APPROACH FOR DIGITAL TRANSMISSION OF PICTURES

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"A picture is *worth* a *1000 words"* is a saying confirmed daily. It should be remembered that transmission of picture signals began in the early days of radio. The individual techniques were adapted to the specific needs at the time, thereby resulting in diverse system5 each being optimized in accordance with the requirements and the method of transmission used.

Starting with what we perceive with our eyes, compromises are necessary in all picture transmission systems in order to:

1. limit the information to be transmitted,
2. direct the user's attention to the most essential information.

Television is an example of the first point. In the case of terrestrial transmission, there is just not enough bandwidth on the available frequencies to permit higher resolution5

FAX transmission is an example for the second point, where limiting the data to black and white provides a better understanding of the information.

There is another aspect, typical in all transmission techniques, including picture transmission. Initially the transmission was implemented using analog signals. Only recently have digital methods become more widely used, since a computer is required to support this technique fully. A major advantage of digital transmission is securing the information aqainst interference. This presumes that more information must be transmitted than is the case in analog transmissions.

Regarding the informational content of the pictures, there are two areas which must be considered as separate applications:

1. a still picture which can be studied at length, such as a photo,
2. a motion picture, such as film or television, which provides temporal continuity,

Errors in the pictures or their transmission can be tolerated to a certain extent in the case of motion pictures, since redundancy is assured by the quantity of the pictures, and because the observer cannot study each individual frame down to the finest detail in such a short time. In the case of a still picture, each individual picture element (pixel) is important however. It is remarkable that so much more attention has been paid in recent years to the transmission of motion picture5 than of still pictures, considering that a single still picture frequently conveys more information than does a motion picture,

In the case of analog picture transmission, the picture to be sent is sampled line by line. At the start of the transmission a synchronization signal indicates the start of a frame. Thereafter each line proceeds with a synchronizing pulse and the content of the line in analog form. The conclusion of the frame is marked by either ending the transmission or by sending the synchronizatian signal for a subsequent frame. This system is used in all techniques, though there are obviously variation5 in the technical implementations in each system. A digital system functions according to this same principle, except that the synchronization pulses and characters can contain additional information, and the picture content is transmitted in digital form. In the following article, the emphasis is on the transmission of still pictures, and a suitable application is outlined. The inclusion of digital picture transmission into data nets for packet radio will likewise be described.

Preparation of the Picture

The picture is captured using an electronic camera. For transmission of motion pictures via television, various systems have been developed, whereas for still pictures there are only a few dedicated to very special application5 Therefore such a camera is generally employed in this case. The difference lies in the time needed by the camera to capture the picture. The standard is 1/25 of a second, as defined by the television norms. Motion distortion is uncritical in television, though for still pictures it is an error that is very difficult to correct. Errors of this type arise not only through motion of the photographed object but also due to motion of the photographer. Fortunately this error doesn't result in poor focus from the rapid motion, as is the case in normal photo, as long as the interlaced frame technique of alternate line scanning is not used. In the case of tube cameras, the conversion to non-interlaced operation is difficult, thouqh feasible for CCD cameras.

There are various output standards for the information from an electronic camera, although they will not be discussed here. The following discourse initially presumes a black and white camera supplying analog data during the output of a full frame without interlaced scanning. Techniques of data compression are not considered at this time.

The first step is the transfer of the picture information into the memory of the transmitting station. This process must occur within 40 ms. Two processes are taking place in parallel at this point=

1. forming the memory addresses depending on the picture and line synchronization, and
2. digitizing and staring the picture information.

For both processes, the primary decision to be made is the resolution of the stored picture. The resolution must equal or exceed that used in the receiver. Even when it won't initially be used, it is advantageous to work with an arrangement supporting a large number of pixels and possibly to ignore a portion of them. A matrix of 1024 x 1024 (512 x 512) is suitable for storing a high resolution picture.

The technique must also permit sampling of portions of the picture by line and identifying them in the transmission. This can be done with a two byte address word containing three different data items. The first three bits are used as the frame counter, bits 4-13 are the line counter, and the remaining bits, 14-16, form a block counter within a line. The three portions of the J-bit address word are loaded from three binary counters, in order to keep the computational time short for the creation of the address.

```
        Bit of the 2 byte address
1 2 3 4 5 6 7 8 + 1 2 3 4 5 6 7 8

- - - - - - - -   - - - - - 0 0 0
          first 128 byte block in a line

- - - - - - - -   - - - - - 1 1 1
          last 128 byte block in a line =
                               1028 bytes

- - - 0 0 0 0 0   0 0 0 0 0 - - -
                  first line (status)

- - - i l l  1 1   1 1 1 1 1 - - -
                  last of 1024 lines

0 0 0 - - - - -   - - - - - - - -
                          frame # 0

1 1 1 - - - - -   - - - - - - - -
                          frame # 7
```

The frame counter in the address field can be used for several tasks: a) the consecutive numbering of the pictures being transmitted, or b) the identification of special features, ie. marking frames with the red, green or blue color segments.

If the address field is not fully used, as will be the case for most of the common installations, the corresponding address bits will then be clear, and the memory locations will be unused or vacant.

For the conversion of the analog picture signal into digital data, a fast A/D converter is required. Appropriate components are readily available on the market for this application. The LSI component TDC1025 from TRW has been implemented in a trial circuit. It is a monolithic high-speed analog-to-digital converter with parallel output, using B-bit flash architecture with 50 million samples per second. Using this device, a resolution of 512 x 512 pixels is easily attained.

The picture stored according to this method is then available in the RAM memory for transmission, or it can be superimposed on other carrier signals.

<u>Transmission of the Picture</u>

Depending on the resolution of the picture, each frame results in a corresponding volume of data. For a black and white picture, these amounts are as follows, in accordance with the resolution:

128 x 128 Pixel with 8 bit resolution = 16.3 KByte

256 x 256 Pixel with 8 bit resolution = 65.5 KByte

512 x 512 Pixel with 8 bit resolution = 262.1 KByte

1024 x 1024 Pixel with 8 bit resolution = 1048.6 KByte

In addition the synchronization information must be supplied for control and data security.

This quantity of information can be significantly reduced by techniques of data compression without causing significant degradation in the resolution of the picture. Testing and describing the various techniques are reserved for a subsequent investigation and should initially be employed in connection with the expanded data volume for color pictures. Through the use of various data compression techniques, color pictures can be transmitted with the same data volume as uncompressed black and white pictures. Since no other procedure has been established, the transmission of color pictures will be in frames containing the three component colors, red, green, and blue.

Mother point to consider is the transmission of the necessary overhead information. This consists of the synchronization word per block (24 bits), the control information, such as memory addressing, and an error recognition code of a 16 bit frame check sequence (FCS) or the implementation of a BCH code, that can correct at least three errors and recognize even more due to 40 additional bits. Consequently the transmission overhead lies between 5 and 10%.

When discussing error recognition or correction, the operating mode used by the picture transmitter needs to be additionally considered. In the case of a paint-to-point connection, error recognition including determination of the number of errors per block is preferable, since incorrect blocks can be requested following transmission using the ARQ method. For broadcast transmission on the other hand, error recognition does not provide any advantages, whereas beyond a certain number of errors, error correction does,

The main criterion for the transmission of individual pictures is the available bandwidth of the, transmission channel. Direct relationships exist between the bandwidth of a channel, the transmitted resolution of a picture, the modulation method, and the duration of a transmission.

	Resolution		
Speed	128x128	256x256	512x512
4 kB/s	35.3+	141.0	565.0
8 kB/s	17.6	70.6	282.0
16 kB/s	8.0	35.3+	141.0
32 kB/s	4.4	17.6	70.6
65 kB/s	2.2	8.8	35.3+

Transmission time in seconds

Using an experimental system, a first attempt was made by transmitting the pictures in increasing resolution and at different speeds. In this case, the picture is transmitted initially every eight pixel in every eight line at a speed of 4 kB/s. This corresponds to a low resolution (LR) picture of 128x128 pixels after decoding at the receiving station.

The next step is enhancing to a medium resolution (MR) picture by transmitting the missing pixels at a speed of 16 kB/s, for a resolution of 256x256. Following this phase of the transmission, every fourth pixel in every fourth line is present.

The third step is advancing to a high resolution (HR) picture in the same form at 64 kB/s, so that every second pixel in every second line can be displayed.

The last step, increasing the resolution of the picture to a very high resolution picture (VHR), involves considerable expense and is not considered in this design.

In accordance with the entries in the previous table, the transmission time of a picture amounts to 88.25 seconds. For the table entries marked with "+", only 75% of the times can be taken into account at the higher speeds, since a portion of the picture has already been transmitted.

Control over the transmission and access to the picture data at-e easily accomplished due to the addressing scheme.

Upon completion the transmitted picture with its line and block addresses appears as follows, where the pixel for 128x128 are marked with #, those for 256x256 with *, and those for 512x512 with +.

Phase 1 at 4 k&/s - 128*128 Pixel

'Line/Block				
8 / 1	#	#	#	#
16 / 1	#	#	#	#
24 / 1	#	#	#	#

Phase 2 at 16 kB/s - 256*256 Pixel

Line/Black							
8 / 2	#	*	#	*	#	*	#
12 / 1+2	*	*	*	*	*	*	*
16 / 2	#	*	#	*	#	*	#
20 / 1+2	*	*	*	*	*	*	*
24 / 2	#	*	#	*	#	*	#

Phase 3 at 64 kB/s - 512*512 Pixel

Line/Block													
8 / 3+4	#	+	*	+	#	+	*	+	#	+	*	+	#
10 / 1+2+3+4	+	+	+	+	+	+	+	+	+	+	+	+	+
12 / 3+4	#	+	*	+	#	+	*	+	#	+	*	+	#
14 / 1+2+3+4	+	+	+	+	+	+	+	+	+	+	+	+	+
16 / 3+4	#	+	*	+	#	+	*	+	#	+	*	+	#
18 I 1+2+3+4	+	+	+	+	+	+	+	+	+	+	+	+	+
20 / 3+4	#	+	*	+	#	+	*	+	#	+	*	+	#
22 / 1+2+3+4	+	+	+	+	+	+	+	+	+	+	+	+	+
24 / 3+4	#	+	*	+	#	+	*	+	#	+	*	+	#

The procedure in which the picture is

transmitted with increasing transmission speed and resolution was chosen for several reasons:

1. At the lower speed and with identical channel characteristics, correspondingly better transmission conditions are achieved. If the channel is designed for the highest transmission speed, assuming an error rate of 10-3 to 10-4 at 64 kB/s, then error rates of 10-6 to 10-7 at 4 kB/s and 10-5 at 16 kB/s result. Corrective algorithms based on the appropriate evaluation of the data can be implemented at the receiving stations, taking into account the results from the slower and hence less error-prone phases. Such algorithms are especially applicable when the volume of data is reduced through data compression techniques. In any event, interference to blocks during transmission don't always result in disruption, but rather appear merely as picture areas with reduced resolution.

2. In implementing the necessary modems, simplifications can be applied since initial synchronization occurs at the slower speed and at transition to the higher speed, the clack/4 is already known, hence eliminating the need for a full synchronization phase.

3. The degree of complexity in the transmitting and receiving stations can vary. A simple receiving installation, with a modem for only 4 or 16 kB/s or lower computer capacity, can receive the pictures at reduced resolution. In the other direction, simple installations can also process and send pictures at lower resolution.

4. Techniques of data compression are deliberately ignored at this point, since premature rules always result in constraints on further development. This would not yet be desirable, especially in view of the project described next.

Reception of the Picture

A receiving station will basically consist of the following three functional components:

1. Receiver with appropriate modems,
2. Computer for picture storage,
3. Picture display via screen and/or hard copy.

The receiver must conform to the requirements of the transmission parameters. The experimental system under discussion has a channel bandwidth of 200 kHz and a DPSK demodulator for 64 kB/s. The choice of the highest transmission rate of 64 kB/s is based on the current availability of suitable components for ISDN nets.

The task of the computer is first to store the on-line data and possibly the picture display. It can additionally handle error correction and picture processing. The presently available standard PCs having a 80286 processor are adequate for the task. A memory expansion sufficient to permit handling and processing complete pictures should be provided.

The direct display of the pictures by the computer using the currently available graphic cards, i.e. EGA, is only possible with reduced picture quality. With special cards or additional display equipment, all options are open.

A specially constructed picture display driver accepts and stores the picture data from the modem or computer, and produces the necessary signals for the monitor.

Transmission in Packet Radio Nets

The design of the data structure for digital picture transmission resembles the frame layout currently used in packet radio nets. If picture transmissions are to be incorporated into the current nets, several questions need to be answered and agreed upon.

The data quantity to be transmitted is very large and would completely disrupt existing traffic in most nets, Just the transmission times disregarding the additional overhead needed by the packet radio protocol practically forbids implementation at speeds less than 9.6 kB/s. At this speed, the transfer time just for the pure picture data already amounts to four minutes. Nets of this type, running at even higher speeds, will be installed on the UHF/SHF bands in the future.

A further point is the overhead due to the packet radio protocol. The present day nets are oriented around datagramms. For picture transmission it appears more sensible to incorporate virtual connection techniques.

Another question concerns the handling of transmission errors. Different than for example in file transfers, a certain error rate can be tolerated in picture transmissions. It therefore seem5 reasonable to use error recognition such as BCH coding during validation of the received data rather than FCS control. The content of a packet would then only be requested when a permissible number of errors is exceeded or a portion of the data is missing, which can be determined by the address data.

An Interesting Project

During flight STS 61 A of the space shuttle and the first German Space Lab mission (D1), amateur radio was present as station DP0SL, for which I was responsible. Unfortunately due to the tragic accident of the space shuttle *Challenger*, the date for a subsequent German mission has been postponed, and hopefully not canceled.

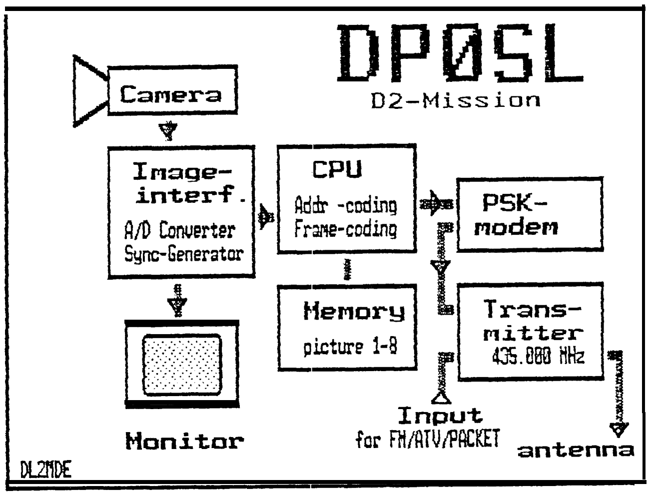
For the upcoming mission, we wish to have even more ambitious equipment aboard, and the digital picture transmission just described has been specified during the planning stage. Should this project be carried aut, positive result5 would consequently result for other applications. This is also a reason to include other interested circles early in the planning, since we do not wish to perform an experiment for only a small group. We would be quite pleased if through this project a unified standard for digital picture transmission would result, since a mission of this nature would offer the best conditions to establish one.

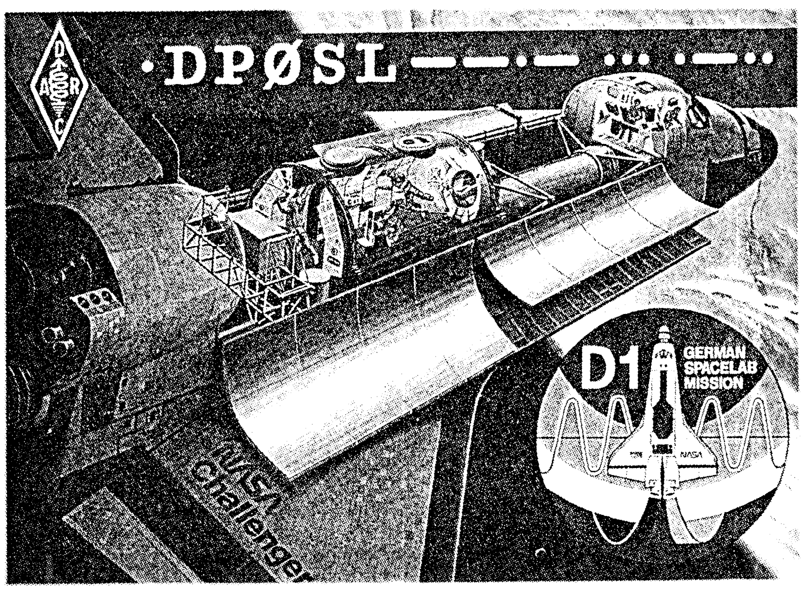
Fur DPOSL, picture transmission equipment will be constructed consisting of a camera, memory for four to eight pictures, and a 435 MHz transmitter. When the operators aboard Space Lab find the time, they will take up to eight pictures, that will then be continuously transmitted in sequence, when the 435 MHz transmitter is not required for other tasks. The transmission of one picture takes approximately 1.5 minutes, so that all pictures can be received during most passes. Thanks to the addressing scheme, missing picture5 or disrupted Portion5 of pictures can be captured and inserted during subsequent passes, unless the operator at DPOSL has taken some new pictures in the interim-

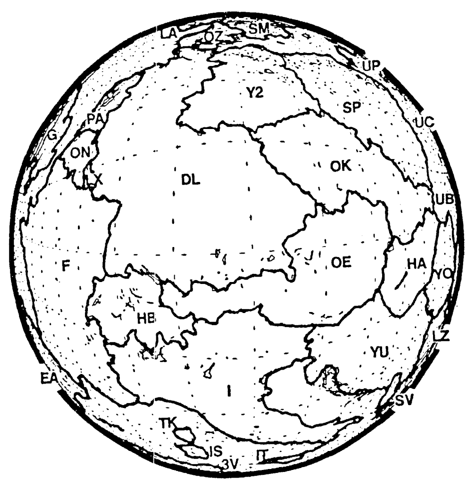
In total, four goals are under discussion in the group which previously implemented DPOSL:

1. improved voice communications,
2. ATV connections in both directions,
3. packet radio, possibly with satellite interlink,
4. picture transmission, the project just described.

I believe these goals have a good chance, since besides getting some really interesting pictures it will provide significant technical enrichment, which is the life-blood of an experimental radio service. But one other point speaks for this project= from experience we know that the operators in space have very little spare time and for this project they only need a few seconds per day,







Range of sight of' D P Ø S L in Spacelàb while crossing the control center in Oberpfaffenhofen at the D1 Mission.