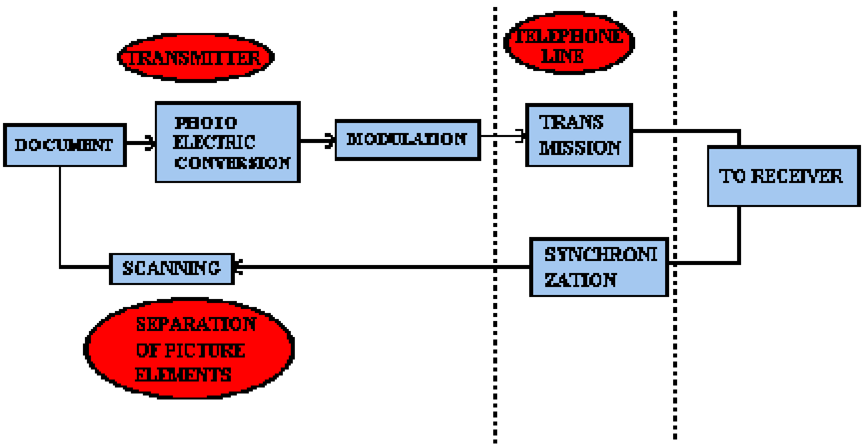
A fax machine electrically breaks up a document into very small pieces, which are called picture elements or pixels and sends them one by one to another fax by way of a phone line. The density of each element is converted to an electrical current which is sent to the receiver. The receiving fax puts the picture elements together as it receives them, until a copy of the original is made.

Types Of Facsimiles

- **GROUP I (G1) / Old FM Transmission time : Approx. 6 MIN.**
- **GROUP II (G2) Transmission time : Approx. 3 MIN.**
- **GROUP III (G3) Transmission time : Less then 1 MIN.**
- **GROUP IV (G4) Transmission time : Approx. 10 SEC.**

The operation of a fax machine is strictly specified by the International Telegraph and Telephone Consultative Committee called "CCITT". This committe sets the standards for all fax equipment thereby allowing different manufactures and faxes in different countries to communicate with each other.

Basic Process

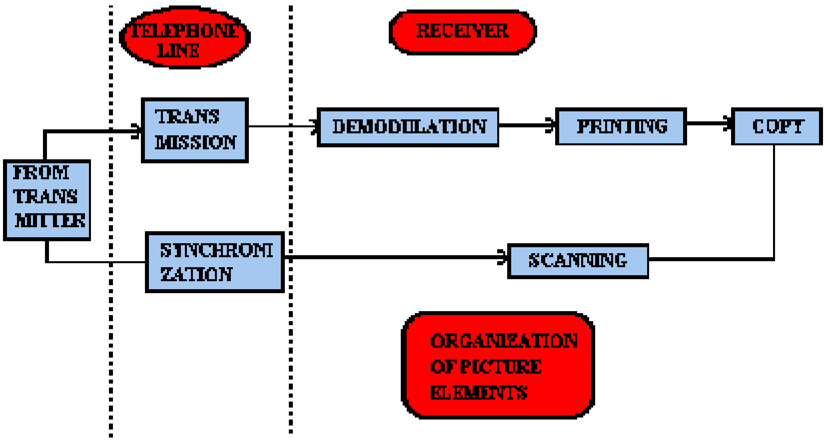


Transmiting Fax Machine

During transmission the document is broken down into pixels. This is accomplished by

reflecting the image of the document being scanned through a lens which is focused to a

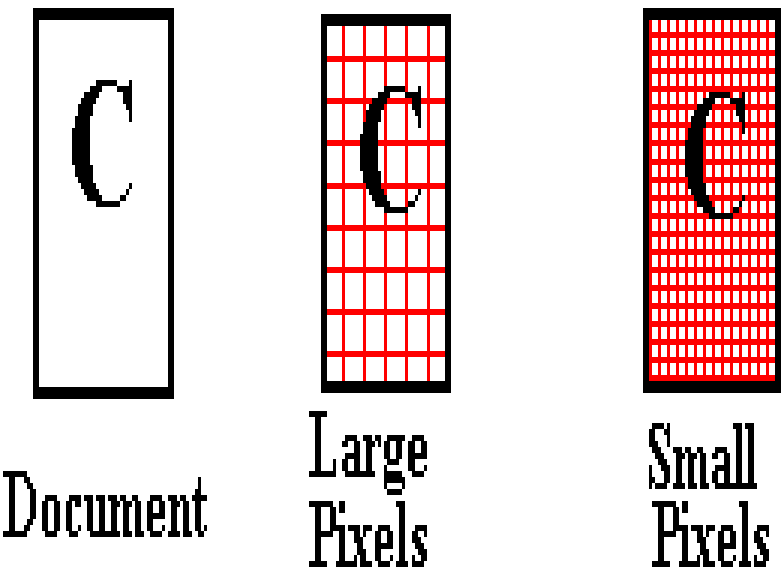
called photoelectric conversion. The electrical signals are then modulated and sent over the



Receiving Fax Machine

During reception the signal is demodulated and the electrical signals are sent to a printing device. Typically this device would be a thermal print head, bubble jet print head or laser printer. In the case of a thermal head, which is made up of many heating elements in a row, it would turn on the individual heating elements which would cause spots on the paper to turn to black. The image of the original document transmitted would then be created.

Scanning Process



The most common type of scanning method used in fax machines is the flat bed type. With this method the document moves across an optical unit one line at a time in the vertical

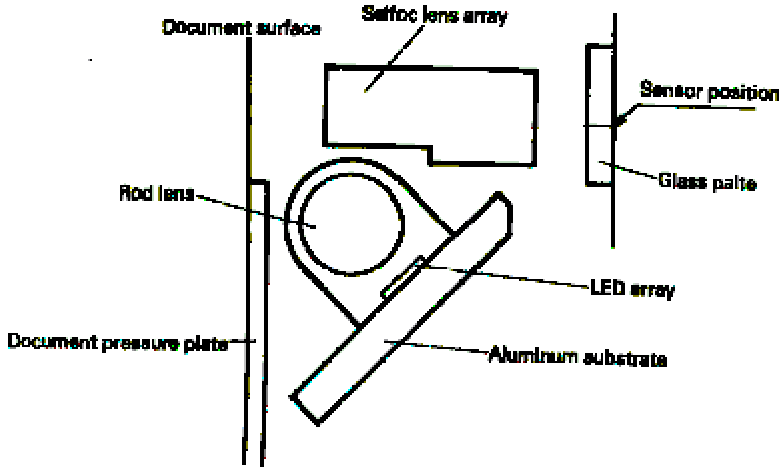
direction and then the optical device scans the line in the horizontal direction. The vertical scanning density is determined by the stepper motor moving the document over the optical device. The smaller the step the motor takes, the smaller the vertical scanning density will be. The optical device determines the horizontal scanning density. The resolution of the image being scanned can be different and therefore the size of each picture element or pixel can be different. The smaller the pixel the higher the resolution of the document. This will also increass the amount of picture data sent over the phone which will be discussed latter.

CCD (Charge Coupled Device)

The most common optical units are the CCD and the contact sensor. The CCD unit is an intergrated circuit that has 2048 image sensors on it. An image sensor works similar to a photodiode. When light shines on a photodiode a voltage is created. The level of that voltage is directly related to the intensity of light that was on it. The image sensor acts similar to a capacitor and stores this voltage and transfer it throughout the rest of the circuitry to the output of the CCD. The higher the intensity of light, the higher the voltage produced. Therefore light reflected off white paper is high and the voltage would be high. The light reflected off black print would be low and would output a low voltage. Obviously any grays or colors would create voltage levels in between these two ranges. Typically fax machines that use CCD units also have an optical unit made up of a light source, to reflect light off the original, a set of mirors and a lens to direct, reduce and focus the image into the CCD unit.

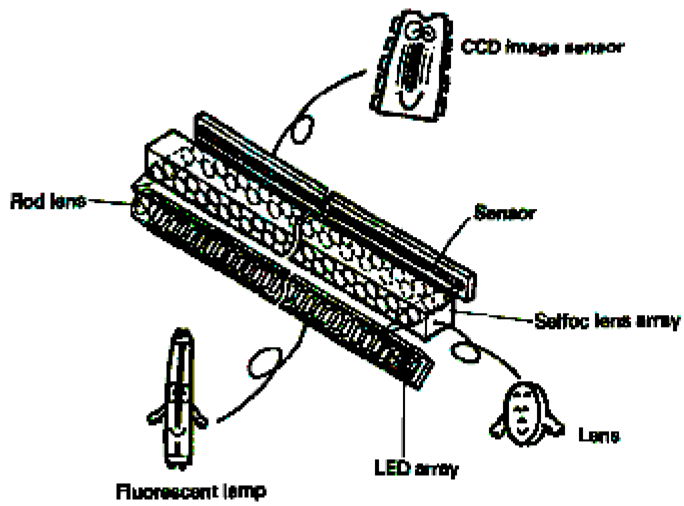
Contact Sensor

The contact sensor is very similar to the flat bed design except that the contact sensor incorporates the light source, optical unit and CCD device into one compact unit. This design allows the fax machines physical size to decreass while still maintaining quality.



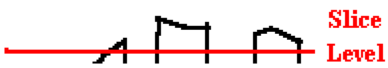
Cross section of the CS unit

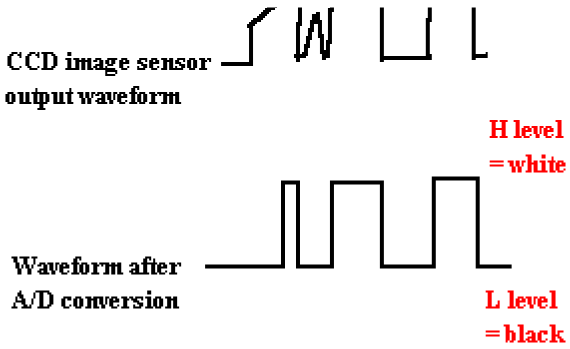
Comparison between the CS and optical system using the CCD



A/D Conversion of Image Data

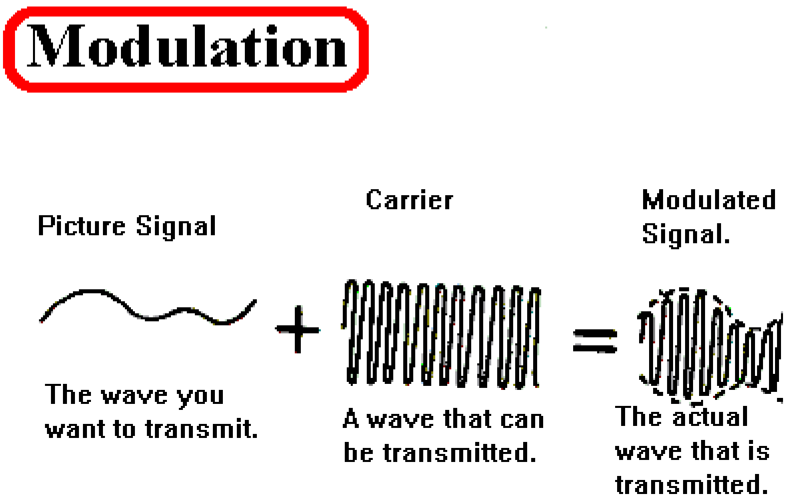
After the original document is broken down into picture elements and are converted to varying voltage levels the CCD unit outputs an analog signal for each line of data. Before the data can be transmited over the phone line it must be converted to a digital signal. Therefore the analog signal will be divided into two groups or binary signals based on the voltage level. These binary signals indicate whether the pixel will be black or white. To determine this a reference voltage is used to divide this analog signal into two groups. This reference voltage is called the slice level. Any voltage from the CCD that is above the slice level will be a white pixel (high level) and any voltage below the slice level will be a black pixel (low level).

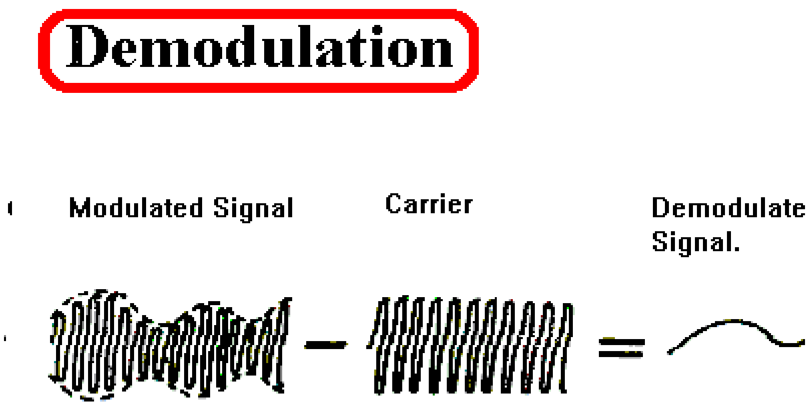




Modulation and Demodulation

There are typically three types of modulation used in fax equipment. AM (amplitude modulation), FM (frequency modulation) and PM (phase modulation). An example of amplitude modulation and demodulation is below.





With Group 3 Fax equipment there are two different modulation schemes used; Phase Modulation and Quadrature Amplitude Modulation. The modem specifications are set by CCITT and the modem types are V.27 ter and V.29. Each type of modem will transmit data at different speeds.These transmission speeds are dependent on phone line conditions and capabilities of the receiving fax machine. These speeds are:

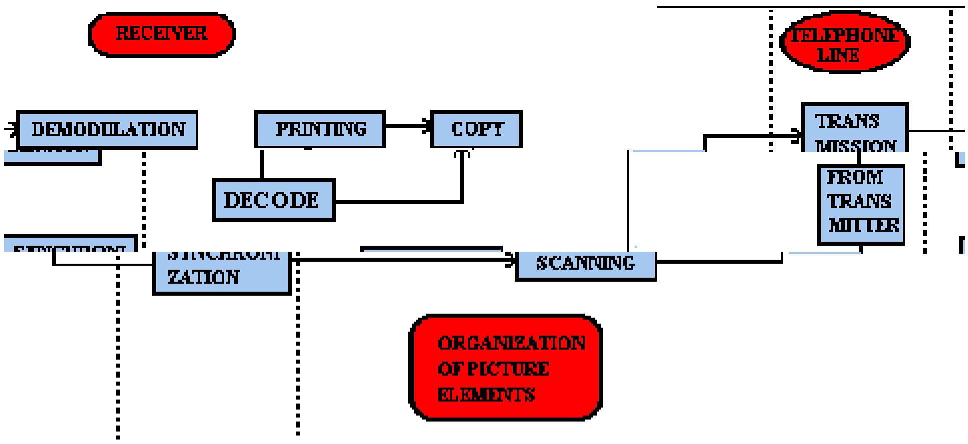
- **2400 bps V.27 ter**
- **4800 bps V.27 ter**
- **7200 bps V.29**
- **9600 bps V.29**
- **12000 bps trellis and non trellis coding/modulation**
- **14400 bps trellis and non trellis coding/modulation**
- **33.6k bps**

G3 Facsimile Picture Transmission

This section will be broken down into the following subjects:

- **Codeing Schemes**
- **Structure of the Picture Signal**
- **Transmission Time**
- **Modulation Methods**
- **Transmission Control Procedures**
- **Structure of the Binary Signals**

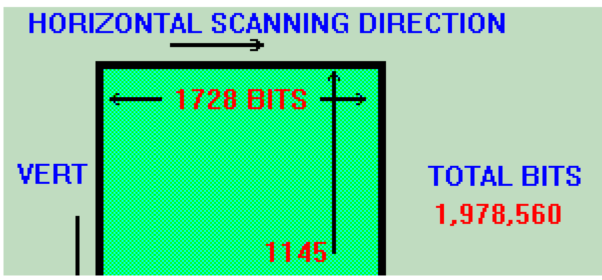
Coding Schemes



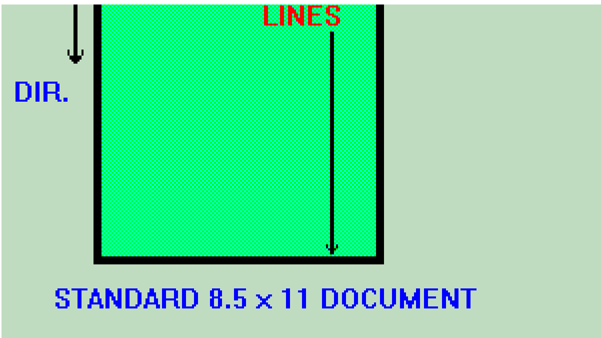
Receiving Fax Machine

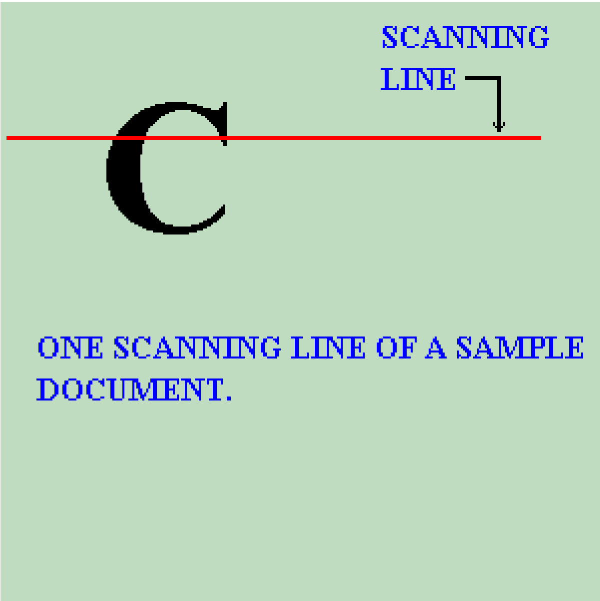
One of the features that seperate the G3 fax units from G2 or G1 is that between the a/d conversion and the modulation process is the coding process. Coding of the data prior to modulation is why G3 fax machines are considered digital transmission.

On a standard A4 size document (8.5" x 11") there are 1728 bits of data or pixels in the horizontal direction and 1145 lines of information in the vertical direction. Therefore there is a total of 1728 X 1145 = 1,978,560 bits of information on a page or approx. 2 million bits. Without coding it would take over 3



minutes to transmit this data at 9600bps, therefore we must find a way to reduce the amount of data being transmitted and thereby reduce the transmission time.



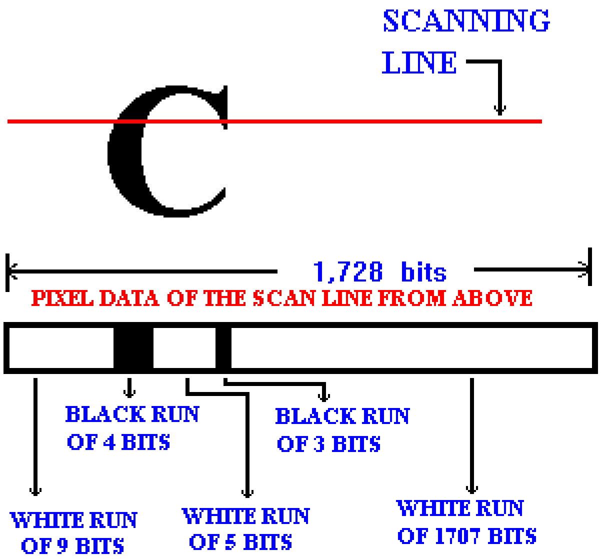


The method that G3 fax machines use to reduce data is called coding.Typically with any line of data read by a fax machine there are white areas and black areas that make up the document line. If we look at the pixel information that makes up a line of picture data you would find groups of black pixels and groups of white pixels. These groups are refered to as black run lengths and white run lengths. Based on these characteristics of run lengths of black or white data, codes can be assigned to the diferent size run lengths and only these codes need to be transmitted over the phone lines. There are many coding schemes but the most efficient one which is used by all G3 fax machines is the Modified Huffman Scheme or MH. Also a variation of this is the Modified Read Scheme (MR) and the Modified Modified Read Scheme (MMR). A newer coding scheme is the Trellis Coding Scheme. Each one of these coding methods reduce the amount of data needed to be sent over the phone lines and therefore each improvement in coding yeilds an improvement in data transmission speed

Modified Huffman & Modified Read Coding Schemes

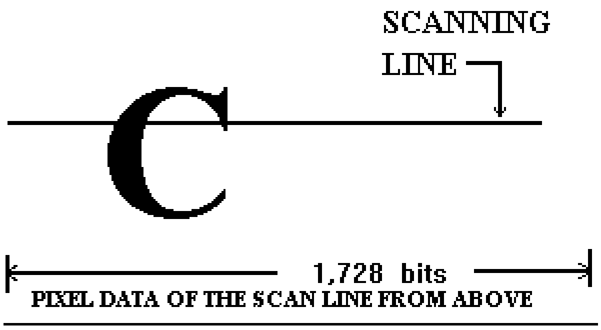
The MH coding scheme is referred to as a one dimensional coding scheme. One line of data is scanned and coded for transmission. The MR coding scheme, which is very similar to Modified Huffman, will scan each line of data, compare it to the previous line and then only code the changes. Even though MR coding is more efficient in reducing the amount of data

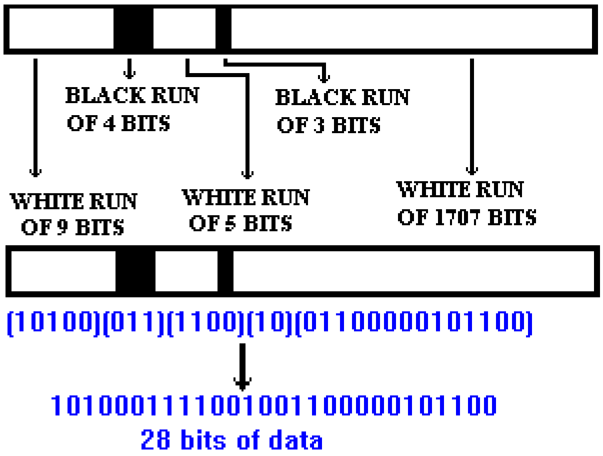
needed to be sent, the MH coding is tougher against transmission errors.



As shown above, the document that is being scanned is a large letter "C". One line is indicated which is 1,728 bits long. This line is broken down into run lengths of black and white. As shown the first run is a white run of 9 bits, the second run is of black and is 4 bits long this breaking down of the scan line to run lengths continues to the end of the line and then a new line will be scanned and broken down into run lengths.

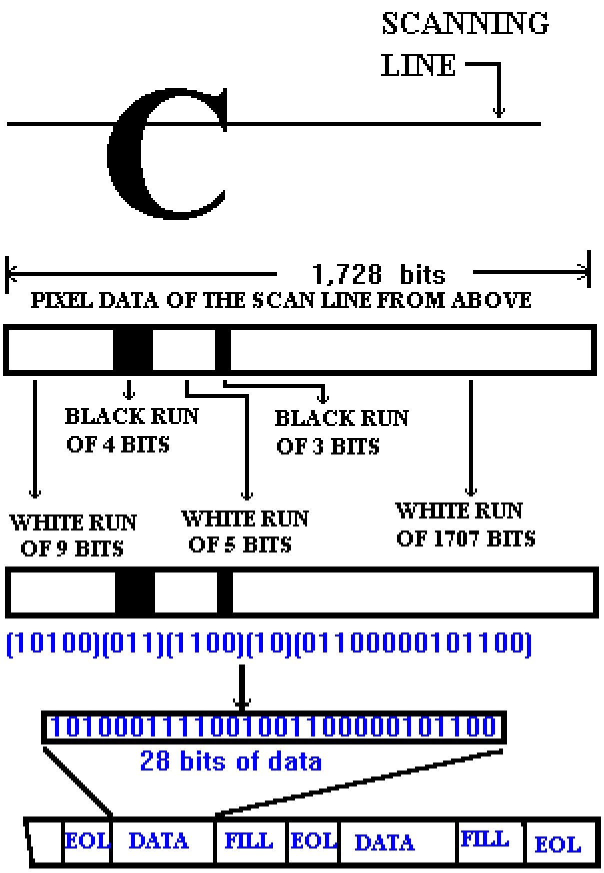
After the line is broken down into run lengths, the next step is to code it. MH coding is made up of two factors, the run length (bits) and the run color. Once the run lengths are created they are referenced to the MH coding table to determine what the binary code is that represents that particular run.





Shown above is the scan line converted to MH code which is then inserted into a standard data line.

As you can see the scan line started out as 1728 bits of information but with the MH coding performed on this line it is reduced to only 28 bits of data. Therefore the transmission time for this scan line has been greatly reduced.

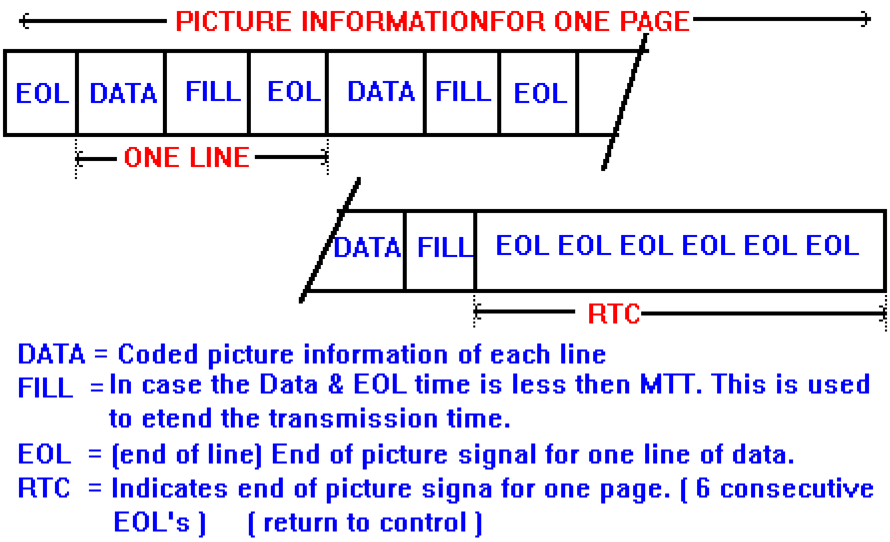


The Modified Read coding scheme is very similar to the MH coding scheme except that it will scan a line of data and then use this line for reference when it scans the next line. After comparing the two lines only the changes will be transmited therefore reducing the data ven farther. Because this coding scheme is more likely to create errors in the picture data, there is a limit to how many lins of data will be compared to a reference line. If the reference line has an error then that same error will be reproduced on any line that was compared to it. For standard transmission quality the reference is set to 2 lines and on fine quality it is set to

4 lines.

Structure of the Picture Signals

Shown below are the componets of a picture signal.



Transmission Time

Transmission time of a page or a line of data is determined by three items.

- **Transmission speed (Modulation method)**
- **Coding Scheme**
- **Memory Transmission**
- **Minimum Transmission Time**

Minimum transmission time is defined as the amount of time to send one line of data over the phone line. In G1 and G2 modes the MTT was fixed. Because of coding in G3 communication, the amount of compressed data varies from line to line. Therefore the fax machines must indicate to each other the MTT before communication can take place. If the MTT is different for each fax machine then a componet called " fill " will be inserted into the picture signal to insure that the MTT is not exceeded. One way to reduce the MTT is to perform memory to memory transmission and reception of data. This type of communication is typical in most commercial line fax machines today.

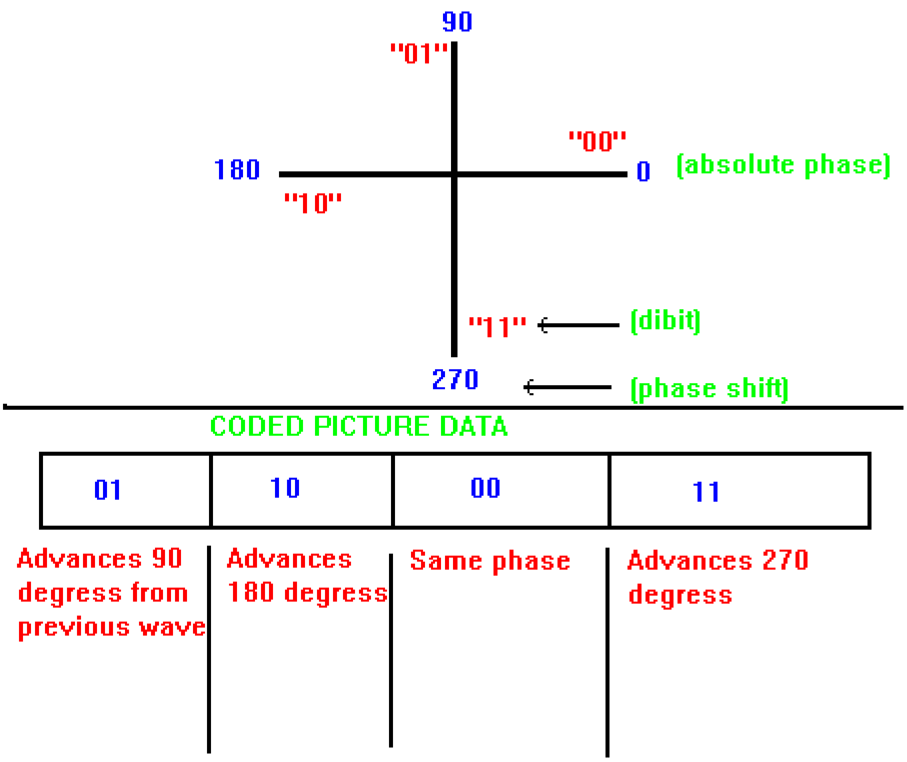
Modulation Methods

The picture information is modulated by any of the following methods.

- **2400 and 4800bps modulation method utilizing Phase Shift Keying Modulation (PSK)**
- **7200 and 9600bps modulation method utilizing Quadrature Amplitude Modulation (QAM)**
- **9600 and 14400bps modulation method utilizing Trellis Modulation**

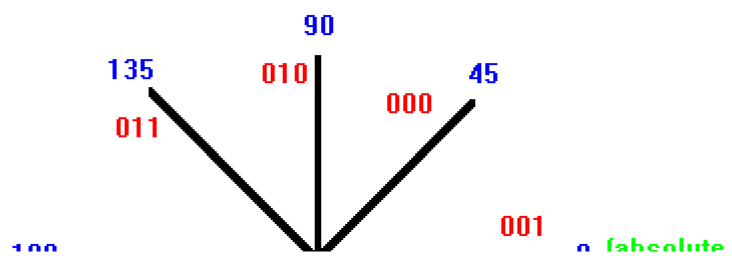
- **PSK at 2400 bps**

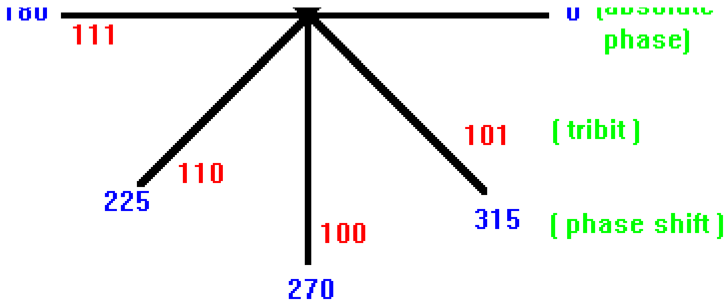
The coded picture data string is divided into consecutive dibit (2 bits) groups and the modulation is performed by shifting the carrier phase in accordance with the relationship between the dibit and the phase shift shown below. However the phase shift is shifted in respect to the preceding signal.



- **PSK at 4800 bps**

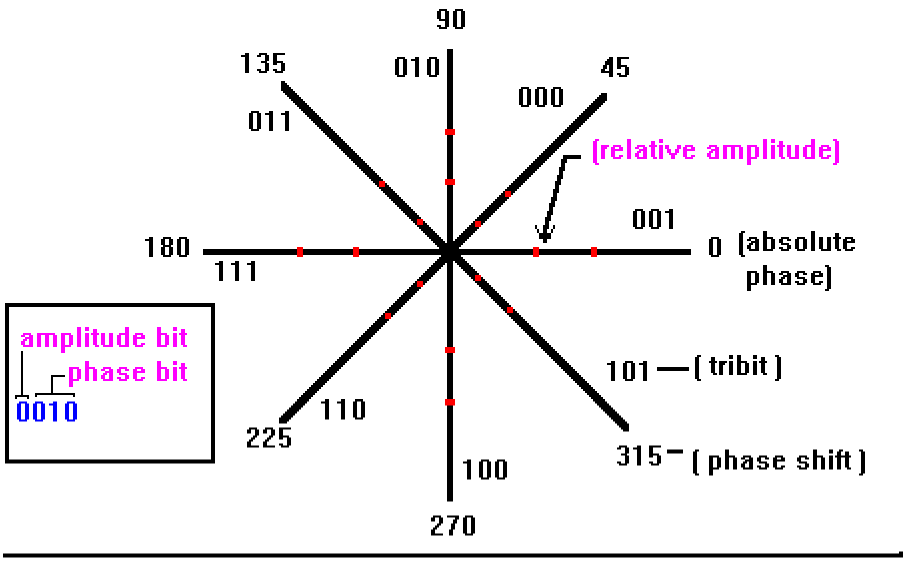
In the same way as 2400 bps, the coded data string is divided into consecutive tribits (3 bits) groups and the modulation is performed according to the relation between the tribit and the phase shift as shown below.





- **QAM at 9600 bps**

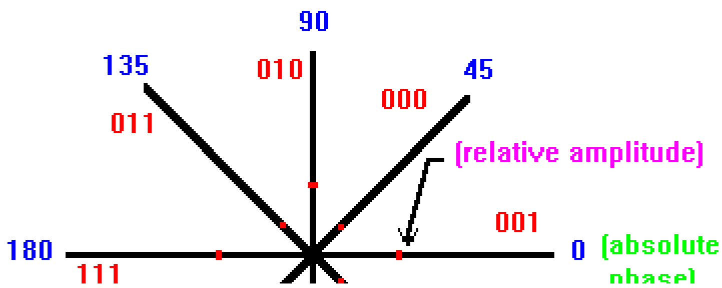
  This modulation works similarly as th PSK except that an amplitude change can also occur. For 9600 bps the coded data string is divided into quadbit (4 bits) groups and the amplitude of the carrier is changed by the the initial bit and the phase is shifted by the remaining tribit.

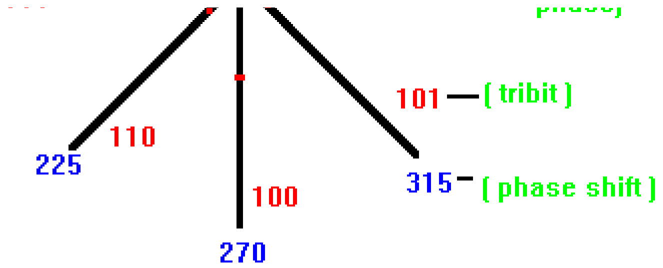


0010	1110	0011	1001
advances 90 degress. amplitude 0 or small.	advances 225 degrees. amplitude 1 or large.	advances 135 degrees. amplitude 0 or small.	same phase amplitude 1 or large.

- **QAM at 7200 bps**

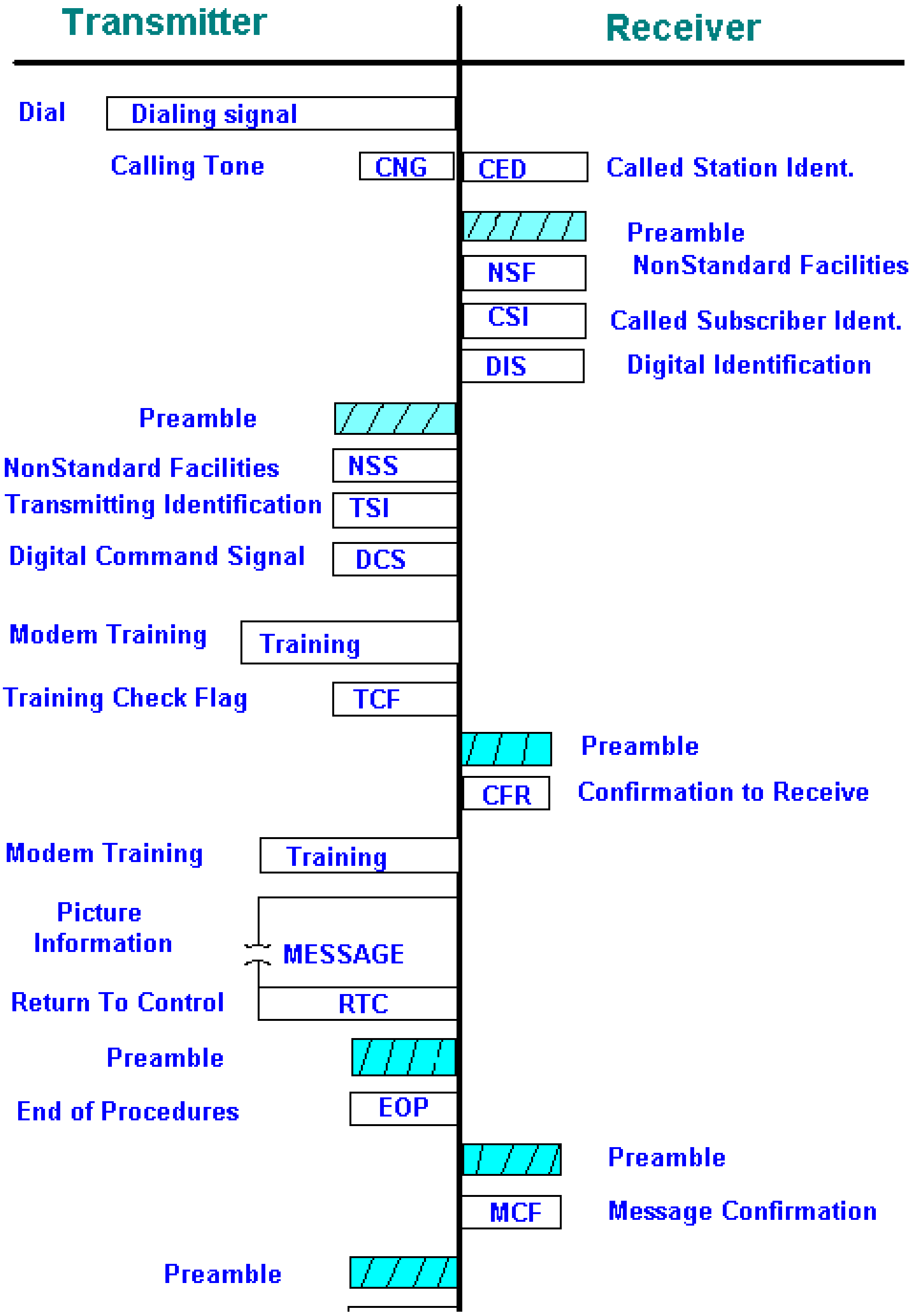
  The coded data string is divided into consecutive tribit groups and works that same as 9600 except that because there is only 3 bits the amplitude never changes.

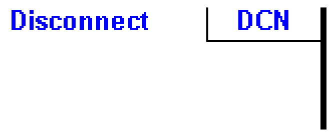




Transmission Control Procedures

The control procedures for a fax communication is in the the form of tonal and binary signals. Shown below is the procedure followed by most Canon fax machines.





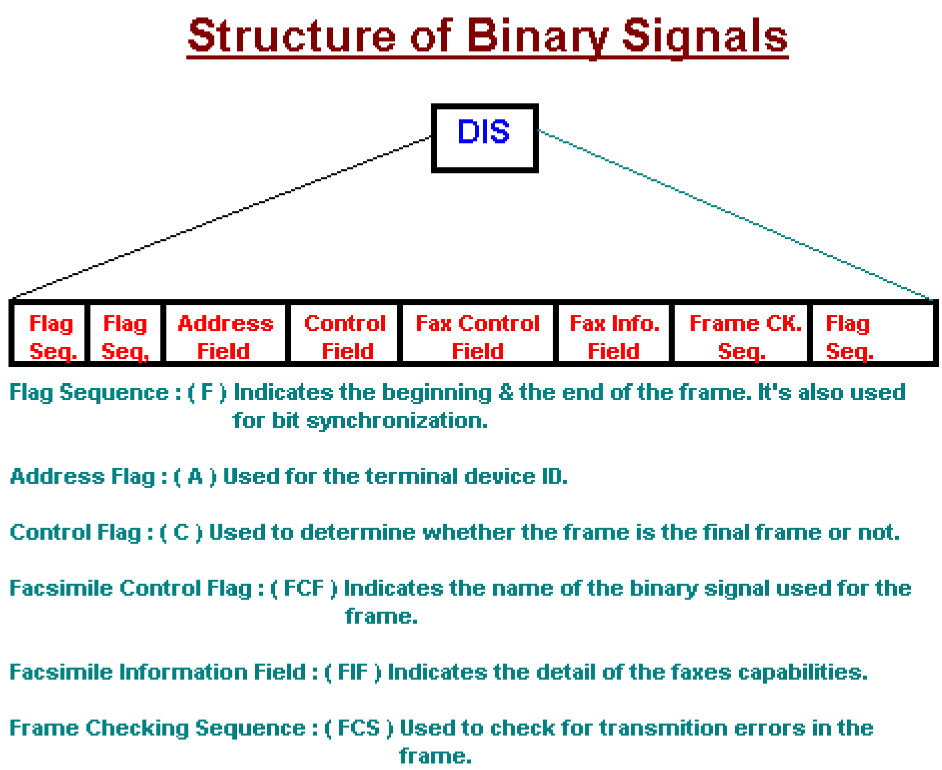
<u>The communication between two fax machines is as follows.</u>

1. **The transmitter calls the receiveing fax machine. The transmitter will generate the dialing signal and then continously send out a *CNG* tone which is used to signal an auto receive fax machine that another fax is making the call. This *CNG* tone is also used with alot of line shareing devices today.**
2. **The phone line on the receiving side will ring and the receiving fax will pick up the line and send out a *CED* tone. This tone only tells the transmitter that it has connected to a fax machine.**
3. **The receiving fax then sends out a *PREAMBLE* signal. This signal is a series of flags that are sent out to condition the phone line and to synchronize the two modems. A *PREAMBLE* will be generated just before any binary information is sent over the phone line.**
4. **The next set of signals are sent by the receiver and are binary signals. The first one is *NSF* Non Standard Facilities. This signal informs the recevier that it is a Canon machine with propritory modes. This signal is not needed for a communication to take place. The next signal is *CSI* Called Subscriber Identifcation. With this signal the phone number of the receiving fax machine is sent out. This phone number needs to be programed into the fax machine before this signal will be sent. If it is not programed then the signal will not be sent, therefore this signal is also optional and is not needed for a communication to take place. The final signal sent by the recevier before the transmitter can respond is *DIS* Digital Identification Signal. This signal sends out all of the receiving faxes capibilities such paper size, modem speeds, resolution modes, etc. This signal is needed for the commincation to take place.**
5. **After the transmitter receives the *DIS* signal it has enough information to continue with the procedure. The next signals that are sent are from the transmitter which is responding to the information sent to it from the receiver. After the *PREAMBLE* is sent the first signal is *NSS* Non Standard Facilities Setup. This signal will only be sent if the *NSF* from the receiver indicated that it was a Canon fax machine. If it is a Canon then the transmitter will send the *NSS* signal which will tell the receiver which Canon features will be used in the transmission. The transmitter has compared it's own Canon features with that of the receivers and commands the reciever to receive a document using certain Canon modes. The next signal sent is *TSI* Transmitting Subcriber Identifcation. This signal informs the receiving fax machine the phone number of the transmitter. This phone number must be programed into the fax machine or the signal will not be sent. Finally the transmitter will send *DCS* Digital Command Signal. The signal also commands the receiving fax to receive a document in a particular mode. This signal is needed for communication to take place. All other signals are optional.**
6. **Now that the transmitter has commanded the receiver on how a document will be sent it, it begins the *TRAINING* signal. The training signal is generated by the high speed modems. For example it would start sending a training signal of its highest communication speed, typically 14.4kbps or 9600 bps. All other prevously sent signals were sent using a 300bps modem speed. After the *TRAINING* has been performed a *TCF* Training Check Flag is sent to the receiver. The *TCF* is a consecutive number of "0" set for 1.5 seconds.**
7. **If the recevier receives the *TCF* correctly then the *CFR* Conformation To Receive Signal is sent back to the transmitter informing it that everything up**

until this point is alright. If the *TCF* is not received properly then the receiving fax will send back *FTT* Failure To Train at which point the transimtter will fall back to a slower modem speed and then try again. If the phone line is really poor the transimitter may need to fall back many times. The Fall back modes are as follows: 14.4kbps (1 try), 9600bps (1 try), 7200bps (1 try), 4800bps (2 tries), 2400bps (2 tries) and then failure.

8. **After the transmitter receives the *CFR* command it begins *TRAINING* again and then begins sending the picture information. Each line of data is checked for errors on the receive side. After all the picture data is sent a *RTC* Return To Control signal is sent which informs the receiving modem that the transmitting modem is going to return control to the slower 300bps modem and away from the high speed modem. After this *PREAMBLE* is sent and then *EOP* End of Procedures is sent. *EOP* signals the receiver that the full page has been sent. If there were more pages to be sent or if a change to the transmission mode was to take place then the transmitter would send *EOM* End of Message or *MPS* Multipage signal.**
9. **If all the data was received properly the receiving fax would send back a *PREAMBLE* and then a *MCF* Message Confirmation signal. If the data had errors in them and it exceded the maximum allowed then the receiver would send back *RTN* Retrain Negative of *RTP* Retrain Positive. Both of these signals indicate that that the data recevied exceded the maximum allowed errors.**
10. **If the communication was proper and the transmitter received the *MCF* signal then the transimitter would send out *PREAMBLE* and then a *DCN* Disconnection notice which informs the receiving fax that it is disconnecting the phone line at which point the transmitter and receiver hang up the phone line.**

Structure of Binary Signals



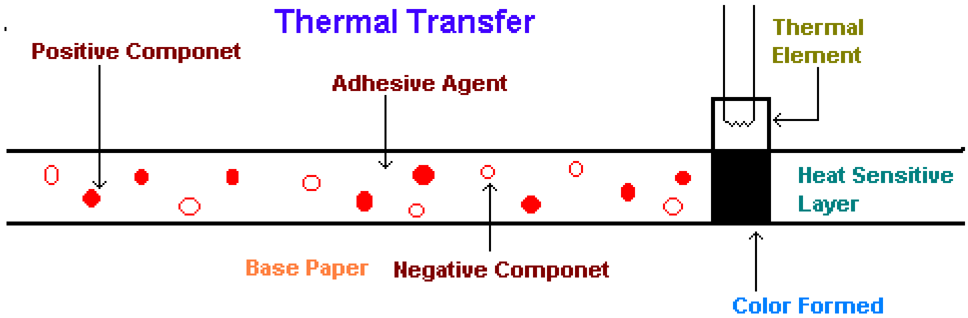
Printing Methods

Printing Methods

There are a few common methods for fax equipment to print the information onto paper:

1. **Thermal Transfer : Using thermal paper or a carbon film and plain paper to heat up areas on the paper to create dots to form an image.**
2. **Bubble Jet : Uses ink to create dots on the paper.**
3. **Laser Beam Printers : Similar to the photocopy process utilizing a laser and a photoconductive drum to create the dots to form an image.**

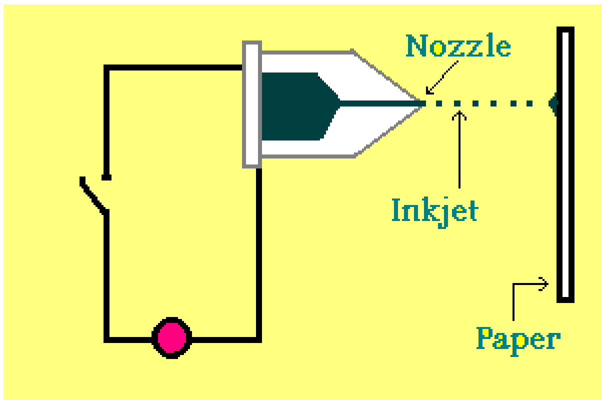
Thermal Transfer Printing Method



The termal transfer method is commonly used because there is virtually no noise, no smell its's simple in design, compact in construction and typically maintenance free. Formation of the print on the paper is done by a pixel size heating element that heats an area on the thermal paper thereby causing it to change color to black. The disadvantages of the thermal paper is that if left out in the light the image will fade with time, the paper is hard to write on and alcohol will cause the paper to discolor. With the thermal transfer method, a carbon film is placed between the thermal head and the paper. When the thermal head heats up in an area it causes the carbon to melt into the paper fibers. The benifit of the thermal transfer method is that the print is of a darker quality and the paper is plain paper. The disadvantage is that the paper is usually on a roll and it will retain its curl. There are devices incorporated in fax equipment to limit the curl effect and are called decurling units.

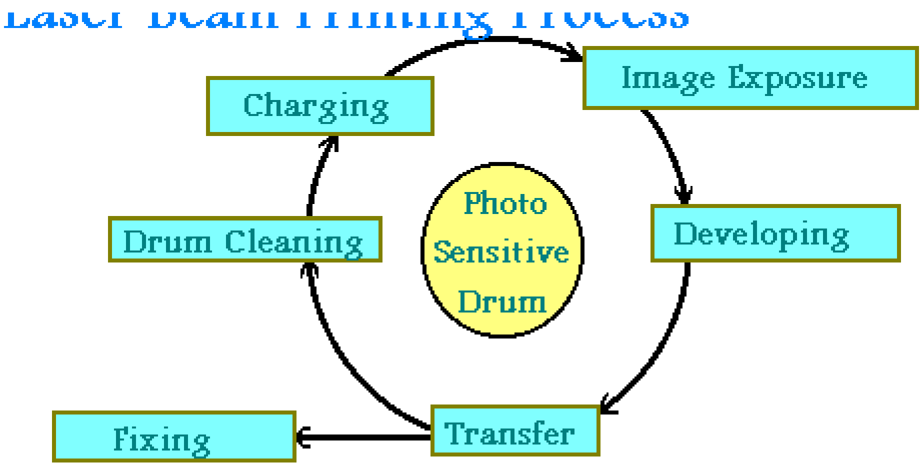
Ink Jet Printing Method

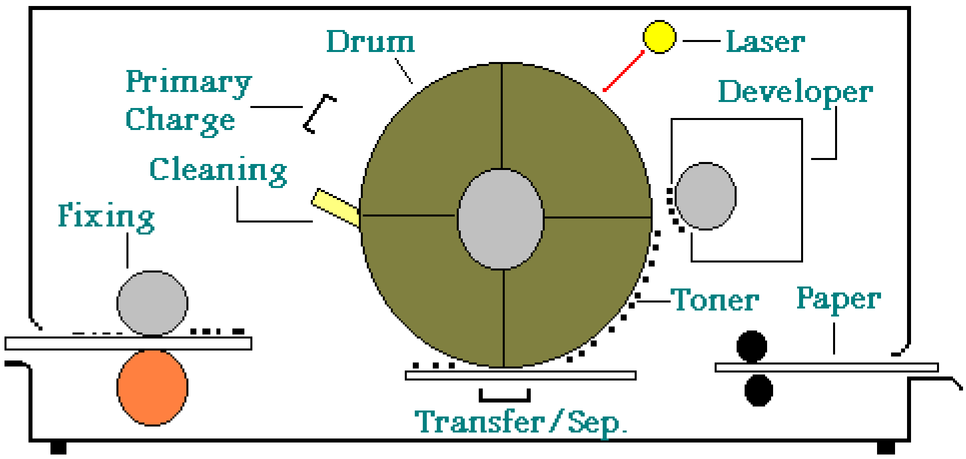
Ink jet printing method is done by haveing the jet output a single drop of ink to the paper. Each drop represents one pixel of information. The advantages of ink jet is that it is done on plain paper, color printing is possible and that the print does not fade with time. The disadvantage is that the ink jet nozzle needs to be cleaned or it will get clogged and cause poor print quality. This problem has been fixed with most new bubblejet and injet print engines.



Laser Beam Printing Method

Laser Beam Printing Process





The laser Beam printing method is very similar to the [photocopy process] which is discussed in great detail in the [copier theory section.] The only difference is that with a laser beam printer the drum, developer, cleaner and toner is in a cartridge type unit which makes the machine itself almost maintenance free and easy for the end user to work with.

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