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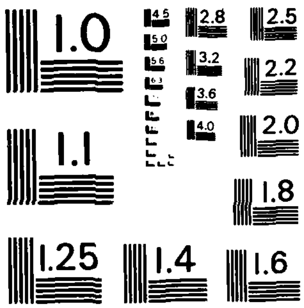
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TECHNICAL MEMORANDUM

AEL-0122-TM

MEDIUM SPEED DIGITAL DATA TRANSMISSION TESTS OVER A 1900 km HF RADIO LINK USING DOPPLER SPREAD OF A CW TEST TRANSMISSION AS A REAL TIME FREQUENCY MANAGEMENT TECHNIQUE

J.R. TILBROOK

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J.R. Tilbrook

S U M M A R Y

This document describes tests conducted jointly by the Advanced Engineering Laboratory (AEL) and the Electronics Research Laboratory (ERL) at the Defence Research Centre Salisbury (DRCS), in December 1981 which attempted to real-time frequency manage HF radio medium speed digital data transmissions between Townsville and DRCS, a distance of approximately 1900 km.

Instrumentation which monitored the Doppler spectra of a CW stepped frequency sounder transmission originating in Townsville was used as an aid in selecting the optimum operating frequency. The work forms part of the HF Enhancement Study being carried out by AEL and ERL and is sponsored by DGJCE.

POSTAL ADDRESS: Director, Advanced Engineering Laboratory,
Box 2151, GPO, Adelaide, South Australia, 5001.

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9. Mode structure indicated by an oblique ionosonde versus instantaneous Doppler spectra width

LIST OF ABBREVIATIONS

AEL	Advanced Engineering Laboratory
AGC	Automatic Gain Control
BER	Bit Error Rate
CW	Continuous Wave
DEA	Data Error Analyser
DGJCE	Director General Joint Communications Electronics
DRCS	Defence Research Centre Salisbury
ERL	Electronics Research Laboratory
HF	High Frequency
IPS	Ionospheric Prediction Service
OWF	Optimum Working Frequency
QSY	Frequency Change (International "Q Code" abbrev.)
RAAF	Royal Australian Air Force
RTFM	Real Time Frequency Management

1. INTRODUCTION

In 1977 and 1978 AEL and ERL conducted HF radio medium speed data tranmission tests between Townsville and Sydney(refs.1 and 2) which confirmed earlier claims for the need for real-time frequency management of HF radio circuits over which medium speed digital data (2400 bits/s) was to be passed. During those tests a Granger 3905/3906 "Pathsounder" oblique ionospheric sounder was used to determine the frequency which would provide a predominantly single moded ionospheric path between transmitter and receiver. During the March and June 1978 tests reported in reference 2 instrumentation was used to measure the Doppler frequency spectral width of two CW tones which were present on the test transmissions. As a result of the analysis of those measurements a negative correlation between Doppler spread and digital data quality was observed(ref.3). A frequency management system based on the received Doppler spectral width was subsequently developed by ERL for further evaluation. That equipment, together with the slightly modified Data Performance Measurement System used in the earlier tests was combined to carry out the December 1981 real-time frequency managed tests reported in this document. This report deals primarily with the communications related aspects of circuit performance for that test period.

It is planned to repeat these tests at regular intervals over the next twelve months to enable this means of real-time frequency management to be evaluated during different seasons. The results of those tests will be published in a future report.

2. DESCRIPTION OF TEST

2.1 General

The test was conducted jointly by AEL and ERL personnel. ERL personnel operated the Doppler Pilot Tone Sounder receiver, analysed the results in real-time and recommended the operating frequency to be used for the ensuing ten minute period. AEL personnel coordinated transmitter frequency changes with RAAF Townsville personnel and operated the Data Performance Measurement Equipment which was used primarily to detect and log the occurrence of errors in the received data.

2.2 Digital data performance measurement

The equipment configuration used for the data performance measurement is shown in figures 1 and 2.

Figure 1 shows the data transmitting system which was located at the RAAF transmitting station at Townsville. A detailed description of the components of the transmitting system is made in reference 1. Note that the Magnavox modem model MX513B was used in lieu of the Collins TE233C modems used in earlier tests.

Figure 2 shows the data performance measurement system equipment configuration. This equipment was located at DRCS and differs from that used in the Townsville-Sydney tests, in that CR304A receivers were used in lieu of the Collins 651-F1 receivers and the Magnavox MX513B modems were used instead of the Collins TE233C type. The two antennae used for space diversity reception were sloping horizontal log periodic types beamed towards Townsville and with a spacing of approximately 450 m. These antennae were located within 10° of being broadside to the incoming signal.

A microprocessor based data logger was used to record the bit error rate (BER) information from the HP1645A Data Error Analyser (DEA).

The bit by bit error output from the HP1645A DEA was processed into a form suitable for recording on cassette tape. Depending upon the options selected, the recorded information related to arbitrary 7 bit and/or 256 bit blocks of the original data. Processing was continuous except for periods when the buffer contents were written onto the cassette tape (approximately 2.5% of operating time).

During the test periods a regular printout of the average number of errors per 10^5 and 10^6 bits was made, enabling a real-time analysis of the circuit quality to be made. One of the playback options available from the data logger provided an analysis of the error count per 10^4 bits received. This option allowed a deeper analysis of the recorded results to be made.

The received signal strengths from each receiver, together with received pilot tone signal strength, measured noise level on alternative available frequencies, and an indication of the presence of bit errors were recorded on a chart recorder.

2.3 Doppler spectra analysis and frequency management

Figure 3 shows the equipment configuration used both in the transmitter at Townsville and the receiver and analysis equipment at DRCS.

At the transmitter end a control unit controlled a synthesizer such that it continuously stepped onto one of ten RAAF allocated frequencies over a ten minute period, dwelling on each frequency for one minute. A wideband amplifier raised the synthesizer output to a level of approximately 50 W and this was applied to a sloping-vee antenna orientated towards DRCS.

At the receive end of the Doppler pilot tone sounder system a control unit stepped the Doppler receiver frequency in synchronism with the transmitter frequency. The Doppler receiver final intermediate frequency output was applied to an Audio Spectrum Analyser which enabled the Doppler shift present on the received signal to be displayed on an X-Y recorder.

A second receiver, also controlled by the control unit, was used to "look ahead" at the noise level present on the allocated frequency on to which the Doppler transmitter signal would step at the end of each one minute dwell period. The AGC level from this receiver was recorded on the data performance measurement system chart recorder and was used in determining the signal-to-noise ratio of the pilot tone signal.

Frequency management was based on a weighted average of the received Doppler spectra width together with consideration of the amount of difference between the Doppler spectra width on the current channel and the channel being identified as a probable better quality channel. A set of ten Doppler spectra plots was obtained every ten minutes, one for each allocated frequency. The algorithm used for this particular frequency management test consisted of the following.

(a) Measure the width of the top 14 db of the hard copied Doppler spectra and record for each allocated frequency.

(b) Initial frequency allocation for the data transmission could not be made until the Doppler spectra for each allocated frequency had been recorded for the previous thirty minutes. This meant that three Doppler spectra for those frequencies which supported propogation between Townsville and DRCS had to be measured before the first data transmission transmitter frequency could be selected correctly.

(c) A weighted average of the latest three values of the spectra width for each frequency was calculated, based on the formula;

weighted spectra width = (3 x most recent spectra width + 2 x the spectra width measured ten minutes earlier + the value of the spectra width measured 20 minutes earlier), divided by 6.

(d) The initial frequency allocation for the data transmission was made by selecting the allocated channel having the smallest weighted Doppler spectra width determined in (c) above, together with a suitable signal-to-noise ratio.

(e) Subsequent frequency changes to the data transmission channel were made when the lowest weighted Doppler spectra measured in (c) above had a weighted Doppler spectra width of at least 0.1 Hz less than that for the current operational frequency. This requirement was introduced into the algorithm to prevent frequency changes being required too frequently.

It should be emphasised that this algorithm was the first to be utilised by DRCS and is considered to be non-optimum. It is expected that further experiments will be conducted which could result in modifications to the algorithm.

3. RESULTS

The method used to record and evaluate the Doppler spectra width was manual and tedious. As a consequence, operating for periods greater than eight consecutive hours was considered impractical. Frequency management was therefore restricted to periods of approximately eight hours with subsequent tests timed to overlap the periods not previously covered.

The tests were conducted on six days over an eleven day period in December 1981 with the time periods 0900 to 1600, 1600 to 2340 and 2340 to 0700 being covered in separate tests over a six day period. No data was collected between 0700 and 0900 hours due to manning difficulties.

The results for the twenty two hour overlapped collection period are shown graphically in figures 4 and 5. In these figures the circuit performance has been expressed in terms of the percentage of time that the bit error rate is less than or equal to 10^{-4} or 10^{-3}. It should be noted that this twenty two hour period was not continuous due to the manual measurement technique used (discussed above) and that it is made up from data collected over the following periods.

0900-1600	16 December 1981
1600-2340	17 December 1981
2340-0700	22 December 1981

Automated Doppler spectra width measurement equipment currently being developed at AEL will permit performance evaluation over continuous twenty four hour periods in the next set of tests.

The most significant factors highlighted in figures 4 and 5 are;

- Average BER over twenty two hours = 6 x 10^{-4}.
- Average percentage of time BER was better than 10^{-3} was 91.7%.
- Average percentage of time BER was better than 10^{-4} was 79.2%.
- 9 QSY's were required to achieve the results with the minimum time between QSY's being twenty four minutes.

4. DISCUSSION

4.1 Bit error rate versus time

Figure 4 illustrates the percentage of time that the BER was better than 10^{-4} over the twenty two hour test period. This was obtained by recording each block of 10^4 bits of received data in which one or no errors were present. This analysis was repeated for every one hundred blocks of 10^4 bits. The percentage of time that one or no errors were recorded in each of the one hundred 10^4 bit blocks was then plotted for the twenty two hour test period.

Figure 5 illustrates the percentage of time that the BER was better than 10^{-3} over the twenty two hour test period. This was achieved in a manner similar to that described above for the bit error rate of 10^{-4}, however, in this case each 10^{-4} bits were examined for the presence of ten or less errors. The percentage of time that each block of 10^4 bits had ten or less errors in each one hundred blocks of 10^4 bits was then plotted for the twenty two hour test period.

4.2 Doppler spectra width versus bit error rate

Figure 6 is a plot of the weighted Doppler spectra width and the percentage of time the BER was less than 10^{-4} versus time of day. Some correlation between weighted Doppler spectra width and percentage of availability of a BER $\leq 10^{-4}$ is evident with the minimum weighted Doppler spectra width being coincident with points of higher percentage of availability of a BER$\leq 10^{-4}$. It should be noted that the BER results plotted in figures 4,5,6 and 7 are from a space diversity receiving system and one of the reasons for using space diversity is to reduce the effects of multipath fading. A better correlation may have been achieved had non-space diversity results been plotted and correlated with weighted Doppler spectra width. Unfortunately non-space diversity results were not gathered during this test.

Instantaneous Doppler spectra width and percentage of time that the BER was less than 10^{-4} have been plotted in figure 7. The correlation between these two parameters was not as good as that obtained using the weighted Doppler spectra values. This is considered to be due to the fact that the instantaneous Doppler spectra width was only measured on the data channel operating frequency for sixty seconds every ten minutes. The Doppler data is therefore only a sample measurement whilst the BER values used in figure 4 were obtained from continuous analysis of the circuit performance each one million bits (approximately 6.94 minutes). The weighted Doppler spectra width however, is a weighted value determined from three sixty second measurements taken ten minutes apart. Future tests will incorporate instrumentation which will allow instantaneous Doppler spectra width and BER for each one minute period to be measured, thus allowing a more detailed analysis.

Whilst a correlation between weighted Doppler spectra width and bit error rate was observed from figure 6 these results do not identify a direct relationship between the absolute value of the weighted Doppler spectra width and the BER, ie a particular weighted Doppler spectra width did not relate to a particular BER. The use of space diversity reception during these tasks, as well as the short sampling time of the Doppler sounder versus the 6.94 minutes data analysis period, could mask the detection of any likely relationship between weighted Doppler spectra width and absolute BER values. The author does not expect such a direct relationship to exist however, since multipath propagation, whilst the major factor, is not the only factor which affects the BER of digital data over HF links. Interference (man made and natural), signal-to-noise ratio and equipment performance (particularly the Kineplex modems) are other factors which would tend to mask any direct relationship.

4.3 Comparison of IPS predicted and pilot tone sounder measured optimum working frequencies

Figure 8 is a plot of the recommended optimum working frequency (OWF), as provided by the Ionospheric Prediction Service (IPS) for the Salisbury to Townsville path for December 1981, versus time of day. Also plotted on figure 8 is the RAAF frequency allocations for the Townsville to Salisbury path and the periods for which the data transmission channel used that frequency. The frequency of the data transmission channel was determined by the pilot tone sounder equipment. Generally the frequency determined by the pilot tone sounder as being most suitable was the closest allocated frequency to the OWF as predicted by the IPS except for the periods 0100 to 0540 and 1530 to 1700 hours when frequencies considerably higher than the predicted OWF were used. It should be noted that at approximately 0140 hours the pilot tone sounder indicated that the optimum frequency was 14545 kHz but as the RAAF were using that channel for their Townsville to Sydney traffic a QSY was not effected. Had a QSY to 14545 kHz been possible the operating frequencies would have been slightly different to those used in the test (the frequency changes required, but not implemented, are shown dotted in figure 8 between 0140 hours and 0700 hours). The differences in the weighted Doppler spectra values recorded for the alternative channels were significant enough to assume that an improvement in the received digital data performance may have been possible. Figure 8 shows however that the IPS OWF values would have indicated a frequency allocation compatible with that obtained from the pilot tone sounder equipment except for the periods between 1530 to 1700 and 0100 to 0540 hours. Future test results will be analysed, to compare the IPS OWF and the pilot tone sounder OWF over a longer period of time.

4.4 Comparison of propogated mode structure as determined by an ionosonde and a pilot tone sounder

During the twenty two hour test oblique ionograms were recorded for the Townsville to Salisbury path, simultaneous with the measurement of instantaneous Doppler spectra width. The number of modes present at the data transmission frequency was extracted from the ionograms and was plotted against the instantaneous Doppler spectra widths in figures 9(a),(b),(c) and (d). The graphs of figures 9(a) and 9(b) are of particular significance in that the ionosonde identified the presence of up to four propagation modes whilst the pilot tone sounder indicated a very narrow instantaneous Doppler spectra width.

The fact that considerable multimode propagation conditions were indicated by the ionosonde while the pilot tone sounder indicated minimum mode propagation supports AEL and ERL beliefs that the ionosonde display has limitations in its ability to correctly describe the mode structure for a particular path. This is due primarily to the fact that the ionosonde display processing circuitry does not attempt to identify the relative amplitude differences of each mode and therefore any propagated signal received above a certain threshold level will be identified as an equally likely mode of propogation. The instantaneous Doppler spectra width, on the other hand, is a composite presentation of the relative Doppler shift and signal amplitude due to each propagated mode. Therefore the relevant signal strengths via each mode of propagation is incorporated into the measured instantaneous Doppler spectra width value. It should be noted however that during the tests reported in this document the receive and transmit antennae were different for each system and this ffect the validity of the conclusions drawn from the results shown figures 9(a) and (b). The ionosonde used vertical log periodic antennae he transmit and receive sites whilst the pilot tone sounder used a slop vee antenna at the transmit end and a horizontal log periodic antenna he receive end. The author feels that the vertical log periodic anten. sed on the ionosonde equipment, by virtue of their lower take off angles, would have minimized the number of received modes. In contrast, the sloping vee and horizontal log periodic antennae would tend to support relatively more modes of propagation. It is expected that had vertical log periodic antennae been used on the pilot tone sounder equipment, the instantaneous Doppler spectra width would have been narrower. This would further confirm the trend shown in figures 9(a) and 9(b) and the claim that the pilot tone sounder is a better indicator of path mode structure than the oblique ionosonde.

5. CONCLUSIONS

Real-time frequency management using the measured Doppler spectra width of a received pilot tone transmission as an indicator of the mode structure at a particular operating frequency is feasible. A 1900 km HF radio circuit carrying 2400 bits/s digital data was frequency managed using this technique to produce an overall average BER of 6×10^{-4} for a twenty two hour period. The BER was better than 10^{-3} for 91% of the test period.

The presence of a large number of significant operating modes of propagation at a particular frequency as indicated by an oblique ionosonde is not necessarily associated with a wide Doppler spectra width of a received pilot tone signal. This is considered to be attributed to the threshold processing involved in the ionosonde display electronics and it highlights one of the advantages offered by the pilot tone sounder technique over the use of ionosondes.

6. RECOMMENDATIONS

The priority development of automated test equipment, which will enable automatic measurement and evaluation of the received Doppler signal, should be continued to allow its use in future tests. This equipment, together with an existing upgraded data logging system, should then make semi-automated real-time frequency management tests possible.

With semi-automated equipment available, tests should be carried out on frequencies indicated by the pilot tone sounder as being both "good" and "poor".

Further tests should be carried out to conclusively show the correlation between data bit error rate and Doppler spectra width. Particular attention should be given to this analysis using both diversity and non-diversity reception techniques.

The technique should be tested over other circuits including east-west and those of shorter distances, eg Melbourne to Canberra.

A chirp sounder and the pilot tone sounder system should be simultaneously operated over an existing circuit and the data quality results from each test compared.

Future test results should be analysed with an emphasis on the percentage of time that the BER is less than or equal to 10^{-3}. In addition, the method of analysis should be modified so that each 1000 bits are analysed rather than averaging over 10000 bits as was done for these tests.

7. ACKNOWLEDGEMENTS

The guidance and support given by Dr R. Clarke of ERL during testing and analysis is gratefully acknowledged. The support of personnel at the Townsville RAAF transmitting station in operating both the pilot tone sounder and data transmission equipment is also acknowledged. The keen support given by Messers A.M. Goodway and G. Thamm of AEL in the development and operation of the Data Performance Measurement Equipment is also acknowledged. My thanks are also due to Mr J. Ball of AEL and to Miss S. Dearman of ERL for their help in the consolidation and graphical presentation of the results.

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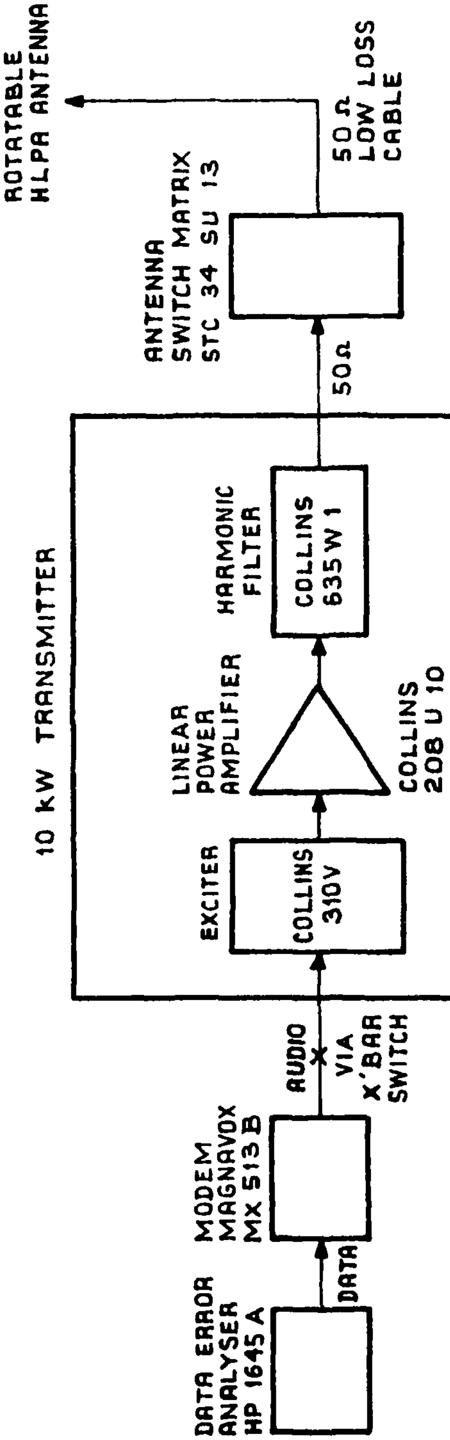

Figure 1. Data transmitting system - Townsville

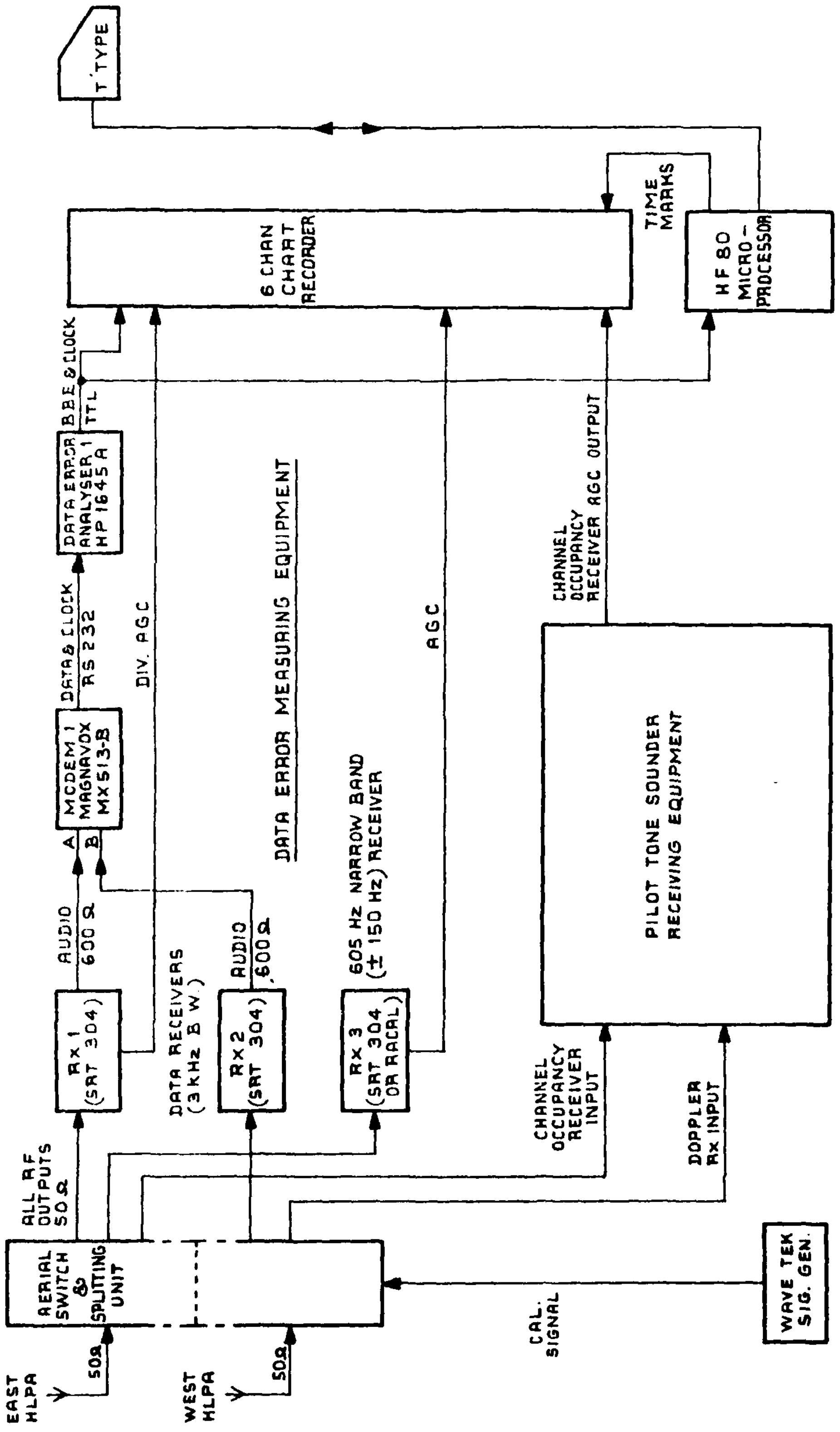

Figure 2. Data performance measuring system - DRCS

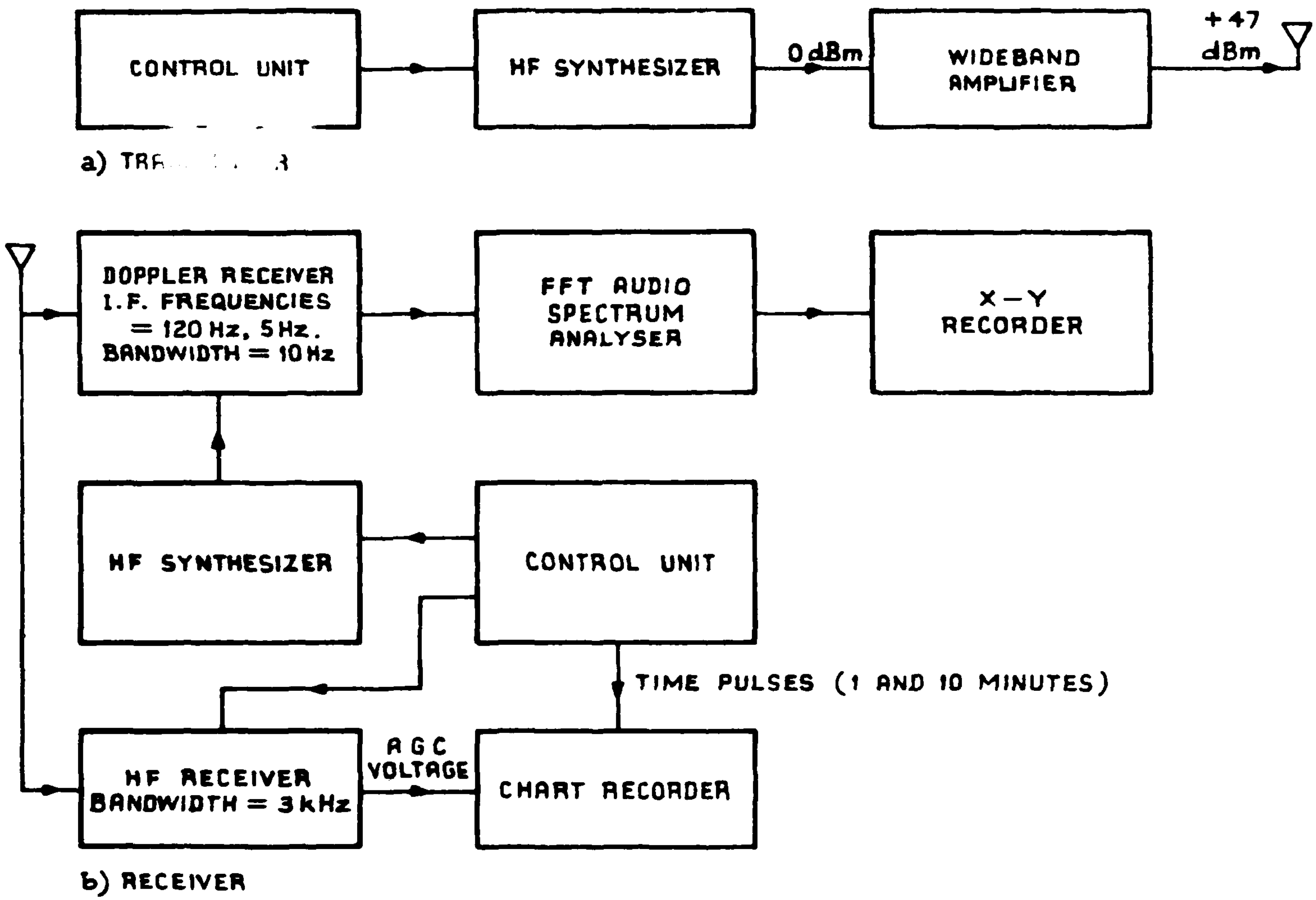

Figure 3. Doppler pilot tone sounder - block diagram

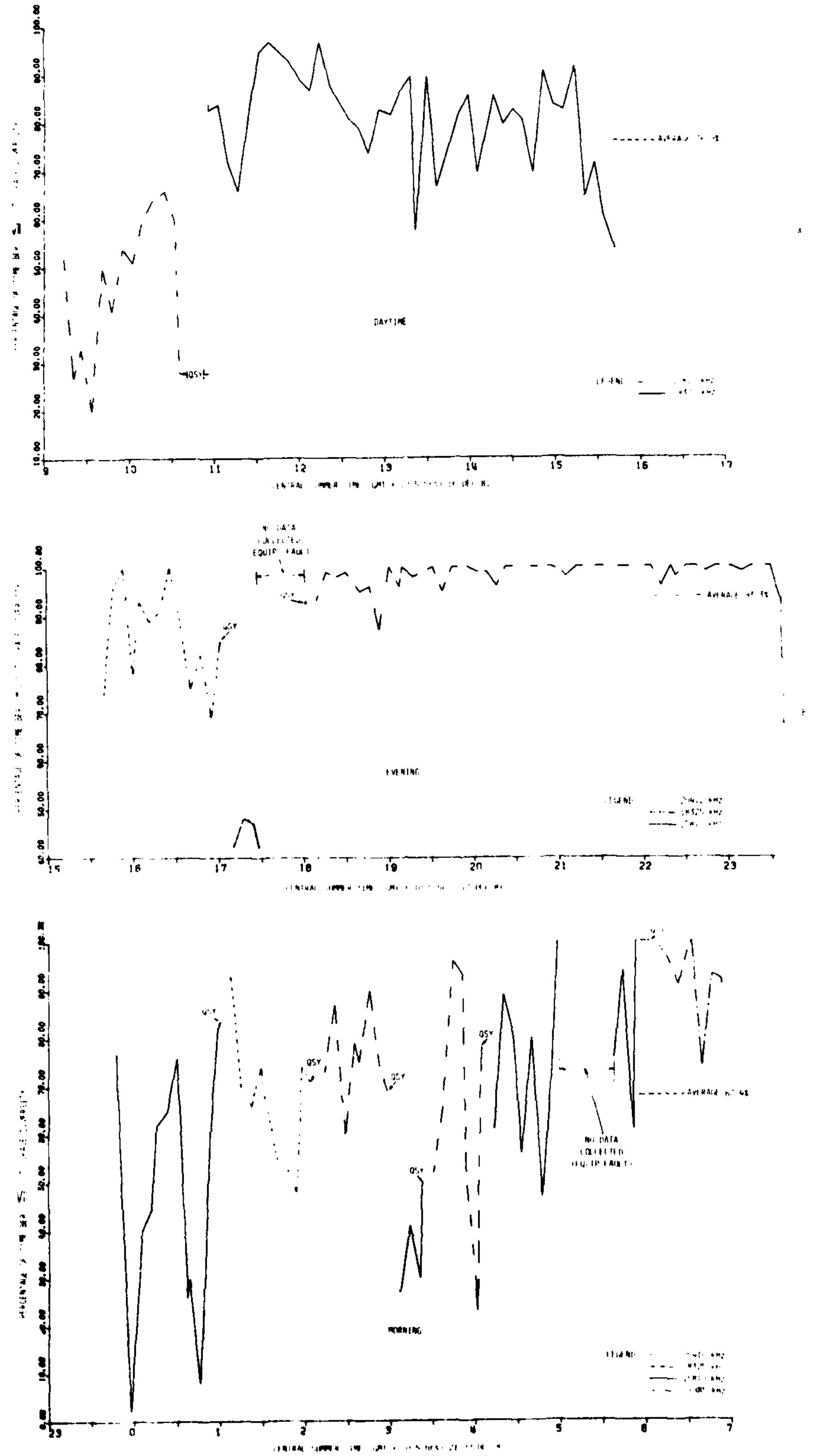

Figure 4. Twenty two hour test - percentage of time BER was better than 10^{-4}

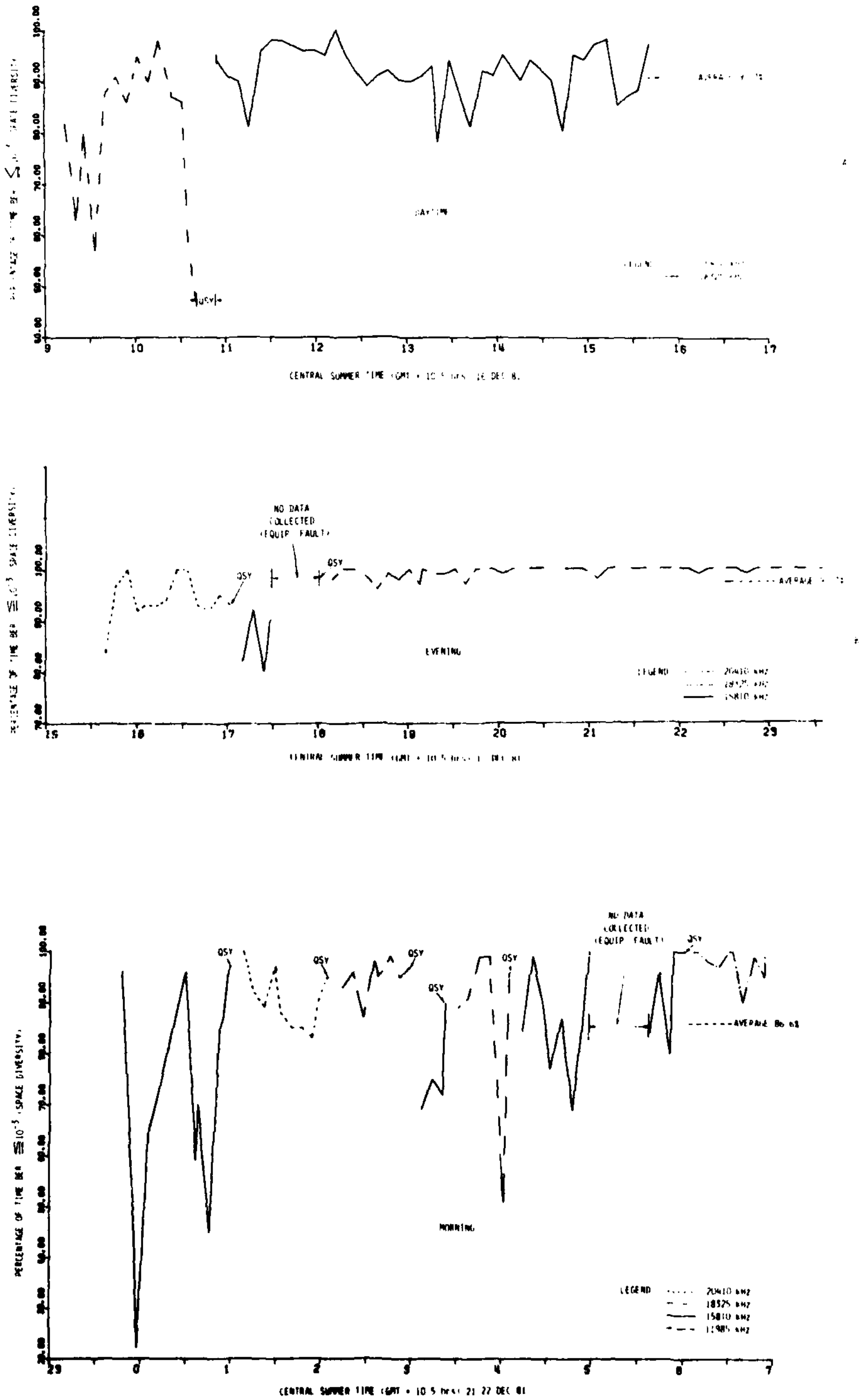

Figure 5. Twenty two hour test - percentage of time BER was better than 10^{-3}

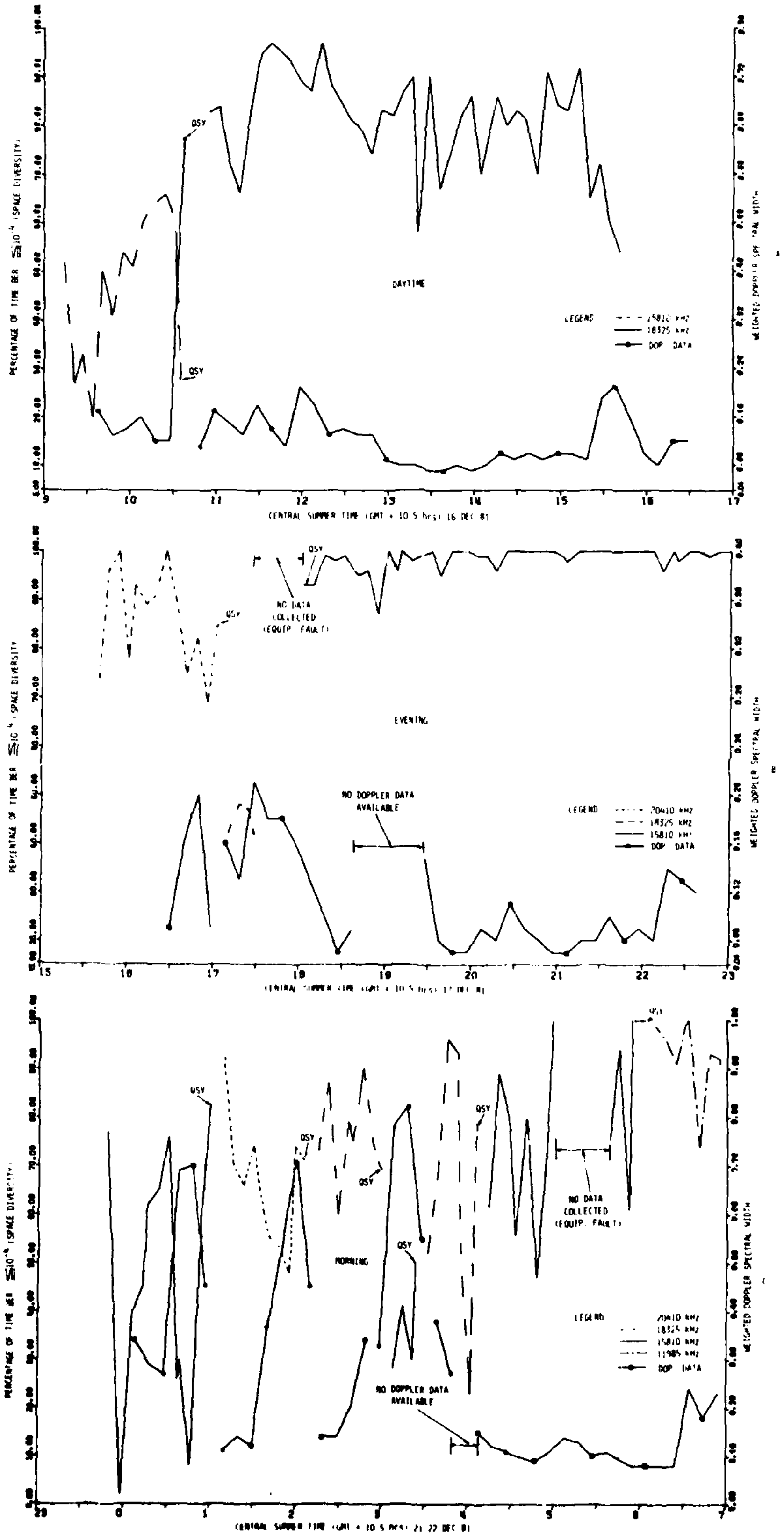

Figure 6. Plot of percent of time BER $< 10^{-4}$ and weighted Doppler spectra width versus time

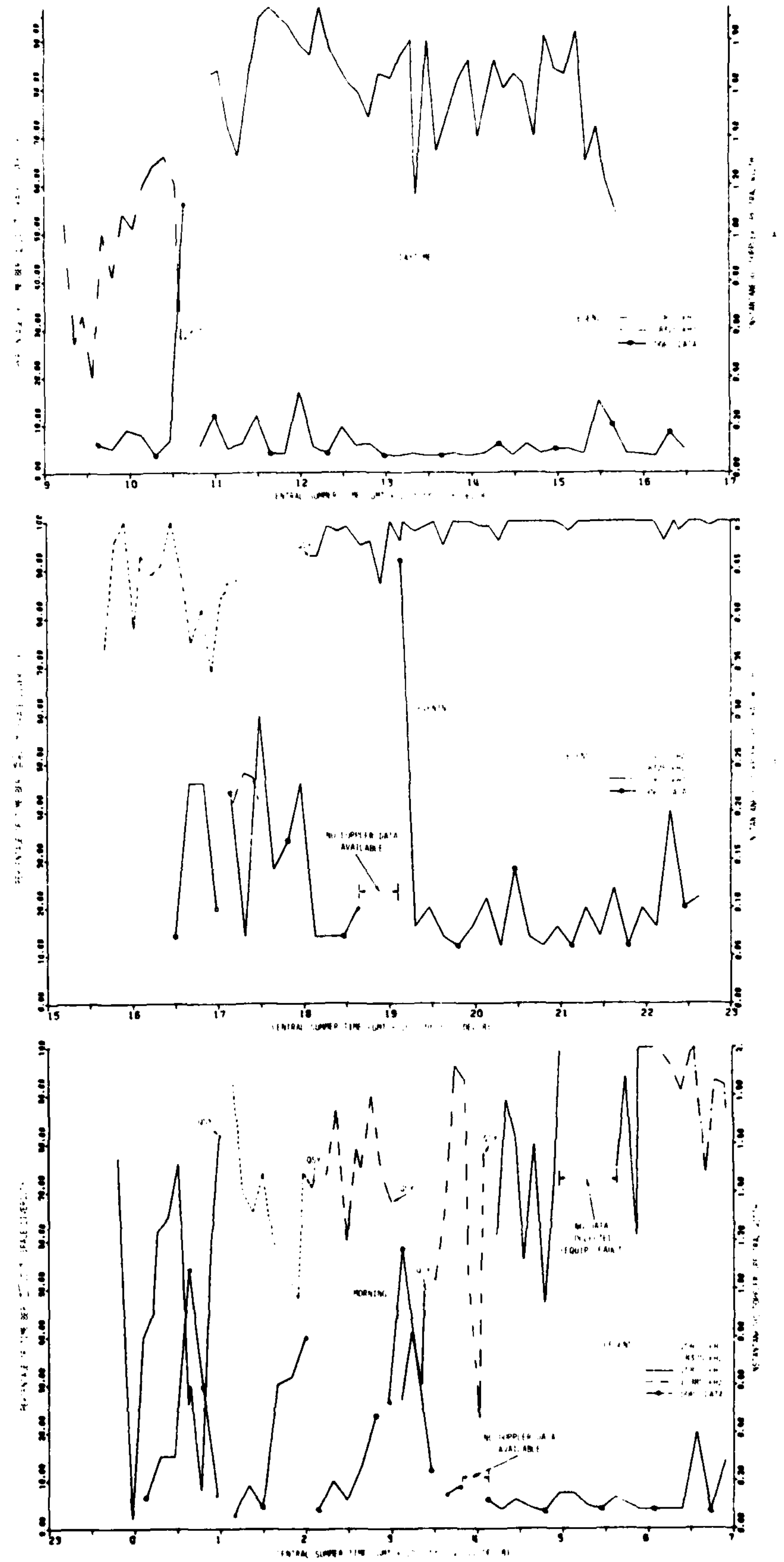

Figure 7. Plot of percent of time BER $< 10^{-4}$ and instantaneous Doppler spectra width versus time

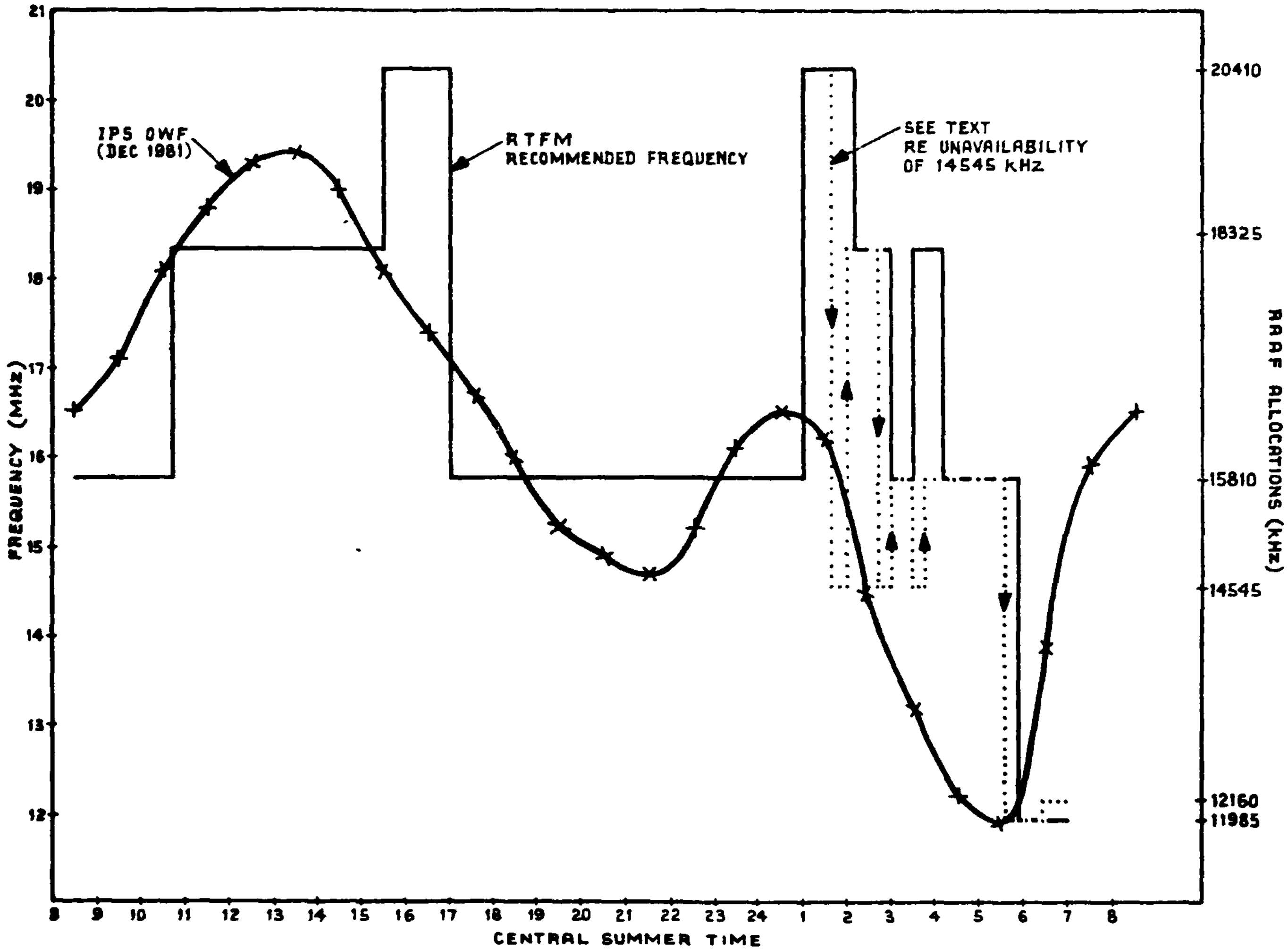

Figure 8. Plot of IPS predicted optimum working frequencies (OWF) and real time frequency management (RTFM) recommended frequencies versus time of day

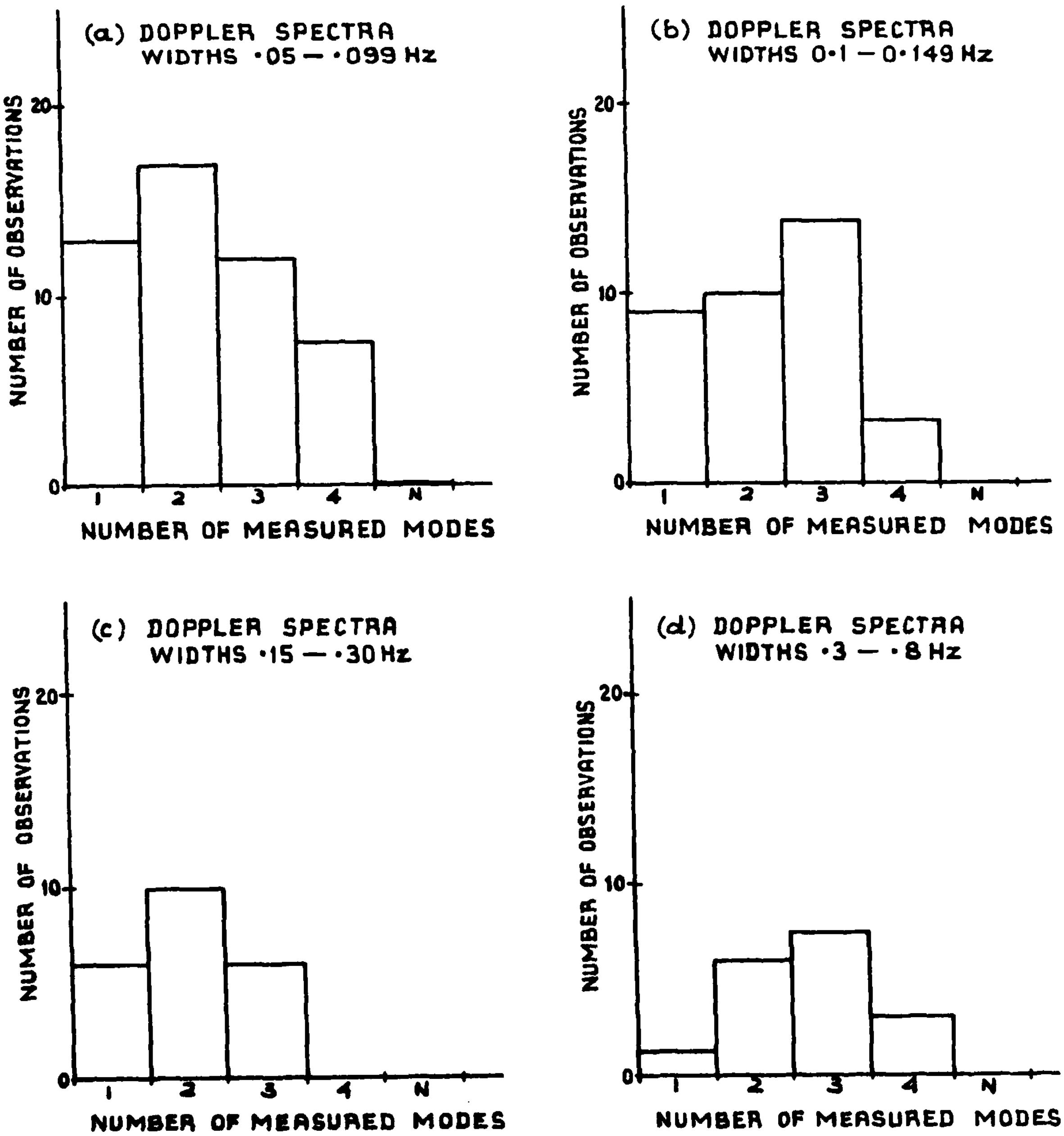

Figure 9. Mode structure indicated by an oblique ionosonde versus instantaneous Doppler spectra width

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Instrumentation which monitored the Doppler spectra of a CW stepped frequency sounder transmission originating in Townsville was used as an aid in selecting the optimum operating frequency. The work forms part of the HF Enhancement Study being carried out by AEL and ERL and is sponsored by DGJCE.

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