RECOMMENDATION ITU-R F.1113

RADIO SYSTEMS EMPLOYING METEOR-BURST PROPAGATION

(Question ITU-R 157/9)

(1994)

The ITU Radiocommunication Assembly,

considering

a) that experiments have already shown the practicability of utilizing the frequency band between 30 and 50 MHz for transmission by meteor-burst propagation to distances well beyond the horizon;

b) that systems using this mode of propagation are already in service for burst data transmission,

recommends

1. that Annex 1 be used as guidance for the application of radio systems employing meteor-burst propagation.

ANNEX 1

Radio systems employing meteor-burst propagation

1. Introduction

The phenomena of meteor-burst propagation using reflections from ionized meteor trails is described in Recommendation ITU-R PI.843. Recent advances in microprocessors and digital electronics mean that it is now possible to construct a meteor-burst communication system at a realistic commercial cost. This Annex describes two such systems and presents results of tests carried out on these systems.

2. Example meteor-burst system A

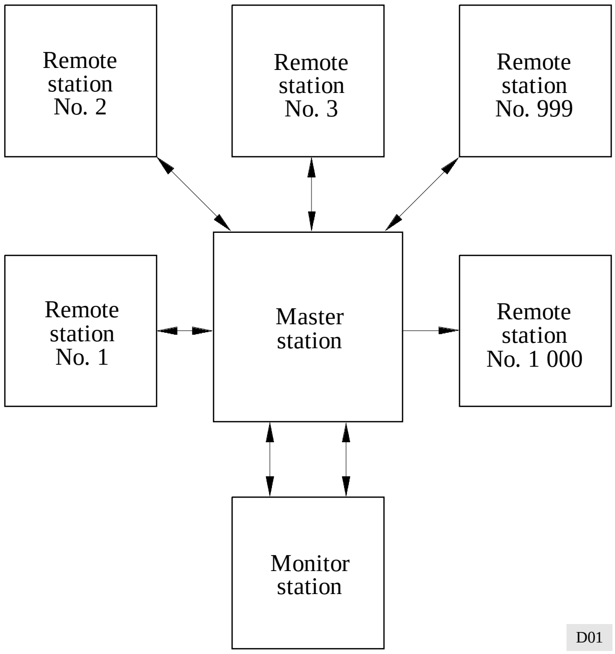
2.1 System description

The system is configured as a star network with a central master station and a capacity of up to 1 000 remote stations within the coverage area of 2 000 km radius (see Fig. 1). The system uses a half-duplex packet protocol with single segment automatic repeat transmissions in the presence of errors. Each of the remote stations is able to communicate with any number of other remote stations via the central master station.

Larger systems may be built using several master stations communicating with each other by full duplex meteor-burst propagation such that all remotes can communicate with each other via combinations of master stations over a series of 25 kHz channels. It is also possible to construct a system without a master station by using point-to-point techniques when the remote stations perform the control functions. This latter system is not flexible and has to be reconfigured for any change in the number of stations.

FIGURE 1

System block diagram



One network system in Europe is designed with the maximum number of system functions concentrated in the master station. This is to minimize the size, cost and power consumption of the remote stations. The master station performs the functions of meteor trail illumination, system synchronization and message routing, but is transparent to the user. It is the only component of the system which needs mains power.

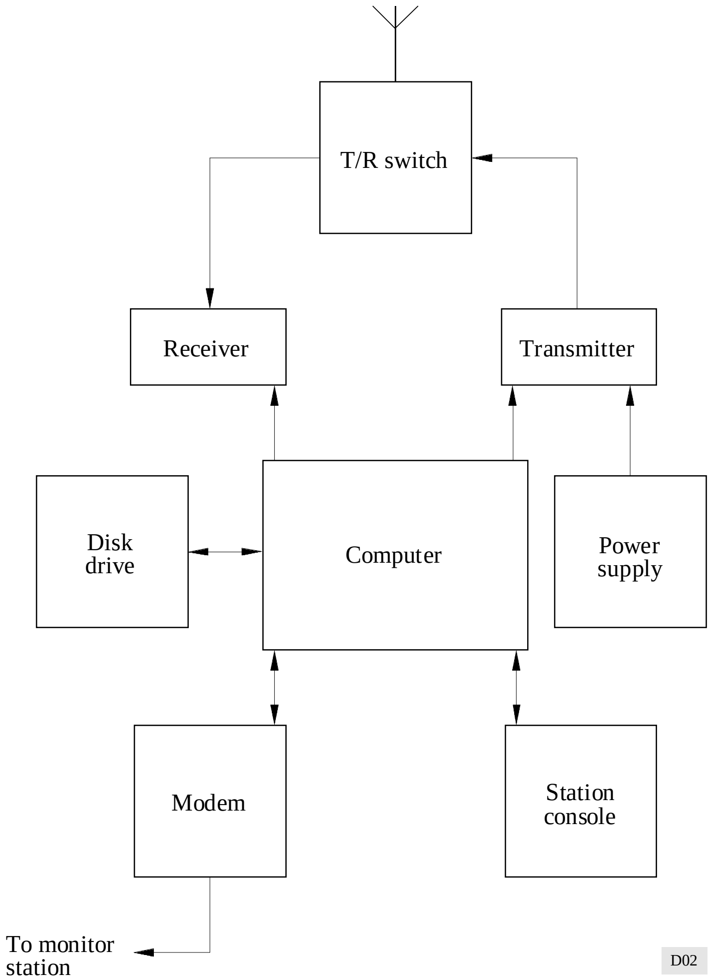
2.1.1 Essential system characteristics

The system described operates in half-duplex mode using two frequencies around 46.9 MHz with a single horizontally polarized antenna at each station. In practice the master station antenna is an array of four "Yagi" antennas connected together for omnidirectional coverage. It would be possible to use vertical polarization if required for operational reasons such as mobile remote stations. The transmitter (see Fig. 2) is rated at 500 W. A transmit/receive switch allows call/listen cycles of approximately 80 ms duration. This alternate 40 ms call, 40 ms listen cycle is used to illuminate the meteor trails and is known as probing. The probe transmissions may be addressed to individual remote stations or may be non-specific depending on system priority. The master station transmitter modulation is binary low index ($\pm 30°$) phase shift keying (PSK) to minimize interference on adjacent channels. Synchronization of remote stations is achieved with Manchester encoding of the clock signal within the data.

Remote stations transmit with high index ($\pm 90°$) PSK modulation for maximum chance of detection by the master station. Two protocols are supported, one for data acquisition and one for communication. In normal operation, the master station sends probe words and checks received signals for valid data segments from a remote station (see Fig. 3). Immediately a valid segment is found, an acknowledgement is sent back to the remote source. At the same time a computer memory check is made for any segments addressed to that remote station and if found, the first segment of the return message is appended to the acknowledgement. If a segment is returned in this way, an acknowledgement from the remote station is sought. In all cases if no acknowledgement is received, the segment is repeated until it is.

FIGURE 2

Master station



The system is controlled by a monitor, connected to the master station by radio or landline. This connection enables the monitor to be at the administration offices while allowing the master station to be remote in an ideal low ambient noise location. The system monitor checks overall performance and stores all the data transmitted so that users can collect from the monitor rather than receiving in real time.

In this system a remote station for data acquisition is optimized for low power consumption and reliable operation in conditions typically from –30 °C to +60 °C. The 100 W transmitter duty cycle is limited to 1%. The receiver has a sensitivity of –118 dBm and there is a buffer store for packets of data or short text messages (see Fig. 4).

A second type of remote station for communication is optimized for maximum information transfer rate which is related to signal-to-noise ratio. The 300 W transmitter duty cycle is limited to 10%. The receiver has a sensitivity of –121 dBm and there is a buffer store with up to 20 kbytes of memory (see Fig. 5).

The communication protocol makes use of the natural diversity in space and time of the meteor trails to provide automatic polling to a maximum of 1 000 remote stations. When a path is present, the data is sent and acknowledged during the same event. Long data strings require several events and recombination at the receiver. Text is transmitted in a series of segments which are all acknowledged at the end of the message. It is possible to continuously monitor the signal-to-noise ratio and adaptively change the data rate between 2 kbit/s and 64 kbit/s to maximize the throughput.

FIGURE 3

Typical meteor-burst data exchange protocol

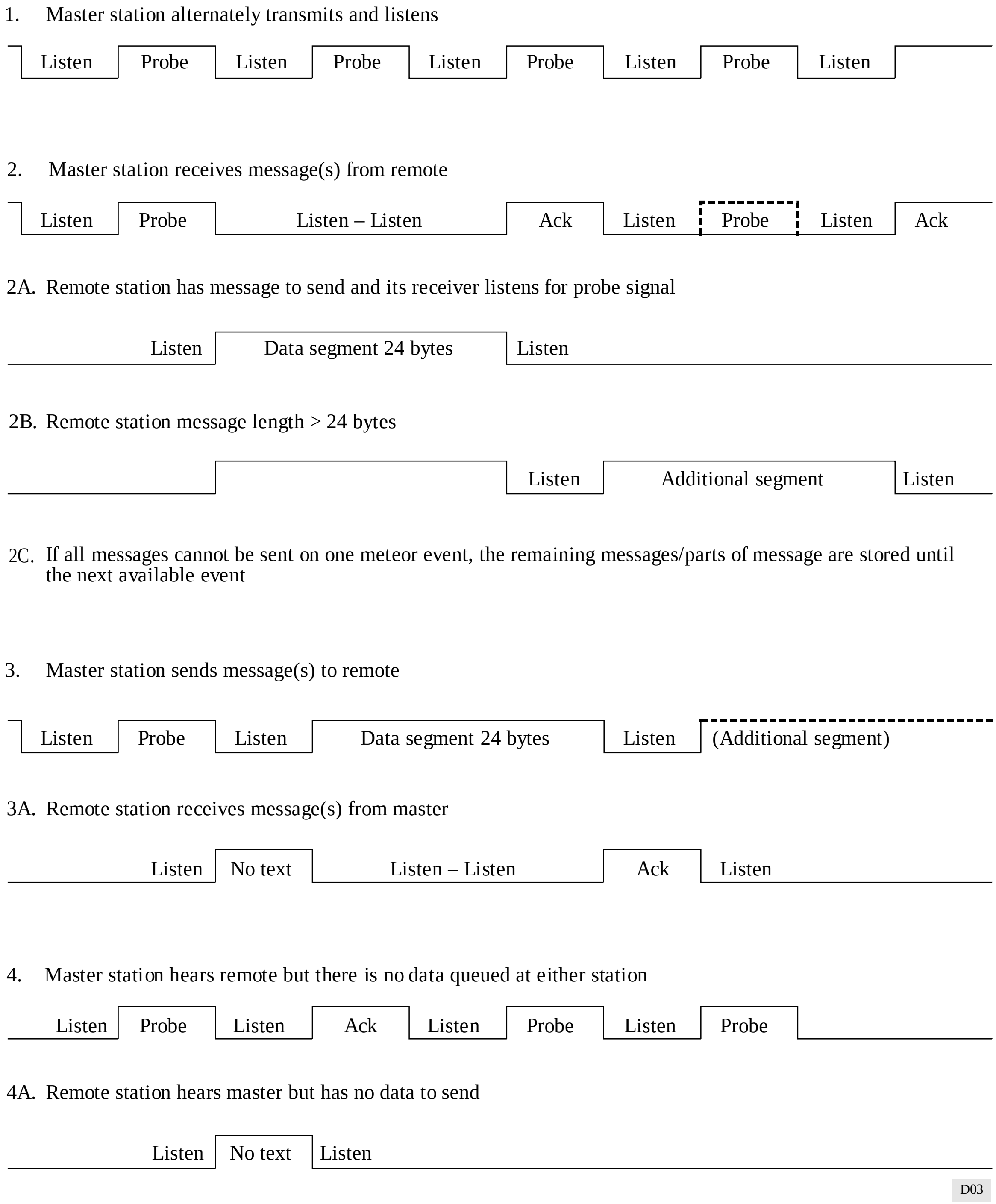


FIGURE 4

Typical data acquisition station

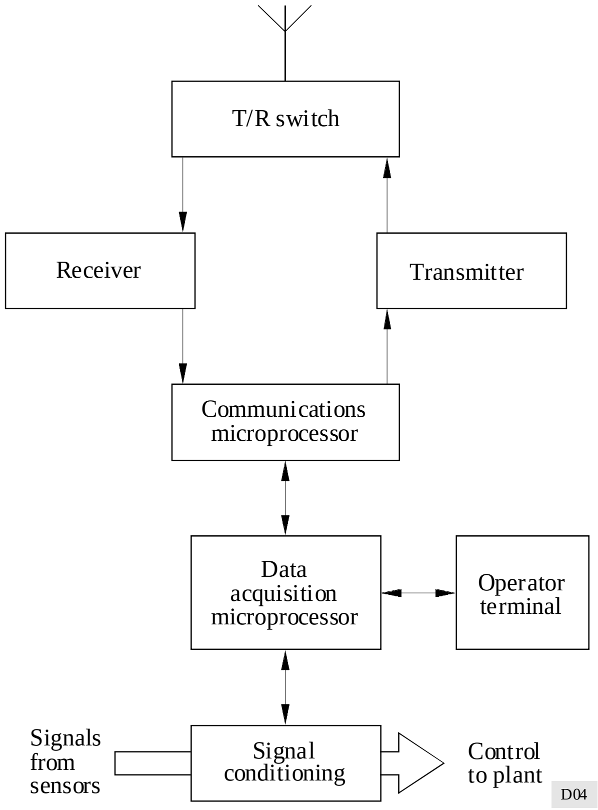
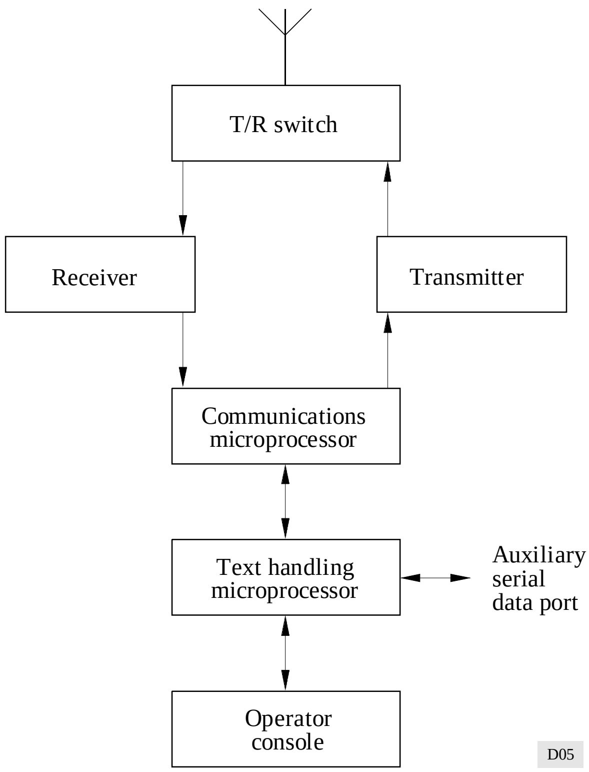


FIGURE 5

Typical text and data communication station



2.1.2 Noise sensitivity of meteor-burst systems

Meteor-burst links have been shown to be relatively unaffected by atmospheric disturbances such as the Aurora Borealis. In the ideal case the performance of a system using meteor-burst propagation would be limited only by galactic noise. The receiver therefore has to be designed to decode signals whose magnitude is comparable with galactic noise. In practice there is also man-made noise which is often transient and very large compared with galactic noise. For this reason, the receiver has to have high dynamic range and some form of protection to obviate the saturating effects of high energy spikes.

2.1.3 Design and use, variation with frequency

The system could work at any frequency from 20-120 MHz provided that regular ionization was not present. The range would be up to 1 600 km using ionized trails from meteors at 80-100 km above the Earth. The preferred frequency range is 40-50 MHz to maximize the information duty cycle.

2.2 Test results

2.2.1 Results from operations

Performance achieved within the European network for all ranges has been better than predicted by most of the published computer models. The greatest differences are at short ranges where achieved data rates have been up to five times the predicted values. Experience in the British Isles has proved that reliable communication is provided at all ranges between 0 and 1 600 km. The system is used to take measurements at remote locations and regularly send the resulting data back to offices. Typically 8×12-bit samples are sent from each remote location during each 15 min interval.

In tests during December and January of years from 1986 to 1989, eight low power data acquisition remote stations were set up to send data at 5 min intervals over meteor-burst links having ranges of: 1 520, 1 040, 816, 608, 464, 256, 141 and 24 km. All data were successfully received throughout the test period within the 5 min interval before the next data were released.

2.2.2 Observed interference and noise sensitivity effects

Experience in Europe shows that the single most significant factor in determining the performance of a meteor-burst link is the level of in-band interference at the site location. Other services in that frequency range use line of sight propagation. Interference effects can often be reduced by rotating or changing the elevation angle of the antenna away from its normal position. A rotatable low gain wide beam antenna allows the use of a wide area of sky: variations of antenna angle of up to 25° in any plane can be accommodated with little effect on the link performance. It should be noted that the meteor-burst technique is able to work with reduced signal-to-noise ratio, thus maintaining the link integrity, albeit at a lower data rate.

2.2.3 Observed variation with frequency

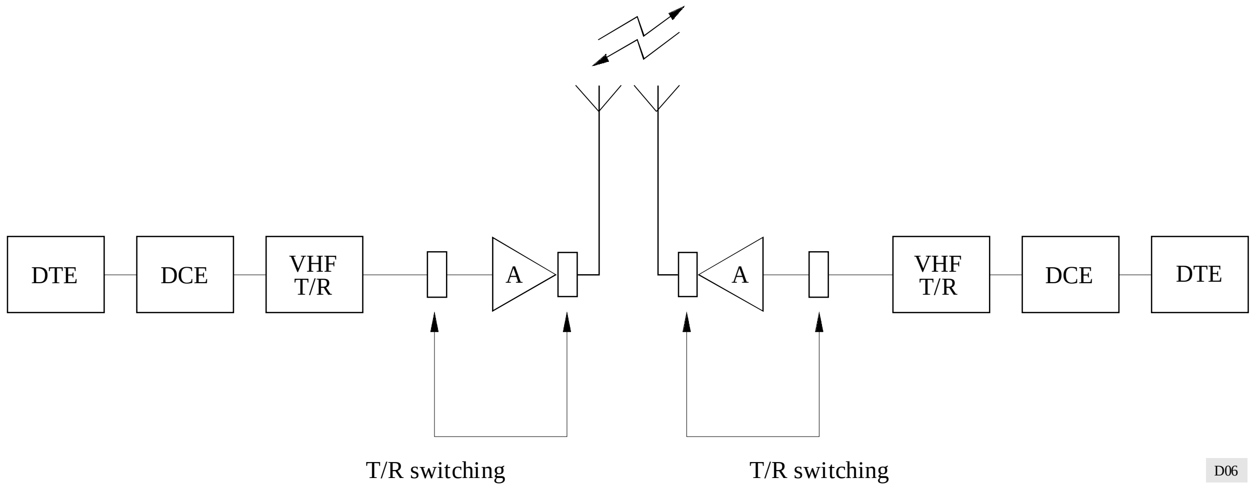
The system described uses only a single pair of frequencies around 46.9 MHz; hence there is as yet no operational data on variation with frequency.

3. Example meteor-burst system B

3.1 System description

Tests on a data transmission system using a meteor-burst channel were carried out in France during the first half of 1988, at various times of day and night, on a point-to-point link between two fixed stations 350 km apart.

FIGURE 6
Basic block diagram of the link



– The DCE sub-assembly performs FSK modulation and synchronization functions (RF modem).

– The DTE sub-assembly performs communication, coding and data processing functions.

The transmitted message is formatted in blocks. There are two types of blocks:

– header blocks (one block per message),

– data blocks (number of blocks dependent on message length).

Encoding is based on blocks and involves a Reed-Solomon error correcting code (23.13) which may compensate error rates of up to 5%.

The bit rate used is 16 kbit/s; characters are made up of 6 bits.

The procedure is of the stop-and-wait "half-duplex" type with repeat transmission (repetition of only the blocks not received).

Tests were carried out:

– At several transmitter power levels: 1 kW – 200 W – 100 W, a few tests at 50 W

– At different frequencies: around 40 MHz

– With different message sizes: 900 – 500 – 250 – 100 – 50 – 10 characters.

Horizontally polarized 5-element Yagi antennas were used, with a radiation pattern which illuminates the entire coverage area with a high concentration of meteors.

These antennas are therefore particularly suitable for this type of transmission; they have a gain of 9.5 dBi.

3.2 *Test results*

Three types of tests were carried out.

3.2.1 Channel test

Measurement of the following characteristics for a given observation time T:

τ_m: mean duration of a meteor trail

$$\tau_m = \frac{\sum \text{trails duration}}{\text{number of trails}}$$

θ_m: mean duration between two meteor trails

$$\theta_m = \frac{\sum \text{duration between two trails}}{\text{number of trails}}$$

Hence, d_o: channel opening duration, i.e. average percentage of time during which the channel is open.

$$d_o = \frac{\tau_m}{\tau_m + \theta_m}$$

The mean duration of a meteor trail, τ_m, is calculated by determining continuity of operation of the procedure.

For a 1 kW power level, meteor-burst channel activity gave a mean trail duration of 400 ms and a mean duration between two trails of 700 ms.

For a 200 W power level, there was a slight drop in activity (mean trail duration: 330 ms – mean duration between two trails: 800 ms).

However, at a power level of 100 W, there was very little activity (mean trail duration: 350 ms – mean duration between two trails: 43 s).

It may be deduced that the channel opening duration was 36% at 1 kW, 29% at 200 W and 0.8% at 100 W.

The tests also showed that mean effective meteor activity is practically stable over 24 h; increased activity at 0600 h and reduced activity at 1800 h, as indicated in Recommendation ITU-R PI.843, was not apparent.

Note 1 – These test results for channel activity at high transmission power levels (1 kW – 200 W) are appreciably higher than the theoretical results obtained using the formula derived from the COMET experiments.

It would seem that they can be explained only by the simultaneous presence of another propagation mechanism. The antenna height above ground (17 m), chosen to provide links of up to 1 000 km, gives appreciable gains at low angles of elevation. This might tend to favour tropospheric scatter links, theoretically possible over the distance concerned and operationally feasible with the procedures used for the meteor-burst channel. The existence of this phenomenon has been confirmed by estimating, opening by opening, propagation time of the signal (tropospheric diffusion at low altitude corresponds with a much shorter propagation time than reflections from meteor trails at high altitude).

3.2.2 Bit error ratio test

The test allowed measurement of bit error ratio on the trails due only to channel characteristics, without the use of error correcting codes.

A received message was compared with a 900 character reference message. All errored bits (per character) were stored in a file: a window of 60 characters was slipped into this file in one character steps. When the bit error ratio was 5% in this window (this figure corresponds to the maximum capacity of the Reed-Solomon error correcting code used), the meteor-burst channel was considered to be closed. The position of the last character of the window was stored.

The bit error ratio was calculated over all data preceding this last character.

– This ratio was 1.7% at 1 kW and 2.5% at 200 W.

– At a power level of 100 W, it was very high (7.4%) and only the head of the trails could be used with the code employed.

3.2.3 System test

This test measured system performance to determine how well the system was adapted to the channel and assessed the suitability of the procedure used.

This is the only test to take the "message size" parameter into account.

3.2.3.1 Transmission rate

The main characteristic is the mean transmission rate *D* measured in effective characters per second:

$$D = \frac{\text{size of message received}}{\text{transmission time}}$$

At constant power, the mean transmission rate increases as a function of message length. The maximum rate (187 characters/s) was obtained for 500 character messages at a power level of 1 kW. At 200 W, the rate was only 122 characters/s. For 250 character messages, the rate was 158 characters/s at 1 kW and 116 characters/s at 200 W.

A major drop in transmission rate occurred at power levels below 100 W: for 100 character messages, the rates were 84 characters/s at 1 kW, 63 characters/s at 200 W, 13 characters/s at 100 W, 1 character/s at 50 W and 0.02 characters/s at 30 W.

The transmission rates were seen to be relatively stable over a time period of approximately 15 min.

3.2.3.2 Procedure suitability

For point-to-point links, a message of a given size is received after a considerable number of exchanges between the two stations. The block error ratio, given by the following formula:

$$BER = \left(1 - \frac{\text{number of blocks received}}{\text{number of blocks transmitted}}\right) \times 100$$

indicates procedure effectiveness by determining the number of exchanges.

The system worked well at a power level of 1 kW. A message of given length was received with few procedural exchanges (block error ratio: 27%).

At a power level of 200 W, there were numerous exchanges (block error ratio: 48%) causing a drop in efficiency, which was no longer optimum but still remained satisfactory, as the system was not saturated by the exchanges.

At a power level of 100 W, a message was received after a very high number of exchanges between the two stations (block error ratio > 50%). The procedure was unsuitable for power levels below 100 W.